Luca Belli Editor

The Community Network Manual: How to Build the Internet Yourself

Official Outcome of the UN IGF Dynamic Coalition on Community Connectivity

Preface by **Bruno Ramos**

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This volume is the result of the annual Call for Papers Dynamic Coalition on Community Connectivity (DC3), which is open to all interested stakeholders. DC3 is a component of the United Nations Internet Governance Forum and this book is the official 2018 outcome of the DC3. Paper submissions have been evaluated for their novelty and their academic rigor as well as for the impact that the initiatives described in the paper may have. All accepted submissions have been peer-reviewed.

For further information on DC3, see www.comconnectivity.org

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1 FGV is a world-renowned institution of research and quality education. In 2018, FGV was deemed as one of the top 10 think tanks in the world, according to the Global Go To Think Tanks Index 2017, produced by the Pennsylvania University. Besides being the 7th most influential think tank globally, FGV has been ranked as the most influential think tank in Latin America over the past nine years. Currently, FGV has 10 Schools and more than 50 Applied Research Centres in the areas of economics, business administration, public administration, law, social sciences, applied mathematics and international relations. See <http://portal.fgv.br/>.

2 ISOC is a global cause-driven organisation governed by a diverse Board of Trustees that is dedicated to ensuring that the Internet stays open, transparent and defined by the users. ISOC currently features more than 140 member organisations and 130 local and regional chapters, bringing together ISOC members and facilitating a number of programmes and activities. See <https://www.internetsociety.org/>.

3 ITU is the United Nations specialised agency for information and communication technologies. ITU is committed to connecting the entire world's people – wherever they live and whatever their means. ITU is organisation based on public-private partnership since its inception and currently has a membership of 193 countries and almost 800 private-sector entities and academic institutions. Through its work, ITU protects and supports everyone's fundamental right to communicate. See <https://www.itu.int/>.

CONTENT

PREFACE

by *Bruno Ramos*

Encouraging New Formulas for an Inclusive Information Society

The International Telecommunication Union (ITU) has in its DNA the vision[1] of an Inclusive Information Society, where Information and Communication Technologies (ICTs) foster social and economic development and collaborate for the sustainable growth of the environment, which results in improving the quality of life for everyone.

In this modern Information Society, the ways of social interaction and cultural and economic development are being rapidly altered, due to the new technologies' evolution. Connectivity enables the exchange of information and knowledge between individuals and communities, enhancing human development in a global sphere.

The main driving force behind the change in the way people interact is therefore education through access to knowledge. The exchange of information between people allows us to reflect on the stage in which the communities are in comparison with the others, resulting in a qualified view of the world in which we live and to which we want to go.

However, in particular in developing countries, not all people have access to ICTs, being left out of this new Information Society and therefore without any possibility of choice, including to be able to choose another growth and development path.

This lack of access to the Information Society ensues from the difficulties in the provision of telecommunication services, resulting from the economic incapacity or technical inability to implement it.

Therefore, it is necessary to think alternatives to the current forms of telecommunication service provision, either through proposals

1 ITU Vision: "An information society, empowered by the interconnected world, where telecommunication/information and communication technologies enable and accelerate social, economic and environmentally sustainable growth and development for everyone".

of new governmental public policies, by stimulating competition and the entrance of new private agents or by encouraging new formulas of social organisation in favour of a common goal.

Within the many available options to narrow the access gap, Community Networks have the ability to gather some important items for sustainable development: social organisation with shared objectives, cultural and educational balance, government definitions – with specific regulatory measures aimed at motivating interconnection to the backhaul and backbone of already consolidated companies in the Market – and cost and benefits sharing among the related communities.

As an alternative to the traditional private investment options, these initatives make this possibility of building access networks in regions with low financial returns well adapted to the cases of establishment of access networks, both wireless and by fiber, particularly in isolated and rural areas. This phenomenon is justified by the fact that regions with low attractiveness to conventional investment establish themselves as an ecosystem of similar characteristics, both in terms of resources and demands.

In this way, the establishment of a specific solution expands to the whole community, allowing the growth of a common mechanism to support the construction of networks, such as the use of local manpower for deployment and maintenance of the networks, user support service, among others.

It is in this context that this Manual is inserted.

The solutions and experiences presented are an inspiring and transparent guide to how communities wishing to undertake this digital inclusion mechanism can organise themselves to this end. The terms presented in the handbook deal with how to build Community Networks and how to make Community Networks scalable, sustainable and legally based.

The Manual serves as the basis for starting the creation of a Business Plan that will analyse the best way of implementing the networks in the community and, more importantly, the viability and sustainability of the chosen technological solution.

The ITU, in its work to support its Members in bridging the digital divide, implements technical cooperation projects and this Handbook will be one of the inputs in the implementation of projects in the Americas region with concrete results for the construction of access networks for the inclusion of isolated and vulnerable communities.

For the four-year period 2018-2021, ITU has as a priority the implementation of practical actions to achieve the results expected by its Members, especially through the Regional Initiatives – priority areas for ICT development, defined for each world region during the World Telecommunication Development Conference (WTDC-2017), held in Buenos Aires, Argentina, in October 2017.

One of these actions considers the implementation of a project to assess models of cooperative and community networks, including the legal, regulatory and technical aspects, in order to identify the best practices that can be replicated in the Americas Region and to promote alternative models of provision of broadband access in currently unattended or under supervision areas.

The goal is to implement pilot solutions in many Latin American countries, with an in-depth analysis of each solution vis-a-vis its deployment location, and also generate toolkits to replicate identified solutions in other areas of the region.

This Manual will be an important part as input in the implementation of this Project, which has as ITU partners, the other two participants in its elaboration, the FGV[2] and ISOC[3].

The reading and use of this Manual has more than an academic character, and can bring real results so that we can increasingly work towards the inclusion of all in the modern Information Society.

2 Fundação Getulio Vargas

3 Internet Society

About the Authors

Luca Belli, PhD is Professor of Internet Governance and Regulation at Fundação Getulio Vargas (FGV) Law School and associated researcher at Centre de Droit Public Comparé of Paris 2 University. Before joining FGV, Luca worked as an agent for the Council of Europe Internet Governance Unit; served as a Network Neutrality Expert for the Council of Europe; and worked as a consultant for the Internet Society. Over the past decade, Luca has authored and edited more than 30 research outputs in English, French, Italian, Portuguese and Spanish, amongst which "De la gouvernance à la régulation de l'Internet" (Berger-Levrault, 2016); the "Net Neutrality Compendium" (Springer, 2016); "Platform Regulations: How Platforms are Regulated and How They Regulate Us" (FGV, 2017); "Community Networks: the Internet by the People, for the People" (FGV, 2017); and "Gobernanza y Regulaciones de Internet en América Latina" (FGV, 2018). Luca's works have been i.a. quoted by the Organization of American States Report on Freedom of Expression and the Internet (2013); used by the CoE to elaborate the Recommendation of the Committee of Ministers on Network Neutrality (2016); featured in the French Telecoms Regulator (ARCEP) Report on the State of the Internet (2018), and published or quoted by various media outlets, including Le Monde, BBC, The Hill, O Globo, El Pais and La Stampa. He holds a PhD in Public Law from Université Panthéon-Assas, Paris 2 and a JD in Law from the University of Turin.

Bruno Ramos is the Regional Director of the Americas Regional Office of the International Telecommunication Union. Bruno graduated in electronic engineering from the Escola Politécnica da Universidade de São Paulo (USP) and holds two Master's degrees, one in telecom regulation and the other in Electronic Engineering, from the University of Brasilia (UnB). He worked for companies such as TELESP (Telecomunicações de São Paulo) and TELEBRÁS (Telecomunicações Brasileiras) before joining the Brazilian regulatory body, Anatel where he worked for over 16 years as Superintendent for data, mobile and satellite communication. Since 2013 Bruno Ramos is the ITU Regional Director for the Americas Region, He is the responsible for the direct supervision of all the work of ITU in the Americas, highlighting assistance and support to countries related to telecom/ICTs regulation, manage and monitoring of the radio electric spectrum, strengthening of telecom institutions and capacity building in telecom/ICTs in Americas among others.

Panayotis Antoniadis is the co-founder of NetHood Zurich. He has an interdisciplinary profile with background on the design and implementation of distributed systems (Computer Science Department, University of Crete), Ph.D. on the economics of peer-to-peer networks (Athens University of Economics and Business), post-doc on policies for the federation of shared virtualized infrastructures (Pierre and Marie Curie University, UPMC, Paris), and interdisciplinary research on the role of ICTs for bridging the virtual with the physical space in cities (ETH Zurich). NetHood is a transdisciplinary non-profit organization that aims to design and develop tools for self-organization and conviviality, bringing together different forms of commoning in the city like community networks, complementary currencies, and cooperative housing. It also aims to bridge academic research with civic action, through its participation in three EU Horizon2020 projects: MAZI (A DIY networking toolkit for Location-Based Collecive Awareness) <http://mazizone.eu>, netCommons (Network Infrastructure as Commons), <http://netcommons.eu>, and Heteropolitics (Refiguring the Common and the Political), <http://heteropolitics.net>.

Virginie Aubrée is a legal researcher for the University of Trento. She is part of netCommons, a European Commission-sponsored Horizon2020 research project, utilising a transdisciplinary methodology to study network infrastructure as commons, for resiliency, sustainability, self-determination, and social integration. Virginie's research focusses on digital commons, telecommunication law and access to knowledge. She also works on data retention obligations and intelligence legal frameworks within the European Union.

Roger Baig Viñas joined the guifi.net community network in 2006 as a volunteer and since 2011 is an employee of the guifi.net Foundation, the organisation responsible for promoting and developing the guifi.net network. His current activities include the coordination of international collaborations, the organisation of community events and talks, the development of infrastructure projects, etc. As a researcher, he is doing his PhD at Universitat Politècnica de Catalunya. His current research interests are on business models, sustainability and governance of community networks. He holds a degree in industrial engineering, one in industrial electronics and automation and one on computer science.

Aris Dadoukis is currently a Research Engineer at the Department of Electrical and Computer Engineering, University of Thessaly, Greece. He received the diploma of Computer and Communication Engineering from the University of Thessaly (UTH) in 2007 and the M.Sc in Science and Technology of Electrical and Computer Engineering, from the same department, in 2008. From 2012 until now, he is a Researcher Engineer in University of Thessaly (UTH). He has participated in several of EU projects including Fed4FIRE, Fed4FIRE +, FLEX, ForLab, MAZI and eCOMPASS. He is experienced in the development of testbed related frameworks for monitoring and management, as well as the implementation of OMF extensions for testbed management. His research interests lie in the area of Testbed management, Cloud Computing, DIY networks and Wireless

Paolo Dini received a PhD in Aerospace Engineering from Penn State University in 1990. He taught undergraduate physics at Carleton College and St Olaf College, Minnesota, while consulting and researching in wind turbine aerodynamics. In 1997, he started working as a Senior Scientist for a wearable computer company and continued working in hardware R&D at Philips Research Laboratories, in Redhill UK, until 2001. He was then a research group leader at the MIT Media Lab Europe in Dublin. In 2003, he joined the Department of Media and Communications at LSE, working on and leading many EU projects. He currently divides his time between LSE, where he pursues mainly social science research topics, and the School of Computer Science at the University of Hertfordshire, where he pursues mainly theoretical computer science research topics. In social science, Paolo is interested in studying social theory, economic theory, and political theory and how they apply to bottom-up socio-economic phenomena such as complementary currencies, which can be seen as "laboratories of institutional learning". He is also interested in the study of epistemology and interdisciplinarity, and in the social construction of technology. Since 2016, Paolo has also been working as an R&D consultant for Sardex S.p.A.

Melanie Dulong de Rosnay, PhD in law (University Paris 2, 2007) is an associate research professor (permanent researcher since 2010) at the French National Centre for Scientific Research (CNRS). She heads the Information and Commons Research Group at the Institute for Communication Sciences of CNRS/Sorbonne University. Melanie's research focuses on the techno-legal infrastructure and policy for information and digital commons. She is a work package lead of the H2020 CAPS project netCommons on community wireless networks. She also works on algorithmic regulation, distributed architectures, peer production, open access and licensing (public sector information, scientific data and publications, public domain works and digital native heritage). She was a visiting fellow at London School of Economics, Department of Media and Communications from 2013 to 2017. She co-founded in 2011 Communia association on the digital public domain, which she represented at the World Intellectual Property Organization (WIPO). She was Creative Commons France co-founder and legal lead (2003-2013) at CERSA CNRS/University Paris 2, and was employed as a researcher staff member by the Berkman Center for Internet & Society at Harvard Law School, Nexa Center for Internet & Society at Politecnico di Torino, and the Institute for Information Law of the University of Amsterdam.

Nicolás Echániz, president of AlterMundi, has been involved in Community Networks for the past 15 years. He co-designed the multi-radio mesh network model that AlterMundi shares with communities willing to build their own communications infrastructure. He co-designed the LibreMesh firmware, the Librenet6 mesh tunel broker and the LibreMap federated mapping tool. Nicolás is project manager for the ongoing LibreRouter project funded by FRIDA (LANCIC), FIRE (Afrinic) and the Internet Society. He is project leader for the Descentralized Culture Repository (funded by APC). He co-founded the Dynamic

Coalition on Community Connectivity (DC3). He is the current Chair of the Internet Society Community Networks Special Interest Group (CNSIG). He is a regular speaker in connectivity-related events and he has authored numerous articles on Community Networks on printed as well as online media.

Kurtis Heimerl is an assistant professor of Computer Science at the University of Washington working on Information and Communication Technology and International Development (ICTD), specifically universal Internet access. Before that, he received his PhD from the University of California, Berkeley, working under Professors Eric Brewer and Tapan Parikh. Kurtis has published widely, including top conferences such as ICTD, CHI, and NSDI. He was a recipient of the 2014 MIT "35 under 35" award, the 2018 UW early career Diamond Award, and won "Best Paper" awards at both CHI and DySPAN.

Matthew Johnson is a graduate student in the ICTD lab at the Paul G. Allen School for Computer Science and Engineering, where he works with Kurtis Heimerl on the challenges of rural Internet access. He earned his BSEE at Rice University in Houston Texas. He is a current NSF Graduate Research Fellow, and previously received the Gaetano Borriello Endowed Fellowship at the University of Washington and the President's Engineering Fellowship at Rice University. He is most interested in the networking challenges associated with building high performance networks that can be maintained sustainably by non-experts.

Pathirat Kosakanchit is a third-year undergraduate student studying Computer Engineering at the University of Washington. Pathirat is working at the ICTD lab on developing community LTE networks where she is supervised by Spencer Sevilla. Her areas of interest are web development and wireless networking.

Florencia López Pezé participates in QuintanaLibre, a community network in Argentina, since 2012. She is a member of AlterMundi, contributing as a communicator and graphic designer. She is part of the documentation team for the LibreRouter project and it's software tools. She is also a member of the Training Group of the CNSIG. She is is based in the sierras of José de la Quintana and participates in experiences of social and collective organization in the territory that are grouped around the defense of environmental rights, land for a dignified life and gender equality.

Stavroula Maglavera, is Electrical and Computer Engineer, B.Sc. She focuses on high-level coordination and on strategic developments. She is specialised in the field of ICT and she gained expertise on designing and executing international scale events in ICT. Her skills encompass exploitation, promotion, and dissemination of technology, and IPR issues. Extensive experience in providing consulting services supporting Public Administration and organisations in the formation and implementation of national and regional strategies for the development and management of ICT applications. With more than twenty-seven years of hands-on experience in European, National & Regionally funded programmes and in project management, she still maintains an active interest on design and implementation of research projects in the field on ICT. Her current research interests comprise Networked Information Systems, ICT for Health, e-Inclusion, and e-Government. She is involved in scientific and business committees dealing with medical informatics. She was the coordinator of several EC funded projects. Participates is SMARTFIRE, FLEX, EINS, MED-GOLD, DREDBOX, MAZI and CHIC projects.

Steven Mansour is a well-known expert on cyber-infrastructure, cyber-activism, Internet privacy policy, and knowledge transfer on the web. Steven provides training and support to scientists, non-profits and community groups throughout the U.S., Canada and Latin America since 2004. He has given Linux & Open Source Software workshops in Cuba, and worked closely with the Fundación Canguro in Colombia, developing knowledge transfer strategies for doctors and researchers working with premature & low birth weight (LBW) infants. He was Director of Technology & Partnerships at the World Association of Young Scientists, a UNESCO project to support young scientists and early-career researchers. Steven worked closely with the McGill University Health Center, the Centre Hospitalier Universitaire Sainte-Justine and the Alberta Children's Hospital to develop social research and e-learning tools for professors and students in Mother-Child research. His work on Internet privacy and security has been featured in international media. Steven currently works with the X-Lab think tank on tech policy issues, and is also involved with a number of local technology startups, creative writing organizations and non-profit projects in Montreal, Canada.

John Mavridis holds a degree in Electrical and Computer Engineering, University of Thessaly, Greece (2018). At present, he is a M.Sc. student in Science and Technology of Electrical and Computer Engineering. From 2015 until now, he is an Assistant Research Engineer in University of Thessaly (UTH). He was involved in the EU Project MAZI (A DIY networking toolkit for location-based collective awareness) and more specifically in the design and development of the backend software. He is also fully experienced in the control, management and operation of experimental infrastructures for implementing wireless networking experiments for academic and research purposes.

Sascha Meinrath is the Palmer Chair in Telecommunications at Penn State and director of X-Lab, an innovative think tank focusing on the intersection of vanguard technologies and public policy. Professor Meinrath is a renowned technology policy expert and is internationally recognised for his work over the past two decades as a community internet pioneer, social entrepreneur and angel investor. He was elected as an Ashoka Fellow for Social Entrepreneurship in 2012, and has been named to the Time Magazine "Tech 40" as one of the most influential figures in technology, to the "Top 100" in Newsweek's Digital Power Index, and is a recipient of the Public Knowledge IP3 Award for excellence in public interest advocacy. Professor Meinrath is widely published in both academic and media outlets, including Critical Studies in Media Communications, International Journal of Communications, Journal of Communications Law and Policy, Journal of Internet Law, Journal for Community Informatics, IEEE Internet Computing Magazine, IEEE Spectrum, Foreign Policy, The Hill, Time Magazine, Politico, Slate, The Guardian and many others. Prior to founding X-Lab, Meinrath was vice president of the New America Foundation, where he founded the Open Technology Institute in 2008 and built it into one of the largest public interest tech policy organizations in Washington, D.C. He also founded the Commotion Wireless Project.

Jens Martignoni is a cooperative and currency researcher working on community currencies, commons based economic models and game design for networks and cooperatives. He is a co-founder of the Zurich-based nonprofit organization nethood.org and is doing a PhD on cooperative currencies at Cologne University, Germany. He serves also as a lecturer for management at the Swiss Distance University for Applied Science, Brig. Above that he is engaged in the discussion about monetary innovations, ethical banking and the future of finance in Switzerland. His background includes a degree in mechanical engineering from Technikum Winterthur and later on an executive master of business administration in nonprofit-organisation-management from the University of Fribourg, Switzerland.

Leandro Navarro is associate Professor at the Universitat Politècnica de Catalunya (UPC) in Barcelona. Ph.D. in Telecommunication from UPC in 1992. His research interests include the design of scalable and cooperative Internet services and applications. He coordinates the Computer Networks and Distributed Systems (CNDS) research group at UPC. He coordinated the FP7 CONFINE IP project from 2011-2015 about community networks and the Community-Lab.net testbed. Currently, he coordinates the Erasmus Mundus Joint Doctorate in Distributed Computing (EMJD-DC), and is co-chair of the IRTF.org working group GAIA (Global Access to the Internet for All). He is also executive board member of the Association for Progressive Communications (https://www.apc.org/).

Harris Niavis is a Research Engineer at University of Thessaly, Greece, where he focuses his research activities on community networks and technologies that could complement them, such as blockchain. He received the diploma of Computer and Telecommunication Engineering from the University of Thessaly, Volos, Greece and the M.Sc in Science and Technology of Electrical and Computer Engineering, from the same department, in 2011 and 2013 respectively. From 2012 until now, he is a Researcher Scientist in Centre for Research and Technology Hellas (CERTH) and in University of Thessaly (UTH). He has participated in a lot of EU research projects including OpenLab, FLEX, SmartFIRE, EINS, Fed4FIRE, MAZI leading the development of open source software platforms. He is experienced in control and management of wireless experimental facilities and in the programming of wireless, open source drivers. His research interests lie in the area of experimentally driven research, including the provision of experimental infrastructures, and in the areas of community networks, blockchain, social computing and wireless mesh networks.

Ramon Roca i Tió is co-founder and the President of Fundació Privada per a la Xarxa Oberta, Lliure i Neutral guifi.net (The Foundation for the Open, Free and Neutral Network -guifi.net). He has always been involved in IT social projects. In 2003 he had set up the first link of what few months later became the guifi.net community network. That wireless link was his proposal to overcome the lack of ISPs Internet supply in his village located in the rural area in the countryside of Catalonia. Immediately after, he started promoting his solution among his neighbours and started enhancing the Free Networks' model. Nowadays he is repeating that process with optical fibre, deploying it according to what he has called the FFTF model, i.e. Fibre From The Farm, a wordplay to stress that the Fibre deployment is made by active common people, From The Farm, instead of by the telcos, To The Home. This model, called as "Bottom-up Broadband initiative" by himself, was one out of eight selected ideas of the The Digital Agenda Stakeholder Day on 25 October 2010. His professional career has always been related to international IT companies.

Spencer Sevilla is a postdoctoral researcher at the University of Washington, where he works with Kurtis Heimerl and the ICTD lab on expanding Internet access via community cellular networks. Previously, Spencer did his PhD at the University of California at Santa Cruz, where he was advised by J.J. Garcia-Luna-Aceves. Spencer has published 13 peer-reviewed papers, is the author of 10 US patents, and has received numerous awards for his work, including two best paper awards (IFIP 2013, ICNP 2015), a UC Presidential fellowship, third place in the Mozilla WINS Challenge, and an Amazon Catalyst fellowship.

Félix Tréguer is a post-doctoral researcher at ISCC-CNRS Paris-Sorbonne. His research looks at power struggles surrounding the Internet and more generally communication technologies, at the intersection of political history, law as well as media and technology studies. He holds a PhD in political studies from the School for Advanced Studies in the Social Sciences (EHESS), and is a founding member of the advocacy group La Quadrature du Net.

1 Community Networks: Bridging Digital Divides through the Enjoyment of Network Self-determination

Luca Belli

Abstract

This chapter provides an introductory framework to understand this book, exploring why the emergence of community networks (CNs) has been particularly beneficial by nurturing multistakeholder cooperation, fostering sustainable expansion of connectivity and promoting the advancement of fundamental rights. The first section of this chapter briefly explores the idea of a right to Network Self-determination, providing concrete evidence of why the development of CNs allows individuals to enjoy this right. The second section, offers an overview of the strategies that can be adopted to develop CNs, by exploring the contributions featured in this book, while emphasising the great public-interest role that such contributions play, by sharing the knowledge necessary not only to build new CNs but also to make such initiatives scalable, sustainable and legally compliant.

CNs are collaborative networks, developed in a bottom-up fashion by groups of individuals that conceive, deploy and manage the new network infrastructure a common good. At the centre of CNs and the socio-economic ecosystems they generate lay the communities who are essential to initiate, maintain and guarantee the success of these connectivity efforts. This chapter argues that CNs provide tangible examples of valuable alternative approaches to expand connectivity – and, consequently, to fulfil the United Nations Sustainable Development Goals – in a bottom-up fashion. It stresses that the raise of CNs also offers a solid demonstration of how Internet governance processes can allow different stakeholders to cooperate, achieving common goals and concretely influencing the evolution of the Internet.

1.1 Introduction

This chapter provides an introductory framework to understand this volume, exploring why the emergence of community networks (CNs) has been particularly beneficial by nurturing multistakeholder cooperation, fostering sustainable expansion of connectivity and promoting the advancement of fundamental rights. The first section of this chapter briefly explores the idea of a right to Network Self-determination,[4] providing concrete evidence of why the development of CNs allows individuals to enjoy this right.[5] The second section, offers an overview of the strategies that can be adopted to develop CNs, by exploring the contributions featured in this book, while emphasising the great public-interest role that such contributions play, by sharing the knowledge necessary not only to build new CNs but also to make such initiatives scalable, sustainable and legally compliant.

CNs are collaborative networks, developed in a bottom-up fashion by groups of individuals – *i.e.* communities – that conceive, deploy and manage the new network infrastructure as commons. It important to stress that, at the centre of CNs and the socio-economic ecosystems they generate lay the communities and their members, who are essential to initiate, maintain and guarantee the success of these connectivity efforts.[6] Furthermore, such initiatives represent a long-awaited solution for members[7] of the International Telecommunication Union to implement concretely its Recommendation D.19 on Telecommunication for Rural and Remote Areas.

Indeed, while considering "that the provision of telecommunications, ICT services and applications can make significant contribution to

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4 Network Self-determination can be defined as "the right to freely associate in order to define, in a democratic fashion, the design, development and management of network infrastructure as a common good, so that all individuals can freely seek, impart and receive information and innovation." (Belli 2017a). The right to free development of network infrastructure stems from the fundamental rights to freely associate, to freedom of expression, to self-determination of peoples as well as to enjoy the benefits of scientific progress and its applications and can be seen as an instrumental condition to allow the full exercise of individuals' fundamental rights. (Belli 2017a and 2018). An introduction to Network Self-determination is also provided by the TED talk "From Network Neutrality to Network Self-determination" delivered by the author of this paper at TEDxRoma 2018. See <https://www.youtube.com/watch?v=2-xlBqbNzGU>.

5 This section is based on the work previously published in on Luca Belli. (28 March 2018) Network self-determination: When building the Internet becomes a right. IETF Journal.

6 In this perspective, the 2017 DC3 Report was tellingly dedicated to "Community Networks: the Internet by the People for the People." See <http://communityconnectivity.xyz/>.

7 For the list of 193 ITU member states, see <https://www.itu.int/online/mm/scripts/gensel8>

the quality of life of the population living in rural and remote areas [and] that access to telecommunications/ICTs for all will maximise social welfare, increase productivity, conserve resources and will contribute to safeguarding human right", the ITU recommends to its members "that local institutions, such as village committees should be involved in planning and implementing ICT" stressing that "[b]usiness models which can achieve financial and operational sustainability can be operated by local entrepreneurs supported by a variety of initiatives [...] including Universal Service Funds [...]."[8]

Besides offering a significant example of the existence of alternative and valuable approaches to expand connectivity – and, consequently, to fulfil the United Nations Sustainable Development Goals[9] – in a bottom-up fashion, the raise of CNs also offers a demonstration of how Internet governance processes can allow different stakeholders to cooperate, achieving common goals and concretely influencing the evolution of the Internet. Indeed, although CNs have started to be developed and studied more than twenty years ago,[10] the appearance and the rapid gain of prominence of CN discussions in the international policy arena is mainly due to the United Nations Internet Governance Forum (IGF) and the work spearheaded by the IGF Dynamic Coalition on Community Connectivity (DC3).[11] Undeniably, DC3 has provided a much needed platform through which various individuals and entities interested in the advancement of CNs have the possibility to associate, organise and develop, in a bottom-up participatory fashion collective "principles, rules, decision-making procedures and shared programs that give shape to the evolution and use of the Internet."[12]

In this sense, since the creation of DC3, a growing number of individuals and organisations from all over the world have come together to

8 See ITU Recommendation D.19 (03/10) <https://www.itu.int/rec/D-REC-D.19-201003-I/en>.

9 Notably, Goal 9 establishes the United Nations members' commitment to "build resilient infrastructure, promote sustainable industrialization and foster innovation." See <https://www.un.org/sustainabledevelopment/infrastructure-industrialization/>.

10 See the seminal work of Schuler (1996) and Flickenger (2002).

11 See <https://comconnectivity.org/> members For an overview of the DC3 outcomes and activities, see <https://www.intgovforum.org/multilingual/content/dynamic-coalition-on-community-connectivity-dc3-0?qt-dynamic_coalition_on_community_c=4#qt-dynamic_coalition_on_community_c>.

12 This is indeed the very definition of Internet Governance as provided by paragraph 34 of the Tunis Agenda. See <https://www.itu.int/net/wsis/docs2/tunis/off/6rev1.html>.

organise joint programmes and actions, conduct research, elaborate policy suggestions and advocate for such policy, with the goal of facilitating the development of CNs and increase visibility of the CN potential to bridge existing digital divides. It is important to note that the development of the Declaration on Community Connectivity, through an open and participatory multistakeholder process,[13] offers a telling example of the fact that the IGF is not a mere "talking-shop" and can produce concrete outcomes and policy recommendations, as foreseen by its mandate.[14] Indeed, the Declaration, which is a non-binding "living document", periodically updated by DC3 members, represents the first example of an international consensual document dedicated to the characteristics of CNs, the CN users and policy elements that allow such networks to thrive.

According to the Declaration, CNs are "structured to be open, free and respect network neutrality. These networks rely on the active participation of local communities in the design, development, deployment and management of shared infrastructure as a common, community-owned and democratically operated resource." These initiatives give rise to new infrastructures, new governance models and new business opportunities and facilitate the free flow of information, filling the lacunae left by the traditional Internet access-provision paradigm. As argued by the following section, CNs empower individuals, giving them the tools to stop being digital outcasts and become the protagonists of their digital futures, by enjoying their right to Network Self-determination.

1.2 When building the Internet becomes a right

Access to well-functioning network infrastructure on affordable and non-discriminatory terms facilitates significantly the full enjoyment of one's fundamental rights as Internet users can easily access knowledge and education, conduct businesses, and utilise digital public services, ranging from paying taxes to applying to schools and receiving remote medical consultations. As connected individuals,

13 This process began with an open consultation online, between July and November 2016, continued with a public debate and a collection process during the IGF 2016, and ended with a new online consultation between December 2016 and March 2017. The Declaration is available at <https://www.intgovforum.org/multilingual/index.php?q=filedepot_download/4391/1316>.

14 See Tunis Agenda paragraph 72.g <https://www.itu.int/net/wsis/docs2/tunis/off/6rev1.html>.

we can safely state that the Internet has become an integral part of our lives and our environment, affecting substantially how we form our opinions, how we socialise and learn and, ultimately, what opportunities we are able to grasp over the course of our lives. Such observation, though, makes even deeper the divides between those who can enjoy unrestricted and affordable connectivity and those who cannot, and demands the adoption of innovative thinking to give to the currently unconnected a credible chance to enjoy the same opportunities that the connected are already enjoying.

This section briefly explores how CNs allow groups of unconnected and scarcely connected individuals to regain control over their digital futures, building their own infrastructure and enjoying Network Self-determination. The section also stresses that, by developing CNs, the affected communities foster a distributed, interoperable and generative Internet, while also enjoying a number of positive externalities in socio-economic terms. In this perspective, CNs provide concrete examples proving that "the design and development of the Internet infrastructure have a growing impact on society"[15] and foster a digital environment that enables human rights. After having provided a brief introduction to CNs and the positive externalities that these initiatives generate, this section will argue that Network Self-determination, as a right to free development of network infrastructure, stems from already existing fundamental rights, consecrated in binding international-law instruments as well as in the majority of national Constitutions. Indeed, as argued in previous publications (Belli 2017a and 2018), the concept of Network Self-determination finds its solid juridical bases in the fundamental rights to freely associate, to freedom of expression, to self-determination of peoples as well as to enjoy the benefits of scientific progress and its applications.

1.2.1 Mainstream networks are not so mainstream

In almost every country in the world, Internet connectivity predominantly relies on the existence of network infrastructure built and managed by for-profit operators. Such infrastructure is primarily composed of "mainstream networks," which are those networks that

15 See RFC 8280 <https://trac.tools.ietf.org/html/rfc8280#page-40>.

RFC 7962[16] characterises as controlled in a top-down fashion by the operators; spanning large areas; requiring a substantial investment to be built and maintained; and not foreseeing the possibility for users to participate in the network's governance.

Not surprisingly, mainstream networks are mainly deployed and operationalised in densely populated areas, where return on investments can be quite fast and straightforward, due to the high demand for connectivity by thousands – or millions – of city dwellers. The situation, however, is not the same in rural areas or in the peripheries of major metropolises, where the scarce density and lower standards of living cannot guarantee immediate and sufficient return on investment for operators.

In rural and peripheral areas, which are home to the 48% of the world population that is currently unconnected,[17] the sole reliance on mainstream networks does not prove to be an effective strategy to expand connectivity. Indeed, the lack of return on investment discourages development of infrastructure, leading to lack of coverage or to such high prices and low quality of service that potential or existing users might be discouraged from subscribing to available Internet access offerings. In this context, several studies have pointed out that limited coverage and lack of competition can make Internet access offerings so prohibitively expensive that locals need to sacrifice food to afford communications.[18]

Most importantly, individuals living in unconnected or scarcely connected areas may rightfully fail to see the appeal of Internet access because any services or content that would improve their welfare – such as local government services, information and educational material in local languages and platforms making available local products and services – are not available online. In other words, the lack of locally developed, locally accessible and locally comprehensible – i.e. understandable by individuals only speaking local languages – makes internet connectivity uninteresting for the local population. (Belli, 2018)

16 See RFC 7962 <https://www.rfc-editor.org/rfc/rfc7962.txt>.

17 See e.g. <https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf>.

18 See e.g. Rey-Moreno et al. (2016).

1.2.2 Do-It-Yourself Internet

Despite the above scenario, many individuals living in unconnected or scarcely connected communities have realised that Internet connectivity is a vector for the economic, social and cultural development to which they have a fundamental right.[19] For this reason, they have taken action to stop being digitally marginalised, due to market failures and inefficient public policies, and start building their own CNs, to become the active designers and implementers of their digital futures. Concretely, such reasoning has become possible thanks to the steady reduction in infrastructure costs – particularly, regarding bandwidth and network equipment – that, over the past decade, has facilitated the deployment of CNs with reasonably low investments.

CNs are crowdsourced initiatives. Described by RFC 7962 as "alternative networks [...] that do not share the characteristics of mainstream network deployments." On the contrary, as already emphasised, CNs are better characterised by their bottom-up development and by the fact they are managed by the local community as a commons. Importantly, besides representing a viable solution to fill the connectivity gaps left by mainstream networks, CNs also ensure that Internet traffic is managed with no commercially motivated discrimination, thus respecting net neutrality[20] by default. Indeed, all network users are partners in the provision of connectivity and in the development of services for the local community, thus making it much less likely that the provider – which is the community itself – will discriminate against content, applications or services based on commercial considerations, as the greatest interest of the community is to have access and be able to share all possible content and applications.

Therefore, the raise of CNs demonstrates that connectivity, openness, free choice and full enjoyment of fundamental rights are not amenities reserved to opulent city-dwellers but basic needs to which everyone is entitled and that everyone can and must enjoy. Moreover, they prove that "connectivity increases the capacity for individuals to exercise their rights."[21]

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19 See art. 1 Universal Declaration of Human Rights, art 1.3 of both the International Covenant on Civil and Political Rights and art 1.3 of the International Covenant on Economic, Social and Cultural Rights.

20 For an ample collection of analyses exploring the net neutrality debate, see <http://www.networkneutrality.info/>.

21 See RFC 8280 <https://trac.tools.ietf.org/html/rfc8280#page-40>.

1.2.3 When the last mile becomes the first mile

Community networking shows that in many circumstances the unconnected can connect themselves as long as they have information on how to build[22] their network infrastructure and the freedom to choose this option. It is precisely in these circumstances that a wide range of CNs have emerged in many countries presenting radically different socio-economic and geographic contexts.[23]

Broadband for the Rural North or B4RN[24] (pronounced "barn"), for example, was initiated in 2011 by a group of farmers in Lancashire, U.K., who decided to overcome the lack of connectivity by starting to self-install fibre. Today the B4RN network connects about 5000 properties, where thousands of individuals enjoy speeds as high as 10 gigabit per second.

The non-governmental organisation (NGO) AlterMundi,[25] which is behind QuintanaLibre, a community network in the Argentinian province of Córdoba, prides itself on having successfully developed a "geek-free" model to overcome the main challenges posed by rural environments, the scarcity of engineers and reduced incomes, by developing an easy to implement and cost-efficient network technology. Importantly, the connectivity brought by QuintanaLibre has stimulated the development of several applications by the locals for the locals, including information portals, chat services, Voice-over-IP (VoIP) servers, community radio streaming services, file sharing systems and gaming applications.

The AlterMundi-affiliated networks also provide Internet access to three schools, giving students – who otherwise would be totally disconnected – the opportunity to access online resources, train online and, potentially, share the fruit of their creativity as entrepreneurs. Similarly, the Brazilian NGO Coolab[26] provides connectivity and training to dozens of children through the *Casa dos Meninos* project while connecting an entire village via the Fumaça community network in Rio de Janeiro state. It is important to reiterate that, besides being

22 The first part of this book offers a selection of resources explicitly aimed at providing such information to all interested individuals. See Part I.

23 For a thorough, although non-exhaustive, list of existing CNs, see Navarro (2016:84-98).

24 See <https://b4rn.org.uk/>.

25 See <http://altermundi.net/>.

26 See <http://www.coolab.org/quem-somos/>.

a direct fruit of the local community engagement, the development of CNs has provided access to opportunities the newly connected communities were completely excluded from.

Importantly, the development of CNs has also demonstrated that such initiatives can be scalable[27] and reach relevant size and number of users. The most successful example in this sense is guifi.net[28] that, besides being the biggest CN in the world with over 85,000 users, is particularly outstanding for its common-pool-resource philosophy that favours the establishment of "a disruptive economic model based on the commons model and the collaborative economy,"[29] encouraging small, local entrants to develop new applications and to extend the network themselves.[30] Indeed, Guifi.net members have generated a variety of services[31], amongst which are VoIP servers, chat servers, videoconference and mail servers, and broadcast radio.

Importantly, besides expanding the Internet and promoting innovation in a decentralised fashion, CNs like guifi.net have created dozens of new jobs related to network maintenance and entirely new digital ecosystems. Indeed community networking generally features capacity-building programs for locals to acquire the skills they need to be developers, creators and online entrepreneurs. This generative effect deploys a further positive externality, making the locally developed Internet more interesting (Belli, 2018) for the local population that, finally, has the possibility to find content and services catering the local needs and in the local languages.

In this perspective, it can be stated that CNs are built by the people for the people,[32] and the access network they provide should not be considered as the last mile of the Internet but rather as the first mile. Indeed, these networks play a vital role in maximising the generative nature of the Internet, decentralising innovation at the edges and empowering the unconnected by providing new learning, networking and employment opportunities.

27 See chapter 6 of this book for a discussion on CN scalability.

28 See <http://guifi.net/>.

29 See <https://guifi.net/en/what_is_guifinet>.

30 See Baig et al. (2015).

31 A complete list of services developed by the guifi.net community can be found at <https://guifi.net/en/node/3671/view/services>.

32 See Belli (2017b).

1.2.4 Network self-determination

These examples of CNs briefly explored in the previous section provide a sample of the positive externalities triggered by such initiatives and offer sound evidence based on which a right to Network Self-determination can be constructed. The concept of Network Self-determination equals to the right to freely associate to define, in a democratic fashion, the design, development and management of network infrastructure as a common good, in order to freely seek, impart and receive information and innovation.[33]

While community networking proves that Network Self-determination already exists *de facto* even without being explicitly consecrated *de jure*, it is important to stress that this concept is also solidly grounded in international human rights law.[34] Indeed, the first article of both the Charter of the United Nations and the two International Covenants of Human Rights decisively affirm that, by virtue of the fundamental right to self-determination, all peoples are free to pursue their economic, social and cultural development as well as self-organisation. According to both Articles 1(3) of both Covenants, all states have an obligation "to promote the realisation of the right to self-determination," which is considered the collective right of a given community to determine its own destiny. The first part of the Network Self-determination concept corresponds to the right to freely associate, which is explicitly protected by art. 22 of the International Covenant on Civil and Political Rights (ICCPR), numerous binding international law instruments and the majority of national constitutions. Th last fragment of the concept, on the other hand, is a simple rephrasing the right to freely seek, impart and receive information and ideas, enshrined in ICCPR, art. 19 and many regional and national binding instruments creating enforceable rights and obligations.

CNs clearly foster Network Self-determination, for they allow individuals to decide how to pursue their economic, social and cultural development, choosing which kind of technology, applications and content are best suited to meet the needs of the local community and using and developing them in a quintessentially distributed fashion. The goal of community networking is indeed

33 See Belli (2017a).

34 For a discussion in this sense, see Belli (2017a:39-46) and Belli (2018:49-54).

to empower individuals who will become new, active participants in the Internet, thus enjoying the benefits of connectivity while contributing to the evolution the network of networks as "a large, varied and evolving space of technology."[35]

Crucially, Network Self-determination empowers individuals rather than creating additional burdens on them. This means that every individual must be free to create new Internet infrastructure, as well as new applications and new content, but it does not mean that governments should be relieved from their universal service obligations nor that operators willing to provide access service should be impeded from doing so. Indeed, we must consider Network Self-determination as a right and an opportunity rather than an obligation to develop new network infrastructure.

1.2.5 Rights, as technologies, are the product of history

As mentioned above, the enjoyment of Network Self-determination through the development of CNs can prompt several positive externalities, fostering a decentralised Internet and allowing previously unconnected or scarcely connected individuals to access knowledge and education, create new applications and find occupations, having access to the entire spectrum of opportunities to which any individual should be entitled.

Enthusiasm and optimism regarding community networking should be tempered with a good dose of pragmatism, though. Indeed, alternative networks should be seen as a valuable complement to existing approaches rather than a silver bullet that can solve all connectivity problems. As mentioned in the second part of this book, CNs require sound planning and good governance to be successful, scalable and sustainable, and may face many technical and policy obstacles over their path.

As the Italian philosopher Norberto Bobbio famously argued, human rights are the product of historical evolutions.[36] In this spirit, everyone should be free to enjoy Network Self-determination, associating and building new pieces of the Internet. Communities around the

35 See RFC 1958 <https://tools.ietf.org/html/rfc1958>.

36 See Bobbio (1996).

globe are discovering they have the potential to create alternative networks and many of them are already doing so, thus concretely enjoying their right to network-self-determination. There is no doubt that Network Self-determination reinforces the distributed nature of the Internet and there is no reason why individuals should not have the possibility to build the Internet themselves, improving their standards of living while bridging digital divides. For these reasons, the first section of this book provides concrete instructions on how to build CNs, as underlined by the next section.

1.3 How to enjoy Network Self-determination

The fundamental goal of this volume is to provide to any interested person a manual offering instructions, strategies and useful suggestions to create CNs, make them sustainable and scalable, while being mindful of complying with regulation, thus keeping networks as spaces for the enjoyment and promotion of rights and respect of legislation. This section offers an overview of the content of the volume in this respect.

1.3.1 Instructions for aspirant community network builders

The first part of this book is opened by Steven Mansour and Sascha D. Meinrath's analysis on "**Building Community Wireless Networks: A How-to Guide for the Curious**", providing concrete instructions helping the reader to take the first steps towards building a community wireless network. The Guide is a starting point for understanding the basic building blocks to community wireless networks, which digitally connect communities, and allow neighbours to share Internet access or use locally hosted applications. The authors stress that there are many ways to design a community wireless network, but many options can lead to confusion. Based on the experience of several CNs and Wireless Internet Service Providers, Mansour and Meinrath provide initial guidance on how to build community wireless networks, starting from the very basics of Wi-Fi and networking (such as IP addresses, 2.4GHz vs 5GHz wireless frequencies) and identifying concrete steps that any interested group of individuals should follow in order to successfully establish a community wireless network.

Subsequently, Spencer Sevilla, Pathirat Kosakanchit, Matthew Johnson, Kurtis Heimerl deliver an excellent complement to the previous chapter with their study on "**Building Community LTE Networks with CoLTE**", which provides detailed, step-by-step instructions on how to build, deploy, and operate a small-scale community Long Term Evolution (LTE) network. The manual assumes a reader who is somewhat familiar with networking concepts – and the reader of this book will be thanks by reading the previous chapter – but is explicitly not a technical expert or knowledgeable about the cellular space. The authors provide a brief overview of LTE architecture; cover the need-to-know topics for a network operator; provide suggestions for selecting and buying hardware; discuss the variables around band selection and corresponding licensing concerns; and provide step-by-step instructions for installing, configuring, and running our community LTE network-in-a-box project, which the authors define as "CoLTE".

In "**The MAZI Toolkit for Do-It-Yourself Networking**," Harris Niavis, Stavroula Maglavera, Aris Dadoukis and John Mavridis describe, from a system design point of view, the MAZI toolkit, which consist of a Do-It-Yourself networking toolkit for enabling the easy deployment, operation, configuration and maintenance of local wireless networks by communities. The MAZI toolkit encompasses diverse Free-Libre / Open Source Software (FLOSS) applications and services for social innovation and addresses generic social challenges towards shaping a more human-centric Internet. Importantly, the MAZI toolkit is based on low-cost open hardware and open-software platforms, like the Raspberry Pis, sensors and other Internet of things (IoT) devices. The authors stress that the conceptualisation, design and development of the toolkit was a crowdsourced community effort, taking place within participatory processes that were open to engaging researchers, developers and actors of diverse communities.

This bottom-up approach facilitated the emergence of ideas that rapidly materialised into applications and tools towards addressing real community needs and challenges. In this perspective, the MAZI toolkit integrates popular already existing open-source, self-hosted applications (such as NextCloud, Etherpad, LimeSurvey and Wordpress) thus including existing open-source communities in the MAZI ecosystem.

In "**LibreRouter: the Hardware and Software Platform for Community Networking**", Nicolás Echániz and Florencia López Pezé describe the emergence and materialisation of the LibreRouter project. The authors emphasise that, for a large part of the disconnected population – eminently rural, poor and living in the global south – the business and networking models that have connected the first half of the world population will not be viable. In this scenario, CNs have acquired prominence, as a promising solution to expand connectivity in disadvantaged areas, a model that can reach where others cannot. The authors stress that challenges to deploy these CNs "on the field" are still very significant – especially in the global south – and, to provide concrete solutions to this challenges, the LibreRouter project has been conceived. LibreRouter is a device, which would finally allow community mesh networks to count on a hardware and software platform, designed with their specific needs in mind.

This chapter explores the challenges and successes of the LibreRouter project. The design and development process of LibreRouter combined the efforts of more than 20 specialists from all over the world, long time CN activists from different continents, electronic engineers, hackers, and communicators. The chapter briefly describes the multiple stages of prototyping of LibreRouter and provides an overview of the results that, to date, seem promising.

1.3.2 Scalable, sustainable and law-compliant community networks

The second part of this book explores some critical dimensions of CNs: scalability, sustainability and legality. These dimensions have to be pondered carefully by would-be CN developers, as they are critical for the success of any CN.

Roger Baig Viñas, Leandro Navarro, Ramon Roca i Tió open this part with their analysis of "**The Multiple Dimensions of Community Network Scalability**", which deliver some essential food for thoughts for aspiring CN developers. The authors stress that diverse initiatives around the world show the feasibility to build bottom-up community networking infrastructures to join the Internet. However, they admit that an experimental network by and for hackers has very different implications, at all levels, compared to a general-purpose production network for an entire population. Scalability in the design of CNs makes the difference between clubs, with entry barriers of complexity and limited service, and extensible network commons able to accommodate and serve every user in an area. To foster such reflection, the authors tackle scalability from what they consider the four main dimensions of CNs: social, legal, economic and technological. Importantly, the authors utilise the experience and lessons learned by guifi.net and other CNs to illustrate the discussion and ways to achieve scalability in CNs.

Successively, in "**Federating Community Networks: A case study from France**", Félix Tréguer explores the challenges of coordinating various CNs with different models and governance features. Tréguer considers the case study of Fédération French Data Network (FFDN), an acknowledged success of the CN movement, created in 2011 and federating CNs across the country. The chapter notes that, when FFDN was established, interest in grassroots communication networks managed as a commons was booming, and rather than growing existing ones, swarming (i.e. the creation of several independent local organisations) was deemed a better strategy. Although communities in other states have explored other forms of coordination, this process of federation provides an interesting model for ensuring the coordination of various CNs with different models, and for establishing solidarity and fostering resiliency in the face of the many challenges entailed buy the maintenance and defence of CNs.

The author posits that, despite some difficulties, FFDN represents an interesting precedent for other national and regional CN environments willing to foster collective cohesion. After offering a brief history of the CN movement in France, up to the creation of Fédération FDN in 2011, Tréguer explores the federation's main organisation features and accomplishments.

In "**Fostering Sustainability of Community Networks: Guidelines to Respect the European Legal Framework**" Virginie Aubrée and Mélanie Dulong de Rosnay propose guidelines to help CNs to cope with the applicable European legal framework and mitigate legal risks while protecting users' rights and enforcing core values such as privacy. The authors cover three main topics that are key to the activity of CNs: civil liability, data protection, data retention and provides concrete recommendations on the legal choices to be made, as well as suggestions for CN governance choices. The chapter is based on the analysis of the EU legislation and case law applicable to "electronic communications services", "electronic communications network", and providers of an "information society service". The analysis is informed by a survey, which gathered replies on the practices of CNs from six EU countries (France, Italy, Germany, Greece, Portugal and Slovenia) in five main areas: organization, services offered, relationship with users, data protection and data retention law. The authors present the findings of the research putting forward recommendations in the areas of civil liability, data protection law, data retention, and proposing governance recommendations to address these challenges and mitigate CNs legal risks.

In "**Complementary Networks Meet Complementary Currencies: Guifi.net Meets Sardex.net**", Panayotis Antoniadis, Jens Martignoni, Leandro Navarro and Paolo Dini develop a parallel analysis of CNs and community currencies. This comparison reveals many similarities and differences between these two models of self-organisation around networking infrastructures and monetary systems, respectively. This chapter brings together experts from both domains in an effort to share knowledge and experience, using as case studies two emblematic projects, Catalonia's success story on CNs, Guifi.net, and Sardinia's success story on community currencies, Sardex.net. The long-term objective is to build a better common understanding of the individual models but most importantly the stimulation of synergies and collaborations of researchers and activists from both sides.

Lastly, Panayotis Antoniadis and Jens Martignoni close the second part of this volume, exploring "**What Could Blockchain Do for Community Networks"** The authors argue that an increasing number of blockchain-based initiatives claim a revolutionary role as technological solutions that will facilitate the sharing and management of resources in CNs and Internet access sharing in general. Many of such initiatives focus on the accounting, measuring and then monetising of data-streams as an idea to enforce individual contribution to infrastructure, maintenance and service. This Chapter builds on the analysis developed in the previous chapter, establishing an analogy between CN's and Community Currencies, highlighting the variety of possible models that exist in both domains.

Antoniadis and Martignoni advance this work by exploring two different ways through which an alternative currency model can support existing CNs. Although blockchain could be the underlying implementation solution for any alternative currency, the authors discuss alternative currencies separately from recent blockchain solutions that are part of the global cryptocurrency ecosystem, since these latter phenomena entail certain important threats that need to be understood for CNs in order to truly benefit from this new technology and not get absorbed by it.

1.4 Conclusions

This book does not only offer a sample of the vitality, quality and interest of the contributions, projects and policy suggestions developed by DC3 members. It also demonstrates that the vitality, quality and interest of such initiatives are not decreasing over time but, on the contrary, DC3 members are are increasing cooperation and their ideas and projects are cross-fertilising each other's, reaching such a level of maturity that some of the most relevant institutions in the world are recognising their importance and impact. This makes the initiatives developed by DC3 members even more relevant and valuable.

Over its first three years of activities, DC3 has demonstrated to be an incredible platform for cooperation, coordination and engagement. A simple and old-fashioned mailing-list has proven to be an incredible venue for synergy, where ideas are regularly proposed and discussed, and frequently find a way of being implemented, minimising costs and maximising benefits. Individuals and entities form literally all around the world are utilising this platform to initiate research, finding reliable partners for new or ongoing projects and critically analyse the research and project outcomes, while utilising such outcomes to propose concrete policy recommendations. Exactily as a CN, the coalition has a bottom-up, open and distributed nature and members join to cooperate for the advancement of the collective interest, contributing as much as they can.

This book concludes the first trilogy of DC3 volumes,[37] demonstrating that Network Self-determination is already enjoyed and can be

37 The 2017 DC3 report was dedicated to "Community networks: the Internet by the people, for the people." See <http://communityconnectivity.xyz/>. The 2016 report was dedicated to "Community Connectivity: Building the Internet from Scratch." See <https://bit.ly/2gZB2kn>. Both volumes are freely available, under Creative Commons License.

enjoyed not only by networking experts but also by neophytes, who understand they have the right to associate and communicate, to pursue their social and economic development and contribute to the progress of the Internet. This book offers concrete instruction to build the Internet, allowing anyone to become a creator of connectivity and a true Internet prosumer, enjoying the ability to access, but also to create and share, any content, applications and services, actively contributing to the evolution of a decentralised network of networks while enjoying the opportunities that connectivity offers. This volume provides concrete instructions on how to enjoy your right to Network Self-determination.

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PART I

How to Build Your Community Network

2 Building Community Wireless Networks: A How-to Guide for the Curious

Steven Mansour and *Sascha D. Meinrath*

Abstract

This How-To Guide is intended to help the reader take the first steps towards building a community wireless network. It is derived from documentation tools that the Open Technology Institute has used in workshops around the world and at home. It is a good starting point for understanding the basic building blocks to community wireless networks. Open community wireless networks digitally connect communities, and allow neighbors to share Internet access or use locally hosted applications. Neighbors are linked from rooftop to rooftop using wireless equipment.

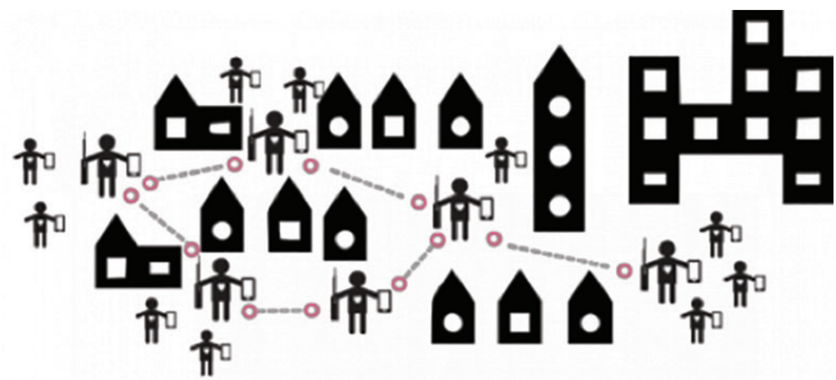
There are many ways to design a community wireless network, but many options can lead to confusion. Fortunately, many community networks and Wireless Internet Service Providers (WISPs) have had many years of experience to learn from. In these pages, the reader will learn the very basics of Wi-Fi and networking, such as IP addresses, 2.4GHz vs 5GHz wireless frequencies, various Wi-Fi modes- infrastructure vs. ad-hoc, etc. The goal is to provide initial guidance on how to build community wireless networks, identifying concrete steps that any interested group of individuals should follow in order to successfully establish a community wireless network.

More in-depth, technical guidance to develop a community wireless network can be found consulting the Commotion Construction Kit at <http://communitytechnology.github.io/docs/cck/>.

2.1 Community Wireless Networks

Open community wireless "mesh" networks digitally connect communities, and allow neighbors to share Internet access or use locally hosted applications. Community networks differ from other business models in many ways, but especially in their implementation, ownership, and management.

Community Networks (CNs) are built by coalitions – community anchor institutions, community-based organizations, municipal representatives, and individuals work together to plan, design, and deploy these networks. Ownership and management duties are distributed among the community – often to individuals and organizations who volunteer their time and expertise. "Digital Stewards" are an increasingly common term we use for the community members that administer these networks – their role being to facilitate the growth, stability, and inclusiveness of the network.



The goal of this paper is to provide guidance on how to build community wireless networks, identifying concrete steps that any interested group of individuals should follow in order to successfully establish a CN. Particularly, the following networking building steps should be observed.

2.1.1 Identify Community Partners and Define Partnership

The essential step in deciding which partners will develop, plan and maintain the network; what roles/responsibilities each will have and how mutual accountability within the initiative is structured.

1. **Determine Pilot Network Area:** Plan the initial network to connect key locations in the community (which may often include individual residences, the roofs of community anchor institutions, small businesses, and other supporters of the initiative).

2. **Outreach and Planning:** Surveys, community meetings, and transparent and/or participatory budgeting can ensure that the network receives vocal local support. Manage expectations by presenting the project as a collaborative effort, not a free service. It is important to remember that there are always costs associated with these networks but often one can find innovative ways to minimize them or get expenses defrayed in their entirety.
3. **Installation:** Installation varies widely depending on hardware and software platforms used.[38] Please see <https://commotionwireless.net/docs/get-started/> for more in-depth information. Most importantly, Wi-Fi is an approachable technology that anyone (from kids to the elderly) can implement. If there is one take-home message, it is that every community can build their own 21st Century telecommunications infrastructure if they so wish.
4. **Train Digital Stewards to Manage the Network:** For long-term sustainability, think early about who will handle maintenance and troubleshooting. Anyone can become a wireless networking expert in a matter of months. We strongly encourage skills sharing as an integral part of the entire CN implementation process: often, by the time the network is actually deployed, entirely new cohorts of Digital Stewards have developed their skills to the point that continuing maintenance and sustainability becomes an easy lift.

2.1.2 The essential role of partnerships and connections

Community networking begins with people. When starting the organisation of a CN, interested individuals should think strategically, trying to forge partnerships with established institutions and work with the local community to determine communication needs, interests, and willingness to participate and help.

The work starts with conversations or meetings about how your group could use mesh networking to improve everyone's quality of life. In this sense, CN builders should aim at involving the entire local community and establish cooperation with:

- Public institutions (libraries, post offices, museums, schools, universities, etc.)

38 For more in-depth information, please see <https://commotionwireless.net/docs/get-started/>.

- Public gathering spaces (parks, coffee shops, etc.)
- Community-based organizations
- Businesses (especially social entrepreneurs, start-ups, locally-owned mom-and-pops)
- Municipal governments
- Local arts and media groups

2.1.3 Build and explore your network

The goal of CN developers should be to deploy the network and get multiple devices to communicate throughout the local community. As such, CN builders should teach users in the community how to connect to the network and how to continue to extend its coverage area.

It is important to continuously experiment with services that can be offered by mesh applications on the network or share Internet connection with the network so others can get online. CNs should be seen, not only as a connection to the Internet, but also as a new platform for developing and implementing Local Area Networking applications and services. A CN can function as a local radio station, local television station, a communications medium, and as a platform for development of new services. CNs allow developing community-run multimedia platforms with far more options than traditional (Internet-only) connectivity options.

2.2 Introduction to Networking

This section covers the basics of how networking works, and how to use different kinds of devices to build your network. Computer networking has existed for decades, and as time has passed the technologies have become both far faster and much less expensive. Networks are made up of various components — computers, switches, routers — connected together by cables or wireless interfaces. Understanding the basics of how networks are interconnected is an important step in building a wireless network in a community or neighbourhood; and knowing this information will help you in deploying networks, whether in your living room or at metro-scale.

This section covers the concepts of

1. **Clients and servers:** how services such as e-mail and web pages connect using networks.
2. **IP addresses:** how devices on a network can be found.
3. **Network hubs, switches and cables:** the hardware building blocks of any network.
4. **Routers and firewalls:** how to organize and control the flow of traffic on a network.

2.2.1 Clients and servers

An important relationship on many networks is the communication between servers and their clients. A server is a computer that holds content and services (e.g., a website, a media file, or a chat application). An easy-to-grasp example of a server is the computer that holds the website for Google's search page: <http://www.google.com>, <http://www.google.com>. The server holds that page, and sends it out when requested by a user.

A client is a different computer, such as your laptop or cell phone that requests to view, download, or use the content held by a server. The client can connect over a network to access information held by a server. For instance, when you request Google's search page with your web browser, your computer is the client. In the example below, two computers are connected together with an Ethernet cable. These computers are able to see each other and communicate over the cable. The client computer asks for a website from the server computer. The website is delivered from the server, and displayed on the client's web browser.

Most requests and content delivery on networks are similar to, or are based on, a client to server relationship. On a network, the server can be located almost anywhere, and if the client has the address, it can access the content on the server.

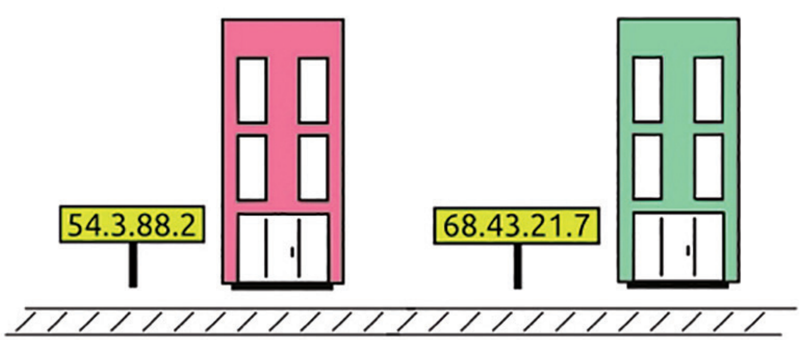
2.2.2 IP addresses

In order to send and direct data across a network, computers need to be able to identify destinations and origins. This identification is an IP—Internet Protocol—address. An IP address is just a set of four numbers between 1 and 254, separated by dots. An example of an IP address is **208.67.222.222**.

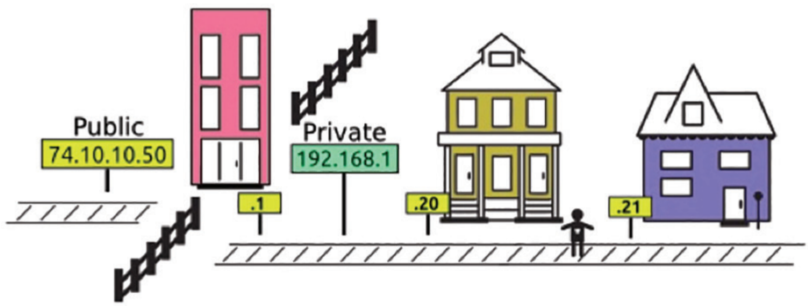
An IP address is similar to a street address. Parts of the address describe where in the world the building is located; another part narrows it down to a state or city, then the area within that state or city, then the location on the street. Below we can see 192.168.1 Street. On it are three houses:

The complete addresses for each of these houses is 192.168.1.20, 192.168.1.21, and 192.168.1.22.

There are two key different classifications of IP addresses. A network address can be public, or it can be private. Public IP addresses are accessible anywhere on the Internet. Private IP addresses are not, and most are typically hidden behind a device with a public IP address. In the example below, we can see a street with two buildings with public IP addresses, representing computers with addresses that are visible to the entire Internet. These buildings might be anywhere in the world, but their addresses are complete, so we know exactly where they are and can send messages to them.



To see an example of how public and private IP addresses are commonly used, let us consider, again, the instance of the imaginary 192.168.1 Street. We have a new building on the street that we can call “the postal service building”. That building has a public IP address, and a private IP address. In practice, this means that a fence, close to the postal service building, blocks the rest of the Internet from seeing and passing messages to addresses on the street.

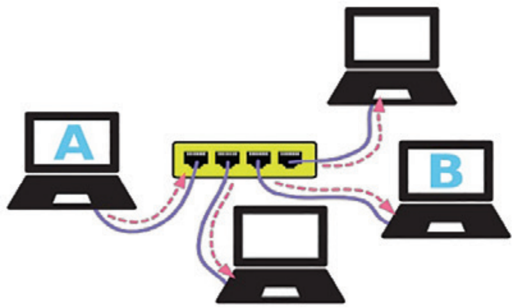


The postal service building controls messages that travel between the Internet and the street, keeping track of messages that leave the street, and directs return messages to the right house. On the street, it has the address 192.168.1.1, but on the Internet, it has the address 74.10.10.50 (in other words, the Internet cannot see the private house’s address).

2.2.3 Network hubs and switches

Traditionally, computers are connected to each other using cables, thus creating a network. The cable used most often for local connectivity is Ethernet, which consists of four pairs of wires inside of a plastic jacket. It is physically similar to phone cables, but can transport much more data. For long-distance communication, the cable of choice is fibre optic, which uses pulses of laser light to encode data.

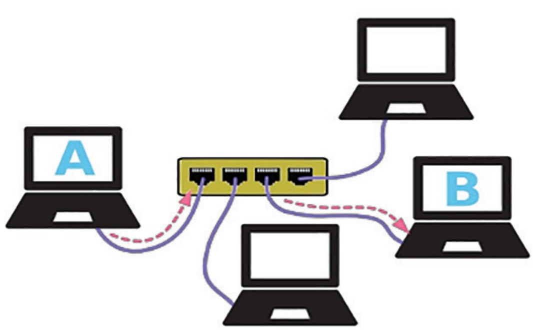
However, because connecting every computer directly to one-another would be impractical, we also use network hubs to help organise the flow of data. For example, in most homes and offices, Ethernet cables from various computers connect to the device similar to the hub of a bike wheel, where all of the spokes come together in the centre. An example of how a hub works can be seen in the picture below. Computer A wants to send a message to computer B. It sends the message through the Ethernet cable to the hub, and then the hub repeats the message to all of the connected computers.



The picture below exemplifies how a hub works. Computer A wants to send a message to computer B. It sends the message through the Ethernet cable to the hub, and then the hub repeats the message to all of the connected computers.

However, a network using a hub can slow down if many computers are sending messages, since they may try to send messages at the same time and confuse the hub. To help with this problem, networks began to use another device called a switch. Instead of repeating all messages that come in, a switch only sends the message to the intended destination.

This eliminates the unnecessary repetition of the hub. Using a switch, computer A sends a message to computer B and the other computers do not see the message. Thus, computers can send other messages at the same time without interfering with one-another.



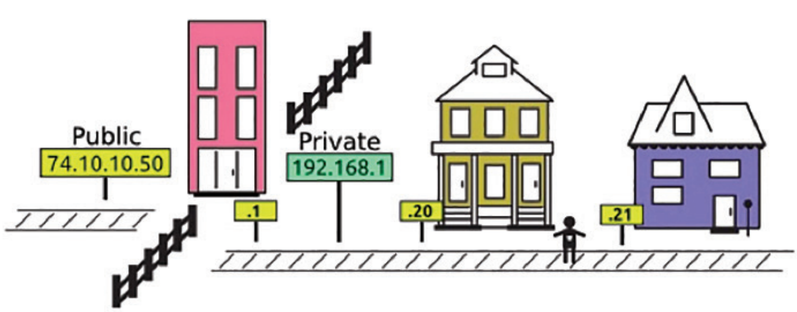
Switches do have a limitation though: they only know about the addresses of equipment that is plugged directly into them. Therefore, you can only send messages to a small number of devices, regardless of how many ports the switch has. If you need to send a message to a computer on another network, it will need to be sent through a router, which we discuss next.

2.2.4 Routers and firewalls

Routers do the majority of the hard work on a network: they make the decisions about all the messages that travel on the network, and whether to pass to and from outside networks. Routers implement three main functions:

1. **Separate and Bridge.** Routers separate networks into sections or bridge different networks together, as we see in the example above, in which the private network of 192.168.1 Street is bridged to the Internet with a public IP address.
2. **Assign IPs.** They can assign IP addresses. In the above example of 192.168.1 Street, if a new house is built on the street, it would get whatever the next highest house number available. In the case of routers, they assign IP addresses using a process called Dynamic Host Configuration Protocol (DHCP). If you have ever connected to a Wi-Fi hot spot, you have already used DHCP to get online.
3. **Firewall and Protect.** They can filter messages or keep users out of private networks. Most routers have a Firewall built in. This is a software function that keeps unwanted messages from reaching the computers on the inside, or private part of the network.

Let us take another look at 192.168.1 Street, and the postal service building we included when it had a public address for the entire street. As it turns out, that postal service building is acting as a Router.



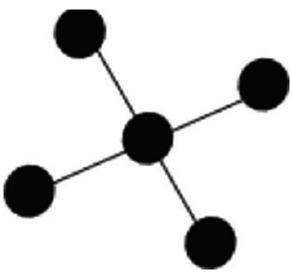
In this case, the postal service building is routing messages between the rest of the Internet using its public address (74.10.10.50) and the street with private addresses (192.168.1.x).

Congratulations, you now know more about network architecture than 99% of the population!

2.3 Introduction to Mesh Networking

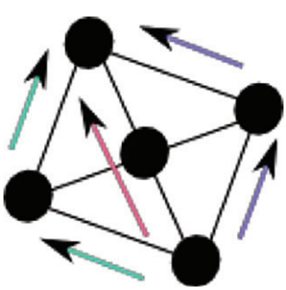
There are many ways to build networks and many technologies one can use. Understanding mesh networking is important for designing your network, and for talking to people in your neighbourhood who may want to support or be involved with your project.

Networks can have a hierarchical or mesh structure.



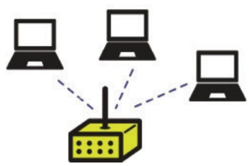
Networks are groups of connected devices that move information or messages from one device to another. Most networks (including cellular phone networks) use a "hub and spoke" (hierarchical) architecture, with users connecting to other users via a central device that controls connections and traffic on the network. This means that any time you communicate through the network, the message or data must first go to that central hub, then be sent on to its destination. Your cell phone network uses this architecture.

Mesh networks route differently than non-mesh networks.



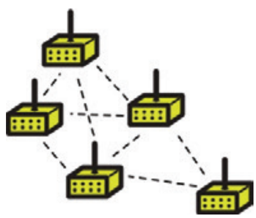
The difference between mesh networks and other kinds of networks is that mesh networks can interconnect devices directly, without a central hub. While there are numerous technical protocols and network architectures for mesh, the commonality is that devices do not necessarily need a central hub to communicate. Walkie-talkies and CB radio often utilize a mesh architecture.

Routers are devices that determine how information moves across the network.



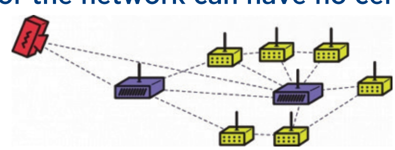
Standard Wi-Fi access points, like the one you might have at home, talk to computers or smartphones, but they cannot easily talk to other routers. Thus, your home Wi-Fi network (or the network in your local coffee shop) uses a hub-and-spoke architecture

Mesh-enabled routers can dynamically talk to each other, allowing them to flexibly route traffic within the network.



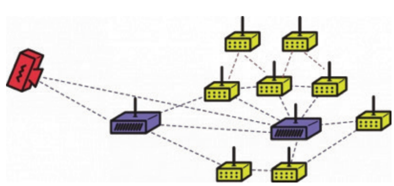
By default, most routers and devices are not able to mesh. However, with the right software, some routers, cell phones and laptops can mesh. Often, builders of mesh networks can install open-source software to enable mesh networking on devices that were previously used on a hub-and-spoke network.

Mesh devices can be the hub or central point in the network – or the network can have no central point.



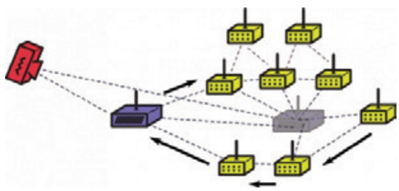
With mesh, the more devices that are part of the mesh network, the more flexible the network can become. Mesh is so flexible that a device can be the central point in the network, or the network can have no hub.

Mesh devices can form the edge of the network, able to extend its reach and form new connections.



A dynamic mesh network, unlike a more "static" traditional network, constantly adapts to new conditions. It automatically adjusts its pathways to integrate new nodes that join the network and has the flexibility to reroute information when a node leaves the network.

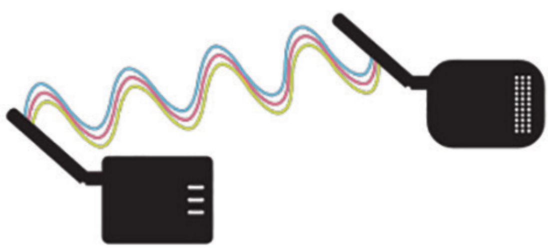
Mesh networks are strengthened and expanded as the user base grows.



When there are many interconnected mesh nodes, the network can bypass interference, blockage, or network congestion. When your friend sends a reply text to you, if one of the nodes stops working, the mesh network will adapt accordingly, ensuring you get the message.

2.4 Learning wireless basics

Wireless signals are important because they can transfer information, such as audio, video, our voices, or any kind of data, without the use of wires. wireless signals are electromagnetic waves traveling through the air. these signals form when electric energy travels through a piece of metal, for example a wire or antenna.



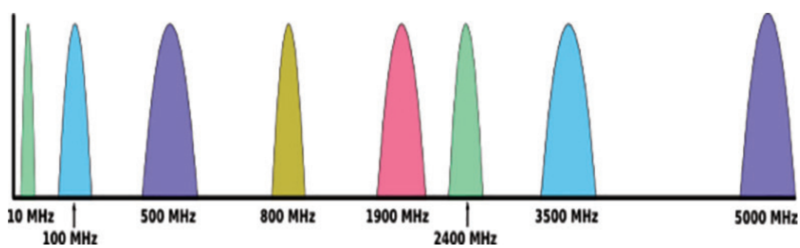
2.4.1 Types of wireless signals

There are many types of wireless technologies. You may already be familiar with FM radio, Television, Cellular phones, Wi-Fi, Satellite signals such as GPS and television, and Bluetooth. The wireless signals most often used for local computer connectivity operate on several different frequencies. If the signal "vibrates" slowly, it has a low frequency. If the signal vibrates very quickly, it has a very high frequency. Frequency is measured in Hertz, which is the count of how quickly a signal changes every second. As an example, FM radio signals vibrate around 100 million times every second. In fact, your favourite FM radio station will tell you exactly how fast it's signal "vibrates": a radio station at 88.5 FM is "vibrating" 88,500,000 times per second!

Since communications signals are often very high in frequency, we abbreviate the measurements for the frequencies: one million of vibrations a second is a Megahertz (MHz), and one billion vibration a second is Gigahertz (GHz). Therefore, one thousand Megahertz is equal to one Gigahertz.

2.4.2 Example Frequency Ranges

Below we can see the span of frequencies that are commonly used in communications. Broadcast transmitters for AM, FM and Television use frequencies below 1000 MHz; Wi-Fi uses two bands at higher frequencies: 2.4 and 5GHz; and cellular phones use many different frequencies.



The picture above represents the following frequencies, from left to right:

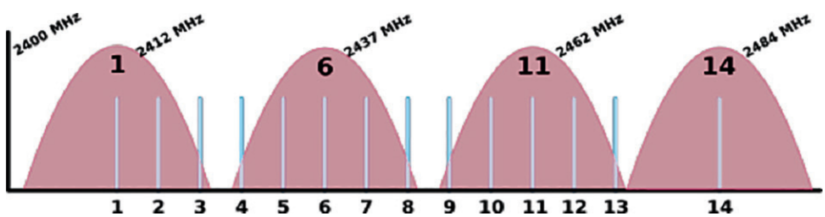
- **AM Radio:** Around 10MHz
- **FM Radio:** Around 100MHz
- **Television:** Many frequencies from 470MHz to 800MHz, and others.
- **Cellular phones:** 850MHz, 1900MHz, and others
- **Wi-Fi:** 2.4GHz and 5GHz
- **Satellite:** 3.5GHz

2.4.3 Wi-Fi signals

When building a wireless network, the group of individuals involved will be using Wi-Fi technology, which has some unique characteristics that must be understood. These two types of Wi-Fi are often named based upon their frequency bands, or just bands for short. They are:

- **2.4 GHz** is the lower main Wi-Fi band. This was the first common Wi-Fi technology used for local wireless networking. Many legacy devices use it, so the signals are often more congested (especially in city environments), which can lead to interference and slower throughput speeds. However, this band can pass through walls and windows better than the 5 GHz band.
- **5 GHz** is a higher frequency Wi-Fi band, which has been added to Wi-Fi more recently and can sometimes achieve higher speeds, because the frequencies are less crowded. Therefore, while its range is shorter and it cannot pass through walls and windows as well as the 2.4 GHz band signals, its throughput can often be higher.

Each frequency band used in Wi-Fi is divided up into multiple “channels”. Each channel may be considered as one of many rooms at a party: if one room is crowded it is hard to carry on a conversation. You can move to the next room, but that might get crowded as well. As soon as the building is full, it becomes difficult to carry on a conversation at the party.



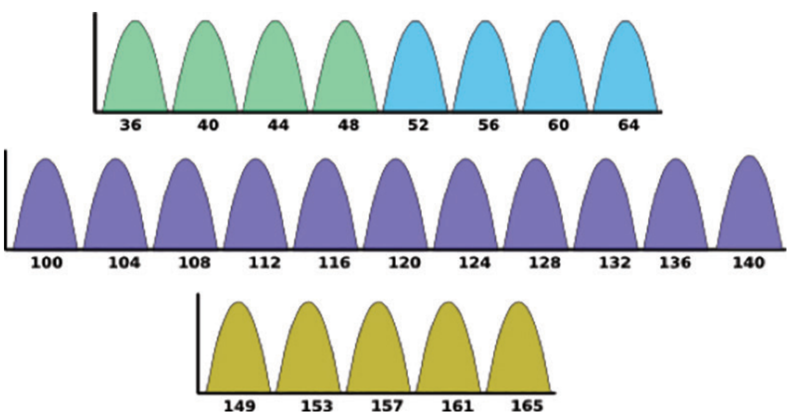
2.4.3.1 The 2.4 GHz Band

The 2.4 GHz band includes 14 channels in total. However, the available channels vary depending on where you are in the world. For example, in the United States channels 12, 13 and 14 cannot be used Wi-Fi. Hence, if you are building networks in the United States, you can only use channels 1 through 11. In the rest of the world, channels 1 through 13 are generally usable, and in a few places channel 14 is also available. Making things a bit more complicated, these channels overlap. If we utilise the abovementioned party rooms metaphor, channel overlap may be considered as hearing noise from a conversation in the next room. For this reason, an optimal choice is often to space your channel utilization out. This is why the most often used channels for 2.4 GHz WI-Fi equipment, in most of the world, are channels 1, 6, and 11.

It's possible to use other sets of Wi-Fi channels – ideally, these would also be spread at least five channels apart (such as 3, 8 and 13). However, in the 2.4 GHz band, 1, 6, and 11 are the only non-overlapping channels, in many places in the world channel 13 is not available. To be able to establish a CN, it is therefore, essential to start by verifying what channels are most in use. Numerous applications can be freely downloaded to check, using any smartphone, what channel is in use nearby and, subsequently, plan to use a channel that does not overlap in order to build the new CN.

2.4.3.2 The 5 GHz Band

The 5 GHz frequency band is much wider than the 2.4 GHz band and has many more channels, as the diagram below illustrates. This enables networks to utilize many more non-overlapping channels than exist in the 2.4 GHz band.



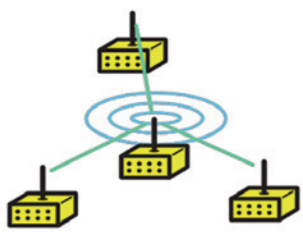
Because there are many more channels available in the 5 GHz band, it is often easier to select a channel in this band that causes minimal interference although, as more and more wireless equipment is using the 5 GHz band, that may not always be true. In this context, it is important to note that the availability of additional unlicensed Wi-Fi bands for wireless networks is a type of evolution that would greatly facilitate the expansion of CNs.

Importantly, when setting up a wireless CN, the CN founders will need to think about what frequency band(s) to use, and what channel(s) within the chosen band(s) to use.

2.4.4 Antennas

Wireless routers also utilise many different types of antennas. Some routers will have antennas built in (like modern smart phones), and sometimes the routers will provide different options for what kind of antennal you want to attach. There are many kinds of antennas, but three basic types are used most of the time, and will be useful in building a wireless network. The first type of antenna is also the most common: it is the omnidirectional antenna.

2.4.4.1 Omnidirectional Antennas



An omnidirectional antenna sends a signal out equally in all directions around it. One can picture how omnidirectional antennas work by considering connectivity as the waves rippling out from a rock dropped into a still pond.

Using omnidirectional antennas has the benefit of creating connections in any direction. As a CN developer you will minimise planning that you need to connect with multiple neighbours or buildings. However, the all-direction strength of these antennas comes with the drawback of transmitting a weaker signal in any one direction. Because the signal is going in all directions, it spreads out and gets weaker with distance very fast. Therefore, if routers or clients are far away, they may not connect well.

In addition, if there are only nodes or clients in one direction of the router, then the signals going in the opposite direction are wasted (or worse yet, may interfere with someone else's wireless communications). Almost all off-the-shelf home routers use omnidirectional antennas.

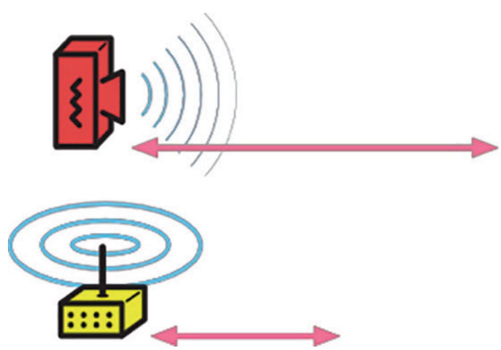
2.4.4.2 Directional Antennas

The next type of antenna is known as directional and it sends out a signal in a more focused way. There are two main types of directional antennas.

Sector antennas send out a pie-shaped wedge of signal. They are usually anywhere between 30 degrees (a slice equal to 1/12th of a pie) and 120 degrees (a slice equal to 1/3rd of a pizza) wide. These often long, rectangular antennas are separate or integrated in to a router.

A **focused antenna** (or Point-to-Point antenna) sends out a very narrow beam of signal. It is normally around 5 to 10 degrees wide, but it can be a little wider as well. These often have a dish or bowl for reflecting signal.

Using directional antennas has the benefit of increasing the distance a signal at a particular power level will travel in one direction, while reducing it in all other directions. Since the signal is all going one way, the power that would be sent out in all directions with omnidirectional nodes is now focused, increasing the power in that direction.



It can also decrease the interference received at the node. There are fewer signals coming in to the directional antenna, since the node is mostly listening to signals from the direction it is pointing. It will not hear signals behind it or to the sides as well or at all. This reduces the signals it needs to sort out, and allows it to focus on other signals more, increasing the quality of those connections and throughput of your network.

However, directional antennas also have the drawback of requiring more planning to create links in your neighbourhood. Since you, as a CN developer, are defining and limiting the areas where wireless signals go, you need to think about how those signals will cover your neighbourhood so that you do not leave anyone out.

Moreover, while your main directional wireless node has a very powerful signal in a single direction, it does not necessarily mean that less powerful devices (such as laptops) are able to connect back. The laptop may hear the node very well, but the directional node may not hear the laptop. This problem as akin two individuals yelling to each other across an empty stadium when only one of them has a bullhorn: such individuals may end up having a very one-sided conversation.

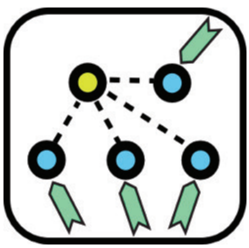
Wireless technology can be used for many types of communication. For example, we use it for networking because it is cheaper and more flexible than running cables. Nevertheless, while wireless networks can be just as powerful as wired networks for many use cases, they do have some inherent drawbacks.

2.4.5 Wireless device roles

A Wi-Fi device can use three major “modes”, operating as clients, access points or mesh. These modes define the role a Wi-Fi device has in the network, and networks must be built out of combinations of devices operating in these different modes. How the devices are configured depends on the types of connections one wants to use between different components of the network. Thus, in addition to the phones, tablets, and laptops one may use in accessing a network, routers may also make up the hardware that runs the network.

2.4.5.1 Wireless Clients (Station)

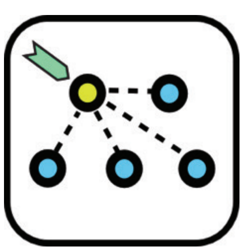
Wireless clients are the devices such as computers, tablets, and phones that are commonly used to connect to a network. Most often, these are the consumer devices in our backpacks and pockets. When you are accessing a wireless hotspot or the router in your home or office, your device is the client. This client mode is also known as "station mode".



While some routers can operate as clients as well, allowing them to act like your computer or smart phone and connect to another Wi-Fi access point (AP) – which can be extremely useful for bridging between two different networks – usually wireless clients are separate devices from APs. A wireless client is similar to a person in the audience of a play or movie. They are one of several or many people accessing information through the same conduit: the stage or screen performance.

2.4.5.2 Access Points (Master)

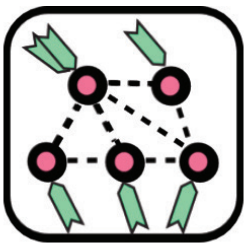
Most wireless networks are created using access points (APs), which are the devices that host and control the wireless connection for laptops, tablets, and Wi-Fi enabled smart phones. If you use Wi-Fi in your home or office, it is most likely through an access point. When a router is set up as an AP, it is said to be in "Master" or "Infrastructure" mode.



An AP is sometimes a stand-alone device that bridges between a wireless and wired (Ethernet) network. At home, you will often use a Wi-Fi AP to connect to the wireline connection of your Internet Service Provider. APs can cover different sized areas with connectivity depending on the power of the device and the type of antenna, but are often limited in range to the size of a house or smaller. There are also some APs that are weatherproof and designed to be mounted outdoors.

An Access Point is similar to a speaker on stage that is answering questions from the audience: it is broadcasting information and is limited in how many questions it can answer at once. Likewise, the audience members can ask questions of the person on the stage and receive a response, but if people are talking right next to them, they may be unable to hear the answer.

2.4.5.3 Ad-Hoc Node (Mesh)



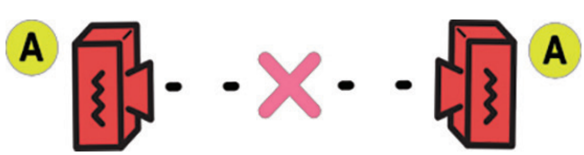
Some wireless devices (laptops, smart phones, or wireless routers) support a mode called Ad-Hoc. This allows those devices to connect directly to one-another, without an AP in-between. This forms a very different kind of network: in Ad-Hoc mode, all devices are responsible for sending and receiving messages from other devices that are within range. In an Ad-Hoc network, every device must be able to utilize this role.

Ad-Hoc devices are used to create a Mesh network, so when they are in this mode, they are called “Mesh Nodes”. An Ad-Hoc or Mesh node is similar to an individual in a well-moderated group discussion. They can all take part in the conversation, raising their hand when they want to speak so the others will listen and, if someone at the end of the table cannot hear, one of the individuals in-between can repeat the original message for the listener.

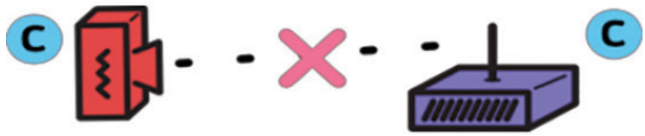
2.4.6 What connects to what?

From the roles above, you can see that Clients always need to connect to an Access Point, and Mesh nodes all connect to each other. It should also be noted that, due to how Wi-Fi is designed, this also prevents different roles from connecting to each other as well.

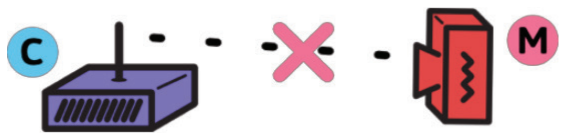
Access Points cannot connect to each other wirelessly:



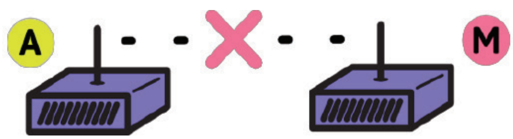
Clients cannot connect to each other wirelessly:



Clients cannot connect to Ad-Hoc (Mesh) devices wirelessly:



Access Points cannot connect to Ad-Hoc (Mesh) devices wirelessly:



2.5 Wireless devices in networks

The three types of roles above – Clients, Access Points, and Ad-Hoc nodes – should be considered as the building blocks for large networks. Below are several examples that demonstrate how devices configured for different roles can be used.

2.5.1 Access Point - home or office network

Wireless networks used in your home or office are generally a combination of a router and a wireless Access Point (AP).

In the diagram above:

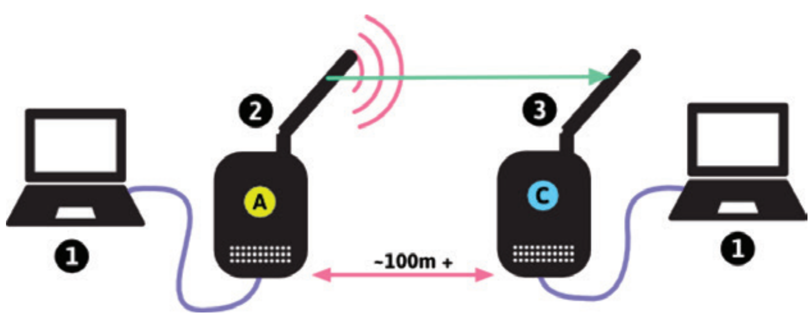
1. Represents the connection to the Internet (though some network functionality can work without the Internet, for example, a shared printer or local file storage device).
2. Represents the router that assigns local IP addresses and provides a firewall between your private network and the public Internet.
3. Represents the Access Point, providing a wireless bridge between the router and the users' devices.

4. Represent user devices, such as laptops, tablets, and smartphones.

In many home and small office networks, the router and AP may be combined into a single device. This is often called a wireless router and may also have a DSL, Cable, 3G, or 4G port to provide the connection to the Internet. In large office scenarios, there may be several AP devices spread throughout the building to provide more even wireless coverage, connected back to the main router through Ethernet cabling.

2.5.2 Point to Point link - Long Distance Connections

While wireless networks can be used to connect distant buildings or areas, this usually requires very focused antennas, such as a dish antenna, that can send a narrow beam in a specific direction. A long-distance connection is often called a "Point-to-Point", or "PtP" link. The name literally describes the concept: two points are connected to one-another and nothing else. This requires two wireless devices: one is usually configured as an access point the other as a client. In the example below, two wireless devices are configured to create a Point-to-Point link.



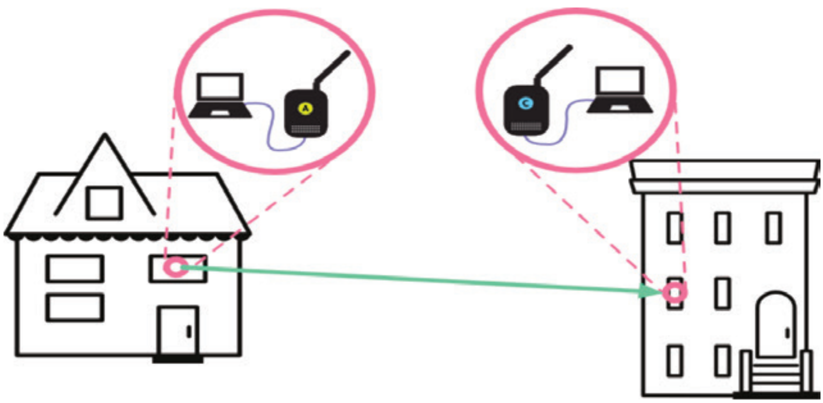
2.5.2.1 Omnidirectional Access Point and Client Link

In the diagram above:

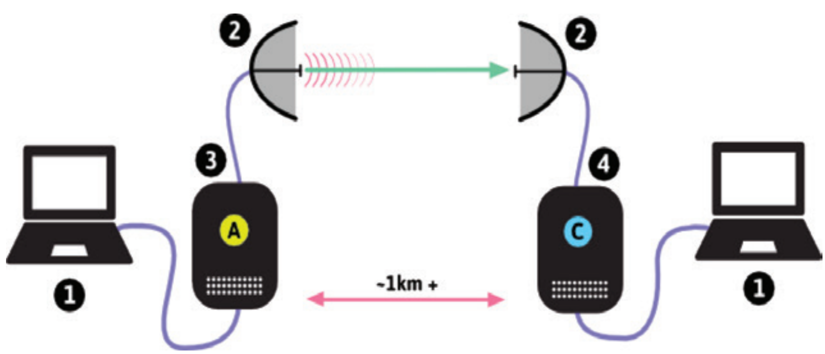
1. Represents computers connected with Ethernet cables to the wireless devices. These computers are connected to each other over the Point-to-Point link.
2. Represents the wireless device setup as an Access Point.

3. Represents the wireless device setup as a Client, connected to the Access Point.represents the wireless device C setup as a client, which connects to access point A via a short-range omnidirectional antenna.

This could look like the building-to-building connection, as shown below:



2.5.2.2 Long-distance directional Access Point and Client Link



In the diagram above, we have another example of a Point-to-Point link but, in this case, routers have dish antennas for greater link distance.

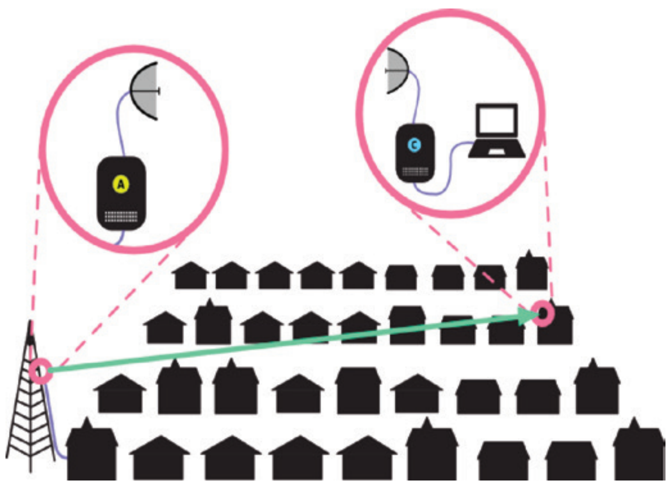
1. Represents computers connected with Ethernet cables to the wireless devices. These computers are connected to each other over the Point-to-Point link.

2. Represents the wireless device setup as Access Point A.

3. Represents dish antennas that focus the wireless signal, allowing connections over long distances.

4. Represents the wireless device C setup as a client, which connects, via the dish antenna, to access point A.

This could look like the network below, where an AP mounted on a tower is able to connect with a Client device in a home very far away, since the dishes are facing one another.



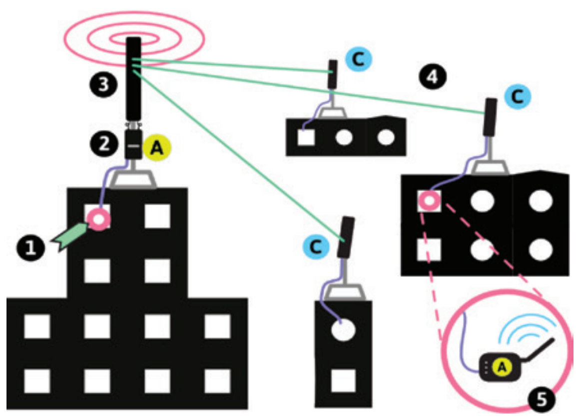
In both of these larger-scale wireless network examples, there are just two wireless devices linked together – with the antennas being appropriately chosen as determined by the range at which they can connect. As a general rule of thumb, the more focused the signal, the further the Point-to-Point link can reach. As the distance between the devices grows, it is increasingly important to focus the signal with antennas at both ends of the connection.

2.5.3 Point to MultiPoint - Wireless Internet Service Provider model

By combining the two principles used in the examples above – *i.e.* by combining many client devices connecting to an access point, and powerful antennas that can be used to create longer links – it is possible to create "Point-to-Multipoint" or "PtM" networks. You may think of these as having the same characteristics as the access point networks in your home or favourite cafe, but at much larger scale.

These types of networks are used by Wireless Internet Service Providers (WISPs) to connect homes and businesses from across their service areas to the Internet. Instead of running cables around a neighbourhood or town, they install one or more powerful access points on a tall building or tower. By installing directional wireless devices in client mode on other rooftops, and pointing them back at the tall building or tower, those buildings can be connected to the WISP's networks, and thereby the Internet.

The diagram below is one example of how this might work: a powerful access point mounted on a high building and several nearby buildings with rooftop wireless client devices. Each of these outdoor rooftop client devices is connected to an indoor router or access point, which allows users (clients) to connect their computers, laptops, tablets, or smartphones to the WISP network and the Internet.



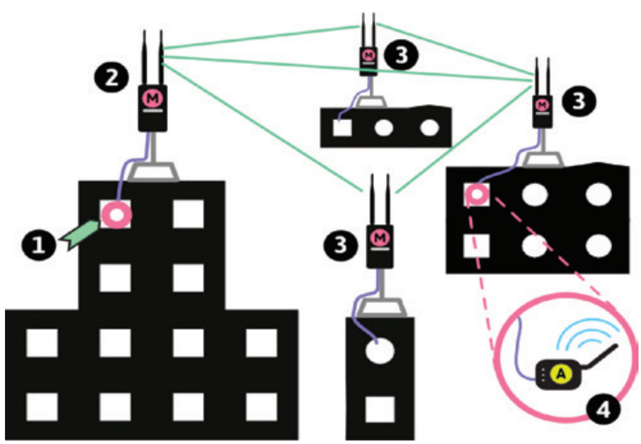
In the diagram above:

1. Represents the WISPs connection to the Internet.
2. Represents an Access Point providing the signal for client devices to connect to.
3. Represents a powerful omnidirectional antenna which sends the wireless signal to a large area around the building.
4. Represents client wireless devices (C) on the roofs of nearby buildings, which are linked to the powerful access point (A), and able to connect to the Internet through that AP.
5. Represents a customer's access point distributing wireless service inside a single apartment.

2.5.4 Mesh - Neighbour-to-neighbour Networks

A mesh network takes the principle of a Point-to-Multipoint network and extends it to the idea of every node connecting to every other node in range. In effect, this creates a "Multipoint-to-Multipoint" network. This network architecture usually requires all devices to be in the Ad-Hoc mode since wireless devices in AP mode or Client mode cannot perform the same peer-to-peer connections.

This example illustrates just one model for how this might look. Wireless mesh nodes are installed on the rooftops of various buildings, and the nodes that are in range will automatically connect to one-another. These nodes will share all resources connected to them (*e.g.*, local servers hosting applications, file servers, printers, audio streams, as well as connections to the Internet). These Ad-Hoc nodes can also be connected to computers, access points, or routers inside the buildings so users can access these resources from anywhere on the network.



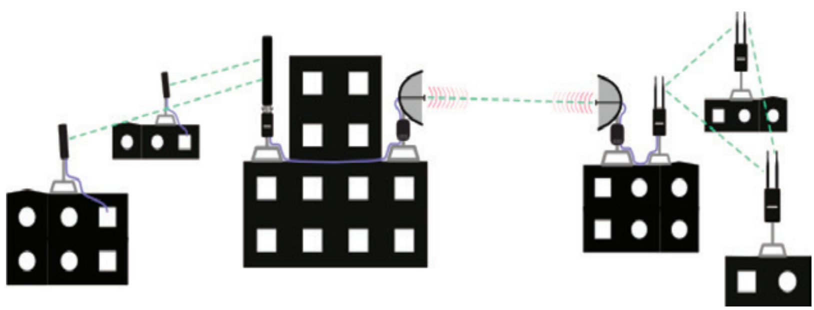
In the diagram above:

1. Represents the connection to the Internet.
2. Represents a Mesh Node (M) with a connection to the Internet, with an omnidirectional antenna.
3. Represents Mesh Nodes (M) with omnidirectional antennas that are receiving Internet access from Mesh Node 2. They may be connected to various different devices inside their buildings as well.

4. Represents small access points (A) that is distributing connectivity within an apartment.

2.5.5 Hybrid Networks

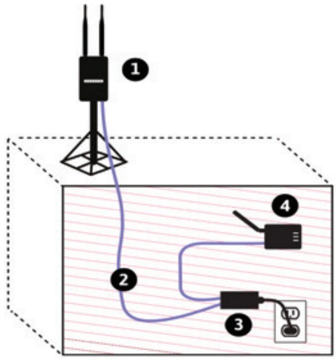
When designing and building CNs, be they small size or and metro-scale networks, it is often advisable to utilise several different architectures in the overall network. Thus, a single Point-to-Multipoint network may not cover the area where an entire community is localised, but could utilise mesh nodes to extend client sites to nearby buildings that could not otherwise receive connectivity; and a Point-to-Point connections can also be used to bridge longer distances and join several disconnected networks together; as illustrated below:



Our examples focus deploying networks across rooftops (from building to building) since this is generally the best way to build networks that can scale to neighbourhoods, communities, towns, and cities. However, the many different ways in which people interconnect is far more diverse than just the ways shown.

For example, rooftop routers may not provide connections to users on the ground (or in buildings), so one often will need to implement extensions to rooftop architectures to serve local parks, basement apartments, or high-density use areas.

We have often found that a good way to provide these network extensions is to attach an access points to an Ethernet port on the rooftop router. This AP can be set up to use the rooftop network as the source of its network and Internet connectivity, as exemplified below:



In the diagram:

1. Represents the rooftop wireless device. It could be a Mesh Node, or Client router.
2. Represents the Ethernet cable running out to the rooftop (*e.g.*, from a Power-over-Ethernet adapter).
3. Represents a Power over Ethernet adapter, which is a common way to power outdoor Wi-Fi equipment.
4. Represents a basement access point, which can now connect to the community network through the rooftop router.

2.6 Planning wireless sites

When it comes time to design and build your community wireless network, it is helpful to have as much detail about each installation site before you visit them. Below are some helpful tips for router placement on, in, and around buildings that we have explored over the past two decades of building community wireless networks. This process should normally come after you conduct an assessment of the community needs and is helpful in deciding which sites should be your highest priority for deployment.

2.6.1 Router placement

Wi-Fi signals like the ones used in community wireless networks are mostly line-of-sight and degrade very quickly if the devices cannot see one another. Line-of-sight is the reason why so much wireless networking equipment is often mounted on tall towers or high rooftops.

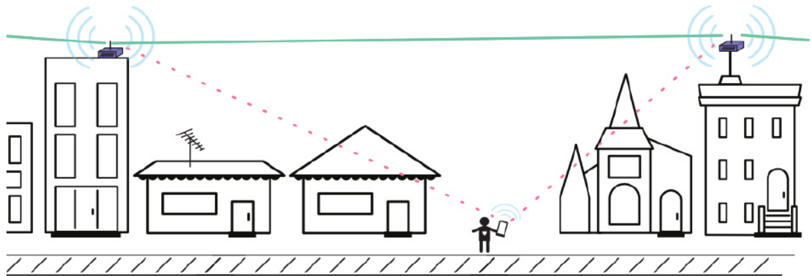
The reason your home access point does not connect very far is that it is likely hidden away somewhere. Because of the distance when you are connecting buildings across a neighbourhood, it is always recommended to place the wireless networking equipment in locations where you can see from one node to the next. Indeed, if two routers have a building or some trees between them, the signals will be degraded and they may be unable to communicate.

Often, the best method for designing networks is to build them in layers:

- The top or backbone layer has the fastest connections, and provides the core connectivity. In a neighbourhood or town network, the backbone would connect distant parts of the network together.
- The middle or distribution layer have fast connections, but also distribute or move large amounts of traffic from people using the network to the backbone layer, which then connects out to the Internet.
- The lowest or access layer provides the means for networks users to get online. One might connect your phone, tablet or laptop to an access point, which in turn is connected to the distribution layer, and out via the backbone to the Internet. In the case of CNs, using multiple layers can lead to better performance, more capacity, and higher reliability across the network:

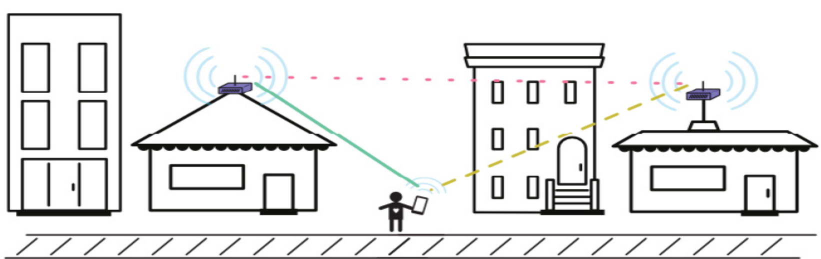
2.6.2 Backbone connections: the network's foundation

The wireless signals can go further, thereby covering more area and linking parts of the neighbourhood or town together. Directional routers can be used for direct Point-to-Point links, bolstering capacity in sections of the neighbourhood or town where the network is becoming congested. Backbone equipment is often mounted very highest possible location and usually does not provide a good connection point for the people on the ground or inside of buildings, as exemplified in figure below.



2.6.3 Distributing connections: equipment in the middle

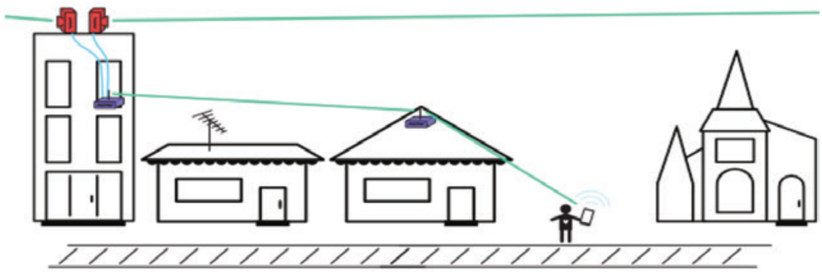
There are many ways to connect from the top of the network to the bottom. Cables can run from the top layer to access points where users connect, or there could be a cluster of mesh nodes wirelessly distributing access to a section of a neighbourhood. In other cases, Point-to-Point or Point-to-Multipoint (commonly utilised by Wireless Internet Service Provider) can be used to provide connections to the Access connections. The most important element is that this layer should be separated from the backbone, as long as this is possible, in order to avoid network congestion.



2.6.4 Access connections: the User-access layer

Wireless routers close to the ground and inside buildings provide better coverage for people to connect their phones, laptops, and other devices to the network. Often, these routers consist of low-cost, off-the-shelf access points from your local (or online) store of choice.

For the most part, installing wireless equipment on rooftops and indoors should be common sense and is no more difficult than installing a TV antenna. When you visit a potential installation site, it will most likely be very clear where the best spot for the equipment will be, where the cables can be run, and where the indoor access points will go so people can access the network.



2.7 Conclusions

This guide aims at providing, in a very concise fashion, the basic instruction and information needed for the organisation and deployment of a Wireless CN. For more in-depth instructions on the entire process of setting up a community wireless network, we encourage you to visit Commotion's website at <https://commotionwireless.net/docs/get-started/>.

3 Building Community LTE Networks with CoLTE

Spencer Sevilla*, *Pathirat Kosakanchit*, *Matthew Johnson* and *Kurtis Heimerl

Abstract

In this chapter, we provide detailed, step-by-step instructions on how to build, deploy, and operate a small-scale community LTE network. This manual assumes a reader who is somewhat familiar with networking concepts (IP addresses, etc.) but is explicitly not a technical expert or knowledgeable about the cellular space. Given this background, this chapter (1) provides a brief overview of LTE architecture; (2) covers the need-to-know topics for a network operator (PLMN IMSIs, etc.); (3) provides suggestions for selecting and buying hardware (along with our personal experiences, when applicable); (4) discusses the variables around band selection and corresponding licensing concerns; and (5) provides step-by-step instructions for installing, configuring, and running our community LTE network-in-a-box project, which we call CoLTE. CoLTE provides an all-in-one LTE EPC stack, but also comes with a wide range of additional services, including a WebGUI, user monitoring and billing software, and many additional locally-hosted services, such as a media server.

3.1 Introduction and Overview

Community networks (CNs) use a wide range of network technologies in their backhaul[39], including but not limited to fiber, long-distance directional WiFi, and microwave links. However, almost all of these networks terminate their fronthaul[40] and connect to end-user devices via WiFi (IEEE 802.11). There are many good reasons for this choice, including widespread support for WiFi in most networked devices, the unlicensed nature of the 2.4 GHz

39 "Backhaul" refers to the part of the network that does not directly interface with customers.

40 "Fronthaul" or "access network" refers to the part of the network that directly connects with users.

spectrum, and the ease of connecting a WiFi access point to a network or the Internet.

Despite WiFi's position as the default choice for fronthaul, LTE (Long Term Evolution) compares favourably to WiFi across a wide range of performance metrics, especially when considered in the context of rural access. These metrics include higher spectral efficiency, longer signal range, protocol-level support for longer transmission times, and asymmetrical power consumption, among others.

Unfortunately, setting up a small-scale LTE network is still a much more challenging and intimidating process for network operators, especially when compared to the plug-and-play nature of commercial WiFi routers today. While some of these challenges (such as acquiring spectrum and printing SIM cards) are fundamental characteristics of an LTE network, many other challenges can be addressed with the same basic network configuration tools and techniques that have dramatically simplified WiFi network establishment over the past ten years.

To address these gaps and enable any network engineer to setup and operate their own community LTE network, we started the Community LTE Project (CoLTE)[41] and wrote the guidelines included in this chapter. CoLTE is a set of open-source software packages designed to simplify and automate the process of setting up and operating a standalone LTE network, either for free or for profit. These guidelines can be thought of as an equal companion to the CoLTE Project, in that they provide not only a guide of how to get started with CoLTE, but also include detailed instructions and information about all the network components that CoLTE cannot simplify or automate, such as hardware selection, antenna configuration, and ordering SIM cards.

This manual is organised into several independent sections. Newcomers to the LTE space should read them in order; veterans should feel free to jump around, as they deem necessary. Section 3.2 ("Background") provides some background information with respect to LTE, cellular network architecture, and what CoLTE is and

41 See <https://communitylte.wordpress.com>.

isn't. Section 3.3 ("Getting Started") covers all the information and decisions you will have to make before you order hardware, which is covered in Section 3.4 ("Hardware Selection"). Section 3.5 ("CoLTE Setup") covers setting up the network, building CoLTE, configuring the evolved NodeB (eNodeB) and the Evolved Packet Core (EPC),[42] and connecting your first phone. Section 3.6 ("CoLTE Operation") covers the operational features of CoLTE beyond network attach, such as (1) billing users; (2) the user web portal and payment system; and (3) how to perform day-to-day network operations and maintenance. Section 3.7 ("Additional Services") describes other non-essential local network services that we have added to and integrated with the CoLTE package for convenience. Section 3.8 ("Feedback and Contribution") concludes these guidelines.

3.2 Background

3.2.1 Understanding LTE

The defining characteristic that separates LTE from previous generations of cellular networks is that in LTE, the underlying network substrate is entirely IP-based. This convergence on an IP base dramatically simplifies network establishment and maintenance, enables tremendous flexibility and interoperability of in-network services, and enables us to approach LTE as both a traditional telecom technology *and* an Internet access technology.

3.2.1.1 Components of an LTE network

An LTE network is comprised of four different key components: the eNodeB, the Home Subscriber Server (HSS), the Mobility Management Entity (MME), and the Serving Packet Gateway (SPGW). The MME, HSS, and SPGW are software components, and when grouped together, are collectively referred to as the Evolved Packet Core (EPC).

The eNodeB can be thought of as the "cell tower," and is a physical device (often a backpack-sized box) located at the edge of the network. The eNodeB establishes, monitors, and maintains communication on the physical-layer link between the cell tower

42 The eNB and EPC are discussed in section 3.2.1.1.

and the phone, and forwards all subsequent communication between the phone and the network core.

The three remaining components that comprise the EPC exist not as physical devices, but as logically separate software components. The HSS maintains, queries, and updates all subscriber-related information, including but not limited to billing, usage, keying, and current IP address. The MME performs the majority of the control signaling in the network, handling operations such as network attach, device authentication, routing and location queries, intra-network mobility (*i.e.* handoff between towers), and inter-network mobility (*i.e.* roaming). Finally, the SPGW forwards communication between phones and bridges communication between a phone and the outside world.

3.2.1.2 Basic Network Operations in LTE

When a phone connects to an LTE network, it exchanges a set of control messages with the eNodeB to synchronize and establish a radio link. Once this link is established, the network establishes a secure tunnel between the phone and the MME using the S1AP protocol. Once this tunnel is established, the phone and MME exchange many more control messages (approximately 6-10, depending on specific variables) to authenticate each other and establish network service. Finally, once the phone is allowed onto the network, another tunnel is established between the phone and the SPGW using the GPRS Tunnelling Protocol (GTP), which is essentially the telecom equivalent of Generic Routing Encapsulation (GRE), and *all outgoing or incoming data* is sent through this tunnel. Note that this architectural design implies and ensures that the "first hop" as seen by the phone will always be the SPGW.

3.2.1.3 Telephony in LTE

Because the LTE network substrate is IP-based, telephony services (*i.e.* voice and text) are implemented as "extra" network services run on top of the IP network substrate. Phone calls are nothing more than Voice-over-IP (VoIP) calls to an IP Multimedia System (IMS) server located in the LTE network, texts are similar, and adding an IMS server to an LTE network is as simple as locating the server somewhere in the network and providing phones with its address during network attach.

3.2.1.4 LTE as an Access Technology

The powerful implication of running IMS over the network substrate is that IMS can easily be removed from an LTE network (or simply never added) without affecting core network operation. When LTE is deployed without IMS, we can think of it as nothing more than an Internet access technology, akin and comparable to WiFi. This framing of LTE as nothing more than an Internet access technology is key to the rest of this document, for two reasons: First, we focus *only* on the development of LTE as an Internet access technology, and explicitly do not cover setting up or running an IMS server. Second, it demystifies LTE (and cellular in general) to the traditional network operator or Wireless Internet Service Provider (WISP), and grounds our intended readers firmly in the familiar territory of IP networking.

3.2.2 Telecom-Scale LTE Networks

Most LTE networks today are operated by national-scale telecom companies. In this architecture, illustrated in Figure 3.1, a single EPC, typically located in a centralised datacentre and distributed across a large number of physical machines, can power tens of thousands of individual eNodeBs. Adding an eNodeB to the network (and thereby expanding coverage) is as simple as connecting it to the Internet and configuring it with the correct addresses by which to contact the EPC. In this design, the major challenge for large-scale telecom companies wishing to expand network coverage is to ensure that a sufficiently wide and reliable Internet connection exists with which to connect the eNodeB to the Internet.

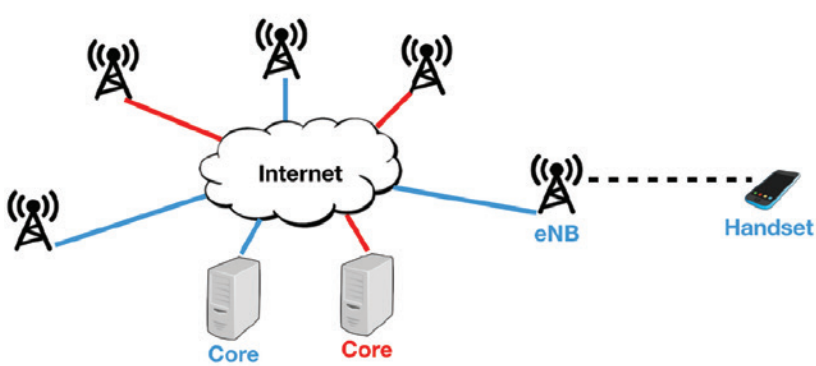


Figure 3.1. Traditional LTE Network

This architecture is well designed and effective for its intended use-case, but has significant drawbacks when considered in the typical community-networking context. First, it is incredibly centralised, and introduces significant failure points into the network, most notably the MME and SPGW: if either component fails, or if the eNodeB is cut off from either component, no network operations can successfully complete. This drawback is incredibly important for areas that encounter intermittent connectivity, and is amplified by the fact that for purposes of branding and legal requirements, telecom networks have to satisfy strict uptime requirements. When these requirements cannot be met in an area (*e.g.* due to satellite as the primary Internet backhaul), the only choice available to telecom companies is to not provide coverage.

This centralised architecture creates another subtle, yet important, drawback to rural CNs with constrained backhaul: because the "first hop" seen by the phone is always the SPGW (see Section 3.2.1.2), all communication to and from the phone must be sent over the backhaul. No local breakout or local hosting of network services is possible, because the entire LTE data-plane is tunnelled through the SPGW in the network core *by protocol specification.* This is a major drawback when compared to regular IP-based networks, which automatically keep local traffic local by virtue of network routing. Given that the IP tunnels in the LTE data-plane are layered on top of an all-IP network (with underlying shortest-path routing), it cannot be stressed enough that this problem is artificially created and not fundamental or intrinsic to the medium of cellular networking.

3.2.3 Cloud-Based Private LTE Networks

Several different Software-as-a-Service (SaaS) providers offer a cloud-based EPC solution. These providers often team up with existing eNodeB manufacturers, with the intent of selling network operators an all-in-one LTE solution: plug the eNodeB into an Internet connection; it will automatically set itself up with the cloud EPC, and nothing else is needed.

Cloud-based solutions are attractive to small network operators for many reasons, including their simplicity, third-party support, and plug-and-play nature. However, they suffer the exact same set of drawbacks described in Section 3.2.2, especially when considered in the context of rural access, which often suffers from unreliable, latent, and bandwidth-constrained backhaul connectivity. Additionally, they often bill at a relatively high price per user, which makes such solutions challenging for resource-constrained or grassroots operators seeking to provide affordable Internet access.

3.2.4 CoLTE Network Architecture

CoLTE is specifically designed to address the aforementioned shortcomings and limitations of centralised or cloud-based EPC architectures. In a CoLTE network, as the one illustrated in Figure 3.2., the EPC is located immediately upstream of the eNodeB(s), and downstream of any latent or unreliable Internet backhaul links (such as the satellite link in the figure).

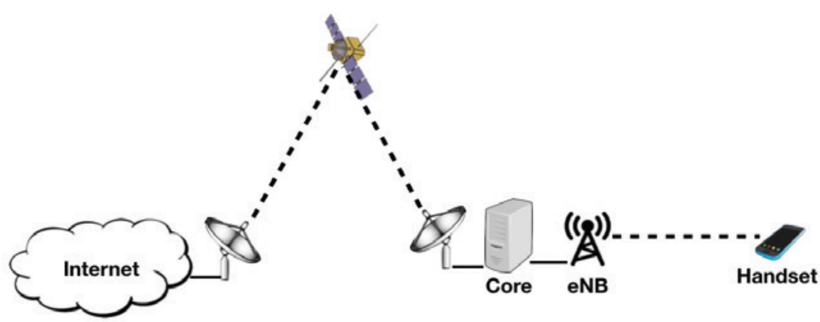


Figure 3.2. CoLTE Network

CoLTE networks are wholly self-contained, and can operate either with or without an upstream Internet connection. CoLTE networks consist of (1) the CoLTE EPC connected via Ethernet to (2) one or more commercial eNodeBs that create the LTE Radio Access Network (RAN). In the event that an upstream Internet connection exists, it is bridged out to the LTE network via the CoLTE EPC.

In the event that no Internet connectivity exists, the CoLTE EPC can provide connected phones with offline web-based services, including but not limited to Wikipedia, OpenStreetMaps, and more.

3.3 Getting Started

This section covers the network information you will need to know, and design decisions that you will need to make, before you can start the process of ordering hardware and building your network. Do not skip any of these steps, or you will just complicate and potentially undo your work later in the process!

3.3.1 The PLMN ID

The Public Land Mobile Network (PLMN) ID is a five- or six-digit number that uniquely identifies your network to the rest of the world. In theory, each network has its own globally-unique PLMN, and every other network is aware of the PLMN-to-network mapping (similar to global IP address assignment). Unfortunately, in practice, there is no authoritative global registry or list of PLMNs, and the PLMN-to-network mapping is a remarkably ad-hoc process. The PLMN is comprised of two separate identifiers, the Mobile Country Code (MCC) and Mobile Network Code (MNC).

The MCC is three digits and identifies the country the network is operated in; the MNC is either two or three digits and identifies the specific mobile network within the country. The PLMN is embedded in almost all network identifiers (including SIM cards) and as such cannot be easily changed once set. The PLMN is appended to a SIM's ID (called the MSIN) to create a globally unique identifier for each SIM known as the IMSI; this structure is illustrated in Figure 3.3. We discuss these numbers further in Section 3.4.4.

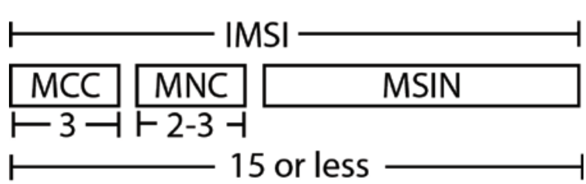


Figure 3.3. MCC, MNC, MSIN, and IMSI

Mapping a PLMN to its corresponding network is only needed to support inter-network features such as roaming. This means that your choice of PLMN can be arbitrary, and does not have any real consequence until you want to establish a roaming agreement with another telecom company. For our pilot network, we looked up the correct MCC on Wikipedia,[43] and then simply chose a MNC that was not listed as taken; we recommend a similar approach to getting started.

3.3.2 Choosing a Band

Like any other radio technology, LTE networks require a certain amount of bandwidth across a range of frequencies for communication. The 3GPP defines a set of "bands," which are just sets of supported frequencies and bandwidths grouped together to make it easy to talk about compatibility. As of this writing, LTE defines sixty standardised bands with a wide range of characteristics. The frequency of operation determines the physics of the antennas and equipment in each band, so any particular device only supports a specific set of bands.

Several variables are important in choosing the right band for the network, as discussed in detail below. Changing the band of your network will likely require purchasing new equipment, so we recommend network operators choose wisely.

3.3.2.1 Legality

LTE systems operate in a wide variety of bands, and depending on the area of operation, certain bands may require a license to use (see Section 3.3.3). Licensing protects existing users from interference, and operating without a license when one is required can carry serious consequences for the operator (usually large fines, imprisonment, etc.). Spectrum policy is different in every country, so before choosing a band, it is important to check local regulations and confirm whether a license is required and, if so, ensure that the operator can get one.

3.3.2.2 User Device Support

After narrowing the selection to which bands the network can legally operate in, operators should consider which of the remaining bands are compatible with devices commonly available

43 See <https://en.wikipedia.org/wiki/Mobile_country_code>.

in their area. GSM arena[44] provides a comprehensive list of device specifications, allowing operators to look up the locally common devices and compile data about their supported bands. Operators looking to deploy an LTE network for fixed wireless applications, or in an area with few existing handsets, may be able to convince users to buy new devices specifically supporting the operator's bands, but be aware that this does add friction and cost to the deployment process.

3.3.2.3 RF Characteristics

Spectrum bands behave differently in the way they interact with terrain, enter buildings, or penetrate foliage based on the underlying physics of radio propagation at their frequencies. Details for specific frequencies can be researched on a band-by-band basis, but some general heuristics can help give you an intuition for how bands will likely perform.

Particularly, it is important to note that:

1. Low bands will propagate further at a given power and antenna gain than high bands. This increases coverage, but makes it harder to deploy a dense network of cells without co-interference.
2. Low bands penetrate foliage and buildings better. Exactly like bass vs. treble in acoustics, the lower bands propagate better through obstacles than higher bands.
3. Low bands diffract more. This is a very useful property, as low bands will diffract around terrain obstacles better than high bands. Therefore, it is often possible get low band coverage behind gentle hills that would be blocked without line of sight in a higher band.
4. Low bands require bigger hardware. Since low bands have longer wavelengths, equivalent gain antennas are correspondingly larger. A 15dBi antenna is twice as long and heavy in the 900MHz bands as it is in 1800MHz, and 4 times as long than 3700MHz. Increases in antenna gain can often make up for the high band's worse propagation, especially over long distances with line of sight.

44 See <http://gsmarena.com>.

3.3.3 Spectrum Licensing

As noted above, licensing is a tough, but surmountable challenge to building a quality LTE network. Licensing regimes are determined by country, so you will need to consult a licensing expert in your area to operate with legal authority. **These guidelines are not a substitute for such an expert**, but can still provide with some tips on how to start the conversation.

In our experience, regulators in certain countries have been receptive to granting licensing exemptions (either explicitly or unofficially) for CNs, particularly in rural areas that are not already served by an incumbent telecommunications provider. Licensing is important and competitive in dense urban areas, but in rural areas there are often large swaths of unused spectrum in high performance bands. There is growing interest and international momentum around use-it-or-share-it licensing,[45] wherein if an incumbent is not using its spectrum in a specific area, local users can broadcast in it, provided that they don't interfere with anyone else. TV whitespace (TVWS) licenses fall into this category, as do permissive secondary use licenses worldwide. The United States' Citizen's Broadband Radio Service (CBRS)[46] also relies on use it or share it principles, and is being closely watched as the first large scale rollout of its kind.

Operation of an LTE network in the unlicensed bands is also an option, but comes with the range, power, and interference limitations of the 2.4 and 5GHz ISM bands where WiFi operates. The two LTE unlicensed technologies, LTE-Unlicensed[47] and MuLTEFire,[48] are relatively new to market, so there exist few handsets available at the time of this publication (August 2018) though support may grow over time.

45 See <https://www.internetsociety.org/policybriefs/spectrum/>.

46 See <https://www.fcc.gov/wireless/bureau-divisions/broadband-division/35-ghz-band/35-ghz-band-citizens-broadband-radio> and <https://en.wikipedia.org/wiki/Citizens_Broadband_Radio_Service>.

47 See <https://en.wikipedia.org/wiki/LTE_in_unlicensed_spectrum>.

48 See <https://www.multefire.org/>.

3.4 Hardware Selection and Purchase

3.4.1 The EPC

The EPC, otherwise known as the network core, exists only as a software package, and has relatively low processing requirements. As such, it can be run on any x86-64 computer capable of running Linux, including but not limited to most desktop and laptop computers.[49] During our fieldwork, we found the Zotac ZBox to be a good, cheap, and reliable platform. The ZBox costs approximately 120 USD without memory or a hard disk, which brings its total cost up to approximately 200 USD, depending on the exact hardware options you choose. We suggest maximizing the CPU option and RAM (8gb), but hard disk size is flexible. If you are planning to run the Media Server listed in Section 3.7, more storage is always better, and it is almost always cheaper per-byte to upgrade the size of a single hard disk, as compared to buying a second storage device later on.

In terms of OS support, CoLTE has been tested and is known to work on Debian 9.4 (Stretch) as well as Ubuntu 18.04 (Bionic). There do not currently exist plans to explicitly support CoLTE on other Linux distros, but the open-source and software-contained nature of the project encourages and supports contributions of this nature.

3.4.2 The eNodeB

In the CoLTE architecture, the eNodeB is a physically separate machine from the EPC. The eNodeB is typically a specialised piece of commercial equipment, but for small-scale test and lab-bench purposes, can also be a Linux computer equipped with a software-defined radio (SDR). If you are building an actual production network, you should buy a commercial eNodeB. If you are simply curious about CoLTE, we have included SDR suggestions/instructions for proof-of-concept, but note that the current SDR eNodeB implementations are known to perform poorly even under the best of conditions.

3.4.2.1 Commercial Equipment

As mentioned in Section 3.3.2, commercial eNodeBs are highly

49 Please note that we have not yet ported CoLTE to ARM platforms such as the RaspberryPi.

specialised pieces of equipment, and typically run only on a specific frequency band. Once chosen, this frequency is a part of the hardware platform itself, so you will not be able to change it for a specific eNodeB (for help choosing a band, see Section 3.3.2). In our experience, we found a BaiCells Nova-233 to be a good, affordable, and reliable platform. It costs us approximately 4000 USD and is available in a wide range of bands, but note that several other eNodeB manufacturers exist.

3.4.2.2 Software-Defined Radios

Software defined radios, such as the USRP B200 series, are great tools for prototyping and experimenting. SDRs are small, programmable radios that can connect to a computer over USB 3.0.[50] The computer then downloads/installs specific SDR drivers (The GNURadio library is a common choice) and these drivers power the radio on any frequency with any protocol it wants, such as LTE, WiFi, or AM/FM.

The big trade-off between SDRs and normal radios is that in a standard radio, most of the lower-level operations are baked into the hardware itself (this hardware can be, for example, a WiFi dongle or card). This leads to better performance and lower costs, but much less flexibility than the SDR.

The SDR environment depends on many variables (CPU architecture, CPU speed and cores, OS, system motherboard, etc.) and as such is much less standardised than the software EPC environment. We do not provide an extensive guide to SDR configuration here, except to note some common problems, solutions, and software packages:

- We have had success with the srsLTE package[51]
- If you are using Linux, you will want to install a low-latency or real-time kernel. These kernels trade overall system performance for tight schedule-bounds, and these tighter bounds are necessary for the driver to stay in sync with the SDR.
- Make sure the SDR is powered over USB 3.0, not 2.0

50 Note that to run LTE on an SDR explicitly requires USB 3.0. USB 2.0 is too slow to achieve the correct time synchronization, and this will lead you to spend a lot of time debugging. Additionally, you will likely have to install the Linux low-latency kernel on the controlling computer.

51 See <https://github.com/srsLTE/srsLTE>.

3.4.3 Antennas

The choice of antenna will strongly influence the performance of the network, particularly at long range. Key metrics to look at when buying antennas are the antenna gain (the focusing power of the antenna) and the antenna pattern (the shape of the coverage produced by the antenna). Most cellular networks use either omnidirectional stacked dipole antennas (that look like a stick) or directional panel antennas (that look like a flat board). Some fixed wireless application of LTE use even more directional parabolic dish antennas (that look like a satellite dish), but these require precise pointing and are not suitable for most mobile users.

Higher antenna gain means that the energy from the radio is more tightly focused in the target area, increasing the signal strength in the pattern at the expense of coverage outside the pattern. It is important to remember that high gain antennas do not add extra power to your system, but just focus it more. High gain "omnidirectional" antennas do not actually send power in all directions: they focus power into a donut shape around the antenna, creating a strong null above and below the antenna itself. High gain panel antennas create a cone shaped pattern shooting out of the front of the antenna, with strong nulls to the sides and above as well as below the pattern.

Directional antennas are very useful in LTE systems to create "sectors" of coverage, where multiple eNodeBs are deployed in a single location to cover different areas. This can allow for spatial re-use of spectrum to improve the overall data rate of the system within an allocated bandwidth. Directional antennas also allow the LTE system to reach further from the base station in a specific direction than it otherwise would with stock non-directional antennas. Antennas are reciprocal, so any gain is made in both transmit and receive at the base station.

Most LTE systems make use of MIMO technology to increase throughput and spectral efficiency. MIMO stands for Multiple Input Multiple Output, and is a way to get increased throughput through antenna diversity. MIMO requires multiple antennas per base station, and importantly the antennas need to be roughly uncorrelated from each other. One way to do this is to physically separate the antennas to get spatial diversity. Another way is to use different polarisations (a physical property of the antenna) to get polarisation diversity. It is possible to purchase antennas that are "dual polarised" or "cross polarised," incorporating two antennas of orthogonal polarisation into the same antenna case. These kinds of antenna work well to keep the base station deployment compact while still providing the diversity required for MIMO.

3.4.4 SIM cards

3.4.4.1 Vendor

To run your own LTE network, you will need to obtain and distribute your own SIM cards. You can obtain LTE SIM cards relatively easily on a variety of e-commerce platforms. For example, a quick search for "LTE SIMs" on alibaba.com, which is a large Chinese-based e-commerce site targeted towards product manufacturers and other parts of the supply chain, yields dozens of results. The CoLTE team can recommend a supplier called GreenCard, which offered us everything we needed, all for $0.65 USD per SIM, minimum order size of 1,000 units.

3.4.4.2 Technical Details

During the order process, you will have to provide the vendor with lots of technical information. Key points to look for include the following:

- Ensure that the SIMs are LTE-specific and support the Milenage algorithm. You may want to ask the vendor, if necessary.
- The IMSI is a 15-digit number that uniquely identifies the SIM to the network. It is comprised of the PLMN ID, followed by the MSIN (see Figure 3.3), which can be any identifier of choice, as long as it is unique within your network. In our network, we simply utilised the numbers 0000000000 to 0000000999.
- The ICCID is an 18-20 digit number that uniquely identifies the SIM card. It starts with "89", followed by your IMSI.
- The KI is the SIM's private key, and must be different for each SIM.

- The OP is the network's private key, and is the same for all SIMs. The OPc is a symmetric key used for SIM-network communication, is different for each SIM, and is generated from KI and OP.
- The MSISDN is the phone's phone number.
- The SPN is the network name that appears in a phone using your SIM.
- **Warning:** Once you have printed your SIMs, be careful with where your keys are stored. Your EPC will need to know the KI for each phone and the OP for the network, but these are not changeable once the SIM is written. This means that if you accidentally leak a KI, the corresponding SIM is insecure, and if you accidentally leak the OP, *all* your SIMs are insecure.

3.4.4.3 Visual Design

For an extra $0.05 USD per SIM, we were able to get our cards printed with a custom design. We strongly recommend this practice, as it adds a *lot* of visual, tangible, community pride and value. Figure 3.4 provides an illustration of the proof sheet we used to design the SIM cards, as well as our community's final SIM card design (for inspiration).

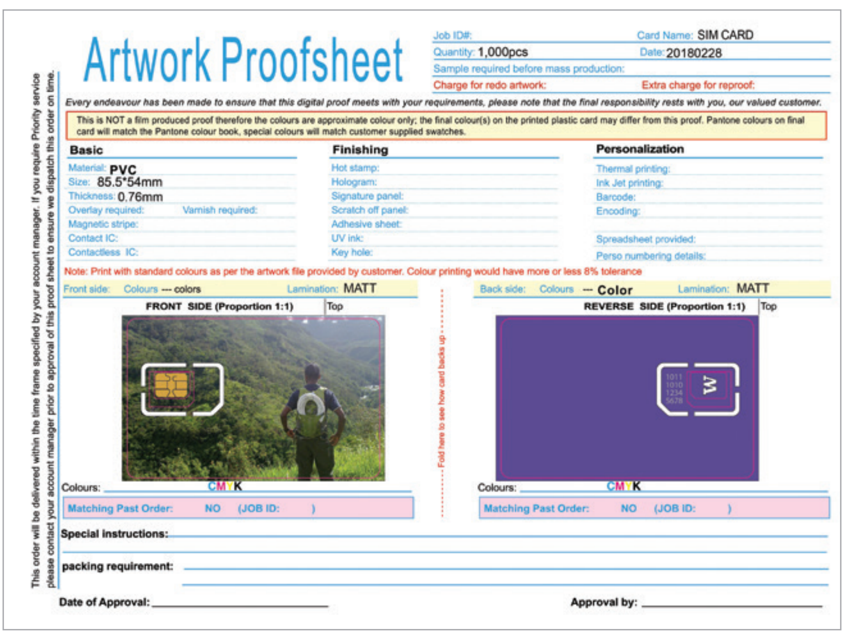


Figure 3.4. SIM Card Artwork Sheet

3.5 CoLTE Setup

3.5.1 EPC Basic Requirements

Once you have chosen the machine for running the EPC, there are two options available: we provide a disk image you can install onto a fresh machine, or you can manually install CoLTE onto a machine with an existing system on it. Installation generally goes smoother on a fresh machine, and the CoLTE team offers more support and testing of that case, but CoLTE supports both modes of operation.

3.5.1.1 Install from Disk Image

You can download the latest CoLTE disk image from <http://colte.cs.washington.edu/images>, burn it onto a bootable USB drive, boot from it, and run the CoLTE Autoinstaller. This install will run automatically and completely wipe out any existing content on your primary hard drive, so be careful.

Once the installation is complete, the machine will be configured with one user (username colte, password colte). Log in, run ~/setup.sh, and then go to Section 3.5.2, with the knowledge that the colte repository will be fetched from github and placed in ~/colte.

3.5.1.2 Install on an Existing OS

OS Requirement

CoLTE currently supports Debian 9.4 (Stretch) and Ubuntu 18.04 (Bionic).

Clone CoLTE from GitHub

Once you are setup with the correct prerequisites, clone the CoLTE repository from GitHub with the following command:

git clone <https://github.com/uw-ictd/colte.git>.

System Preconfiguration

Before you get started with our install scripts, there are a number of packages you must have. You can obtain them by running the following script:

./colte/system_setup/setup.sh

3.5.2 EPC General Configurations and Installation

Before building the EPC, you **must** look at and edit the file generate_coltenv, which generates the environment variables, and is located in the main CoLTE directory. Most of the values in the first part of the script can be ignored,[52] but make sure you read them for your information. Regardless of your setup, you will likely have to look through and change the two sets of options described below: network configurations and compilation options.

3.5.2.1 Network Configuration

You must read all of the options under this heading, make sure you understand them, and ensure that they are set appropriately. You can set your network name by setting the value for COLTE_NETWORK_NAME. This variable sets the network domain name used for all the services listed in Section 3.7. COLTE_WAN_IFACE should be set to your upstream connection interface and COLTE_ENB_IFACE to your downstream interface (that connects to the eNBs).

COLTE_ENB_IFACE_ADDR is the downstream interface's IP address. COLTE_LTE_SUBNET is the subnet that phones will be assigned addresses out of. You should not need to change this, and CoLTE currently does not support values outside of 192.168.151.0/24.

3.5.2.2 Compilation Options

Besides the software that operates the network, different web services are included in CoLTE for your convenience, such as chat application and maps. Details on the majority of these services are provided in Section 3.7, but for core network operation, you must enable COLTE_BUILD_EPC_SOURCE. Additionally, you must ensure that COLTE_DISTRO is set to your correct OS (either "stretch" or "bionic"). For your reference, the table below contains these options, their meanings, and where they are covered in this document.

52 Note that if you are installing CoLTE not from scratch, you will have to set COLTE_USER accordingly.

COLTE_EPC	Section 3.5.3	The core network
COLTE_BILLING	Section 3.6.2	Per-user billing/monitoring
COLTE_WEBGUI	Section 3.6.2	User-facing Web portal
COLTE_MEDIA	Section 3.7.5	Locally-hosted media server
COLTE_WIKI	Section 3.7.2	Locally-hosted Wikipedia
COLTE_MAP	Section 3.7.4	Locally hosted mapping
COLTE_CHAT	Section 3.7.3	Locally hosted RocketChat

Table 3.1. CoLTE Compilation Options

After you have looked through the script and made any changes, enter the command below to load all the environment variables:

source generate_coltenv

The list of the variables will be printed to the terminal if the script was run successfully. Finally, to install all of the components you enabled, run:

./system_setup/ansible.sh

3.5.3 Starting the EPC

Once you have successfully built the EPC, you must add the OP, or the network's private key. For obvious reasons, we do not provide this setting or automate this process. To set the private key, open the file /usr/local/etc/colte/oai/hss.conf and change the value operator_key at line 30. Once entered, the EPC is set up, and should be ready to run.

As explained in section 3.2.1.1., there are three components, which make up the EPC: MME, HSS, and SPGW. To start the EPC, all of the three components must be run. Though these components can be run in either order, as a general practice we have found best results starting first the HSS, then the MME, and then the SPGW. You can start any of these components in a new terminal window by running sudo {oai_hss,mme,spgw}

Long messages will be printed in all windows, but the main window to focus on is the MME.

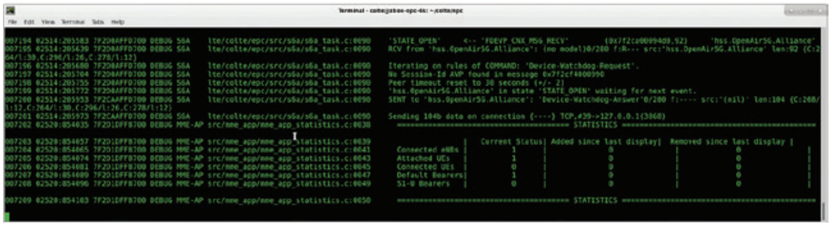


Figure 3.5. Successful MME Terminal Window Output

The table on the right is the status of the EPC. The first line is the number of the connected eNodeBs. It should be zero when you just started the script, and change to one when you successfully connect an eNodeB to the EPC. Similarly, "Attached UEs" and "Connected UEs" shows the number of attached and connected phones in the network.

3.5.4 Configuring and Starting the eNodeB

Once the EPC is running, you need to configure the eNodeB so that it will talk to the EPC. This process depends heavily on the exact eNodeB you are using: for the srsLTE platform, you will need to edit the enb.conf file; for the BaiCells Nova-233, you will need to edit a WebGUI hosted at 192.168.150.1. Regardless of your specific eNodeB, you will have to set at least the following parameters:

- MME IP address: set this to the address of your EPC's interface connected to the eNB
- MME Port: if this option exists, set it to 36412
- GTP Bind Address: if this option exists, set it to the address of your EPC's interface connected to the eNB
- PLMN ID: set this to your network's PLMN

In addition to these options, depending on your eNB there exist several more options you may want to change (including but not limited to bandwidth, frequency, and EARFCN). These options deal primarily with the physical characteristics of the broadcasted radio wave, so you will want to make sure that your system is legally compliant (see Section 3.3.2), but should not affect the connection between the eNodeB and EPC. Once these options are set, and you start your eNodeB, you should see it perform a handshake and connect to your EPC (indicated by a “1” in the “Connected eNBs” category of the MME).

3.6 CoLTE Operation

3.6.1 Connecting your First Phone

Once you have started the EPC and connected an eNodeB to it, you are ready to attach your first phone. Power off the phone, insert your SIM, make sure that (1) you are within range of the eNB, (2) all three components of the EPC are running and talking to each other, and (3) the eNB is connected to the EPC, and then start up your phone.

The phone should attach to the CoLTE network, and you will be able to verify this three separate ways. First, the phone should show full signal, 4G/LTE, and display whatever network name you set in the APN when ordering SIM cards.[53] Second, in the EPC’s MME window, you should see “1” under Attached UEs and Connected UEs. Finally, when you filter the Wireshark capture for the “s1ap” protocol, you will see the exchange illustrated in Figure 3.6.

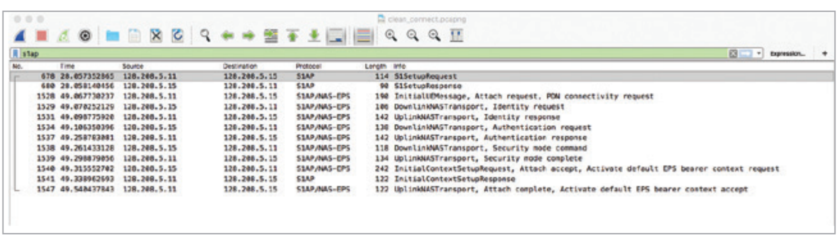


Figure 3.6. Wireshark PCAP For Successful Attach

3.6.2 Billing and the Web Portal

As a bare-minimal install (only enabling COLTE_EPC), CoLTE acts as an unmetered LTE hotspot, bridging connected phones to the Internet. However, if you want to run a commercial network

53 If you see a little “X” near the signal, do not worry! This means that you have connected to the LTE network successfully, you just do not have Internet access. See Section 3.6.3 for more information.

and charge users for service, you will want to enable two more compilation options: COLTE_BILLING and COLTE_WEBGUI. COLTE_BILLING sets up a billing system that logs traffic per user, updates the database, and cuts users off as necessary.

Meanwhile, COLTE_WEBGUI sets up a web portal at "<http://network.mynetwork>", which is designed to be the main interface by which CoLTE users interact with their network account and perform tasks such as checking the status of the network, checking the status of their account, topping up their account, and purchasing service.

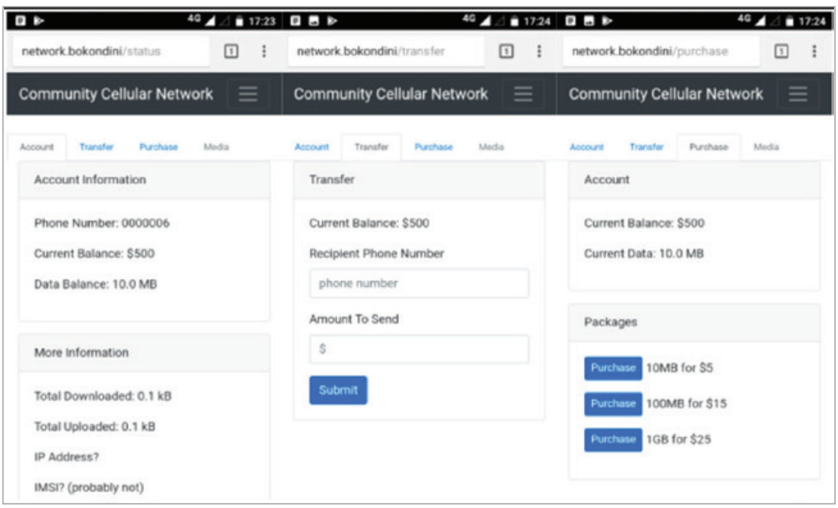


Figure 3.7. Screenshots of CoLTE Web Portal

3.6.2.1 Data Packages

Each CoLTE user has two balances: the amount of *money* in their account, and the amount of *data* that they have already bought. Users can send money to another user (indexed by either IMSI or phone number) via the interface at <http://network.mynetwork/> transfer, and can purchase data packages at <http://network.mynetwork/purchase>. Commercial network administrators can change the package sizes and costs in colte/lte_extras/webgui/routes/purchase.js, just make sure to restart the webgui afterwards (sudo systemctl restart colte_webgui).

3.6.3 Adding and Removing Users

Ideally, you will want to have all your SIM cards added to the CoLTE network before you turn the network on, but life often does not work out that way. Fortunately, CoLTE is designed such that any alterations to the database are immediately reflected across all CoLTE services simultaneously. This means that you can dynamically add or remove users without having to restart any services. If you want to add a user, there are four tables you must keep in sync: pdn, users, customers, and static_ips. To simplify this process, we have provided a python script (colte/epc/spencer_scripts/add_remove_user.py) that does all of this for you automatically.

To add a SIM, you need to know four fields: the IMSI, the MSISDN, the private key of the SIM, and the OPc.[54] With these four values, you can use the command "python add_remove_user.py add imsi msisdn key opc". Removing a SIM is much simpler: you only need the IMSI, and can use the command "python add_remove_user.py rm imsi".

3.7 Additional Services

The core of the CoLTE project is an LTE network-in-a-box, but CoLTE networks can also be considered as local area networks. To this point, we have bundled CoLTE with a wide set of additional services that network operators may choose to deploy.

3.7.1 Microservices, Nginx, and BIND

CoLTE currently comes with baked-in support for several different web services. The basic model for these services is a standard microservice architecture, in which each individual service is run in its own virtual machine environment (CoLTE comes with support for both Vagrant and Docker), and then a front-facing webserver (bound on port 80) forwards web requests to the appropriate microservice, as illustrated in Figure 3.8. The microservice architecture is powerful because it supports a large degree of flexibility and autonomy in the development and

54 For more information about any of these values, consult Sections 3.3.1 and 3.4.4.

system configuration of individual webservices, enables multiple webservices to coexist regardless of their system requirements, and ensures strong isolation between individual services.

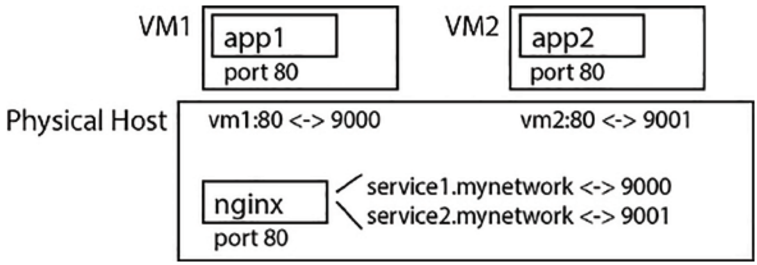


Figure 3.8. Microservice Architecture

Despite the benefits of microservices, they also require significant system configuration. For multiple webservices to successfully coexist on the same machine and be accessible by end-users: each microservice must have its own port; a port-mapping must be made between this port and the VM's port 80 (assuming that the microservice runs over HTTP); the web service must be assigned a unique DNS name (*e.g.* "service.networkname"); users must be somehow instructed to use this DNS name; and the front-facing webserver must be configured to forward these requests to the correct microservice.

CoLTE accomplishes all of the above-mentioned points through a combination of (1) BIND to locally serve DNS within the CoLTE network and (2) nginx as the front-facing web server bound to port 80 on the EPC.

The BIND server operates as a client resolver, so all phones on the CoLTE network first send their DNS requests to the BIND server, and the BIND server forwards the requests and caches the responses as appropriate. The BIND server *also* operates as an authoritative DNS server for a "fake" DNS zone that corresponds to the "COLTE_NETWORK_NAME" value in generate_coltenv. This means that if you set that value to "mynetwork" then the server will setup a zone and respond authoritatively for DNS queries such as "service.mynetwork" with the address of the EPC. In case you want to understand BIND better, the zone file that contains all authoritative records can be found at "/etc/bind/zones/db.mynetwork".

After CoLTE clients resolve the DNS query for "service.mynetwork" and get the address of the EPC, they send a Web request to the EPC on port 80. This request is handled by nginx, which maps the DNS hostname in the request to the correct local port (e.g. "service1.mynetwork" maps to localhost:9000, "service2.mynetwork" maps to localhost:9001) and then forwards the request to this port, which is handled by the correct microservice.

The basic tool for configuring nginx is a .conf file. .conf files are generally located in the "/etc/nginx/sites-available/" directory, and each .conf file refers to a different website. Individual sites are turned on or off by creating a symlink in the "/etc/nginx/sites-enabled/" directory, generally with the same name, that points at the corresponding file in sites-available. These .conf files are largely self-explanatory, with the most relevant lines for a specific service being "server_name" and "proxy_pass". The other lines are primarily window-dressing and serve to ensure that site and request names are translated correctly during the forwarding process.

3.7.2 Wikipedia

The Xowa project[55] is a free and open-source version of Wikipedia designed for offline use. CoLTE can download, configure, and start Xowa on port 9082 by enabling the "wiki" role in generate_coltenv. In addition to the core Xowa software itself, Xowa requires a Wikipedia dump to be placed in "colte/lte_extras/wiki/storage". You can run multiple Wikis simultaneously by placing them in this folder.

CoLTE comes preconfigured with the simple English Wikipedia, which is essentially a dump of simple.wikipedia.org. You can access Xowa at "http://xowa.mynetwork".

3.7.3 RocketChat

RocketChat[56] is a free and open-source chat server application with a similar look and feel to Slack. You can enable RocketChat

55 See <http://xowa.org>.

56 See <https://rocket.chat/>.

with the “chat” role in generate_coltenv, and it runs on port 9081. The RocketChat service preconfigures itself with a domain based on the COLTE_NETWORK_NAME macro, and individual users can make accounts and login to chat. You can access RocketChat at “http://chat.mynetwork”.

3.7.4 OpenStreetMaps

OpenStreetMaps[57] is a free and open source alternative to Google Maps. You can enable it via the “maps” role in generate_coltenv. The OpenStreetMaps architecture is comprised of two independent services: the tile server (running on port 9085) provides rendered .pngs of background map tiles, whereas the mapping server (running on port 9084) takes these tiles and overlays them with additional content (e.g. routes, pins, etc.).

To setup OpenStreetMaps and provide locally-hosted mapping services, you must first download the set of maptiles that correspond to the area you wish to serve. There exist many different free tile providers, but the CoLTE team has had success with the tiles downloaded from <http://openmaptiles.com>. You must download this tileset and place it in the “colte/lte_extras/maps/ts_data” directory before running the tile server. Please note that even small amounts of regional data can take up a large amount of storage on-disk. This is the primary reason why CoLTE does not come preloaded with any tilesets. Once installed, you can access the OpenStreetMaps service at “http://maps.mynetwork”.

3.7.5 Media Server

The final service that CoLTE 1.0 comes with is the UMS Universal Media Server. This service is enabled via the “media” role, can be found at “http://media.mynetwork” and runs on local port 9086. UMS, which is an open-source offshoot of the PS3 Media Server, streams both video and music, and supports a wide range of content format types.

By default, the media server comes with two sample videos that you can use for testing. To add content to UMS, just drag and drop files

57 See <http://openstreetmap.org>.

into "colte/lte_extras/media/files" and they will be immediately detected and served by UMS without any need to restart the service.

3.7.6 Adding a Webservice

The CoLTE team strongly encourages network operators, community networking enthusiasts, and any interested developers to develop their own locally hosted web services and share them with the greater community. Once you have set up your own web service, locally hosting it on a CoLTE network is a relatively straightforward and painless process.

Step 1: Choose a port for your service that is not already taken, and start the service.

Step 2: Choose a service name that is not already taken, and add the corresponding line to the BIND zone in "/etc/bind/zones/db.mynetwork". If you are hosting it on the EPC, use the address of the EPC itself (which will be "colte.mynetwork"). Once this line is added, you will have to restart BIND with the command "sudo service bind9 restart"

Step 3: Create an nginx .conf file by looking at and copying any one of the examples in /etc/nginx/sites-available, making sure to edit it as necessary. At the minimum, you will have to change the "server_name" line as well as the port number (and potentially IP address) in the "proxy_pass" line. Place this file in /etc/nginx/sites-available, and make sure the permissions and owner are correct.

Step 4: To enable the nginx site mapping, create a symlink from /etc/nginx/sites-enabled with the same name that points to the .conf file you created in /etc/nginx/sites-available. Finally, restart nginx with the command "sudo service nginx restart". If nginx starts successfully then you do not need to perform any further tasks, and the service should work properly.

Common Debugging Problems/Tips:

- If you see an error message when trying to restart nginx, something is wrong with your .conf file. Common errors could include choosing the same service name as another website, a syntax/formatting error, or setting multiple sites as the "default" entry.

- In case of a "500 Bad Gateway" error, when trying to access the site, it means that nginx is forwarding the request appropriately and the service is dropping the request. It could have crashed, or be configured to forward incorrectly.
- If you are trying to access your site from a web browser running *on the EPC itself*, remember that the local BIND server only serves requests coming from clients on the CoLTE network, not the EPC itself. Adding a line in "/etc/hosts" that redirects the server name to 127.0.0.1 should help.

3.7.7 Telephony and IMS

In Section 3.2.1.3, we explained how telephony services (*i.e.* voice and text) in LTE are simply IP-based services that communicate with an IMS server. The CoLTE team expects IMS support (powered by the open-source ClearwaterIMS project) to be forthcoming in later releases as a major feature-add, but for now, CoLTE does not come with IMS support. If you successfully integrate IMS (via Clearwater or some other IMS server) with CoLTE, *please* upstream your work, or at least let the CoLTE team know about your work.

3.8 Conclusions: Feedback and Contribution

The value-base of the CoLTE project starts with open community investment, engagement, and contribution, and these values absolutely apply to our developers and users as well.

CoLTE is under active development and is *always* seeking more feedback and contribution on the user-base and development efforts. If you are a user and encounter bugs, have a problem during the setup process, or think something in this manual is not sufficiently clear, please contact the CoLTE team at colte@cs.washington.edu, as we are very interested in receiving feedback.

If you are a developer and want to help with the bugfixing effort or extend CoLTE in some way, get in touch with the CoLTE team as well. If you are a network operator and end up extending CoLTE to fit your use case, please send us a pull request. Lastly, if you are happy and want to share with the CoLTE team your experience, please feel free to contact us.

4 The MAZI Toolkit for Do-It-Yourself Networking

Harris Niavis, *Stavroula Maglavera*, *Aris Dadoukis* and *John Mavridis*

Abstract

In this chapter lies the description from a system design point of view, of a DIY networking toolkit - the MAZI toolkit - for enabling the easy deployment, operation, configuration and maintenance of local wireless networks by communities. The MAZI toolkit encompasses diverse FLOSS applications and services for social innovation and addresses generic social challenges towards shaping a more human-centric Internet.

MAZI toolkit is based on low-cost open hardware and open-software platforms, like the Raspberry Pis, sensors and other IoT devices. The conceptualization, design and development of the toolkit was driven by the community and took place within participatory processes that were open to engaging researchers, developers and actors of diverse communities. During this bottom-up approach, various ideas emerged and were materialized in applications and tools towards addressing real community needs and challenges. In addition, popular already existing open-source, self-hosted applications (NextCloud, Etherpad, LimeSurvey and Wordpress) are integrated in the toolkit, incorporating existing open-source communities in the MAZI ecosystem.

Finally, the toolkit integrates comprehensible guidelines which assist people to further facilitate the adoption of the toolkit from communities through examples and other media. Even those without any technical knowledge are empowered to deploy a Wi-Fi Access Point, configure Internet accessibility or take advantage of the sensors in their MAZI Zone.

Acknowledgements

This work was carried out in the context of the MAZI project (2016-2018) which has received funding from the European Union's Horizon

2020 ICT CAPS initiative under grant agreement no 687983, <http://www.mazizone.eu/>. We thank Luca Belli for all his efforts and comments on the first drafts of the document and we would also like to show our gratitude to the whole MAZI consortium for sharing their expertise with us during this research. Their feedback as well as active contributions throughout the design and development phase was a critical factor for the MAZI toolkit's success.

4.1 Introduction to the MAZI Toolkit

The MAZI toolkit is a concrete set of hardware components, open source software, artefacts and guidelines, which enable citizens to deploy their own local networks and services.[58] It can serve two complementary objectives:

- to improve Internet connectivity in a local area and
- to support local interactions and services

The MAZI toolkit does not target an audience of technology experts, but rather communities and individuals as diverse as researchers, activists, artists, social scientists, urban designers and in general the wide majority of citizens who are willing to take control of their digital world. To this end, it includes low-cost off-the-shelf equipment that can be assembled and operated following the easily intelligible guidelines that accompany the toolkit. It offers a user-friendly interface that allows the creation and customisation of a local wireless network – called a MAZI Zone – hosting a variety of free software services and at the same time keeping – on demand – alive the connection to the Internet and the vital, online services.

A **MAZI Zone** is an instantiation of the toolkit and encompasses not only the digital part (network infrastructure, software etc.) but also the physical space in which the MAZI Wi-Fi signal extends to, as well as the analogue social interactions happening there. It is comprised of either one single MAZI node connecting users in low physical proximity or more nodes forming a wireless mesh network and expanding the coverage range to a whole neighbourhood.

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58 See <https://firstmonday.org/ojs/index.php/fm/article/view/7123/5661>.

From the user perspective, there are four main possible actors interacting with a MAZI Zone and involved in its design, deployment, and usage:

- The owner: an individual (e.g. a researcher, an activist or a community champion), a community (e.g. a non-profit, a neighbourhood association or another group of like-minded individuals), or a local institution (e.g. the municipality, the public library, etc.).
- The administrator: the person responsible for choosing the various configuration and customization options. It could be an individual or a community through a participatory process led by a research group and/or a local institution. The administrator could be the same as the owner of the MAZI Zone.
- The catalyst: the person that introduces the MAZI zone in the physical space, interacts physically with passers-by, identifies societal issues and proposes innovative approaches to connectivity, such as the development of services for the local community.
- The users: community members who are expected to interact through the MAZI node and consume its outputs.

A single person playing multiple from the above roles is very common in several deployments.

4.2 System Overview

4.2.1 Hardware

The central hardware platform employed is the Raspberry Pi (Raspberry Pi products, 2018), which was selected instead of its competitors after thorough investigation of their characteristics. Open-source, low-sized, low-powered platforms and Single Board Computers (SBCs for short) such as the BeagleBone (BeagleBone Black, 2018), official Arduino products (Official Arduino products, 2018), or other Arduino-certified products (Intel Galileo Gen2, 2018) could also be considered and utilised. However, due to its computational power, the diversity of its interfaces, its cost and the large community following its activities, we chose Raspberry Pi as the main platform.

It should be clarified that Raspberry Pi is simply the recommended platform for installing the MAZI software, but it is not compulsory at all, since the MAZI software (Debian-based) is compatible to other similar SBCs with small adjustments.

The toolkit follows a truly modular architecture, which allows the on-demand attachment of hardware modules, according to the requirements and the desired characteristics of each MAZI Zone. It supports the extension with diverse commercial products, such as USB Wi-Fi adapters, microSD cards, USB flash drives, OpenWRT routers, cameras and sensors, which are tested and listed in the MAZI Wiki as compatible accessories[59].

4.2.2 Software

Towards supporting the effortless configuration of the above hardware, MAZI toolkit features an extensible software architecture of multiple layers including a command-line back-end interface as well as a web-based graphical interface, as highlighted in Figure 4.1.

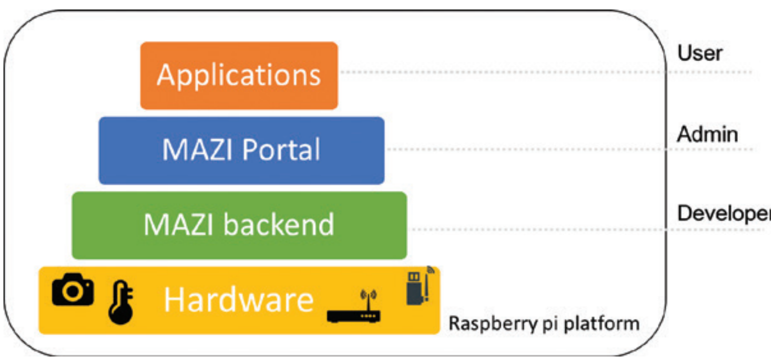


Figure 4.1. MAZI software architecture

The back-end interface (MAZI back-end, 2018) has been designed and developed for handling "low-level communication"[60] between the MAZI toolkit's hardware and the MAZI Portal. Moreover, it can be also used by developers or advanced MAZI toolkit users to control and manage a MAZI Zone through command line. It is comprised of bash scripts which employ Linux packages and libraries allowing the customisation of the hardware, e.g. the *mazi-wifi.sh* script for controlling the Wi-Fi Access Point of the MAZI Zone, the *mazi-sense.sh* script for managing sensors that could be attached to the Raspberry.

59 See <https://github.com/mazi-project/guides/wiki/Products>.

60 We use the term "low-level communication" to signify the Linux scripts interacting with the hardware (Raspberry and any other attached device).

The web-based Portal is comprised of an administration panel restricted only to the administrator of the MAZI Zone and a user interface allowing the user's interaction with the toolkit, both shown in Figure 4.2.

Through **the administration panel**, local administrators are able to have an overview of the network and observe information (place, date/time etc.) and statistics (connected users, application clicks, available storage, number of installed applications etc.). The user-friendly design of the admin panel allows restructuring of fundamental functionalities, including but not limited to Wi-Fi Access Point parameters, starting/stopping of applications and services, creation of multiple instances of the installed applications and one-click update of the software. In addition, administrators are able to replicate their deployment by exporting their configuration to a file or a USB disk and uploading it on another MAZI Zone.

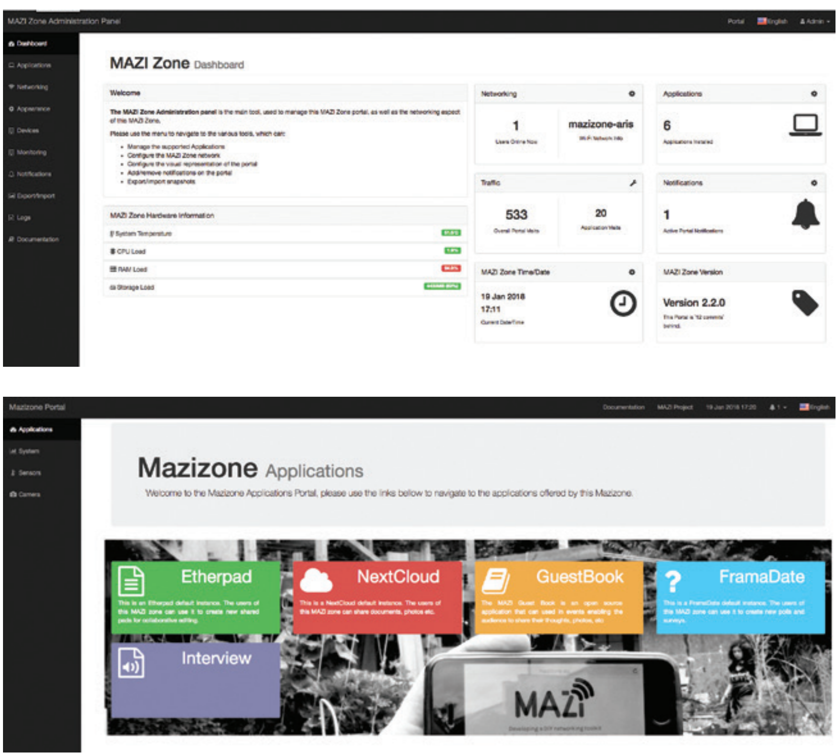


Figure 4.2. MAZI Portal administration and user interface

The **user interface** provides access to local applications (see more in 4.2.3) and services. A MAZI Zone user is able to access applications that have been activated through the administration interface, to observe system statistics and sensor measurements from attached sensors, or even see monitoring data on a map sent to this device through the MAZI Data Collection service (see more in 0).

The MAZI toolkit's software architecture provides flexibility and enables installation in diverse setups. The software can be configured in different "flavours" and serve the corresponding purpose of the local context. Except from the "portable" set-up with the user/admin interface and all the different features and services for setting up a local network it can be also installed in any Linux-based physical or virtual machine and be configured in a light "desktop" flavour[61] to play the role of a publicly accessible server for gathering MAZI Zone data and showing them on a map, as described in 0.

4.2.3 Applications and Interfaces

MAZI toolkit is based on the most advanced FLOSS applications, which are carefully selected through participatory processes and are properly integrated in the Portal. It features, among others, applications for collaborative editing, file sharing, content management, documentation and social media applications. The MAZI team maintains an extensive list of open-source, self-hosted applications, but only those that survived from the interactive co-design procedures with communities and had the most impact on them have been integrated in the toolkit. This selection of applications can be found in the table below together with a brief description.

Application	Description
Etherpad <http://etherpad.org/>	Etherpad is a highly customisable open source online editor providing collaborative editing in real-time. It can be used as an alternative to commercial products (*e.g.* Google docs) in cases where there is no Internet connection to write articles, press releases, to-do lists etc. together with partners, fellow students or colleagues, all working on the same document at the same time. There are also several plugins that enable the customisation of the Etherpad instance to suit our needs.

61 More details can be found on the technical guide of the MAZI toolkit at <http://nitlab.inf.uth.gr/mazi-guides/data_collection.html>.

Application	Description
Nextcloud <https://nextcloud.com/>	Nextcloud is a suite of client-server software for creating and using file hosting services. It can be used as an alternative to Dropbox and Google Drive, although Nextcloud is free and open-source, allowing anyone to install and operate it on a private server.
Wordpress <https://wordpress.org/>	WordPress is a free and open-source content management system (CMS) based on PHP and MySQL. Features include a plugin architecture and a template system. It is mostly associated with blogging, but it can be used in a MAZI Zone as a tool to describe the local context and demonstrate the purpose of the deployment in a website built using Wordpress.
MAZI Guestbook <https://github.com/mazi-project/guestbook>	MAZI Guestbook is an open source application for sharing ideas, photos and more, related to the specific place where a MAZI Zone is deployed, a form of a digital Guestbook. It can also be complemented with a physical one (a real guestbook). A few previous postings from the "digital space" could be also printed for breaking the ice and stimulating participation of the community. This will allow guests to share their impressions about their visits to the venue and collectively build its digital identity.
Interview archive + Interview mobile app <https://github.com/mazi-project/archive>	These two complementary tools are an attempt to capture the knowledge generated in the local space. The mobile Android application is used to set up an interview, take interviews from people inside a MAZI Zone, record the interviews, tag them and upload the sound recordings on a MAZI node. Consequently, the Interview archive browser-based application is used to curate and broadcast the content created.
Sphinx <http://www.sphinx-doc.org/en/master/>	Sphinx is a tool that makes it easy to create intelligent and beautiful documentation. It uses reStructuredText as its mark-up language and many of its strengths come from the power and straightforwardness of reStructuredText. Sphinx is utilised for building the technical guidelines for the advanced MAZI owners and administrators <http://nitlab.inf.uth.gr/mazi-guides/>.

Application	Description
LimeSurvey <https://www.limesurvey.org/>	The LimeSurvey application is a popular Free Open Source Software survey tool that provides comprehensive features allowing running nearly every survey with grace. It offers multi-lingual surveys, user-management, 28 different question types to choose, integration of pictures and videos, anonymous and not-anonymous surveys, template editor for creating your own page layout and an extended, user-friendly administration interface. The installation procedure is very straightforward, reminding the Joomla installation procedure and there is a detailed documentation for installation, usage and configuration to be followed from anyone interested.
Framadate <https://framadate.org/>	Framadate is an online service for planning an appointment or making a collective decision quickly and easily. Users can create a poll, send the poll link to friends and finally discuss and make a decision.

At the moment of writing of this report, MAZI team is in the process of integrating an open source private chat server for enabling direct messaging between those connected in local proximity. Importantly, a MAZI Zone administrator is able to add any other application through the administrator interface and enable it in the user interface next to the other pre-installed ones.

4.2.3.1 Managing and Controlling Applications and Interfaces

An administrator has access to useful configurations related to MAZI applications and interfaces in order to adjust the accessibility and user experience of a MAZI Zone. The Portal's appearance is fully adjustable in terms of text/titles/colours/images etc. Other settings such as time and date of the Zone (for offline deployments where no Internet synchronization is available), mySQL password and maximum file size upload are available to configure, providing full control of the network.

One of the main functionalities is the capability to create multiple instances of each application and display them as separate tools in the user interface, allowing flexibility and adaptability of the toolkit according to the context. For example, a MAZI Zone could feature an instance of Etherpad for taking minutes of a meeting and at the same time provide another Etherpad for collaboratively preparing a document.

Another exceptional feature of the administrator interface is the capability to change the splash page of the captive portal. The administrator is able to configure any of the application instances created, as the page where the user will land upon his/her connection to the Wi-Fi network. Finally, each application instance can be enabled or disabled at will.

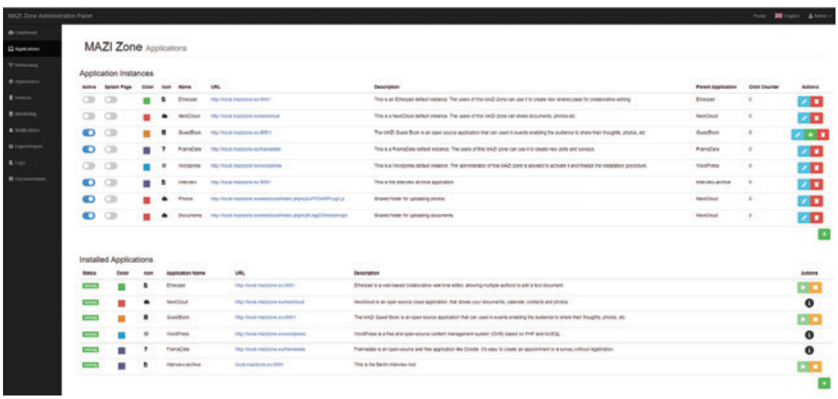


Figure 4.3. Application settings in the MAZI admin interface

4.2.4 Network

As mentioned before, all interactions within a MAZI Zone happen through the Wi-Fi network exposed, which enables users to have constant access to local services and potential access to Internet, given the fact that there is physical connection (either through an Ethernet cable or through a USB Wi-Fi adapter).

Upon the connection of a user to a MAZI Zone, a captive portal automatically pops up showing information about the current deployment. The default network mode is offline, thus blocking Internet connection to connected users, allowing them to access only local services, namely the MAZI Portal and the installed applications. The administrator is able to change the mode to either “online”, for providing both Internet access and local services to all the MAZI Zone users, or to “restricted” mode, to allow access only to a specific group of users, according to specific criteria. Finally, administrators are able to edit the Portal’s URL from the default portal.mazizone.eu to any valid URL such as local.mazizone.eu, or mazi.zone.local.

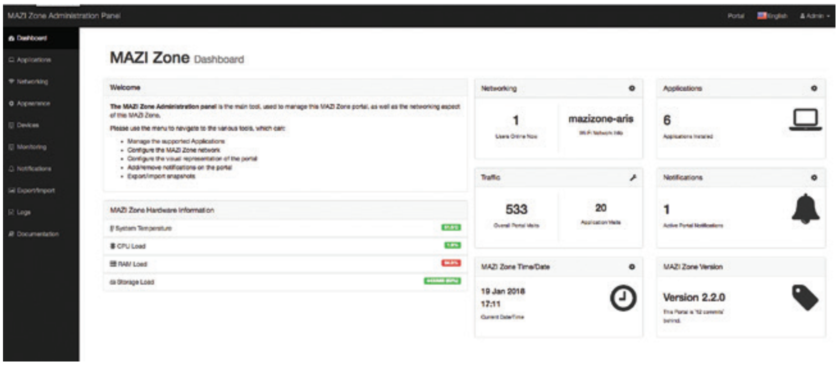


Figure 4.4. Network configuration in the MAZI admin interface

4.2.4.1 Network Accessories

In order to enable extra functionalities, MAZI toolkit supports the attachment of network accessories, such as USB Wi-Fi adapters and OpenWRT Routers which are automatically detected by the toolkit and manipulated through the MAZI portal administration panel[62].

To this end, except from the built-in Wi-Fi module of the Raspberry Pi board which is very useful but of limited capabilities, administrators are able to attach a USB Wi-Fi adapter to the USB port of the Raspberry Pi and take advantage of its advanced network capabilities. In addition, to provide even better network characteristics, MAZI toolkit supports the connection of OpenWRT routers. Network aspects, such as the number of devices that can be connected as well as the coverage range of the Wi-Fi network can therefore be fundamentally improved, enhancing the quality of interaction of users with local services.

On the other hand, the extra network accessories can be utilized as the physical connection to an external Wi-Fi network in range that provides Internet access, thus enabling the forwarding of

62 The network accessories tested and supported can be found in <https://github.com/mazi-project/guides/wiki/Products>.

Internet connectivity to MAZI Zone users. This functionality can be very effective in areas where there is no wired access to the Internet (through an Ethernet cable) allowing the configuration of the MAZI Zone to dual or restricted mode and providing Internet connectivity to users.

Figure 4.5. MAZI node featuring a USB Wi-Fi adapter at the left and an OpenWRT router at the right

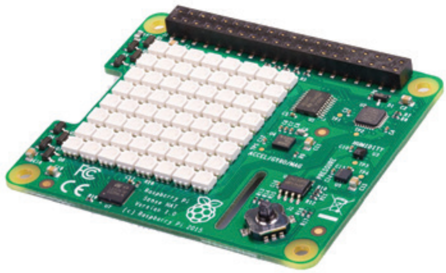
4.2.5 Sensing the environment

Following requests from a wide range of community members, several types of input-output devices have been integrated in the MAZI ecosystem for sensing the environment of a MAZI Zone. Sensors for reporting environmental measurements and cameras for providing live streaming capabilities are supported and, in addition, they are reinforced with interfaces for their easy manipulation.

4.2.5.1 Sensors

The MAZI toolkit features in-house support for the Sense HAT board (Sense HAT, n.d.) and the SHT11 module from Sensirion (Digital Humidity Sensor SHT1x (RH/T), n.d.), both shown Figure 6, but also supports the integration of any other type of sensor which complies with the open interface built for collecting data produced in MAZI Zones[63].

63 See section 4.2.6 and the MAZI backend Wiki (MAZI back-end, 2018) for further details.



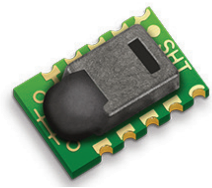


Figure 4.6. SenseHAT board at the left and Sensirion SHT11 at the right

Sensirion SHT11 is a simple, relative temperature and humidity sensor that provides a digital output and is individually calibrated in a precision humidity chamber. **Sense HAT** features an 8X8 RGB LED matrix, a mini joystick and the following sensors: (1) Gyroscope (2) Accelerometer (3) Magnetometer (4) Temperature (5) Humidity (6) Barometric pressure, which are all integrated in the MAZI administration panel for easy control and management by the administrator. In addition, administrators are also able to start and stop the sensing procedure, select the desired target server to send the measurements (default is locally) and manage the locally stored measurements.

4.2.5.2 Camera

In order to enable video streaming and capturing of photos and videos in a MAZI Zone, the Raspberry Pi Camera Module v2, shown in Figure 4.7. was employed. This features a IMX219 8-megapixel sensor and enables capturing of high-definition video as well as still photographs. As illustrated in Figure 4.8., the default software libraries allowed the easy integration in the MAZI ecosystem and the MAZI interfaces.

Figure 4.7. Raspberry Pi Camera Module v2

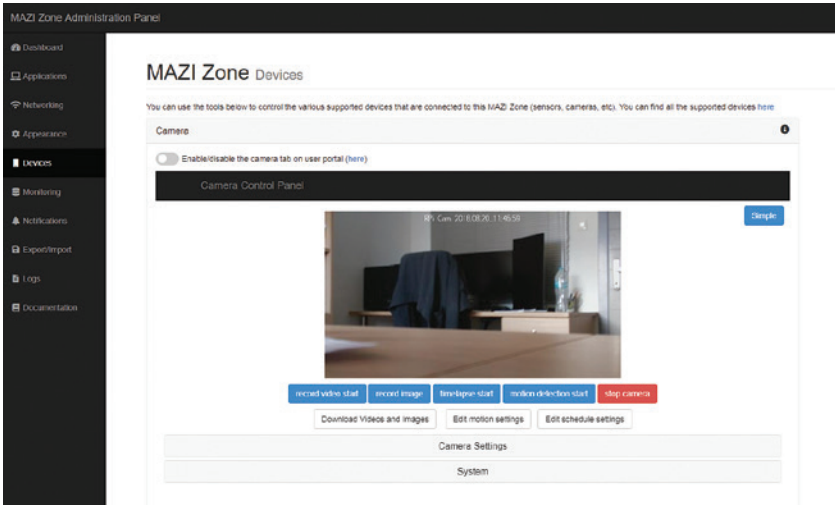


Figure 4.8. Camera control panel in the MAZI admin interface

4.2.6 Data Collection

MAZI toolkit features a Data Collection framework providing the means to collect, store either locally or in a remote database, and consequently monitor data coming from MAZI Zones. Administrators are able to collect the data from their MAZI nodes residing in different locations and provide an integrated view at different levels (*e.g.*, a single user can observe the data collected by his/her own MAZI nodes in different locations). Another scenario facilitated by this configuration could be that of a local institution able to collect data shared voluntarily by multiple MAZI zone administrators, thus building collective awareness at larger scale (than the coverage of a single MAZI node), through a truly bottom-up process.

Such procedure is strictly initiated only by MAZI Zone administrators, who are able to select through their administration panel between:

- System activity (CPU/RAM usage, available storage,)
- Sensor measurements (environmental data coming from MAZI Zones featuring sensors)
- Application data and statistics (posts in MAZI Guestbook, number of collaborative documents, number of clicks for each application)

and send these in a local or remote MAZI Data Collection Server for further processing. For privacy reasons, the local administrator has full control of the Data Collection service and the data are only being sent from a MAZI node to a server and not the opposite. Moreover, administrators are able to select which specific measurements are going to be sent or simply turn off the Data Collection Service in their MAZI Zone. The data gathered in a server are visualised on a map providing an overview of the deployments across a certain region or across the whole world.

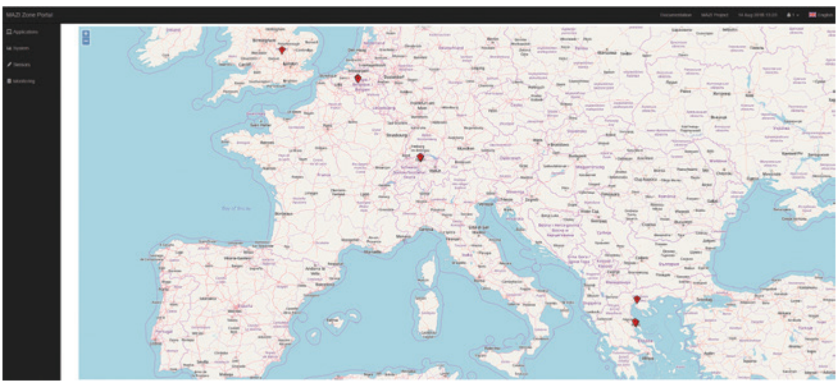


Figure 4.9. Public MAZI Data Collection server showing collected measurements on a map

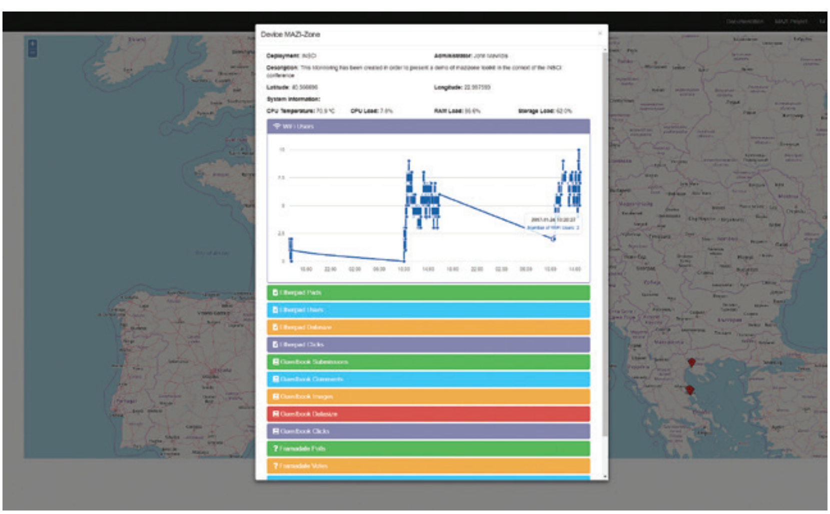


Figure 4.10: Graphs and details from a specific pin of the Data Collection map

4.3 Deployment, Maintenance and Sustainability

The MAZI toolkit is built through participatory processes involving communities in each step of the development and assisting them towards the deployment, operation, configuration and maintenance. To support MAZI toolkit users in the aforementioned activities, online guidelines were compiled targeting a wide range of users, from non-technology savvy ones (mainly users and administrators) who only need to download a SD card image, to Tec enthusiasts (developers) who are able to build the toolkit's software from scratch following detailed documentation[64].

The documentation for beginners can also be retrieved online, as part of the official MAZI website, aimed at guiding the potential MAZI Zone owners to acquire the necessary equipment, download a ready-made MAZI toolkit image, copy it to a microSD card and, eventually, deploy their MAZI Zone[65].

4.3.1 Keeping your MAZI Zone updated

One of the key functionalities of the toolkit is the one-click update feature enabling the MAZI Zone administrators to follow the development of the toolkit and get updates for new features or bug fixes. This is achieved through the administration panel, which facilitates the update process of already deployed MAZI Zones.

4.4 Conclusions: getting involved

The MAZI toolkit is in a continuous developing process through participatory methods, directly involving communities who provide feedback about the different aspects of the toolkit. Their involvement is accomplished leveraging diverse platforms and channels, including reporting issues in MAZI GitHub[66] direct face-to-face meetings during MAZI workshops, or public mailing lists e.g. toolkit@mazizone.eu.

The involvement of new interested individuals is very welcome and is a key component of a sustainable development and evolution of the MAZI project.

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64 See <http://nitlab.inf.uth.gr/mazi-guides/>.

65 See <http://www.mazizone.eu/toolkit_guidelines/>.

66 See <https://github.com/mazi-project/portal/issues>.

4.2 References

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5 LibreRouter: The Hardware and Software Platform for Community Networking

Nicolás Echániz and *Florencia López Peze*
Illustrations by *Ana Daniela Caballero*

Abstract

For a large part of the disconnected population – eminently rural, poor and living in the global south – the business and networking models that have connected the first half of the world population will not be viable. In this scenario, community networks (CNs) have acquired great prominence, as a promising solution to expand connectivity in disadvantaged areas, a model that can reach where others cannot. Challenges to deploy these CNs "on the field" are still very significant – especially in the global south – and, to provide concrete solutions to this challenges, the LibreRouter project has been conceived. LibreRouter is a device, which would finally allow community mesh networks to count on a hardware and software platform, designed with their specific needs in mind.

This chapter explores the challenges and successes of the LibreRouter project. The design and development process of LibreRouter combined the efforts of more than 20 specialists from all over the world, long time CN activists from different continents, electronic engineers, hackers, and communicators. The chapter briefly describes the multiple stages of prototyping of LibreRouter and provides an overview of the results that, to date, seem promising.

5.1 Introduction

In the article "Fostering Connectivity and Empowering People via Community Networks: the Case of AlterMundi"[67], published in the 2016 edition of the DC3 annual report, we mentioned the development of the LibreRouter as a future challenge for the progression of community networking. The LibreRouter is a device, which would finally allow community mesh networks to count on a hardware and software platform, designed with their specific needs in mind.

67 See Belli, Echániz and Iribarren (2016).

The design and development process of LibreRouter combined the efforts of more than 20 specialists from all over the world, long time community network (CN) activists from different continents, electronic engineers, hackers, and communicators.

The project was started with initial funding from a FRIDA[68] grant, sponsored by LACNIC, and received further support from FIRE[69] (an initiative sponored by AFRINIC) and the Seed Alliance Interregional Fund.[70] During 2017 and 2018, the development software and hardware projects aimed at supporting LibreRouter was supported by the Internet Society and the Technology Innovation Agency of South Africa (TIA).

The results, to date, seempromising. The router went through multiple stages of prototyping and is currently entering the manufacturing phase of the first batch of units. A number of prototypes have been installed and operating at the heart of the CN QuintanaLibre, in Argentina, where they have transported over 1TB of weekly data traffic for over 6 months.

In the initial survey that was run for a week, communities expressed interest in acquiring more than 3500 units during the next year.[71]

The price point for a fully equipped node (complete with casing and antennas) will be around $150 USD.

5.2 Hardware characteristics

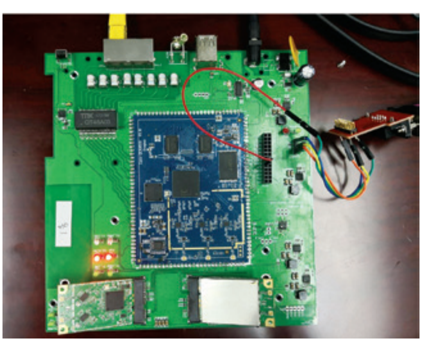

Figure 5.1. LibreRouter board

The LibreRouter is based on the QCA9558 SoC, which has a longstanding stable support in OpenWRT, the base operating system. The main characteristics of the LibreRouter board are:

- QCA9558 SoC and AR8327 Gigabit Switch
- 128 MB DDR RAM

68 See <https://programafrida.net>.
69 See <https://www.fireafrica.org>.
70 See <http://seedalliance.net>.
71 See <https://librerouter.org/article/the-librerouter-is-almost-out-who-wants-one>.

- 16 MB flash
- Hardware watchdog based on PIC10F200
- 1 on-chip 2.4Ghz 802.11bgn MIMO 2x2 Atheros radio
- GPS module
- 2 mPCIe slots populated with 2 mPCIe Power Amplified 5Ghz 802.11an MIMO 2x2 Atheros radios based on AR9582
- 2 Gigabit Ethernet sockets
- 1 USB 2.0 internal connector
- 1 Serial console pin-out
- POE and POE Pass-through to allow chaining two devices.
- Exposed GPIO pins, which will allow tinkerers to connect other electronics to the device

The LibreRouter package includes a weatherproof outdoor casing, sector antennas for the 5Ghz and 2.4Ghz radios, pigtails, mounting elements, a PoE injector and power adapter.

The full spec sheet as well as initial layout and schematic are available on the LibreRouter web site.[72]

5.3 Initial tests

A team from Toronto Mesh (ToMesh)[73] independently tested the performance of the LibreRouter 5Ghz radios paired with their 12dbi antennas. After having tested LibreRouter, the ToMesh team expressed its positive appreciation, affirming that

> *"we conducted many tests that are described in detail* [in our assessment brief]*, but our key findings are as follow:*

- *The radio and antenna combo creates stable links over hundreds of meters at 150 Mbps.*
- *Wall penetration is excellent even when a client node has an omnidirectional antenna on a radio with average sensitivity.*
- *Continuous transmission for 10 minutes at 26 dBm show no performance drop or heating-related issues.*

72 See <https://www.librerouter.org/media/documents/LibreRouter_specifications_v6.pdf>; <https://librerouter.org/document/schematic-v1/>; and <https://librerouter.org/regularfile/layout-v1/>.

73 See <https://tomesh.net/>.

- *The 12 dBi antenna makes an excellent 5Ghz antenna even for other radios.*
- *Linux driver support is trivial, as expected from a ath9k device*

Toronto Mesh is overall very impressed with the performance of these devices."[74].

Tests conducted in QuintanaLibre, Argentina, and in Can Masdeu,[75] Catalonia, reached very similar conclusions.

5.4 LibreRouter, not just a hardware

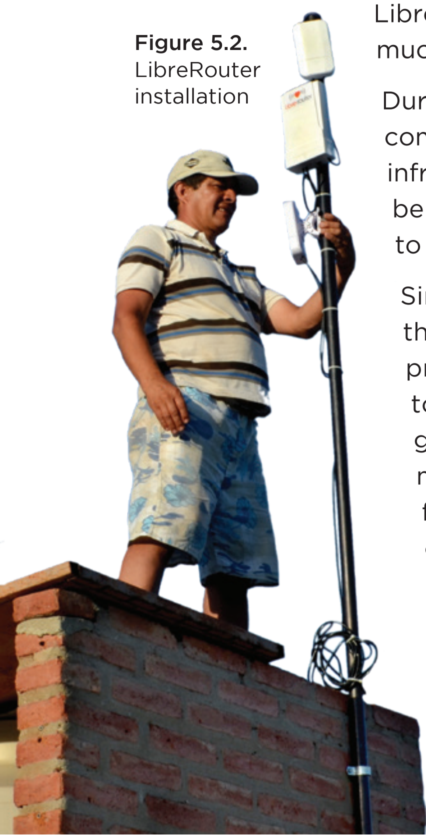

Figure 5.2. LibreRouter installation

LibreRouter is the core of a project that covers much more than just a hardware solution.

During the years of experience in accompanying communities that begin to deploy their own infrastructure, the community of developers behind the project understood that solutions need to be comprehensive in order to be successful.

Since the first Internet governance gatherings, the expansion of connectivity has been presented as one of the most pressing challenges to be tackled. Over the past years, the Internet governance scene has increasingly realized that more than half of the world is still disconnected from the Internet and that, for a large part of this disconnected population – eminently rural, poor and living in the global south – the business and networking models that have connected the other half will not be viable. In this scenario, CNs have acquired great prominence, as very promising solution to expand connectivity in disadvantaged areas, a model that can reach where others cannot. In this context, recommendations from

74 See <https://github.com/tomeshnet/documents/blob/master/technical/20180530_hpm5g-radio-tests.md>.

75 See <https://en.wikipedia.org/wiki/Can_Masdeu>.

international organizations,[76] regulatory initiatives[77] and financing programs from global and regional organisations have started supporting CNs, increasingly facilitating their development.

Nevertheless, those going out "on the field" to deploy these networks – especially in the global south – can witness that challenges are still very significant. It is unrealistic to believe that CNs will connect billions of people in the near future if we do not seriously address pending issues. Furthermore, it is possible that the movement promoting CNs may be advancing faster than the ecosystem that allows them to materialise. Such mismatch should be avoided.

During the development of the LibreRouter project, it became clear that the hardware market for wireless connectivity has not identified mesh community networks in low-income regions as a segment for which it is necessary to develop specific products. This situation has obliged CNs to use products that were not designed for their realities. Hardware and software solutions do not respond to the needs of communities that lack the technical skills to operate standard networking equipment. Consequently, there is also a lack of organised support processes from hardware suppliers for these communities.

In cases where communities with sufficient trained technical personnel decide to deploy solutions based on commercial products designed for other segments, the networks become dependent on the support of these technicians for their daily operation and for their expansion. This scenario goes against the community empowerment.

At AlterMundi,[78] we think that the same people who have the ability to buy a cell phone and use it to communicate daily without having to take a specialised training course, should be able to install and maintain their own community network nodes. The technical barrier to entry must be reduced to a minimum, so that the community's

76 See <https://www.itu.int/rec/D-REC-D.19>.

77 See CITEL PCC.I/RES. 268 (XXVIII-16) at <https://www.citel.oas.org/en/SiteAssets/PCCI/Final-Reports/CCPI-2016-28-4000_i.pdf>.

78 See <http://ww.altermundi.net>.

efforts can turn to challenges that are more complex. The CN as an infrastructure must be a fertile ground for the community to express and share its local culture and communicate, serving as a vehicle for the co-creation of the Internet in all its dimensions.

5.5 Comprehensive documentation

Figure 5.3. Documentation: booklets

We understand that another situation that holds back the deployment and survival of CN experiences is the lack of spaces, tools and training material designed to accompany the learning processes in the communities. For this reason, the documentation material of the LibreRouter project is designed to help people with no specialised technical training to learn the basics of mesh community networking.

We think that the ability to organize themselves represents the main drive for community networks to thrive. The documentation proposes methodologies, tools and experience examples that allow new CNs to walk through this process from both a technical and a social perspective.

The documentation, which is complemented by video tutorials, is structured in a series of booklets:

- Free networks and community networks. Shares some theory and examples on what community networks are.
- Planning a community network.

- Participatory mapping. Proposes methodologies to facilitate the process of understanding the terrain and it's limitations and how to design a good network structure.
- The LibreRouter and its components.
- Installation of a LibreRouter node. Explains the details of a successful node installation.
- Antenna alignment. Explains the required tools and techniques.
- Node configuration using the mobile app.
- Diagnosis, analysis, improvements and solutions.

5.6 Software

Another crucial component in the LibreRouter project is its software and service stack.

The central piece: the LibreMesh firmware is a free software operating system based on the well-known OpenWRT project. LibreMesh automatically handles the different aspects of mesh CN deployment. Importantly, a group of LibreRouters can create a mesh network right out of the box. IP address blocks, routing, name resolution and network mapping are all handled automatically. The community can decide to just set a name for the network, which will be publicly visible as the WiFi SSID, and they are ready to go.

Furthermore, LibreMesh not only automatically configures the whole system supporting a CNs, it can also handle inter-community communication transparently. Multiple routes among communities as well as to the global Internet can be established and selected automatically, providing fault tolerance at an inter-community level as well as inside each community network.

Within the community, each LibreRouter behaves as a multi-radio mesh node using its 5 Ghz radios for inter-node communication, while the 2.4 Ghz radio exposes a WiFi AP for client devices. By default, all nodes share the same WiFi SSID, so client devices are able to roam between nodes covering an area.

The mobile app, which can be accessed from any node, provides relevant information on the node status such as link quality to its neighbours, selected path to the Internet, path metrics (latency, packet loss and throughput) for each hop, etc. It also provides an antenna alignment helper tool, which can read link quality aloud in real time as the alignment is adjusted.

The set of tools available is completed by services provided to the LibreRouter devices, developed by AlterMundi and its partners, which include LibreMap and Librenet6.LibreMap provides a visual geographic representation of the CN, which can show the status of its nodes and links. Data is updated automatically by each node without the need for user interaction.

The Librenet6 tunnel broker provides public IPv6 addresses, which can be used to expose services from the CN to the world but it can also be used to ease external remote monitoring and support.

5.7 Way forward and future challenges

5.7.1 Support network

As we highlighted above, the LibreRouter anticipated demand is already in the thousands of units, by communities from all over the world. We only expect this demand to grow over time, considering the exposure that CNs are getting globally. This creates a need for a support system that helps communities solve those issues that cannot be addressed locally.

Although the whole model helps communities take care of the day-to-day operation of the network, there are problems that are difficult to anticipate, diagnose and solve. In those cases, external support is usually needed. The support network to make this possible has been described in the LibreRouter Phase 2 project, which has recently secured funding from the Internet Society's Beyond The Net program.

One challenge we have started to explore in this context is guaranteed external access. There are communities in regions, which cannot connect to the rest of the Internet through terrestrial networks; in those cases we are looking to create partnerships with satellite access providers which can help guarantee low bandwidth connectivity through which communities can still get remote support.

5.7.2 The LibreRouter family

During the time that the LibreRouter was discussed, designed and produced, many possibilities were evaluated regarding the production of alternative models to address different needs. The first production version of the LibreRouter uses a split-board design where a higher complexity board holds the core components (core module) and another, less complex circuit, implements the rest of the design.

This design decision makes customisation easier. While the core module stays the same, the main board can be produced in different versions. One such option that will be important to produce is a "Lite" version to accommodate for communities that struggle to afford the cost of each node. Over time, we expect the LibreRouter project to produce newer generations of devices, always keeping in mind affordability, performance and the specific needs of CNs.

5.7.3 Localise production

In the path to empower communities in their appropriation of technology, we believe that it is important to consider how to move production of the different components of LibreRouter to their own regions. As a first step, the localisation of non-electronic components: outdoor casings, antennas, pigtails, etc. is the least complex task and we are exploring unconventional logistics strategies to make it possible.

The LibreRouter main board local production would be a natural second step. Due to the low complexity of its circuits, it is easier to find the capacity to produce them at a national level. Universities from different countries are already evaluating this possibility.

If this was to be accomplished, over two thirds of the router cost would be moved to local production. This would lower the impact of transportation, it would create local jobs, it would promote inter-regional cooperation and it could lower the total cost. Fornthese reasons, this option must be explored further.

Transversally to the LibreRouter production, all the documentation material will always be available not just for local printing but also for local adaptation and translation.

Critically, all LibreRouter hardware, software and documentation are released with open licenses.

5.8 Conclusions

The LibreRouter journey is really just starting. It has already been an incredibly rich experience for the people involved in the different aspects of its materialisation. Since the first talks, in Berlin back in 2013, regarding the need to produce an affordable router with dual 5 Ghz radios, to the realisation of this device, which implements the original idea and so much more, we can say it has already been a success.

The ride has been bumpy at times, with the prototyping iterations being by far the hardest ones. We believe that a project of this characteristics being steered by a collective from the global south, with the collaboration from people in every continent, is a great example of how much we can do when we decide to pull our creativity and our will together.

The way ahead is both promising and challenging. We hope the community that is already building around it and the projects that are being planned with the LibreRouter at their core will help establish a collective that can keep this dream alive for a long time to come.

We also expect that governments, global organisations and international cooperation agencies will realise the potential in supporting the continued growth of a truly community centred technological ecosystem that can really make the "let the unconnected connect themselves"[79] motto become a reality.

Technology is only a piece of the puzzle.Support and training, access to infrastructure, sufficient spectrum, special licensing and a general mind-set shift regarding "sustainability" is needed if we

79 The motto is frequently heralded by CN supporters in opposition to the "connect the unconnected" narrative.

expect CNs to live to the expectations that have been set on their shoulders. The LibreRouter project is an important step in the direction of CN sustainability.

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PART II

Scalable, Sustainable and Law-compliant Community Networks

6 Multiple Dimensions of Community Network Scalability

Roger Baig Viñas, *Leandro Navarro* and *Ramon Roca i Tió*

Abstract

Diverse initiatives around the world show the feasibility to build bottom-up community networking infrastructures to join the Internet. However, an experimental network by and for hackers has very different implications at all levels compared to a general-purpose production network for an entire population. Scalability in the design of community networks (CNs) makes the difference between clubs with entry barriers of complexity and limited service and extensible network commons able to accommodate and serve every user in an area. In this paper, we analyse the overall strategies and tackle scalability from what we consider the four main dimensions of CNs: social, legal, economic, and technological dimensions. We utilise the experience and lessons learned from guifi.net and other CNs to illustrate the discussion and the ways to achieve scalability in CNs.

Acknowledgements

This work was funded by the Beyond the Net program from the Internet Society, the EU netCommons contract H2020-688768, the Spanish Government contract TIN2016-77836-C2-2-R, the Generalitat de Catalunya as Consolidated Research Group 2017-SGR-990 and the Industrial doctorate contract DI-006, the guifi.net Foundation, and the Association for Progressive Communications. The work would not have been possible without the generous effort of the guifi.net community and other community networks as part of the Dynamic Coalition on Community Connectivity (DC3). We also appreciate the comments by Luca Belli on a draft of this report.

6.1 Introduction

Scalability is a property related to the ability or sensitivity of a system to accommodate change in a relevant dimension. Scaling up relates to 'an increasing number of elements or objects, to process growing volumes of work gracefully, and/or to be susceptible to enlargement' (Bondi, 2000), but finding the right size and determining how the size in terms of orders of magnitude affects a system are challenges.

The aforementioned terms are widely used in the fields of computer science, telecommunications, and economics. In the information technology (IT) field, the capability of physical systems and theoretical designs to handle a growing amount of work is commonly analysed in terms of resource consumption (time, CPU, RAM, and storage). The potential to be enlarged falls into two broad categories: horizontal scaling, which refers to the addition of nodes, and vertical scaling, which refers to the enhancement of existing nodes (Wikipedia, Scalability, 2018). In economics, the term is usually applied to companies or business models to denote their capacity 'to maintain or even increase its level of performance or efficiency even as it is tested by larger and larger operational demands' (Investopedia, Scalability, 2018).

In this paper, we elaborate on the scalability of community networks[80] (CNs) understood as the potential of these initiatives to deliver connectivity to their current members and to extend it to larger populations. Particularly, we look at scalability in the design of CNs, arguing that, despite starting out tiny, pioneers should be aware of and plan for the size and characteristics of the potential group of participants and beneficiaries. That makes the difference between clubs – organisations restricted to a few – from institutions for the common good – extensible network commons able to accommodate, serve, and benefit all members of

80 To the best of our knowledge there is not a generally accepted definition of community networks – thus, there is neither a generally accepted classification criteria for establishing what initiatives falls under the category and what are excluded. For us, in a broad sense, the term refers to bottom-up participatory initiatives aimed at extending Internet connectivity.

a given community or area.[81] We base our analysis on our personal experience in guifi.net[82] combined with our knowledge of other CNs with the sole ambition to share our thoughts and vision.

The reader must be aware that a comprehensive analysis of the factors that may influence the scalability of any of the initiatives that can be regarded as a CN and how they should be faced is out of scope. Solid scientific evidence on these aspects is needed for the consolidation of CNs as a worldwide alternative for its target population because, today, despite the existence of models and many promising practical experiences, CNs as a whole are not yet mature enough to deliver such an ambitious objective at the scale of demand. We hope the research community will tackle this challenge further, as our contribution aims at contributing positively, setting the basis for such an all-important debate on CN scalability. We first discuss the reasons CNs should scale and the general strategies to achieve it. Then, we analyse the reasons and strategies to tackle scalability more in-depth from the perspective of what we consider to be the four main dimensions of CNs: social, legal, economic, and technological[83] dimensions.

It is followed by a cross-cutting analysis to address the relevant aspects that do not fit well in the previous thematic approach or that needed further discussion from another point of view. The arguments are illustrated with experiences and lessons learned by guifi.net and other CNs and each of them concludes with a footnote with a proposed set of activities to be completed by the reader. We conclude our analysis with a review of the main actions that global external organisations can take to boost the uptake and development of CNs. Finally, the conclusion section summarises our main contributions.

81 "In the past, networking infrastructures were considered a club good (excludable and virtually non-rival as a commercial service) provided by for-profit ISPs to those fortunate to be in coverage areas and willing to pay the service fee. CNs are a social response to the wide recognition of connectivity as a basic human right, and therefore the network infrastructure connecting people becomes non-excludable." (Navarro et al., 2016)

82 See the appendix for information on this particular CN.

83 In fact, from the technological perspective, CN are not so different from any other network deployment. Even though, technological aspects too often mistakenly attract the attention of the debate.

There are four main reasons for scaling up. The first is the willingness to share a satisfactory experience with new people. Indeed, the keenness to share is one of incentives most commonly invoked by many contributors for participation (Micholia *et al.*, 2018). By getting involved in a CN, the participants not only have the opportunity to help their peers but also help extend the Internet, which has fostered sharing and collaboration in an unprecedented manner. In addition, the larger the CN, the more opportunities to share one's experience and to learn from others. In the specific case of guifi.net, sharing knowledge and resources and helping neighbours were the fundamental conditions set by the mayor of the village where the CN was born (Gurb, Catalonia) to give access to the council's DSL, the only existing internet access in the village at that time. These conditions aligned with the spirit of the promoters of the project.

The second reason relates to reaching economic sustainability. To persist over time, any project must grow at least to the point where the contribution of beneficiaries meets the resources required to maintain the activity, the so-called break-even point in economics. In the case of the CNs, the costs to be covered include at least the hardware (routers, antennas, cables, etc.), but from a given time, manpower costs should also start being included, as the projects that are purely based on voluntary work do not scale well and tend to decay.

To attract enough users to reach the break-even point, CNs must offer value, that is, competitive services that maximise the satisfaction of the user needs in comparison to competitors. In turn, competitive services can only be offered after a minimum outlay, meaning that only projects over a certain budget are viable in the long term. In addition, scaling up also helps reach the critical mass to counteract the demotivating effect that the stabilisation of the infrastructure and the access to good quality Internet access may have over those initial members who were looking for technical challenges.

The third reason is that growth strengthens self-protection. The larger the community, the larger the community knowledge is and the higher the chances to provide mutual support are.

Moreover, the stronger the dependencies on a given resource, the more difficult is to be obstructed by potential adversaries. Social pressure is a recourse to warn against situations of injustice, like unfair and discriminatory treatment by public bodies or private companies. For instance, guifi.net has used its presence in the territory and its social support to denounce malpractice cases by public administrations and by the incumbents.[84] As a result, many public administrations had to backtrack on policies that were manifestly abusive and discriminatory, like levying a tax only on new operators after the established operators deployed their networks and the incumbents had to review their initial positions.

Finally, yet importantly, larger scales increase efficiency and are conducive to economies of scale. Some cost savings, such as in procurement, are quite predictable. Others, though, are not so obvious beforehand. As an example, wholesale Internet access is generally significantly cheaper and of much better quality than domestic connections; thus, a CN makes a qualitative leap when it is able to switch from retail connections to wholesale and, at the same time, it reduces costs. Similarly, quantity discounts are common among hardware providers. In addition, less obvious savings appear with the increase of the activity within the CN ecosystem. For instance, in guifi.net, we have observed that, as economic activity increases, the professionals tend to specialise, fostering their expertise and improving their productivity. The repetition of tasks leads to optimised procedures and good practices that can be collected, documented, and some even automated. In turn, these optimisations enable further growth.

Furthermore, the spirit of sharing that characterises CNs amplifies the ordinary positive effects of growth, as any progress (in software, methodology, etc.) is immediately available to all practitioners – also from other CNs – and the adoption rates are usually very high. Sometimes, the spirit of sharing is so deeply rooted that practitioners are not even aware of the benefits that come along with it. In guifi.net, for instance, the contributors are

84 For instance, the first connection between guifi.net's fibre deployment and the public fibre network of the Catalan Government was only achieved after pressuring the authorities with roadblocks in Sunday afternoons to show the visitors that despite the two infrastructures were side-by-side the Catalan Government was rejecting to connect them.

so used to automatically getting the configuration parameters of their devices through the website that is highly likely that many of them are not even able to estimate the resources needed to do so manually, which is probably no longer possible given the size of the network.

However, growth has some drawbacks as well. As the community becomes larger, information exchange and personal interaction across the community may become costlier and require additional coordination to avoid overload. A larger community may increasingly need to stipulate and formalise procedures to reduce the burden of otherwise unstructured interactions across a larger set of participants without increasing complexity. Larger constituencies may benefit from distributing functions and responsibilities and more clearly defining the organisational structures. Thus, the challenge is how to accommodate growth with coordination mechanisms that keep the community equally or more effective in delivering benefits to its participants without disempowering them by centralising decision making or overloading them.

6.2 Strategies for Scaling Up

There are many approaches and factors to be considered when it comes to quantifying the size of a network. Our viewpoint is from the socio-economic value of the infrastructure; thus, the most representative indicator is the number of beneficiaries. The maximisation of this indicator with respect to the size of its constituency, that is, the potential beneficiaries, should be the target of any non-speculative infrastructure[85] of any kind. Importantly, the strategies leading to this type of maximisation must always be subordinated to the principle of social fairness, which includes respect for the environment, fair wages and working conditions, inclusion and non-discrimination of minorities and the vulnerable, etc.

To maximise the number of beneficiaries, the ultimate goal of any action, direct or indirect, must be either the expansion of the network (acquisition of new beneficiaries) or the improvement

85 Speculation has its own logic which is out of the scope of this paper, but certainly does not have social good as its ultimate goal.

of the services delivered (loyalty of beneficiaries). These actions must be prioritised by the principle of opportunity and repayment maximisation, again, carefully combined with social fairness goals. Direct actions include the deployment of new nodes (horizontal scaling), enhancement of the existing infrastructure through technology upgrades or migration (vertical scaling), and the improvement of services offered to the participants. Indirect actions include improvements in the governance system (licensing, agreements, procedures, etc.), development of software tools, dissemination activities, stakeholder engagement, and influencing public policies and regulations, among others.

As discussed in the following section, the realisation of CNs generally leads to disruptive innovation. As such, it can create relevant resistance on the part of well-established interests, which see any innovation that they cannot control as a threat. Countering the strong influence of these interests demands cleverness and perseverance. In this respect, the basic literature on strategies and tactics offers appropriate tools. For instance, in guifi.net, the frequently used tactics of distributed action, rapid action, and exploitation of apparently minor opportunities to provoke significant changes are very reminiscent of the lessons from Sun Tzu (Wikipedia, The Art of War, 2018).

In the following sections, we deepen the analysis on the factors influencing scalability. We structure our study around the four main areas that, in our opinion, every CN should consider, followed by a section analysing the cross-disciplinary requirements. We elaborate on external and internal threats and on internal mistakes and make recommendations based on our experience and research on guifi.net and other CNs.

6.2.1 Social Considerations

The social objectives are the main shaping factors of any project. Computer networks, aiming at an experimental network for hackers,[86] have very different implications at all levels than aiming at a general-purpose production network for an entire population.

86 It is not our intention to establish a classification schema for CNs, but for us such restrictive initiative does not meet the minimum requirements to be labelled as CNs.

In the same manner, the implications of aiming at a network for dozens of users are not the same as aiming at one for every one of the hundreds, thousands, or millions nearby. The social objectives do not need to be necessarily prescribed since the beginning and might evolve over time,[87] but an early tentative definition[88] facilitates initial progress because many of the critical decisions needed to move forward depend on them.

Moreover, explicit definitions and clear positioning on fundamental relevant topics (e.g. support of the right of participation in the decision-making process) are needed to ensure that there is common ground among the participants on these topics for an effective progress. Nevertheless, it is important to note that the requirement of consensus must be strictly restricted to the truly relevant matters to avoid unnecessary and undesirable exclusion.[89] One of the first decisions to be explicitly made with a determinant influence on the nature and potential of our project is the choice of the socio-economic model for the infrastructure: the network.

To this end, we propose to learn about the predominant ones considering their (real) social objectives[90] and understand their (unwanted) implications[91] and to raise a number of questions, such as whether we envision the network to be self-sufficient by allowing economic activity and, if so, under what conditions (e.g. do we allow profit making? Do we allow competition?). Our social objectives do not match those underlying the traditional network models. Thus, finding a suitable socio-economic model requires us to be innovative. For instance, it is clearly incompatible to pursue a user-centric network and to choose a model prone to speculation. The topic to address in this decision-making chain relying on social objectives is to select the governance model.

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87 See the discussion on the iterative development process in cross-disciplinary considerations section.

88 We can start being conservative and then become more ambitious.

89 The example of open content is illustrative. A sympathy for open materials and services can be presumed among most of the participants. Nonetheless, in a participatory project the rule on openness must and can only be imposed on the content and services that are strictly necessary to run the project but not on others contributed by the members.

90 For instance, maximization of the dividend to shareholders.

91 For instance, that the network resources and customers are mere speculative assets.

We again propose to review the existing solutions and address some questions, such as who may participate in the CN governance, how decisions should be taken, what the usual practices emerging at the local level are in similar initiatives, etc. As in the previous case, given the divergence between social objectives, most likely we will have to be innovative because, arguably, the top-down traditional governance practices will not satisfy our needs.[92] Such divergence in aims and fundamental approaches leads to the emergence of disruptive models and practices.

In guifi.net, for instance, the social objective is stated as 'a fair Internet for everyone.'[93] At first sight, it may resemble the motto of any of the existing large telecom companies, but the terms *fair* and *for everyone* have implications that few of them would ever fully implement. Regarding *fair*, one could argue that the concept may hold different meanings for different people, but certainly it is quite apart from the real underlying principle of the business models of the current dominant telecom operators, which is the profit maximisation of the investors.[94] In any case, the other guifi.net motto 'neutral, open and free network'[95] makes the implications of the term clear on the properties of the network to be implemented. The use of *for everyone* leaves no room for interpretation: *for everyone* means *exactly for everyone* regardless of one's individual capability to afford it or not.

From the socio-economic model viewpoint, in guif.net, the infrastructure is conceived as an open common pool resource (CPR), and it is basically governed following Elinor Ostrom's (*1990)* principles. The guifi.net community has followed a long process to establish its theoretical basis. The concept of CPR and Ostrom's principles had to be adapted to suit the specificities of an artificial resource (the network) because the previous experiences – and

92 Strategies of organizational maturity: debate (learning), construction (testing, implementation): scaffolding and consolidation, replication (in new areas, communities). Related to Ostrom's principles for sustainability (every time, short term) and adaptability (to changes, medium or long term) (Navarro, 2018).

93 Una internet justa per a tothom in Catalan.

94 This explains overbuilding (deploying excessive capacity) while there are underserved areas at the same time, the business concentration, etc.

95 Xarxa oberta, lliure i neutral in Catalan.

the academic studies – were restricted to natural resources.[96] In conjunction with the governance system, the stakeholder groups and their rights and duties must be defined. Special care should be dedicated to the definition of the non-transferable roles of each stakeholder to ensure that there are no intrinsic incompatibilities or uncovered tasks.

The solution should strike a clear distinction between for-profit and not-for-profit contributors, as there are tasks that cannot be transferred from one to another. For instance, we argue that core governance activities must be under the responsibility of not-for-profit participants (to avoid conflicts of interest), while delivery of services to customers should be done by for-profit actors (to prevent market distortion).

Lastly, it is clear that, to create value, any network infrastructure must be connected to the Internet. Even more, it is not a matter for the active participants to decide whether the users may have access to the Internet or not. Their duty is to ensure proper Internet connectivity and let the users decide for themselves.[97]

6.2.2 Legal Considerations

The telecommunications sector is a highly regulated area, and CNs cannot afford disrespecting established rules, as the lack of compliance to the legal framework would only jeopardise their development. Although CNs are local initiatives and thus develop their activity under diverse legislative and regulatory frameworks, some practical guidance is applicable to nearly all contexts, regardless of the specific domestic legislation.

The first is to acquire knowledge on the legal system as a whole: how the legal system is structured where the CN will be developed, what the fundamental components are, such as the authorities that can regulate and bodies that can legislate, and how they relate to each other. The internalisation of this knowledge is crucial given

96 These adaptations the most important contribution of guifi.net at the theoretical level; at practical level, it is the size achieved.

97 Recommended activities:
a) Read more on guifi.net's governance system at section 3 of (Baig, 2018).
b) Make the design of the social business model canvas after reading (Navarro, 2018).

the existing strong economic interests of the telecommunications sector and the influence that their lobbies usually enjoy.

The telecommunications sector is very dynamic with a global trend towards liberalisation. As a result, the legislation is constantly evolving, making compliance even more complex. This changing scenario is harnessed by a wide range of lobbies aiming at shaping the new rules towards their interests (influencing policy) and influencing the public perception of these rules when they are not satisfied with the existing provisions (manipulation, FUD[98]).

Importantly, CNs organisers willing to lobby for legislation and regulation facilitating CNs should consider that legislative and regulatory competences are often distributed between several public administrations, and this situation increases the difficulty even more for the general population to participate in public affairs, while favouring the activities of those interests enjoying well-funded lobbying organisations. In addition, CN organisers should be prepared for the frustrating reality that critical decisions may be left undecided or in the hands of less than expeditious bureaucratic processes.

Under these circumstances, CNs have no other choice but to be smart and creative. A good knowledge on legal matters will facilitate a clear understanding of the limits posed by our legislative frameworks, that is, what is allowed and what is not. It is important to reiterate that the public understanding on these matters is

98 FUD: Fear, uncertainty, and doubt. A clear example that illustrates the bad practices by public authorities and the private sector is the case of the Torelló council against guifi.net. The first key point is that it should have been guifi.net against the Torelló council because it was guifi.net who complained about an abusive tax for ducts usage, but the Torelló council took advantage of its longer experience to open a case first at the regulator with a question that was not the substance of the matter. Instead of asking about the prices, they asked about the right to levy taxes on public infrastructure usage. This right was something that guifi.net never discussed and it was not until the allegations made by guifi.net that the prices were considered as well, which was the question really disputed. To this, the council alleged that there had been an error in the calculation of a parameter and proposed a newer one which resulted in a fair amount. Unfortunately, the regulators resolution (available at <https://www.cnmc.es/sites/default/files/1538376_7.pdf only in Spanish>) is written in a way that makes the reader think that it says that the council is right because it answers the initial question: yes, councils have the right to levy taxes on public infrastructure usage, which, again, is something that guifi.net never discussed and it is just later in the text body that addresses the tax quantities issue, and just stating that thought the process of the dispute resolution a technical error for its calculation was fixed.
Despite it is a clear case lost by the council (they had to change the prices) it is being presented by the council as well as by the competitors as a case lost by guifi.net because they still claim that guifi.net wanted to use the public ducts without paying.

typically confused and may even reveal contradictions between what it is generally assumed to be legally possible and what the law really says. Furthermore, in several occasions, we have realised that just a fraction of the true potential of the legislative framework is put into practice. The rest remains unexplored and unrealized.[99]

This generalised lack of knowledge and the unexplored possibilities of existing legislation bring us to the first line of action, which is to make creative proposals, working hand in hand with public servants whenever possible, and pursuing win-win situations through proactive actions. This must always be the first choice for CN members because positive attitudes are undoubtedly much more effective than any confrontation.

These win-win tactics, which should not be restricted to legal matters but should be extended to the other areas, have been very satisfactory for guifi.net. As an example, the guifi.net Foundation, in collaboration with some small city councils, developed an ordinance to make the coexistence of the public, propriety, and commons usage of fibre ducts compatible.[100] Nevertheless, it is important to be on guard against malicious collaborations, and CN members should always consider that public administrations and regulators may be constrained by special interests.[101] In this respect, we have observed

99 For instance, one of the keys to success of the XAFOGAR project has been a new finance scheme for the municipalities. This perfectly legal instrument ensures the capacity of the municipalities to make sure that the public money is allocated to build commons network infrastructure, that is, for what it is intended for, and it is not captured by traditional telecoms that build private infrastructure. In summary, the innovation is to allocate the money to an NGO instead to a private company directly through a public contracting process because these processes are completely dominated by the big telecoms. Nevertheless, the public procurement law direct allocation to NGOs. Through this novel procedure the guifi.net Foundation, which is only allowed to deploy network in commons, receives certain amounts of money from the municipalities under the commitment to deliver connectivity to the municipal buildings. This money represents just a fraction of the total project budget, but it is helpful to start and at the same time proves commitment of the local authorities to third party participants such as beneficiaries or investors. XAFOGAR <https://xafogar.cat/ in Catalan only> is a flagship project that aims to expand guifi.net's fibre network to all the dwellings and industries of the Garrotxa county (Catalonia) an area that has always been underserved by the traditional telecom industry.

100 <http://people.ac.upc.edu/leandro/docs/ordinancePEIT-rev14-en.pdf> (outdated version – original in Catalan available at <https://fundacio.guifi.net/web/content/2322>. Unfortunately the ordinance could not have been passed by any municipality despite many of them are interested in doing so due to the (deliberate) lack of a clear response of the upper public authorities. In this case the administrations involved are the Ministry of Industry and the regulator. They always respond at the limit of the legal period of time allotted, with irrelevant observations or further requests, etc. but never entering into the substantive debate. This is terribly harmful because in the meanwhile the traditional telecoms are deploying in the same areas, in most of which there is market for just one deployment.

101 For an analysis of the regulatory capture phenomenon, see e.g. Carpenter & Moss (2014).

delaying tactics aimed at harming the project, for instance, by giving time to the competitors to deploy first.

The second line of action is to lodge complaints using all the resources available (ordinary courts, higher courts, national regulatory agency, etc.), thus exploiting reactive actions. These legal actions must be used very selectively because they might be costly in both time overruns and money. Nonetheless, they are worth doing because they can have a strong effect on the success of the case. They establish legal precedents and demonstrate maturity, strength, and capacity for action on the side of CNs.

The third line of action, influencing policymaking processes, is also very demanding but must not be left unattended because, to a large extent, the success or failure of our project depends on the laws to be passed. A single modification can kill an initiative or can drastically boost it. For instance, in the regulation of access to the backhaul, the introduction of a discriminatory fee on a resource, such as one based on distance, directly makes remote rural projects unfeasible, while a fixed price taxation with low prices fosters the rise of connections not only in rural areas but also in urban areas, as they become denser.

The number of policymaking bodies and the diversity of their competences demands distributed and coordinated action among the CNs. To be efficient, the international and regional activities must be led by international specialised organizations (like La quadrature du net[102] in Europe, APC,[103] and Internet Society globally) to better cope with the requirements of this field, which is full of subtle details unknown to the layman. Furthermore, CN members must be ready to provide support and become involved in specific actions when needed. Conversely, national and local policy influence must be conducted by the affected CNs, possibly being endorsed by international organisations.

The power of apparently small successes should not be underestimated. Even small victories should not be kept unpublicised but should rather presented to other legislators and regulators for

102 See <https://www.laquadrature.net/>.

103 See the Association for Progressive Communications (APC), www.apc.org

their consideration. For instance, the 2G spectrum-licensing scheme for indigenous communities developed by the Mexican government together with Rhizomatica[104] is currently being adopted by other Latin American states[105] with the help of the respective CNs.

Civil disobedience or disrespecting rules is something that we can only understand for very specific cases, where rules or their application are patently illegitimate or unjust and should never be considered a means to consolidate an illicit situation. Nonetheless, it is indispensable to distinguish between truly illicit actions and those that are deliberately presented as such by some stakeholders but, in reality, are perfectly legal. A clear example is the position of the Spanish incumbent against the usage of the telephone poles by guifi.net to deploy fibre cable. As long as the technology used by guifi.net was limited to WiFi, the position of the incumbent towards the initiative was mainly that of disregard, probably with the objective to make the CN look irrelevant. However, its position completely changed when guifi.net started deploying fibre cable in 2009.[106] Since then, the incumbent has been hostile and the denial of guifi.net's rights to use the existing telephone poles has been one of the most-used weapons by the incumbent.

On one hand, this combative attitude clearly demonstrates that established telecommunications operators feel threatened by the emergence of CNs. On the other hand, the fact that operators, who certainly do not lack legal advice and funds, have never initiated a lawsuit in court shows that they are very aware that the utilisation of the poles by guifi.net is completely legal.[107] The certainty set by a judgment would be fateful for the operators' interests; thus, the tactics of coercion and misinformation seem more profitable, as established operators usually enjoy relevance and influence. The guifi.net example demonstrates that, when dominant operators applied these tactics, only the most motivated supporters stayed with guifi.net, while the rest were frightened.

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104 See <https://www.rhizomatica.org/>.

105 At least in the case of Colnodo, with the government and Telecom regulator in Colombia.

106 Obstructive strategies such as letters, minor litigation, etc. to create doubt, lengthen processes to delay and discourage deployments, while avoiding any clear public decision that would clarify competition.

107 Reinforced by the adoption of the The Broadband Cost Reduction Directive (Directive 2014/61/EU) of the European Parliament and of the Council on 15 May 2014.

On another front, the conception of the network as a CPR has proven to be a very powerful legal shield against speculation. The network is a crowdsourced CPR from which the contributors can withdraw and have the right to be compensated for their contributions, but those who stay have the right to retain the infrastructure. So, as long as a participant is staying, the infrastructure remains in commons. In guifi.net, the whole system is secured through the foundation, which has the ineluctable foundational mission[108] to protect the network commons.[109]

6.2.3 Economic Considerations

The development of an economic system with revenue streams and economic exchanges is fundamental to achieve sustainability and thus to expand the CN at a later stage. Even in resource-limited environments where external funds are needed to initiate the project or to contribute and maintain it over time, the development of a local economy is the most effective way to ensure the healthy survival of the network and its successful evolution, that is, to expand in the quality of services and the number of users served.

Any strict and self-imposed limitation of the scope of the project in terms of the area or the type of population to be served must be avoided. A project restricted to unprofitable regions or certain excluded segments of the population will rarely be self-sustainable, and it will most probably depend on external help; thus, its self-determination will never be achieved[110] (Belli, 2017, 2018). Limitations can be induced by third-party agents (external threat) but are also sometimes self-imposed (internal mistake) due to misconceptions.[111] Some of the external attempts to limit the scope of CNs are also

108 The Catalan legislation establishes that a foundation cannot change its foundational mission and in case of dissolution of a foundation its assets are kept under guard by the Catalan Government until they can be reallocated to another entity that respects the conditions under which the assets were donated to the initial organization.

109 Recommended activities. After reading section 3 of (Baig, 2016) discuss:
a) The usefulness of establishing an NGO to protect the project. Which roles should it have and which not?
b) The convenience of having written rules and if they should be hierarchical.
c) Find out a list of public organizations with regulatory and legal attributions, starting from the local, to the regional, national and global scope.

110 Self-determination in combination with the disruption capacity is the most frightening for the well-established business.

111 Fortunately, the term wireless is not used any more to refer to CNs as it clearly was an unfortunate self-limitation towards a specific technology, which – paradoxically – also implied the violation of the network neutrality.

due to more misconceptions,[112] but others may be intentionally instigated by adversary lobbies. Restrictions due to misconceptions can be prevented by raising awareness, for instance, by raising the question regarding why we should limit the potential of something positive. On the contrary, intentional attempts to limit scope must be countered by other means, such as judicial disputes, policy advocacy, etc. It is also important to note that access to profitable segments are not only needed to ensure sustainability but also to be able to implement redistributive policies because it will be the users of these segments that will generate the surpluses to sustain these policies.

In addition, to have access to profitable markets and to enable economic activity and thus investment, trust is needed. Initial investment by pioneers has several positive effects on building trust and increasing predictability. First, they allow covering the initial costs of the initial installations. These initial installations, in turn, allow the start of delivering services, which make repaying the investment possible, and they can be used as working examples in the dissemination activities aimed at expanding the network. Another positive effect of the increased trust resulting from the initial investments is that they are considered proof of commitment by new investors, thus facilitating new funding rounds.[113] It must be noticed that, currently in guifi.net, the term *investor* usually refers to anyone putting money in the network, regardless of whether he or she does it to obtain connectivity (final users) or as an economic benefit either directly through an interest (money lender) or indirectly through creating business opportunities (service providers).

Transparency is a key component to create trust. In guifi.net, transparency about what is done and predictability about what can be done are achieved through clear interdependent rules of 1) governance, 2) recognition of investments, 3) inventory of network assets, 4) costs sharing, 5) monitoring of network

112 There are still too many well-intentioned international organizations that circumscribe CNs to unprofitable spheres.

113 The full-cycle of a funding round was described in guifi.net in 2007: 1) dissemination, 2) techno-economic proposal, 3) crowdfunding, 4) execution, and 5) re-start the cycle <https://guifi.net/node/7934 available only in Catalan and Spanish>.

resources consumed, and 6) dissemination of good social, economic, technical, and legal practices.[114] Predictability is related to accountability (auditable statements for transparency that include investment, consumption, expected return of investment, depreciation, and margin) and the ability to plan and forecast social and economic impact and growth based on whatever goals and metrics are critical. For instance, cost accounting allows determining an estimate of the unit cost to expand the network to a new location or maintain a unit of network infrastructure, which determines the investment required and the critical mass for feasibility as a CN expands. Predictability and planning relate to risk mitigation, which becomes more critical as CNs grow.

Furthermore, organisational resilience is a concern, particularly for a commons infrastructure. In a cost-oriented ecosystem, reserve funds in the form of monetary deposits from participants are a key instrument to face and mitigate financial risks. Risk mitigation plans and the corresponding reserve funds must include the response to the technological evolution and hardware obsolescence. As a reference, the depreciation period of electronic components (WiFi, Ethernet, and optical fibre) should be no longer that four years, and the cabling (copper and optical fibre) from 10 to 15 years.[115]

In guifi.net, the conception of the network as CPR has enabled a flourishing non-speculative economic system based on services in which over 30 Internet service providers (ISPs) are offering their services on equal terms to tens of thousands of customers and coexist with many other stakeholders, such as volunteers, public institutions, etc. From the economic perspective, the CPR is a crowdfunded infrastructure because it is paid by its users.[116]

114 See Baig et al. (2015) for a diagram and further explanations regarding these elements.

115 These are pretty conservative estimations, especially for copper and optical fiber (electronics and cabling). The conservative estimations enable sound financial housekeeping and hardware reallocation policies. Cheaper deployment costs may increase maintenance costs (e.g. shallower or less protected fiber deployments accelerate deployment but increase the risk of cuts)

116 Recommended activities:
a) Study the business plan of Broadband for Rural North (B4RN) at <https://b4rn.org.uk/business-plan/>.
b) Read more on guifi.net's economic aspects of guifi.net in (Baig 2016).
c) Discus how to sustain the activities that benefit the whole community, like software development, governance activities, etc.

6.2.4 Technological Considerations

Technological matters must be addressed in accordance to social objectives. From this perspective, technological decisions must also be driven by the opportunity criterion to optimise the extension of the network and the quality of services offered. Furthermore, these decisions must be taken in line with the economic capability and legal possibilities.

Therefore, it is important to elucidate technology challenges from a neutral perspective. A given solution might be the right choice at a specific time but inappropriate at another time. For instance, fibre-optic technology has unrivalled performance characteristics. Nonetheless, it is so demanding in terms of capital expenditures (CAPEX) and deployment time that it is the suitable technology for starting CNs only in very special occasions. In most cases, WiFi is the right option to initiate a CN due to its good value for the money and the legal and administrative facilities, as there are radio-frequency unlicensed bands in most states. Nevertheless, a WiFi-only network cannot grow infinitely due to the operating expenditure (OPEX) costs and capacity constraints of these technologies. Thus, in the long term, the adoption of fibre is cost effective even for most of the small WiFi deployments and is necessary and indispensable for a network that is growing.

The potential congestion of a resource (routers, links, etc.) is not a threat to combat with restrictions but an opportunity to improve the network. For instance, in guifi.net, the rule is to double capacity when the usage exceeds 50% of the capacity. The additional capacity enables better services for the current users, attracts new users, and makes the infrastructure more resilient because the spare capacity can be used to mitigate the effects of planned or unplanned outages in other segments of the network.[117] The challenge is to turn the demand for these assets into resources to enhance them. To this end, we need procedures to know who is using them and in which proportion and how to contact the users, gather the contributions, and track their usage, etc.

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117 Alternative paths allow to keep the network operational despite planned or unplanned outages. Monitoring, routing and load balancing mechanisms can automatically reconfigure the network to mask any effect.

Technologists must provide effective tools – mostly software – to develop and implement not only the aforementioned procedures but also many others that are crucial for the healthy development of CNs, like those mentioned in the section of this chapter dedicated to economic matters. Most likely, the fulfilment of the social objectives will entail the publication of the source code (free software) and the data (open data), obviously in compliance with the law.

From the network architecture perspective, it must be understood that all components (last mile, backhaul, backbone, and interconnection) play a critical role in delivering connectivity to the users. Thus, they must be maintained in good condition and must be harmoniously engineered. Initial Internet gateways might be built by pooling consumer-grade Internet connections, but the sooner to access the wholesale market the better, not only for the reasons of economy of scale already discussed but also because, from the technological and management viewpoints, it implies major upgrades. Emergency and technology upgrade interventions must be scheduled to maximise the benefit of users served, but in the long run, the benefits must be extended to all users.

Community networks must exchange traffic with third parties in Internet exchange points (IXP) whenever possible, as peering (swap)[118] is better aligned with CNs principles[119] and network neutrality in general than transit (paid). From the management perspective, the community must ensure control over all critical resources (software and hardware), as loss of control of any critical resource might be misused to favour particular interests (internal attack) and jeopardise the collective interests of the CN community.

For instance, in guifi.net, we have observed that technical control over access routers from a given ISP has been used to harm the interests of competitors. In terms of content, CNs must promote the development and hosting of local content accessible locally and from the Internet. This way, not only does the content remain under

118 The interconnection fees in IXP usually depend on the symmetry of the traffic exchanged (cheaper or even free with a balanced mix of content to provide and readers, while more expensive for only readers: also called eyeball networks)

119 Technically speaking, internally guifi.net is a fully distributed IX because its license makes compulsory to peer with the rest of participants.

the control of the community but it also increases the symmetry of traffic, which results in reduced interconnection costs.[120]

6.2.5 Cross-disciplinary considerations

Community networks are likely to start out tiny, but their contributors must develop the strategic planning according to the target size of participants and beneficiaries. The strategic planning must have a holistic vision, the strategy to develop it, and the priorities and action plan to implement it (the so-called VMOSA).[121] Given that the composition of the initial group of 'pioneers' has a determining effect on the initial choices, the character of the CN, and how it is perceived by the surrounding environment, special care must be taken to include representatives from different perspectives with different skills to reach a balance in terms of multiple dimensions that can represent a large community (e.g. gender, cultural, economic, and geographic dimensions). While some members may be more active than others, the involvement of all of them will help make the organisation more representative of the target community and therefore more suitable to serve their needs as it scales up.

Moreover, CNs develop their activity in such a demanding environment that, to be able to succeed, they need to take a holistic view, adopting a multidisciplinary approach without preconceived ideas beyond the driving principles that define the essence of the initiative.[122] That is, once the driving principles[123] are accepted, a rational attitude is the most effective to address the emerging challenges. Furthermore,

120 Recommended activities:
a) Make a list of all the procedures and tools needed by a CN in which the technological support can make a difference. Following the social, legal, economic, and technological sequence may help to avoid bias.
b) Assign one of the following categories to each item of the list: system engineering, network engineering, software engineering, system administrator, network administrator, software developer. Add any other you miss.
c) Discuss how to attract the talent needed and how to coordinate efforts, inside the community as well as internationally.

121 VMOSA: Vision (what aim), Mission (what and why), Objectives (what to accomplish by when), Strategies (how), and Action Plans (what change will happen). See <https://ctb.ku.edu/en/developing-strategic-plan-and-organizational-structure>.

122 In guifi.net, for instance, decisions are taken by voting and not by consensus because in the past, the consensus process had been used to block the decision-making process because the blocked situation benefited the blockers.

123 In this document we have discussed the driving principles as part of the social axis, but given their importance (they are the foundation of the project) and their nature (they are indisputable – either one accepts them or not) they could have been analysed in a specific section.

from the risk management perspective, a multidisciplinary approach is optimal, as all areas or viewpoints previously discussed are equally important since any major failure in any of them would seriously undermine the whole project. Even more importantly, it would be difficult to find tasks or decisions to be made that would fit exclusively in one of the fields. For instance, the maturity level of a technological solution determines the amount of people able to actively contribute to implement it and thus the degree of dependency of skilled contributors, which is a social issue.

Decisions must be taken giving the highest priority to the less restricting options while trying to foresee the future consequences. Nonetheless, given that not all the consequences can be predicted beforehand and that decisions must be made to move forward, a compromise between design and planning tasks and actions on the ground must be found. Moreover, on the ground activities provide valuable knowledge – difficult to achieve otherwise – that helps to make better choices in the subsequent decision-making rounds.

An iterative and incremental approach with short iteration cycles enables finding a good balance between the need for design and planning and the need for action in a harmonious manner. It also allows us to rectify issues when needed without much loss of effort and to quickly integrate learning lessons from experience. The decisions of the subsequent iterations must be based on the objective assessment of the results of the previous ones (quality metrics). Thus, a continuous monitoring system is needed, and with such a system in place, quality assurance and quality assessment can be implemented. In addition, such formality and rigor also increases trust, which, as already commented, is essential to attract new investors and beneficiaries. Another reason in favour of short iteration cycles is that it allows the gradual introduction of changes in isolation, which is necessary to be able to well understand their effects. Lastly, changes must have specific and assessable objectives.[124]

124 Recommended activities:
a) After reading about strategic planning in the Community Toolbox (CTB, 2018), develop you own answer to a VMOSA strategic planning exercise and discuss it with a few members of your organization.
b) Prepare materials for a public presentation and discussion with to your community and invite a sample small group of them for a first exercise. Keep your ears and eyes open and collect feedback to improve these materials for a larger open audience.

6.3 External Support

The case of guifi.net shows that a single CN can scale at least up to more than 100,000 beneficiaries with the latest networking technology[125] in a self-sustained manner. So far, we have analysed what practitioners can do to enlarge and strengthen their CNs. To conclude, we briefly discuss what are, in our opinion, the main external actions that can be implemented to support the development of CNs and ensure that they can develop all their potential to expand the Internet worldwide. External support is crucial to accelerate the development of CNs and make the efforts of their contributors more productive because, although many CNs are working to improve their procedures and methodologies, their margins are too narrow – if any at all – to make any significant progress at a world scale.

In our opinion, the most important thing is that these organisations also fully comprehend that CNs can be large-scale fully competitive networks and thus do not confine themselves to marginalised corner cases. From the legal perspective, the legislators and regulators must ensure at least the equality of treatment with the rest of the ISPs. Ideally, they should give preference to CNs given their openness and unequivocal social value and the wide range of positive externalities they trigger (Belli, 2017), but in any case, they should combat malpractice by commercial providers, such as predatory overbuilding or misinformation about their deployments.

In economic terms, external funds should be allocated to develop a comprehensive platform (methodologies, databases, and software as well as training and seed funds) with global reach for supporting and assessing the creation and growth of CNs with regard to network design, monitoring, and management, project management, conflict resolution, etc. The development should follow an approach able to deliver operational products as fast as possible to make them available to existing CNs and to use them in all the deployments funded by international organisations, such as Internet Society (ISOC), Institute of Electrical and Electronics Engineers (IEEE), development agencies, etc.

125 Other indicators for the health of the guifi.net project: doubling inter-networking capacity (transit and IXP) every 18 months, +30 microISPs, +20.000 customers for professional services, etc.

Ideally, the development of the aforementioned platform could be led by an international organisation[126] commissioned to keep track of all CN initiatives around the world and to provide them technical assistance and assessment, while offering financial support. This international organisation could be funded with national universal access funds because their objectives are totally aligned and because the effect would certainly be more visible than any of the actions funded – and frequently failed – so far. Furthermore, universal access funds could also fund the deployment projects promoted by this organisation.

Lastly, international organisations must work to ensure that CNs have appropriate access to wholesale and backbone networks and to local IXPs, as these resources are critical for the healthy development of CNs. Nonetheless, they must also ensure that their actions do not (unintentionally) contribute to perpetuating the dominant position of the owners of these resources, as it could happen, for instance, if the access is achieved through a co-funding model or directly subsidising the connections. The right way to do so is to ensure that the owners of the infrastructure charge fair, reasonable, and non-discriminatory (FRAND) prices for their services.

6.4 Conclusions

The sustainability of a project, that is, the capacity to persist over time, requires a minimum critical mass of beneficiaries to raise the required resources to repay the initial investment and continue the operations, thus reaching the so-called break-even point. Once reached, CNs may consider expanding their activity beyond that, that is, to scale up. We claim that they must do so not only because it helps realise their fundamental values of social justice but also because they become more resilient. By becoming larger, CNs enable the creation of local job opportunities which, in turn, reduces the dependency on volunteers, who then can focus their efforts on more specific tasks that cannot be professionalised, like those related to the governance of the project. Growth also brings savings through economies of scale and strengthened self-protection

126 It could be newly founded or operate as a section of an existing one. In any case it must be an independent body.

against external and internal attacks and against internal mistakes, as there more people involved and thus overseeing the project.

For a proper development, CNs must adopt an inclusive multidisciplinary approach to cover the needs of the social, legal, economic, and technical dimensions without leaving any of them unattended. External organisations can help the CN movement to become a truly driving force for the expansion of the Internet by developing tools to make the existing initiatives more effective and to incubate new ones. We propose that these tasks be supported by the creation of an international organisation to be funded with the universal access funds, which would lead the development of these tools (methodologies, databases, and software) and provide technical assistance and financial support to CNs.

6.5 Appendix – guifi.net

Guifi.net is a bottom-up, citizenship-driven technological, social and economic project with the objective of creating a free, open, and neutral telecommunications network based on a commons model. The development of this common-pool infrastructure eases the access to quality, fair-priced telecommunications and broadband Internet connections for everybody. Moreover, it generates a model for collaborative economic activity based on proximity and sustainability.[127]

Guifi.net started in 2004 as a telecommunications technological project in Osona county (Catalonia) to solve the broadband Internet access difficulties in rural areas, given the lack of traditional operators to provide services there. By means of radio links built with commodity WiFi routers, the neighbours deployed their own network to interconnect different locations (the so-called nodes), such as houses, offices, farms, public buildings, etc., to be able to benefit from telecommunications and access the Internet whenever and wherever they needed. A foundation was created in 2008 by the guifi.net community to give a legal identity to the guifi.net project.[128]

127 See <https://guifi.net/en/what_is_guifinet>.

128 See <https://fundacio.guifi.net/en_US/page/aboutus>.

The Fundació Privada per a la Xarxa Oberta, Lliure i Neutral Guifi.net (the Guifi.net Foundation for the Free, Open and Neutral Network) was established in July 2008. Its foundational objective is to work in favour of the guifi.net principles by developing and applying a sustainable, collaborative, and commons-based economic model. The foundation is both an NGO and a registered telecommunications operator under Spanish regulations.

The guifi.net community has five main stakeholder groups according to their roles in the ecosystem and their motivations for participating in it: volunteers, governing bodies, professionals, customers, and public administrations, which form three sets: non-profit, for-profit, and public interest. As of August 2018, guifi.net accounts for more than 35,000 operating nodes and delivers connectivity to over 100,000 people. Most of these nodes are located in Catalonia and the Valencian community in Spain, but the network is growing in other parts of the world. The network is self-organised and operated by its users using unlicensed wireless links and open optical fibre links. The guifi.net Foundation has received numerous awards on behalf of the guifi.net community, including the Broadband Award of the European Commission in 2015 in the category of innovative models of financing, business, and investment.

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7 Federating Community Networks: A case study from France

Félix Tréguer

Abstract

Coordinating various Community Networks (CNs) with different models and governance features can be a challenge. In France, an acknowledged success of the CN movement was the creation in 2011 of Fédération French Data Network (FFDN), a federation uniting CNs across the country. When FFDN was established, interest in grassroots communication networks managed as a commons was booming, and rather than growing existing ones, swarming (*i.e.* the creation of several independent local organisations) was deemed a better strategy. Although communities in other states have explored other forms of coordination, this process of federation provides an interesting model for ensuring the coordination of various CNs with different models, and for establishing solidarity and fostering resiliency in the face of the many challenges entailed buy the maintenance and defence of CNs.

This chapter posits that, despite some difficulties, FFDN represents an interesting precedent for other national and regional CN environments willing to foster collective cohesion. We start by offering a brief history of the CN movement in France up to the creation of Fédération FDN in 2011, before surveying the federation's main organisation features and accomplishments.

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7.1 Introduction

Coordinating various Community Networks (CNs) with different models and governance features can be a challenge. In France, an acknowledged success of the CN movement was the creation, in 2011, of Fédération FDN (FFDN), a federation uniting CNs across the country. When FFDN was established, interest in grassroots communication networks managed as a commons was booming, and rather than growing existing ones, swarming (*i.e.* the creation of several independent local organizations) was deemed a better strategy.

Although communities in other states have explored other forms of coordination, this process of federation provides an interesting model for ensuring the coordination of various CNs with different models, and for establishing solidarity and foster resiliency in the face of the many challenges entailed buy the maintenance and defence of CNs.

This chapter posits that, despite some difficulties, FFDN represents an interesting precedent for other national and regional CN environments willing to foster collective cohesion. We start by offering a brief history of the CN movement in France up to the creation of Fédération FDN in 2011, before surveying the federation's main organisation features and accomplishments.

7.2 A short history of Community Networking in France

At the end of the 1970s, personal computers were finally coming to France. Magazines specialised in computer cultures reported at the time that more than 100,000 machines had been sold in France.[129] In 1985, an official report claimed that 860,000 households possessed a desktop device. By the end of the decade, France would become the first European market for PCs. Over that period, the number of computer clubs also rose significantly.

This rise of computer penetration and its growing use was significantly facilitated by the government's voluntarist approach.

129 See Thierry, B. (2012). «Révolution 0.1». Utilisateurs et communautés d'utilisateurs au premier âge de l'informatique personnelle et des réseaux grand public (1978-1990). Le Temps des médias, n° 18(1), 54–64.

In 1978, when France was still lagging behind, the Nora-Minc report called on the coming together of computers and telephone networks and would launch the unique experience of the Minitel.[130] First intended as a way of granting to the public access to databases, it would morph into a large-scale social experiment to turn it into a communication device, with the creation of France's earliest so-called "virtual communities." At the end of the 1980s, a quarter of French residents had access to the Minitel. Despite their reduced popularity, other computer networks were also accessible through dial-up connections, such as Calvacom, launched by Apple and the American College in Paris.

All of these early experiences of popular computer culture, with their novices and enlightened amateurs, formed the background against which the Internet would sweep the country. In 1992, as Request for Comments 1366 underlined in October of that year,[131] the Internet was undergoing such a "growth and increasing globalization" that it would soon result in a historical democratisation of communications. 1992 was also the founding year of the first French citizen-owned Internet access provider, French Data Network (FDN).[132]

FDN was not only the first French CN, but also the very first Internet access provider open to the public that has survived to this day. First giving access to Usenet and then to the Internet, FDN relied on the landline infrastructures of existing telecom operators, and in particular that of the incumbent France Télécom. However, connectivity was entirely managed by the organisations on behalf of its member-subscribers. Within two years, the number of users across the country rose to 400, including about thirty for-profit and non-profit organisations who acted as proxies for their members. Each of them paid an annual membership fee of 100 Francs (15 Euros) and a monthly flat-rate subscription of 180 Francs (27 Euros) for their dial-up connection with a generous data allowance. The hub

130 See Gonzalez, A., & Jouve, E. (2002). Minitel: histoire du réseau télématique français. Flux, n° 47(1), 84–89. See also Mailland, J., & Driscoll, K. (2017). Minitel: Welcome to the Internet. Cambridge, MA: The MIT Press.

131 See Gerich, E. (1992). Guidelines for Management of IP Address Space. <https://www.rfc-editor.org/rfc/rfc1366.txt>.

132 See <http://ffdn.org/>.

of FDN was located in one of FDN founders' living room in Paris, and was formed by three NEXT computers and their attached modems, through which members would connect to global networks.

FDN would face many challenges in the subsequent years, with the rapid take-up of commercial access providers and the rapid increase in speeds and quality of service. It also came to face a rather hostile regulatory environment. In this context, its user-based started to shrink by the late 1990s. At first, FDN was one of the few ways by which it was possible to join the Internet. Within a few years, however, partly thanks to FDN's new president – a young computer engineers named Benjamin Bayart –, the non-profit became loosely connected to this emerging scene of Internet activists. Indeed, for FDN's active volunteers, this citizen-owned and run Internet service provider seemed to be a natural avenue for resisting the trend towards commodification and political control over this communications architecture (Bayart, 2016).

Through the leading members of the emerging digital rights scene did not necessarily perceived FDN's political potential, all shared the goal of equipping newcomers with the technical know-how and to cultivate an understanding of the Internet's political importance, allowing for the emergence of a "critical Internet user" (Paloque-Berges, 2015).

Almost ten years later, in 2007, after having successfully transitioned FDN's network from dial-up to ADSL, Bayart became more politically involved, addressing crowds of free software activists during public events. In one famous conference that gathered much viewership online, Bayart described the Internet's enclosure and growing centralisation as a move towards a "Minitel 2.0". This conference stroke a chord in an activist milieu. A year later, a new digital rights advocacy group, called La Quadrature du Net (LQDN),[133] was founded in France by Free Software activists, with Bayart originally acting as LQDN's treasurer.

Soon, coupled with the growing ability of a better-resourced digital rights movement to frame these issues at the political

133 See <http://laquadrature.net>.

level, Bayart's advocacy in favour of non-profit Internet access providers led to a revival of the burst of the CN movement across France. In 2010-2011, many events impacting the digital rights debate took place and FDN leaders played a role in them. Such was the case during WikiLeaks "Cablegate", where FDN created a mirror site of WikiLeaks and helped channel donations to Julian Assange's organisation to circumvent the banking blockade it was subjected to. During the Arab Spring, FDN set up modems and share call-in numbers to allow Egyptian protesters to connect to the Internet through dial-up connections during the Internet shutdown, and collaborated with Reporters Without Borders to provide VPN services to political dissidents. Echoing the successes of the French Free Radio Movement,[134] FDN formed part of a global movement of activists resorting to decentralisation and creative networking to help others circumvent the repressive policies of state authorities.

7.3 Features of Fédération FDN

This was the moment when Bayart and other FDN active volunteers started motivating people across France to join their movement and start building their own CNs.

Rather than concentrating on a single organisation, or even the handful of other CNs already existing across France at the time, FDN participants chose to "swarm" in a decentralised mode by creating many local non-profit organisations, all incorporated as non-profit entities under the French 1901 law on the freedom of association.[135] "Rather than growing indefinitely, which would inevitably lead to impersonal functioning, it seems preferable to swarm," explained a blogpost published on the occasion. "To swarm means that there should be 10 free Internet access providers operating on a human scale rather than only one 10 times bigger."[136]

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134 See Lefebvre, T. (2011). La bataille des radios libres: 1977-1981. Paris: Nouveau Monde Editions.

135 See **Loi du 1er juillet 1901 relative au contrat d'association at** <https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=LEGITEXT000006069570>.

136 See FDN. (2011). Essaimage et Fédération FDN. <https://archive.is/Nb9lL>.

7.3.1 Federated in diversity

As of 2018, FFDN comprises 29 member organisations, operating in both rural and urban areas, using both wireless and leased landline networks, whose individual members are automatically members of FFDN.[137] This makes for a very diverse community of CNs in geographical, technical as well as socio-political terms. As a participant to the 2016 General Assembly suggested, "some [of us] work in suits, other don't work at all". Now, to give a sense of the diversity found among FFDN's member organisations, this section presents some of the CNs that are the most representative of the whole spectrum of governance, economic and technical models found in the Federation:

- FDN (French Data Network),[138] as we have seen, is the historical French CN, founded in 1992. Providing ADSL connectivity at a national scale on last-mile landline infrastructures leased from incumbent operator Orange (either through partial unbundling through the proxy of another major telecom operator, SFR, or directly through non-unbundled access with Orange). FDN has around 500 members with memberships rights in the organisations, about 330 of which are also subscribers (actually using one or several of the services provided by the organization).
- Scani (formerly known as PCLight)[139] was founded in 1998, first as a non-profit *association*. It is now evolving towards the status of "for business and employment cooperative" incorporated under French law 2001-624.[140] Scani is particularly interesting, not only for being the first venture of an FFDN member to include professional organisations including a few paid employees (rather than just active volunteers), but also for being the first FFDN member to foray into the deployment of last-mile fibre optic connectivity.
- Faimaison was created in Nantes in 2011 with the help of FDN. Faimaison started by providing ADSL connections and is now

137 See FFDN. Members of the FDN Federation. Retrieved August 15, 2018, from <https://archive.is/jV559>.

138 See <http://fdn.fr/>.

139 See <https://www.scani.fr/>.

140 See French Law n° 2001-624 of 17 July 2001.

moving to expanding its network with WiFi links. Still small (about 80 members of which 15 are subscribers). It is very active on the advocacy front, frequently organising social events around digital rights campaigns led by French or European NGOs.

- Tetaneutral.net[141] is a wireless CN founded in 2011 in Toulouse. Its starting goal was to provide Internet access rivalling commercial ADSL offers that, in certain parts of the city, were limited to 512K. Its coverage soon expanded to half a dozen rural areas in the surroundings of Toulouse that previously did not have access to a decent quality broadband connection. After seven years of existence, Tetaneutral.net now counts more than 500 members, including 400 subscribers. It is currently experimenting with the deployment of fibre-optic networks.
- Rézine[142] is based in Grenoble and was founded in early 2012 and, though smaller, it presents a similar structure to the one of Tetaneutral.net. It provides a mix of ADSL and WiFi Internet connectivity in Grenoble. This CN has also explored the option of providing a public radio broadcasting network developed by local authorities in the district of Isère, but the CN organisers arestill looking for interested potential subscribers to make the operation financially viable. It currently counts 57 members, of which 43 are also subscribers.

The various FFDN members provide a variety of services. Except for 7 out of 29 member organizations, all FFDN's CNs provide Internet connectivity (with a static IP address) to their subscribing members, often for a fee ranging from free price at Tetaneutral.net (20 euros suggested, radio equipment being provided for free) to 30-40 euros for ADSL at Faimaison (cheaper when the connection is unbundled). CNs including FDN and Faimaison lease landline networks to incumbent operators to provide access to their subscribers. The 7 CNs in the federation that do not provide Internet connectivity offer only VPN service to their member-subscribers. In such cases, subscribers need to subscribe to traditional Internet access service.

141 See <http://www.tetaneutral.net/>.

142 See <https://www.rezine.org/>.

What the CN provides is an encrypted tunnel routing the subscriber's traffic to one of their VPN servers, along with a static IP address, which can immunise a subscriber against its incumbent provider's technical restrictions (for instance, Orange banning the use of port 25 on ADSL offers and, therefore, preventing users from running a mail server at home). About 5 CNs, including Tetaneutral, offer hosting services, allowing members to install their own servers in the building or data-centre, where the organisation's servers are based. Hosting a small machine such as laptop, a NAS or Raspberry Pi costs 5 to 10 euros at Tetaneutral, or 17 euros at Faimaison. FDN and Faimaison provide subscriptions to a service offering access to Virtual Machines hosted on the CNs' servers.

An important technical project carried on and distributed by the FFDN community in the past years is the "Brique Internet" (or Internet cube), a small device to be plugged to one's Internet box. It provides a WiFi hotspot channelled to FFDN member's VPN service and embarking a Debian-based self-hosting OS called Yunohost, which runs a mail server and embarks platforms like Owncloud or a PirateBox for local file sharing.[143] 8 FFDN CNs currently distribute the Internet cubes configured with a VPN access they provide, for a price of about 65 euro per unit (plus the monthly cost of the VPN subscription).

A team of volunteers close to members of the FFDN have set up some of the most popular BitTorrent Tracker[144] freely used by tens of thousands users daily. Finally, Tetaneutral.net and other FFDN volunteers have assisted a national network of 42 independent movie theatres in setting up an online distribution system for digital copies of films.[145]

7.3.2 FFDN's founding documents

FFDN's organisation relies, primarily, on the principles laid out in three important texts that provide a framework for corresponding

143 See <https://internetcu.be/> and <https://yunohost.org>.

144 See <http://www.torrent.eu.org/>.

145 See <http://www.indecp.org>.

practices: its bylaws,[146] its internal rules,[147] and its "Charter of good practices and common commitments"[148] which defines the notion of an "*associatif* (non-profit) Internet service providers." According to this document, the Federation's member organisations "shall not use commercial methods, such as for instance the purchase of advertising space." People sitting on the boards of FFDN's CNs must be unpaid volunteers and earnings should be "systematically kept on the books or reinvested." Member organisations have a "duty of solidarity, among other things in the form of technical assistance, with the other member associations of the Federation, as well as with their members."

The Charter also requires members to commit to "protecting and/or promoting the Internet" and Net Neutrality. In that spirit, FFDN's members for instance commit to providing each of their member subscribers with a public and routable IP address (preferably static). Member organisations also have to provide a domain name or subdomain to subscribers interested in such option. With regard to Net Neutrality, which was a hot topic in France at the time of the Federation's creation, the Charter provides that FFDN's members shall not "impair in any way the data transmitted on behalf of subscribers, without the consent of the affected subscriber." The document further makes clear that the service provider "shall not modify the content of the exchanged messages (...)."

In the same spirit, the Charted states that the "ISP shall make no judgment on the relevance or significance of a data stream on behalf of the subscribers," and shall not filter (by blocking specific content) the Internet access of its subscribers, except in case of legal obligations (in which case these obligations as well as the technical means used to comply with them shall be fully transparent). All of these rules are FFDN's own way of framing Internet networks as a commons.

146 See FFDN. (2018, August 15). Règlement intérieur. Retrieved August 15, 2018, from <http://archive.is/hZfSo>.

147 See FFDN. (2013, July 4). Statuts. Retrieved August 15, 2018, from <http://archive.is/EpDaF>.

148 See FFDN. (2016, June 6). Charte des bonnes pratiques et des engagements communs. Retrieved August 15, 2018, from <http://archive.is/M4Wkx>.

7.3.3 Who are FFDN's stakeholders?

As the above-mentioned documents make clear, FFDN's stakeholders are first and foremost the 29 non-profit member organisations united under FFDN's umbrella. FFDN's internal rules demands that they be registered as telecom operators before the French Telecoms Regulator, ARCEP. Other legal persons, such as businesses, which share FFDN's values and goals and wish to take part in FFDN's activities, cannot be considered as members but the bylaws include a "correspondent" status for joint action (correspondents do not have the right to vote). Currently, the Federation does not have its own budget and runs entirely on volunteer-work. Member CNs who can afford to do so are the one providing funds on an ad hoc basis, when necessary for the organisation of events, such as the General Assemblies.

FFDN's participants, including its board members, usually have leading positions within one or several member CNs. FFDN's active volunteers take an active part in the strategic discussions held on the future of the organisation, and gather the technical and regulatory know-how necessary to the operation of member organisations (this is particularly the case through informal working groups where the volunteers of various CNs work together). Such working groups may deal with very diverse issues, such as regulation, FTTH deployments, training and seeding new CNs, system administration, social inclusion, etc.

The second circle of stakeholders comprises all of the almost 2500 official members of FFDN member organizations. Among these, about 40% do not subscribe to any of services provided by CNs (for technical or practical reasons), but have decided to adhere to these organisations out of political conviction on the importance of community ISPs.

A third category of stakeholders includes partner organisations such as a handful of small-and medium businesses, which are member-subscribers of FFDN CNs, social projects (other non-profit organisations or advocacy groups) and public administration that subscribe to (or use the free) service provided by FFDN members, because such services offer flexible and/or cheap solutions to their needs.

7.4 A framework for collaboration and political representation

After having elucidated FFDN's main governance features, let us look at what the Federation actually brings to its member organisation and the French CN movement as a whole.

7.4.1 Mutual assistance and collaboration

One of the first task for the federation is to ensure solidarity and collaboration between its member organisations. FFDN is indeed a key channel for mutual support between members. For instance, established CNs will help new ones by giving or lending resources like IP addresses, AS, equipment, servers, cheaper bandwidth, etc. Such assistance is conducted more on an *ad hoc* basis than on agreements, even though the FFDN charter also mandates such collaboration, as highlighted in previous sections. More recently, the working group dedicated to seeding new CNs organised a workshop on wireless networking to train the volunteers of emerging CN.

To foster daily coordination, FFDN has a a mailing list for all the members of its CNs, where major issues or decisions are presented and debated. Another mailing list is dedicated to the activities of the board. Specific mailing lists are also created for specific working groups (dedicated to regulatory or technical issues).[149] FFDN also has a public IRC channel on Geeknode with an average of 150 daily participants, as do most of its member CNs (the Tetaneutral.net IRC channel on Geeknode, for instance, has about 130 participants). IRC is where most of daily interactions, coordination and debates between FFDN's members happen.

Although community events and workshops organised throughout the years allow for coordination and joint work, most of it happened actually happens during General Assemblies (GAs) which act as "community building" events, where most member organisations are usually represented. In May 2018, the author of this paper attended the GA with a colleague. The 2018 GA was

149 See the list and short description of the 16 mailing-lists of FFDN at the following address: <https://lists.ffdn.org/wws/lists>.

held in a rural district one hour south of the city of Toulouse, where a joyous crowd of geeks and activists gathered to debate about community networking in an old castle. In this great environment – with stunning views over the hills at the footsteps of the Pyrenees –, about 70 participants came to recount the successes and failures of the CN organisations taking part in the federation, work on existing technical projects (fibre soldering, setting up radio antennas, etc.), start new working groups and discuss the governance of this federation.

In the vein of Free Software communities in which many FFDN participants are socialised, the group often works as a "do-ocracy," in which individuals choose roles and tasks for themselves and execute them. A member's recent interest in boosting the activity of the group in the field of telecom regulation resulted in many discussions being held at the 2016 GA on the matter and to the creation of a dedicated working group with its own mailing lists. Two years later, a similar process led to the creation of a working group on inclusion, to reflect on how to bring more diversity within FFDN and its member organisations. People interested in developing the Internet cube similarly got together and carried the project autonomously.

7.4.2 Policy coordination

FFDN core volunteers have become telecom experts (some of them participate in research on computer science) and their capacity in articulating the techno-political stakes associated with digital telecommunications has ensured their status as an influential "citizen voice" in national policy discussions on issues such as Net Neutrality.[150] Benjamin Bayart, who has been on the board of FFDN since its foundation, has worked since then to ensure than Net neutrality would be framed not only as an issue of economic regulation (with two opposing camps: telecom operators on the one hand, online service providers on the other), but also as a civil liberties issue. Through digital rights groups

150 See the case studies related to FFDN and its members in: Tréguer, F., & Dulong de Rosnay, M. (2018). Community Networks and Political Advocacy (netCommons Deliverable n° 1.5). ISCC-CNRS. <https://halshs.archives-ouvertes.fr/halshs-01792045/document>.

like La Quadrature du Net, his expertise was also relayed at the European level and positively contributed to the successful adoption of Net Neutrality protection in EU law through the 2016 Telecom Single Market regulation.[151]

In 2016, the EU Commission also introduced a vast legislative package reforming the bloc's telecom rules. FFDN soon met with the ARCEP and the government to offer its view on the major stakes of telecom regulation and give a general opinion on the EU Commission proposal. Along with Guifi.net,[152] La Quadrature du Net and the research project netCommons,[153] FFDN played an important role in the subsequent legislative debate in Brussels, one that saw the emergence of the first rules tailored for CNs in EU law.

In the spring of 2017, Bayart and other FFDN representatives were invited by ARCEP to a BEREC meeting, as regulators sought feedback on the appropriate tools to monitor the traffic-management practices of telecom operators.[154] Perhaps more significantly, because it allowed them to stress their own regulatory needs, they also responded to another BEREC consultation related to Net Neutrality, one about interconnection practices and their regulation. In their response,[155] they strongly criticised the BEREC approach, its "lack of political vision" and unwillingness to engage in systematic monitoring of interconnection agreement. They particularly highlighted the fact that major telecom operators and online service providers were increasingly resorting to bilateral agreements thought Content Delivery Network (CDN) bypassing traditional Internet eXchange Points (IXP).

151 See Regulation (EU) 2015/2120 of the European Parliament and of the Council of 25 November 2015 laying down measures concerning open internet access.

152 See <http://guifi.net/>.

153 See <https://netcommons.eu/>.

154 See Net Neutrality: Respect my Net presented at BEREC. (2017, April 11). La Quadrature du Net. Retrieved December 21, 2017, from <https://www.laquadrature.net/en/berec-net-neutrality-respectmynet>.

155 See Response to the BEREC consultation about the draft report on IP-Interconnection practices in the context of Net-Neutrality. (2017, May 7). Retrieved December 21, 2017, from <https://www.ffdn.org/en/etude/2017-07-05/response-berec-consultation-about-draft-report-ip-interconnection-practices-context>.

7.4.3 Joint litigation

Another interesting avenue through which FFDN has defended the values of the CN movement in France is litigation. In the fall of 2013, in the midst of the Snowden controversies, the French government decided to legalise hitherto illegal capacities of its intelligence agencies regarding extra-judicial access to the metadata held by telecom operators and hosting providers.[156] To do so, it worked with several members of Parliament then elaborating the Military Planning Bill (or "LPM" in French).

At first, the amendment aimed at legalising intelligence practices went unnoticed. It was only after a few weeks, and an initial criticism by a trade group representing large for-profit online services, that advocacy groups ranging from the League of Human Rights to La Quadrature du Net and Reporters Without Borders engaged in a short but intense mobilisation to get the amendment repealed.[157] The mobilisation eventually failed, but it led to new coordination among human rights groups working to protect civil liberties in the digital sphere.[158] Approximately a year later, on Christmas Eve 2014, the French government adopted the implementation decree of this new legislation, legalising and extending the surveillance capabilities of law enforcement agencies. When this became public, a volunteer from the board of FDN with a legal and policy background proposed the idea of introducing a legal challenge against the decree before the Council of State, France's highest jurisdiction for administrative law.

Within a few days, a network of connections and multi-level involvements of a small group of individuals in FDN, FFDN and LQDN led to the formation of a dedicated working group of half a dozen persons, including four individuals with a legal background and previous experience in policy advocacy (either at LQDN or FDN). The group also included two computer engineers from FDN

156 See Tréguer, F. (2016). From Deep State Illegality to Law of the Land: The Case of Internet Surveillance in France. Presented at the 7th Biennial Surveillance & Society Conference (SSN 2016): "Power, performance and trust". Retrieved from <https://halshs.archives-ouvertes.fr/halshs-01306332/document>.

157 Idem.

158 See Tréguer, F. (2017). Intelligence Reform and the Snowden Paradox: The Case of France. Media and Communication, 5(1), 17–28.

and FFDN. A month later, an initial legal challenge was introduced against the LPM's implementation decree, applying the case law of the EU Court of Justice on data retention to French law.[159]

In February 2015, two decrees were also published to implement recent laws allowing for the administrative, extra-judicial censorship and blocking of websites hosting child abuse or pro-terrorist content, also before the Council of State.[160] Then, that spring, a major policy debate took place on the upcoming Intelligence Bill, a sweeping overhaul of the legal framework for the communication surveillance activities of French intelligence agencies.[161] Six months later, the group would start working on challenges to the implementation decrees of the law, and assist a member of the EU Parliament in a legal challenge against the law's provisions on international surveillance. The same group also introduced a still-pending legal challenge against the EU-US Privacy Shield agreement governing the transfer of personal data from the EU to the US.[162]

This litigation work soon extended to other issues closer to the direct interests of CNs, in particular to gain access to publicly funded fibre-optic networks. It cannot be denied that these activities mobilise the political values that drive the engagement of FFDN's volunteers. Indeed, amongst its member organisations, litigation plays an important role in enacting the movement's vision: lawsuits are systematically reported upon and debated at the GA.

7.5 Conclusion

Can FFDN be a model for other communities hoping to coordinate? Can it serve as a canvass for successful coordination at the national and translational levels? To be frank, FFDN could learn many lessons from what other communities across Europe and across the World have done. In fact, FFDN has grown in relative isolation

159 See Loi de programmation militaire (LPM) sur l'accès aux données de connexion: URL: <https://archive.is/4ewqa3>.

160 See Filtrage LOPPSI / Cazeneuve (blocage DNS et déréférencement): <https://archive.is/rMwO1>.

161 See Tréguer, F. (2016, October). Internet Surveillance in France's Intelligence Act. Retrieved from <https://halshs.archives-ouvertes.fr/halshs-01399548/>.

162 See Privacy Shield. <https://archive.is/7Bl3r>.

from other CNs in Europe. While British "Free Network activists",[163] Freifunk,[164] Guifi.net and other networks united around CN events in Europe like the Battle of the Mesh, FFDN has remained largely outside of the existing forms of collaboration between other national CN communities.

FFDN is still a fragile organisation, and it faces important challenges. On the governance level, there seems to be a lot of strain put on a few active volunteers who deal with the bulk of the work necessary for the operation of the organisation. While issues of diversity and horizontality are discussed at the level of the federation, there is relatively little collective reflection about how to recruit more member-subscribers, member-participants and active volunteers to make existing CNs more resilient and maximise their impact locally and at the national level.

Even on the policy side, FFDN's work does not always translate into positive legal outcomes. The French Telecommunications Regulator, ARCEP, has been very keen on receiving FFDN's comments, which often contrast with the submissions they receive from traditional players in the telecom market. Sometimes, ARCEP policy officers even directly call out to leading FFDN members – in particular Bayart and Oriane Piquer-Louis (currently FFDN's co-presidents) – to ask them to participate in their consultation. However, unfortunately, these discussions have largely failed to result in any policy change favouring CNs at the national level.

Therefore, FFDN is not necessarily a full-fledged model. Other national communities – like Guifi.net and Freifnuk in Europe – have found also robust institutional mechanisms to establish such coordination and scale up their operations and may offer more complete examples of what can be done via CN organisations. Nevertheless, with all its shortcomings and peculiarities, FFDN still provides interesting cues on the benefit brought about by collaboration and systems for coordination for ensuring the

163 See the section on Consume.net in: Trudel, D., & Tréguer, F. (2016). Alternative Communications Networks Throughout History (report). ISCC-CNRS. Retrieved from <https://halshs.archives-ouvertes.fr/halshs-01418826/document>. See also: Medosch, A. (2014). Network Commons: dawn of an idea. In The Next Layer. Retrieved from <http://www.thenextlayer.org/node/1233>.

164 See <https://freifunk.net/>.

sustainability of the CN movement. Most importantly, its institutional arrangements could provide inspiration for thinking about how to preserve maximal autonomy for its member organisations – ones with diverse technical models or political cultures –, valuing their diversity and locality, while fostering collective cohesion through mutual assistance and the political and legal defence of CNs.

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8 Fostering sustainability of Community Networks: Guidelines to Respect the European Legal Framework

Virginie Aubrée and *Mélanie Dulong de Rosnay*

Abstract

This chapter proposes guidelines to help Community Networks (CNs) to cope with the applicable European legal framework and mitigate legal risks while protecting users' rights and enforcing core values such as privacy. It covers three main topics that are key to the activity of CNs: civil liability, data protection, data retention and provides concrete recommendations on the legal choices to be made, as well as suggestions for CN governance choices.

The chapter is based on the analysis of the legislation and case law applicable to 'electronic communications services', 'electronic communications network', and 'services providers' of an 'information society service'. The legal analysis was informed by a survey, which gathered replies on the practices of CNs from six EU countries (France, Italy, Germany, Greece, Portugal and Slovenia) in five main areas: organization, services offered, relationship with users, data protection and data retention law.

The chapter presents our findings and recommendations in the areas of civil liability, data protection law, data retention, and makes governance recommendations to address these challenges and mitigate CNs legal risks.

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8.1 Introduction

This chapter proposes guidelines to help Community Networks (CNs) coping with the applicable European legal framework and mitigate legal risks while protecting users' rights and enforcing core values such as privacy (De Filippi and Tréguer, 2015).

It covers three main topics that are key to the activity of CNs: civil liability, data protection, data retention and provides concrete recommendations on the legal choices to be made, as well as suggestions for CNs governance choices.

The proposed guidelines are based on the analysis of the legislation and case law applicable to 'electronic communications services', 'electronic communications network', and 'services providers' of an 'information society service'. The legal analysis was informed by a survey which gathered replies on the practices of CNs from six EU countries (France, Italy, Germany, Greece, Portugal and Slovenia) in five main areas: organization, services offered, relationship with users, data protection and data retention law.

The chapter present our findings and recommendations in three areas of civil liability (Section 8.2), data protection law (Section 8.3), data retention (Section 8.4), and make governance recommendations to address these challenges and mitigate CNs legal risks (section 8.5).

It is important to note that service providers can be held liable if they do not comply with specific behaviors requested of them by law. Regarding civil liability of open WiFi networks, we are considering the 2016 MacFadden ruling of the Court of Justice of the EU, on data protection law, the recent General Data Protection Regulation (GDPR) update, and on data retention legal obligations, the 2014[165] and 2016 Tele2[166] rulings, which invalidated obligations for indiscriminate, blanket data retention.

165 See CJEU, Judgment of the Court (Grand Chamber), 8 April 2014. Digital Rights Ireland Ltd v Minister for Communications (C 293/12 and C 594/12).

166 See CJEU, Judgment of the Court (Grand Chamber), 21 December 2016. Tele2 Sverige AB (C 203/15) Secretary of State for the Home Department (C 698/15).

8.2 Civil liability

Civil liability has proved to be a problem for a number of CNs, particularly in Germany where Freifunk participants for years had to deal with the risk of third party infringement[167]. To ensure the lawfulness of personal data processing, the chapter provides suggestions for security measures and transfer of data, anonymizing and "pseudonymizing" data.[168]

Entering into a contract with the users of CN services can be an interesting solution to mitigate the risks associated with both the applicable liability regime and the data protection framework. For the same reasons, incorporating a CN through a non-profit legal status could also help alleviate legal risks and clarify the distribution of liability within the community. In this sense, the community can reflect on these risks and anticipate them rather than being forced to act in the context of a legal crisis.

Regarding civil liability, it is important to stress that providers can be held liable only if they do not comply with specific behaviors requested of them by law (Baistrocchi, 2002; Busch, 2015; Giovanella, 2015). These behaviors vary depending on the different roles played by CNs, which can qualify as "mere conduit", "caching" or "hosting" providers.[169] For instance, hosting providers can be held liable if they do not remove expeditiously an allegedly illegal piece of information when they receive a notification by a third party (*e.g.* a user of their services) highlighting the existence of the infringing information.[170]

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167 Germany used to have a form of strict secondary liability, the so called doctrine of Störerhaftung. This doctrine was abrogated by the new version of the Telemedia Act of October 2017 (§7-10). The full-text in German is available here: <https://dejure.org/gesetze/TMG> ; For further information on this issue, see CJEU, Judgment of the Court (Third Chamber), 15 September 2016, Tobias Mc Fadden v Sony Music Entertainment Germany GmbH (C-484/14) and an analysis on CNs in Aubrée et al (2018).

168 According to GDPR recital 26 "The principles of data protection should therefore not apply to anonymous information, namely information which does not relate to an identified or identifiable natural person or to personal data rendered anonymous in such a manner that the data subject is not or no longer identifiable."
According to GDPR art. 4(5) "'pseudonymization' means the processing of personal data in such a manner that the personal data can no longer be attributed to a specific data subject without the use of additional information, provided that such additional information is kept separately and is subject to technical and organisational measures to ensure that the personal data are not attributed to an identified or identifiable natural person;"

169 These terms are defined in articles 12, 13 and 14 of EU Directive 2000/31/EC, commonly referred to as the E-Commerce Directive.

170 See art.14 E-Commerce Directive.

Such an obligation to remove online content is applicable to any kind of data, regardless of the source. This means that, when the CN is considered as a hosting provider, it does not matter whether the data to be removed come from within a CN or not, as long as it is hosted within the networks and to the extent that the CN – and the persons responsible for it – can take active steps to take the targeted content down.

Furthermore, in the context of open WiFi networks[171], CNs can be held liable if they do not comply with an injunction measure requiring to prevent third parties from engaging in copyright infringement. According to the Court of Justice of the EU (CJEU), such measures might involve subjecting the possibility to utilize the CN to the use of passwords so that users "are required to reveal their identity in order to obtain the required password and may not therefore act anonymously".[172]

A general recommendation for CNs would be to distribute as much as possible obligations and liabilities among members of the community and make sure that this distribution is clear for all involved parties.

In terms of liability, two different situations should be distinguished. First, liability concerning unlawful information or content. In reliance with the McFadden case law and specific national provisions, CNs should enjoy the liability exemptions introduced by Directive 2000/31, but at the same time they might be the target of injunctions to secure their connection (such as password-protect it).

Second, liability concerning the whole management of the network as a physical infrastructure able to generate physical damages. As a network is composed of different parts, those can be under the control of a CN – or, more precisely, of the entity through which the CN is incorporated and that is responsible for its management –, a user or a third party. Each situation implies a different outcome regarding liability. In each situation, choices have to be made

171 See Mac Sithigh (2009).

172 For further details, see the McFadden ruling of the Court of Justice of the European Union; Giovanella and Dulong de Rosnay (2017).

between responsibilization of users, mutualization of risks – with an insurance – or decentralization of obligations and responsibility – with a dedicated agreement.

When there is an entity, the use of end-user licenses or terms of use might be a way both to inform users and to limit the CNs' liability: exactly as commercial providers do, CNs may impose specific obligations on their users, interrupt service and/or ask for damages when users do not comply with these obligations. This is for instance one of the clauses included in the FONN License[173] adopted by Guifi.net.

8.3 Data protection law

In the context of the new European data protection framework, established by the entrance into force of the GDPR, a general recommendation would be to anonymize as much as possible the data processed – aside from technical or legal requirements. At the same time, we recommend to pay attention to the provision of intelligible information to users in a clear and plain language and the purpose for data processing for which consent is requested.

The scope of the GDPR and data protection principles does not apply to anonymous[174] data, defined as "information which does not relate to an identified or identifiable natural person or to personal data rendered anonymous in such a manner that the data subject is not or no longer identifiable". Simply put, data can be deemed as anonymized as long as they cannot be attributed to any individual, by anyone, in any circumstance (Mourby et al, 2018). Thus, anonymizing data would be a good practice to reduce legal risks. As underlined in the results of our survey, it is encouraging to note that some CNs seem to achieve this goal.

They declared: "we do not collect anything we think is personal data about our users, we also do not know which data we collected is by which user". This assertion could also mean that they do not have knowledge of the link between data and data subject. Now,

173 See the Compact for a Free, Open & Neutral Network (FONN Compact) <https://guifi.net/en/FONNC>.

174 See Art. 29 Working Party, "Opinion 05/2014 on Anonymization Techniques," Apr. 10 2014.

even when CNs apply absolute anonymization, it is still possible to de-anonymize that data and link it to a specific data subject[175]. So even anonymized data can be regarded as personal data and fall within the scope of the GDPR. Therefore, it would be safer for CNs to also take into account obligations regarding informed consent and transparency[176].

Any CN should provide its users/members with information about their rights with regard to their personal data processing. In particular, the information provided through the web page of the CN should comply with the requirements introduced by art. 12, Reg. 679/2016: Information should be provided "in a concise, transparent, intelligible and easily accessible form, using clear and plain language". All CN should provide its users with such information before processing data.

8.4 Data retention

With regard to data retention, CNs face a particularly thorny issue considering the legal limbo surrounding these legal obligations established across Europe to facilitate law enforcement. Given the 2014 and 2016 Tele2 rulings of the Court of Justice of the EU, which invalidated obligations for indiscriminate, blanket data retention, not less than seventeen Member States are, according to our analysis, still in breach of this crucial case law as of June 2018. It will probably be months, or years, before all ambiguities are finally resolved. In the meantime, we have highlighted various strategies that we have observed in the course of research, inviting CNs to choose the path they deem to be most appropriate for them.

These strategies range from the most "conservative" option (*i.e.* deciding to respect national law at the expense of the right to privacy as construed by the "Supreme Court" of the EU in its case law), to

175 For research on re-identification of de-anonymized data, see Purtova, N. (2018). The law of everything. Broad concept of personal data and future of EU data protection law. Law, Innovation and Technology, 10(1), 40–81. <https://doi.org/10.1080/17579961.2018.1452176> and Sweeney, L. (2000).Simple Demographics Often Identify People Uniquely. Carnegie Mellon University, Data Privacy Working Paper 3.

176 On this subject, Art. 29 WP published guidelines regarding consent at <http://ec.europa.eu/newsroom/article29/item-detail.cfm?item id=623051>.

the most "activist" stance (*i.e.* defying national law while invoking this European case-law to highlight the discrepancy between some EU member laws and fundamental rights), which bears the risk of litigation and, possibly, fines or even jail.

Importantly, according to the primacy principle, EU law shall have primacy over any law of the Member States. This implies that if a national rule is contrary to a European provision, the binding force of this Member State's rule is regarded as suspended[177]. As a consequence, on principle, CNs should comply with the European legal framework. Regarding data retention, this refers to the Tele2 case law[178]. To be specific, in light of this decision, national laws should not provide for:

a) Indiscriminate and general collection of data,

b) Access to personal data for an objective wider than fighting serious crime,

c) Access to personal data without prior review by a court or an independent administrative authority, or

d) Retention without an obligation to store these data within the European Union.

In light of the above, several national frameworks were declared inconsistent with EU law or unconstitutional by local judges (Milaj, 2015). In some Members of the EU, laws were repealed, such as in the Netherlands[179] or Slovakia[180]. In other countries, laws were set aside and operators that did not retain data as prescribed by their national laws were not sanctioned[181]. However, in most of them, there is no clear legal answer to whether national laws should still be in force. In accordance with EU criteria, it is highly doubtful that data retention legislation in Italy, France, Germany, Greece, and Spain comply with CJEU jurisprudence[182].

177 See Court of Justice of the European Community, 15 July 1964, Flaminio Costa v E.N.E.L, Case 6/64; For a clear introduction to the principle, see: <https: //eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=LEGISSUM:l14548&from=FR>.

178 See <https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:62015CJ0203&from=FR>.

179 See <https://edri.org/dutch-data-retention-law-struck-down-for-now/>.

180 See <https://edri.org/slovakia-mass-surveillance-of-citizens-is-unconstitutional/>.

181 See, for instance, three German decisions: OVG Münster 13 B 238/17, VG Köln 9 K 7417/17 and 9 K 3859/16.

182 For Russian data retention requirements, see Zhuravlev et al (2018).

Therefore, where a country has a national statute in breach of EU case law, CNs could theoretically be free not to comply with the law. Yet, in all of these framework serious fines exist for CNs which do not comply with data retention obligations. Therefore, a legal risk does exist for them.

Thus, several hypotheses should be considered:

a) If CNs want to reduce legal risks, they could strictly comply with national law – except when a public statement provided expressly that no fine proceedings would be started against non-compliant providers (as in Germany[183]). However, overcompliance also generates legal risks for CNs. Indeed, if a CN has a data retention system exceeding its legal framework – *e.g.* in terms of scope of data or duration of retention – this activity could be regarded as an unlawful processing since this additional retention would no longer be "necessary for compliance with a legal obligation to which the controller is subject"[184].

b) If CNs want to comply with practical requirements while avoiding overcompliance issues, a compromise could be reached. They could reduce the scope of data retained to the one that is actually demanded by public authority while conducting their investigations: IP addresses and subscriber ID. This would not respect the letter of the law, and therefore implies theoretical legal risks. However, such data would be enough to comply with most request of access – which are very rare in the experience of Community Networks. Empirical evidence from several CNs we have interviewed suggests that law enforcement authorities generally accept this as satisfactory.

c) If CNs want to actively take part of the advocacy against blanket data retention, their third option is to choose to ignore data retention provisions. However, they should keep in mind that this choice come with a legal risk, as they could be prosecuted by national authorities. To mitigate this risk, if they are sanctioned, they still have the possibility to challenge this decision before

183 In reliance with the official press-release of the federal telecommunication regulatory authority (Bundesnetzagentur), available (in German) here: <https://www.bundesnetzagentur.de/DE/Sachgebiete/Telekommunikation/Unternehmen Institutionen/Anbieterpflichten/OeffentlicheSicherheit/Umsetzung110TKG/VDS 113aTKG/VDS-node.html>.

184 See GDPR, art. 7, (c).

national courts, arguing that the obligation is inconsistent with EU law and so is the fine applied to them.

8.5 Governance

This section deals with the internal organizational form of the CNs and the relationship with users or members they may adopt in order to better manage requirements pertaining to the three main legal issues CNs are facing – which were described in the three previous sections of this chapter.

Entering into a contract with the users of CN's services can be an interesting solution to mitigate the risks associated with both the applicable liability regime as well as the data protection framework. For the same reasons, incorporating a CNs through a non-profit legal status could also help alleviate legal risks and clarify the distribution of liability within the community, so that it can reflect on these risks and anticipate them rather than being surprised by law enforcement and obliged to act in the context of a legal crisis.

As regards organization, the survey we conducted highlighted that most respondents are organized as an association. Yet, some of the analyzed CNs do not have a legal form with clearly redefined responsibilities attributed to specific individuals. This absence of official structure allows them to enjoy an informal relationship.This idea is in line with the way decisions are taken in these structures (in a bottom-up consensus-driven fashion). In this regard, all respondents acknowledged the importance of a distribution of power and a horizontal approach as well as a participative and collective decision process within the community. Regarding services provided by CNs, the core of their activity is to provide an Internet access (through Wi-Fi mostly, but sometimes through landline networks too) although, they very often stimulate the development[185] and offer several additional services such as hosting, e-mail, online fora or Tor node services which can imply extra subtleties in terms of civil liability.

185 See Belli, L. (2017). Network Self-Determination and the Positive Externalities of Community Networks, in Belli, L. (Ed.). (2017). Community Networks: the Internet by the People for the People, 35-64. <http://hdl.handle.net/10438/19401>.

In order to be able to undertake their important social and economic function while minimizing risks of liability, we recommend that CNs adopt a suitable legal form to conduct their activity, being incorporated in the form of associations, cooperatives, foundations or other non-profit organization, depending on what legal options are provided by their national frameworks.

Importantly, insofar as CNs determine the means and purpose of the processing of users' data, they qualify as data controller under art. 4(7) of the GDPR. When a CN is organized as an association or cooperative, there is a legal entity and therefore there are no issue in determining who the data controller is, being it a natural or legal person. On the contrary, when the CN does not have any specific legal form, it becomes more difficult to understand who is the controller, and liability might weight on private individuals participating in running the network. Thus, to mitigate legal risks and share liability, it is more suitable for CN to adopt a specific legal form.

Concerning the nature of the relationship with users, the results of the survey we conducted reveal that the 'informal' relationship is also favored in practice. The results show that most of the CNs we interviewed[186] do not use a contractual form to establish a relationship with their members. However, there is a different kind of proximity built with the CN user since there is often a requirement to be a member[187] of the community in order to access to the service provided. This implies a flexible and trust-based relationship with the users. Yet, it can create difficulties regarding data protection law. Besides, CNs tend to highly favor privacy in their relationship with their users. This concern is also shown though their data retention habits, as a large part of the respondents declared that they do not retain any data.

We recommend that Community networks sign a contract or an agreement with their user when acting as legally definable "service provider", be the service Internet access or an additional service.

186 The questionnaire which circulated among Community Networks is available in Aubrée et al (2018) Annex 1, p. 94. See also, for the analysis, Ibid, p. 63-72.

187 A member of a CN "Participant" in the sense of the terminology employed in the Declaration of Community Connectivity available at <https://comconnectivity.org/article/dc3-working-definitions-and-principles/>. and in Belli, L. (Ed.). (2017): 237. <http://hdl.handle.net/10438/19401>.

Concerning data protection law, the GDPR states that a lawful processing of personal data – which CNs have to do in order to provide their services – requires a legitimate interest, consent or contract[188]. For all these legal basis for personal data processing, the most reliable solution is the establishment of a contractual relationship between specifically designated data processor and users. Indeed, in the case of CNs, the extent of the legitimate interest is difficult to evaluate with certainty. Such an agreement could help establish a transparent relationship between a CN and its members and users and could also contain provisions to distribute civil liability.

8.6 Conclusion

The analysis of EU and relevant national laws allowed us to produce a mapping of legal requirements CNs have to respect or to implement in the areas of liability, data protection and data retention. Interacting with CNs through a survey about their practices further contributed to our analysis. It helped us identify gaps and needs, which led to the development of applicable legal guidelines to cope with legal hurdles, towards legal sustainability of CNs, which have special regulatory needs.

In light of these findings, we produced general guidelines in the actual practice areas of CNs, balancing between legal requirements and CNs political ethos: maintaining privacy in their relationship with their users and having a horizontal distribution of power as a participative and collective decision process within the community. These guidelines represent an important step towards the full compliance of CNs with national legal frameworks and, although are limited to the EU framework, can serve as inspiration for other initiatives aimed at fostering CN legality.

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188 See GDPR art. 6.

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9 Complementary Networks Meet Complementary Currencies: Guifi.net Meets Sardex.net

Panayotis Antoniadis, *Jens Martignoni*, *Leandro Navarro* and *Paolo Dini*

Abstract

Reading in parallel the description of community networks and community currencies reveals many similarities and differences between these two models of self-organisation around networking infrastructures and monetary systems, respectively. This chapter brings together experts from both domains in an effort to share knowledge and experience, using as case studies two emblematic projects, Catalonia's success story on community networks, Guifi.net, and Sardinia's success story on community currencies, Sardex.net. The long-term objective is to build a better common understanding of the individual models but most importantly the stimulation of synergies and collaborations of researchers and activists from both sides.

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9.1 Introduction

Community (wireless) networks (CNs) are communications networks built out of the individual contributions in time, money, hardware, and software by the community members. The most typical image behind the construction of such a network is the mounting of antennas on rooftops, which create wireless links that can cover from small to large areas. Successful community networks like guifi.net and Freifunk.net include in their collective infrastructure also fibre cables, and more. The resulting networking infrastructure is a *commons* that can offer access to the Internet in so called "market-failure areas", such as rural regions, where commercial Internet Service Providers (ISPs) do not have a benefit to invest. The newly created common networking infrastructure can be also used as a basis to provide a wide variety of local services, hosted and sometimes only reachable inside the geographic area covered by the network. The latter has been always considered as one of the big advantages of CNs but until now it has not delivered its promises.

Indeed, the Internet could in principle support also local online interactions. The promotion of local interactions would represent a substantial change of the current situation, which is rarely analysed critically by Internet users. Indeed users do not seem to consider the potential problems of using online platforms based in a foreign jurisdiction, very far from the local area served; owned by multinational corporations completely disconnected from local institutions, whose main concern is the extraction of (local) value for a limited number of external investors; and if sensitive private information is gathered, processed for vaguely communicated purposes and shared with unspecified "third parties" for the exclusive profit of platforms' shareholders (Belli et al., 2017).

Is it possible to build more ethical platforms that support local development instead of being based on an extractive model, while still operating on a global scale? Should we focus instead on local solutions that are in principle more "complementary" than "alternative" to the Internet and may consider scaling up at a later stage? In this latter case, should network infrastructure be clearly treated as a community resource by the services offered on top of it? Can we act just as a *homo civicus* would do, sensitive to the collective implications and local effects of our individual choices, or are we always going to behave like a *homo economicus*, purely driven to the cheapest option at any cost?

Interestingly, advocates of community currencies (CCs) face different but in some sense analogous challenges to the ones faced by CNs. For example, community or complementary, or regional, or alternative, or social currencies are also subject to the "why?"

question. As the global Internet can support local communications, similarly the globally established national currencies like the US-Dollar or the Euro (also called fiat money) are perfectly capable of supporting the functionality of a local community currency, *i.e.,* the exchange of goods and services in localities. Moreover, they do so avoiding the limitations and the increased risk of failures introduced by an extra currency limited to a specific geographic location.

As in the case of communication networks, most people do not feel empowered or even allowed to operate their own local economy. "Is it legal?" is often the next question when one starts debating the pros and cons of a community currency. The answer is that, depending on the scale, a local currency can be more or less easily designed to be perfectly legal and compliant with, for example, tax regulations. Nevertheless, for this to happen it requires the mobilisation and cooperation of many different actors and a broader awareness of how the economy works and why local currencies play an important role from the perspectives of sustainability, resilience, social learning, self-determination, and more.

The same holds for CNs, which similarly to CCs are not well understood by the wider public and face various social, political, economic, legal, regulatory, and educational challenges. They also have to compete with global institutions with tremendous power and require a level of social cohesion and local collaboration that is more and more difficult to take for granted, while the solutions they offer may be complex to implement and prone to failures. In some countries, furthermore, communications regulation can make it difficult on legal grounds to establish a separate and independent communications infrastructure.

Both types of community initiatives share similar long-term objectives: to close digital (for CNs) and economic (for CCs) divides, which often depend on and influence each other; to offer easier access to information and services; to promote local social and economic development and employment; and to strengthen local identity and culture.

However, not all CNs and not all CCs are the same. Most importantly, there are different levels of "complementarity" in relation to the global system, the Internet and the global economy, respectively, for which such platforms provide an alternative local solution. For example, the most well-known CNs – both in rural and urban areas – are mainly perceived by outsiders as free or cheap gateways to the Internet, while failing to understand the significant differences between them on how such access is achieved. In addition, when they do support *local* interactions besides providing Internet access, this is often between those who contribute in the construction of the network, the "node owners" typically tech enthusiasts and hackers. Some CNs have successfully engaged the local community in a more inclusive way, as is the case of the Redhook[189] WiFi initiative in Brooklyn (Baldwin, 2011) or Quintanalibre in Argentina (Belli, 2017), but their overall impact is still rather limited. As will be further discussed below, guifi.net[190] is a special case that distinguishes completely between the network infrastructure and the services provided on top, including the Internet connectivity.

At the same time, the CC ecosystem is filled with numerous important design variables that generate a very complex design space. There are solutions putting small and medium-sized enterprises (SMEs) at their centre like WIR[191] in Switzerland and Sardex.net[192] in Italy, others that have expanded this idea towards customers, like RES[193], established in Belgium and now expanding to Catalonia. Others aim to support the regional economy and sustainability as the English transition currencies Totnes Pound[194] and Bristol Pound[195] or the German Regiogeld Chiemgauer[196]. There are also examples of currencies with social and environmental motivations like Torekes[197] in Gent, Belgium or Spice Credits[198] in

189 See <https://redhookwifi.org>.

190 See <http://guifi.net>.

191 See <http://wir.ch>.

192 See <http://sardex.net>.

193 See <https://www.res.be>.

194 See <https://www.totnespound.org>.

195 See <http://www.bristolpound.org/>.

196 See <https://www.chiemgauer.info>.

197 See <http://www.torekes.be>.

198 See <http://www.wearetempo.org/>. (Spice changed its name in Oct. 2018 and is now called Tempo Time Credits)

England and there are many hundreds of time banks[199] and LET-Systems[200] worldwide.

In the following sections, we develop a parallel introduction of CNs and CCs as collaborative "commoning"[201] activities, around six key characteristics:

1. The "commons" resource (characteristics, properties)
2. Community building (bootstrapping, membership, vision)
3. Managing the commons (participation, accounting, rules, decision-making)
4. Boundaries and complementarity (interactions with the global system)
5. Growth model (distributed vs. centralized architecture)
6. Computer-support tools (proprietary vs. free software)

Reading in parallel the description of CNS and CCs will already reveal many similarities and differences. However, the goal of this paper is not only to highlight those similarities but engage in a discussion with the stakeholders in a wide range of community-based initiatives that will allow to learn from each other's successes and failures. Such exercise may also lead to collaborations on the production of more holistic models of local ownership and governance of these core common resources, networking and financial infrastructures.

For this, we have chosen to focus on two success stories, and somehow special cases: the guifi.net CN and the Sardex.net CC. We discuss their particular interpretation of complementarity, how they managed to scale, and the key compromises that they had to make on the way. This analysis leads us to understand better the concept of "complementarity" in the case of CNs, inspired by the importance that this has played since the financial crisis in the case of CCs, and vice versa.

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199 The term time bank refers to a reciprocity-based work exchange system in which hours are the currency.

200 LETS: Local Exchange and Trading System

201 See <http://wiki.p2pfoundation.net/Commoning> for a definition of the term.

This analogy and knowledge sharing exercise between these two different domains of collective action will also hint to possible integrated models of both complementary networks and currencies in specific geographic areas. For example, an appropriately designed complementary scheme can place a CN into a broader local economy. This would enable, on the one hand, the provision of incentives for investments in infrastructure and effort for deployment and maintenance of the network and, on the other hand, the inclusion in the community of people and companies that do not have ICT expertise, but can bring other resources and competence.

9.2 Two success stories: the guifi.net Community Network and the Sardex.net Community Currency

CNs are communication networks built by citizens and organisations who pool their resources and coordinate their efforts to develop a local networking infrastructure (Baig, 2015). The infrastructure is built, via a collaborative process, by individuals who, typically, install some kind of network equipment at home or at a participant organisation. They deploy an antenna on their roof, or a cable or optic fibre, and connect with others in an urban or rural area over short or long distances.

The resulting network infrastructure can then be used for internal communication between those that have access to the network or for delivering local content, such as live video, or providing services, such as symmetric access to the global Internet. This is possible when an "Internet source", an Internet gateway, is made available inside the network infrastructure. They are sometimes referred to as wireless community networks (WCN) when built fully with wireless technologies (point-to-point, access points, or mesh topologies, with WiFi or GSM links).

Our selected example of a successful community network is guifi.net, a citizen project in Catalonia with over 34,000 nodes branded as "a network infrastructure as commons"[202], on top of which a wide variety of entities take advantage of

202 See also the EU Horizon2020 project (2016-2018) netCommons: <http://netcommons.eu>.

the local connectivity to offer a variety of services, including Internet access for clients and servers. Many people use the network infrastructure for the good-quality connectivity that it provides. One of its most important strengths is that connectivity is managed cooperatively, while at the same time the core infrastructure is managed purely as a commons. These are some of the reasons why the CN received the European Commission's 2015 European Broadband award on "Innovative models of financing, business and investment"[203].

In the case of currencies, differences between community currencies that are not national currencies (legal tender or fiat money) have led to different designations:

- *Alternative* is maybe the broadest term, indicating all non-official currencies but also a competitive stance with respect to the dominant national currencies.
- *Community*, or *social*, highlights democratic and social goals, and tendency to foster the benefits of society, emphasising self-help and caring and often focusing on social projects and services that are not part of the mainstream market.
- *Complementary* indicates a more cooperative relation towards national currencies, complementing them where they do not succeed, while remaining compatible with them (e.g. by paying taxes on the payments and deposits in CCs).
- *Regional* or *local* are often used to stress the limited geographical area where CCs apply.

In this chapter we use the fairly generic term "community currencies", since this is also used for the case of networks, and the term "complementary" for the special category of community currencies, like Sardex.net, that we want to draw attention to.

203 European Broadband Award 2015: <https://ec.europa.eu/digital-single-market/en/news/five-projects-got-first-ever-european-broadband-award>.

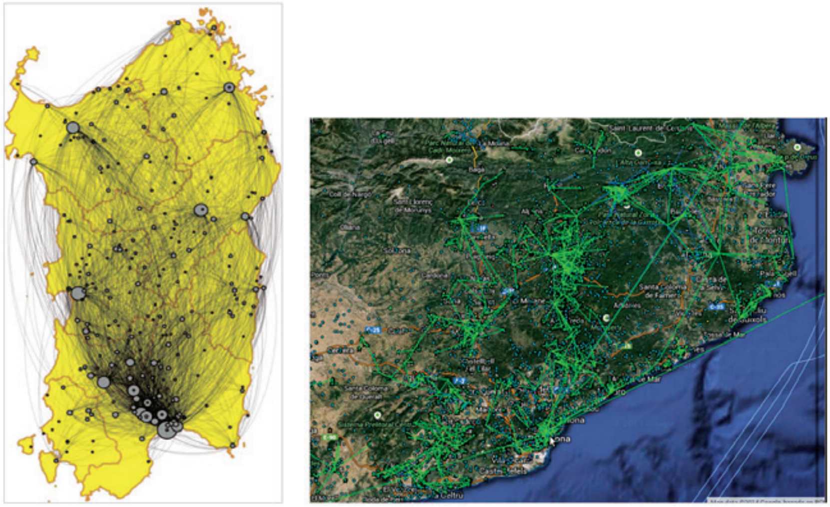

Figure 9.1. Comparison: economic transactions using Sardex.net in Sardinia, Italy (reproduced from Iosifides *et al.* 2015) and guifi.net network graph sector around Barcelona, Spain.

Similarly to guifi.net, Sardex.net is a very successful complementary currency in Sardinia, Italy, founded in 2009 (Littera *et al.*, 2017; Posnett, 2015). Figure 1 depicts two popular graphs of the two networks. The graphs might look similar, but in reality, they represent two different communication layers. The Sardex.net graph corresponds to the actual transactions between members of the Sardex.net network that are limited only by demand-supply relationships. The guifi.net graph corresponds to the communications network, the network infrastructure itself, which is limited by the geography and equipment costs, and thus results in a more structured network with "highways" and "low traffic roads". However, like in Sardex.net, the guifi.net network allows the implementation of a wide variety of services that could mediate interactions between any set of nodes.[204]

Sardex.net has managed to offer a local currency system that is operated by local actors, offering credit without interest to local businesses, and promoting the local economy while at the same

204 Every participating business could be seen as "node" in a CC that is connected through buying and selling to other "nodes".

time remaining compatible with the global economy. That is done by setting one Sardex equal to one Euro but not allowing convertibility between the two. Mixed payments, however, are allowed, e.g. an article offered at a price of 100€ by a participant might be paid with 50€ plus 50 Sardex by the buyer.

Sardex is in fact a commercial credit circuit which gives a credit-limit to the member businesses that is a fraction of their estimated ability to produce (and sell) goods and services. This credit can be used to buy from others and should be repaid by selling to others. Most important here is "the absence of interest on all balances" (Dini and Kioupkiolis, 2014, p.9). Even if there is no direct exchange between Sardex and Euro, every transaction in Sardex is subject to VAT tax in Euros, as the business keeper books it as if it were an income in Euros.

The success of Sardex.net is impressive: after only seven years of existence, around 3.800 businesses representing more than 2% of all enterprises in Sardinia are participating to the initiative. The accumulated transaction volume, until June 2017, exceeded already more than 212 Million Euro (in 2015, the volume was 51m and, in 2016, 67m). Like guifi.net, Sardex.net was awarded several prices, including the 2013/14 European Business Award.

It is interesting also to note how both these systems started in small villages out of a pressing need (the lack of Internet connectivity in the case of guifi.net and the lack of credit from banks in the case of Sardex.net[205]) and were founded by small teams of highly motivated and trusted people. Those individuals keep, until today, the decision-making power while trusting that their actions are toward the common good.

The strong regional identity is another common characteristic of the environments (Catalonia and Sardinia) where these two systems managed to develop further than the majority of their counterparts. Is this the most important requirement for success or perhaps a small extra driving force that could be replaced by clever design choices derived from the lessons learned from these pioneering systems?

205 In times of crisis, weak economies experience a lack of the medium of exchange, which in the case of SMEs is experienced as a lack of credit from banks.

Finally, another key reason behind our choice of guifi.net and Sardex.net as the leading examples of the two domains of local action, which we wish to study in comparison, is their innovative models of governance and sustainability; and especially the way they have positioned themselves in relation to the dominant players, not as potential replacements but as complementary solutions.

9.3 Six common characteristics of CNs and CCs, in comparison

9.3.1 Common resource

9.3.1.1 CNs

The collection of antennas, cables, hardware (i.e., routers, servers), and services, sometimes including Internet connectivity form an infrastructure that serves as a common-pool resource (i.e. common property) for those that have contributed individual resources. Thus, unlike traditional ISPs, the ownership and management of the infrastructure are collective and cooperative: since they are distributed amongst the members of the community, they constitute in essence a framework for "commons" governance (Ostrom, 1990). CNs are characterised by being open, free, and neutral.[206] They are open because everyone has the right to know how they are built. They are free (as in freedom) because the network access is driven by the non-discriminatory principle; thus they are universal. In addition, they are neutral because any technical solution available may be used to extend the network; and because the network can be used to transmit data of any kind by any participant, including for commercial purposes (Baig *et al*., 2015).

CNs generally feature three types of resources: *individual* or peer-contributed such as routers in a small mesh network or individual content servers that can self-organise in a purely decentralised manner; *group* or local resources to be crowdfunded, contributed and managed by a regional group, such as local backbone capacity and maintenance of local services (*e.g.* software and services such

206 See Declaration on Community Connectivity <https://www.intgovforum.org/multilingual/index.php?q=filedepot_download/4391/1316>.

as telephony, conferencing, media, Internet); and *global* resources to be contributed and managed by the community at large (*e.g.* node database, public website, Internet interconnection, traffic exchange). While the first is typically based on contributing your own device and on emergent behaviour, the other two types of resources rely on coordination mechanisms that require more abstract contributions and the aggregation of money and effort to crowdfund these resources.

In the case of guifi.net all above resources are present and managed collectively as a commons as described in Section 3.3 below.

9.3.1.2 CCs

The currency itself can be considered as a common pool resource[207], and be conceived like a network through which participants can compare, exchange or store economic values. In the same way that a CN, as a commons, is not just a passive set of routers and links, in the case of currency the governance framework that ensures the fair operation of the currency and the corresponding market are a commons. Finally, the stability of the network is based on trust which is another common resource deeply connected with the behaviour and trust relationships among the participating humans.

Typically, community currencies are organised as legal entities (*e.g.*, associations, cooperatives, non-profit organisations or for-profit companies). Many currencies run on centralised ICT infrastructures and platforms like Cyclos[208], CES[209], etc. In some cases, paper notes are used alone or alongside with electronic money. However, the costs associated with the maintenance of this infrastructure have to be covered. This is done through voluntary work, membership fees, and demurrage fees or, in the case of professional currencies, by transaction costs, fixed fees, or even a taxing system. The

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207 A good explanation is given by Graham Barnes (2014, p.1): "From one particular point of view – that of money as private property – the idea that money could be treated as a Common Pool Resource (CPR) seems patently absurd. [...] But going forward money is either a reward for past work, or (when issued through the device of credit) an advance secured in expectation of future work. From this viewpoint we can see money as an aspirational commons – a Common Pool Resource backed by our collective efforts, that with the right governance regime could be managed equitably and to mutual benefit."

208 See <http://cyclos.org>.

209 See <http://community-currency.info/>.

currency survives as long as its operational costs are covered, as it is well operated by the management, and is regularly used by the members of the community.

In the case of Sardex.net, unlike guifi.net, the core infrastructure is centrally managed by the Sardex S.p.A. (Inc.) company, but the mutual credit network itself and most importantly the trust relationships built around it (Littera *et al*., 2017), are certainly a commons built step-by-step through the individual contributions of all participants.

9.3.2 Community building

9.3.2.1 CNs

CNs are typically constructed either out of social or economic need (in most cases due to limited or no access to the Internet) or out of political reasons related to sovereignty, independence, network neutrality,[210] affordable Internet access for all, and more. Being fully inclusive to their natural community, the fundamental principles revolve around i) the openness of access to the infrastructure (usage), and ii) the openness of participation (construction, operation, governance) in the development of the infrastructure and its community.

Nevertheless, there are often misunderstandings since the word "community" could have a different meaning depending on the situation. A "community" could refer to a community of like-minded people connected through their own "overlay" network in a big city. It could refer to the wider community of any people enjoying the services of a local network, as for example a rural village. It could generally refer to services organised by public administrations.

Antoniadis (2016) analyses in detail the differences between the first two interpretations of the term community in "community networks", which together with the two basic services offered (local vs. Internet connectivity) form a two-dimensional matrix, which could be used to characterise a specific CN. The netCommons

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210 For further information on the concept, see <http://www.networkneutrality.info/>.

project's report (Navarro *et al.*, 2016) provides a descriptive and comparative analysis of the organisation and governance of several CNs.

Guifi.net is an example of a network that cannot be easily classified and thus provide a single point in a two-dimensional matrix for the whole network. Indeed, guifi.net is a big federated social community with multiple local network infrastructures, including rural networks offering connectivity to certain small to medium communities, or urban CNs such as in several neighbourhoods in Barcelona.

Therefore, different types of communities operate at different layers of this complex social arrangement, from the local "traditional" communities of rural areas, to the overall guifi.net social community coming together at the annual meeting and assembly, to the international community of policy makers, researchers, activists, and other key actors, like the DC3[211], GAIA[212], and battle of the mesh community[213].

However, the guifi.net social community has succeeded in reducing the dependence of the network operation and sustainability of local or regional network infrastructures, from the strong face-to-face ties between like-minded individual volunteers. Opportunities to develop professional services, have become a way towards local economic sustainability, but also have become attractive not only to those that share the same values of self-determination, but also to those who just wish to have access to affordable Internet access of high quality in exchange of a service fee.

9.3.2.2 CCs

Similarly to CNs, most CCs are built and maintained by groups of like-minded people. Those "core" groups need to promote the currency, motivate participants and foster engagement. Time-exchange or LETS-groups[214] for example gather in regular meetings to facilitate the exchange of services and goods. Larger systems organise

211 See <https://www.comconnectivity.org/>.

212 See <https://irtf.org/gaia>.

213 See <http://battlemesh.org/>.

214 See <http://www.lets-linkup.com/>.

market events or even big regional fairs as the WIR-Messe[215]. Online marketplaces and maybe forums or discussion groups are also essential for most currencies.

The effectively realised transactions are the most important success metric for the majority of all CCs. For this support by brokering could be crucial, but is not often used. Nevertheless, US or British time banks use professional brokers and Sardex.net, and its off-springs in Italy, have been very successful by following such a strategy. Part of the success of the Sardex brokers stems from the fact that they are employees of Sardex S.p.A. (Inc.) and do not receive a commission on successful matches. This improves the perception of the quality of service offered and fosters trust between the circuit members and the central credit clearing company.

Another approach is used by the German Chiemgauer Regiogeld, which introduces all sorts of local cultural and sports clubs by sponsoring them through exchange and demurrage fees. The members of Chiemgauer decide, by declaration, which of these clubs should get their turnaround-benefit.

Sardex.net is also very active in community building events at different scales, with most prominent the annual Mitzas conference[216]. However, as in the case of guifi.net, the motivations for the participation in the network go beyond the community spirit and shared values, and include the access to high-quality brokering services, interest-free loans, and a robust local economy with many concrete benefits for local SMEs.

9.3.3 Managing the commons

9.3.3.1 CNs

One of the key challenges of CNs and in general peer-to-peer systems is the fair sharing of the available resources, efforts and costs, and the existence of the appropriate incentives for participation and investments required to sustain the infrastructure. In the case of "locally-driven" communities, this may

215 See <http://www.wmzag.ch/>.

216 See <https://www.sardex.net/mitzas-intelligenza-connettiva/>.

not be a big issue since most participants have strong motivations for participation and there is a significant level of contributions, without the need of incentives, as additional common costs such servers, backbone, maintenance are negligible and can be easily assumed by some members. However, when Internet connectivity is one of the main services offered there are non-negligible common costs that need to be taken into consideration. In this case, there are different approaches.

On the one hand, there is the "free Internet for all" approach of highly decentralised systems like Freifunk.net and WLANSlovenja, which depend mostly on voluntary contributions of their members to offer Internet connectivity to all that have access to the network, without exceptions. On the other hand, there are more structured approaches like the French FFDN, which operates as a network of "ethical" ISPs, offering good quality and non-discriminatory connectivity, at lower prices compared to commercial ISPs.

Between these two instances, there are various alternative options in terms of ownership, management and contribution of the common resources, including Internet connectivity. Guifi.net has developed a unique model, in which the network infrastructure is treated as a separate commons from the services on top of it, and Internet access is just one of them. A *compensation* scheme is being implemented to create an economic balance between consumption and contribution of connectivity that works for both voluntary and commercial services (Baig *et al*., 2016).

The result is a diverse offer of fee-based and free-of-charge Internet connectivity provided by volunteer or professional ISPs reachable through guifi.net. The same model applies to any other service. For instance telephony (via Voice over IP) is offered as free or fee-based by diverse voluntary or professional providers.

Among other governance instruments (Crabu *et al*., 2017), the guifi.net licence (Network Commons Licence[217]) establishes the participation framework. It sets the freedoms and boundaries of the commons (Baig, 2015).

217 The FONN licence can be accessed at <http://guifi.net/en/FONNC>.

Any guifi.net participant must subscribe to the community licence. The licence preamble has four freedoms, comparable to libre software licences:

1. You have the freedom to use the network for any purpose as long as you do not harm the operation of the network itself, the rights of other users, or the principles of neutrality that allow contents and services to flow without deliberate interference.
2. You have the right to understand the network and its components, and to share knowledge of its mechanisms and principles.
3. You have the right to offer services and content to the network on your own terms.
4. You have the right to join the network, and the obligation to extend this set of rights to anyone according to these same terms.

Importantly, the guifi.net licence is written to be enforceable under the Spanish legislation. Legal certainty is essential to stimulate participation and investment that, in turn, is at the base of any economic activity. The licence has been developed as part of a long-lasting participatory deliberation process over several years, with contributions from many community members, reaching a consensus, revised and approved in several versions by the Foundation's Board.

9.3.3.2 CCs

In addition to the basic accounting functionality that is inherent in every currency, sustainable CCs need to take measures against failures. In many systems, members that fail to pay back their negative credit could be difficult to handle because the legal situation is often based on weak membership agreements. On the contrary, members that have too much positive credit and do not spend it, and therefore block the flow, might become serious obstacles. Another important point is the guard of the boundaries as mentioned later. For instance, in a non-convertible currency like WIR it is forbidden to exchange WIR-francs into Swiss francs but still some businesses do that and, in such circumstances, the management has to take measures to punish rule breakers (*in extremis* by exclusion).

An important decision-making process to this end, and especially when there is no exchange between the local and the national currency, is the "credit lines" offered to different members of a community currency. This is a very complex risk assessment process that requires intuition and good knowledge of the community on behalf of the currency managers and a high-level of trust by the community toward the management.

In Sardex.net, credit lines are a fraction of turnover (about 2% on average). Any (*multilateral*) debt created by the company must be recovered within one year by selling back to the circuit its 'spare capacity' in terms of products and services, which represent the 'backing' of the currency. Since the backing (about 10% of turnover) is much larger than the credit lines, the financial model is the opposite of a speculation bubble and very stable. In addition, Sardex is very active in helping to avoid irrecoverable debt situations through a very effective brokering and sales service,[218] which strives to maintain a healthy local economy for instance with sector-specific interventions if a weak link in a supply chain is detected, while at all times seeking to extend the circuit to all product and service sectors.

9.3.4 Boundaries and complementarity

9.3.4.1 CNs

The fundamental principles of open and non-discriminatory access, and open participation, in the life of a CN are integrated with instruments such as the community licence, the management tools, and the specific collaboration agreements with professionals and third parties. These instruments prevent exclusion and regulate open and fair usage of the resource, clearly defining the boundaries, the 'bundle of rights' (Schlager, 2015).

When discussing the design and deployment of local services offered by a community network, a very challenging question arises: What does local actually mean? What are the borders inside which a local service is made available? Moreover, how are they related to the complementary Internet services?

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218 The sales persons are called "Community Trade Advisors" or CTAs. They are not employees and receive a commission on successful onboarding instances. The Brokers provide a post-sale customer service, they are employees, and do not receive a commission on successful brokering events.

Today, most CNs advocate for the development and hosting of local services inside the CN. That provides very cost-effective service hosting facilities (community data centres) allowing dual-sided services that can be reached from inside the CN (an intranet) or from the Internet (using a single or double local and global IP address).

In guifi.net cheaper and safer local connectivity is used for local traffic (e.g. IoT applications, local videoconferencing), whereas Internet services are reached through global Internet connectivity as each participant can be attached to both networks. The costs of both are defined and governed separately, one being the local network infrastructure commons, and the other being the Internet access commons. In each one, the overall costs are shared among all participants, again, as a commons.

9.3.4.2 CCs

Perhaps the most important decision while designing a complementary currency is whether and how local currency can be exchanged to the predominant national currency. In other words, how the boundaries of the currency are defined and managed. Schroeder (2016) recognised this feature as crucial and links the extent to which a new currency is competing or complementing national currency to the long-term success of that currency in being socially just. Blanc distinguishes four dimensions – commensurability, convertibility, co-use, and coincidence – to determine the relation between different currencies (Blanc, 2009:6). Currency design and rule setting can determine these features and the resulting boundaries, but these will be also influenced by the actual use of the currency.

For example, allowing the seamless exchange of a CC to the national one facilitates the participation of people since there is no fear for lost income in case the local currency is abandoned. However, this can reduce significantly the impact of the currency in the local economy and the overall economic behaviour that it promotes since it does not pose strong incentives to avoid economic exchanges with external actors (Sartori and Dini, 2016; Motta *et al.*, 2017). In other words, because the CC is only valid for a small spectrum of purposes compared to the national currency it is much more likely to exchange CC into national instead of national into CC.

This leads to a very limited or decreasing liquidity, making the CC even more unattractive. For this, many schemes implement a “penalty” for such an exchange while others do not allow it at all. The compliance with the national tax regulations is also a very crucial aspect since it is necessary for a community currency to adapt to the existing legal framework especially if it wishes to extend its reach to traditional markets and increase its scale.

In Sardex, transactions below 1000 EUR are paid in Sardex, while transaction above 1000 EUR can be partly paid in EUR. Most importantly, for every transaction VAT is paid on the whole amount in EUR. As we discuss in more detail in the following section, although this feature might be considered a “weakness” of Sardex, it is actually one of the reasons that allows Sardex to grow at a significant scale and make feasible an alternative interest-free economy here and now.

9.3.5 Growth model

9.3.5.1 CNs

There are different ways to approach the concept of “growth”. A first one may entail a specific network under a certain administration, growing bigger and bigger, scaling up with more and more nodes connected, as it includes more users (higher density) in the same area, or more space (wider coverage). A second one may focus on a specific set of technology, rules, and branding, in other words a certain “model” being replicated in different places, as part of a single federation (under a single governance) or as a new disjoint community.

When these two forms of growth are combined it is not always easy to identify the borders of a single “autonomous system”. However, we can always assess the growth of a certain network by considering two important characteristics: how easy it is for a new participant to join the network (for scaling up) and how easy it is to create a new network of the same type from scratch (for replication or federation). Note also that scaling is usually non-linear: *e.g.* in infrastructure mode, a supernode[219] (not trivial

219 The term supernode refers to a central node of the network.

to install) can allocate tens of end-user nodes (relatively easy to install); on the other hand, in the ad hoc mode mesh clouds at some point saturate, such that going beyond the point of saturation is not easy.

As community networks grow and become a significant or even a critical infrastructure for local or regional connectivity, they also serve more purposes, from experimentation to sustainable or even critical infrastructures. That brings specialization, professionalization, institutionalization, and therefore strong service expectations, and regulatory and governmental pressure.

9.3.5.2 CCs

The scaling or the number of users and transactions are of course also crucial for any currency to become stable and sustainable. Usually, this depends on the type of currency and its goals. A time bank can be very successful and stable with 200 active members, whereas a regional currency needs maybe around 200 businesses and 1000 users to be stable. These numbers stem from empirical evidence around many examples, both failed and successful (see Martignoni and Gmür, 2012), but there yet is little scientific research to produce more accurate numbers or a deeper understanding of the success factors.

In practice, the majority of CCs fail to scale more than a few hundred active members and therefore rarely manage to engage a wider part of the local economic actors. There are some exceptions, however, like the Swiss WIR with around 45,000 business members representing around 8% of all Swiss SMEs. For social purposes, a small number of participants might be sufficient to sustain a small-scale currency scheme. However, for the economic part, without a sufficient number of transactions, a currency becomes literally useless and therefore people will reject it or step out.

One possible way out of the too-small-to-succeed-trap is the nesting of small currencies in networks of inter-trade and interchange (Martignoni, 2015). One such successful example is the South African but worldwide operating Community Exchange System (CES), which allows and supports trade between different member currencies using conversion rates and an integrated clearing centre. “CES users can also trade with CES users of exchanges hosted on other servers, as well as with users of exchanges hosted on servers belonging to other trading systems altogether.”[220] The entire system has an actual total of 844 registered CCs operated on three main servers in South Africa and Australia.[221]

Another way to address the problem of scale is to build tools and knowledge for supporting the creation of new systems. Growing to a sustainable size and replicating a success to other regions is, for example, the strategy followed successfully by Sardex.net (Littera *et al*., 2017). Then interconnecting the different regions running compatible currency systems would depend on the specificities of the environment and the potential balance between the different economic activities in the different regions. Another factor for scaling is the work of the brokers, already described above.

9.3.6 Computer-support tools

9.3.6.1 CNs

There are different types of shared tools required to operate a CN. It goes from shared knowledge (catalogues, documentation, best practices), shared artefacts (hardware developments like Mesh Potato[222], software distributions like OpenWRT[223], routing protocols like BMX6[224], coordination services like node databases) that can be used to develop and implement specific community procedures. More specifically, communities have knowledge repositories for sharing useful information and experience across a given community. This shared knowledge promotes collective efficiencies, saving time for participants and reducing the complexity of the collective effort (e.g. what hardware, software, installations are known to work well, best practices).

Second, certain routing solutions require the replacement of the proprietary software of routers (also called “flashing”) with

220 According to <https://www.community-exchange.org>.

221 Idem.

222 See <https://villagetelco.org/mesh-potato/>.

223 See <https://openwrt.org/>.

224 See <https://bmx6.net/projects/bmx6>.

free, libre, and open source (FLOSS) software, which among other benefits offers advanced security solutions, maintained by an ideally global community and tailored by local teams. This may also provide the means to keep operational devices that are no longer supported by their manufacturers with positive economic and ecological impact. And most importantly it protects consumers from lock-in and non-transparent policies by big corporations: for instance, the qmp.cat firmware in mesh areas of guifi.net, or the Freifunk Firmware.

There are also different management tools being developed by the involved communities. Examples are node databases, monitoring systems, address allocation services, crowdfunding tools, and decision-support systems. These allow the implementation of specific community procedures in a cost-effective manner that facilitates the governance of the community and the quick resolution of conflicts, without imposing additional burden on specific participants.

Finally, there is a wide variety of FLOSS software applications that can be easily hosted on one's own server and which could be in principle used for providing local services and a more "intimate" digital space for the members of a CN, but also people, not necessarily members, that have access to the network through access points in public spaces. Until recently, there were not many such easily customizable applications having a level of quality and usability comparable with commercial products, with only few exceptions, such as Wordpress[225]. Today more and more applications reach a state of maturity, like Etherpad[226], NextCloud[227], Limesurvey[228], and more. Containerised services like Docker[229], or application servers like Cloudy[230], make it also easier to "self-host" them.

225 See <https://wordpress.com/>.

226 See <http://etherpad.org>.

227 See <https://nextcloud.com/>.

228 See <https://limesurvey.org/>.

229 See <https://www.docker.com/>.

230 See <https://cloudy.community/>.

9.3.6.2 CCs

To operate a CC, in most cases a special software is used. There are many proprietary solutions but also some open source developments, which have proven to be successful. Two main products are *Cyclos*, a universal solution developed by the STRO foundation[231] in the Netherlands which in the meantime has developed also a "closed" source banking system-branch with the option of a "social licence" for non-profit organizations and small scale projects. Another solution, *Hamlet*[232], is developed by Community Forge Association Geneva, and is mostly used by time banks and LETS. The above-mentioned CES does have a proprietary software framework closely related to the Community Forge solution[233].

In recent times, more and more initiatives are considering building CC based on blockchain technology. There is even a specially designed social digital currency Freecoin developed by the EU Horizon2020 CAPS-Project D-CENT (Decentralized Citizens ENgagement Technologies) which provides a solution for operating distributed CC (D-CENT, 2015). This is a necessary step because the standard crypto currencies like Bitcoin do not support community building. Instead, they are designed to replace the critical trust-building process through social and other interactions with cryptographic algorithms and machine-intelligence.

Sardex's operation is based on the Cyclos software, which was actually improved through the experience with Sardex, which today explores in parallel innovative blockchain technologies as well (INTERLACE, 2017).

9.3.7 Summary

The following table provides a brief high-level mapping of key characteristics of community networks and community currencies as collaborative "commoning" activities:

231 See <https://www.cyclos.org>.

232 See <http://communityforge.net/en/our-solutions>.

233 See <http://communityforge.net/>.

Characteristics	Community networks	Community currencies
The “commons” resource (characteristics, properties)	• Contributed resource: network routers, links, computers. • Extractable resource: connectivity and optional services (partially rivalrous).	• Contributed resource: available assets and services, market infrastructure. Extractable resource: the established “market” and network of trust, the currency itself as infrastructure for exchange.
Community building (bootstrapping, membership, vision)	• Membership: Any citizens and organisations in an area. • Bootstrapping: developing connectivity in an area. • Vision: infrastructure for connectivity and services for all.	• Membership: Any citizens and organisations in an area. • Bootstrapping: building a small but balanced economic circle between trusted entities. • Vision: Stable and resilient local economy for all, disincentives for accumulation.
Managing the commons (participation, accounting, rules, decision-making)	• Participation: accept licence, establish links to existing nodes. • Design variables: unit of account (bandwidth, throughput, delay), relative value of resources (hardware, maintenance, etc), voluntary and professional work. • Accounting: local compensation scheme (guifi.net). • Decision-making: consensus, conflict resolution.	• Participation: accept currency. • Design variables: credit limits, membership and transaction fees, transparency. • Accounting: centralized accounting system, currency notes, blockchain based solutions. • Decision-making: various mechanisms.

Characteristics	Community networks	Community currencies
Boundaries and complementarity (interactions with the global system)	• Service: local services vs. Internet access. • Membership: defined by community licence. • Compatibility: Compliance with telecom regulation (e.g., data retention).	• Service: local products and services. • Membership: acceptance of the currency, eligibility criteria (for mutual credit systems). Compatibility: Exchange with fiat currency, tax compliance.
Growth model (distributed vs. centralized architecture)	• Federation of small groups, peering, economic compensation, professionalization. • Replication of successful model. • Inclusion of different actors (SMEs, customers, public institutions, etc), professionalization.	• Nested structure of federated small groups, bound together by negotiated exchange rules and exchange rates. • Replication of successful model. • Inclusion of different actors (SMEs, customers, public institutions, etc), professionalization.
Computer-support tools (proprietary vs. free software)	• Building blocks to reduce complexity (planning nodes and links). • Participation (communication) and coordination tools (shared knowledge, node database, accounting).	• Accounting and Marketplace tools with integrated management abilities. • Communication and extraction of data for economic stirring processes.

In addition to this short summary of our comparison, note that a key concern in both CNs and CCs is that the more the system grows the more its internal workings become more layered and complex, and less visible. The main novelty of CNs compared to the commercial ISP services is that the nodes of the network belong to its users and they do not form a “black box” managed by external companies, in terms of technical functionality, economics and governance. When there is additional "professional" infrastructure required, e.g., an access network in public spaces or fibre cables, this is also owned by individuals and/or local institutions, *e.g.*, municipalities, non-profit organisations, etc.

Bitcoin, based on blockchain technology, is an example of an effort to do something similar in the domain of currencies at a global level. At the local level, CCs are typically centralised systems from a technological point of view, at least. That means that, traditionally, there is a single server storing all interactions, while with blockchain, the interactions are stored in many if not all nodes – indeed for this reason the technology is called distributed ledger. However, despite the centralisation or not of the ICT infrastructure, all the members of the network need to install their own "node" in the system. This node needs to be equipped with all required infrastructure to exchange goods using a local currency (special receipts, card readers, hardware wallets, etc) and advertise this information (*e.g.*, through the use of the "we accept local currency" sticker on the store window).

Trust plays also a critical role in both domains of local action. Indeed, trust is one of the most important investments required to build the "nodes" of a local currency. First, all members of a community currency network need to fully trust those that run the underlying accounting infrastructure and/or the printing process. In addition to safeguarding the integrity of the accounting information, the management team needs to take complex decisions in relation to credit lines, and other thresholds required to guarantee a balanced economy. However, most importantly, everyone needs to trust the currency itself and its future survival. For this, the exchangeability with fiat currency plays a key role.

When a local currency is not exchangeable with fiat currency, the failure of the system is translated to loss of income. However, allowing for such exchanges reduces significantly the impact of the community currency in the local economy. Moreover, the threat of failure of fiat currencies, which recently became more likely due to the unsolved monetary problems and the big amounts of currencies distributed by quantitative easing of central banks, might reveal the important role of non-exchangeable CCs as an insurance, and therefore the increase of trust.

In CNs, trust plays also a very important role. First, there is the issue of integrity of the infrastructure, which has a direct impact in terms of net neutrality and privacy. Second, there is the long-term perspective and the expectations of the future sustainability of the network. However, one of the most important aspects of both CNs and CCs is their commonly-shared character, and how the more the system grows the more it becomes possible for all actors to benefit from the success of the network, triggering positive network effects. For this, trust is critical for the system to reach the required critical mass to have the envisaged impact.

9.4 Complementary networks meet complementary currencies

Both CNs and CCs are known with different names, sometimes with common adjectives such as “community”, “alternative” or “local”, and sometimes with more specialised terms like “mesh”, “ad-hoc” or “wireless” for the case of networks and “regional”, “sectoral” or “transition” for the case of currencies.

The term “complementary” is a term that is used widely in the case of CCs, pointing to a very important active mechanism of initiatives that allows them to operate “in parallel”, both dependent and independent from the mainstream economy, as discussed above. Such currencies complement the predominant national currency and are able to compensate some of its disadvantages and weaknesses for a better functioning of the local economy. Similarly, community networks are complementary to other forms of development or governance of networking infrastructures, that may produce effective connectivity in dense and wealthy areas, but do not work in less developed and challenged areas.

Complementary models based on inclusive cooperative models that rely on local investment could provide alternatives to exclusive competitive models based on extracting profit. Therefore, we wish to motivate the readers to think about such networks more as “complementary” to the Internet rather than either, on the one extreme, as alternatives, or on the other extreme, as simple gateways to the Internet.

So, what could today's CNs learn from the Sardex.net experience and other complementary currencies? What would a "complementary network" look like?

Perhaps the most important lesson to be learned by systems like Sardex.net is the combination of compatibility with the "system" (*i.e.,* paying taxes and allowing mixed purchases) while at the same time being radical in the design of the "local" currency which operates completely isolated from the national currency (no exchange possible). It is exactly this compatibility with the global system that allows for significant innovation and radical approaches for core elements of local infrastructures, like for example the development of appropriate local applications, identity management, etc. at a significant scale.

The other important lesson from Sardex.net is that a local solution for a critical part of our everyday life (economic activities and communication) should not be constrained to its core functionality (*e.g.,* running the CC) but engage in additional educational, cultural, and social activities. For example, Sardex.net collaborates with an online TV channel, ejatv.com, organizes various social and educational events, including the Mitzas annual conference bringing together experts around the world with local stakeholders and citizens.

This is important both because such a grassroots institution with a good reputation can engage more people in such activities and, on the other hand, the social interactions and knowledge shared during such events are extremely effective at building trust and transforming people from passive consumers and producers to active citizens and open-minded members of a vibrant local economy. However, all this additional activity requires a lot of time, in addition to the highly demanding management of a complementary currency. This is perhaps the main reason why guifi.net has experimented but not fully developed yet similar activities, until now.

However, guifi.net has also an important lesson to offer as complementarity is concerned. Although not used often as an explicit term, guifi.net advocates in favour of the complementarity of a network infrastructure as a whole, built as a commons, coexisting with other solutions. As Roger Baig stressed in his presentation at a recent workshop in Barcelona[234], guifi.net wants "to be treated exactly as the other players in the market, not favourably." In other words, guifi.net offers an alternative that is complementary to the standard *de facto* way of doing networks, *i.e.* the traditional telcos.

It does not position itself against them, but claims that the commons-based model is fairer in terms of social justice, and economically more efficient. Moreover, the separation of the network infrastructure from the provided services on it is exactly an enabler of complementarity, in a sense a form of "vertical" complementarity, and this is an interesting aspect to be considered also in the case of currencies.

For example, vertical complementarity in the case of currencies would help distinguish the two layers of accounting and of social value and understand them better. That would especially help currency designers and managers take more accurate measures to tackle malfunctions. For instance, today one malfunction of the fiat currencies is their systemic support for growing inequality. In a "vertically" complementary CC, it will be easier to differentiate between its members that become "rich" through their increased contribution toward other members of the system, and those that become "rich" by speculating and exploiting systemic failures, or by the manipulation of rules. Diversity and complementarity of models, therefore, are two ways to contribute to sustainable and stable systems.

9.5 Opportunities for integration

After analysing the similarities and differences between CNs and CCs, a natural question arises: could they be combined to enhance each other's operation and sustainability?

Would a CC help the management of resources shared in a CN and, therefore, empower economic sustainability? At a first glance, the two models seem to be able to complement each other very

234 See <https://netcommons.eu/?q=content/workshop-community-networking-infrastructures-barcelona>.

well. The network is somehow difficult to develop beyond its role as a carrier and connector. By using a CC, the value side and therefore more "meaning" to use and maintain the network could be developed. The currency on the other hand could gain from the pure technical and logical structure of a network to assure its accounting side but also provide a more attractive medium of communication for the local "market".

A CN could be itself the driver for a wider local economy, in which Internet connectivity could become one of the goods exchanged. For example, imagine guifi.net becoming member of one of the under-development CCs in Catalonia, the Mercado Ecosol[235], which is part of a wider network of cooperatives, XES[236], of which guifi.net could also become part. Then also members of guifi.net could be involved, maybe by a subset of the currency which would also fit in the special needs of these members.

If cleverly adopted, this collaboration could boost both sides. However, during such an integration one should be careful not to threaten one of the success factors of guifi.net: the clear distinction between network and content, and the clear focus on the network, leaving the participants to organise and populate it with the content they want. Currently, there are also more opportunities in the Barcelona region, because the municipal government plans to support social and solidarity economy with a new plan for the period of 2016-2019. In this plan, a so-called social currency has been introduced in a first pilot since 2017[237]. This might open a window of opportunity to a new kind of combination between CNs and CCs.

An interesting practical development along these lines would be to attempt the creation of a small-scale CN in Sardinia (like in Catalonia there are many underserved rural areas) and explore the feasibility of its participation in the existing Sardex mutual credit network.

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235 See <https://www.economiasolidaria.org/xes-catalunya/noticias/nace-el-ecosol-una-moneda-que-garantiza-un-consumo-responsable>.

236 XES - Xarxa d'Economia Solidària de Catalunya see <https://www.economiasolidaria.org/xes-xarxa-deconomia-solidaria-de-catalunya>.

237 See <http://www.euronews.com/2016/11/16/barcelona-set-to-introduce-local-currency>.

9.6 Conclusions

This chapter has attempted a somewhat stretched analogy between CNs and CCs, which is still an ongoing learning process for all parties. The main reason that motivated us to engage in such an intellectual experiment is that CNs and CCs are systems not well understood: neither by outsiders, nor by insiders. Even people active in these domains do not always see how guifi.net or Sardex.net are different from similar initiatives. In addition to a mere analogy for educational purposes, bringing closer together experts on CNs with those on CCs is also a first step toward interesting potential integrations between the two models.

However, the introduction of a complicated and not well-understood mechanism as a CC, or a CN, in an equally complicated domain of collective action, is subject to a number of challenges that need to be carefully addressed for the suggested integration to be successful.

First, the *duality between the global and the local*, between Internet access and local services, between the global and the local economy. For example, the fact that most people see CNs as ways to get affordable Internet access makes it difficult to promote the role of these networks as "catalysts" in a local economy, because the Internet resembles a commodity service and, if Internet access is the only service offered by a CN, it is difficult to imagine balanced loops, cycles in graph theory, for resource exchanges.

Second, the need of *quantification of voluntary activities.* The quantification of labour, that until now was meant to be voluntary, is one of the most common negative feedback from people introduced to CCs, like in the case of the district currency simulation game (Martignoni, 2017; Antoniadis *et al.*, 2017). Such reactions exist also in the case of CNs and guifi.net makes a lot of effort to keep a balance between the professionals and volunteers that are part of the network.

Third, the huge success of Bitcoin and the *hype behind the blockchain* has attracted the interest of hackers and technical people on the idea of an alternative currency. However, the accounting infrastructure is only a small part of an alternative economy and, for example, it is not concerned with the ways one can fulfil the requirement for balanced "cycles" as discussed above. Nonetheless, technologies like blockchain have a considerable potential and generate enthusiasm.

Despite the challenges, we believe that it is worth exploring further these models individually and in collaboration since every person has the right to participate in society and both infrastructures are enabling components for participation, interaction and coordination. Legacy models have proven their limits and the models explored in this paper are clearly complementary. Diversity and complementarity of models should therefore be explored as a way to contribute to expanding these universal rights.

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10 What Could Blockchain do for Community Networks

Panayotis Antoniadis and *Jens Martignoni*

Abstract

An increasing number of blockchain-based initiatives claim a revolutionary role as technological solutions that will facilitate the sharing and management of resources in Community Networks and Internet access sharing in general. Many of them focus on the accounting, measuring and then monetising of data-streams as an idea to enforce individual contribution to infrastructure, maintenance and service. This Chapter builds on previous work establishing an analogy between Community Networks (CN's) and Community Currencies (CC's), highlighting the variety of possible models that exist in both domains. We advance this work by exploring two different ways through which an alternative currency model can support an existing Community Network. Although blockchain could be the underlying implementation solution for any alternative currency, we discuss separately recent blockchain solutions that are part of the global cryptocurrency ecosystem, since they entail certain important threats that need to be understood for Community Networks in order to truly benefit from this new technology and not get absorbed by it.

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10.1 Introduction

There is a long tradition of designing alternative to the mainstream fiat money currencies around the world. Such Community Currencies (CCs), like Community Networks (CNs), are very different from each other, also because they aim to serve likewise different local communities and needs. Although most CCs are born in times of economic crisis (much as most CNs were born to address Internet connectivity problems), their benefits extend beyond the satisfaction of direct needs. They raise awareness about the nature of money and they contribute to the engagement and emancipation of communities. Hence, in many cases, CCs have evolved to something more than "emergency" solutions. Success stories like the WIR (Stodder, 2009) and Sardex.net (Littera *et al.*, 2016) provide evidence that they can play a long-term complementary role to the global economy. The same holds for CNs, with the successful examples of guifi.net, B4RN, and Freifunk.net expressing both the diversity and potential longevity of CNs (see Navarro *et al.*, 2016).

The deep understanding of the past and present of CCs is even more important today since numerous new initiatives have recently appeared proposing the use of cryptocurrencies for the realization of almost every conceivable distributed system, including various forms of Internet access sharing and user-centric networking[238], which is main focus of this work.

Most significantly, all these cryptocurrency-based schemes are still under development and a deep understanding of CCs can be very helpful both for *their* developers and *their* potential members. It is very important to imagine these blockchain technologies as enablers of a wide variety of economic models and systems, besides and beyond the management of tokens, and not as part of the overall speculation-driven hype of easy fortunes and techno-solutionism (Morozov, 2013). This is so especially if the goal is to

238 The following are four different documents released all toward the end of 2017: <http://ammbr.com/docs/20171121/Ammbr_Whitepaper_v2.3_21Nov2017.pdf>, <https://www.coindesk.com/plan-b-ethereum-innovators-reviving-fight-net-neutrality/>, <https://iungo.network/docs/iungo-network-whitepaper.pdf>, <https://www.forbes.com/sites/forbestechcouncil/2017/12/20/improving-global-digital-inclusion-with-tokenized-mesh-networks/>.

use blockchain to provide alternatives that lie closer to the values of "commoning"[239] and serve the multiple dimensions of CNs' sustainability.

More specifically, a currency designer for CNs needs to understand in depth a) the economy around a CN as a flow of goods and services that should be ideally balanced between participants, forming what is called *exchange circles;* and b) the relationships of such exchange circles with the "global" system.

The key characteristic of CCs, unlike national (or fiat) currencies, is that they lead to "balanced economies"[240] that discourage accumulation and ever-growing debts. The price of this characteristic, however, is that their very survival depends on the sustainability of exactly this balance which does not evolve "naturally" and thus requires constant effort to maintain (New Economics Foundation, 2015:117-136). The difficulty of the task increases significantly because of legal, social, educational, even technical (*i.e.*, the complexity of running a parallel accounting infrastructure) barriers.

We summarise below a few important reasons why members of CNs should care to understand the basics of CCs (besides the "liberating" role of blockchain technologies) and consider collaborating with other actors in their localities for building more holistic ecosystems:

- CCs face various challenges (social, economic, political, legal) that are very similar[241] to those faced by CNs and there are many lessons to be learned from their past and recent experiences but also many possible synergies to be developed.
- The cryptocurrencies hype and especially their potential use in the context of CNs brings CCs (and the corresponding theory, history, and existing tools) into the centre of attention. Hence, it is crucial that a better understanding of monetary theory and currency design is shared among those that will try to implement economic mechanisms using the new technology.

239 See <http://wiki.p2pfoundation.net/Commoning>.

240 See for example Amato & Fantacci (2012).

241 See chapter 9 of this book.

- The core design elements of any CC is the collection of resources and services that the community can provide internally (and which should be balanced), which is a necessary exercise for the design of any economic sustainability model, either including the use of a CC or not.
- CCs can mediate in the creation of links between different commons initiatives developed in urban or rural areas, in domains like housing, energy, food, and more, thus placing CNs in a wider ecosystem that can help to support their own objectives and communicate their existence and needs beyond the narrow circles that work in the CN area today.

Note also that CNs require an important amount of voluntary work and their success often depends on a variety of more or less important tasks for maintaining the common infrastructure. In such context, the introduction of an alternative currency is not straightforward, since voluntary work is often performed in a decentralised manner and without central coordination. Moreover, the common work is restricted to technical aspects, while the complementary skills that could benefit the growth and sustainability of a CN (like community engagement, communication, crowdfunding for the infrastructure, etc) often are not taken properly into account.

Finally, there is also limited understanding of the economic aspects of currency design in general. Currencies are not yet a thoroughly researched topic. Only over the last few years, since the emergence of the cryptocurrency, a greater amount of attention has been devoted to this field. But the central question "how the interdependence between a currency and socio-economic interaction could be described" is still not answered. The strong techno-driven excitement around blockchain makes the comprehension of the potential role of an alternative scheme even more difficult to communicate.

Blockchain is a Distributed Ledger Technology,[242] which allows the accurate and permanent recording of transactions, typically

242 See Antonopoulos (2014) and Hsieh (2018) for a comprehensive introduction to Blockchain and Scott (2016) for an insightful critical perspective, while Wüst & Gervais (2017) and Koens and Poll (2017) provide an analysis with introductory elements of the reasons why (or not) blockchain might be suitable for different case studies.

the transfer of “tokens” between peers, without the need for a central trusted entity. Simply put, this is achieved by the storing of all transactions over time in a way that guarantees their integrity, through cryptography, extensive replication, and in the case of Bitcoin, the so-called “proof of work”. Proof of work refers to very demanding computation tasks required to ensure the integrity of the blockchain, rewarded through the generation of new tokens (the so-called “mining”), which is increasingly more and more difficult: the generation of one token demands more and more computation as the size of the blockchain increases and the maximum total number of tokens is reached.

This means that the maintenance of a blockchain requires very high levels of energy consumption, which additionally to its disastrous ecoogical impact, leads to the gradual centralization of the system[243] and reinforces speculation tendencies.[244]

From a currency design perspective, blockchain offers a revolutionary way to account for transactions and to store the corresponding currency without the need of banks, but does not provide any particular innovation in terms of the management of currency in terms of addressing inflation/deflation, ensuring liquidity, and other important aspects of a healthy economy.

So, introducing a “new” (crypto)currency, without understanding the implications in the local ecosystem can have disastrous consequences. As an instance, one may consider, by analogy, the case of AirBnB, which was initially welcomed as a platform “facilitating” the sharing of accommodation, bringing to the mainstream the well-known until then Couchsurfing platform. After some years, it has been possible to understand that the platform business model entails also some negative externalities and has been considered by some observers as highly extractive and disrespectful to the local economy model.[245] Similarly, blockchain

243 The reason is that when the energy demands increase it is only large players can efficiently “mine” the cryptocurrency

244 The value of the token tend to increase as the cost of their mining increases, which results in huge profit margins for the “early adopters”

245 See, Donati and Klaus (2017), Segú (2017), and Wachsmuth (2018), among others. Also <http://fairbnb.ca/>.

cryptocurrencies can appear as benevolent "enablers" of digital transactions and connectivity, for example. But if linked to global speculative networks they can at the same time harm severely the local economy and the values of the CN ecosystem.

Such "magic" techno-solutions promising fortune and "removing the need to trust central authorities" (Scott, 2016) are very attractive alternatives to traditional CCs, whose design is rather complex and time consuming leading to an almost unique model for every different (successful) case study (Kennedy *et al*., 2012). The same rationale holds for CNs as well, until today (Navarro *et al*., 2016).

This chapter is a follow up of Chapter 9, "Complementary networks meet complementary currencies: guifi.net meets sardex.net", which establishes the analogy between the CN and CC models. After examining the characteristics of these models, it argues about the need to explore different combinations between them. This chapter makes a first step toward this direction discussing three speculative scenarios:

- A CN as a participant in a wider CC (joint solution)
- A CN creating its own local CC (internal solution)
- A CN technically implementing a specific blockchain solution (technical solution)

10.2 A community network as a participant in a wider community currency

A CN can be seen as a more or less distributed system that can produce and aggregate abundant and widespread connectivity at the local, regional scale. Through this role, a CN could participate in existing community currency schemes, and more specifically centralised mutual credit systems like WIR and Sardex.net, simply as a factory of Internet connectivity, where participants can join to either produce, share or consume that connectivity, and therefore organise differently than a typical Internet Service Provider (ISP). We could call this a joint solution.

The central currency type for this solution would be the so-called mutual credit systems such as Sardex.net (Littera *et al*., 2016) since they provide the most successful models using the mechanism of mutual credit. In WIR and Sardex.net, the value of the services is kept the same as in the real economy (so the rate is 1:1 between Sardex, for example, and the Euro) but no direct exchangeability is allowed between the local and the national currency. This has proven to be a successful model because it really helps to develop an extra market following a more cooperative behaviour.

Concerning the aspect of sustainability as mentioned in the case of CNs in WNDW (2013:369) "potential users could consist of a wide variety of individuals and organisations that include, but are not limited to: farmers' associations and cooperatives; women's groups; schools and universities; businesses and local entrepreneurs; health clinics and hospitals; religious groups; international and local non-governmental organisations (NGOs); local and national government agencies; radio stations; and organisations in the tourism industry."

All these entities mentioned as target "users" of a CN do match very nicely the target groups of a CC of this type. Therefore, both systems could attract together more preferred users and they could be easier convinced to become active members of a whole healthy ecosystem.

10.2.1 Services provided by the community network

To be a member of a wider CC, the CN as an organisation has to offer services (or goods) to "earn" that currency. What could this be? The business models of CNs[246] illustrate the value propositions of diverse CNs. The following list is generic and non-exhaustive, and the actual candidate services would depend on the individual CN's circumstances and organisation:

1. Internet connectivity (interconnection with external networks);
2. Local connectivity (regional connectivity, like an Internet exchange point);
3. Local infrastructure (links, computing, storage);
4. Local cloud computing services (PaaS or SaaS);

246 See Crabu et al. (2017) and Navarro et al. (2018).

5. IT-services (installation and maintenance of infrastructures, provision of services like VOIP, VOD);
6. Technical assistance Education and events.

In this scenario, all the above options must be provided by members of the network in the name of the network. For the wider system, especially the Internet connectivity could be a unique and valuable resource and it would be particularly interesting to be able to use the local currency for such a service, which in essence could play even the role of "backing" for the whole currency, since Internet access, both for accessing or serving content, is always needed and paid for.

10.2.2 Services consumed by the community networks

After earning the currency, the CN would have the ability to spend the money for its own needs but also for the needs of the membership, and surrounding community (the beneficiaries). The main things consumed can be found as costs already in a conventional CN.[247] Other services may be made possible only through the community currency, which could include:

- Cultural activities;
- Running of open spaces for training and dissemination;
- Maintenance of local services including data centre, moderation, etc;
- Training and education;
- Local food provision for meetings.

As mentioned already, one of the roles of CCs for supporting the sustainability of CNs could be exactly to encourage and, thus, reveal complementary needs for the proper functioning of a CN and its role in the society, beyond affordable connectivity.

10.2.3 Balance of the local economy

As closed loops of exchanges are very important drivers and a requirement for stability of a currency, a possible important loop for this first scenario could look as follows: CN would ask for a credit

247 See WNDW (2013:349); Crabu et al. (2017) and Navarro et al. (2018).

limit of 4000 units and would use 2000 to buy the yearly electric energy from a solar-energy supplier A. This company would rent a roof at a hotel B for 2000 a year. The hotel B would ask the CN for the installation of their WLAN-network (at cost of 1000 units) and the yearly support of the network for another 1000 units. Hence, at the end of the first year, 2000 would be spent and 2000 came back in the balance of the CN. For the second year, another income should to be found for 1000. Additionally, the potential of the credit-limit of the CN is not yet exhausted.

Because the possibilities of spending or earning are fewer in the CC than in the national currency, special attention has to be put on finding good opportunities. Within Sardex.net, special "brokers" or "mediators" help the participating members find favourable opportunities and close economic circles or loops. In the guifi.net economic compensation system, there are also such circular mechanisms to account for contributions to the infrastructure commons (Baig *et al.* 2016).

10.2.4 Challenges

As a first challenge, it should be noted that there are only a few successful currency schemes in which a CN could become a "member." In addition to WIR and Sardex.net perhaps also RES, a currency in Belgium and Catalonia, not more than a handful of other systems worldwide would allow this possibility. But the CN community faces similar challenges and this challenge could be also seen as an opportunity for the two areas of local action to support each other.

Second, many CNs are not organized entities to be able to participate in a centralised mutual credit system like the WIR or Sardex.net. Such business currencies usually only take enterprises or legally constituted and credit-worthy organisations as members. In fact, the only practical solution for a CN to enter the WIR system, for instance, would be to apply as an established legal person (e.g. association) for membership. Many CNs do not fulfil today this requirement but there are examples of CNs that could play this role like some of the members of the FFDN, or other well established CNs (Navarro *et al.*, 2016).

Third, depending on the internal organisation of a CN, it might be more or less complicated to decide how the “profits” from Internet access service provision will be “shared” amongst the individual members of the CN. If only the association itself used the currency, it would be ideal. However, if also the members were offered the possibility to receive the currency, the organisation would be more difficult. A possible (in the sense of the utilisation of the CC) solution could be the following: The members of the CN could be registered as employees and get their individual account receiving a remuneration by the association in the CC. Of course, this interferes strongly with the issues of voluntary work and would be difficult to reconciliate with the social security and tax-systems. In some countries, very moderate compensations could be tax exempt or some special regulations for quasi-voluntary work exist, but in others this would turn the network fully into a professional enterprise.

10.3 A community network democratically managing its own local community currency

It is a key premise of this work that CNs could be much more than structures providing affordable Internet access and possible a variety of ICT-based services. In other words, a CN could also constitute an actual community of diverse individuals sharing knowledge and services both online and offline, which could be even a cooperative housing project like the ones experimenting with the idea of the District Currency (Martignoni, 2018). A possibility to consider combining the CN and CC models would therefore be the implementation of an internal CC in an existing CN or the integration of both CN and CC together in another community project like a Cooperative Housing project of appropriate scale.

To illustrate this approach, the District Currency (Martignoni, 2018) is a suitable candidate model because it is based on the commons, aims at organisations with the intention to boost their internal economy and helps surrounding districts to develop economically. As a CN is always bound locally to its physically deployed nodes and antennas, this solution fits also in this respect. In the CN guifi.net, the existing compensation scheme comes already very close to the scheme of a District Currency.

The District Currency brings the focus of a collective organisation on a wide variety of "commons" tasks that were either neglected or not properly and democratically managed inside the CN. More specifically, it aims to

1. Enlarge the community and stimulate contact and democratic processes between technical and non-technical people;
2. Remunerate the efforts of the highly engaged people, like members of the board;
3. Develop an internal drive by making internal investments easier;
4. And stabilise the activities in the community because the amount of currency in circulation can easily be adjusted towards the actual needs and efforts.

For the following discussion, it could be soon as an example of a local currency like LETS[248] but more generalised to include democratic decision processes for the collective management of the currency over time with a goal to enhance commons-based activities.

10.3.1 Services provided and consumed by the community network and its members

In this scenario, we consider the possibility to transform a CN into a local economy run with the help of a district currency[249]. The central tasks, in this case, are the ones needed for the commons, *e.g*. maintenance of the network, deployment of infrastructure and software, complementary services, etc. The guifi.net compensation scheme does already manage to balance contribution and consumption between the more professional members, companies and groups but still using the national currency to do the final clearing. This could easily be replaced by a calculation in a CC but would not really make sense on its own. The scheme would have to be integrated into a whole currency-concept, what *e.g.* the District Currency would provide.

Especially in this case, the services exchanged between the members should go beyond networking services or technical

248 LETS (Local Exchange and Trading System) founded in the 80s in Canada was one of the first approaches reinventing the mutual credit scheme after WW-II.

249 For other more traditional community currencies like LETS, similar arguments would hold.

issues and create more "loops and circles" outside the direct management and maintenance of the network, to achieve the needed balance of the economy.

Usually, CN members represent a group of technically oriented people but include also individuals skilled and talented in other fields. For the functioning of such an internal currency it is important to have enough complementary skills and needs and a minimum number of active members.

One important question would be how the cost of the main Internet access service (that is paid in the national currency) is covered. As long as the provider does not become a member of the CN, the national currencies have to be utilised for payments and therefore earned. However, by using the District Currency, the CN gets the ability of shifting costs strategically. It could resell Internet access to its members (maybe partly) against Qs (the name of the District Currency, as described in Martignoni, 2018), as far as it has the possibility to buy services formerly paid in national currency from its members, using Qs.

10.3.2 Implementation issues

A unique characteristic of guifi.net as a CN is the introduction of a concrete notion of a "commons" as an integral part of a compensation system. According to Ramon Roca[250], guifi.net places the members of the network in three categories based on their commitment to the support of the common infrastructure:

- Fully committed with the commons: 100% of business activity created and investments made will be under a commons ecosystem giving priority to the commons;
- Mixed commitment with the commons: Sometimes doing business with the commons, but also including others with proprietary infrastructures;
- Opportunist: Just using the Commons occasionally / for some interest or under request, while promoting business/investments, remain and believe always on a proprietary network.

250 In an interview included in COOK (2015).

In addition, volunteers should be compensated for their contributions to the commons. Some form of compensation could avoid the phenomenon of volunteers typically feeling less legally bound to the project and, therefore, disregarding accounting, paperwork, or procedures that may be very important for the administration of the CN. This phenomenon is, for instance visible, in guifi.net. Thus, the local community must understand that a methodology and some metrics are needed for recognising results and reputation and that there is no way to claim contributions made without accounting for them first. It is easy to see the common characteristics with this aspect of guifi.net with the commons-based currencies introduced above and more specifically the District Currency, which tries also to balance professional and voluntary contributions highlighting the importance of the commons and the need to devise specialised mechanisms to manage them efficiently.

Also Freifunk.net has a policy regarding voluntary work vis-a-vis the sustainability of the network. As stated by Juergen Neumann and Iris Rabener[251] of the Freifunk Network[252], the idea of making the contributed working hours more visible, maybe compare them or even remunerate them by a CC has been already discussed several times. But the idea was not followed up until now. Four reasons for that were identified:

- The volunteers are happy to learn and contribute and mostly do not have a feeling of lacking remuneration (as they are, indeed, volunteering) or urge for more transparency of others' contributions;
- The network of contributors is relatively small and therefore reasonably transparent, as most know each other;
- There were always enough volunteers in number and in skills, ready to help, until now;
- The volunteers can afford to donate their work, *i.e.* they are able to make their living out of their profession or have other income; as Juergen Neumann mentioned "one has to afford to contribute as a volunteer".

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251 Juergen Neumann, co-founder of Freifunk and Iris Rabener, member of the board of Förderverein Freie Netzwerke e. V., Berlin, Germany.

252 Interview by Jens Martignoni, 29.03.2017.

The difference between Freifunk and guifi.net lies in the use of the compensation system by guifi.net. In many areas both CNs are self-sustaining. In small settings such as small rural towns, there is no need to actively seek to compensate volunteers for their services: volunteers develop small and isolated networks in a locality and these networks are self-sustaining, since the contributions of the volunteers in economic or effort terms gets compensated and exceeded by the social benefits. In larger settings such as a city or a neighbourhood, there are cases of private of public partnerships and sponsorships (*e.g.* libraries, municipalities, universities, corporate social responsibility) to reduce the costs of larger and more costly infrastructures.

Guifi.net has gone one step forward to enable the development of SME companies that expand, operate and offer services connected to the infrastructure commons. To handle the sustainability of a much more expensive, widespread and capable infrastructure such as fibre-based regional interconnection, guifi.net has created the compensation tables to balance these costs.

Hence, interestingly, for the moment a CC seems not to be necessary to improve the sustainability in the Freifunk network while guifi.net is open to this possibility as an exploratory activity or in the form of a research question. Big local associations like Freifunk Rheinland[253] or Hamburg[254] might have another situation and different needs and could be interested in talking about such a tool.

We next try and provide a more detailed view of how the district currency model could be integrated in an existing CN.

10.3.3 Balance of the local economy

To describe a very basic economy using a CC let us assume an idealised CN with 200 members. It would start a fibre project and create a budget of 4000 units to remunerate the work (the material would have to be bought using national currency on the market). The project cost should be covered within one year and use a flat rate compensation scheme, so the membership fee would be X unit

253 See <https://www.freifunk-rheinland.net>.

254 See <https://hamburg.freifunk.net>.

of national currency plus 20 units of the District Currency that year. Twenty of the members would help in this project doing maybe survey engineering, digging trenches, deploying the fibre, or dealing with the electrical and engineering issues. It would be in total 400 hours of work, each hour paid with 10 units of the District Currency, so the average payment for the 20 working members is 200 units each. By this, each member could pay the membership (20 units) and have 180 units left to spend for their personal needs against services from other members, not helping directly in the project. If all the other 180 members would find a way to contribute something to members and get at least 20 units reward, everybody would be able to pay the membership fee and the loop would be closed (the economy would be balanced at the end of that period).

The current version of the guifi.net economic compensation system is designed as a periodic process of clearing or - parallel to the above example - as a circle of compensation for investments into maintenance or expansion of the network: "The economic compensation system has been developed and implemented to compensate for imbalances between investment in the commons infrastructure and network usage among the professionals. Expenditures are declared by the professionals and are periodically cleared according to the network usage. The calculations are performed by the guifi.net Foundation and are made available to the professionals. The Foundation centralises and manages the billing system (each professional only makes or receives a single payment)." (Baig *et al.,* 2015:155)

A non-periodic process was made at the CN B4RN, where the labour spent by members was turned into shares. "Clearly equipment and materials have to be purchased so there is no way of avoiding needing to raise the cash for these. However, the labour element can be contributed by the community in return for shares. From our viewpoint there is no difference between us receiving funding via shares purchased which we then spend to build the network and community members doing the work directly and taking the appropriate number of shares in return."[255]

255 See B4RN Business plan at p.22 <https://b4rn.org.uk/wp-content/uploads/2011/11/B4RN-Business-Plan-v5-2.pdf>.

If instead of a share, the members would have been paid with an internal currency, then later they could pay, for example, their net-use by this and the currency would be redeemed.

10.3.4 Challenges and next steps

The above account cannot possibly reflect the whole complexity of the District Currency model. In each case there are additional rules needed (according to the laws of the commons, Ostrom 1990, and the needs of the specific community) to define exceptions, rebalancing methods, fines or exclusion and so on. This would need a community culture friendly towards negotiation, discussion and willingness to accept the self-defined rules. In this perspective, it is important to emphasise that one of the objectives of the district currency is the activation of skills and talents of the community.

As stated in WNDW (2013:354): “A network is only as good as the people who work and operate it. The team you put in place can mean the difference between success and failure. That is why it is important to reflect on your team’s qualifications and skills, including those of staff and volunteers, in comparison to the competencies needed for a wireless project.”

The personal abilities of the team and of the people are not directly affected but of course the ability of understanding a second likewise complicated topic of economy and money at least basically pushes the level of skills. In case of an internal CC, the difficulties rise again to find at least some key people that are able to bridge the connection between network and IT based discussions with the currency and economy-based ones. This is for sure a critical point for the first networks that would try this innovation and combine CN and CC without having a running example somewhere else to get guidance and support.[256]

Notice also that most CNs are not legal entities and especially not cooperatives. The District Currency might be adapted also to a (legally) loose network, but the commitment of the users/

256 The District Currency simulation game (Martignoni, 2018) is an effort to educate people on the nature of money and the possible alternatives for currencies that help communities to build local economies that promote the commons.

members nevertheless has to be on a high level. If the CN is already a co-operative, like for example B4RN (Broadband for the Rural North) then an easier adaptation should be possible.

10.4 A CN implementing a blockchain solution

During the last two years, a very fast and disruptive process of new cryptocurrency creation has started and it appears that, on a weekly basis, another white paper goes online describing a new solution to an old problem, raising millions of EUR through the so-called Initial Coin Offerings, without any proper evaluation of the feasibility of the proposed solution.

The increasing hype around the use of blockchain and distributed ledgers for cryptocurrencies such as Bitcoin, Ethereum and numerous others has led to more ambitious efforts in this area, and only recently some specific solutions for networks are appearing also.

10.4.1 The case of Ammbr

Perhaps the most interesting approach for the CN ecosystem is Ammbr[257], whose vision is to build "the world's largest decentralised, community-distributed, telecommunications network based on blockchain technology". The fact that it is supported by two of the most important European CNs, guifi.net and ninux.org, and not supported by many others, will likely generate debates among CN researchers and activists and play a key role in the development of blockchain-based solutions for CNs.

Current information on the approach of Ammbr is based on a white paper.[258] The paper was released in the context of an Initial Coin Offering (ICO), which on the way was cancelled since enough investments were secured through other means and the offering was deemed redundant, and since then the company, as explained by its CEO Derick Smith, "decided to go dark on our development, primarily because of the tendency for plagiarism by startups keen on participating in the ICO feeding frenzy".[259]

257 See <https://www.ammbr.com/>.

258 See <http://ammbr.com/docs/20171121/Ammbr_Whitepaper_v2.3_21Nov2017.pdf>.

259 See <https://medium.com/@globalsecurepayments/finding-the-rhythm-38fd55aeb7e9>.

Even if inaccurate today, it is interesting to consider closely the above-mentioned public narrative, as it was presented initially,[260] since it represents a lot of the misunderstandings that CN members are exposed to by other similar initiatives. The main idea is straightforward. "Each Ammbr unit (or node) consists of a core router capable of communicating across a combination of WiFi, Bluetooth®, LoRaWAN™ etc. for broadband and IoT a first for consumer router devices. Additionally, each unit presents computation and storage resources facilitating edge computing applications. This turns a network of Ammbr nodes into a dedicated mesh of micro-datacenters at the edge of the network, as well as "last mile" connectivity."[261]

In other words, besides being a standard wireless router, an Ammbr node includes a blockchain module. This module is responsible for accounting for the exchange of service (typically Internet access) between the owner of the node and an external user and/or between nodes of a mesh network to which the Ammbr node is attached. This is intended as an "economic incentive that allows users to share their unused bandwidth for profit. Monetising the free exchange of bandwidth, via a secondary market, allows for free market forces to drive network growth where it is most needed."[262] This incentive is implemented as a blockchain-based currency using tokens or "coins" named AMMBR (upper-case).

The first key decision that the designers of the Ammbr system will have to face is, as stressed above, the exchangeability of the tokens accumulated by Internet access providers in the Ammbr network with other currencies. In the current version (v2.3) of the Whitepaper, it is stated that the Ammbr tokens will be "a micro payment medium of exchange among the network's participants" and "its value would be determined by market forces such as supply and demand."

The initial intention is to allow the exchange of Ammbr tokens with other cryptocurrencies[263]: "the exchange rate of AMMBR relative to other cryptographic assets will be the largest determining factor in

260 See the main document linked in Ammbr's home page <http://ammbr.com>.

261 See the Ammbr Whitepaper, at p.18.

262 See the Ammbr Whitepaper, at p.21.

263 Ammbr is an ERC-20 currency, and was recently listed in the coinsuper exchange, which was unsuccessful, since according to coinsuper a "total of 40.901389127132ETH was liquidated and withdrawn to a known Ethereum address." by a hacker.

the valuation of AMMBR." The main assumption behind this choice is that "as the Ammbr network grows and the volume of activity on the Ammbr network increases, the underlying value of the services on offer, i.e. Internet connectivity, will drive the value of AMMB*R."*

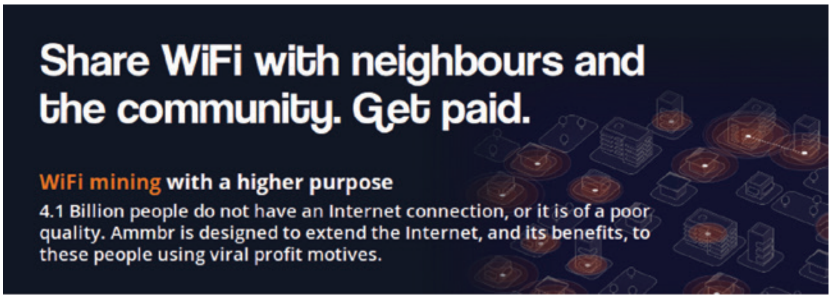

Figure 1: The overall approach is made clear also from the motto on Ammbr's web page: "*Share WiFi with the neighbours and the community.* **Get paid**. *[...] Ammbr is designed to extend the Internet, and its benefits, to these people using* **viral profit motives**." (emphasis added; accessed on October 9, 2018)

In essence, the AMMBR as proposed now, is a kind of voucher for connectivity. But the "economic model" as described in the White paper (p.41) is in fact a very narrow proposition of how AMMBR could be used, but far from any necessary model, which needs at least a probable currency circulation and overall description about systemic stability and balances. Maybe the inventors of AMMBR thought that AMMBR tokens would be used "naturally" for other transactions or start up as a new kind of general transaction currency or Bitcoin rival, but no measures for such a transformation seem to have been initially planned.

If no exchange was allowed between AMMBR and other cryptocurrencies (and thus to fiat money) the whole system would suffer severely from imbalances, since in that case the "exchange" would "fill" the nodes with best locations and "empty" all the other ones in less favourable places. This is a well-known result since the early days of WiFi sharing both in theory[264] and in practice (as the evolution of FON[265] from a "credit-based" P2P system to a commercial service for big telecom operators can illustrate).

264 See e.g., Antoniadis et al. (2003) and Efstathiou et al. (2006).

265 See <http://fon.com>.

By adding the possibility for exchange with fiat currency (through Ethereum for example[266]), the incentive to collect AMMBR and thus to provide services increases as well. Still, the inherent imbalance of an access network is not addressed and in the currently proposed case Ammbr may be considered just as a way to resell Internet access for real money, which actually could encounter legal limitations.

However, the above is just one possible outcome, depending on the business models adopted. One possibility is that participants in the Ammbr network will be treated as economic agents free to maximise their profit. However, this is by no means the only possibility. Indeed, blockchain technology could empower a community to share a single Internet connection and account for the level of consumption of each participant in a very accurate and trustworthy way, if this is what a community decides.[267] How these levels of consumptions will determine the individual contributions to the overall cost of the Internet access, and the corresponding mesh network would be then subject to a collective decision, and implemented as a smart contract. Even schemes like the District Currency could be implemented with the support of such technology.

But this would be possible only if the blockchain is independent from global cryptocurrencies like Ethereum **which have the potential to cannibalise the incentives for engagement in the Community Network activities and needs.** [268]

10.4.2 Other cryptocurrencies

There seems to be a "wave" of "mesh" crypto-currencies in addition to Ammbr[269]. For example, a similar to the initially planned by

266 Ethereum or its cryptocurrency Ether are widely used as a transfer between newly issued tokens or small cryptocurrencies and fiat or national currency due to the fact that Ether is worldwide known, available, accepted and has broad technical abilities but is less speculative and volatile than Bitcoin.

267 Freifunk.net has proven that in many cases people are willing to freely share their Internet connectivity as long as they can protect their own use, which is a form of sharing that does need any form of accounting and identification.

268 Browsing the Ammbr's Telegram group @ammbrICO, one can see very clearly that many of the participants are engaged more for the prospect of easy profits than for supporting an alternative way to provide connectivity.

269 See a recent analysis of different cryptocurrencies by Dean Bubley (AMMBR's advisor), which resonates with many of the points we make in this article <http://disruptivewireless.blogspot.ch/2018/01/update-telecom-network-cryptocurrencies.html>.

Ammbr ICO just took place for the IUNGO.network, a solution that states that: “ At iungo we believe that affordable internet access is a basic human right.“[270] This idea is economically very close to the Ammbr as it is fully based on exchange into “real” currencies and therefore could also be called a voucher system.

Another idea to use crypto-currencies stems from the fight for independence and net neutrality. In this sense, an idea of a “mesh-coin” using Ethereum as a technology was lately proposed in a tech meetup in New York reported on coindesk.[271]

One activist called Floersch described[272] an Ethereum-based system that runs “in the background” of any mobile device. Using an interconnected series of smart contracts, the mobile device could theoretically be turned into a Wi-Fi-enabled “node,” helping expand the mesh network’s reach. And all this could be incentivised with a blockchain-based “meshcoin.” “Ethereum and mesh networks are a fantastic combination,” Floersch said, adding: “Ethereum will allow for the kind of payment back-end which makes a mesh network scalable.”

On the other hand, in the same article software engineer Brian Hall (from the CN NYCMesh) is quoted stressing that there are “two things that all these projects fail to adequately understand: first, mesh nodes have to be in geographically close proximity to one another, unlike blockchain nodes, and second, growing these networks requires huge amounts of social capital to gain adopters.” [273] He added that “Ninety percent of the work is a social problem … and that’s kind of left out of all these meshcoin ideas.”

The RightMesh whitepaper[274], states that “Any device on the RightMesh network can buy and sell bandwidth from other users. Users reselling their data can name their price and, like

270 See <https://iungo.network/ and its Whitepaper <https://iungo.network/docs/iungo-network-whitepaper.pdf>.

271 See <https://www.coindesk.com/plan-b-ethereum-innovators-reviving-fight-net-neutrality/>.

272 See <https://www.coindesk.com/plan-b-ethereum-innovators-reviving-fight-net-neutrality/>.

273 See Idem.

274 See <https://www.newsbtc.com/press-releases/rightmesh-releases-white-paper-outlining-first-truly-decentralized-internet-sharing-network/>.

any marketplace, supply and demand will ultimately determine the rate." Such questions are surely very interesting and offer additional arguments for the use of complementary or in this way alternative currencies, but will be only successful, when also economic and social impacts to the stakeholders are considered and adapted to the currency design.

In other words, these developments make the knowledge on CCs more and more relevant if we do not want all those solutions to end up as high energy-consuming supporters of the current inflationary economy (as in the case of bitcoin), instead of commons-based alternatives. To this respect, there are three very challenging issues that one needs to keep in mind:

- The huge hype and the mixing in people's minds of the role of cryptocurrencies as "alternative economies" with the speculation and easy profit-making in the current economy;
- The energy costs that are important both for ecological purposes but also for the balance of the economy around cryptocurrencies since the resources needed to sustain the corresponding infrastructure have non-negligible costs;
- The high-cost of accounting in terms of privacy, since in blockchain all transactions are stored for ever and made public, and even if anonymous, strong identities can be linked to real identities through accidents, use of services by mediators, attacks, or controls by authorities..

In any case, the key decision for a "mesh currency" designer is whether to allow the currency to be exchanged (eventually) to fiat currency. Models like Sardex and district currency depend exactly on the non-exchangeability of the local currency, while maintaining "compatibility" with the global economy. Such a decision could lead to a more "social" and commons-based currency but then it should operate at a small-scale (and be replicated across different regions with the possibility for exchangeability between the different "local" currencies) and a fair way to recover the computational costs, among others, should be devised.

10.5 Conclusion: solving the right problem

One could argue that sharing of Internet access is more a political than an economic problem. If people are given the means to "protect" their own usage of their Internet connection, which is technically feasible, they are in principle happy to share it with others. This has been demonstrated by the widespread adoption of Freifunk.net, despite the legal obstacles that such a simple and natural act of sharing is facing today.

If cryptocurrencies will end up commercialising such sharing processes, transforming it into a renting process as AirBnB did for the "sharing" of accommodation, this may be seen as a failure of the social aim of the CN movement. Indeed, a likely scenario may be the appropriation of the CN narrative, supporting not-for-profit community driven networks, by global for-profit businesses, this time not based on a single mega-platform like AirBnB but on the worldwide cryptocurrency speculation market, possibly offering huge profits to the initial creators of the cryptocurrency that will eventually dominate in this market.

In this chapter we went back to the fundamentals of what we consider as the true alternative to the mainstream economy currencies, the so-called community currencies, and discussed ways to use such currency models, implemented with blockchain technology or not, to re-inforce the wider local economy as a commons for which democratic participation and active engagement is a strong requirement. Cryptocurrencies offer computational trust for very little human effort (but huge power consumption), solving only the easiest, and often unnecessary, part of the problem.

The most important problem for building network infrastructures as commons is the conceptualisation of the Internet as the object of a right to be claimed from the grassroots, with participation, democratic decision-making, and deliberation, and not "delivered" from the top-down as a ready-made product. In this context, the difference between community empowering tools and magic tech-solutions is thin, but clear, as it is the difference between food security and food sovereignty (Echániz, 2017).

Leandro Navarro, co-director of AmmbrTech Labs and a key figure in the CN community over the last decade, in a recent netCommons workshop at the European Parliament[275] made a similar analogy between eating at a restaurant and eating at home. He argued that CNs are offering a means for people to build their own connectivity "at home" instead of having to pay for it every day "at the restaurant".

Developing further this analogy, one should notice also that there are also many different ways to prepare food at home, ranging from buying a ready-made meal at the supermarket and warming it with microwaves, all the way to growing vegetables in one's own backyard with many intermediate options.

In this context, the work of Ivan Illich on "tools for conviviality" from 1973 is still relevant and inspiring today. With this conceptual framework in mind, the readers are encouraged to browse through the published documents of the Liberouter project,[276] and Ammbr,[277] and identify themselves elements of the two under development narratives which are more likely to lead or not to tools that promote local empowerment and conviviality. Which of the two approaches can become true enablers of "Network self-determination" (Belli, 2017) and a more "organic Internet", toward more net-diversity and community empowerment (Antoniadis, 2018)?

Despite being subject to speculation and misunderstandings, blockchain technologies can help toward this direction, but only if they allow for democratic decision-making of their design, independence from global financial markets, and appropriate education of their internal operations.

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275 See <https://www.youtube.com/watch?v=AMF3t0q-lYg>.

276 The project is described in chapter 4 and can be explored at <http://librerouter.org>.

277 See <http://ammbr.com>.

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11 Declaration on Community Connectivity

This Declaration was elaborated through a multistakeholder process, between July 2016 and March 2017. This participatory process was initiated and facilitated by the UN IGF Dynamic Coalition on Community Connectivity (DC3). Initial inputs and comments to this document have been provided through an online consultation, open to both DC3 members and non-members via the mailing list of the DC3, between July and November 2016.[278] Subsequently, an ample range of stakeholders gathered during the 2016 IGF meeting, in Guadalajara, to provide feedback and further discuss the text resulting from the consultation. Feedback provided on site and via the IGF website were consolidated into a further version of the Declaration that was subsequently shared on the DC3 mailing list – which is open to the participation of all interested individuals – for a further open consultation, between December 2016 and March 2017. The final comments were consolidated into this version, to which no DC3 member not any other subscriber to the DC3 mailing list has manifested opposition.[279] It should be noted that the Declaration is a living document and, as such, it may be updated by future versions, should this be the common view, emerging from the discussions facilitated by the DC3.

11.1 Preamble

Over four billion people may remain unconnected to the Internet, including approximately one billion who do not have access to basic telephony services. Most people in rural and economically disadvantaged areas are unlikely to realise the benefits of connectivity in the near term. Rural communities and slum dwellers represent almost 60% of the worldwide population and, to date, traditional Internet access models have failed to provide coverage to such populations.

To reverse these trends, it is necessary to create appropriate frameworks that allow communities and local entrepreneurs to solve

278 The version of the Declaration that was debated at the IGF 2016 can be accessed at <http://www.intgovforum.org/multilingual/index.php?q=filedepot_download/4189/174>.

279 See the DC3 open archives <http://listas.altermundi.net/pipermail/dc3/> as well as <http://www.intgovforum.org/multilingual/content/2016-dynamic-coalition-output-documents>.

their own connectivity challenges. Bottom-up strategies that embrace non-discriminatory treatment of data traffic and diversity in the first mile can empower individuals and communities, allowing them to play an active role as co-creators of local Internet and communication infrastructure. We acknowledge that communication technology does not have a neutral impact and can exacerbate unequal power relations in the community, and so community networks should strive to implement more inclusive and just alternatives.

11.2 Connectivity

Connectivity is the ability to reach all endpoints connected to the Internet without any form of restriction on the data-packets exchanged, enabling end-users to run any application, access and share any type of content and service via any device as long as this does not harm the rights of others. Connectivity is the goal of the Internet.

11.3 Community Networks

We embrace the potential of community networks as a vehicle for transformation that increases the agency of all community members, including by fostering gender-balance. Community networks are structured to be open, free, and to respect network neutrality. Such networks rely on the active participation of local communities in the design, development, deployment, and management of shared infrastructure as a common resource, owned by the community, and operated in a democratic fashion. Community networks can be operationalised, wholly or partly, through individuals and local stakeholders, NGO's, private sector entities, and/or public administrations. Community networks are recognised by:

a) Collective ownership: the network infrastructure is managed as a common resource by the community where it is deployed;

b) Social management: the network infrastructure is technically operated by the community;

c) Open design: the network implementation and management details are public and accessible to everyone;

d) Open participation: anyone is allowed to extend the network, as long as they abide by the principles and design of the network;

e) Promotion of peering and transit: community networks should, whenever possible, be open to settlement-free peering agreements;

f) Promotion of the consideration of security and privacy concerns while designing and operating the network;

g) Promotion of the development and circulation of local content in local languages, thus stimulating community interactions community development.

11.4 Community Network Participants

Community network members are considered active participants, and should be considered both producers and users of content, applications, and services. Notably, community network participants must:

a) Have the freedom to use the network for any purpose as long as they do not harm the operation of the network itself, overburden the network, the rights of other participants, or the principles of neutrality that allow content and services to flow without deliberate interference;

b) Have the right to know the technical details and operation of the network and its components, and to share knowledge of its mechanisms and principles;

c) Have the right to offer services and contents to the network, while establishing their own terms;

d) Have the right to join the network, and the obligation to extend this set of rights to anyone according to these same terms.

e) Promote full gender balance

11.5 Policy Affecting Connectivity and Community Networks

National as well as international policy should facilitate the development of community connectivity and the deployment of community networks. National and international policy should:

a) Take into account individuals' human rights to freedom of expression and privacy;

b) Lower barriers that may hinder individuals' and communities' capability to create connectivity, including gender barriers;

c) Allow the commons-based use of existing unlicensed spectrum bands or unused licensed spectrum for public-interest purposes, and consider the growth in use of unlicensed spectrum bands and the establishment of special licenses which address the needs of community connectivity;

d) Incentivise the development and adoption of technologies based on open standards, free software and open hardware to improve the replicability and resilience of community networks;

e) Allow for the deployment of technologies based on dynamic access of spectrum and other new technologies that do not necessarily have a full regulatory framework in place supporting them;

f) Promote the elaboration of appropriate frameworks and the utilisation of existing funds, such as universal service funds or other specific telecommunication development funds, towards advancing community connectivity.

The **Authors** of the analyses featured in this volume are (in alphabetical order): Panayotis Antoniadis, Virginie Aubrée, Roger Baig Viñas, Luca Belli, Aris Dadoukis, Paolo Dini, Mélanie Dulong de Rosnay, Nicolas Echániz, Kurtis Heimerl, Matthew Johnson, Pathirat Kosakanchit, Florencia López Pezé, Steven Mansour, Stavroula Maglavera, Jens Martignoni, John Mavridis, Sascha Meinrath, Leandro Navarro, Harris Niavis, Bruno Ramos, Ramon Roca i Tió, Spencer Sevilla, and Félix Tréguer.

This volume is jointly published by the Fundação Getulio Vargas (**FGV**), the International Telecommunication Union (**ITU**) and the Internet Society (**ISOC**). This volume is the result of the 2018 Call for Papers of the UN IGF Dynamic Coalition on Community Connectivity (**DC3**) and is the Official 2018 DC3 Outcome. DC3 is a multistakeholder group, fostering a cooperative analysis of **community networks**, exploring how such initiatives may be used to improve connectivity while empowering Internet users, triggering the creation of new content, applications, services and organisations, developed by the local community for the local community.

Community networks rely on the active participation of local communities in the design, development and management of network infrastructure as a common resource. These networks give rise to new infrastructures, new governance models and new business opportunities and facilitate the free flow of information and knowledge, filling the lacunae left by the traditional Internet access-provision paradigm.

This book is the third volume of a trilogy demonstrating the vitality, quality and interest of the contributions, projects and policy suggestions developed by DC3 members. It also proves that such vitality, quality and interest are not decreasing over time but, on the contrary, ideas and initiatives developed by DC3 members are increasing and cross-fertilising each other's, while some of the most relevant institutions in the world are recognising their importance, value and impact.

"Community networks represent a valuable alternative model that deserves to be explored to improve access to Information and Communication Technologies to underserved communities worldwide. ITU is committed to connecting the entire world's people and this book and the work of the UN IGF Dynamic Coalition on Community Connectivity offer inspiring and transparent guidance to foster digital inclusion."

Bruno Ramos,
Director for the Americas Regional Office of the International Telecommunication Union

"Community Networks offer a credible solution for building a digital future that puts people first. This volume is a testament to the excellent work of the IGF Dynamic Coalition on Community Connectivity. It is a long-awaited guide that will allow many to participate in the Internet's evolution, building an Internet for everyone.."

Andrew Sullivan
President and Chief Executive Officer of the Internet Society

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