guifi.net, a crowdsourced network infrastructure held in common

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Abstract

The expression "crowdsourced computer networks" refers to a network infrastructure built by citizens and organisations who pool their resources and coordinate their efforts to make these networks happen. "Community networks" are a subset of crowdsourced networks that are structured to be open, free, and neutral. In these communities the infrastructure is established by the participants and is managed as a common resource. Many crowdsourcing experiences have flourished in community networks. This paper discusses the case of guifi.net, a success case of a community network daily used by thousands of participants, focusing on its principles and the crowdsourcing processes and tools developed within the community, and the role they play in the ecosystem that is guifi.net; the current status of its implementation; its measurable local impact; and the lessons learned in more than a decade.

Key words: Community networks; crowdsourced networks; self-organized governance systems; self-provisioning; common pool resource; Do-It-Yourself

1. Introduction

Crowdsourced computer networks are built by citizens and organisations who pool their resources and coordinate their efforts to build network infrastructures. The coverage of underserved areas and the fight against the digital divide are the most frequent driving factors, but motivations such as contributing to development of a new telecommunications model or just for pleasure are also often mentioned by their contributors. Technologies employed vary significantly, ranging from very-low-cost, off-the-shelf wireless (WiFi) routers to expensive optical fibre (OF) equipment [1].

Models of participation, organisation, and funding are very diverse. For example, some networks are freely accessible, others are cooperative based, some are run by federations of microISPs, etc. A few examples follow[1]. Broadband for Rural North (B4RN) in Lancashire, UK, and Nepal Wireless Networking Project (NWNP) are networks built in response to the lack of coverage of the conventional operators. B4RN deploys and operates optical fibre in a cooperative way. NWNP [2] is a social enterprise that provides Internet access, electronic commerce, education, telemedicine, environmental. and agricultural services to a number of remote villages, using wireless technologies. The French Data Network Federation (FFDN) is a federation of French Do-it-Yourself ISPs which comprises DSL resellers, WISPs, collocation centres, and the like. HSLnet is one of the many cooperative fibre-optic networks in the Netherlands.

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[1] BARN: http://b4rn.org.uk/, NWNP: http://www.nepalwireless.net/, FFDN: http://www.ffdn.org/en, HSLnet: http://www.hslnet.nl/

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Community networks (CNs) is a subset of crowdsourced networks that is characterised for being open, free, and neutral. They are open because everyone has the right to know how they are built. They are free because the network access is driven by the non-discriminatory principle; thus they are universal. And 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 commercial purposes.

Representative examples[2] are Freifunk (FF) in Germany, the Athens Wireless Metropolitan Network (AWMN) in Attica, Greece, FunkFeuer (0xFF) in Austria, and Ninux.org in Italy, all of them with thousands of links, mostly wireless[3], but gradually integrating also optical fibre and optical wireless links.

Although CNs have already been studied from several angles [3] [4], there is still insufficient understanding of the practises and methodologies which have given rise to such complex collaborative systems. This paper tackles this lack by analysing guifi.net[4] [5] [6], the largest CN worldwide.

In 2004, guifi.net began as a group of people who met regularly for network planning and deployment. The group was seeking ways to create amateur networking infrastructures in remote rural areas, ignored or underserved by conventional ISPs, taking advantage of open spectrum, open software, and inexpensive WiFi devices. Along with the expansion of the network, the participants also discussed ways to structure the fast-growing community. Bringing a network to new locations requires coordination for planning the links, configuring the hardware, aligning antennas, etc. In addition, new tasks such as network design, routing coordination, and address allocation become increasingly critical as the network and the community grow. These tasks have resulted in many tools that have been developed specifically for guifi.net and are used by the guifi.net community.

In this paper we describe the fundamental principles of guifi.net, and how their application results in a collective good, the network infrastructure, that is built collectively from contributions from many participants, and governed as a common-pool resource (CPR).

We identify and analyse the most relevant of these tools and discuss their impact on the expansion of guifi.net. As a result of our investigations, we firmly believe that guifi.net has made very significant contributions, not only to the formalisation of the CN concept itself, but also to the development and application of effective social and technical tools to make CNs sustainable and scalable. These tools are in constant evolution to better put the commons model into practice.

The remainder of this paper is structured as follows. Section 2 presents the underlying guifi.net principles that structure the participation and usage of the network, and discusses how these translate into a social production process that results in a collective good that is governed collectively as a common-pool resource. Section 3 surveys the stakeholders and presents the architecture of the governing mechanisms. Section 4 introduces the tools and strategies developed to implement these principles, such as software tools to share information, communicating among groups, coordinating contributions, overseeing and regulating the community, stipulating collaboration agreements, resolving conflicts, and compensating for imbalances. Section 5 presents the results achieved in terms of the commons infrastructure, interconnection with other networks, the community of participants, the organisational framework, and the measurable impact in areas with strong infrastructure development. in Section 6 we analyse and discuss the results. Section 7 discusses the correspondence with academic models of CPR. Section 8 presents lessons learned that can be generalised. in Section 9 some recommendations for future work are made. Finally, conclusions are presented in Section 10.

Computer networks are hereinafter referred to as *networks* and network infrastructure as *infrastructure*.

2. Principles

The fundamental principles of guifi.net, defined at the start to be fully inclusive, revolve around i) the openness of access (usage) of the infrastructure, and ii) the openness of participation (construction, operation, governance) in the development of the infrastructure and its community.

[2]FF: `http://freifunk.net/`, AWMN: `http://www.awmn.net/`, 0xFF: `http://www.funkfeuer.at/`

[3]The term *wireless* was broadly used to refer to this type of community, with wireless community networks (WCNs) the most common name. Nevertheless, currently it is preferred to avoid the term for technology agnosticism.

[4]`http://guifi.net`

Non-discriminatory and open access. The access is non-discriminatory because the prices are determined using the cost-oriented methodology (vs. market-oriented) with the fair-trade principle for labour pricing. It is open because everybody has the right to join the infrastructure.

Open participation. Everybody has the right to join the community. According to roles and interests, four main groups can be identified: i) volunteers, interested in aspects such as neutrality, independence, creativity, innovation, DIY, and protection of consumers' rights; ii) professionals, interested in aspects such as demand, service supply, and stability of operation; iii) customers, interested in network access and service consumption; and iv) public administrations, interested in managing specific attributions and obligations to regulate the participation of society, usage of public space, and even in satisfying their own telecommunication needs. A balance among these four groups must be preserved, as every group has natural attributions that should not be delegated or undertaken by any other.

These fundamental principles applied to an infrastructure result in a network that is a *collective good*, *socially produced*, and governed as a *common-pool resource (CPR)*.

The network is a *collective good* or a peer property in which participants contribute their efforts and contribute goods (routers, links, and servers) that are shared to build a computer network, which combined by several Internet protocols results in a peer property, provided that the community rules, as a community license, are respected by all participants.

The development of a CN is a *social production* or a peer production because the participants work cooperatively, at local scale, to deploy an infrastructure to build network islands, and at global scale to share knowledge and coordinate actions to ensure the interoperability of the infrastructure deployed at local scale.

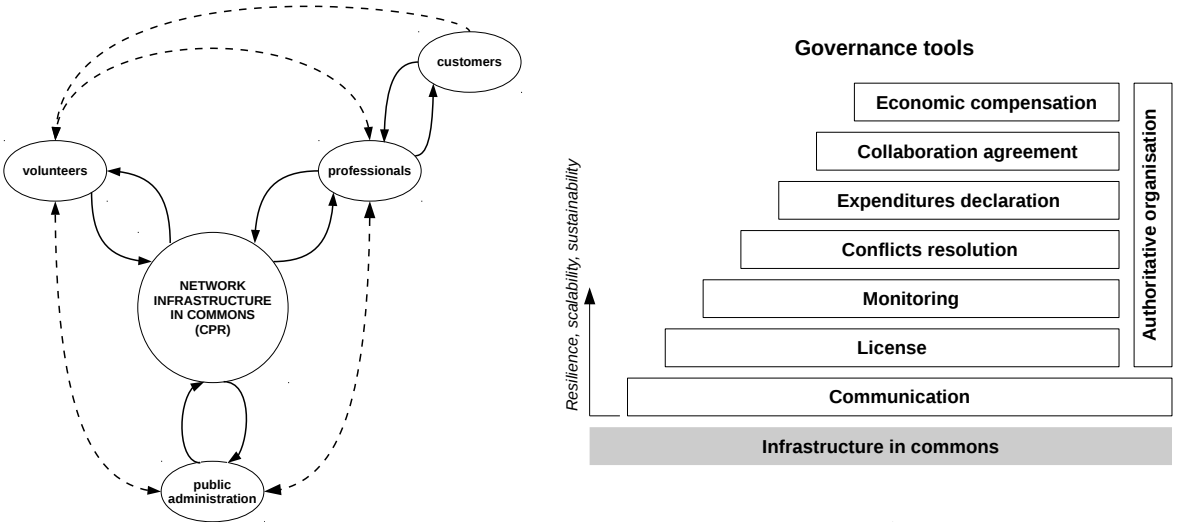
The *common-pool resource (CPR)* is the model chosen to hold and govern the network. The participants must accept the rules to join the network and must contribute the required infrastructure to do it, but they keep the ownership of hardware they have contributed and the right to withdraw.

Some of the expected benefits of the paradigm change resulting from these principles are:

- Disappearance of the multiplicity of infrastructure because all participants operate on the same infrastructure on a cooperative basis. The CPR defines the means to reduce the transaction cost of sharing, promoting this practice.
- Increase of the efficiency of the infrastructure, as a consequence of the previous point.
- Cost savings, including environmental savings, as a consequence of the first point. These cost savings result from aggregation and resource sharing. Additional capacity can be obtained at the marginal cost of the required capacity, due to sharing, lower than the cost of deployment of additional infrastructure. This cooperative model allows new, small, local entrants that can easily develop, given this reduction of the entry costs and initial investments, to bootstrap new infrastructure and new services.
- Cost-of-access savings, not only due to the first point, but also because pricing is cost-oriented (fair trade oriented). That has positive economic spillovers in favour of digital services and more opportunities for local economic development as a result of lower access and usage barriers for more population.
- Empowerment of the citizens to bring the network where needed, given the reduction in cost, complexity, risk, and required knowledge to expand the network, severing the dependency on ISPs' deployment plans.
- Universalisation of the access to the infrastructure, as a consequence of the two previous points.
- Creation of the required context for a true fair competition market of services.

3. Stakeholders and governance architecture

Nonetheless, as any other CPR, CNs are fragile. More precisely, they are congestion prone, because connectivity is subtractable, and subject to the free riding problem, because CNs are intentionally non-



(a) Stakeholders. (b) Governance architecture.

Figure 1: Stakeholders and governance architecture.

excludable. Thus, efficient and effective governance tools are needed to protect the core resource from depletion, that is to say, to protect it from the *Tragedy of the commons* [7].

To build an effective governance architecture, it is essential to clearly identify the stakeholders based on interests, specific tasks, and potential conflicts of interest. As depicted in Figure 1a, there are four main stakeholders. The *volunteers*, the initiators of the project, due to their lack of economic interests, are responsible for the operation of the tools and mechanisms of governance and oversight. The *professionals* contribute quality of service, and their *customers* bring the resources which make the ecosystem economically sustainable. The *public administrations* are responsible for regulating the interactions between the network deployment and operation, and the public goods, such as public domain occupation. All participants that extract connectivity must contribute infrastructure, directly or indirectly, and can participate in the knowledge creation process.

Figure 1b depicts the architecture of the governance tools. Effective means of *communication* are essential for any peer production project. The *license* establishes the participation framework and sets the boundaries of the CPR. The participation framework must be flexible enough to enable mechanisms for self-sustainability such as economic activity, but at the same time must safeguard the essence of the project. The *monitoring* system is essential for the network operation (bottlenecks, failures, etc.) and for resource usage accounting. A clear *conflicts resolution system* avoids arbitrariness and lessens the number of disputes. Through the mechanism of *expenditures declaration* the participants indicate the resources they contributed which must be accounted for. The *collaboration agreement* system regulates the for-profit usage of the resources. The *economic compensation* system balances the contributions that were accounted for and the resource usage of for-profit participants. Finally, a authoritative organisation recognised by all the participants is needed to operate the aforementioned tools and mechanisms.

4. Implementation

This section discusses how the governance architecture presented in Section 3 are implemented as tools in guifi.net.

4.1. Communication tools

Due to their technical nature, collaborative tools of all kinds have flourished in guifi.net. Predictably, almost all of them are free software and are hosted in servers of the community. The following are the most

significant ones.

Website It is the main participation and coordination tool. It integrates all the software tools described above, providing a complete platform for designing, deploying, and operating CNs.

Mailing lists Mailing lists[5] are the preferred communication method for discussion. Mailing lists can be global, territorial, or thematic. They are open by default[6].

Social Media A social platform[7] has been put in place to handle documentation and discussions. Working groups are public by default, but closed ones also exist to protect sensitive information.

Face to face meetings Face to face meetings play a very specific role in strengthening social relationships. Local meetings are typically weekly or monthly based. In these meetings the participants work on their projects and help newcomers to join the group and the network. A global guifi.net community meeting generally happens once a year; it is itinerant and always hosted by a different local group. The most relevant international CN events are usually attended at least by one or two guifi.net members.

4.2. Participation framework

The following tools develop the legal framework for participation in the network.

Network Commons License (NCL) The license is called *Llicència de Comuns per a la Xarxa Oberta, Lliure i Neutral (XOLN)*[8] is the license to which any guifi.net participant must subscribe. It sets the fundamental principles, and the articles precisely establish the participant's rights and duties. It is written to be enforceable under the Spanish legislation. Legal certainty is essential to stimulate participation and investment, which in turn, is at the base of any economic activity. The license 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. The initial version dates from January 2005[9].

The guifi.net Foundation. The *Fundació Privada per a la Xarxa, Lliure i Neutral guifi.net* was created by the guifi.net community to give a legal identity to the guifi.net project. Its foundational mission is to protect and promote the networks held in common. To protect the network, it maintains the NCL and enforces its compliance when necessary. The promotion activities include the development of strategic and innovative projects, the operation of critical parts of the infrastructure, dissemination tasks, etc. It has a set of tools (e.g. IP address space, legal identity, possibility to operate under its name) available to anyone who wants to contribute to expand the network, professionals included. It also performs many dissemination activities. The Foundation is composed of the Board of Directors (unpaid) and the workers. It is funded from the services it gives to the professionals, such as activities in the Network Operation Center (NOC) and operation of the economic compensation system, and

[5] `https://llistes.guifi.net/sympa/`

[6] Closed mailing lists are just accepted in very justified situations.

[7] `http://social.guifi.net/`

[8] `http://guifi.net/en/FONNC`, Comuns XOLN in Catalan `http://guifi.net/ca/CXOLN`. The NCL Compact preamble is:

- *You have the freedom to use the network for any purpose as long as you don't 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.*
- *You have the right to understand the network and its components, and to share knowledge of its mechanisms and principles.*
- *You have the right to offer services and content to the network on your own terms.*
- *You have the right to join the network, and the obligation to extend this set of rights to anyone according to these same terms.*

[9] `http://guifi.net/ca/ComunsSensefils`

from specific projects to which it may participate (e.g. research projects and consulting activities). The Foundation plays a vital role for the coordination and management of the guifi.net ecosystem. Nonetheless, its power is rather limited because, as with the rest of the participants, it just owns the part of the infrastructure it has contributed, and all its actions are constrained to its foundational mission of coordination and arbitration. Thus, its authority is mostly reputation based.

Collaboration agreements are a set of standardised templates based on the experience of many specific agreements over the years. The number of specific agreements justified the standardisation process, which was led by the Foundation. The Foundation is always one of the signing entities. This way, a web of trust is built, having the Foundation as the hub. The agreements have the mission to grant the commitment of the parts to the NCL, enhancing and strengthening the legal frameworks set by the license.

Professionals can choose between three options[10] according to their level of commitment to the commons. *Type A*, *full commitment*, the preferred for the Foundation, implies that all the infrastructure deployed by a professional is contributed to the commons; *type B*, *partial commitment*, is for those professionals that only partially contributed to the commons; *type C*, *opportunistic*, is for the professional who does not contribute any infrastructure to the commons (that is to say, they use what is available but do not contribute at all). The agreement implies the acceptance of a set of Service Level Agreements (SLAs) that orchestrates the coexistence among the professionals. Customised agreements are not accepted.

The Public Administrations have a single template. Although they often want to modify the template, it is important to keep the texts as close as to the standard as possible for the sake of homogeneity. The standard text is aimed at i) alleviating the legal limitations of Public Administrations to participate in telecommunication activities as well as they avoid certain responsibilities, which fall outside of the scope of their standard tasks, especially for small- and middle-size administrations[11], and ii) orchestrate how they make their public resources available to the CN, and thus to all ISPs (e.g. those which do not want to contribute to the CN have access to this resources through the type C of the subset of agreements for professionals).

Finally, agreements are in place with other entities such as universities or NGOs. Due to the small number and heterogeneity of cases, they have not been standardised yet.

4.3. Network management and provisioning software tools

The community of guifi.net has developed a set of software tools[12] to ease the design, deployment, management, and operation of the network. The tools are oriented to support a self-provisioning style and supporting crowdsourced efforts by members of the community given the intrinsic inter-dependence in the computer and social network. Most of them are integrated into the guifi.net website[13]. All tools have been developed following the Open Source model using a public collaborative development platform[14] and are publicly available under the GNU Public License[15]. Automation is essential to reduce the learning curve for participation and to avoid human mistakes. Consistent and comprehensive public data sets are essential to make the network implementable in the territory.

Network map tool[16] Network planning requires maps and several tools to calculate distances and lines of sight, select neighbouring nodes, contact people in charge, etc. This tool combines geographic maps

[10](Catalan) `http://social.guifi.net/groups/guifi-coord/conveni-dactivitats-econ%C3%B2miques-instal%C2%B7lacions-connectivitat-i-manteniments-en-la`.

[11]In the European Union as well as in most of the Western countries, telecommunications is a public service that must be delivered by the private sector. In this context, the room for manoeuvre in public administrations is limited to very specific actions (self-provisioning, undeserved areas, etc.) and under very special conditions (separate account, self-financed, etc.)

[12]The guifi.net website uses the Drupal CMS and the MySQL database. All the tools developed are Drupal modules.

[13]`https://guifi.net/en/guifi/menu`

[14]`https://gitorious.org/guifi`

[15]`http://serveis.guifi.net/debian`

with network maps to collect and share all the knowledge about the network and the participants involved in it.

IPs assignment and routing configuration[17] This is a back-office tool that manages IPs assignment and routing configuration. These procedures are fully automated. The resulting information is stored in the main database.

unsolclic[18] The configuration of all routers is fully automated. The human interaction has been reduced to *copy & paste* or *reflashing* procedures. This helps to avoid configuration errors that can create conflicts in the network, and ease the process of setting up nodes, which in turn promotes more participation.

Community Network Markup Language (CNML)[19] The CNML is an XML specification developed in guifi.net through which the guifi.net database information is presented. All interactions should be done through it.

Network monitoring[20] A fully distributed network monitoring system has been developed and implemented. It has been key to helping the community visualise usage, and identify problems or bottlenecks.

Network crowdfunding[21] Since very early in the development process, a tool was developed to coordinate the collection of voluntary contributions of money to fund new or upgrade nodes or links that could benefit several users directly or indirectly. The tool enables creation of a proposal with a detailed plan including a description of the project, its cost, and a deadline for contributions. If the target budget is met within the deadline, the initiator will collect the money and launch the action. This mechanism has proven to be very successful to share costs among the community to upgrade bottleneck links or provide new nodes to benefit several citizens.

Expenditure declaration[22] This tool enables the declaration of expenditures, tracking, and analysis of previous ones. It has been developed as part of the economic compensation system (described in 4.4). It distinguishes between contributions made by professionals from those made by volunteers, treating the information accordingly. It was developed from the realisation that professionals were not investing in the infrastructure, they were only consuming with the excuse they would not suffer abuse from their investments from others. This tool records any expenditure, such as investment in capacity or maintenance, so that participants have an equitable environment that accounts, promotes, rewards, and creates certainty to promote fair and proportional compensation in terms of access to resources proportional to the long-term cooperative investment in the infrastructure among all participants. That results in sustainable growth of the infrastructure and avoids its abuse.

4.4. Governance tools

These are the socio-economic tools the project has developed to keep the infrastructure and the project itself operational. The Foundation is responsible to keep these tools in place.

Conflicts resolution system. A systematic and clear procedure for resolution of conflicts with a scale of graduated sanctions has been developed[23]. It consists of three stages—conciliation, mediation, and arbitration—all of them driven by a lawyer chosen from a set of volunteers. The cost of the procedures is charged to the responsible party or to both parties in case of a tie. This system was developed based on experience and has defined in a precise manner to help in addressing these conflicts in a quick and standard way, with help from lawyers, and scalable for a growing community. It was developed at a time when the flame wars between a few participants threatened the entire project. The Foundation had to take a leading role in its development and implementation.

[23] `http://social.guifi.net/groups/guifi-legal/reglament-dels-procediments-de-resoluci%C3%B3-de-conflictes`

Economic compensation system. 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 declared by the professionals are periodically cleared according to the network usage. The calculations are performed by the 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). A typical income for the Foundation is a percentage, depending on each professional type, which is charged to the result of these calculations[24]. In addition, professionals are allowed to charge a reasonable amount for opportunistic connections[25] until theirs investment are covered. The economic compensation system also provides for measures to compensate those who, having contributed critical infrastructure, want to withdraw from the CPR.

5. Results

In this section we present the most relevant results of the guifi.net project. First we analyse the commons infrastructure. Its physical parameters can be perfectly quantified thanks to the database and the information on its website. Nonetheless, the costs must be estimated because the software tool for reporting the expenditures has just been established recently. The description of the interconnection to other network infrastructures follows. In this case, the costs can be established with a high level of precision because the information about most of them is shared between the Foundation and the operators. Regarding participation, the data presented is rather qualitative because, due to the openness of the project, only indirect metrics can be quantified. The description of the impact of the project is based on third parties' information.

5.1. The commons infrastructure

Currently, at the physical level, guifi.net combines several technologies: the wireless and the optical fibre are the most common. Due to its affordability, accessibility, and ease of deployment, WiFi was the first technology to be used and is still the most popular, up to the point that it is considered fully integrated into the ecosystem (i.e it is fully supported by the web tools and its use is widespread among professionals and volunteers). The initial nodes of guifi.net were deployed by 2004. Figure 2a depicts the evolution of the total operational nodes over time. Optical fibre was first introduced in 2009[26].

As of June 2015, guifi.net has a total of 44,824 nodes, 28,675 of them declared as operational, accounting for 32,672 WiFi links (29,946 AP-Client and 2,726 Point-to-Point) and making a total length of 52,443Km. Most of the nodes, 44,432 of the total, are located in Spain. Figure 2b shows their distribution on the map. Figure 3 shows two cases of implementation at local level (general views at the top and detailed views at the bottom).

Regarding optical fibre, due to the fact that registration of this type of link is not yet in production [27], at the moment the numbers can only be estimated by alternative means. We estimate around 100 links[28].

Topologically speaking, WiFi and optical fibre networks are rather similar [6]. In both cases end-user-nodes (the *nodes*) are connected to a central point (the *supernodes* in WiFi and the *PoPIX* -Point-of-Presence Internet Exchange- in optical fibre)[29], and supernodes are connected to each other through dedicated links forming the backbone. In WiFi practically all links are deployed by guifi.net members. In contrast, in

[24]Type A 10% (to cover administrative costs), Type B 50%, and Type C 100%.

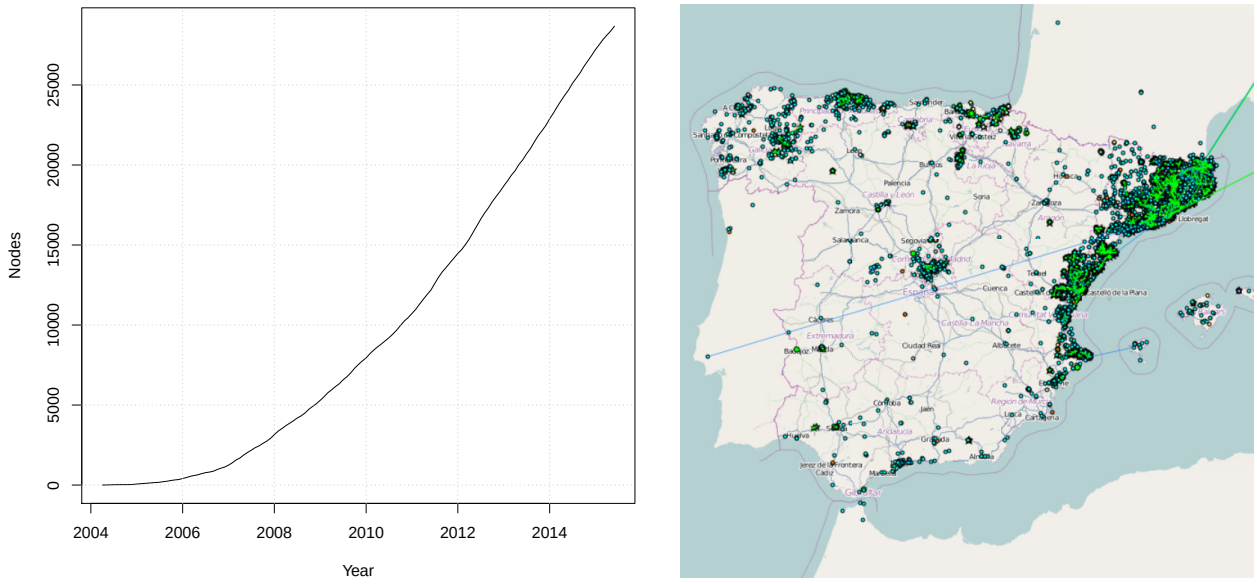
[25]A client node that connects in a DIY manner to a supernode that has been paid by a professional.

[26]`http://guifi.net/node/23273`

[27]This feature, which involved redesign and a significant amount of new code, was developed in summer 2014 and is expected to be in production in 2015. The large amount of optical links already deployed will require additional time to register all this data.

[28]This estimation has been made with information contributed by each ISP and cross-comparing responses with the amount of transit and the amount of IPs assigned

[29]In WiFi the *infrastructure mode* (i.e. the combination of master-client mode for nodes to supernode connections and dedicated Point-to-Point -PtP- links between supernodes) has shown to be much more efficient than solutions based on IEEE802.11 Ad-Hoc mode. Nonetheless, some parts of the network operate in Ad-Hoc mode.



(a) Total number of operational nodes.

(b) guifi.net deployment (June 2015).

Figure 2: guifi.net summary

Table 1: guifi.net CAPEX estimation (June 2015)

		Quantity [units]	**Estimated average cost [€/u.]**	**Total [€]**
	WiFi node	28,500	250	7,125,000
	OF node	100	1,500	150,000
	PoPIX	15	2,750	41,250
Commons				**7,316,250**
	PoPIX	15	2,750	41,250
Interconnection				**41,250**
TOTAL				**7,357,500**

optical fibre deployments most of the PtP links are subcontracted dark fibres[30]. Figure 4 shows the current distribution of the operational PoPIX (15 in total). In the areas where the two technologies coexist, optical fibre links are replacing WiFi ones in the backbone, and these are forming a backhaul, resulting in a more efficient topology[31]. The economic compensation system is applied at PoPIX level. The metric used to quantify the network usage is the percentage of the total aggregation of inbound and outbound traffic to networks that are not held in common (i.e. traffic to and from the NIX or to the carriers).

According to guifi.net Foundation estimations presented in Table 1 and Table 2, the capital expenditure (CAPEX) of the infrastructure built in commons is over 7.3M € and the operating expenditure (OPEX) over 3.0M € per year.

At the IP level, guifi.net uses IPv4 RFC1918 private addresses. IPs assignment was initially made respecting Free Networks[32] allocation, but currently the full *10/8* address space is considered, although

[30]So far all to the Catalan national dark fibre provider `http://www.xarxaoberta.cat/about/xoc`

[31]Amending the abnormal situation of a backbone of several tens of WiFi hops.

[32]A project started by the year 2000 intended at harmonising the *10/8* block allocation among CNs. It has been unmaintained for years.

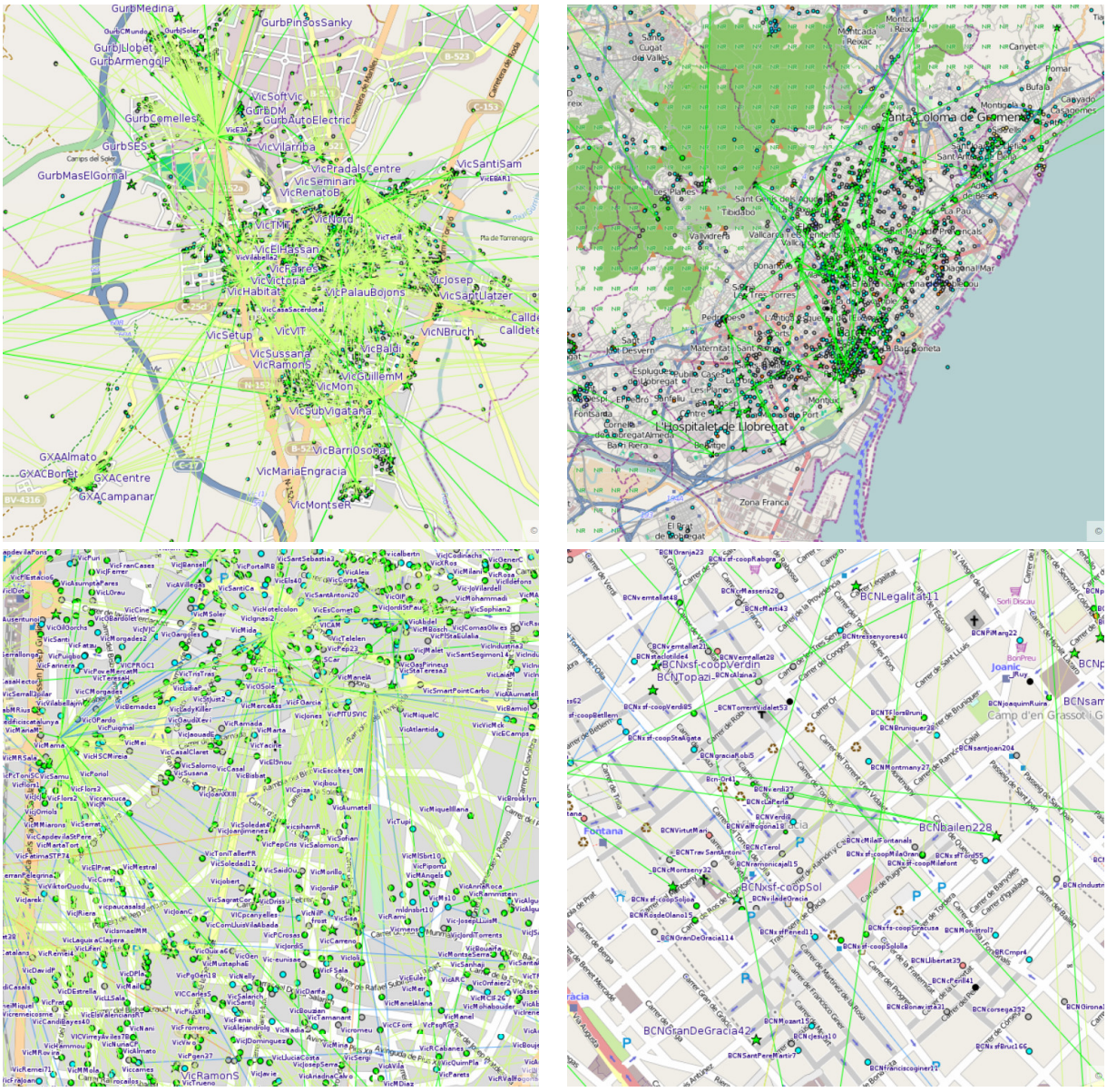


Figure 3: guifi.net maps (June 2015). Cities. Left: Vic. Right: Barcelona. Top: general. Bottom: detailed.

in practice just a few */16* blocks are being used[33]. IPs are allocated to supernodes in */27* chunks[34] and nodes receive one of these IPs each. In addition, the *172.16/12* block[35] is used for the PtP backbone links. Nonetheless, this range is not routed, and hence *10/8* and *172.16/12* addresses are frequently referred to as, respectively, *public addresses* and *private addresses*.

At the routing level, the network is split into *Autonomous Systems*, most of them internally running OSPF, interconnected via BGP. Numbers and name assignments and allocations are made foreseeing the

[33] Geographical allocation.

[34] Such a small netmask is a legacy of the address space scarcity of the times of Free Networks (*10/8* were assigned to each CN regardless of its size—while guifi.net already had thousands of nodes, the other CNs had tens at most).

[35] At the time of writing, just the *172.25/16* block is used. Assignments are made in */30*.

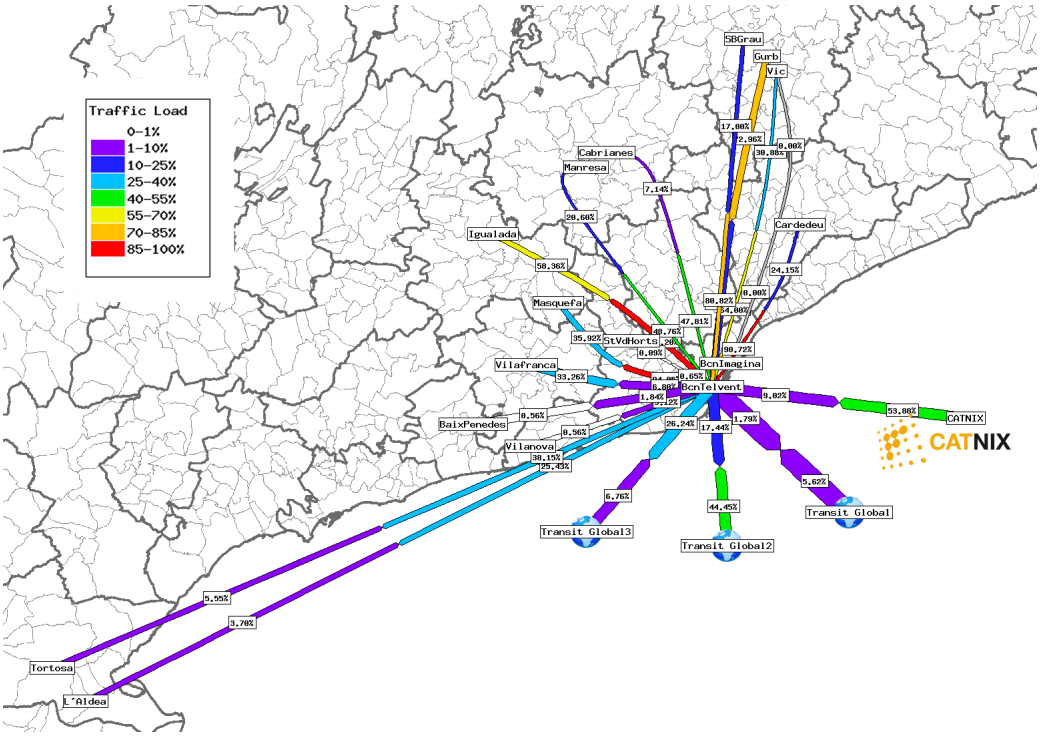


Figure 4: guifi.net Optical Fibre backbone (June 2015). The thickness of the lines is a function of the capacity of the links, from 100 Mbps to 10 Gbps.

Table 2: guifi.net OPEX estimation (June 2015)

		Quantity [units]	Estimated average cost [€/u./year]	Total [€/year]
	WiFi node	28,500	96	2,736,000
	OF node	100	96	9,600
	PoPIX	15	3,600	54,000
Commons				**2,799,600**
	Proxies	100	720	72,000
	PoPIX	15	3,600	54,000
	CATNIX	1	7,200	7,200
	Uplink	3	12,000	36,000
	Colo. Bararcelona	1	18,000	18,000
	Colo. Vic	1	2,400	2,400
	RIPE-NCC	1	1,800	1,800
	Provision	1	48,000	48,000
	Administration	1	18,000	18,000
	Technical management	1	18,000	18,000
	Insurance	1	840	840
Interconnection				**276,240**
TOTAL				**3,075,840**

network as one single network (i.e. respecting compatibility). As of June 2015 about 3,500 routes were announced at the biggest BGP cloud[36].

[36]Because block aggregation is not automated

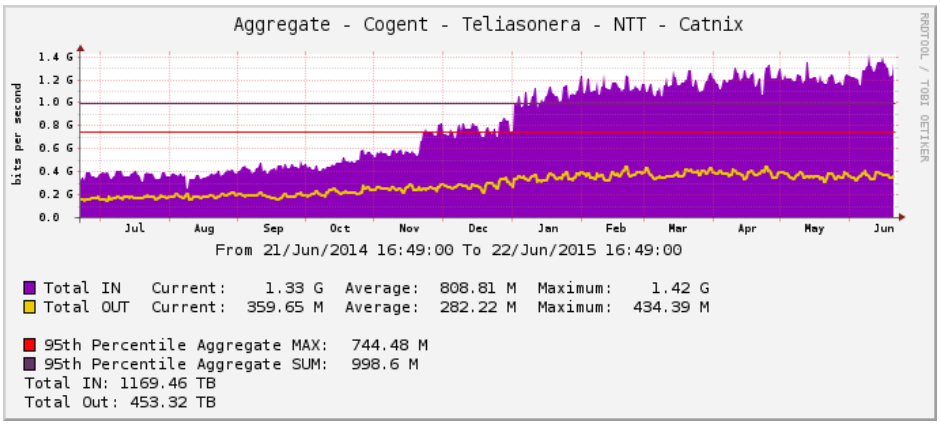


Figure 5: Total inbound and outbound guifi.net transit (July 2014 - June 2015).

5.2. Connection to other networks

guifi.net is connected to many networks, including the global Internet, in a number of ways. The preferred way is by peering with other networks, because this method is closely aligned with the cooperative principles of the project. Less preferred ways, but also possible and currently used, are through paid carriers and by sharing domestic Internet connections. Network interconnection is conceived as content, so as such, it is made available according to the conditions of the one who offers it.

The guifi.net Foundation is a member of the Catalan Exchange Point (CATNIX[37]), which has about 39 peers (counting IPv4 and IPv6) and has three Internet uplinks from independent providers: one at 10 Gbps, another one at 1 Gbps, and the last at 300 Mbps. The capacity of the uplinks and the CATNIX connections are distributed to the ISPs, which in turn distribute them among their customers. Figure 5 shows the evolution of the total inbound and outbound guifi.net transit over the last twelve months[38]. In addition, most of the operators have retail public IPv4 and IPv6 ranges distributed in the same way. The network is also connected to the Community-Lab.net experimental testbed and as part of that guifi.net has a network-level federation with several other European CNs.

The standard way for users to make their domestic Internet connections available to other guifi.net members is through proxies. A federation of Internet access proxies, which was developed by the guifi.net community, allows each user to employ all of them with the same credentials and for free. DSL lines of public administrations (councils, libraries, telecentres, etc.) are usually made available to guifi.net participants in this way because it offers several technical and, most important, legal guarantees.

According to the estimates made by Foundation the CAPEX of the interconnections is around 41,250 € and the OPEX over 276,240 € per year.

5.3. Participation

As already indicated, the guifi.net ecosystem is very rich in terms of variety of participants, each of them playing a strategic role. A study [8] in 2014 found 13,407 registered users in the guifi.net portal and 55 mailing lists. A description of the current state of the most relevant groups follows.

Volunteers. As for most open projects, the number of volunteers can merely be quantified by indirect metrics such as the number of posts in the mailing lists, etc., but qualitatively we can say that the guifi.net community of volunteers is healthy. Volunteers contribute in many tasks such as bootstrapping new areas, assisting newcomers, improving the software tools, doing maintenance, etc. Thanks to their locality and their commitment to the project, they are a key component in the task of ensuring that

[37] `http://www.catnix.net/en/`

[38] Discontinuities of early November and mid December are clear examples of the effect of the integration of new PoPIX.

the rules are fulfilled, especially in areas where the Foundation presence is limited. As an indicator of size, apart from the 13,407 registered portal users, there are 40 regional mailing lists.

Professionals. Nine SMEs participate in the economic compensation system. In addition, many SMEs and self-employed people conduct installations and other paid activities related to guifi.net[39]. Despite the fact that competition for customers is always a (desired) source of tension, which occasionally leads to conflicts, we can state that the coexistence is positive and the level of collaboration is rather high. As an indicator of size, the professionals mailing list has 270 subscribers.

The Internet access is still the most popular service. Nonetheless, others such as VoIP and remote backups have also been offered for quite some time, and new services such as video streaming and video on-demand are becoming popular, especially in the areas with optical fibre. The professionals offering infrastructure services are commonly referred to as *installers*, and content providers as *operators*.

The Foundation. The guifi.net Foundation was set in July 2008. It has become member of the CAT-NIX as well as of the RIPE-NCC[40] from which it has obtained the following resource: ASN 49835, IPv4 109.69.8.0/21, 5.10.200.0/21 and 185.32.16.0/22, IPv6 2a00:1508::/32. From the legal viewpoint, through the corresponding notification to the Spanish National Regulatory Organisation[41], it is the operator of the network infrastructure by default (i.e. of those parts of the network which are not operated by anyone else) which is very convenient for participants who are not familiar with these specific legal and administrative details of the telecommunication sector, such as volunteers or public administrations.

As part of its actions to stimulate the economic activity, the Foundation promotes network projects (e.g. an optical fibre deployment in a neighbourhood) which afterward are executed by the professionals (project allocations are made according to pre-established rules, and the Foundation always keeps the role of project supervisor). In addition, the Foundation helps these professionals by sharing its resources, especially when they start, and accompanies them during their growth process.

Its dissemination activities include promotion in public administrations, with politicians, private companies, and citizens, dialogue with the regulator and in response to any public call that may affect the commons network, etc.

Its research activities are mostly tied to collaborations with universities. The Foundation has participated (period 2011-2015) in two FP7 projects, one CIP project and one H2020 project of the European Commission.

Other guifi.net organisations. A diversity of non-profit organisations complement the activity of the guifi.net Foundation. Local associations of users are typical, some having legal identity[42], and others being just informal groups. Some of these groups are former wireless communities that joined guifi.net, many keeping their identity[43]. Cooperative initiatives[44] have also emerged and have started promoting projects.

This type of organisation is a typical entry point for newcomers because they do a lot of dissemination activities and provide support to beginners. Associations and informal groups are preferred by technical skilled people, while cooperatives are preferred by people who supports guifi.net principles and ideas, but either they do not have the required skills or the time to put them into practice. Two associations participate in the economic compensation system.

Grup LIR (GLIR) is the technical group in charge of operating the guifi.net NOC. It consists mostly of professionals, but volunteers also have the right to participate. Currently, 42 persons are in the group. The group is closed to protect sensitive information.

[39] `https://guifi.net/en/node/3671/suppliers`
[40] `http://www.ripe.net/`
[41] Comisión del Mercado de las Telecomunicaciones (CMT), `http://cmt.es/`
[42] E.g. *Associació per a l'expansió de la xarxa oberta*, *E.g. Delegació territorial de la Fundació al Maresme*
[43] E.g. Badalona Wireless, Gràcia sense fils, Pineda sense fils, etc.
[44] E.g. *Sestaferia.net*, *Eticom/Somconnexió*, *Guifi Baix*, etc.

Public administrations. As in any other infrastructure, public administrations have strategic roles (policy making, promotion, etc.) in the telecommunications sector. Thus, collaboration is almost mandatory. Collaboration agreements have been signed by guifi.net with many of them, mostly small- to middle-size municipalities (e.g. with almost all of the Osona county), but also with counties (e.g. *Consell Comarcal d'Osona*). A correlation between size of municipalities and the level of commitment with the commons network can easily be identified; the smaller and the less served by conventional telcos, the stronger the commitment and the bigger the contributions. At the moment, more than one hundred councils are actively collaborating with guifi.net, most of them through the Foundation but also through local installers and operators.

Universities. The Foundation has signed collaboration agreements with almost all Catalan universities. Collaboration activities include infrastructure deployment, research projects, students mentoring, dissemination, etc.

Other third parties. The following are examples of the many cases of successful collaborations with third parties to contribute to the network commons. These cases show that almost any entity or organisation can contribute. Since 2008 the Catalan top level domain (.cat) has most of its hardware in the guifi.net facilities; their contribution was crucial to launch the first PoPIX. The Hospital of Vic[45] self-supplies its connectivity needs through an optical fibre cable deployed by it and held in common.

5.4. Governance

Conflict resolution system. Only three cases of conciliation have occurred since the conflict resolution system was established in 2013. The number of flames in the forums and in the mailing lists has been substantially reduced.

Economic compensation system. The compensation system was started in the Barcelona PoPIX in April 2014. Currently it is implemented in four other PoPIX and the plan is to extend it to the rest by the end of 2015.

5.5. Impact

Figure 6 presents the data about penetration of the bandwidth and Internet access in the households of Catalonia in 2013, released by the public Catalan Statistics Institute (*Institut Català d'Estadística* (IDESCAT)[46]) per county [9]. It also contains the average rate of Internet access of the European Union, Spain, and Catalonia. The first thing to notice is that, despite the fact that Catalonia is about three points above the Spanish average, it is still seven points below the European average. Second, and most relevant regarding guifi.net impact, the Catalan county with the best results and the only one above the EU average, is Osona, where guifi.net was born. Moreover, it is the only county where broadband access is above Internet access. The indicators of other counties where guifi.net presence is significant, such as Bages and Baix Ebre, are also larger when compared to similar counties but where guifi.net presence is irrelevant.

Osona has about 9,000 nodes[48]. Combining this number with others coming from IDESCAT[49]. We conclude that about 22,4% of the Osona inhabitants have guifi.net access: around 30,500 people.

[45] The capital of the Osona county.

[46] `http://www.idescat.cat`

[48] `http://guifi.net/ca/Catalunya`, 8,958 adding Osona and Lluçnęs and substracting Santa Maria de Marlès and Sant Feliu Sasserra, as they belong to other counties (*comarques*).

[49] Osona has 71,597 households, Catalunya 2,944,944 `http://www.idescat.cat/pub/?id=aec&n=700`; in Osona 38,029 buildings have at least a household, 75.6% of the households are single family houses `http://www.idescat.cat/pub/?id=aec&n=692&lang=en`; Osona population (2013): 155,069 `http://www.idescat.cat/pub/?id=aec&n=246&lang=en`; thus, 4.08 inhabitants/building. The rate supernodes to nodes is 0.1; estimates are that half of them are not installed in homes.

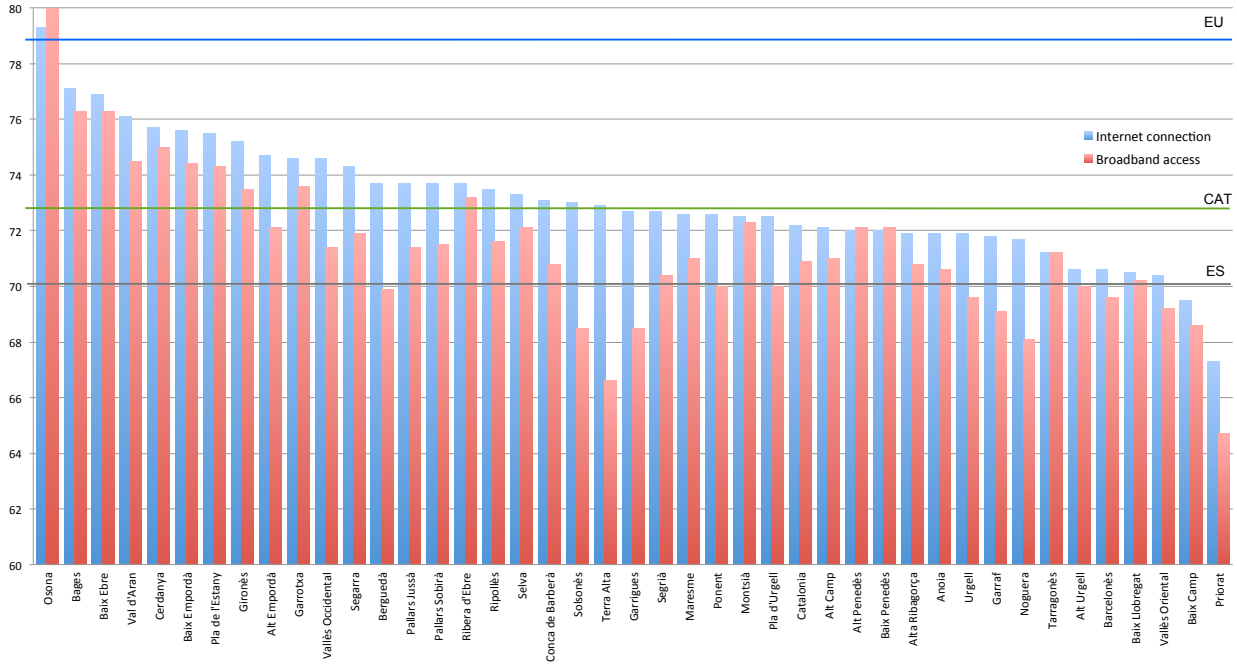


Figure 6: Households bandwidth and Internet access in Catalonia per county (*comarca*) in 2013. Source: IDESCAT [47]

6. Discussion

More than 28,500 operational nodes have been deployed over ten years, with an estimated CAPEX greater than 7.3M € and an estimated OPEX greater than 3M € per year. These are sufficient indicators to state that the guifi.net case proves that telecommunication infrastructures can be held in common and also that CNs have great potential to bootstrap the local economy.

The heterogeneity of the technologies used, as well as of the participants, and the level of collaboration among them reinforces the previous statement. The nurtured community of participating volunteers proves that the project is truly open. The number of professionals indicates that it provides business opportunities ensuring its sustainability. The amount of municipalities involved shows its social value. The guifi.net community is characterised by a high self-awareness and a general will to push the project forward. All this is accomplished by following a very successful crowdsourcing model, based on contributions from a large community of more than 13,000 registered members and a set of organisational structures, agreements, and support tools, with only a couple of part time employees devoted to these tasks.

Considering that the number of new nodes of the last year is over 4,500 (Figure 2a), the significant amount of small and middle network clouds (Figure 2b), and that a region that has adopted guifi.net, Valencia, already accounts for over 17% of the nodes, we can say that guifi.net is a successful crowdsourcing project that has a real impact on society (Figure 6).

Collaboration from public administrations is crucial in the effective development of guifi.net by the community. It becomes clear when comparing the guifi.net penetration in the cities of Vic and Barcelona (Figure 3)—both cities with more than one conventional operator available. Indeed, despite the fact that the Vic council commitment has never been as strong as the commitment of smaller municipalities of Osona county, it has treated guifi.net rather decently (e.g. signed the agreement with guifi.net, given similar treatment as to the conventional operators but understanding its traits). On the contrary, the collaboration with the Barcelona council has never succeeded. The results are not only evident in terms of operational nodes, 1243 to 329, although Barcelona has about forty times the population, but also in terms of rates such

as planned to operational nodes[50], 0.32 to 0.60, or nodes to supernodes[51], 0.02 to 0.3.

Explaining why guifi.net has started in Osona and not elsewhere, and why it has had such a spectacular evolution, requires a detailed discussion. The fact that it is under the European regulatory framework has obviously been an enabler. The state of the art of technology helps to explain when it started (i.e. after WiFi became affordable and hackable) but fails to answer why its use is so strong in a given county, because there are older European wireless initiatives (e.g. FF dates from 2000). We believe that the key factors are the vision of the starters in applying the *commons* concepts to the infrastructure to be designed and deployed, combined with the fact that they had the background and they committed enough efforts to implement their ideas. Undoubtedly, the self-service approach, the understanding that the existence of a solid economic activity is essential for the sustainability of any project, and the evolutionary approach for solving the problems are additional reasons.

It is interesting to note that CNs can perfectly coexist with the conventional network operators. Figure 6 shows that not only CNs contribute to ameliorate digital exclusion, but they do not replace conventional operators. According to IDESCAT, in 8.54% of the households the price is a reason for not having Internet access[52], [53], which matches the differences in Figure 6 between the Osona and Selva counties[54]. In this regard, while a few guifi.net participants have cancelled their contracts with conventional operators, they are more than exceeded by those participants who also have Internet provision contracted either from conventional operators or from guifi.net' operators.

7. The Network Infrastructure as a Common Pool Resource

As already discussed, the underlying principle behind guifi.net is the firm conviction that the optimal way to hold a network is by establishing it as a CPR. CPRs were studied in depth by E. Ostrom [10]. In this section we compare her findings with guifi.net evolution. Interestingly, until recently, Ostrom's works were unknown to the guifi.net community. Nonetheless, the evolution of most of the concepts and governance tools developed by the community perfectly match Ostrom's findings.

According to Ostrom, a CPR typically consists of a core resource which provides a limited quantity of extractable fringe units. In our case, the core resource is the network, which is nurtured by the network segments the participants deploy to reach the network or to improve it, and the fringe unit is the connectivity they obtain. Resilient CPRs require effective governance institutions to keep a long-term direction and deal with the struggle to handle many actors and changes in a complex system. The long-term direction is defined as sustainability in remaining productive or operational under the fundamental principles of the CPR, and the short-term goal is defined as adaptability in reacting and adapting to change.

7.1. Sustainability

Analysing the design of long-enduring CPR institutions, Ostrom [10] identified eight principles which are prerequisites for a sustainable CPR. We now discuss their application to our case:

1. Clearly defined boundaries. The fundamental principles of open and non-discriminatory access, and open participation in the life of the network translate into prescriptions defined by the participation framework, the network management tools, and the governance tools. The participation framework is implemented, as described in Section 4.2, through the community license, the Network Commons License (NCL), and the specific collaboration agreements with professionals and third parties, which prevent exclusion and regulate open and fair usage of the resource. The network management tools regulate the infrastructure itself, described in Section 4.3. The governance tools regulate the conflict resolution system and economic compensation system, which is required to preserve its fundamental principles, is described in Section 4.4.

[50] This rate indicates the loss of opportunity, i.e. people that would join guifi.net if it were easier.

[51] This rate indicates the participants' commitment, especially when combined with the planned to active nodes rate, i.e. those who are in the network are committed enough to afford a supernode.

[52] `http://www.idescat.cat/pub/?id=ticll13&lang=en`

[53] `http://www.idescat.cat/pub/?id=ticll13&n=2.4.2&lang=en`

[54] As stated in Section 5, guifi.net presence in Selva is negligible.

2. Rules regarding the appropriation and provision of common resources that are adapted to local conditions. The congruence between appropriation (usage of the network) and provision (expansion of the network) is mediated by the common network management and provisioning tools that assist in assessing the status of the network and its usage, and the tools to assist in the expansion of the infrastructure covering the mapping of the nodes, configuration, and even crowd-funding or sharing the cost of new or upgraded network nodes and links. These tools, described in Section 4.4, embody and implement the principles defined by the Network Commons License.

3. Collective-choice arrangements that allow most resource appropriators to participate in the decision-making process. Complexity and transaction costs grow as the network grows in size (number of nodes, links, distance, participants). This complexity is managed by social structures such as the Local Internet Registry (LIR) operating the network (NOC) with diverse representation from all CPR stakeholders, and such open structures as the local and global face-to-face meetings, and the digital participation tools such as social media and mailing lists, described in Section 4.1. In all these structures, the community of those who use or participate in the construction of the resource can participate openly, despite the fact that the members of the LIR and the patrons of the Foundation depend on a core group of representative senior appropriators.

4. Effective monitoring by monitors who are part of, or accountable to, the appropriators. Monitoring is performed with the assistance of network management and provisioning software tools, described in Section 4.3, that provide a common information base about history and status of the common infrastructure resource; and the lead of many local trusted senior members that rely on that open data and coordinate decisions when needed. These decisions are accountable, deliberated, and reported in the communication tools, described in Section 4.1, and recorded in the organisational history as part of the extended community license.

5. Graduated sanctions for appropriators who do not respect community rules. The conflict resolution system, described in Section 4.4, has clear and systematic methods to deal with users that negatively affect the common infrastructure resource. Problems typically occur due to imbalances between investment in the infrastructure and the network usage, generally among professional members. The cost reporting is collected, and it is publicly reported by the guifi.net Foundation that is also in charge of the billing to compensate for imbalances.

6. Conflict-resolution mechanisms which are cheap and easy to access. The conflict resolution system provides a structured procedure with three stages of escalation, and progressive levels of complexity and economic cost to the parts, all driven by a lawyer selected from a set of volunteers. This system has been proven to be cheap, easily accessible, efficient, effective, and scalable, which enable it to address a wide range of conflicts around the network.

7. Self-determination of the community recognised by higher-level authorities. The community license has been examined by lawyers and written to be valid and enforceable under the Spanish legislation where guifi.net is mainly deployed. In addition, the guifi.net Foundation has signed collaboration agreements with local and regional public administrations and is legally established for its function. It is also registered as a network provider or telecom service provider in Spain and a member of the public market regulator, where it validates its service provision mechanisms. This is in the participation framework described in Section 4.2.

8. In the case of larger CPRs, organisation in the form of multiple layers of nested enterprises, with small local CPRs at their bases. The Foundation mediates among the complex structures of internal members (such as individuals, professionals, service providers, public entities), the many local CPRs at the base, providing a federated CPR with many aspects in common, and interacts with external organisations in the local and global scope in many aspects. This is in the participation framework described in Section 4.2.

7.2. Adaptability

As already shown, in guifi.net the concepts and governance tools have been developed and refined as new problems and obstacles were appearing, in a complete adaptive governance fashion. Ostrom [11] outlined five basic requirements for achieving adaptive governance:

1. Achieving accurate and relevant information, by focusing on the creation and use of timely scientific knowledge on the part of both the managers and the users of the resource. The community produces open knowledge about practices and experience, and works with the scientific community to co-develop and apply scientific knowledge for the best development, management, and usage of the CPR. Collaboration agreements with academic and research organisations are the instrument to develop this principle, described in Section 4.2.

2. Dealing with conflict, acknowledging the fact that conflicts will occur, and having systems in place to discover and resolve them as quickly as possible. The facts about the CPR are collected and managed by the Network management and provision tools. The rules in the community license and collaboration agreements define the limits that determine conflicting situations, quantified and discovered by inspection of the facts collected by the previous tools. The mechanisms for discussion are based on the participation tools with which the conflicts are defined and then solved using instruments to reach consensus, such as the conflict resolution system, and finally the economic compensation system, described in Section 4.4, and all coordinated by the guifi.net Foundation.

3. Enhancing rule compliance, by creating responsibility for the users of a resource to monitor usage. The openness principle requires users to publish open data about the network and allow the monitoring of nodes and their traffic. This requirement is supported and facilitated by the network management tools, described in Section 4.3. The communication tools also help to facilitate any discussion and promote responsibility to the usage of the CPR.

4. Providing infrastructure, that is flexible over time, both to aid internal operations and create links to other regimes. The Foundation provides that infrastructure and the flexibility to understand and adapt to changes over time, oversee the evolution of the CPR, facilitate the internal operation, and maintain links with external organisations and other regimes that coexist, interact, and interoperate with the CPR.

5. Encouraging adaption and change, to address errors and cope with new developments. The Foundation and its patrons, in its overseeing and steering role (sometimes referred to as a second level or umbrella organisation), play this role of driving feedback, organisational learning, and forecasting.

8. Lessons learned

This section discusses what, to our understanding, are the main lessons learned. Based on our active participation and research on guifi.net, and in comparison to other CNs, this patchwork of loosely connected ideas and practises is intended to be a wide set of guidelines for other projects. We strongly recommend that these projects build upon what exists already, devote their efforts in refining it, and contribute back their improvements.

Open and non-discriminatory access. Although these concepts are implicit to CNs, it is essential to safeguard them. Thus, it is good to make them explicit. The success of guifi.net has been demonstrated, as it has provided access to infrastructure in areas where other traditional infrastructure provision models have not been available or effective.

Early adoption of a network license. The existence of such a precise framework for participation has proven very effective in focusing the community efforts and in creating an appropriate environment for business development and local investment. It is important to notice that, i) to the best of our knowledge, guifi.net is the only CN with such well-defined rules, and it is much larger than the second largest, ii) the initial version of the license was adopted when there were just a few tens of nodes, and thus, the idea of the need of a formal regulation was introduced from a very early stage, iii) several CNs, many inspired by guifi.net, have unsuccessfully tried to adopt a similar license when they were already accounting for several hundred nodes; generally they have failed because the number of participants was too high to be able to achieve a consensus on such a radical matter. The license has been instrumental to ensure access to the collective infrastructure and ensure participation rights in the production and governance of the CN. It has also enabled its growth.

Diverse participation. As a result of the particular nature of the resource that it is crowdsourced in CNs (i.e. a physical infrastructure), as already discussed broadly, the balance in participation of the three groups identified in Section 2 is crucial to the proper implementation and development of the project due to their specific and irreplaceable roles. In summary, the volunteers have the responsibility to guarantee the project neutrality and its independence, boost creativity and innovation, maintain the DIY spirit, and maintain the consumers' rights. The professionals must supply goods and services, because they are responsible for covering the market demand and, for their own interest, they have to raise the funds to maintain the entire ecosystem. The Public Administrations are responsible for the public resources (access to road ducts, poles, etc.), including the network infrastructure, and using it to satisfy their own telecommunication needs.

The infrastructure as common pool resource. The *commons* is the most suitable and most effective resource management principle known that guides the life and development of the community.

Effective tools for participation and coordination. They are essential to put in practice the theoretical framework. Tools around open data, procedures, automation, and coordination tools help to lower the barrier to access the infrastructure and to participate in its social production. They reduce the cost of decision-making and of action, and are imperative for transparency and accountability. They are also critical for the expansion of the CN. Therefore, they must be constantly refined.

Multi-level organisation. A large and complex network requires a multi-level structure for feedback and interactions at many local communities that are coordinated by a second-level organisation, such as the guifi.net Foundation, that also interacts with external agents.

Leadership/stewardship. The entire process is very innovative and therefore, due to its open nature, susceptible to deviations. Clear ideas and strong leadership have proven very effective in stopping useless discussions and isolating disturbing attitudes. Nonetheless, the stewardship must always be reasonable, inclusive, and accountable. The higher the organisational level, the greater the importance.

Balance effort between development of support tools and network deployment. The main goal and the way to keep the project alive is to deploy infrastructure and to maintain it operationally. Obviously, to accomplish it, a full set of tools, many of them discussed in this paper, must be in place. Nonetheless, it is crucial to balance the efforts spent in building this enabling set of tools and those spent in fieldwork. Unfortunately, we have witnessed many projects that have failed due to excessive efforts in one of the two aspects, leaving the other unattended. Our general recommendation is to take any opportunity to deploy new infrastructure and to solve the problems as they appear (do not forget that the value of the network increases with each new node).

Society engagement. Reasons to start a CN project vary. The most frequent ones are experimentation and research by a group of highly skilled technical enthusiasts. However, the CNs of this type that we are familiar with have not been able to engage the society because these motivations are not appealing to the public in general, and thus, these networks have remained as marginal projects. On the contrary, guifi.net has been envisaged as a production network since the beginning, and thus, it has attracted the attention of many people who have found in it an opportunity to solve their connectivity problems. Once they have understood the social value of the proposition, some of them have become very active contributors.

9. Future work

Even though the guifi.net project development is extremely positive, as already discussed, it is nonetheless true that it must keep evolving to face the challenges of a globalised context. The inadequate and expensive services of the conventional ISPs have been and remain an opportunity for entrepreneurs to establish a foothold in the telecommunications market. However, this market niche is expected to be significantly reduced in the coming years as a result of the modernisation policies that conventional ISPs are implementing.

The project as a whole must take the opportunity of this time window to consolidate its position in the market by deploying as much infrastructure as possible, as well as by developing differentiating products, commercialised by the professionals, because competition based only on price will not be attainable. At ISP level, a proper balance between the economy of scale and tailored products is needed. In one respect, aggregation of customers is an evident strategy for cost reduction, but in the other, customised service offerings have shown to be highly appreciated, especially by SMEs. At the regional level, the collaboration among ISPs must continue and even be increased to strengthen the project and to continue benefiting from demand aggregation. Initiatives such the development of a regional Exchange Point governed by the guifi.net principles (the *CommonsIX*) and promoted by the Foundation are well aligned to this goal.

Internationalisation is a stimulating challenge with many opportunities. The benefits of the adoption of the guifi.net framework by other communities, that is to say new people with new skills and new ideas, with a need to adapt the framework to different realities, with contributions to the formalisation and modularisation processes, etc., would significantly enhance the model. This is particularly true if the adopter were from a different state due to different regulatory, language, or other challenges. For instance, many CNs have shown interest in the guifi.net CN license. However, they object that it is too dependent on the Spanish legal framework. Working within a different state would bring the opportunity to decouple global matters from the local specifics. This way, for instance, the CN license could be split into parts, the first to be shared with all the adopters, thus setting the collaboration framework, and the second tailored for each specific CN to address its local needs. Following the multi-level organisation approach discussed in Section 8, this process would bring the opportunity to create a higher-level (international) organisation to coordinate the CNs and take care of the global matters. The internationalisation process would also contribute to creating awareness of the social value of the commons model, not only for the network infrastructure, but also for other cases.

Internally, the growth of the guifi.net project entails interesting challenges. At the social level, for instance, the community of contributors is about to reach a size where they will not know each other easily. This situation will test the tools and social resources developed, and it is very likely to involve changes. Technically, the IPv4 exhaustion is a major challenge for the community, as well as regarding the technological obsolescence of hardware and software.

10. Conclusions

Community networks, neutral and open crowdsourced local computer network infrastructures, are a successful model developed within the last 10 years or more, with guifi.net as a success story. The guifi.net community has created and developed a methodology based on the commons management principles that has scaled up and has become sustainable by being open and neutral to diverse technological choices, to traffic, and to participants, including volunteers, professionals, and public administrations.

The guifi.net community has evolved to accommodate growth throughout the collective development and usage of tools for coordination. That includes i) tools for communication; ii) tools for network planning and management; iii) a participation framework with organisational tools such as the community license, the Foundation, or collaboration agreements; and iv) governance tools including conflict resolution, and economic compensation. The result is a healthy community of more than 13,000 registered participants, a network infrastructure of more than 40,000 declared nodes with more than 28,500 operational, and a total length of around 50,000 km of links, connected to the global Internet.

The guifi.net case is solid proof that infrastructures can be effectively managed as a commons. In fact, the guifi.net case has enough differences, complexity, coherence, and completeness that it may deserve its own specific model, the *guifi.net model*. This model of telecommunications infrastructures, compared to conventional models, is socially, economically, and environmentally more effective in its context: socially because it is based on the non-discriminatory and open access principles which empower people and preserve the infrastructure's sovereignty; economically and environmentally because the sharing paradigm on which it is based, the common pool resource, maximises the utilisation of resources; and the model shows to scale well. Contrary to the trend of privatising public infrastructures, such as the telephone network, we claim the opportunity for transformation and development of network infrastructures held in common.

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