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Abstract

This document presents the socio-technical evaluation and sustainability model for the community network clouds of the CLOMMUNITY project.

Executive Summary

This document presents the socio-technical evaluation and sustainability model for the community network clouds of the CLOMMUNITY project.

The contributions elaborated in this deliverable are first the identification of some key obstacles in the sustainability of community infrastructures. Secondly, we present a study on the interactions between the social and technical layer of Guifi.net. Third, we analyze recent actions and implementations of Guifi.net to consolidate with tools the sustainability of the community network. Forth, we extend these tools in a framework to be applied for reaching the sustainability of community network clouds.

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1 Introduction

1.1 Contents of the deliverable

This deliverable reports the works carried out under task T5.4 from M17-M30. Task T5.4 formally started with the second reporting period of the CLOMMUNITY in May 2014 and ended with the project in June 2015.

Task T5.4 aims at a socio-technical-economic evaluation and a sustainability model for the community network clouds researched in the CLOMMUNITY project.

The research works [1] [2] [3] [4] [5] carried out by the projectd consortium contributed to this deliverable. In particular:

Chapter 2 integrates findings and results from the following works:

- Exploring the Role of Macroeconomic Mechanisms in Voluntary Resource Provisioning in Community Network Clouds. Amin M. Khan; Felix Freitag. In the 11th International Symposium on Distributed Computing and Artificial Intelligence (DCAI 2014), Salamanca, Spain, June 4-6, 2014.
- Sparks in the Fog: Social and Economic Mechanisms as Enablers for Community Network Clouds. Amin M. Khan; Felix Freitag. ADCAIJ: Advances in Distributed Computing and Artificial Intelligence Journal, Vol 3, No 8 (2014).
- Analysis of the Social Effort in Multiplex Participatory Networks. Davide Vega, Roc Meseguer and Felix Freitag. In the 11th International Conference on Economics of Grids, Clouds, Systems and Services (GECON 2014), Cardiff, UK, September 16-18, 2014.

Chapter 3 integrates findings and results from the following works:

- Crowdsourcing tools for designing, deploying and operating network infrastructure held in commons. Roger Baig, Ramon Roca, Felix Freitag, Leandro Navarro. Submitted to Special Issue on Crowdsourcing in Elsevier Computer Networks.
- On the Sustainability of Community Clouds in Guifi.net. Roger Baig, Leandro Navarro, Felix Freitag. Submitted to the 12th International Conference on Economics of Grids, Clouds, Systems and Services (GECON 2015), Cluj-Napoca, Romania, September 15-17, 2015.

1.2 Relationship to other CLOMMUNITY deliverables

Deliverable D5.5 takes into account the deliverables of WP2 D2.3, D3.3 and D3.4 of WP3 and the deliverables of WP4 that describe the different aspects of the experimental system. There is a tight relation with WP2, since the scope of the potential development and the developed system experience influences on how the sustainability of the model can be designed. There is also a tight relation with WP3, which indicates directions for future research to remove obstacles for sustainability. The existing deployed system made operational through WP4 is the basis for short-term success and progress to enable take-up and further growth.

1.3 Obstacles for sustainability

Community network is a term used broadly to indicate the use of networking technologies by, and for, a local community. Most community networks originated in rural areas which commercial telecom operators left behind when deploying the broadband access infrastructure for the urban areas. Community networks are a successful case of resource sharing among a collective. Wireless community networks use affordable wireless devices to link the community's members. The emergency of cloud services has prompted the idea to reap their benefits by implementing them in community networks, leveraging the existing infrastructure to offer a customised version of these services to the members of the community network.

Nowadays it is common for people to have some files in their home computers, others in a tablet or phone and the need arises to have access to them even when they are physically remote. Services like Dropbox and Google Drive offer this capability, but there are privacy concerns about sharing one's data in other organisations' premises. Keeping the data local and inside the community network offers privacy advantages and quicker access, avoiding also the added latency and cost associated with the access to remote servers. Furthermore, services can be tailored for the specific needs of the community, like some content made available to members that share a particular interest.

It is well known that the Achille's heel of community networks has been the sustainability (or rather, the lack of thereof). Of the great numbers of community networks that have sprouted all over the world over the last two decades, very few have survived the test of time. Among the reasons for the lack of success in sustainability we can mention:

1) Competition from established telecom operators

Many community networks were motivated by the absence of network services in a given region. The building and subsequent operation of the community network proved that there were enough clients to sustain a business case for traditional operators. This was also helped by the technology advances that lowered the price of telecommunications equipment and, sometimes, also on the willingness of certain telecom operators to stomp out perceived competition from community networks even where there was not a reasonable return on investment in a particular region.

2) Insufficient economic incentives

Most community networks were built by enthusiastic individuals that donated part of their time and expertise for the common goal. Over the years, the enthusiasm may vane, or people might change their workload and many find it difficult to dedicate time to the maintenance of the network. This can be overcome by paying for the maintenance work, but most often the compensation offered is not competitive with emoluments payed by telecom operators for the same kind of works.

3) Labor force turnaround

This is related with the previous issue. It has happened that people working in community networks acquire technical marketable skills and are later offered jobs in other organisations. Therefore, a continuous on the job training of community networks employees is required to substitute for people that left for greener pastures.

4) Evolution of the legal framework

In many countries in Latin America, voice over IP services were banned and only small operators where offering them. Later the legislators had to surrender to the evidence and began allowing the offer of voice over IP services, which brought down considerably the cost of international calls. Some community networks' business cases were based on low cost overseas voice calls and the changing of the regulations annihilated their business plan. The work we have been carrying out with the TV White Spaces technology, which can provide significant benefits for community networks and also for cloud in community networks, has encountered an obstacle in the fact that the legal status of the access to the TV spectrum in Europe is still been discussed, while in the US[1] and in other countries a legal framework is in place for reaping the fruition of such technology.

5) Evolution of the technology

Many community networks started offering basic services at modest speeds using wireless technologies that were adequate to satisfy the untapped demand. As time passed, they could not keep up with the growing requirements from their customers who aspired at greater speeds and lower latencies, like those offered by commercial service providers which relied on ADSL or fibre networks. Some community networks have been able to meet this challenge by adopting fibre technologies as well, but this requires a complete new set of skills, equipment and often additional legal exigencies.

In the dynamic world of technology, the user's needs and the best way to satisfy them are constantly evolving, therefore the assessment of sustainability is an ongoing process. This is particularly relevant at this time of the project, since we are still experimenting with some of the cloud services to identify the best suited to the particular needs of community networks. Cloud based services are provided by a software distribution that is hosted inside the cloud infrastructure. Service discovery and distributed storage are examples of these services.

A summary of the main technology elements and involved actors is given in the following:

- **Software Distribution.**
  The software distribution runs on the underlying infrastructure and hardware layers, i.e. it runs in the containers or virtual machines of the community cloud. Using a software distribution provides a way to pack and distribute a common set of cloud platform services.
- **Containers and Virtual Machines.**
  The elements of this layer are containers or virtual machines given as infrastructure service. They are created by the cloud management platform. The virtual machines are the environment where the community software distribution is installed.
- **Cloud Management Platform.**
  This layer contains the software needed to manage the cloud platform. It coordinates the underlaying hardware layer with the software distribution layer using standard Linux tools and manages the containers and virtual machines layer. Examples of popular open source cloud management platforms are OpenStack[2], OpenNebula[3], and Proxmox[4]. Clommunity has developed Cloudy[5] to better suit the needs of the community networks.
- **Hardware.**
  This layer represents the cloud hardware layer. Given the heterogeneity of devices in community networks, this hardware can range from high-end servers to low-end resource-constraint home gateways, and even single board computers like the Alix boards[6], Beagle Bone Black[7]

[1] http://www.fcc.gov/encyclopedia/white-space-database-administration
[2] http://www.openstack.org
[3] http://opennebula.org
[4] http://www.proxmox.com/es
[5] https://redmine.confine-project.eu/projects/cloudy
[6] http://www.pcengines.ch/alix.htm
[7] http://beagleboard.org/bone

and Raspberry Pi[8]. The hardware is connected to the community network through the network nodes. The latter are particularly useful in sensor applications, where the power consumption and cost of the device are significant factors. Components of the cloud management software are installed on it to manage the hardware as cloud resources. Other cloud nodes we have deployed are several Dell OptiPlex 7010 desktops and HP Compaq Elite towers. Since the number of deployed cloud resources in Guifi is in constant evolution, the status of cloud deployment at any can be seen in the Clommunity project's Wiki.

- **Community Network.**

  This is the community network within which the community cloud is deployed. For this project Guifi.net is our target for deploying the cloud infrastructure, since it is the largest community network worldwide, with over 25000 deployed nodes and it has a very active users community.

- **Users and Cases**

  Several stakeholders should become users of clouds in community networks: Community network users, municipalities, educational institutions, SMEs (Small and Medium Enterprises)

  The following scenarios can be developed: a) Community network users: Using application services (e.g. owncloud, Tahoe, video on demand, video streaming). b) Municipalities: explore hybrid cloud approach, e.g. for storage/backup for IoT, provide information about air quality in different parts of the cities gathered by means of the Wireless Sensors Network. c) Education: use community cloud as infrastructure to perform educational tasks, video on demand and video streaming can be exploited for educational purposes, as well as for storage of other content. d) SMEs: Usage of the community cloud for hosting, e.g. storage for IoT applications, usage of computational service for system development.

[8] http://www.raspberrypi.org

2 Socio-technical evaluation

2.1 Analysis of the social effort in participatory networks

2.1.1 Introduction

Community networks are a socio-technical and cooperative ecosystem where, as we expected, user involvement varies among the participants because of their multiple personal and collective interests and objectives.

This participation can be measured in multiple ways and it is not limited to the deployment and and maintenance of physical devices, links or the cloud infrastructures. Community networks usually have participatory forums where users can contribute to the growth and improvement of the network and the whole system. Some community networks maintain on-line discussion forums while others use mailing lists ororganisee face-to-face meeting activities. The particular combination of participatory forums on a community network varies from one to another, but the objectives are always the same: help users to organisee and help new members to integrate into the network.

For the success of Clommunity it is highly important to understand the socio-technical participatory schema adapted in the community network and to find methods to incentivise members to participate in less alluring but nevertheless necessary activities. A previous work [6] reported that community networks members considered finding and keeping volunteers the largest organisational challenge, next to funding and finding people able to do maintenance works, which were the second most important challenge.

During our analysis we focused on Guifi.net [7], the largest (mostly wireless) community network to the best of our knowledge. Guifi.net is defined as a free, neutral and open access wireless telecommunication network built upon an interconnection agreement in which each new participant is given the right to use the network for any purpose that does not harm the operation of the network or the freedom of other users, the right to know and learn any detail of the network and its components and the freedom of joining or extending the network abiding to the same conditions. Guifi.net gave us easy access to the information we needed to complete our study.

2.1.2 Participative schema

The participative scheme of Guifi.net, as that of most community networks, is composed of two related components: the technical deployment and maintenance of the network, and the social interaction between users. In the following we describe these components.

- **Technical deployment and maintenance.**
  The network consists of a set of nodes interconnected, mostly by wireless rooftop equipment although also by fibre optic cable that users -– different stakeholders such as individuals, companies, administrations or universities — must install and maintain. The network grows in response to the needs of the stakeholders. New links are established to satisfy the connectivity needs of their owners or indirect beneficiaries (e.g. users of a community network crowd-funded by municipalities). Hence, there is no prior overall growth planning, and for that reason

the structure of the network follows the geographical distribution of interested people.

The values of freedom and participation of the community network allow users to decide where and when to set up new nodes of the communication network, provided they follow the community agreement. According to the network agreement, for those nodes to be part of the community network, there must be an extension of a node already connected, thus extending the existing network in the process. In practical terms, this requires coordination between owners of nodes and newcomers. Hence, the regular flow when a new or previously existing user wants to attach a new node to the network is: a) check the viability through the public website of Guifi.net b) contact the owner of the connecting node using the participatory social tools making both of them responsible for set-up, configuration and testing of the new link,c) the user must register the new node location in the website in order to inform other members of its existence and to download the node's firmware. Hence, deploying a new node, or improving the connectivity for an existing one, is difficult without the cooperation of the owner/manager of the communication device to which to connect. These interactions can be partially captured in the community website.

The community website contains information about the infrastructure of the network – like the location of the nodes, the hardware specifications, the owner/s – and is used by the members of the community networks to plan and organise the deployment of new hardware and services or to perform status monitoring. Using the public information and a dump of the Guifi.net web database, we were able to relate owners with their active devices, which allowed us to evaluate the individuals' participation in the most technical part of the ecosystem.

- **Social interactions.**

  Social participation in Guifi.net changed along the community network lifetime. When the network started in 2004, the members used on-line forums and mailing lists as interaction tools. Nowadays, mailing lists are the only on-line and social participatory forums left. Lists are usually created by initiative of one or more members to cover a specific communication need, like coordinate tasks, inform about the progress of a particular project of put into contact the users of the network in some specific geographic area.

  Additionally the Guifi.net Foundation maintains two general-purpose mailing lists to coordinate users and developers since 2006. The first one of, *users-list*, is described by their members as a "Guifi.net general users mail list". In practical terms, it is mainly used to discuss general topics, issues on coordinating physical infrastructure creation and maintenance and to help new users. The other one, *dev-list*, is described as a "Research & development mailimg list for Guifi.net project" and serves as a communication channel between some of the most active members in Guifi.net, most of them developers. Each mailing list is currently managed independently and contains only a small subset of the users registered in the web page – i.e. the dev-list reports 401 different users registered, while the Guifi.net web-page reports 13,407. However, they are a valuable source of information to understand how the social interactions occur inside the community.

  This information is public and accessible through the community network mailing-lists dump in the Guifi.net website. We used web scraping to gather it and reconstruct all the conversations since the beginning of both mailing lists. The resulting data set is a great source of information about the behaviour of each individual and the interactions among them, but it is also a useful source to analyse the evolution of the community and the relations between the social part and the technical one.

The sinergy and influence between both participatory forums has been patent since the creation of the Guifi.net mailing lists in their cycles of long and short members' participation. Figure 2.1 shows the activities done day by day by network members in each participatory forum as the simple moving average at intervals of approximately one month (30), quarter of a year (90) and one year (360). We observe that users' participation oscillates from long periods of high activity to short periods of less activity, at the same time in both lists. We identify the periods of lower activity, as those that correspond to the last quarter of every year, which approximately fits with the Spanish winter season.

Recently, the cycle of less technical activity – which started approximately at the end of the second year of the project – has been extended after a long period of increasing activity which lasted for 77 months. It is caused by a slowdown of new users registered over the past 4 years. As a consequence, the building and development of new technologies related with the network is, increasingly, more and more a responsibility of senior users. As an example, we calculated that 80% of the new working devices are installed and managed by users registered more than two months earlier.

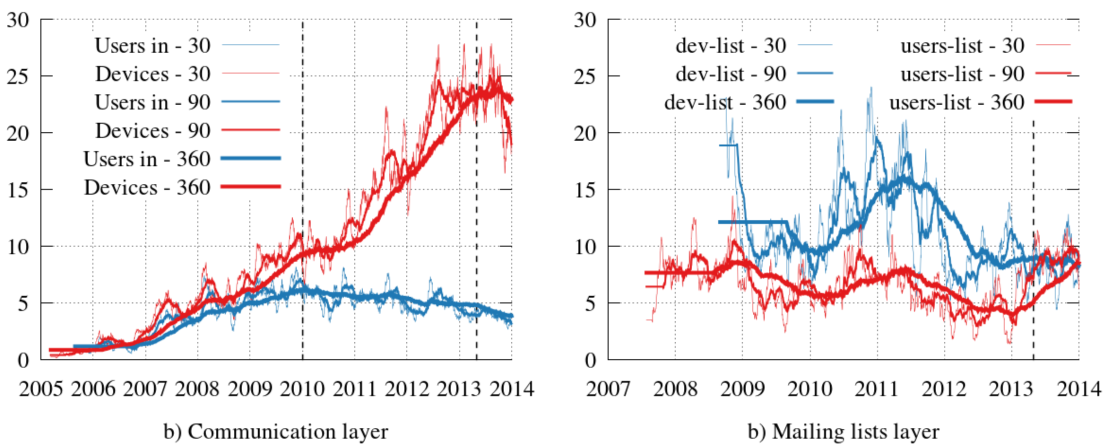

Figure 2.1: Participants' evolution in the participative scheme

The participation on the development mailing list, instead, changed the trend along the development of the Clommunity project. There could be many factors that incentivised such changes, but we believe that the new developments around the tools and software related with Clommunity had a positive influence. Half a year later, the social participation of the users – measured as their activity in both mailing list – also increased to similar levels.

2.1.3 Community networks as a participative ecosystem

The analysis of the different components of the ecosystem gives us an idea about the degree of involvement of the users into both the technical and the social aspects of the network. However, our interest lies in the intersection between both activities and how participants balance their effort between them. To that end, we measured the number of messages and devices created by each user who we were able to identify in both layers, which is summarised in fig. 2.2. We observe that most of the users are selective and choose to collaborate only in one of the participatory forums, contributing with little or nothing to the other. For example, there is a high concentration of users participating in the development mailing list, but these are users which contributed only with one or two devices to the physical communication network.

The difference of interest shown by users is an important observation about their behaviour, because it highlights the need to rethink the metric to evaluate community members according their interests,

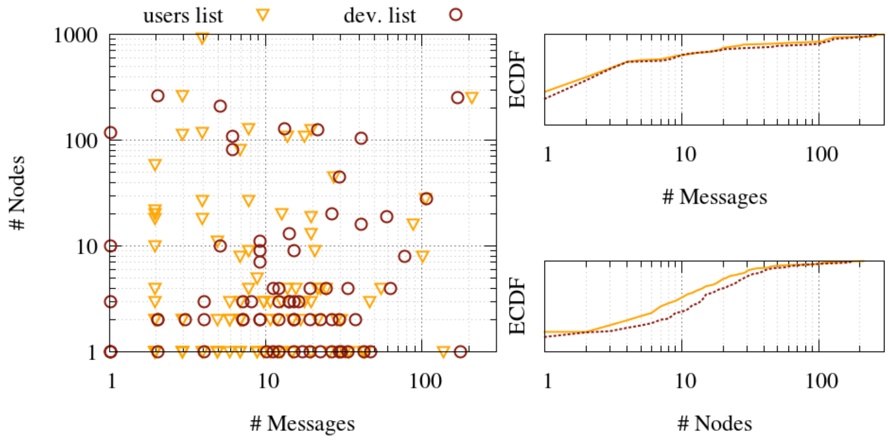

Figure 2.2: Guifi.net users participation measured as the number of messages posted in the mailing lists users-list and dev-list, and the number of new communication devices.

rather than their global work contributed to the community. In practical terms, it is noticeable that the set of cloud managers – those that will provide or develop resources and services to Clommunity – could be very different to the set of cloud users – the consumers. It could have important implications, for example, on inactivation mechanisms that regulates the assignment of resources between users based on their contribution.

This asymmetry of participation also occurs internally in both forums of the ecosystem. While some users may post and answer a lot of messages, other will only participate sporadically. This dichotomy has been captured in fig. 2.3, which shows the empirical cumulative distribution function (ECDF), plotted as the Lorenz curve, of users participation. As before, the participation is measured separately as the number of new devices created by users and the number of messages exchanged in one of its participatory mailing list. The Gini coefficient [8], measured as the area between the line of equality and each of the curves, is close to the absolute inequality in both participatory forums – 0.8358 in the devices creation and 0.8320 in the message exchange.

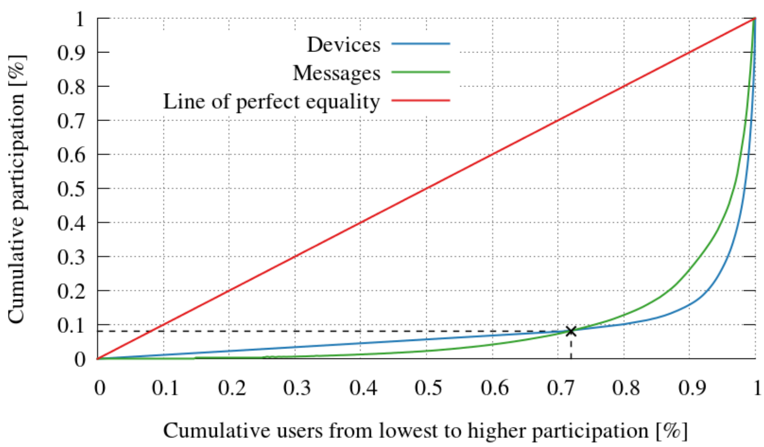

Figure 2.3: Gini coefficient of two participatory forums in Guifi.net.

The intersection of both distributions of the Lorenz curve makes them not comparable, but it states a difference in their distribution function, which suggests that network members behave differently in terms of internal participation in the examined ecosystem.

2.1.4 Communities and social roles

Our interest in the organisational structure of the community network is to understand the causes and consequences of the different levels of involvement between their members. Community structure is a common characteristic shown by most complex networks, which allows us to discuss common properties among their members. We analyse the existence or not of community structures linked to the prominent mailing lists and to the physical deployment of the network. Each boxplot in fig. 2.4 summarises the nodes composition of communities detected in the ecosystem by applying two different techniques. Members not belonging to any community are not represented.

In order to perform our study, we replicated part of the analysis performed in [9], which conducted work on a multiplex and multi-layer analysis of on line and off line users' interaction, where the authors discuss the existence of weak and strong ties among community members.

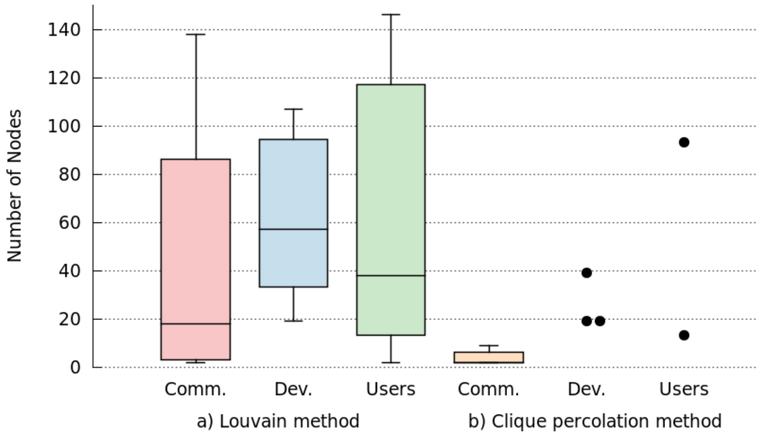

Figure 2.4: Number of nodes by community. Comm., Dev. and Users refer to the physical activities, development list and users list participative forums.

- **Clique percolation method.**

  The clique percolation method [10] is based on the detection and aggregation of k-clique disjoints sets inside the graph, which will have maximum connectivity among their members. As the optimisation is done locally, some members could be part of more than one community. Additionally, communities sub-graph are disjoint.

  Using this method, we find that it is possible to divide all participatory forums into several disjoint communities, where 75% of them have between 2 and 147 users. The median size of the communities formed by members working in the physical infrastructure represents less than 1% of the users, while in the case of the development and users mailing lists it represents 14.4% and 7.11% respectively of the users.

- **Clique percolation method.**

  The Louvain [11] is an optimised algorithm to find partitions of large scale networks very fast, providing that the modularity (the relationship between average degrees inside the community and intra communities) is minimised. As a result, we have a graph partition where all nodes are forced to belong to one and only one community.

  The analysis of the participatory forums using this method reveals another community structure, enclosed by a core group of members. While the core group in the mailing list is formed by a small portion of users – from 17.28% in the users layer to 9.97% in the development mailing list

– the core group of participants in tasks related with the physical infrastructure is the 86.24% of the participants, representing almost the entire network.

Despite the size and the distribution of users into smaller or bigger communities, it is necessary to perform a relationship analysis in order to capture the possible roles and social structure of the community network. Fig. 2.5 shows how communities are related by analysing the distribution of social ties (structural links). Note that 74.38% of the links that happen between users building and maintaining physical devices are internal – meaning that occurs between members of the same community – and only 25.62% of the interactions are between members of two different communities. As a result, we can conclude that these participants are organised – voluntarily or not – in a two-tier structure with users geographically close showing high participation among them. This preferential interactions are not present in the mailing lists.

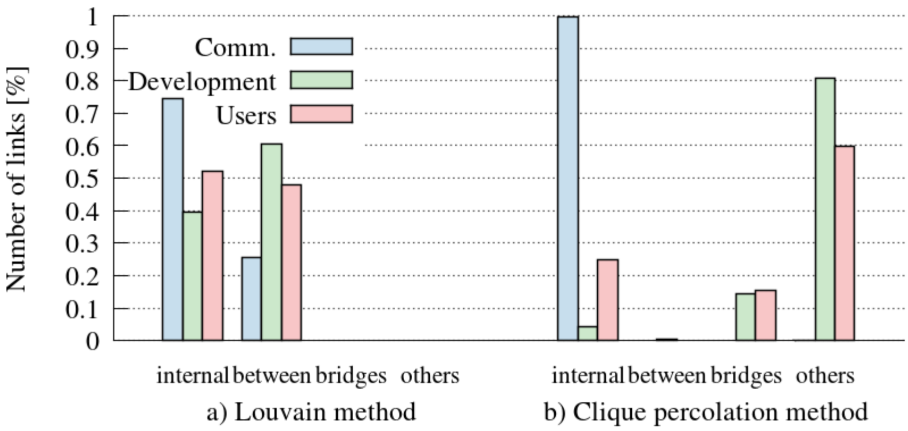

Figure 2.5: Links distribution between communities. Bridges are links between two participants, both members of the same community, but one of them member of another community, too. Others are links to nodes which do not belong to any community.

However, when we allow the algorithms to find communities with heterogeneous sizes and relations between them – like in the Clique percolation method – the social structure of the mailing lists participants appears. Fig. 2.5 shows that in such cases, participants show less ties among members of their communities than with other participants in the mailing list. Communities are connected only through bridges, suggesting that both mailing lists face a two-tier structure too, but with several cores coordinated by some of the members.

2.1.5 Practical implications

The work performed makes several contributions to the analysis of member participation in a community network, which as we said, are important to the deployment of regulation mechanisms. Both forums of the socio-technical ecosystem show a hierarchical structure, where participants are divided in two structural layers. However, while the members of the community working in nodes deployment and infrastructure maintenance are coordinated by a single core, the participants in the mailing lists are governed by more than one core. As a result, social on-line forums are more robust with regard to the disappearance of the most prominent members.

Fig. 2.6 shows the robustness of each participatory forum, when the authority members – those chosen as better source of information according the HITS algorithm [12] – are recursively removed in the

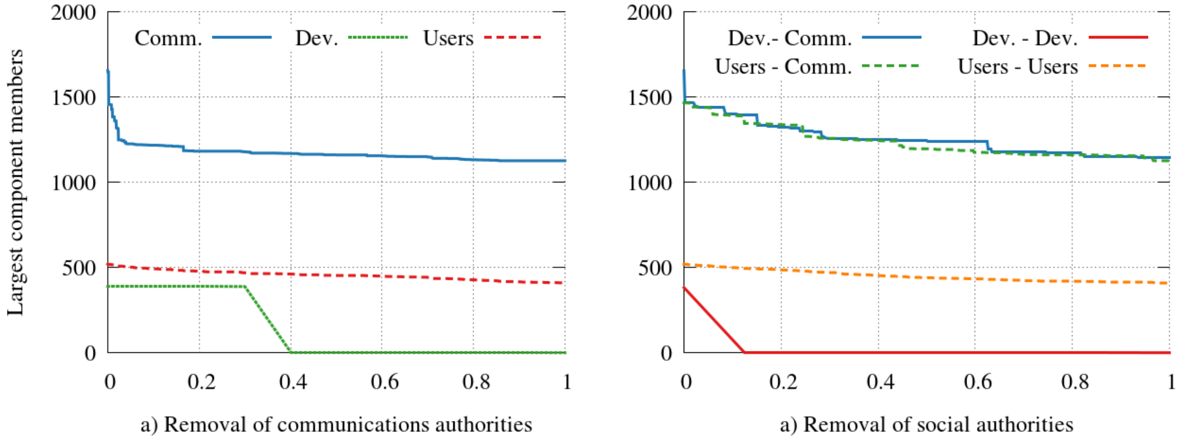

Figure 2.6: Users dependency in the socio-technical ecosystem.

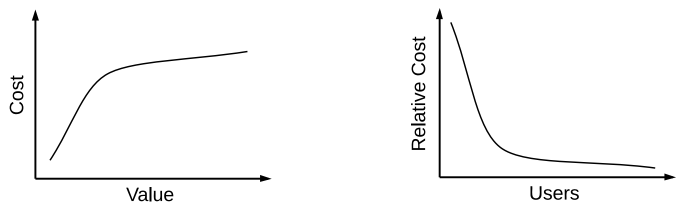

Figure 2.7: Relationship between cost and value in evolution of community cloud

ecosystem. Ideally, when an authority is removed, we expect the size of each network to be reduced only by one member – the authority itself. However, if the authority removed is essential to maintain the connectivity between members of the participative forum, we expect some other members getting disconnected – and the size of the biggest component reduced.

Examining the ecosystem robustness in case of the disappearance of members from a given forum, we observe a huge impact on the dev-list mailing list, and a moderate impact on the physical participants' network. However, the graph structure of the users-list mailing list makes it indifferent to these removals, even of their authorities. Thus, we can argue that the progress of the network in the technical aspect is more dependent on individual contributors.

2.2 Cost and Value Relationship in Community Clouds

The community clouds can be seen as private enterprises with private provisioning of public goods. This model can suffer from social dilemmas, like the tragedy of the commons, meaning that free riding and under-provisioning will destroy the system in the absence of any mechanisms to overcome these issues. The socio-economic context of community networks implies that mechanisms that foresee social exclusion can be effective to direct the users' behaviour [13].

Figure 2.7 shows the desired relationship between the cost and value proposition as the community cloud evolves and gets adopted by wider audience. In the nascent stage, the community cloud will not be able to provide much value until a critical mass of users are using the system. After that threshold, still the relative cost to achieve a little utility will be significant, which means that the early adopters of the system remain highly motivated and committed to the success of community cloud and continue to contribute resources even though they receive little value from the system in return. But once a significant proportion of the overall population has joined the community cloud, the relative cost to obtain value from the system tumbles and in the longer run the system is able to sustain itself with contributions that may be small in size but are made by a large number of users. The objective of the economic mechanisms and the social and psychological incentives is to let the system transition from inception through early adoption to finally ubiquitous usage.

2.2.1 Costs of Participation

The initial costs of setting up nodes in the community cloud involves hardware costs including the price of the computing and networking equipment, and installation costs including the manual labour needed. The continuous operation of the cloud node requires additional costs including network costs due to network bandwidth payment and any other subscription fees, energy costs to pay for electricity bills to run the computer equipment as well as cooling apparatus, maintenance cost to fund any technical support and replacements for parts, and hosting costs to provide storage space for the equipment. Besides these costs at the individual level, there are also the transaction costs [14] or management overheads for group coordination and collaborative production efforts necessary for the operation of community cloud.

2.2.2 Value Proposition

The individuals in community cloud act as private enterprises where they offer services to generate revenue. The revenue for the community cloud users include tangible benefits like the services and applications that they will be able to consume, and intangible benefits like the sense of belonging to the community and personal satisfaction because of their contributions. The services can range from infrastructure to platform to software services covering a gamut of different needs of the users. Once the community cloud gets adopted by a critical mass, the community may also generate revenue by offering computing resources to commercial enterprises, similar to selling excess power capacity in the case of Smart Grids. For example, a community can get into partnership agreements with the ICT providers where the community can buy network bandwidth in return for providing access to the computing resources of the community cloud.

2.2.3 Comparison with Commercial Services

We discuss the community cloud cost and value in comparison with two popular commercial services that are also based in part on the idea of reciprocal sharing, Spotify[1] and Skype[2]. Spotify is a subscription-based music streaming service which reduces its infrastructure and bandwidth costs by serving cached content from users' devices as well as from its own servers. Skype is a communication service which uses caches on users' devices for storing and processing information required for managing the underlying infrastructure. Both Spotify and Skype offer free as well as paid services. Why do users agree to contribute resources, even when they are paying for the service?

An argument is that the costs for users are minimal. Both services consume storage space, computation time, power and bandwidth on the users' devices. Since these resources are not very expensive and the services' usage remains relatively low, the users do not mind this arrangement or do not even notice it. But even more important, these services are designed so intuitively that most users do not

[1] http://www.spotify.com

[2] http://www.skype.com

realise that they are donating the resources, and even when they do, the value these services provide is a sufficient incentive.

The success of such services implies that also for the community cloud the users should be able to join with zero or very little costs. The value proposition of the community cloud services should be strong enough to attract early adopters and keep them committed. The economic mechanisms in place for encouraging reciprocal sharing and ensuring overall system health and stability should be either invisible for non-technical users or very simple to understand and work with.

2.3 Elements and Components of a Socio-technical Framework

We discuss here the the elements we propose for a socio-technical framework for community clouds, integrating relevant issues of the technical, social, economic and legal aspects of the community cloud system we have observed from the development, deployment and evaluation work.

2.3.1 Commons License

The agreement and license to join a community cloud should encourage and help to enforce reciprocal sharing for community clouds to work. The Wireless Commons License[3] or Pico Peering Agreement[4] is adopted by many community networks to regulate network sharing. This agreement could serve as a good base for drafting an extension that lays out the rules for community clouds.

2.3.2 Peering Agreements

When different community clouds federate together, agreements should ensure fairness for all the parties. Agreements between different communities should describe the rules for peering between clouds. Within such agreements, local currency exchanges could be extended to address cases of imbalance in contribution across different zones [15].

2.3.3 Ease of Use

The easier it is for users to join, participate and manage their resources in the community cloud, the more the community cloud model will be adopted. This requires lowering the startup costs and entry barriers for participation. To this end, in terms of an institutional policy, we have developed the Cloudy Linux-based distribution[5], to be used in the Guifi.net community cloud [16]. It will make the process of joining and consuming cloud services almost automated with little user intervention. This effect will make the community cloud appealing to non-technical users.

2.3.4 Social Capital

Community clouds need to appeal to the social instincts of the community instead of solely providing economic rewards. This requires maximising both bonding social capital [17] within local community clouds in order to increase the amount of resources and commitment of the users, and bridging social capital in order to ensure strong cooperation between partners in federated community clouds.

[3] http://guifi.net/es/ProcomunXOLN
[4] http://www.picopeer.net
[5] http://repo.clommunity-project.eu

Research on social cloud computing [18] has already shown how to take advantage of the trust relationships between members of social networks to motivate contribution towards a cloud storage service.

2.3.5 Transaction Costs

The community cloud, especially in its initial stages, will require strong coordination and collaboration between early adopters as well as developers of cloud applications and services, so we need to lower the transaction costs for group coordination [14]. This can take advantage of existing Guifi.net's mailing list[6], but also from the regular social meetings as well as from social and software collaboration tools. It also requires finding the right balance between a strong central authority and decentralised and autonomous mode of participating for community members and software developers.

2.3.6 Locality

Since the performance and quality of cloud application in community networks can depend a lot on the locality, applications need to be network and location aware, but this also requires that providers of resources should honour their commitment to local community cloud implying that most requests are fulfilled within the local zone instead of being forwarded to other zones. We have explored the implications of this earlier when studying the relationship between federating community clouds [19, 20].

2.3.7 Overlay Topology

Community networks are an example of scale-free small-world networks [21], and the community cloud that results from joining community networks users is expected to follow the same topology and inherit characteristics similar to scale-free networks. As the overlay between nodes in the community cloud gets created dynamically [22], the community cloud may evolve along different directions as users of the underlying community network join the system. As the applications in community cloud will most likely be location and network aware to make the most efficient use of the limited and variable resources in the network, the overlay steered concentration and distribution of consumers and providers of services direct the state and health of the community cloud.

2.3.8 Entry Barriers

In order to control the growth of the community cloud and provide a reasonable quality of experience for early adopters and permanent users, different approaches can be considered, for example, a community cloud open to everyone, by invitation only, or one that requires a minimum prior contribution.

2.3.9 Role of Developers

The developers of the cloud applications are expected to play an important intermediary role between providers of resources and consumers of services, for example adding value to the raw resources and selling them to consumers at a premium. End users could have both the roles of raw resource providers and consumers which find the value of the cloud in the provided applications.

[6] http://guifi.net/en/forum

2.3.10 Service Models

Cloud computing offers different service levels, infrastructure, platform and software-as-a-service (SaaS). Similar to the three economic sectors for provisioning goods, the third level, the SaaS of the cloud reaches the end users. For providing value from the beginning in the community cloud, we propose to prioritise provisioning SaaS at the early stage of the community cloud.

2.3.11 Value Addition and Differentiation

The community cloud requires services that provide value for users. In addition, these services need to compete and differentiate from the generic cloud services available over the Internet. In this line, FreedomBox[7] services focus on ensuring privacy, and FI-WARE CoudEdge[8] and ownCloud[9] let cloud applications consume resources locally.

[7] http://freedomboxfoundation.org
[8] http://catalogue.fi-ware.eu/enablers/cloud-edge
[9] http://owncloud.org

3 Sustainability model

Sustainability of the community network infrastructure: In order to ensure the maintenance of the already deployed network, the Guifi Foundation has started establishing a sustainability model where SMEs would contribute to the community in return for the resources they use. The experience gained will help to extend the model from the networking level to the community service level.

Value proposition: Nowadays most of the traffic generated by community users is towards the Internet. However to ensure the independence and sustainability of the network, the Guifi.net Foundation is trying to push the usage and deployment of services inside the community network. The cloud based solutions are a perfect framework to accomplish such purpose. CLOMMUNITY's micro community clouds are expected to create new business models, beyond the currently common Internet selling business. Companies might offer IaaS, PaaS and SaaS services to the community users with an improved quality of experience (in comparison with the current Internet public cloud providers), since the users get the service from a very local environment (the same network), thus bandwidth and latency would make a important performance difference. SMEs are encouraged by the Guifi foundation to exploit and elaborate on these new opportunities.

We first analyse the strategy and the tools of guifi.net developed at network infrastructure level and then we discuss if they are suitable for Clommunity by identifying the adaptations needed.

This section is based on the works elaborated in two research papers [4] [5].

3.1 Crowdsourcing tools for designing, deploying and operating network infrastructure held in commons

3.1.1 Guifi.net Principles

Guifi.net is built upon the two following main principles: the network infrastructure is envisaged as a common pool resource and coexistence of voluntarism and economic activity as the mean to ensure the sustainability of the project.

3.1.1.1 Network infrastructure as a Common Pool Resource

The underlying principle behind guifi.net is the firm conviction that the optimal way to manage a network is doing it as a common pool resource (CPR) [23], being the network infrastructure the core resource, which is nurtured by the network segments the participants deploy to reach the network or to improve it, and the return is the connectivity they get.

Some of the immediate benefits of this paradigm scheme are:

- Disappearance of the multiplicity of infrastructure because all participants operate on the same common infrastructure.
- Increase of the efficiency of the infrastructure, as a consequence of the previous point.
- Costs savings, also environmental, as a consequence of the first point.

- Cost of access savings, not only due to the first point, but also because pricing is cost-oriented (fair trade oriented).
- Empowerment of the citizens to bring the network where needed, 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.

Nonetheless, as any other CPR, CNs are fragile. More precisely, they are congestion prone, because connectivity is a zero sum game, and subject to the free-rider problem. 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* [24]. The network license and the conflict resolution procedure are examples of these tools.

Collaboration tools and public information sets must also be in place to make the CPR possible. Aside from the standard mailing list and WEB forums, guifi.net has developed a set of software tools to ease the design, deployment, management and operation of the network in a self-provisioning style.

3.1.1.2 Sustainability: Voluntarism and economic activity coexistence

Voluntarism is in the roots of guifi.net, with evidence in the current activity in the mailing lists or the number of self-organised community events and the number of attendees. This is not incompatible with the understanding that a key success factor for the sustainability of any project is the existence of a solid economic activity. Guifi.net is a success case of coexistence of both. Project steering tasks are part of the voluntary community activity, while the professional community takes care of attending the service demands. Governance tools play a critical role in keeping the voluntary-professional relationship balanced.

The main sources of economic activity are, on the one hand those related to the infrastructure deployment and maintenance, and on the other the services delivered over the network. Infrastructure services are possible because while people have the right to carry out tasks on their own, they can also relay on professional services, as long as the community rules are observed. Although Internet access is still the most popular service, other initiatives such as VoIP and remote backups have also been offered for a long time. New services such as video streaming and video on-demand are becoming popular, specially in the areas served with optical fibre. The professionals offering infrastructure services are commonly referred as *installers* and content providers as *operators*. These activities are typically done by self-employed individuals and SMEs that frequently combine installer and operator activities. Most of the professionals perform volunteer activities as well.

Similar to the balance that must be found between volunteers and professionals, a balance among professionals is also needed because although they can compete for customers, they must coordinate and collaborate since they are using a shared infrastructure to reach their customers. A system with several type of agreements based on the level of commitment with the commons and an economic compensation system for the investment and resource consumption are the pillars of this collaboration.

The guifi.net Foundation (Fundació Privada per a la Xarxa, Lliure i Neutral guifi.net) is the reference organisation that was founded by the guifi.net community. As such, it plays a vital role for the coordination and management of the guifi.net ecosystem. Nonetheless its power is rather limited because, as the rest of the participants, it just owns the part of 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.

3.1.2 Implementation

This section describes the tools that, to our understanding, play a critical role in the guifi.net ecosystem.

The network started as a result of experimentation to find ways to create amateur networking infrastructures in remote rural areas, ignored or underserved by commercial ISP, taking advantage of open spectrum, open software and inexpensive WiFi devices. Bringing a network to new locations requires coordination for planning the links, configuring the hardware, aligning antennas, etc. In addition, new tasks such as planning the topology including the number of links, its capacity, coordinating routing, address allocation, etc. become more and more critical.

Guifi.net started in 2004 as a group of people who met regularly for network planning and deployment. Along with the expansion of the network, the participants also debated over ways to structure the fast growing community. That resulted in the application of many tools that, except for the mailing lists, have been developed specifically for guifi.net and are used by the guifi.net community. These tools are in constant evolution in order to better put the commons model into practice. They are presented below in roughly chronological order.

3.1.2.1 Network management and provisioning software tools

The community of guifi.net has developed a set of software tools to ease the design, deployment, management and operation of the network in a self-provisioning style and supporting crow sourced 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[1]. All these tools are publicly available as free software. Automation is essential to reduce the learning curve and to avoid human mistakes. Public information sets are essential to make the network implementable.

Network map tool Network planning requires maps and several tools to calculate distances, line of sight clearance and select neighbour nodes. It is necessary to combine geographic maps with network maps to collect and share all the knowledge about the network and the people involved in it.

IPs assignment and routing configuration IPs assignment and routing configuration is fully automatised.

singleclick The configuration of all routers is fully automatised. 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 node setup.

Community Network Markup Language (CNML) The CNML[2] is an XML specification developed in guifi.net through which guifi.net database information is presented. All interactions should be done through it.

Network monitoring A fully distributed network monitoring system has been developed and implemented. It has been key to help the community to visualize usage and identify problems or bottlenecks.

Network crowd funding Since very early a tool was developed to coordinate the collection of voluntary contributions of money to fund new or upgrading nodes or links that could benefit

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

[2]http://en.wiki.guifi.net/wiki/CNML/en

directly or indirectly several users. The tool allows to create a proposal with a detailed plan with a description of the project, its cost and a deadline for contributions. If the target budget is met in 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 satisfying the need for new nodes for the benefit of several citizens.

Expenditures declaration A tool to allow the expenditures declaration has been developed as part of the economic compensation system. It also allows to know with a great precision the total amount of investment.

3.1.2.2 Participation tools

There are many means of participation. The following are the most significant ones.

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

Mailing lists Mailing lists[3] it is one of the most used communication means. There are global, territorial and thematic mailing lists. They are open by default[4].

Social Media A social platform[5] 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 usually weekly or monthly based. A global guifi.net community meeting usually happens once a year, it is itinerant and always hosted by a different local group. In addition, at least one or two guifi.net members attend the most important international events.

3.1.2.3 Network Commons License (NCL)

NCL[6] is the license which every guifi.net participant must subscribe. Its preamble[7] sets the fundamental principles and the articles precisely establish the participants 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

[3] https://llistes.guifi.net/sympa/

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

[5] http://social.guifi.net/

[6] http://guifi.net/en/FONNC. *Llicència de Comuns per a la Xarxa Oberta, Lliure i Neutral (XOLN)* in Catalan http://guifi.net/ca/CXOLN

[7] FONN Compact preamble:

- *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.*

many community members, reaching a consensus, revised and approved in several versions by the community assembly.

3.1.2.4 The Foundation

The guifi.net Foundation aims at giving a legal identity to guifi.net. Its foundational mission is to protect and promote the network held in commons. As part of protection actions, it maintains the FONN Compact and enforces its compliance when necessary. As part of the promotion activities, it carries out strategic and innovative projects and operates critical parts of the network infrastructure. It builds and maintains a set of tools (e.g. IP address space, legal identity, possibility to operate under its name) available to anyone, professionals included, who need them to expand the network. It also does many dissemination activities. The Foundation is composed by the Board of Directors (unpaid) and the workers. It is funded from the services it gives to the professionals (e.g. activities in the Network Operation Center (NOC), operation of the economic compensations system) and from specific projects to which it may participate (e.g. research projects, consulting activities).

3.1.2.5 Collaboration agreements

Collaboration agreements are aimed at strengthening the legal certainty derived from the NCL. These agreements result from the experience of many specific agreements over the years. Nonetheless, the set of agreement models must remain manageable.

Professionals Any professional who wants to carry out economic activities involving guifi.net infrastructure must sign a professional agreement with the Foundation. As part of the agreement, the professional must state its level of commitment to the commons. There are tree options, *type A*, all the infrastructure deployed by the professional is contributed to the commons, *type B*, a part of the professional infrastructure is contributed to the commons, and *type C*, the professional does not contribute any infrastructure to the commons (that is to say, they use what is available but does not contribute at all). The agreement implies the acceptance of a set of Service Level Agreements (SLAs) aimed at facilitate the coexistence among the professionals. Once the agreement is signed, the professional is included in the economic compensations system and is allowed to benefit form the Foundation tools for operators (e.g. wholesale Internet access, Local Internet Registry, Internet eXchange point participation).

Third parties The Foundation also establishes agreements with third parties such as public administrations, private companies or universities. Through these agreements public administrations eschew their legal limitations to participate in telecommunication activities and limit responsibilities which fall outside of the scope of their standard tasks, specially for small and middle size administrations[8]. Agreements with public administrations are rather common and most of them follow the same model. Agreements with private companies are rather specific and infrequent. They are used to set specific collaboration agreements either with the Foundation itself or to extend the collaborations to other entities that already have agreements with it. University agreements are used mostly for mentoring students and for undertaking research projects.

[8] 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, underserved areas, etc.) and under very special conditions (separate account, self-financed, etc.)

Table 3.1: guifi.net CAPEX estimation (Sep. 2014)

		Quantity [units]	Estimated average cost [/u.]	Total []
	WiFi node	25,500	250	6,375,000
	OF node	100	250	150,000
	PoPIX	12	2,750	33,000
Commons				**6,558,000**
	PoPIX	12	2,750	33,000
Interconnection				**33,000**
TOTAL				**6,591,000**

3.1.2.6 Conflicts resolution system

A systematic and clear procedure for resolution of conflicts with a scale of graduated sanctions has been developed[9]. 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 are charged to the loosing party or to both parties in case of a tie. This system has developed from the experience and has defined a precise manner to help in addressing these conflicts in a quick and standard way, with help from lawyers, while scalable for a growing community.

3.1.2.7 Economic compensations system

The economic compensations system has been developed and implemented to compensate 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 done 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[10]. In addition professionals are allowed to charge a reasonable amount for opportunistic connections[11] until their investment is covered.

3.1.3 Impact

According to guifi.net Foundation estimations presented in 3.1 and Table 3.2, the estimated capital expenditure (CAPEX) of the infrastructure built in commons is already over 6.5M and its estimated Operating expenditure (OPEX) around 208,400 per month, that is to say, over 2.5M per year.

Figure 3.1 presents the data about penetration of the bandwidth and Internet access penetration in the households of Catalonia per in 2013 released by the public Catalan Statistics Institute (*Institut*

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

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

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

Table 3.2: guifi.net OPEX estimation (Sep. 2014)

		Quantity [units]	Estimated average cost [/u./month]	Total [/month]
	WiFi node	25,500	8	204,000
	OF node	100	8	800
	PoPIX	12	300	3,600
Commons				**208,400**
	Proxies	100	60	6,000
	PoPIX	12	300	3,600
	CATNIX	1	600	600
	Uplink	2	1,000	2,000
	Colo Bar	1	1,500	1,500
	Colo Vic	1	200	200
	RIPE-NCC	1	150	150
	Provi.	1	4,000	4,000
	admin.	1	1,500	1,500
	techn.	1	1,500	1,500
	Insura.	1	70	70
Interconnection				**11,050**
TOTAL				**228,650**

Català d'Estadística (IDESCAT)[12]) per county It also contains the Internet access 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 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 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 or Baix Ebre are also above when compared to similar counties but where guifi.net presence is irrelevant.

Osona has about 9,000 nodes[14]. Combining this number with others coming from IDESCAT[15], we

[12] http://www.idescat.cat

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

[15] 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. Rate of 0.1 supernodes to

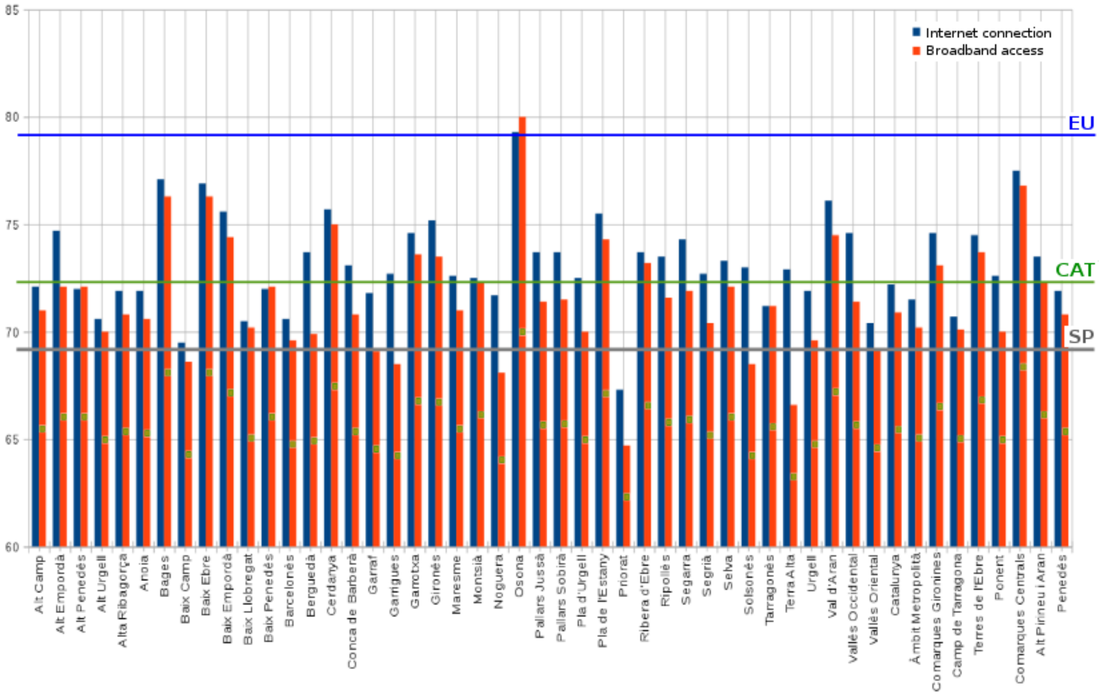

Figure 3.1: Households bandwidth and Internet access in Catalonia per county (*comarca*) in 2013. Source: IDESCAT [13]

conclude that about 22,4% of the Osona inhabitants have guifi.net access: around 30,500 people.

3.2 Specific issues of the sustainability model for community cloud computing

In this section we discuss the applicability of the sustainability model that was described in the previous section and is used by Guifi for the network level, for community network clouds.

3.2.1 Cloud singularities

The following differences of cloud resources compared to the network infrastructure have been identified.

Building elements At network level, the building elements of the common resource are the nodes and the links and the network provides bandwidth which everybody can use. For the cloud, the building set is not so well defined because, since in addition to the physical level, where the host device (the *server*), is a single element, the cloud software stack (IaaS, PaaS and SaaS) is very likely to be part of a larger resource set due to the critical role each of layers plays and the interaction among them.

Dependency and usage of other resources The resulting asset at the network level is a primary infrastructure, that is to say, it has no inherent dependencies on other infrastructures. This is not the case for the cloud, which inherently depends on the network for the federation/interconnection of the servers and for putting theses resources and the users in contact. The

nodes; estimation half of them not installed in homes.

consequences of the deployment of an infrastructure with such dependencies must be studied not only from the additional traffic point of view, but also from a more theoretical prospective to answer questions such as, must the dependant infrastructure, i.e. the cloud, contribute to the infrastructure on which it depends, i.e. the network?

Roles of professionals At the network level the roles of community network members evolved as follows. At the beginning all the work was done by volunteers. It was the time to start the project, to learn from the experience, to start formalising concepts, etc. When the infrastructure started to be stable and the initial atomisation tools had been put in place, the position of the *installer*, the individual who is paid to make installations, appeared. With the advent of the optical fibre and the increase of Internet connection demand, the position of the *service provider* appeared. For community clouds, is there the need for local SMEs which take over the role to offer tailored cloud-based services to community needs?

Infrastructure vs. services division It seems that the rule that is applied for the network infrastructure level, ”the Guifi.net community takes care of the infrastructure as a CPR, the content is left up to the users”, can also be applied to the cloud level, but the criteria to determine what must be considered content and what is considered infrastructure must be set.

3.2.2 Principles

The reasons that apply at network level to the conception of the contributed infrastructure as CPR, e.g. standardisation of resource management, interoperability of individual contributed resources, need for ease of contribution by users, seem also to stand for citizen community clouds. With a set of essential IaaS, PaaS cloud services given as CPR, enhanced and aggregated SaaS services may be built upon them and offered on a per-profit model. Previous volunteer computing proposals, e.g. [25], often addressed the trading of virtual machines (VMs) corresponding to the cloud IaaS, upon which users would deploy their services. VMs and basic cloud services as part of the CPR, however, would enable trading already at the level of complex services built upon this CPR. Similar to how the network CPR reduced the entry barrier for SMEs (by network transparency, neutrality, reduced CAPEX and OPEX cost), which enabled SMEs to offer added network services for profit, a cloud infrastructure hold as CPR might have the same effect, allow SMEs to easily offer value added tailored cloud-based services upon a complex CPR.

The coexistence of volunteer and for-profit participants, already happening at the network level, is desired to extend to the cloud level. Thus, the conception of the resources needed to build the cloud (the hardware and the software) as a CPR will establish a framework for the contributions and the collaboration between volunteers and for-profit professionals, similarly to what has been built at the network level.

3.2.3 Recap of design principles

We recapitulate in this section the design principles given by [23]. These principles provide theoretical foundations and were derived by the author from observing CPRs that are governed successfully. We annotate some initial comments towards their applicability and/or correspondence with the CPR community cloud case.

1. Group boundaries are clearly defined. Comments: Clommunity introduced the concept of microclouds to address social or technical boundaries. In the resource pool the microclouds, however, are expected to federate among each other.

2. Rules governing the use of collective goods are well matched to local needs and conditions. Comments: Clommunity generates a type of community cloud which by its definition matches the needs and conditions of its community. These needs are local ones.

3. Most individuals affected by these rules can participate in modifying the rules. Comments: The licence already in place in Guifi.net and foreseen to be extended for community clouds is expected to arise from the participation of the individual members.

4. A system for monitoring member's behavior exists; the community members themselves undertake this monitoring. Comments: Usage and contribution of resources will need to be monitored and should be addressed in coordination with the compensation system.

5. A graduated system of sanctions is used. Comments: Apply the concepts of the existing system of sanctions at Guifi.net.

6. Community members have access to low-cost conflict resolution mechanisms. Comments: Apply the concepts of the existing system for conflict resolutionat Guifi.net.

7. The rights of community members to devise their own rules is respected by external authorities. Comments: Local rules, e.g. within the scope of microclouds, should be possible and respected.

8. For CPRs that are parts of larger systems: appropriation, provision, monitoring, enforcement, conflict resolution, and governance activities are organized in multiple layers of nested enterprises. Comments: Community network clouds seen as CPR match this case.

3.3 Framework for establishing and maintaining cloud-based services in Guifi.net

As in the case of the network infrastructure, the implementation of the CPR at the cloud level requires effective rules and tools. The design principles identified in [23] for the institutions to govern successfully the collective action for a CPR inspired the tools which are presented in this section. We determine and materialize in the following the tools needed to implement the Guifi community network cloud as a CPR.

3.3.1 Software tools:

In the same way as for the network infrastructure, a set of software is required to ease the tasks of deploying the infrastructure and applications.

Software distribution In order to facilitate the adoption of the required software components, a GNU/Linux software distribution containing all of them has been developed. The distribution, named *Cloudy*[16], is delivered as a standalone version and as a LXC[17] container. The main interaction interface is a Web-GUI and the users are given the option to register the services at the Guifi.net website . Cloudy is expected to have a similar role in terms of standardisation and unification at cloud infrastructure and services level as the Guifi.net website has at network infrastructure level. All Cloudy software is free software developed under Clommunity[18], an EU-funded project, aimed at addressing the obstacles for communities of citizens

[16] http://repo.clommunity-project.eu/
[17] https://linuxcontainers.org/
[18] http://clommunity-project.eu/

in bootstrapping, running and expanding community-owned networks that provide community services organised as community clouds.

Infrastructure as a Service (IaaS)

Virtual machines A service for allocating and managing virtual machines (VMs) is a key enabler of cloud uptake. In Cloudy the service is implemented using OpenVZ technologies through OpenVZ Web Panel[19].

Platform as a Service (PaaS)

Distributed announcement and discovery of services (DADS) In a peer-production context it is essential to have an effective mechanism to find the services available. Similarly, the services announcement mechanism must be as automated as possible. DADS, a distributed service for announcement and discovery of services which uses the Serf[20] gossip protocol for exchanging information about the active services available between nodes, has been developed as a core component of Cloudy. The discovered services are presented to the user grouped by categories and, in similar fashion as the real-time information about nodes availability, information about the convenience of each of them is presented to the user. DADS is a significant advance compared to the previous Guifi.net system to announce services which on a manual list in the website.

Authentication service Through this service the tedious task of authentication of users is done by a recognised independent third party. The concept is a result of the evolution of the solution to authentication needs of the federated proxy system. Currently, it is implemented using LDAP in a redundant master-slave architecture hosted and operated by the Guifi.net Foundation. The requests are done in a self-service fashion and the request validations are done by the proxy operators.

Software as a Service (SaaS)

Guifi.net services The three main services of a Guifi.net server have been integrated in Cloudy:

DNS Service to participate in the Guifi.net DNS system for the resolution of internal addresses (RFC1918). The declarations must be done via the Guifi.net website. Implemented with BIND[21].

Network monitoring service Instance to contribute to the network monitoring system. It is implemented using the SNMP feeding RRDtool[22] buffer rings.

Proxy The federated proxies system accounts for hundreds of Internet gateways contributed by volunteers. The federation is implemented by using the Authentication service of the Guifi.net Foundation. This way any validated user can access any of the federated proxies. The service is base on Squid[23].

Third-party services The following third-party services are currently integrated in Cloudy:

syncthing A decentralised cloud storage system[24] with cryptographic features which gives full control to the users over where their data is replicated.

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[19] https://code.google.com/p/ovz-web-panel/
[20] https://www.serfdom.io/
[21] https://www.isc.org/downloads/bind/
[22] http://oss.oetiker.ch/rrdtool/
[23] http://www.squid-cache.org/
[24] https://syncthing.net/

PeerStreamer A peer-to-peer media streaming framework[25] with a streaming engine for the efficient distribution of media streams, a source application for the creation of channels and a player applications to visualize the streams.

Tahoe-LAFS fault-tolerant encrypted decentralized cloud storage system[26] which distributes the user data across multiple servers in replicated data chuncks. Even if some of the servers fail or are taken over by an attacker, the entire file store continues to function correctly, preserving user privacy and security.

WebDAV server A set of extensions to the HTTP protocol which allows users to collaboratively edit and manage files on remote web servers[27]. In Cloudy it is implemented enabling and configuring the corresponding Apache WEB server module.

3.3.2 Participation tools:

Mailing lists Two mailing lists to give support to Cloudy users have been set, one is for users[28] and the other for developers[29].

Website A website devoted to Cloudy[30] and a wiki with technical information[31] [32] have been set up.

Developer community To contribute to the development of Cloudy or report bugs, users can register at the dev site[33].

3.3.3 License:

We think that a community cloud license (CCL) which harmonises the contributions and usage of the cloud resources will play a key role in the take-up process of the cloud model in a similar way as the influence of the network license has had on the network infrastructure. The license must take into account facts like the relationship between users and service providers, service providers to service providers, etc. and also the coexistence with the NCL, which, as already said in the previous section, must be accepted by any participant to join the community cloud. The CCL has not been established yet. Similar to the NCL process, the steps to write the CCL licence will go through consultations of the community. We argue that the license must cover at least the following aspects.

Service level agreement Mainly to distinguish between the best effort services given for free and the payed ones. As already discussed, the promotion of economic transactions is crucial for the sustainability and expansion of the ecosystem.

Privacy In an architecture where sensible data is distributed across the network, privacy protection must start from the license and be implemented with the latest technical solutions.

Fair use Rules of conduct and means of control should be specified in order to avoid abuse of the common resource.

[25] http://peerstreamer.org/
[26] https://www.tahoe-lafs.org/trac/tahoe-lafs
[27] http://www.webdav.org/
[28] https://llistes.guifi.net/sympa/info/cloudy-users
[29] https://llistes.guifi.net/sympa/info/cloudy-dev
[30] http://cloudy.community/
[31] http://wiki.clommunity-project.eu/,
[32] http://en.wiki.guifi.net/wiki/What_is_Cloudy/
[33] http://dev.cloudy.community

Transparency and accountability As already discussed, accountability is essential in any CPR and thus, so is the access to information.

3.3.4 Reference authority:

The fact of having a license is tightly related to the existence of an authority which maintains it and makes sure that it is respected. A decision on the convenience and the viability of having such organisation must be made. Existing organisations such as the Guifi.net Foundation can be considered to fulfil this role.

3.3.5 Collaboration agreements:

The same way as at the network infrastructure level the commitment of the operators with the commons is expressed through an agreement, a system of collaboration agreements for the cloud shall contribute to enhance confidence among operators offering cloud services. It must be investigated if a graduated commitment system applies to cloud services and/or if it must be service specific.

3.3.6 Conflicts resolution system:

The already existing system for the resolution of conflicts can be applied to cloud issues.

3.3.7 Economic compensations system:

As general goal, the economic compensations system should measure in commercial exploitations what amount of the CPR cloud was used. Potential services, however, are very diverse and their resource usage is complex, and a one fits all solution seems not to be possible, although the principles of Guifi.net should be met (see section 3). The approach to follow is therefore to adapt and shape the compensation system with the upcoming exploratory commercial services, and start with using as base the concept of the existing compensation system. This approach will give experience and feedback to be shared with the community. The compensation system has to evolve in a collaborative process, allowing the participation of the community members in its design. The already existing compensations system may be used as a base for its operation, but the metrics and the costs must be adapted to fit to the cloud conditions.

The engagement of an SME exploring a commercial backup service extending Cloudy's Syncthing and Tahoe-LAFS service is currently under study. This service could offer additional features compared to Dropbox, a service often used by community network members and consumed in Internet. The storage capacity already available in the community cloud could be used as starting point, which would reduce the cost of initial hardware investment for the SME. With Syncthing, the sharing of folders could be done in a more fine-grained way than in Dropbox, which could attract users. If the SME is commercially successful, the economic compensation system for the community cloud will make the SME to invest back into the cloud CPR, contributing to the community cloud sustainability.

Beyond using resources of cloud hosts, the impact that cloud services usage may have on the network infrastructure level must also be investigated, its effect on the economic compensations system of the network, especially in the case of commercial services, and if its current calculation system, which is based on the total traffic at the Internet Exchange, must be changed.

4 Conclusions

Our work contributed to the understanding of the socio-technical system behind Guifi and community network clouds. A scientific study on the socio-technical interactions in the Guifi network was carried out. In addition, an analysis of the cost-value proposition in community infrastructures indicated that once a critical mass of users has been achieved, then the value/cost relation becomes more favourable, which could lead to a large number of users joining the cloud after the basic infrastructure deployment is achieved.

Then, we presented the components of a model for the sustainability of the infrastructure held in commons, which was exemplified by corresponding implementations in Guifi.net. We discussed the applicability of this model to cloud computing resources, and presented a framework and components, which materialize it for the community network cloud case.

It is clear that the key for eventually understanding this type of commons infrastructures requires a large multi-disciplinary effort, well beyond our project. Community initiatives have raised and disappeared. Others have been ”alive” for several years, though stagnating. Guifi.net is a remarkable exception, which with more than 25.000 nodes and it continues to grow, contradicting the belief that an infrastructure held in commons cannot be sustainable. By proposing a model for community network clouds based on CPR, we have contributed a solution to the challenge of making community services sustainable.

Bibliography

[1] A. M. Khan and F. Freitag, "Exploring the role of macroeconomic mechanisms in voluntary resource provisioning in community network clouds," in *11th International Symposium on Distributed Computing and Artificial Intelligence (DCAI 2014)*. 1.1

[2] ——, "Sparks in the fog: Social and economic mechanisms as enablers for community network clouds," in *Advances in Distributed Computing and Artificial Intelligence Journal, Vol 3, No 8 (2014)*, 2014. 1.1

[3] D. Vega, R. Meseguer, and F. Freitag, "Analysis of the social effort in multiplex participatory networks," in *11th International Conference on Economics of Grids, Clouds, Systems and Services (GECON 2014)*, 2014. 1.1

[4] R. Baig, R. Roca, F. Freitag, and L. Navarro, "Crowdsourcing tools for designing, deploying and operating network infrastructure held in commons," in *Submitted to Special Issue on Crowdsourcing Elsevier Computer Networks*, 2014. 1.1, 3

[5] R. Baig, L. Navarro, and F. Freitag, "On the Sustainability of Community Clouds in Guifi.net," in *12th International Conference on Economics of Grids, Clouds, Systems and Services (GECON 2015)*. Cluj-Napoca, Romania: IEEE, 2015. 1.1, 3

[6] J. Avonts, B. Braem, and C. Blondia, "A questionnaire based examination of community networks," in *Wireless and Mobile Computing, Networking and Communications*, ser. (WiMob). IEEE, 2013, pp. 8–15. 2.1.1

[7] "Guifi.net: Open, Free and Neutral Network Internet for everybody," http://guifi.net/en. 2.1.1

[8] C. Gini, *On the Measure of Concentration with Espacial Reference to Income and Wealth*. Cowles Commission, 1936. 2.1.3

[9] D. Hristova, M. Musolesi, and C. Mascolo, "Keep your friends close and your facebook friends closer: A multiplex network approach to the analysis of offline and online social ties," in *Weblogs and Social Media*, 2014. 2.1.4

[10] G. Palla, I. Derényi, I. Farkas, and T. Vicsek, "Uncovering the overlapping community structure of complex networks in nature and society," *Nature*, vol. 435, no. 7043, pp. 814–818, 2005. 2.1.4

[11] V. D. Blondel, J.-L. Guillaume, R. Lambiotte, and E. Lefebvre, "Fast unfolding of communities in large networks," *Journal of Statistical Mechanics: Theory and Experiment*, vol. 2008, no. 10, 2008. 2.1.4

[12] J. M. Kleinberg, "Hubs, authorities, and communities," *ACM Comput. Surv.*, vol. 31, no. 4es, 1999. 2.1.5

[13] M. Greiff, "Rewards and the private provision of public goods on dynamic networks," *Journal of Evolutionary Economics*, vol. 23, no. 5, pp. 1001–1021, Sep. 2013. 2.2

[14] R. H. Coase, "The Nature of the Firm," *Economica*, vol. 4, no. 16, pp. 386–405, Nov. 1937. 2.2.1, 2.3.5

[15] M. Punceva, I. Rodero, M. Parashar, O. F. Rana, and I. Petri, “Incentivising resource sharing in social clouds,” *Concurrency and Computation: Practice and Experience*, Mar. 2013. 2.3.2

[16] J. Jiménez *et al.*, “Deploying PaaS for Accelerating Cloud Uptake in the Guifi.net Community Network,” in *IEEE International Workshop on the Future of PaaS 2014*, Boston, Massachusetts, USA, Mar. 2014. 2.3.3

[17] J. S. Coleman, “Social capital in the creation of human capital,” *American Journal of Sociology*, vol. 94, pp. pp. S95–S120, 1988. [Online]. Available: http://www.jstor.org/stable/2780243 2.3.4

[18] K. Chard, K. Bubendorfer, S. Caton, and O. F. Rana, “Social Cloud Computing: A Vision for Socially Motivated Resource Sharing,” *IEEE Transactions on Services Computing*, vol. 5, no. 4, pp. 551–563, Jan. 2012. 2.3.4

[19] A. M. Khan, U. C. Büyükşahin, and F. Freitag, “Towards Incentive-Based Resource Assignment and Regulation in Clouds for Community Networks,” in *GECON 2013*, ser. LNCS, J. Altmann, K. Vanmechelen, and O. F. Rana, Eds. Springer, Sep. 2013, vol. 8193, pp. 197–211. 2.3.6

[20] ——, “Prototyping Incentive-based Resource Assignment for Clouds in Community Networks,” in *28th International Conference on Advanced Information Networking and Applications (AINA 2014)*. Victoria, Canada: IEEE, May 2014. 2.3.6

[21] D. Vega, L. Cerda-Alabern, L. Navarro, and R. Meseguer, “Topology patterns of a community network: Guifi.net,” in *1st International Workshop on Community Networks and Bottom-up-Broadband (CNBuB 2012), within IEEE WiMob*, Barcelona, Spain, Oct. 2012, pp. 612–619. 2.3.7

[22] A. Nakao and Y. Wang, “On Cooperative and Efficient Overlay Network Evolution Based on a Group Selection Pattern,” *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*, no. 2, pp. 493–504, Apr. 2015. 2.3.7

[23] E. Ostrom, *Governing the commons: the evolution of institutions for collective action*. Cambridge University Press, Nov. 1990. [Online]. Available: http://www.cambridge.org/us/academic/subjects/politics-international-relations/political-economy/governing-commons-evolution-institutions-collective-action 3.1.1.1, 3.2.3, 3.3

[24] G. Hardin, “The tragedy of the commons,” *Science*, vol. 162, pp. 1243–1248, December 1968. [Online]. Available: http://www.sciencemag.org/cgi/reprint/162/3859/1243.pdf 3.1.1.1

[25] A. M. Khan, U. C. Buyuksahin, and F. Freitag, “Incentive-based Resource Assignment and Regulation for Collaborative Cloud Services in Community Networks,” *ournal of Computer and System Sciences (JCSS)*, 2014. 3.2.2

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