Sparks in the Fog: Social and Economic Mechanisms as Enablers for Community Network Clouds

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KEYWORD

community cloud, cloud computing, community networks, economic mechanisms, collaborative resource sharing

ABSTRACT

Internet and communication technologies have lowered the costs of enabling individuals and communities to collaborate together. This collaboration has provided new services like user-generated content and social computing, as evident from success stories like Wikipedia. Through collaboration, collectively built infrastructures like community wireless mesh networks where users provide the communication network, have also emerged. Community networks have demonstrated successful bandwidth sharing, but have not been able to extend their collective effort to other computing resources like storage and processing. The success of cloud computing has been enabled by economies of scale and the need for elastic, flexible and on-demand provisioning of computing services. The consolidation of today's cloud technologies offers now the possibility of collectively built community clouds, building upon user-generated content and user-provided networks towards an ecosystem of cloud services. We explore in this paper how social and economic mechanisms can play a role in overcoming the barriers of voluntary resource provisioning in such community clouds, by analysing the costs involved in building these services and how they give value to the participants. We indicate socio-economic policies and how they can be implemented in community networks, to ease the uptake and ensure the sustainability of community clouds..

1 Introduction

Recent developments in communication technologies like Internet, email and social networking have significantly removed the barriers for communication and coordination for small to large groups bringing down the costs that obstructed collaborative production before the era of Internet (Shirky 2008). The ICT revolution ushered in group communication and collaborative production with popular applications now widely adopted, like social networking, social bookmarking, user-generated content, photo sharing, and many more. Even infrastructures based on a cooperative model have been built, for example community wireless mesh networks gained momentum in early 2000s in response to limited options for network connectivity in rural and urban communities (Braem et al. 2013). Using off-the-shelf network equipment and open unlicensed wireless spectrum, volunteers set up wireless networks in their local communities to provide network and communication infrastructure. These wireless networks have proved quite successful, for example there are several large community networks in Europe, having from 500 to 20,000 nodes, such as Athens Wireless Metropolitan Network (AWMN) (Athens Wireless Metropolitan Network (AWMN) 2014), Freifunk (Freifunk 2014), FunkFeuer (FunkFeuer 2014), Guifi.net (Guifi.net: Open, Free and Neutral Network Internet for everybody 2014), Ninux.org (Ninux.org Wireless Network Community 2014), and many others worldwide. Figure *1* shows the wireless links and nodes of Guifi.net in the area around Barcelona. Community networks successfully operate as IP networks, since the nodes' bandwidth is shared among all the members in a reciprocal manner.

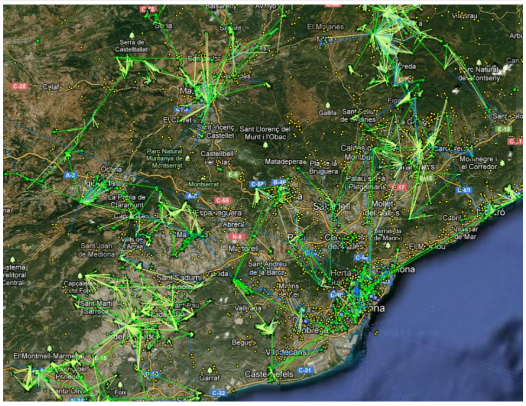

Figure 1: Guifi.net nodes and links in Barcelona

Despite achieving sharing of bandwidth, community networks have not been able to extend this sharing to other computing resources like storage. There are not many applications and services used by members of community networks that take advantage of resources available within community networks. Community networks are based on voluntary contributions of participants, and economic or social incentives to encourage this have been crucial to achieve the sustainability of the community networks (Bina and Giaglis 2006). Apparently the current incentives in community networks are not su□cient enough to overcome the barriers for realising the sharing of other computing resources besides just bandwidth. Applications have a challenging environment to cope with when deployed in community networks, which are characterized by:

- Hardware and software diversity: The network nodes and computers are often inexpensive off-the-shelf equipment with large heterogeneity in the hardware, software and capacity.
- Decentralized Management: The network infrastructure and the computers are contributed and managed by the users. They belong to the users and are shared to build the network. There is usually no (or a rather weak) central authority that is responsible for resource provisioning.
- Dynamics: The number of network and computing nodes may rapidly change when members join or leave the network, or when nodes overload or fail.

Sharing of computing resources in the Internet is now commonplace because of the wide adoption of cloud computing model (Buyya, Broberg, et al. 2011). Cloud computing provides on-demand, elastic, flexible and cost-effective access to computing resources. Today's clouds are mainly provided upon a pay-per-use model, where the cloud services are offered to the consumers as a utility and by commercial providers. Cloud computing allows enterprises and individuals to reduce significantly the time and capital investment in setting up their own infrastructure. Instead, they can request resources on demand from the cloud services providers, which not only lowers the total cost of ownership for consuming resources because of economies of scale, but leaving low level details to the service providers focus can be shifted towards building and using high level applications. This also applies that an individual or organisation is no longer limited by the resources present locally and owned directly. When demand exceeds the current capacity, more resources can be requested on the fly from one or more cloud services providers. This has relevance for community networks as the members in aggregate boast much more resources than owned by a single individual or a small group. When members of community network can share and trade resources based on a cloud computing model, they can sell their excess capacity as the demand fluctuates and in return can take advantage of services and applications that were not possible earlier due to the limited resources locally.

The concept of community clouds has been introduced in its generic form before, e.g. (Mell and Grance 2011; Marinos and Briscoe 2009), as a cloud deployment model in which a cloud infrastructure is built and provisioned for an exclusive use by a specific community of consumers with shared concerns and interests. We refer here to a specific kind of a community cloud in which sharing of computing resources is from within community networks, using the application models of cloud computing in general. Members of community network can share and trade resources, they can sell their excess capacity as the demand fluctuates and in return can take advantage of services and applications that the community cloud enables, which were not possible earlier due to the limited resources on the users' local machines. Realising community cloud involves a lot of challenges both in technological and socio-economic context, but also promises interesting value proposition for communities in terms of local services and applications.

Our main objective in this paper is to explore the social and economic mechanisms that can help in adoption and growth of community cloud model. We contribute first a cost-value proposition describing the conditions under which community clouds should emerge. Secondly, we propose a set of technical, social and economic policies that, if placed in community networks, should accelerate the uptake and help the sustainability of community clouds. In our earlier work, we have explored how incentive-based resource regulation (Khan et al. 2014; Khan et al. 2013; Buyuksahin et al. 2013) and economic policies (Khan and Freitag 2014) can affect collaboration among the members of community networks, and how the scalability issues can affect the design of a community cloud system (Khan, Sharifi, et al. 2013). We have looked into potential distributed architecture for community cloud (Khan, Selimi, et al. 2014), and we are also building a prototype system to be deployed in Guifi.net community network (Jiménez, Baig, Freitag, et al. 2014; Jiménez, Baig, Escrich, et al. 2013), and investigating the performance of cloud services in these real-world settings (Selimi, Freitag, et al. 2014; Selimi and Freitag 2014; Selimi, Florit, et al. 2014).

The rest of the paper is organised as follows. Section *2* provides background to the community networks and introduces possible cloud scenarios in community networks. Section *3* discusses our cost-value proposition of community clouds, and section *4* proposes different mechanisms for enabling participation in community clouds. Section *5* presents the related work, and section *6* concludes and indicates future work.

2 Cloud Scenarios in Community Networks

We consider clouds in community networks, a community cloud that provides services built from using resources available from within the community networks and owned and managed by the members of the community networks themselves. Such a community cloud infrastructure that is deployed in real community networks needs to be designed according to the conditions and characteristics of community networks, which also determine the most likely scenarios for these community clouds.

2.1 Background on Community Networks

A community network like Guifi.net is organised into zones where a zone can be a village, a small city, a region, or districts of a larger city. Mostly, the detailed technical support for the members is only available within the community of their zone (Vega et al. 2012), so we identify a zone to have the highest social strength within the community network. The computer machines or nodes in a community network vary widely in their capacity, function and capability, as illustrated in Figure *2*. Some hardware is used as super nodes that have multiple wireless links and connect with other super nodes to form the backbone of the community network (Vega et al. 2012). Others act just as clients and are only connected to the access point of a super node. As depicted in Figure *2*, resources for the community cloud can be attached to the networking nodes.

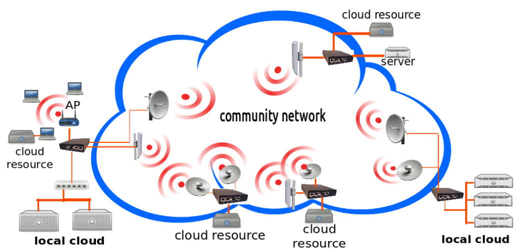

Figure 2: Nodes in a community network with cloud resources

2.1.1 Social aspects of community networks

Personal and social relationships play an important role in the community network deployment. The deployment of new nodes requires the collaboration among people. If a new node is deployed, the owners of the neighbouring nodes need to connect with it, thus there has to be an interaction among the people. Two types of social networks can be observed from Guifi.net's mailing list (Guifi.net's Forum and Mailing Lists 2014). One is at the global level of the whole Guifi.net network. In this list, technical issues are discussed. People from any part of Guifi.net community participate, and even external people who are interested can take part. The second type is the local social network, between node owners within a zone and between neighbouring zones. They use local mailing lists as well as hold weekly meetings.

Guifi.net is organized into zones. A zone can be a village, a small city, a region, or a district of a larger city. The organization of the group within a zone is of many types. Mostly the interests, available time and education of the people drive what happens in the zone. We note that while the allocation of IP addresses and layer 3 networking is agreed among all Guifi.net zones, as it is needed to make the IP network work, the detailed technical support is rather given within the local community of the zone. Therefore, we identify a zone to have the highest social strength within the community network.

2.1.2 Members of community networks

Participants of community networks are principally consumers and producers of the network. Most of them as producers contribute infrastructure and time to the networks, while as consumers they use the available services the network offers. The community network, however, is not maintained solely based on the contribution of infrastructure. Some users must also contribute with their time and knowledge. Time is needed, for instance, for maintenance tasks, which might require technical knowledge or not. Technical knowledge is required because the network is an IP network, which needs to be managed and configured.

2.1.3 Resource sharing in community networks

Community networks are a successful case of resource sharing among a collective. The resources shared are networking hardware but also community network participants' time that they donate, to different extent, for maintaining the network. While the community network infrastructure is the sum of the individual contributions of wireless equipment, the network operation is achieved by the contribution of time and knowledge of the participants. This is because even under the decentralized management of the equipment, the owner of the device ultimately has the full access and control of that network device.

Reciprocal resource sharing is, in fact, part of the membership rules or peering agreements of many community networks. The Wireless Commons License (WCL) (Wireless Commons License for Open, Free & Neutral Network (OFNN) 2010) of many community networks states that the network participants that extend the network, e.g. contribute new nodes, will extend the network in the same WCL terms and conditions, allowing traffic of other members to transit on their own network segments. Therefore, resource sharing in community networks from the equipment perspective refers in practice to the sharing of the nodes' bandwidth. This sharing, done in a reciprocal manner, enables the traffic from other nodes to be routed over the nodes of different node owners and allows community networks to successfully operate as IP networks. We observe that in most community networks the focus at the moment is on the bandwidth sharing alone. There is not much awareness about sharing other computing resources, such as storage or CPU time, inside of community networks.

2.1.4 Ownership of nodes in community networks

Community networks grow organically. Typically a new member that wants to connect to the community network contributes with the hardware required to connect to other nodes. A node of a community network therefore belongs to the member who is its sole owner. Such a node is normally located in the member's premises.

Although less typical, a few nodes in Guifi.net have also been successfully crowd-funded if such a node was needed by several people. Crowd-funding of a node happened when for a group of people an infrastructure improvement was necessary. For example, an isolated zone of Guifi.net established a super node to connect to other zones. In such a case, the node has been purchased with the contributions of many people. The location of such a node follows strategic considerations, trying to optimize the positive effects on the performance that are achieved with the addition of the new infrastructure. We can see that both the options, individual ownership and crowd-funding of resources, occur in practice and could be considered for community clouds.

2.1.5 Services in community networks

Services and applications offered in community networks usually run on the machines that the member connects to the network and these machines are used exclusively by that member. The usage of the community network's services among its members, beyond that of access to the Internet, is however not very strong.

2.2 Local Community Cloud

The cohesive nature of zones gives rise to the scenario of the local community cloud, interpreting the characteristics of the social networks existing within zones and the topology of the community network. In this scenario, some super nodes with their better connectivity and high availability are responsible for the management of a set of attached nodes that are contributing cloud resources.

2.3 Federated Community Cloud

Local community cloud can provide services for the users within its zone. Multiple cloud nodes from different zones in a community network, however, can participate together in a federated community cloud to support greater functionality and higher capacity. The nodes in a given zone are directly managed by a super node in that zone but they can also consume resources from other zones, given that there is a coordination mechanism among zones in place. Within an economic context, the local community cloud is an example of a virtual organisation, and the federated scenario represents the peering agreements between multiple virtual organisations.

3 Cost and Value Relationships in Community Cloud

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 (Greiff 2013).

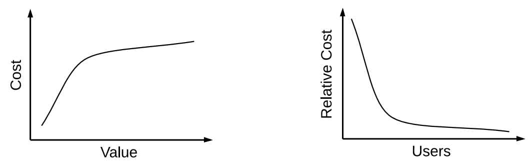

Figure 3: Relationship between cost and value in evolution of community cloud

Figure *3* 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.

3.1 Costs for Participation

The initial costs for 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 given by donating network bandwidth 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 (Coase 1937) or management overheads to direct the group coordination and collaborative production efforts necessary for the operation of community cloud.

3.2 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 meeting a spectrum of different needs of the users. Once community cloud gets adopted by a critical mass, community may also generate revenue by offering computing resources to commercial enterprises, similar to selling excess power capacity in the case of Smart Grid. For example, community can get into partnership agreements with the ICT providers where community can buy network bandwidth in return for providing access to the computing resources of the community cloud.

3.3 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 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, and even when they are paying for the service?

An argument is that the costs for users are minimal. Both services mostly consume storage, 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 not even notice it. But even more important, these services are designed so intuitively that most users do not even realise about donating the resources, and even when they do, the value these services provide has su□cient incentive.

The success of such services implies that for community cloud as well, 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.

4 Design of Social and Economic Policies

We discuss in this section the social and economic policies we propose for community clouds, addressing relevant issues of the technical, social, economic and legal aspects of the community cloud system. We approach the problem by having explored some of the mechanisms previously in simulations (Khan et al. 2013) and also by developing a prototype implementation which is currently deployed in the Guifi community network (Jiménez, Baig, Freitag, et al. 2014) and which will allow to get users involved and participating in a real world scenario.

4.1 Commons License

The agreement and license to join a community cloud should encourage and help enforce reciprocal sharing for community clouds to work. The Wireless Commons License (Wireless Commons License for Open, Free & Neutral Network (OFNN) 2010) or Pico Peering Agreement (Pico Peering Agreement v1.0 2005) 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.

4.2 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 (Punceva et al. 2013).

4.3 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 a Linux-based distribution[3], to be used in the Guifi.net community cloud (Jiménez, Baig, Freitag, et al. 2014). 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.

4.4 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 (Coleman 1988) 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. Research on social cloud computing (Chard et al. 2012) has already shown how to take advantage of the trust relationships between members of social networks to motivate contribution towards a cloud storage service.

4.5 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 (Coase 1937). This can take advantage of existing Guifi.net's mailing list[4], but also of the regular social meetings and other 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.

4.6 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 (Khan et al. 2013; Khan et al. 2014).

4.7 Overlay Topology

Community networks are an example of scale-free small-world networks (Vega et al. 2012), 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 (Nakao and Wang 2010), 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.

4.8 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.

4.9 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.

4.10 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 prioritize provisioning SaaS at the early stage of the community cloud.

4.11 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 services focus on ensuring privacy, and FI-WARE CoudEdge and ownCloud let cloud applications consume resources locally.

5 Related Work

The idea of collaboratively built community clouds follows on from earlier distributed voluntary computing platforms, like BOINC (Anderson 2004), Folding@home (Beberg et al. 2009), HTCondor (Thain et al. 2005), PlanetLab (Chun et al. 2003) and Seattle (Cappos et al. 2009), which mainly rely on altruistic contribution of resources from the users, though various mechanisms have been studied in the context of peer-to-peer systems (Shen et al. 2010) that address different problems of collaborative resource sharing. There are only a few research proposals for community cloud computing (Marinos and Briscoe 2009). Most of them do not go beyond the level of an architecture, and at most a practical implementation is presented. None of these implementations, to our knowledge, are actually being deployed inside of real community networks.

The Cloud@Home(Distefano and Puliafito 2012) project aims to harvest in resources from the community for meeting the peaks in demand, working with public, private and hybrid clouds to form cloud federations. The authors propose a rewards and credit system for ensuring quality of service. Gall et al. (Gall et al. 2013) have explored how an InterCloud architecture (Buyya, Ranjan, et al. 2010) can be adapted to community clouds. Social cloud computing (Chard et al. 2012) takes advantage of the trust relationships between members of social networks to motivate contribution towards a cloud storage service. Users trade their excess capacity to earn virtual currency and credits that they can utilize later, and consumers submit feedback about the providers after each transaction which is used to maintain reputation of each user. Social clouds have also been deployed in CometCloud framework by federating resources from multiple cloud providers (Punceva et al. 2013). Zhao et al. (Zhao et al. 2014) explore efficient and fair resource sharing among the participants in community-based cloud systems. Jang et al.(Jang et al. 2014) implement personal clouds that combine local, nearby and remote cloud resources to enhance the services available on mobile devices.

From the review of related work, we find that none of the above cases correspond to the concrete situation of community networks such as targeted by us. In the cloud system that we propose, we aim to take into account several of the important factors that characterize community networks, such as the scenarios we identified from the conditions of community networks.

6 Conclusion and Future Work

Community clouds take advantage of resources available within community networks for realising cloud-based services and applications tailored to local communities. Being community clouds a case of private provisioning of public goods, economic mechanisms and policies are needed to direct their growth and sustainability. First, we analysed the key socio-technical characteristics of community networks in and presented two community cloud scenarios, the local community cloud and the federated community cloud. Secondly, we identified the cost and value evolution of the community cloud during its emergence and under permanent operation. A core number of highly motivated contributors is needed at the beginning. Once the community cloud is operational, its value should easily exceed the cost of the minor contribution expected from the users. The socio-economic context of community networks forms the basis for the social, technical and economic policies that we proposed for community clouds. We outlined and illustrated these policies that address technical, social, economic and legal aspects of the community cloud system.

Based on the proposed socio-economic policies, our next step is to design and integrate them in our prototype implementation of the community cloud that we currently deploy in the real-world Guifi.net community network. The resulting empirical studies will help assessing the effect of the proposed economic mechanisms further. Our hope is that community clouds will complement the existing public cloud services paving the way for innovative and interesting applications for local communities.

7 Acknowledgement

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