Topology Patterns of a Community Network: Guifi.net

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***Abstract*—This paper presents a measurement study of the topology and its effect on usage of Guifi.net, a large-scale community network. It focuses on the main issues faced by community network and lessons to consider for its future growth in order to preserve its scalability, stability and openness. The results show the network topology as an atypical high density Scale-Free network with critical points of failure and poor gateway selection or placement. In addition we have found paths with a large number of hops i.e. large diameter of the graph, and specifically long paths between leaf nodes and web proxies. The usage analysis using a widespread web proxy service confirms that these topological properties have an impact on the user experience.**

***Index Terms*—Community network, Wireless network, Topology patterns**

I. Introduction

Community networks have generated great expectations in recent years, as a promise of low-cost and participatory connectivity solutions for citizens, particularly useful in under-developed countries or isolated areas left behind by public institutions or private network providers. At the same time, the popularity and interest on wireless devices has increased due the wide range of low-cost laptops and mobile devices bundled with WiFi connectivity. As a natural evolution, in recent years a plethora of non-profit initiatives have flourished to create community networks using a-priory or ad-hoc wireless infrastructure to provide Internet access. A few examples of this success are Guifi.net [1], Athens Wireless Metropolitan Network [2], FunkFeuer [3], Seattle Wireless [4] and Consume [5].

A characteristic of these initiatives is that the network topology has been growing organically, without a strictly planned deployment or any consideration other than connecting nodes from new participants linking to an existing one. This is the model, for example, used by Guifi.net where new participants freely collaborate in creating new links – installing new hardware devices on their roofs, configured by themselves – that expands the network or increases its coverage. However new devices may not contribute to improve the overall capacity of the network but just satisfy individual needs.

Guifi.net [1], [9] is a neutral, independent WiFi community mesh network mainly deployed in Catalonia (Spain) with more than 17,000 operational nodes and more than 30,000 km of links, perhaps the world's largest and still with an exponential growth. As a result of its organic growth, its openness and the pragmatic attitude of its members to try out any inexpensive solution that does the job, Guifi.net has a plethora of heterogeneous wireless devices and, in consequence, a large diversity of routing protocols being used, including infrastructure and MANET routing protocols, and a myriad of end-user oriented services and application protocols.

This paper presents a measurement study of the topology and its effect on usage of Guifi.net, a large-scale community network, with observations about the main issues faced by this network and lessons to consider for its future growth in order to preserve its scalability, stability and openness. This study is similar to others conducted on similar networks such as RoofNet [10], [11], DGP [12], MadMesh [13], Google WiFi network [14], [15] and Meraki [16], but all of them are smaller than Guifi.net and most of them are not as decentralized as community networks.

The rest of the paper is structured as follows. The next section presents the questions to address in this study. In section III we describe the related work. In section IV we present the Guifi.net network. Section V analyzes the Guifi.net topology, addressing the questions 1 to 3 listed above. Question 4, is covered in section VI which is dedicated to network usage. Finally, sections VII and VIII end the paper talking about lessons learned and conclusions.

II. Measurement and study definition

Guifi.net is a mesh community network that grows organically, in a bottom-up way: nodes and links are added or upgraded on demand mainly following population demand patterns and fixing immediate needs with less of a centralized, mid-term, top-down, planned design. That decentralized growth raises a few questions:

- Question 1: *What does the neighborhood of each node look like? What are the connectivity properties of the topology?* As Brik et al. point out in [13], this is the first question to address. To answer these questions we need to understand which kind of network topology arises and how good routing can be.

- Question 2: *Does the network topology follow any Internet pattern?* Scale-Free networks [17] have been recently of interest on the network theory field as a common pattern that arises on multiple logical Internet structures – social, physical, routing. This pattern is relevant in order to discuss the network resilience to random failures.
- Question 3: *How robust is the deployment to failure scenarios?* Identifying the existence – and characteristics – of single points of failure or congestion must be a clear advantage in order to improve future deployments.

While not the focus of our study, we also measure several key metrics on data link performance and the effects of mixing on the same network long distance planned links with short organically grown connections. These results are useful to understand the current network behavior and to know where the Guifi.net community should focus to keep the network growing without major problems.

Regarding the usage of Guifi.net, a few numbers of nodes, namely proxies, act as a gateway to give Internet, usually web only, access to the community network users. Without access to one of these proxies, Guifi.net users can still exploit the benefits of connectivity that Guifi.net provides to share contents and applications with other users, but can't access to any resource outside the network. One main question arises:

- Question 4: *What are the effects of the topology in the usage of the network?* The usage of the popular web proxy service, deployed at many nodes in Guifi.net with Internet access, shows the impact of the network topology in the provision of application services in terms of number of hops or network load.

III. Related Work

In this section we present a summary of previous studies of real-world wireless network deployments.

A study about RoofNet is presented in [10], [11]. This RoofNet network is deployed in an urban environment. It reports findings on the link level characteristics of an 802.11 (2.4 GHz) mesh network. Their study focuses on the link level characteristics of the deployment. We also study the link level but focusing in topology patterns.

In a similar study about the DPG network [12], authors also study the link level characteristics of outdoor mesh networks. However, their work is applicable to rural settings.

Our study was done on a community network while all of the above mentioned studies were conducted on custom testbeds built explicitly for experimentation. There have also been studies on wireless networks with real users, not only experimental networks.

A study about the MadMesh network [13], reports a measurement study of a mesh network deployment and his planning. That deployment is a two-tier architecture and operates in both 2.4 GHz and 5 GHz, while Guifi.net operates in a multi-tier architecture and uses several network technologies. In addition, our study was conducted in a community network, while MadMesh is a commercial mesh network.

The Google WiFi metropolitan-area mesh network has been studied in [14], [15]. It estimates the coverage properties and the usage characteristics for different user devices in that network. Both studies help provide a greater understanding of a metro-area WiFi mesh. Our study was conducted in a variety of environments due to the large size of the network. We focus on the part of Guifi.net deployed in Catalonia. Moreover, the dimensions of the Guifi.net network (over 17,000 nodes) is much larger than all the above studies.

Finally, a total of 110 mesh networks based on Meraki devices have been studied in [16]. This study focuses on link level performance. They look at the impact of SNR on the bit rate for that link, and the impact of opportunistic routing. We also study the link level but instead focusing in topology patterns.

We summarize and compare our study with prior work on real-world WiFi network deployments in Table I. As can be seen from the table, the unique features of our study are, a) our network has a larger scale in terms of nodes, b) usage of several network technologies, and c) the community nature of the Guifi.net network.

IV. The Guifi.net Network

Guifi.net [1], [9] is a free, neutral and open access wireless telecommunications network built upon an interconnection agreement in which each new participant is given the right to use the network for any purpose unless it affects 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, the freedom of joining or extending the network following the same conditions. This is regulated by a community membership agreement[1] and coordinated by the Guifi.net foundation. The network started in 2004 and in 2012 it has more than 17,000 operational nodes.

A. Network Structure

The network consists of a set of nodes interconnected through mostly wireless equipment that users – different stakeholders such as individuals, companies, administrations or universities – must install and maintain in addition to its links, typically on building rooftops. The network grows driven by the needs of individuals. New links only succeed based on the need for connectivity either by the direct beneficiaries or in case of backbone upgrades is crowd-funded from contributions by the indirect beneficiaries. There is no a-priory overall growth planning, and for that reason the structure of the network accommodates to the geographical distribution of people's interest.

Each Guifi.net node, except pure end-user client nodes, acts as a WiFi routing device that provides at least data link and

[1]The Guifi.net agreement is http://guifi.net/ca/ComunsXOLN, in English: http://guifi.net/en/WCL_EN

	No. of Nodes	Typical link length	Intended usage	Architecture	Env.	Wireless technology
DGP [12]	17	Up to few tens of kms	Testbed	High gain antennas on tall towers	Rural	Single Tier 802.11 (2.4 GHz)
Roofnet [10], [11]	≈50	Mostly < 500 m	Testbed	Omni antennas on rooftops	Urban	Single Tier 802.11 (2.4 GHz)
MadMesh [13]	250	Mostly < 500 m	Commercial	Omni & dirnl. antennas on poles	Urban	Two Tier 802.11 (2.4 & 5 GHz)
Google [14], [15]	500	Mostly < 500 m Maximum 9.6 km	Non commercial	Omni antennas on light poles	Urban	Single Tier 802.11 (2.4 GHz)
Meraki [16]	1407 (110 networks)	—	Private	—	Urban & Indoor	Single Tier 802.11 (2.4 & 5 GHz)
Guifi.net	> 17,700	Mostly < 1 km Maximum 34 km	Community	Dirnl. antennas on rooftops and poles	Urban & Rural	Multi Tier 802.11 (2.4 & 5 GHz)

Table I
COMPARISON OF THIS STUDY WITH PRIOR MEASUREMENT STUDIES

IP forwarding services to all users and nodes connected to him. There are some special nodes, *proxy* nodes, that act as gateways to provide Internet connectivity, such as web o VPN proxies, to some members of the community.

The majority of the links in Guifi.net are point-to-point links between two distant locations using the 2.4 or 5 GHz ISM unlicensed radio bands, typically using OSPF, BGP or a combination of these routing protocols. Shorter range links use sectorial antennas that are preferred since that allows seeing more than one node. This allows running mesh routing protocols such as OLSR or BMX6 that can dynamically select which links to select for routing among the available ones. Finally there are many nodes that act as leaf nodes connecting just one end-user with a multipoint access point. The nodes are based on inexpensive devices such as Ubiquity or MikroTik with proprietary software or Alix or other similar boards running an open source community distribution such as qMp[2] based on the OpenWRT Linux distribution.

B. Data Collection

It was difficult to access the majority of nodes to collect the desired information. This limitation has to do with the community nature of the Guifi.net. The network grows driven by the needs of the users and they install, configure and maintain their own nodes. For our study we collected measurement data of about 1,000 nodes, including almost all the nodes of the Guifi.net network backbone.

We have collected information about these nodes, mainly using SNMP requests and scripts reaching nodes via SSH. For example, each node maintains statistics about the total number of nodes linked to it, addresses of its neighbours (ARP tables), the current channel number, the number of failed transmissions, the noise floor level, routing tables, etc[3].

This has been combined with the information from the *Community Networks Markup Language* (CNML) database dump of the Guifi.net database. CNML is a XML schema describing registered nodes, links and its configuration. This information is arranged according to the geographical *zones* in which the network is organized. In this paper we have gathered information about the Guifi.net topology and usage properties for web proxies, respectively[4].

V. TOPOLOGY ANALYSIS OF GUIFI.NET

Along the next sections we are going to study and review the Guifi.net network characteristics from bottom – link structure – to top – users' usage characterization. We begin with our observations about the topological structure in order to use the conclusions as a baseline to understand upper layer behaviors.

We have constructed a *base-graph* of Catalunya zone by considering only operational nodes, marked in *Working* status in the CNML file, and having one or more links pointing to another node in the zone. Additionally, we have discarded some disconnected clusters. All links are bidirectional, thus, we use an undirected graph. We have formed what we call the *core-graph* by removing the terminal nodes of the base graph (i.e. leaf nodes). Table II summarize the base and core graphs. Figure 1 depicts the geographical position of the nodes of the Catalunya base and core graphs.

The consideration of the core-graph is motivated by the strong bias of Guifi.net towards terminals nodes. In fact,

[2]The "Quick Mesh Project" node distribution http://qMp.cat

[3]The data sets used in this paper are available at http://wiki.confine-project.eu/experiments:datasets

[4]Guifi.net data of the *Catalunya* zone downloaded from http://guifi.net/en/guifi/cnml/2413/detail on April 19th, 2012. See [18] for details about CNML.

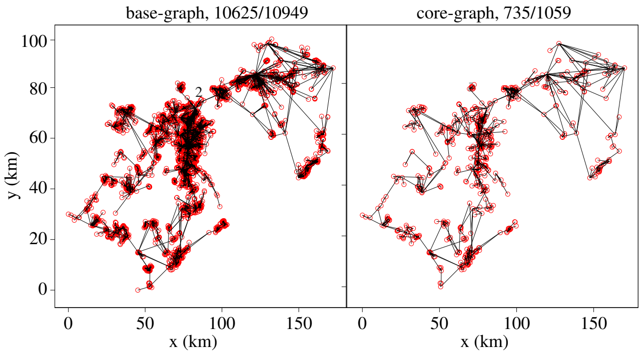

Figure 1. Base and core graphs of the Catalunya zone. Axis are in km.

	nodes/links	degree
base-graph	10,625/10,949	1/2.06/476
core-graph	735/1,059	1/2.88/30

Table II
SUMMARY OF CATALUNYA GRAPHS. NODE DEGREE GIVEN AS MIN/MEAN/MAX.

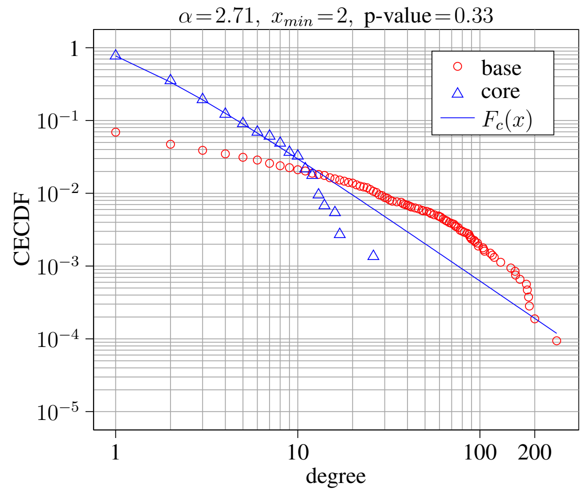

Figure 2. CECDF $\log_{10}$-$\log_{10}$ plot of the degree of base and core graphs of Catalunya zone. Core-graph is fitted by a power law $F_c(x)$.

from table II we can see that from the 10,625 nodes of Catalunya base-graph, only 735 (around 7%) belong to the *core-graph*, the other nodes are terminals. The high number of leaf nodes is consequence of the special structure of Guifi.net: the network consists of a relatively small number of nodes located in strategic geographical points (we shall refer to them as *hubs* in the rest of the paper) which form a core and have a high number of wireless links to end customers. For instance *TonaCastell* is the node having the maximum number of terminals (459). TonaCastell[5] is located in a hill and provides links to the village of Tona and its surroundings.

Terminals nodes do not contribute to the network connectivity between other nodes. Thus, it makes sense to focus on the connectivity properties of what we call the *core-graph*, i.e. the graph interconnecting all hubs.

A. Nodes degree distribution and Scale-Free patterns

A scale-free network is a network whose degree distribution follows a power law pattern. Observations on Internet topologies of Faloustous et. al. [19] together with the works of Barabási et al [17], [20] developed the theory that Internet topology follows a power-law model. As we are especially interested on verify the usage and physical Guifi.net network behavior we have investigated the power law properties of Guifi.net.

Figure 2 shows a $\log_{10}$-$\log_{10}$ plot of the Complementary Empirical Cumulative Distribution Function (CECDF) of Catalunya base-graph and core-graph degree (depicted with circles and triangles, respectively). Note that the last sample (maximum degree), for with the CECDF is 0, is not plotted.

[5]A diagram of *TonaCastell*: http://guifi.net/node/2231

Recall that the power law component of the complementary cumulative distribution function of a discrete random variable X is given by [21]:

$$F_c(x) = P(X > x) = \frac{\zeta(\alpha, x+1)}{\zeta(\alpha, x_{min})},\ x+1 \geq x_{min} \qquad (1)$$

where

$$\zeta(\alpha, x) = \sum_{n=x}^{\infty} n^{-\alpha}$$

is the generalized Hurwitz zeta function. We have used standard techniques to compute the parameters α and x_{min} for the base and core graphs, and estimated the goodness-of-fit by computing the p-value (see [21]). For the base-graph it was obtained a p-value smaller than 10^{-6}, thus, the power law hypothesis must be rejected for the base-graph. This result is clear from figure 2, since the base-graph degree distribution in log-log scale deviates significantly from a straight line. For the core-graph it was obtained a power law fitting with parameters $\alpha = 2.71$ and $x_{min} = 2$ (solid line in figure 2). The figure shows that, up to degree 12, the CECDF of the core-graph degree fits very well the power law. For higher degree it may seem that the fitting is not very good. However, from the 735 nodes of the core graph, only 7 have a degree higher than 13, most of them with frequency 1. Therefore, these points are not representative. In fact, the power law fitting of the core-graph degree yields a p-value$= 0.33$. Thus, it shows that the power law is a plausible hypothesis for the degree distribution of the core-graph.

Compared with other community mesh topologies, Guifi.net clearly shows a mixed structure with aspects typical of urban structures as we could appreciate on Google WiFi [14] and others more similar to deployed networks or organically grown structures as MadMesh [13] and RoofNet [22] that makes the resulting topology unique.

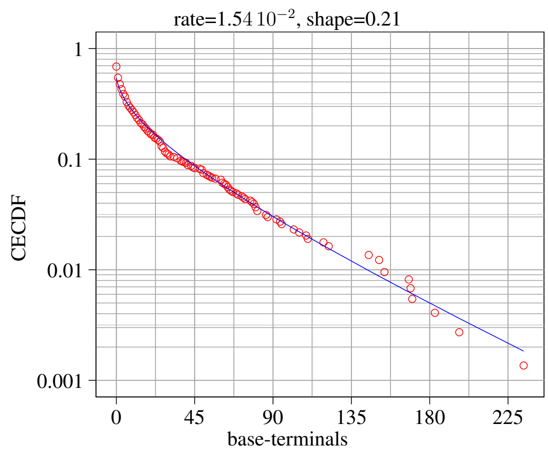

Figure 3. CECDF semi $\log_{10}$ plot of the number of terminals in the base-graph of the nodes in the core-graph.

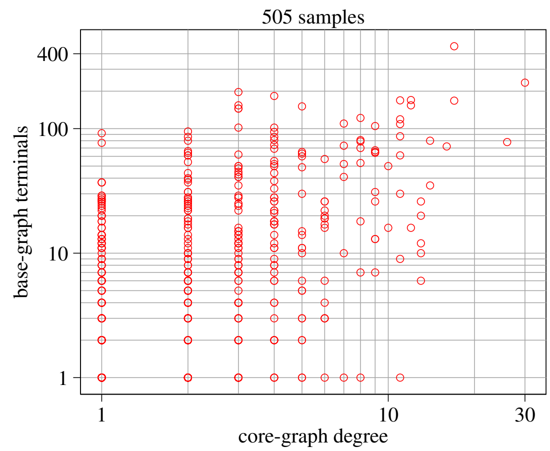

Figure 4. Scatter $\log_{10}$-$\log_{10}$ plot of the number of terminals of the base graph vs. the degree in the core graph.

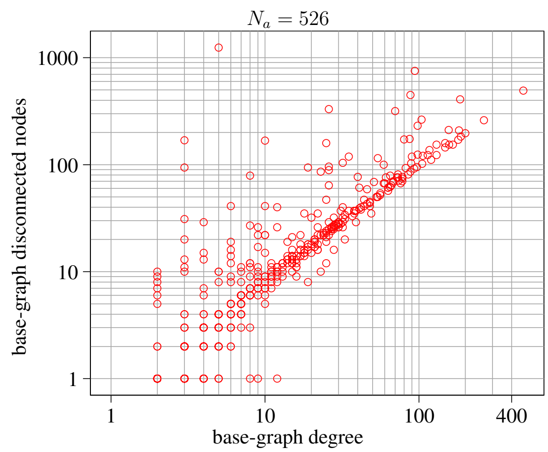

Figure 5. Articulation points degree vs. number disconnected nodes $\log_{10}$-$\log_{10}$ plot of Catalunya zone.

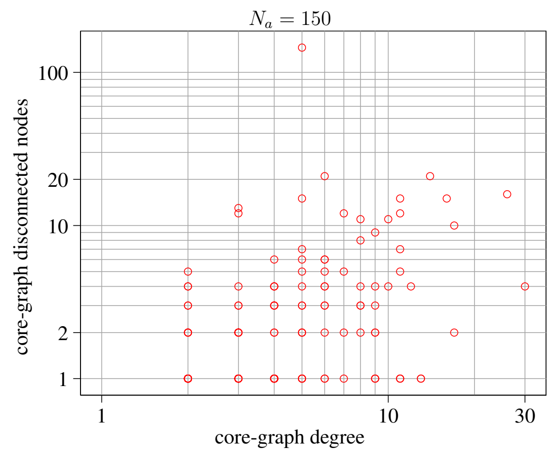

Figure 6. Articulation points degree vs. number disconnected nodes $\log_{10}$-$\log_{10}$ plot of Catalunya zone.

Even though the core-network extends based on preferential attachment, a typical characteristic of scale-free topologies, the growth of the node degree is limited by a combination of technical and economic factors. Nodes with a large number of wireless links can suffer from interference due to sharing of a limited spectrum and high cost due to the higher processing capacity required and the high power consumption implied.

As mentioned before, there is a huge amount of terminal nodes (93%) that don't contribute to enlarge the connectivity of the network. This pattern, common in some wireless community networks is not desirable and can harm the performance of the routing protocols that have to maintain higher number of entries than necessary cached on its routing tables, which also increases the nodes' resources requirement.

B. Robustness of the deployment

The simulation results of Dekker and Colbert [22] on scale-free networks confirm preliminary observations from [19] where authors state that Scale-Free networks are resistant to random failures. In our case the analysis presented above shows that the Guifi.net base-graph degree distribution does not fit a scale-free pattern. Additionally, the special structure of Guifi.net, with hubs connecting a high number of terminals needs to be taken into account.

In order to analyze the distribution of the terminals among the hubs, figure 3 shows the CECDF semi $\log_{10}$ plot of the number of terminals in the base-graph for the nodes in the core-graph. Interestingly, the distribution is very well fitted by a gamma distribution with parameters rate $= 1.54 \times 10^{-2}$ and shape $= 0.21$ (continuous line in figure 3). This means that there are big differences on the number of terminals connected to the hubs. For instance, the mean number of terminals connected to core-nodes is about 64.3, but 31.3% of core-nodes have no terminals, and only 10% have more than 37 terminals. This is a consequence of its decentralized structure with no overall growth planning.

Clearly, it is desirable that hub nodes with higher number of terminals have higher resilience to random failures. In order to assess this goal figure 4 depicts a scatter $\log_{10}$-$\log_{10}$ plot of the degree of the nodes in the core-graph, and the number of terminals they have in the base-graph. Figure 4 shows that hubs having a higher number of terminals tend to be better connected. For instance, the hub having the maximum number of terminals (459), has a degree equal to 17 in the core graph. However, from the 195 nodes having more than 10 terminals, 38 (about 20%) have a degree equal to 1 in the core-graph, and thus, are weakly connected in the core graph.

In order to have more insight on the resilience to random failures we analyze now the articulation points of the graph. Recall that a graph is *biconnected* if, and only if, it can be disconnected by removing only one node [23]. This node, whose disconnection increases the number of disconnected components of the graph, is also called an *articulation point* and is an important point of failure to consider. Figure 5 shows for each articulation point on the base-graph the articulation node's degree and the number of nodes that remain isolated by removing that articulation point.

In total, were identified 526 articulation points. Figure 5 shows that many of them, if removed, create a number of independent – isolated – components proportional to their degree. Clearly, these are the hub nodes, whose degree is approximately equal to the number of terminals they have.

In order to have a better view of the connectivity between the hubs, figure 6 shows the articulation points of the core graph. From the 735 nodes of the core, 150 (about 20%), are articulation points. However, except one node that disconnects 145 core nodes (almost 20%), the other disconnect at most 21 nodes (2.8%). The articulation point that can disconnect about 20% of the network can be easily identified in figure 1. Nevertheless, the failure of this node would not be as catastrophic because the two clusters could still reach each other by means of Internet proxies.

According to Haray [23] definitions, the Guifi.net core network, in its condition of scale-free topology, is robust against random link attacks. Routing algorithms and protocols that need to know information of the whole network can be aware of hubs despite a single failure using one of their other links to contact them and retrieve topology information. However, planned attacks against some of these hubs – as TonaCastell – would leave a high number of nodes without connectivity. Without automatic mechanism for network reconfiguration, backup links or similar, the effect will be extensive.

C. Link Length Distribution

Link length distribution is of capital interest in a wireless network, due to its strong influence on the signal transmission in the radio channel. We have found that the link length distribution can be approximated by a mixture of 2 exponentials. Let L the complementary CDF of the link length, X, then:

$$L(x|\lambda_1,\lambda_2,\theta) = P(X > x) = \theta\,\mathrm{e}^{-\lambda_1 x} + (1-\theta)\,\mathrm{e}^{-\lambda_2 x} \quad (2)$$

Figure 7 shows a semi-$\log_{10}$ plot of the link length CECDF and its fitting using equation (2) (solid line). The figure shows

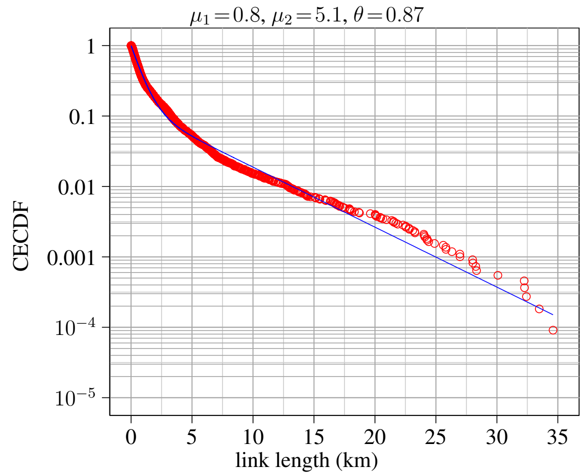

Figure 7. Link length distribution fitting (μ_1 and μ_2 are in km).

that the link length distribution is very well fitted by the combination of 2 exponentials. The reason for that can be explained by the fact that links can be grouped in two sets: One set of short links characterizing connection of nodes located in closer geographical areas, for instance, villages in rural zones, or suburbs in Barcelona. Another set formed by longer distance links interconnecting nodes from different groups of short links. We have that 87% of nodes belong to the first group ($\theta = 0.87$), with a mean link length of $\mu_1 = 0.8$ km. The remaining 13% belong to long distance links with mean $\mu_2 = 5.1$ km.

VI. Usage Analysis

In this section we look at the impact of the network topology on the user experience. Although an experimental analysis will be desirable, the usage characteristics of Guifi.net, which is a production network for thousands of users, poses several limitations. In addition, the usage of diverse routing protocols in different areas of the network forces us to look at the usage experience at the application layer to understand the impact of the network topology and its associated choices on the overall user experience.

From the viewpoint of the wireless physical layer a long routing path means that users' information could traverse multiple hops and can suffer important performance degradation in terms of throughput, protocol overhead, delay and energy consumption [27]. Although the the results of Section V-B suggest that Guifi.net links are highly reliable, the use of multi-hop routing degrades the network performance.

We studied these effects for the Internet access service provided by many proxy nodes located at different nodes in Guifi.net. Figure 8 shows the average and minimum path length distribution (in terms of percentage) between community nodes and proxy nodes. We argue that, although this metric does not exactly fit with the number of hops of network paths produced by routing protocols, it corresponds to the

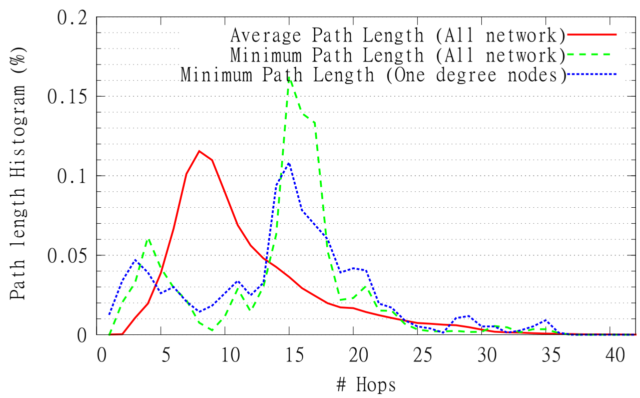

Figure 8. Minimum and Average path length distribution between community nodes and proxy nodes as a histogram.

ideal number of hops that routing protocols should provide to minimize the amount of traffic and latency on the network.

We compared these results with those provided by MadMesh [13] and Google WiFi network [14]. A first analysis of Figure 8 reveals that the average number of hops – the average path length between all network community devices and proxies – is very large compared with typical values on other community networks. The result is coherent with the magnitude of our network in number of nodes and, specifically, its geographic size. The normal distribution of frequency is not surprising taking into account that we're computing averages over the whole network.

The second analysis over the other two frequency plots on Figure 8 represents the minimum path length (MPL) of community nodes to their nearest proxy node. As we expected from Google WiFi [14] and RoofNet [22] analysis, the shape of both curves –with are equivalent to all network points and *users-Google Network* / *MAP-Roofnet* nodes – are equivalent.

Looking at Guifi.net nodes at one degree on connectivity, we can observe that the end-users to proxy nodes MPL frequency is the sum of two normal distributions centered at 3 hops (2% of nodes) and 6 hops (13% of nodes) respectively, which is higher than the number of hops reported on Roofnet and Google WiFi networks. This result is consistent with our first observation, where we pointed out that the geographical size of the Guifi.net network creates urban clusters of nodes inside cities with short long paths to the nearest proxies and *extra-radio* communities far away from cities and, in consequence, to the proxies. That differs from related work. Deployed network patterns, as Roofnet, shows a normal frequency distribution with about 23% of nodes at one hop and another 20% still at only 2 hops to their gateway with a maximum of 8 hops. On the other hand, urban networks, as the Google WiFi network, have a number of hops distribution equivalent to commercially deployed networks but clearly centered at one hop frequency of end-users to community nodes with less than 5% of the nodes at three hops.

The authors of [22] suggest that longer paths might be due to two main reasons: a non-well planned network where the number of routing choices is very limited, or the routing algorithm is not choosing right. As we are evaluating the routing strategies from topological information, and not from routing information, we can point the first reason as our clear drawback with some extra explanation. The argument is that in our case we have only 24 proxy active nodes for a 14.591 nodes network compared with the about 15% of gateways that have RoofNet and Google WiFi network.

VII. Lessons learned

In this section we present observations that came up after our study. They have to do with the process of gathering information from a community network in production and under the control of the users.

The collection of topology information has some small differences between the node database (CNML XML dump) and the real deployment that mainly affects a number of leaf nodes that are not declared but are detected in our network scan. Additional widely spread network scan points would help to have a more precise network view. An open SNMP service would help to collect statistics, but that is limited by diversity of devices and configurations.

Based on the experience of collecting topology information a topology generator for Guifi.net like topologies is proposed in [18].

VIII. Conclusions

In this paper we study the characteristics of the Guifi.net network topology, with special attention to factors that might contribute to improve the specific characteristics of these networks, in terms of decentralization and self-organization. We also look at informing choices for future deployment of nodes or selecting the appropriate routing strategies.

The Guifi.net network shows some typical patterns from urban networks combined with a unusual deployment that neither fit with organically grown networks nor with planned networks. Compared with similar networks (See Table I), it shows a similar structure but one or more orders of magnitude in number of links and number of nodes which makes the network very large and crowded.

The analysis of neighbor distribution, Section V-B, shows a network with high resilience to random attacks, as points the Scale-Free properties discovered on Catalonia base-graph. However, we detected a large number of critical nodes – articulations points – with small degree of connectivity that, in some cases, are responsible for interconnecting different clusters of cities.

Guifi.net, as most community networks, is a highly meshed network which results in very large routing tables. This is slightly alleviated but further complicated by the usage of multiple routing protocols across the network. In addition we have found paths with a large number of hops i.e. large diameter of the graph, and specifically long paths between leaf nodes and web proxies. Two factors contribute to it: i) the wireless technology combined with a very limited public spectrum has limitations for long distance links, and ii) the locality of the organic growth of the network by preferential attachment of new nodes to the closest nodes is driven by the social and economic costs for individuals adding new nodes. Routing protocols as proposed by MadMesh based on SNR instead of the shortest path would further degrade the network by increasing the average number of hops. Instead, Guifi.net uses different routing protocols in different regions of the network according to the local characteristics. The effect of the organic growth of Guifi.net can have an impact on the user experience as the analysis of placement of web proxies show.

Future work includes exploring and comparing with other community network topologies, a look at the mutual influence of routing choices and network topology, and a more detailed look at the effect on transport and applications.

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