On the Topology Characterization of Guifi.net

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***Abstract*—In this paper it is analyzed the topology of Guifi.net Wireless Community Network (WCN). WCN have emerged in recent years organized and deployed by the cooperation of its own customers. WCN keep parallelisms with the construction of the Internet, and seems logical to look for common characteristics among them. More specifically, it is investigated whether there are topology patterns of Guifi.net, and to what extend they share the power-law properties that have been found to obey many topology parameters of the Internet. The paper also proposes a topology generator algorithm that it is able to reproduce specific graph properties that have been obtained for Guifi.net.**

I. Introduction

In recent years a new networking paradigm referred to as *Wireless Community Networks* (WCN) has emerged [1]. WCN have grown by volunteers and hobbyists as a *grassroots movement* [2]. Its remarkable feature is the network organization and deployment by the cooperation of its own customers. Broadband Internet access has been one of main objectives of WCN, but there are other reasons that have foster their interest: self management of networking resources, resource sharing, formation of communities, construction of open and free networks, etc. Initially WCN have been set up employing unexpensive WiFi equipment. But, in some cases, WCN have evolved to sophisticated networks with thousands of nodes and complex infrastructures. Some successful examples of such networks are Guifi.net [3], Athens Wireless Metropolitan Network [4], FunkFeuer [5], Seattle Wireless [6], Consume [7], etc.

Due to its success, WCN are receiving an increasing amount of attention by the research community. Most authors have focused on the motivations and business models of WCN as in [8], [9]. In this paper we focus on the topology analysis of WCN. The collective construction of WCN keeps parallelisms with the growth of the Internet. Thus, it seems logical to look for common characteristics among them. We are interested in questions as, *Are there topology pattenrs characteristic of WCN? Does WCN share the topology properties that have been found for the Internet?*

In our analysis we will proceed as in the well-known three-Faloutsos paper [10]. This article together with the works of Barabási et al [11], [12] developed the theory that Internet topology follows a power-law model. The term *scale-free networks* has been coined to refer to networks having this property [12]. This claim has motivated a significant amount of work in the last decade, although Willinger et al. have questioned recently the extend of the power-law assumption [13]. Nevertheless, our goal it is not to obtain a detailed model of WCN, but have some guidelines by comparison with the results obtained in [10].

We base our analysis on Guifi.net [3], [14]. We have chosen Guifi.net because it is the largest WCN of its characteristics, with more than $15,000$ operative nodes, and its topology information is open. Guifi.net is rather heterogeneous, even some optical fiber links have been added recently [15]. However, the vast majority of the network consists of static bidirectional wireless links setup using linux powered WiFi devices. Even if FON [16] is considered the WCN having the largest number of nodes [1], FON is very much different from Guifi.net: FON is mainly formed by a private hotspot sharing of Internet ADSL lines [1]. FON routers are not expected to establish direct links among them. On the other hand, a main objective in Guifi.net is networking by setting up links between its nodes, and Internet access is only one among many services of the Guifi.net [14]. In fact, Guifi.net is organized in geographical *zones* which are initiated by users installing Guini.net software and interconnecting their nodes. Only a few proportion of nodes in Guifi.net have an additional home ADSL line connected to the Internet [14].

Guifi.net is documented in XML using the so called *Community Networks Markup Language* (CNML). Inside CNML, the information is arranged using the geographical *zones* in which the network is organized. In this paper it is analyzed the CNML information of *Barcelonés* and *Osona* zones downloaded respectively from the following URLs on April the 19th, 2012:

`http://guifi.net/en/guifi/cnml/2435/detail`
`http://guifi.net/en/guifi/cnml/2444/detail`

Barcelonés and Osona are counties in Catalunya, Spain, which capitals are Barcelona and Vic, respectively. The CNMLs of these zones have been chosen because they represent two significantly different scenarios. Barcelonés has a surface of 144.7 km^2 and it is the most populated county in Catalunya, with approximately $2,252,000$ inhabitants. Most inhabitants are concentrated in the capital, Barcelona. In contrast, Osona has a surface of $1,260.1$ km^2 and a population of about $153,000$ inhabitants. We have analyzed more zones in [17], obtaining results in line with those presented in this paper. For the sake of space, these results are not included here. The Guifi.net topology findings presented here are extended in [18], where routing other aspects of Guifi.net are also analyzed.

Even if the population in Osona is a factor of magnitude smaller than Barcelonés, Osona is the Guifi.net zone having

Element	Attributes
cnml	generated, server_id, server_url, version
class	mapping, network_description
network	ap, client, devices, links, nodes, services
zone	access_points, box, clients, created, devices, dns_servers, graph_server, id, links, ntp_servers, parent_id, services, time_zone, title, updated, zone_nodes
node	access_points, antenna_elevation, clients, created, devices, graph_server, **id**, **lat**, links, **lon**, services, **status**, title, updated
device	created, firmware, graph_server, id, name, snmp_index, status, title, type, updated
radio	antenna_angle, antenna_azimuth, antenna_gain, channel, device_id, id, mode, protocol, snmp_index, snmp_name, ssid
service	created, id, status, title, type, updated
interface	id, ipv4, mac, mask, type
link	id, link_status, link_type, linked_device_id, linked_interface_id, **linked_node_id**

Table I
CNML ELEMENTS' ATTRIBUTES.

the largest number of operative nodes. This fact can be explained by two reasons: first because Guifi.net was born in Osona. But secondly because Barcelonés is a highly populated metropolitan area where broadband Internet access is available to almost all homes. On the contrary, Osona is a rural area composed of 51 villages, many with a small number of inhabitants. Due to this sparse and low dense populated area, broadband Internet deployment in Osona has been rather limited by telco operators. This has boost the interest of Guifi.net in Osona, as a cheap and quick way to have access to broadband Internet services.

In the paper we show that these strong differences between Barcelonés and Osona zones are reflected in the properties of their networks graphs. In fact, Barcelonés graph follows the scale-free pattern, but Osona doesn't. Even though, we have found that upon removing the terminals nodes in Osona graph, a new *core-network* arises having scale-free characteristics. This fact is used to propose a topology generator for Osona-like networks.

The rest of the paper is organized as follows. First the CNML documentation of Guifi.net is described in section II. Then the CNML data used to obtain the numerical results is presented in section III. In section IV it is performed the power-law analysis. Based on the specific properties of Guifi.net observed in this section, in section V it is proposed a topology generator algorithm able to synthesize the type of topologies found in Guifi.net. Finally, section VI gives some related work and section VII ends with some concluding remarks.

II. GUIFI.NET CNML

A CNML representation was created inside Guifi.net to describe the network [19]. When a node is added to Guifi.net, its description is stored in CNML format. This information is available from Guifi.net portal [20]. Figure 1 shows the XML-elements of the CNML tree, and table I their attributes.

The attributes that were used to produce the results presented in this paper are marked in bold in table I. The meaning of these attributes is the following (it is used the notation `element@attribute`):

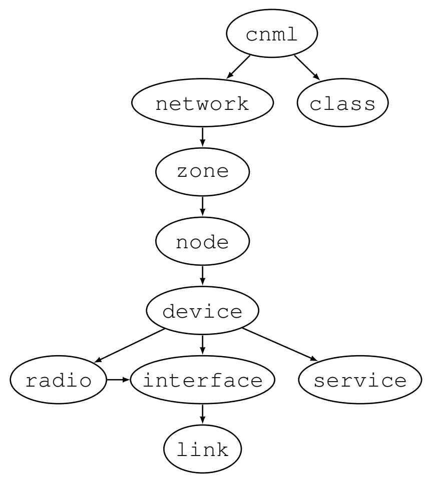
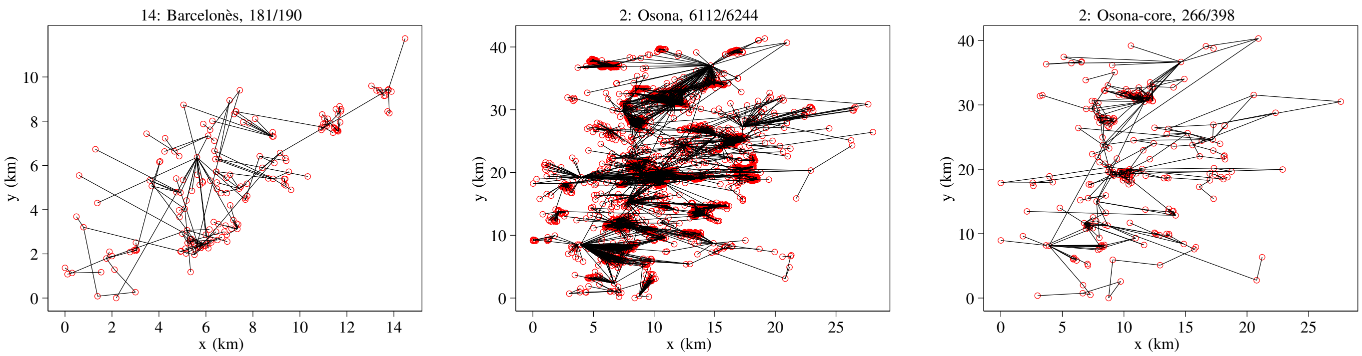


Figure 1. CNML tree.

- `node@id`: node unique identifier.
- `node@lat,lon`: node's geographical position (latitude and longitude).
- `node@status`: Nodes can be in one of the status: `Building`, `Planned`, `Reserved`, `Testing`, `Working`.
- `link@linked_node_id`: node-id of the link endpoint.

In the following we shall refer to the data base storing Guifi.net description in CNML by using the same CNML acronym. This information will be used to analyze some topology properties of Guifi.net. Although the topology extracted from CNML is rather accurate, it must be noticed that CNML information might not be exact in some cases. This imprecision comes from the fact that most information in CNML is introduced manually. Some information might be outdated, e.g. if a link is down, or changed but not updated in CNML. Additionally, some radios are in ad-hoc mode, and links are established dynamically using mesh routing protocols. These links are not reported in CNML. Nodes having radios in ad-hoc mode might be in `Working` status, but having no links with `link@linked_node_id` attribute pointing to other nodes. Thus, apparently disconnected from the network. In [17] we provide more details about CNML



(a) Barcelonés (b) Osona (c) Osona-core

Figure 2. geographical position of the nodes and their links.

	nodes/links	degree
Barcelonés	$181/190$	$1/2.1/18$
Osona	$6,112/6,244$	$1/2.04/476$
Osona-core	$266/398$	$1/2.99/29$

Table II
SUMMARY CNML GRAPHS. FOR NODE DEGREE IT IS GIVEN MIN/MEAN/MAX.

and the zone organization of Guifi.net.

III. CNML DATA

In this paper we analyze the Barcelonés and Osona CNMLs. Only nodes marked in `Working` status and having one or more links with the `link@linked_node_id` attribute pointing to another node in the zone are considered. Additionally, we have discarded some disconnected clusters. This happens with a few nodes in the peripheral of Osona zone, connected to Guifi.net through other zones. Thus, the graphs analyzed do not have disconnected nodes. All links are bidirectional, thus, we use undirected graphs.

Additionally, by the reasons that will be explained in section IV-A, we have analyzed the graph obtained from Osona zone by removing all *terminal nodes*. That is, by removing all nodes with degree 1. By doing this we obtain another connected graph, and with other nodes with degree 1 (those with degree 2 in the original graph, connected to one terminal node). We shall refer to the resulting graph as *Osona-core*. More generally, we shall use the terms *base-graph* and *core-graph* to refer to the original graph, and the one that results upon removing all terminal nodes in the base-graph.

Table II summarizes the resulting graphs. Figure 2 depicts the geographical position of the nodes and their links of the three graphs analyzed in the paper[1]. A more detailed view of Barcelonés and Osona topologies can be observed in the maps provided in the Guifi.net site:

`http://guifi.net/en/barcelones`

`http://guifi.net/en/osona`

[1]All numerical results presented in this paper have been produced using R [21].

IV. POWER-LAWS ANALYSIS

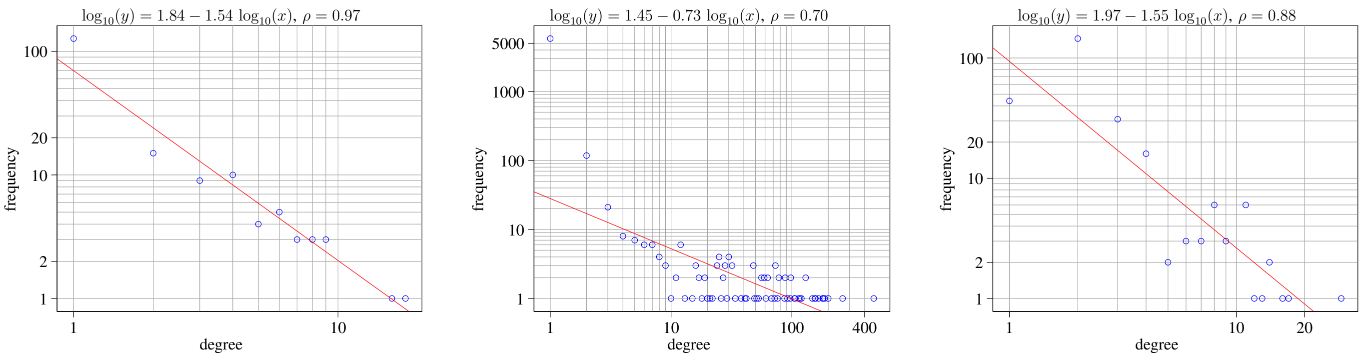
We proceed as in the well-known three-Faloutsos paper [10]. As in [10], we identify power-law relation by using log-log plots and linear regression. We also use the sample correlation coefficient (ρ) between the samples and their linear regression, as a measure of the goodness of fit. Recall that $-1 \leq \rho \leq 1$, being $\rho = 1$ a perfect fit. In the title of each graph we report the resulting linear regression and correlation coefficient. In each figure we plot three graphs corresponding to (a) Barcelonés, (b) Osona, and (c) Osona-core.

We note that there have been proposed better statistical methods for power law fitting than those used in [10] (see e.g. [22], [23]). However we will follow the approach used in [10] for the sake of comparison.

A. Degree Distribution

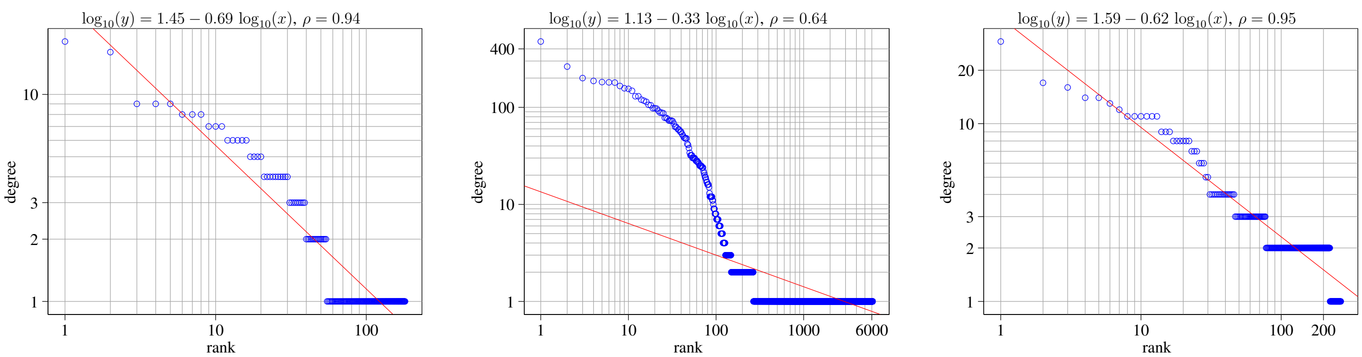
We start analyzing the Degree Distribution in terms of their frequency f_d, as defined in [10]: f_d is the number of nodes with degree d. In contrast to [10], also those points with frequency 1 are considered.

Figure 3 depicts the frequency of the nodes' degree. It can be observed that the degree distribution of both Barcelonés and Osona zones is significantly different. First, we can see that Barcelonés graph fits a power law much better than Osona (their correlation coefficient is $\rho = 0.97$ and $\rho = 0.7$, respectively). Figure 3 (b) also shows that in Osona zone there is a large number of nodes with degree equal to 1. In fact, from table II we can see that from the $6,112$ nodes of Osona, only 266 (around 4%) belong to the *core-graph* (i.e., they have a degree higher than 1), the other 96% are terminals nodes (with a degree equal to 1). On the other hand, there is a node with frequency 1 having a degree as high as 476. This can be explained by the way Guifi.net has been deployed in Osona: the network consists of a relatively small number of nodes located in strategic points which form a core and have a high number of wireless links to end customers. For instance, the node having the maximum number of links (named *TonaCastell*) is located in a hill and provides links to the Village of Tona and its surroundings. A pictorial view of *TonaCastell* links can be obtained in Guifi.net portal: `http://guifi.net/node/2231`



(a) Barcelonés (b) Osona (c) Osona-core

Figure 3. Degree frequency $\log_{10}$-$\log_{10}$ plot.



(a) Barcelonés (b) Osona (c) Osona-core

Figure 4. Rank degree $\log_{10}$-$\log_{10}$ plot.

In contrast to Osona, Barcelonés zone consists of a metropolitan area where broadband Internet access is provided by telco operators to almost all homes at reasonable prices. This fact explains why the deployment in Barcelonés is much more limited than in Osona, but also the strong difference on their network graphs. In Barcelonés much more Guifi.net users contribute actively to increase the network connectivity establishing links among them. This fact explains why Barcelonés zone shares stronger similarities with the Internet networks analyzed in [10].

The special configuration of Osona zone explained above motivates the consideration of two components on the construction of its graph: (i) A *core network* of nodes tightly linked, and (ii) the addition of the many *terminals nodes* which do not contribute to the network connectivity between other nodes. With the aim of separating both components we have removed the terminals nodes in Osona zone, obtaining a new graph that we call *Osona-core*. Figure 3 (c) depicts the degree distribution of Osona-core. We can see that Osona-core fits a power-law much better than Osona (their correlation coefficient is $\rho = 0.88$ and $\rho = 0.7$, respectively). Additionally, Osona-core has a exponent almost identical to Barcelonés zone (1.55 and 1.54, respectively).

B. Rank Degree

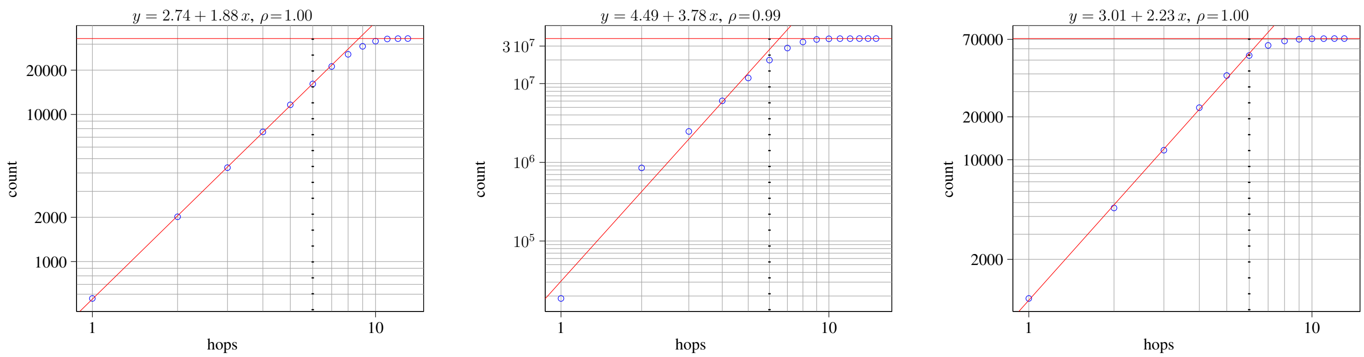
Following the analysis of [10], in this section we sort the nodes in decreasing order of degree, and log-log plot the resulting rank-degree in figure 4. We can see that Barcelonés graph approximates rather well to a power law ($\rho = 0.94$). Additionally, it is obtained a rank exponent of -0.69, which is close to the value obtained in [10] for the Internet inter-domain level (in the range $[-0.84, -0.74]$).

On the other hand, we observe in figure 4 (b) that Osona graph differs significantly, and it doesn't fit a power law. This results confirm the differences between Barcelonés and Osona graphs, pointed out in section IV-A. Finally, we can see in figure 4 (c) that Osona-core fits a power law, as Barcelonés zone, and with similar rank exponent (-0.62 and -0.69, respectively). This results are in line with those obtained in section IV-A. In fact, the distributions of both parameters are closely related (see [24]): being the rank Zipf-like distributed, the frequency distribution follows a power law.

C. Hop Count Distribution

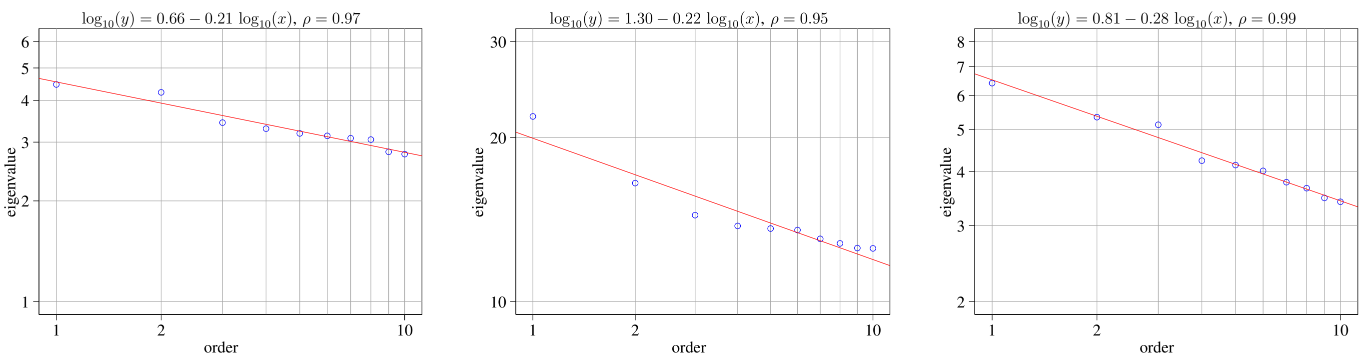
We analyze the hop count distribution as in [10]. Namely, we count the total number of pairs of nodes having less than or equal number of hops, including self-pairs (i.e. every node is considered to be 1 hop of itself), and counting all other pairs twice (i.e. the hops between two different nodes is counted twice). The number of hops of a pair of nodes is given by the *shortest path first* between them.

Figure 5 shows that hop-plots of the three graphs (Barcelonés, Osona, and Osona-core) match the results obtained in [10]: they fit a power law for a number of hops



(a) Barcelonés (b) Osona (c) Osona-core

Figure 5. Hops count $\log_{10}$-$\log_{10}$ plot.



(a) Barcelonés (b) Osona (c) Osona-core

Figure 6. Eigenvalue $\log_{10}$-$\log_{10}$ plot.

sufficiently smaller than the graph diameter, δ (defined as the maximum hop count between any pair of nodes).

It is interesting that Osona graph share this property with Barcelonés and Osona-core, even the strong differences that were observed among them in sections IV-A and IV-B. This can be explained by the fact that the hop-plot is related with the *connectivity* of the graph, while the degree plots of previous sections are more related with the *shape* of the graph.

Recall from [10] that the hop-plot exponent, $\mathcal{H}$ (slope of linear regression in figure 5) gives information about neighborhood of the nodes. For instance, the average size of the neighborhood within h hops ($NN(h)$) is estimated in [10] as $NN(h) = (N + 2\,E)/N\,h^{\mathcal{H}} - 1,\ \ h \ll \delta$, where N is the number of nodes and E the number of edges (links). Thus $NN(h)$ grows as h to the power of $\mathcal{H}$. This explains the fact that removing the terminal nodes in Osona graph, $\mathcal{H}$ decreases (from 3.78 to 2.23, as shown in figure 5 (b) and (c), respectively). Note that the hop-exponent obtained for Osona-core (2.23) is similar to Barcelonés (1.88). Taking into account the results of previous sections we conclude that both Barcelonés and Osona-core graphs have similar statistical characteristics.

D. Eigenvalue Plot

Figure 6 shows a log-log plot of the 10 largest eigenvalues of the adjacency matrix of the graphs. As in [10], it is obtained that the largest eigenvalues follow a power law.

We can see that the figures experimentally validate the result pointed out in [25]: *The largest eigenvalues of graphs whose highest degrees are Zipf-like distributed with slope α, are distributed according to a power law with slope $\alpha/2$.* In fact, we observe that figures 4 (a) and (c) follow a Zipf-like distribution with slopes -0.69 and 0.62, respectively, which is approximately equal to two times the slope of the corresponding eigenvalues graphs shown in figures 6 (a) and (c): -0.21 and -0.28 respectively.

It is interesting to observe that Osona graph is a counter example that shows that the opposite of the above statement is not true. We can see in figure 6 (c) that its largest eigenvalues follow a power law, while figure 4 (a) shows that it is not Zipf-like distributed.

In fact, as pointed out in [26], if $d_1, d_2, \cdots$ are the highest degrees of the nodes of the graphs, then the largest eigenvalues are given approximately by $\sqrt{d_1}, \sqrt{d_2}, \cdots$. Figures 4 (a,b,c) and 6 (a,b,c) experimentally validate this relation. Additionally, for the Osona zone we can see in figure 4 (b) that the 10 nodes having the highest degree have approximately a linear log-log decay, thus, matching the power-law observed in figure 6 (b).

V. Topology Generator

In this section we characterize the Guifi.net graph properties observed in section IV by proposing a topology generator. First, recall that two classes of graphs have been identified:

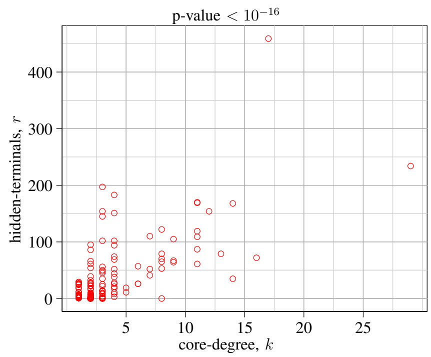


Figure 7. Scatter plot of hidden-terminals vs core-degree in Osona-core.

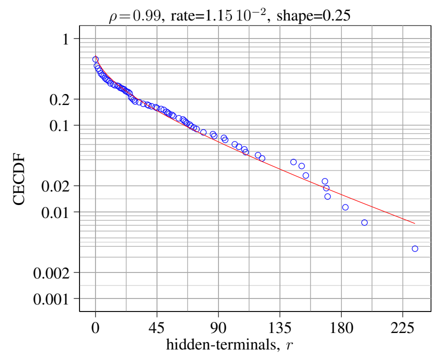


Figure 8. CECDF of hidden-terminals in Osona-core, semi-$\log_{10}$ plot.

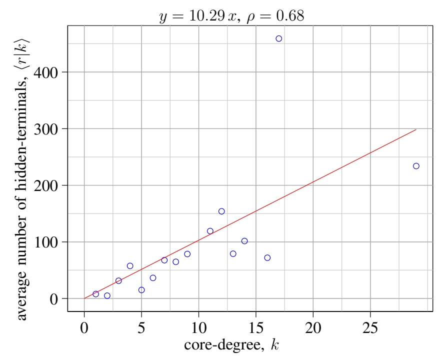


Figure 9. Average number of hidden-terminals vs core-degree in Osona-core.

Barcelonés follows the *scale-free* network model (SF), while Osona does not. Being a pure SF network, a Barcelonés-like graph could be generated using already available SF topology generators, as [27]. Osona graph, on the other hand, demands a more detailed analysis.

Recall that Osona-core is a SF graph obtained by removing terminal nodes in Osona graph. Thus, we shall refer to Osona-like networks as *scale-free hidden by terminals* (SFHT). Clearly, two components are required to synthesize a SFHT graph: (i) a SF *core-graph*, and (ii) the terminals that should be attached to a selected group of nodes in the core-graph.

We shall refer to the terminals added to the core-graph as *hidden-terminals*, and the graph obtained upon adding the hidden-terminals as the *base-graph*. Equivalently, the core-graph is obtained upon removing the terminals of the base-graph. In the following it is investigated a method to synthesize a SFHT graph statistically equivalent to Osona. In order to make clear if we refer to the base or core graphs, in the following we shall use the terms *base-node/core-node* and *base-degree/core-degree* when referring to a node and its degree in the base and core graphs, respectively. For instance, the core-nodes of Osona would be those nodes having degree larger than 1 in Osona graph, and their hidden-terminals would be the number of terminals they have attached. Their core-degree would be their degree minus their number of terminals in Osona graph.

Let N be the number of core-nodes, and T the number of hidden-terminals (the number of base-nodes is $N+T$). Without loss of generality, the set of core-nodes will be identified as $\mathcal{N} = 1, 2, \cdots N$. For instance, in Osona-core $N = 266$, and the number of hidden-terminals of Osona is $T = 6,112 - 266 = 5,846$ (see table II). In our analysis we define the following two discrete random variables (RVs): $r \geq 0$ is the number of hidden-terminals of a core-node; and $k \geq 1$ is its core-degree. Note that $\sum_{i=1}^{N} r_i = T$, where r_i is the number of hidden-terminals of core-node i.

It is likely that nodes of the core-graph having a larger value of k (thus, being better connected) will have a larger number of hidden-terminals, r. Finding the relation between these RVs is a key issue in synthesizing SFHT graphs. Figure 7 shows a scatter-plot of (r, k) in the Osona graph. A Pearson's Chi-squared test of independence of the points plotted in figure 7 gives a p-value lower than 10^{-16}. Thus, the independence hypothesis of r, k must be discarded, as expected.

Computing the joint distribution $P(r, k)$ from Osona data is not possible, since its reduced size would yield extremely noisy results. Thus, it is proceed by computing the marginal distribution of the hidden-terminals, $P(r)$, and its dependency with the core-degree. Figure 8 shows a semi-log plot of the Complementary Empirical Cumulative Distribution Function (CECDF) of the hidden-terminals, r. The figure shows that the distribution of r is very well fitted by a gamma distribution with shape $\alpha = 0.25$ and rate $\beta = 1.15\,10^{-2}$: $\gamma(r) = \beta^{\alpha}\, r^{\alpha-1}\, \mathrm{e}^{-\beta\, r}/\Gamma(\alpha)$, $r > 0$ (the correlation coefficient is $\rho = 0.99$). The number of hidden-terminals would be obtained by taking the floor of random samples generated with such distribution. Note also that

$$\langle r \rangle = \frac{\alpha}{\beta} = \frac{T}{N} \tag{1}$$

where we use $\langle\rangle$ as average operator.

Figure 9 depicts the average number of hidden-terminals in terms of the core-degree: $\langle r|k \rangle$. Computing $\langle k|r \rangle$, even if more informative, would be too noisy due to the reduced size and high variability of r. Figure 9 shows that $\langle r|k \rangle$ is approximately proportional to k: $\langle r|k \rangle \approx a\, k$. Thus, $\langle r \rangle \approx a \,\langle k \rangle$, and using (1) we have:

$$T = N \,\langle r \rangle \approx N\, a\, \langle k \rangle \tag{2}$$

Thus, the slope must be given by $a = T/(N\,\langle k \rangle)$. Using the values from table 2 we have $a = 5,846/(266 \times 2.99) \approx 7.35$, which approximately fits the slope obtained in figure 9 (10.29).

Now we face the problem of sythetizing a SF core-network satisfying the correlation condition imposed by the hidden-terminals distribution. This motivates the construction of the core-network using the *Fitness model* proposed by Caldarelli et al. in [28], and generalized in [29]. The Fitness model generates a SF graph as follows: (i) first create the set of nodes with assigned random numbers generated with a given *fitness distribution* $\rho(x)$, and (ii) for every pair of nodes i, j, create an edge with a *connection probability* $f(x_i, x_j)$, where $f(x_i, x_j)$ is a symmetric function that measures the *importance* of the

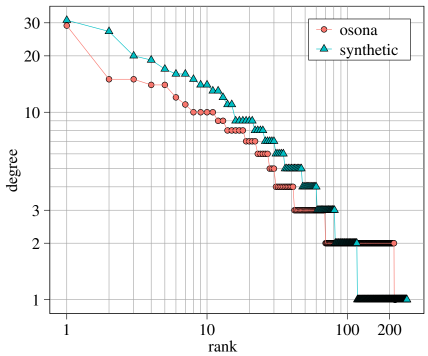


Figure 10. Rank degree $\log_{10}$-$\log_{10}$ plot of Osona-core and the synthetic core-graph.

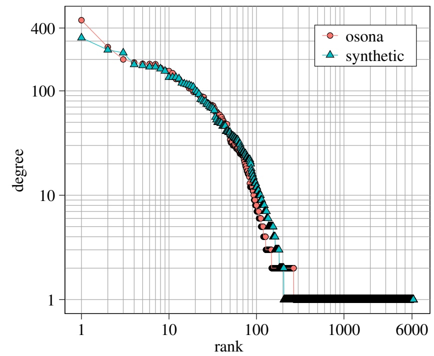


Figure 11. Rank degree $\log_{10}$-$\log_{10}$ plot of Osona and the synthetic base-graph.

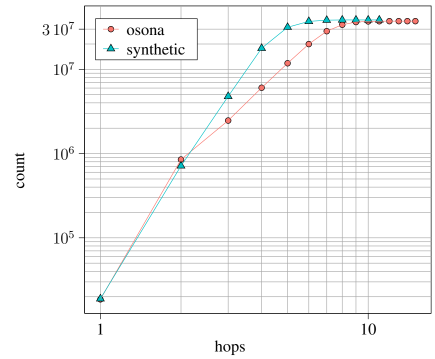


Figure 12. Hops count $\log_{10}$-$\log_{10}$ plot of Osona and the synthetic graph.

nodes. Clearly, in our case the fitness distribution is the gamma distribution that generates the hidden-terminals, r, and the preference of a pair of nodes i, j is given by the number of hidden-terminals they have: r_i, r_j.

The linearity of $\langle r|k\rangle$ with k suggest choosing a connection probability function as:

$$f(r_i, r_j) = \max(r_i\, r_j, 1)/C \tag{3}$$

where C is a normalization constant. By doing this, the average core-degree of nodes having $r > 1$ hidden-terminals will approximately be given by (see [28]):

$$\langle k|r\rangle \approx N \int_{x=0}^{\infty} f(r,x)\,\gamma(x)\,dx = N \int_{x=0}^{\infty} r\,x\,\gamma(x)/C\,dx = \frac{N}{C}\langle r\rangle\, r \tag{4}$$

which is also a linear relation. The intuition behind the connection probability given by equation (3) is that links are preferred among core-nodes having more hidden-terminals. But also nodes having no hidden-terminals are connected to the graph, with preference to nodes with higher number of hidden-terminals (which will have higher connectivity).

Summing up, we propose the following algorithm to generate the topology of a SFHT network. The input parameters are: (i) The number of nodes of the core-graph, N, which is equivalent to the number of nodes of the base graph minus its number of terminals, T. (ii) The desired shape α and rate β parameters to generate the distribution of hidden terminals (satisfying equation (1)). (iii) The number of links of the core-graph (E), which is equivalent to the number of links of the base graph minus its number of terminals, T.

1) Generate N integer random samples, $r_i \geq 0$, taking the floor of the values obtained using a gamma distribution with the desired shape and rate parameters. Create the core-graph of N core-nodes and associate one of the random samples with each of the core-nodes.
2) Add an edge for each core-node using r_i as weights to choose the end point. Doing this way, it will be very unlikely that the final graph is not connected.
3) Use equation (3) as weights to create the remaining desired number of links in the core-graph.
4) Attach the number of hidden-terminals given by r_i to each core-node i.

In order to test the above algorithm we have created a sample synthetic graph using the Osona data: core-nodes $N = 266$, core-links $E = 398$, parameters of the gamma distribution: shape $\alpha = 0.25$ and rate $\beta = 1.15\,10^{-2}$. The hidden-terminals distribution must fit figure 8, since it is generated with a gamma distribution with the same parameters. Figure 10 compares the rank of the Osona-core and the synthetic core-graph, and figures 11 and 12 show the rank and hops, respectively, of Osona and the synthetic base-graph. These figures show that Osona graph is very well fitted by the synthetic graph, demonstrating the goodness of the above algorithm to generate SFHT like graphs.

We have analyzed a higher number of zones in [17]. Except Barcelonés, all Guifi.net zones belong to rural areas. The results obtained in [17] are in line with those shown in this paper. Therefore, we conclude that Guifi.net zones that belong to rural areas can be characterized by SFHT graphs, and generated with the algorithm proposed in this paper.

VI. Related Work

There is a vast work on modeling graph structures that appear in applied sciences as physics, biology and communications networks, see e.g. [30] the the references therein. Regarding communication networks, many works have follow the initial contribution of Faloutsos [10] and Barabási et al [11]. The main research efforts have tried to characterize the topology of the Internet at the AS level [31], [32], [33]. Spectral graph analysis has been used to study the clustering properties [26]. These researches have been used to propose Internet-like topology generators [34], [27] or study the robustness of the Internet [35], [36], among others.

VII. Conclusions

In this paper it is analyzed the topology properties of Guifi.net, a large Wireless Community Network (WCN) with more than $15,000$ operative nodes. The analysis is based on the information stored in CNML-XML available at Guifi.net's portal. Two zones of Guifi.net are analyzed: Barcelonés is a metropolitan area and Osona is a rural area, but having the largest number of operative nodes.

We have followed the power law analysis introduced in the three-Faloutsos paper [10]. Our results show that both zones are significantly different. Barcelonés zone, even if it is smaller, fits better with the *scale-free* (SF) properties obtained in [10] for the Internet. Osona, instead, has some properties that deviate, and might be characteristic of community networks in rural areas. For instance, its degree analysis does not even fit a power law.

Nevertheless, we have observed that upon removing terminal nodes in Osona network, it is obtained a graph that is indeed SF. We have introduced the term *Scale-Free Hidden by Terminals*, SFHT, to refer to these type of graphs. We have analyzed more rural Guifi.net zones in [17]. The results have been not included here for the sake of space, but they are in line with the results presented for Osona zone. Based on our analysis, we have proposed a topology generator that is able to synthesize SFHT-like graphs.

We conclude that WCN emerging in recent years have complex topologies that doesn't seem to follow an homogeneous pattern. More specifically, we have found two topology classes: One is scale-free and the other has a *hidden* scale-free graph that appears upon removing terminal nodes.

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