Analysis of End-User QoE in Community Networks

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ABSTRACT

Community networks are a potential model for the Future Internet, where the users form and operate the network instead of a central, commercial entity. Socio-economic studies show that community networks are an excellent model to develop networking infrastructure commons (as common-pool resources or public goods) that promote sustainable development, with greater effects in less developed areas. The performance of parts of community networks has been studied extensively, often focusing on routing protocols or applications on top of community networks. This work focuses on the end-to-end quality of Internet access in community networks, as a validation of the technical applicability of this concept in under-served regions. A comparative analysis with other ISPs per country shows the effectiveness of these community networks in providing satisfactory networking services to end-users, particularly effective for underserved areas or people.

1. INTRODUCTION

Community networks are often referred to as *bottom-up broadband*, where the people form the network instead of the network being pushed on the people, with a price tag[5]. While network sharing is not a novel idea, the availability of cheap off-the-shelf wireless hardware in the nineties has led to a strong adoption of wireless mesh networks as the backbone for community networks, which now span entire regions. For thousands of users in both developed and under-served countries, community networks form the only means to access the public Internet or even just local community services.

From a sociological point of view, the concept of community networks closely aligns with the availability and sharing of information and services within a community[9]. Especially for developing countries, but even in higher income countries, to most users the local information regarding e.g. crop prices or bus times is an important piece of information. As an illustration, even in the European Union many regions are underserved by traditional ISPs, because of technical reasons but often also because of economic reasons. If the distance between the nearest high bandwidth fiber loop and a particular location is too large, ISPs tend to charge the end-users for their costs. In many cases this cost becomes prohibitive, e.g. in the case of mountainous areas.

Today a large number of community networks are operational around the world, from Argentina to Tibet[2]. Some networks consist of just a few nodes, others are composed of hundreds and even thousands of nodes in the case of AWMN in Greece and guifi.net in Spain[23]. Notice that in the latter case parts of the network do not have access to the public Internet and other parts can only reach the Internet through proxy servers with varying performance[18]. The equipment used to build and operate the network is often low-cost or even DIY, the software running on top of it is usually open source[12, 8].

In this paper we present the results of a large-scale measurement campaign, where we specifically analyse the network performance as experienced by the end-user in community networks in comparison to other ISPs. To the best of our knowledge, this is the first end-to-end measurement study of the quality of Internet access in community networks, as a validation of their deployment for development projects.

The rest of this paper is structured as follows: in section 2, we describe the tools we used to perform measurements on nodes in a network and how these tools are then deployed in existing community networks, described in section 3. In section 4, we describe and compare the results obtained from our measurements. In section 5, we discuss the implications of these results in developing regions and some of the requirements for that to happen. Finally, in section 6, some conclusions are formulated.

2. MEASUREMENT TOOLS

In order to evaluate the performance of a network accessing the Internet, measurements need to be performed. For this, we selected several tools to be deployed in three community networks.

RIPE ATLAS provides a widely deployed tool for measurement of end-user experience[4]. The project has deployed small hardware, called RIPE ATLAS probes, all over the world in thousands of locations. These provide an excellent vantage point within the network. However, the RIPE ATLAS project requires custom hardware by design, to provide very strict guarantees on measurements. For reasons of cost deploying the required amount of RIPE ATLAS probes

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within the community networks under study was not possible.

Project BISMark wants to measure home network performance, and it realises this by means of custom gateway firmware[20]. It is however not feasible to deploy this specific firmware on all nodes in a community network.

NLNOG-RING is a non-profit software project designed to share shell access in participating ISP (core) networks to study and debug network behaviour[16]. The approach is elegant, however it requires connecting existing servers to this ring network in order to increase the sharing scope. Therefore, it was not an option for this study.

Finally, perfsonar-ps is a suite of measurement tools which can be deployed freely, containing a number of systems and techniques to study the performance of networks[6]. Data gathering and open data set publication and analysis is more out of scope for this project, therefore and for support reasons we chose Measurement Lab for the measurement of Internet access, combined with the Community-Lab testbed for launching the measurements from inside of several community networks.

2.1 Measurement-Lab

We selected the Measurement Lab[11] (M-Lab) platform to perform our measurements on. M-Lab is an open, distributed server platform on which researchers can deploy open source Internet measurement tools. The data collected by those tools is released in the public domain. M-Lab was founded by the New America Foundation's Open Technology Institute (OTI), the PlanetLab Consortium, Google Inc. and academic researchers. M-Lab servers are distributed globally, but most of the servers are located in North America and Europe. The M-Lab platform offers a number of measurement tools, enabling its users to do different kinds of measurements, such as Paris traceroute and reverse traceroute[1, 14], testing for application-specific blocking or throttling, testing for traffic shaping, checking up- and download speeds and more. The tool we selected to use in our measurements of Internet access is called "Network Diagnostic Test" and is described in more detail below.

2.2 Network Diagnostic Test

The Network Diagnostic Test (NDT) reports upload and download speeds. It tries to determine the cause of limited speeds and checks for proxies, NAT devices or middleboxes between the machine running the test and one of the M-Lab servers[7]. Therefore it can provide several objective indications of the user's experience of an Internet connection. Below, we included the output of a typical run of the NDT tool:

```
Testing against host ndt.iupui.mlab1.ath02.measurement-lab.org
Testing network path for configuration and performance problems  --  Using IPv4 address
Checking for Middleboxes . . . . . . . . . . . . . . . . . .  Done
checking for firewalls . . . . . . . . . . . . . . . . . . .  Done
running 10s outbound test (client to server) . . . . .  4.45 Mb/s
running 10s inbound test (server to client) . . . . . . 45.92 Mb/s
sending meta information to server . . . . . Done
The slowest link in the end-to-end path is a 10 Mbps Ethernet or WiFi 11b subnet
Information: Other network traffic is congesting the link
Server 'ndt.iupui.mlab1.ath02.measurement-lab.org' is not behind a firewall.
[Connection to the ephemeral port was successful]
Client is probably behind a firewall. [Connection to the ephemeral port failed]
Information: Network Middlebox is modifying MSS variable (changed to 1410)
Server IP addresses are preserved End-to-End
Information: Network Address Translation (NAT) box is modifying the Client's IP address
Server says [79.131.35.128] but Client says [ 10.255.18.237]
```

The most important values in this output for the analysis in this paper are the bitrates for the upload and download tests. What is not included in this output is the RTT value. In addition to producing this output, the NDT tool logs all test data to M-Lab. This data can later be queried using Google BigQuery.

2.3 Google BigQuery

Google BigQuery is a tool to analyse big data in the cloud[21]. It offers an SQL-like interface to query data stored in the cloud. The NDT tool described above logs all results to M-Lab, which can then be queried using BigQuery. The data logged by the NDT tool contains much more information than the output shown above. It contains RTT values, node identifiers, IP addresses, geolocation information and more. The node identifier can be manually specified by the user running the NDT test and can as such be used to group measurement results for each node.

2.4 Community-Lab

To gather the data required for the analysis performed in this work, we have used the CONFINE Community-Lab testbed[1]. Community-Lab supports experimentally-driven research on community networks developed and operated by the European FP7 CONFINE Project. To allow researchers to perform experiments it has more than 200 nodes integrated in five existing community networks: guifi.net (Spain), FunkFeuer (Austria), AWMN (Athens Wireless Metropolitan Network), Sarantaporo.gr (Greece), Wireless Belgium (Belgium) and Ninux.org (Italy). Three of these networks have been studied in this paper: guifi.net, Ninux.org and AWMN.

Using the Community-Lab testbed, it is possible to deploy virtual machines on so-called "research devices". Research devices are connected to the community network through a "community device", a node in the community network, but research devices do not have to adapt to the requirements of the community network. This approach allows researchers to flexibly deploy virtual machines throughout a community network without having to configure the VMs specifically for each individual network. Additionally, by separating the research devices from the community devices, the community networks themselves need not explicitly support the research tools deployed on the network. Figure 1 shows the Community-Lab nodes used in the experiment.

We have deployed the NDT tool on virtual machines running on all the available nodes (211) in the Community-Lab testbed. The tool was scheduled to run once every hour. The data of the test runs are logged to Measurement-Lab to allow access via Google's BigQuery service.

3. COMMUNITY NETWORKS

All over the world citizens and organisations pool their resources and coordinate their efforts to build network infrastructures. The coverage of underserved areas and the fight against the digital divide are the most frequent driving factors, but motivations such as contributing to development of a new telecommunications model or just for pleasure are also often mentioned by community network contributors. Technologies employed vary significantly, ranging from very-low-cost, off-the-shelf wireless (WiFi) routers to expensive optical fibre equipment[2].

Models of participation, organisation, and funding are very diverse. For example, some networks are freely acces-

[1] https://community-lab.net

sible, others are cooperative based, some are run by federations of microISPs, etc.

Community networks (CNs) correspond to the subset of these networks that is characterised for being open, free, and neutral. They are open because everyone has the right to know how they are built. They are free because the network access is driven by the non-discriminatory principle; thus they are universal. And they are neutral because any technical solution available may be used to extend the network, and because the network can be used to transmit data of any kind by any participant, including commercial purposes.

We have selected three main community networks involved in the Community-Lab testbed considering the number of network nodes and the number of research devices available for experimentation. These are the Athens Wireless Metropolitan Network (AWMN) in Greece, guifi.net in Spain, and Ninux in Italy[2]. All of them consist of thousands of links, mostly wireless, but gradually they also integrate optical fibre and optical wireless links. The fundamental principles of these networks, defined at the start to be fully inclusive, revolve around:

- Non-discriminatory and open access to the network infrastructure. The access is non-discriminatory because contributions, either economic or in-kind, are cost-oriented instead of market-oriented. It is open because everybody has the right to join the infrastructure.
- Open participation. Everybody has the right to join and participate (construction, operation, governance) in the community.

These fundamental principles applied to an infrastructure result in a network that is a *collective good*, *socially produced*, and governed as a *common-pool resource (CPR)*, as defined by E. Ostrom [17].

Started in 2002 in Athens, Greece, the Athens Wireless Metropolitan Network (AWMN) is a grassroots wireless community, taking advantage of state of the art wireless technologies, to connect people and provide services. The network comprises (as of July 2015) 2385 active nodes out of 12233 registered nodes, 1238 backbone nodes, 2655 links, 835 access points, 744 active services.

guifi.net started in 2004 in Gurb, a rural and underserved area in Catalonia, Spain. It combines several technologies, mainly wireless and optical fibre. Due to its affordability, accessibility, and ease of deployment, WiFi was the first technology to be used and is still the most popular. The initial nodes of guifi.net were deployed by 2004. Optical fibre was first introduced in 2009[3] and currently there are around 100 optical links. As of October 2015, guifi.net has a total of 29,664 nodes declared as operational, accounting for about 34,000 WiFi links (31,000 AP-Client and 3,000 Point-to-Point) resulting in a total length of 55,000 Km. Most of the nodes (29,600) are located in Spain.

Ninux.org was born in Rome around 2002 and now spans all over Italy. Its name currently stands for "Neighborhood Internet, Network Under eXperiment". Ninux.org is a network of computers connected without wires, created by a community of geeks, radio amateurs and fans in Italy. The network comprises (as of October 2015) 349 active nodes out of 2120 potential nodes, 176 links, and 25 access points.

[2]AWMN: `http://www.awmn.net/`, guifi.net: `http://guifi.net/`, Ninux: `http://ninux.org/`

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

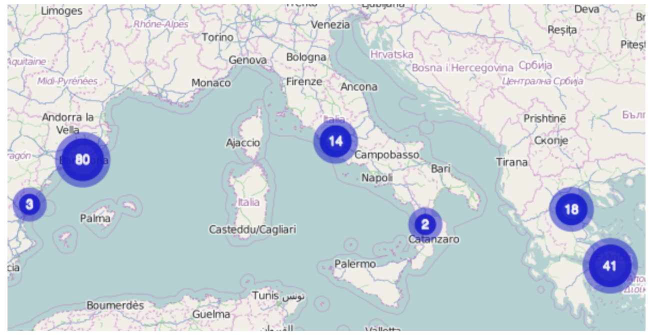

Figure 1: Nodes in the experiment

4. RESULTS AND ANALYSIS

To analyse the behaviour of nodes in a community network accessing the Internet, we have used the measurement data on Ninux.org, guifi.net and AWMN from June 9, 2015 to August 31, 2015 (158 nodes in these three networks). We only have valid data starting from June 9, as the version of the NDT tool used prior to that date could not tag individual nodes with a unique identifier. We need to be able to do this, since we are running our tests across different community networks, which use the same (private) IP address ranges internally. This means that we cannot distinguish nodes based solely on their IP address, as different nodes (on different networks) might be using the same IP. As the Community-Lab testbed already uses internal unique identifiers for each node, we re-used those identifiers as the node identifier in the NDT tests, enabling us to uniquely match each measurement result to the node running the test. During the measurement period, 21,483 download tests have been run on AWMN, 18,907 on guifi.net and 20,171 on Ninux. For the upload tests, we have 21,854, 19,380 and 20,881 measurements, respectively.

4.1 Round-Trip-Time Measurements

The Round-Trip-Time (RTT) is one of the measures to assess the "quality" of a community network. Not only high RTTs are an indication of degraded QoE, but also the degree of variation in RTT is important to take into account.

Figure 2 shows the cumulative distribution of RTT values in the three community networks considered. The RTT measurements are taken from the download tests. The maximum RTT in the graph is capped to 1,000 ms. Figure 2 shows that the distribution of RTTs is very different depending on the community network considered. In the Ninux network, low RTTs are the norm, with 90% of the measurements being less than 200 ms. In AWMN, very low RTTs are uncommon. Most RTT measurements on this network are situated between 100 and 300 ms. The situation in guifi.net, however, is very different. Although a significant amount of measurements show low RTTs (less than 200 ms), the distribution has a very long tail, with 10% of the measurements taking more than 1 second.

This cumulative distribution is taken over all nodes during the entire period considered. As this only gives an indication of the RTTs one can expect in these networks, time information is not included in this graph. Therefore, figures 3, 4 and 5 each show the measured RTT values for two nodes in AWMN, guifi.net and Ninux, respectively. The

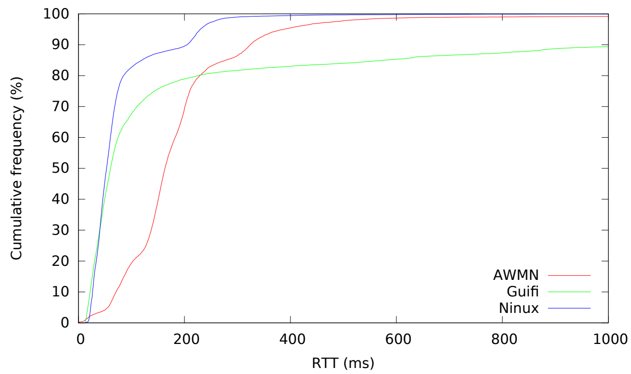

Figure 2: Cumulative distribution of RTT measurements, capped to 1s

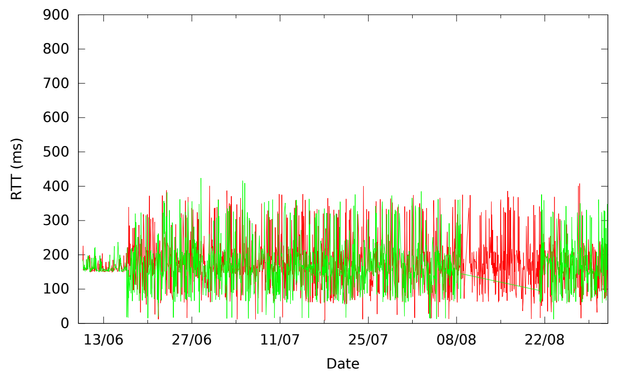

Figure 3: RTT measurements, AWMN

nodes were chosen randomly amongst those that contained sufficient and realistic measurements. With this we mean that some of the nodes that ran the tests are located in data centers belonging to e.g. universities that participate in the community networks. These nodes skew the results, as they tend to have very fast and reliable Internet access, while a typical end-user node does not have this luxury. The graphs clearly show the unstable nature of the networks. In the AWMN network, both nodes behave similarly. From June 9 to June 16, they both experience a relatively high but constant RTT around 160 ms. However, on June 16, something changed in the AWMN network, causing the RTT values to become very unstable. These unstable RTT values are observed continuously for the rest of the measurement period. Also visible on figure 3 is that one of the nodes (represented by the green line) has gone offline for a period of about two weeks, in August. When looking at the guifi.net network, it is clear that one node consistently has a very low RTT, apart from some rare anomalies, whereas another node exhibits a very unpredictable behaviour. The same is true for the nodes in Ninux, in figure 5. Not only does this graph show that RTT values can be very different for different nodes in the network, but also that the behaviour can change over time: the first few days of the measurement period, both nodes experience constant, low RTT times, until something changes in the Ninux network, affecting only one of the two nodes. At the end of the measurement period, another event leads to a sudden change in RTT values for the second node.

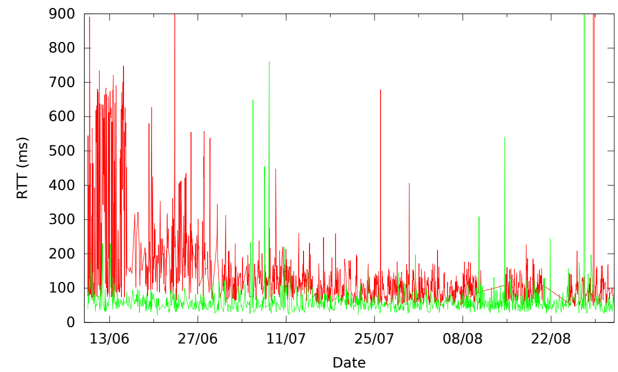

Figure 4: RTT measurements, guifi.net

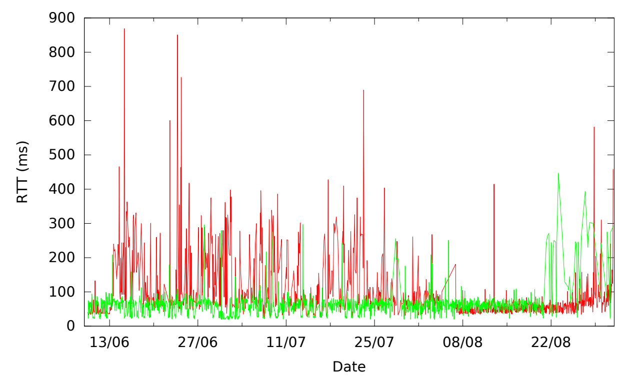

Figure 5: RTT measurements, Ninux

These measurements indicate that the network quality in all three networks considered is variable, both in time (the same node may experience good or bad RTT values over time) and in place (different nodes might exhibit a different behaviour).

4.2 Throughput Measurements

In addition to RTT measurements, the other measure to assess "quality" is throughput, both upload and download. This is also measured by the NDT tool. Figures 6 and 7 show the cumulative distribution of download and upload measurements on the three community networks considered. Both graphs are capped to a maximum throughput of 400 Mbps, as they contain long tails.

Figure 6 shows that a user on the the AWMN network on average experiences lower download speeds than on Ninux and guifi.net. The Ninux network especially logs many very high-speed download tests, as 30% of the measurements exceed 400 Mbps. Although of course very promising results, we consider these to be measurement errors where the nodes were located in data centers or other less realistic locations, as explained above. Because of the setup and the configuration of Community-Lab combined with M-Lab NDT, these results are hard to filter out. Figure 7, on the other hand, shows that the upload speed measurements show less difference between the three networks.

Figure 8 shows the download speed measurements on the same two nodes in the Ninux network as in figure 5. What is immediately visible, is that the download speeds are very

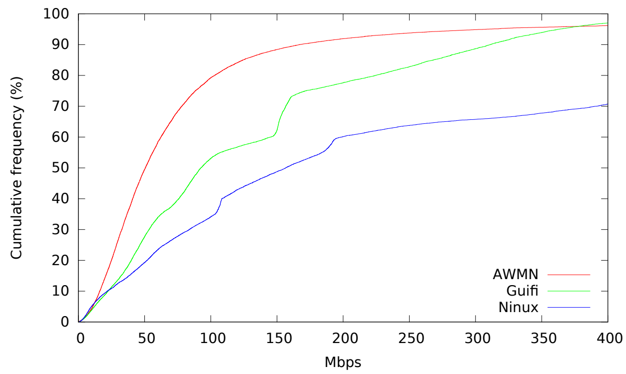

Figure 6: Cumulative distribution of download measurements, capped to 400 Mbps

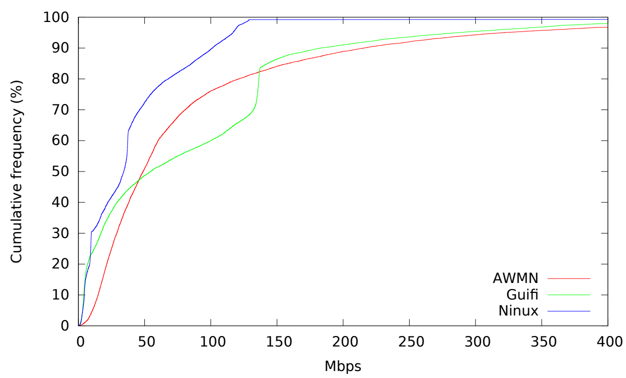

Figure 7: Cumulative distribution of upload measurements, capped to 400 Mbps

variable. However, for the green node (the one with relatively stable RTT times), most measurements lie around the same average throughout the duration of the tests. The red node, on the other hand, shows more erratic behaviour. For a relatively long duration in June, the download speeds measured are very low. These are encountered during a time when the RTT values are very high and unstable. However, in July the RTT values are still high and unstable, while the download speeds are considerably higher. This shows that RTT measurement based monitoring of the quality of a community network is insufficient to assess the overall performance experienced by the end-user.

Figure 9 shows the upload speed measurements for the same nodes in the Ninux network. Again, the results for the red node change suddenly at several points in time, while the values for the green node remain stable throughout the entire measurement period.

4.3 Comparison with Other ISPs in the Region

The experiment reported in this paper using Community-Lab nodes embedded in the three community networks has helped to raise the number of measurements contributed to M-Lab to allow comparisons with other ISPs. On the Ninux (through the FusoLab AS), guifi.net (through the guifi.net Foundation, labelled as "Fundacio Privada per a la Xarxa Lliure") and AWMN (as part of the LANCOM AS) networks, the number of measurements has reached the threshold of 200 samples within the same month, which enables the comparison with other ISPs in the respective countries.

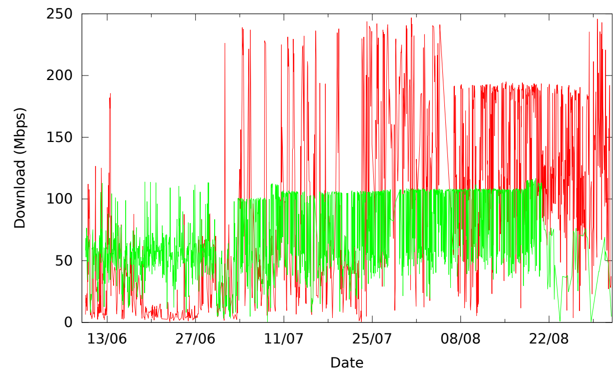

Figure 8: Download speeds, Ninux

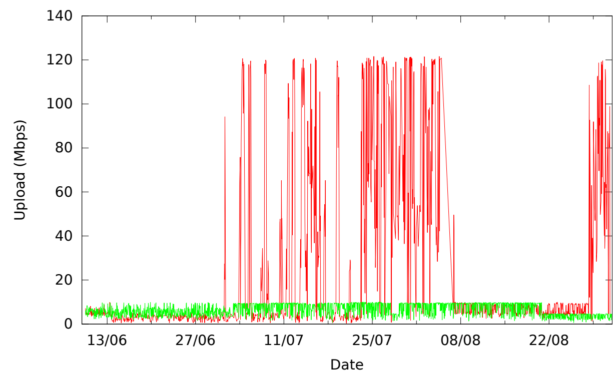

Figure 9: Upload speeds, Ninux

A comparison of results of our measurements in M-Lab with equivalent measurements from top ISPs in the same countries should show how well community networks can serve its users. The resulting performance, measured by M-Lab tools such as NDT, for the three community networks under evaluation is among the top eight ISPs in each country. Figure 10 shows the results for the most typical measurement of median upload and download speed and median latency. The three networks are among the top eight ISPs in download speed. guifi.net is ranked first in Spain both in median upload speed and best median latency; Ninux (FusoLab) is ranked second in upload, and fourth in best latency; AWMN (part of LANCOM) is first in upload speed, 8th in best latency. In the area of Barcelona, where guifi.net has its connections to Internet carriers, the results are excellent: first in upload speed (guifi.net 7.82 Mbps, the Academic network 4.23 and Cableuropa ONO 3.31), third in download speed (Cableuropa-ONO 18.1 Mbps, the Academic network 9.8, guifi.net 9.79) and first in best latency (guifi.net 14 ms, Vodafone 25, Cableuropa-ONO 35).

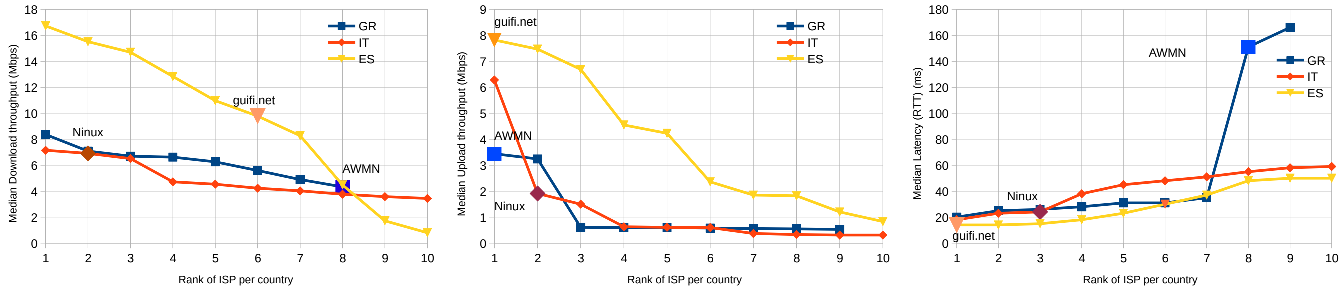

Figure 10: Median Download and Upload throughput (Mbps) and Latency (RTT in ms) per Country and ISP, sorted by Download speed (M-Lab July 2015)

Table 1: Values in Figure 10

ISP in Greece	Down	Up	RTT	ISP in Italy	Down	Up	RTT	ISP in Spain	Down	Up	RTT
Lancom (AWMN)	4.33	3.44	151	GARR	6.51	6.28	38	guifi.net	9.78	7.82	14
OF-Larissa	8.37	3.24	166	Fusolab (Ninux)	6.91	1.91	24	Telecable Ast.	14.7	6.69	18
TELLAS	6.69	0.61	26	Telecom IT	3.77	1.50	58	Euskaltel	15.51	4.55	15
FORTHNET	6.62	N/A	31	Convergenze	4.72	0.63	55	CESCA	9.79	4.23	48
Greek Research	8.85	N/A	20	UNIDATA	7.15	0.61	18	Cableuropa-ONO	12.83	2.36	37
OTE	4.90	0.58	31	FastWeb	3.44	0.60	45	CableTel Galicia	10.97	1.82	50
CYPRUS TA	6.26	0.56	25	Vodafone O.	4.02	0.37	59	PROCONO	16.73	1.2	23
ON	7.08	0.55	35	NGI	3.58	0.33	23	Jazz Telecom	3.19	0.67	76
Hellas OnLine	5.59	0.53	28	Tiscali IT	4.54	0.31	48	Iberbanda	0.8	0.61	99
				Wind Tel	4.23	0.31	51	Telefonica	1.72	0.54	74

5. IMPLICATIONS ON COMMUNITY NETWORKS FOR DEVELOPMENT

The study shows several areas to explore by researchers in networking, social and economics, practitioners and regulators.

The measurement results, despite being more favourable than we initially expected, all come from a well-know third party (M-Lab). Without going too far, we can easily say that the user experience perceived from users located where the probes are must be good to excellent. It is also relevant to see that, at country level, the three community networks are first or second in upload speed, with very symmetric transfer rates, a clear signal of good quality (QoE) and lack of the typical distinction between asymmetric client-oriented broadband connections versus much more expensive server-oriented connections. We encourage additional community networks to setup measurement points or encourage its users to contribute measurements that allow expanding this analysis.

Although it cannot be directly extrapolated to other countries, particularly in developing areas, the experience from many community networks around the world in all continents shows that community-driven cooperative initiatives can create network infrastructures run as a formal or informal network commons and bring connectivity to disconnected or under-served areas, as shown around the world[2] with contributions from nine community networks in North America, three from South America, six in Europe, and one in South Africa. Collaboration over the last two years with UWC in South Africa in the development of a local community network has shown in detail how remote rural communities can bootstrap network infrastructure offering voice and more recently data services to local communities where no commercial models would initially work. The resulting model is described in [19] and in a booklet[25]. These results show how community networks can satisfy the local needs of citizens, administration and businesses. Instead of extracting money from the community towards big Telecom operators, the study shows ways where the money flow can go to local entrepreneurs and start-ups who do maintenance, troubleshooting, and computer help for local users, including local schools and community groups. This can create a sustainable ecosystem, even a competitive market, of local businesses that contribute to local development. In fact, guifi.net has enabled local business models, with about 270 professional installers involved, including about 15 local micro-ISPs. However this socio-economic impact has only been studied with sufficient detail in guifi.net.

Regarding measurable impact in population from under-served areas guifi.net has collected evidences. guifi.net is mainly deployed in the region of Catalonia, starting from a rural area with very bad or nearly no connectivity [3]. Statistical data is available from a large scale survey about penetration of the bandwidth and Internet access in the households of Catalonia in 2013, released by the public Catalan Statistics Institute (IDESCAT)[4] detailed for each of the 42 counties in Catalonia. Despite the fact that Catalonia is about three points above the Spanish average, it is still seven points below the European average. The Catalan county with the best results and the only one above the EU average, is Osona, where guifi.net was born. It is surprising to see higher penetration than in Barcelona, the largest urban area in the region of study. Moreover, it is the only county where broadband access is above Internet access (showing that guifi.net is a local broadband infrastructure where most but not everyone use it to reach the Internet, and many also use it for internal communication). The indicators of other counties where guifi.net presence is significant, such

[4] `http://www.idescat.cat` Data source: `http://www.idescat.cat/novetats/?id=1724&lang=en`

as Bages and Baix Ebre, are also larger when compared to similar counties but where guifi.net presence is irrelevant.

While Ninux and AWMN are yet limited to their own countries, local initiatives following the guifi.net network commons model [3] and using its tools are starting or have developed in other regions of the world. In Africa a few nodes are operational in Ethiopia (about 20 are planned). More are planned in Morocco, Nigeria and Occidental Sahara. In Asia there is one operational node in Pakistan and 8 planned nodes in India. In America there are 5 operational nodes and 22 planned or under construction in Argentina, 5 operational in Colombia, for a total of 169 nodes in different states of development, including in Bolivia, Brazil, Chile, Cuba, Ecuador, El Salvador, Haiti, Mexico, Nicaragua, Paraguay, Peru, the Dominican Republic, the United States of America, Uruguay, and Venezuela.

The principles, governance mechanisms, and results, in terms of service (QoE) and coverage, shown by these community networks among many other around the world demonstrates the effectiveness of the model to serve the needs for connectivity and participation in the digital society for all, particularly for the underserved by other commercial or public offerings. These community networks become a *collective good* or a peer property in which participants contribute their efforts and contribute goods (routers, links, and servers) that are shared to build a computer network. Its development is a *social production* or a peer production because the participants work cooperatively, at local scale, to deploy an infrastructure and build network islands. The resulting infrastructure is governed as a *common-pool resource (CPR)* to avoid the tragedy of congestion or destruction by abuse and to become a key resource for widespread participation and socio-economic development.

In fact, the International Telecommunication Union in its report[22] in 2008 proposed regulatory reforms to promote widespread, affordable broadband access, rooted in enabling and promoting diverse practises of sharing. Similarly as with competition, sharing is seen as very beneficial in multiple aspects such as passive infrastructure like ducts, civil works, towers, poles, rights of pass, radio spectrum, international gateways, undersea cables, mobile roaming, content distribution. A recent study[15] also confirms the opportunities, economic benefits, and its growth, with best practises identified in Africa (Kenya, Nigeria, South Africa, Uganda, Côte d'Ivoire, Mozambique), and Asia (India, Indonesia, Thailand and the Philippines). Therefore infrastructure sharing appears to be a good principle for national regulators to promote cost effective and therefore sustainable network infrastructures, that can enable competitive service offers.

African countries are known for network inefficiencies: excessive latency due to circuitous routing paths, going many times across Internet exchanges in Europe to connect two nearby countries[13], and lack of local caches and servers[24]. Our measurements show that the observed communities rank among the best infrastructures in median upload speed and median latency, with allows and promotes the production and provision of local content. The network commons model enables and promotes traffic exchange among nearby networks. This is demonstrated by guifi.net acting as a de-facto regional 10 Gbps backbone Internet exchange that interconnects with small local ISPs reducing latency and widening the offer of local services and content. In fact, these non-profit neutral initiatives can help build cooperative efforts that can result in the bootstrapping of local markets for connectivity and services.

Recent studies by the European Commission[10] show that many studies conclude that broadband has a significant and positive impact on economic growth (measured by GDP) through improvements in productivity, a positive relationship between broadband speed and GDP, with greater effects for countries and regions with lower income. The study arguments that high-speed networking service shares characteristics of a public good (such as street lighting) that can be supplied by different levels of public and private sector collaborations. Although this is part of the EU Broadband Vision, it applies globally, and community networks appear to be a successful model to cooperative build and improve infrastructures to achieve that vision under a network commons model.

In fact, the feasibility of a community network and its network commons model of a local network infrastructure requires the support of local governments, as they regulate access to public spaces, a neutral telecom regulation that allows and promotes low barriers for new infrastructures, a local community that has the need, motivation and experience to manage a commons resource, and a team of local champions that have the vision, will, leadership and credibility of the locals.

6. CONCLUSION

In this paper we presented the results from the first end-to-end measurement campaign in community networks using the M-Lab measurement infrastructure and the Community-Lab experimental testbed embedded in several community networks. The results from a user perspective with NDT show promising network performance in general, however with high variability over time and over different nodes. This is clearly illustrated by measurement results which exceed multiple seconds.

The contribution of many more NDT measurements to M-Lab originating in community networks from our experiments has enabled a comparison with other ISPs of the performance of the Internet access service and the quality of experience (QoE) from a user perspective. The country results show that each community network is among the top eight ISPs in its country in end-user network metrics, and achieves top results for upload speeds, which shows the symmetry of connectivity compared to the typical asymmetric service from commercial ISPs.

Despite several community networks have proven their feasibility with sustainable local infrastructures and society impact, our experimental results can not be considered conclusive so far. Therefore, we believe more prolonged and extensive measurements are necessary.

Moreover, we plan future work to consider additional quantitative analysis of Quality of Experience in community networks, as end-users from the communities are fairly happy with the results shown in this work. Additionally, it would make sense to correlate the end-to-end data with more information on the underlying network, including topology and e.g. routing algorithm knowledge. Given the requirements of real-time, correlated data, this might be particularly hard to realise.

Results from community networks and recommendations from global organisations such as ITU, Deloitte, APC and the European Commission show the great direct and indirect impact of cooperative (sharing) efforts to develop networking infrastructure and services under a commons model of governance. Supportive regulation and financial support of these initiatives can have a major impact in local socio-economic development and quality of life improvements, even with greater effects in developing areas.

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