Community Network QoS Monitoring System

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Abstract

This literature review looks into research that has been conducted in relation to community networks, monitoring systems in networks with a small aspect looking at research done in data-driven networking. We start by looking into research conducted in community networks, what they are and how they are different from other networks. After this, we pay attention to research that has been conducted in relation to monitoring of network systems, including the systems that have been built for collecting data within networks and how this data can be analyzed and used to facilitate data-driven networking. We finally look at research that has employed machine learning techniques to being able to detect anomalies in the network where anomalies are considered as unusual network behavior. In doing all this we comment on things that we think are useful to coming up with a monitoring system for community networks.

CCS Concepts • **Networks** → Network measurement

Keywords Community Networks, Data-driven Networking, Quality of Services

1. Introduction

Community networks are large-scale decentralized networks that are built and operated by the citizens [21]. The networks are at times run by non-profit organizations who can cooperate with stakeholders to develop community services which include internet and local networking [6]. These networks are becoming more and more popular for providing Internet access to remote areas. They are ideal as they are distributed and meaning that there is no single point of failure and also as they can be managed by the users of the network. As these networks are mostly managed by the users in the network it will be good to have a monitoring system that users and the providers of the network could have use to look at how the network is performing. As a result this literature review looks into Community networks, Network measurement tools and network monitoring tools that have already been established for other different types of networks. The end result is investigate what other research has been done for Quality of Service monitoring systems for other networks and get a good idea into the good practices that one should consider when building a monitoring system.

This literature, also looks into how other systems best store network measurements aswell as how they perform Anomaly detection using Machine Learning and network measurement data that was collected. We hope by the end of the review we will have a clear picture of how different network measurement systems are developed, which machine learning algorithms can be used to detect anomalies in the network given some data and the architectures of these systems. We lastly take a brief look into the different methods that are used to visualize measured data that will be accessible to all users to view the network activities. For each section we look into different research on that section comment on them and then look into how we can potentially use these ideas into building a QoS monitoring tool for community networks.

2. Quality of Service

Quality of Service (QoS) is a term used to describe technical parameters in a network that signals the quality of the internet connection [13]. It is closely related to the term Quality of Experience(QoE) which refers to how the users experience a particular service [13]. QoS and QoE are related as some metrics withing QoS affect the experience of a service by users. For example if we have the raw throughput to be low, and we were watching a YouTube we will definitely not have a good experience of this service hence the QoE is affected by the technical description of the network. QoS looks at metrics like raw throughput and signal strength of the network. For these to be meaningful and effective each data should be tied to a particular location, device that recorded the data, and possibly the time the data was collected.This review focused on seeing how other sys-

tems have designed their systems paying more attention into storage of data collected from the measurements.

3. Community Networks

Community networks are defined to be large-scale self-organized distributed and decentralized networks which are built and managed by the citizens for citizens [6]. In attempt to reduce costs, community networks are usually built with low cost hardware with the nodes often running an open source software [6]. Community Networks are part of the subset of networks characterized as: (i)open because everyone has a right to know how they are built, (ii)free because networks access is not based on discriminatory principles (iii)neutral as the network can be used to transmit data of any kind and by any participant [5].

3.1 Background

Community networks have been around since the late 1990s and since then have taken different shapes and forms[16]. The setup of community networks make them more appealing for providing internet access to unrepresented areas. This is because of their characteristics:

- Decentralization of the network [21] which removes the chances of having a single point of failure within the network.
- Community networks are also self-managing [6], which already suggests that they are not so costly as they will not require a body to manage the network since the networks are managed by the users of the network.

An example of this type of network is guifi.net that operates in Spain [14], which by 2015 was the world's largest community networks in terms of number of nodes and coverage with over 27000 operational nodes [1].

One important aspect of community networks is a Node, which can be a device that relays data within the network or devices that provide other nodes network access [16]. The community network also constitutes of links between the nodes and these can be wireless or wired [16].

3.2 Research on Community Networks

Researchers who study community networks are faced with challenges. Most of the challenges are classical network challenges that face all other networks and some that peculiar to these networks. One of the papers [6] enlists some challenges in community networks that researchers may face [6].

One of the challenges within these networks stems from the fact that the networks at the physical layer usually use wireless networks, which then means that there has to be extensive wireless planning involved [6]. The paper goes on to present an infrastructure that aims to remove obstacles for community networks in terms of sustainability and scalability called Community-lab [6].

Example of challenges with posed by Community networks stems from the issue of privacy. Community networks should permit users to participate in the networks while maintaining the privacy of their data and the data they relay, however, this leads to a different notion of threat models and a new notion of trust between the users [6]. Also, turning requirements like the need for network traffic to be organized in a fair way such that network neutrality is respected is a challenging task and it is even more challenging which is even more challenging when attempting to address this automatically [6].

Lastly on examples of Challenges associated with Community networks is the concept of standardization. Standardization includes but is not only limited to protocol design according to Braem and his team [6]. Braem and his team [6] claim that currently very little effort has been put into standardization but however standardization is needed for the further growth and sustainability of community networks.

Community-lab is said to be a open infrastructure that provides to researchers and experimenters a testbed to carry out experiments within wireless community networks [18]. It comes with a testbed that support experimentally-driven research on community based networks. [6]. More research has since sprung from this infrastructure. An example of such research has been a monitoring system for the community-lab that demonstrated a monitoring system while proposing a new architecture for self management to automate management of these networks [18]. Another research related to this is [5], which explored end-to-end quality of experience on community networks. Quality of experience is widely used to describe how users experience a particular service [13].

As stated above, most of these community networks are based in Europe and thus most of the research developed in relation to community networks is with respect to the European countries. Limited research has been done for using community networks in developing regions of the world leading to scarcity of most tools for the community networks in these regions. There is need to explore some of these tools and investigate how they can be adapted for use in community networks in the context of developing countries.

4. Monitoring systems

Monitoring systems are essential to network systems as they give an overall view and many different metrics for a network. Monitoring networks is crucial not only for the end users of the network who need to know the performance metrics of the network but is also important for the policy makers and the network regulators [2]. [4] says that there are three stakeholders in network performance measurements and these are the end-users, the ISPs and the regulators. [2, 4] seem to agree on the different groups of people that are affected by the data collected from these measurements. All these groups of people all have different use cases for the measurement data, for instance ISPs can use the data to identify, and isolate network faults and also to have an understanding of user's end-end service experience [10]. Drawing parallels from the argument made in [2] where they claimed that the data collected from monitoring networks by running certain measurements is not only important to improve user experience on the network, but also important for providing feed back on the design of other upcoming technologies [2]. This sentiment is true for community networks. Monitoring these networks can help the funders of the community network with feedback that can then be used into making advancements into the existing networks. The results from monitoring the systems could also be useful for research that involves community networks.

Monitoring of networks consists of being able run some measurements on the networks. Different systems have been built thus far to take networks measurements. Some of these are accessible to end-users like by going to their website, like OOKLA Speedtest [2]. Tools like OOKLA Speedtest where criticized by [2] as they are not scalable and also not repeatable. Repeatability has to do with the fact that we cannot continuously take measurements on the network. However, there have been more internet measurement platforms that have been introduced through research. Internet measurements platforms refers to infrastructure that has been dedicated to periodically run network measurement test on the internet [4]. [4], claims that one needs to worry about factors like signal strength, device type, radio type e.t.c when collecting these measurements from the network. One example of a internet measurement platform is the MONROE platform which is service for collecting measurements data and allows for running of experiments for Mobile Broadband networks [2]. This platform is explored further in the following section.

4.1 Measurement Tools

There have been different network measurement tools designed for collecting network measurements for community networks in particular. Some of these studies where mentioned and discussed by [5] and include:

- RIPE ATLAS which is a measurement infrastructure that is deployed by the RIPE network Coordination Center and consisting of thousands of hardware probes all around the globe aswell as anchors[4, 3]. While hardware probes obtain active measurements determine network connectivity and global reachability, anchors serve as dedicated servers that can act as sources and sinks for the network measurement traffic [3]
- Another tool is the BISMark tool that seeks to measure home network performance by means of custom gateway firmware [5]
- We also have perfsonar-ps which is a suit of measurement tools which can be deployed freely [5].

The above mentioned tools where all used in the study performed by Braem and team, where they sought to analyze the End-user Quality of Experience in Community Networks. They needed to perform measurements as they claimed that evaluation of network performance needs measurements to be performed [5].

4.2 Network Measurement Platforms

4.2.1 Using Smart phones for network data collections

A naive approach to taking network measurements is to make use of the users mobile phones, that is have the phones constantly take network measurements and then sending these to a central database server for analysis. This can be via an application installed on mobile phones that will collect measurements on fixed time intervals. The advantage of this approach is that it will give the network providers a clear picture of Quality of Service at different locations in the network as according to [17], a mobile user is likely to use different application at different locations and access different websites at different times of the day. These assertions can be explored to find out if there is a relationship between this behavior and the network metrics and if there is Providers can then try to work on the network so that all users in different location can all have the same experience at all times.

This approach has problems which include privacy issues, power demands of measurements that will affect the mobile phone's battery life to mention but a few. The authors of [22], come up with a solution LiveLab to address some of the challenges that arise from using mobile phones for taking network measurements. Livelab is method for measuring real-world smart phone usage and wireless networks with a re-programmable indevice logger [24].

Livelab is built to overcome privacy and power challenges. To overcome privacy challenges, the authors conducted a survey that showed that participants in the research did not mind the information content being sent from their phones aslong as that cannot be traced back them. The system leverages hashing of data for uniqueness and there after packaging of data from the users phone to be sent [22]. For power saving, the logger uses 4 different logging methods which are [22]:

- Interrupt depended logging as opposed to polling method
- Piggy-backing which is save all the data on the phone and then collecting them when the phone is connected to power and idle
- Optimizing logging intervals for periodically logged items
- Lastly having the logger hitch hike on other system application and services waking up

Most of the approaches describe in Livelab, although for iPhones, can still be explored and applied into building application that will collect measurements from any kind of mobile phones from participants in community networks respecting their privacy and also paying in mind to power usage of the phones. We can especially the adopt the idea of hashing the owner of the data being sent to the database for the sake of keeping the recording devices unique.

4.2.2 MONROE PLATFORM

MONROE platform according to [2] is an independent multi-home open access hardware-based platform for running large-scale measurements and experiments in operational Mobile Broadband networks. MONROE platform is said to consist of 250 Nodes both mobile and stationary with each of the software in these Nodes open source [20]. Each node runs 3 software, the management software to ensure that the node will always remain operational and also enable remote update to all of the other software components. Another software is the maintenance software monitoring operational status and the last software is an experiment enabler [20].

Monroe can handle experiments that range from continuous latency measurements to real-time flows together with meta-data collection where meta-data is information like location of data type of device for measuring data and so on [2]. The platform comes with a website for viewing the measurements being collected in the network, Nodes and software for orchestrating the collection of the measurements [2]. Other papers like [20] have extended into this platform by adding a tool to measure Quality of Experience for Youtube-streaming services.

The MONROE platform provides a platform for measuring the Quality of Service in Mobile Broadband networks as already stated above. However, the design of the system seems well thought out that it could easily be implemented or cloned to measure network services in a community networks. The nodes in the MONROE platform can be implemented into community network as other nodes as the community networks already consists of nodes. Therefore, we believe that the platform MONROE lays good foundation to building a new internet measurement platform. Since the work is open source it is also open for extension.

Another approach to explore will be to use the Livelab methodology together with the MONROE like platform into increasing number of nodes that are collecting measurements in a network while also having a testbed for conducting experiments in the network.

4.2.3 Measurement-Lab and Community Lab

Measurement lab(M-Lab) is "an open, distributed server platform for researchers to deploy active internet measurements tools" with the data collected released to the public domain [9, 5]. M-Lab only runs active measurement tests and in addition it conducts measurements between the user/client and the M-Lab servers to examine the end-end performance along the path [9]. Some of the tools provided by M-Labs currently include:

- **Network Diagnostic Tool (NDT)** which is a tool that measures the through put between the client and host in terms of download and upload speeds [9, 5]. The tools also tries to determine the causes of slow speeds as well as checks for proxies, Nat devices or middle boxes between the machine running the tests and the M-Lab server collecting the tests hence providing several objective indication of user experience of an internet connection [5].
- **Network Path and Application Diagnosis (NPAD)** which uses TCP to measure end-to-end throughput and information about the switch/route queues along the path [9]. According to Dovroli and team "The tool reports specific events and creates web100 snaplog files along with metadata" [9].

Community-Lab as mentioned earlier on above is a platform developed and operated by EP7 Project which supports experimentally driven research on community networks [5]. The testbed provided by Community-Lab is inspired by Planet lab which is not a measurement platform but still rather supports development and testing of new network services [4, 5]. Each node in Community-Lab consists of two to three devices and these include the community device, the research device and an optional recovery device connected together via a local network [18]. Community devices are wireless

routers, research devices are low powerd system that are running OpenWRT distribution that makes it possible to allow simultaneous virtual containers [18].

4.3 Network measurement Analysis

After being able to collect measurements from a network it is then necessary to analyze the data so we can make meaning of it and use it to make better decisions in he network. As stated by [10] the measurement results need to influence internet operations for them to have impact. Therefore there is need for analysis of the data. The analysis of this data can provide us with different things including being able to study the user patterns on the network so we can be able to spot or detect anomalies in the future. Other advantages that can come from taking network measurements are as follows:

- It gives users the ability to have performance visibility of the network [7].
- For network operators and service operators it will be good for them to have the ability to isolate the faults within a network, that is them knowing which part of the network is at fault [7] and this can be achieved with enriched network measurements analysis.

4.3.1 Storing of Network Measurement Data

One important issue that comes up when we collect data and try to analyze the data is not only how the data is measured but also how the data is stored. The storage of data affects how easy it is going to be to extract the data for analysis and also to what extent we will be able to run machine learning algorithms on the data. Therefore it is important that we pay close attention to this. Since data will be collected from different devices and different applications(phone application and computer application), we have to have a good design for the data storage.

One idea to consider is taken from MONROE [2], where the system consisted of:

- Remote repository and Data Importer for. The remote collect experimental data from each node after every experiment. In our case, this type of repository can also collect network measurement from the. This aspect can however can be excluded from the initial design of Quality of Service monitoring system.
- Database System which consists of two tables one for experiment measurements and the other for metadata like location device type. The database that is used in MONROE is the Cassandra database. Casas and team also used the Cassandra database in their paper for storage of data for the reasons that Cassandra is a fully distributed database with no single point of failure [8]. Therefore for our system we could also use Cassandra database/ Cassandra like database for storing network measurement data.

4.3.2 Data-Driven Networking

Analysis of the network measurements can drive into the idea of Data-driven networking [11] which is the design and management of network systems via analysis of network measurements. Jiang and team explored some of the problems associated with data-driven networking and concluded that most of the problems are a result of predictive approach of data-driven networking [12]. Some of the problems include the fact that this approaches suffers from biases and that it the approaches cannot respond to sudden changes in the network [12]. They then explores another approach which is real-time exploration and exploitation which also comes with its challenges to which they provided a framework Pytheas that addressed some of the challenges [12].

4.3.3 Machine Learning Applied to Measurement Data

The high-volume and dimensionality of data provided by the network measurement systems opens a door for machine learning approaches to help improve data-driven networking problems [8]. Machine learning will then help with producing algorithms that help detect anomalies in the network, predict future network measurements and since community networks are self-managed it will be worth exploring the effects that arise from adding intelligence into the community network via using machine-learning algorithms to analyze measured data.

Casas and team presented two major problems that one can face when using machine learning algorithms and these include [8]:

- Network measurements application very large amount of heterogeneous network monitoring data to be processed in real time.
- It is hard to select the best learning method algorithm as it is the accepted notion that there is no best solution to addressing different problems simultaneously.

The problem pertaining the complexity involved with choosing a certain Machine learning model is solved by employing the Ensemble Model where different Machine Leaning algorithms are combined to form one Model that provides better predictive performance than the ones emplyed [8]. This gets rid of the need to select only one Model as we can select the best Models and combine them to form one good model in the hopes that it will be even better. The research by Casas and team produced GML a Generic Machine Learning Model generalizes one of the well known stacking approach to

ensemble learning deployed ontop of a Big Data analytic framework for network measurement applications [8].

5. Data Visualization

We have thus far looked into the measurements of data which included collection of data from different devices within the community network and then we looked into the different ways we can use the analysis of data which included how best to store the data after recording it. We will now look into how we can display the data to the user so that the collected data can make meaning to the user and influence their actions. We recognize that the stake holders as mentioned earlier that are affected by the measured data include the end-users, the ISP and the regulators of the network. In the case of community network the user groups can be reduced to 2 and that is the end-users in the network and the network providers.

Visualization as stated by Ruan and team is an important tool for capturing network activities [19]. In their paper Ruan and his team come with a method for visualization of network data using "Principal Component Analysis and Multidimensional Scaling to reduce dimensionality and use color map to enhance visual quality for human beings" [19].

Again since MONROE was a full platform it also provides a visualization system for viewing the data measurement in form of a website [2]. The system uses passive traffic measurement tool like Tstat to analyze the traffic generated. Data and metadata stored in the databases was visualized using MONROEs visualization tool which integrate active and passive measurements int a web interfaces [2]. The visualization tool shows time-based performance measurement at the same time providing device tracking through GPS information taken from each node and also a summary of the metadata in forms of tables.

For the Qos monitoring system, we will also need a web based visualization tool that uses data from the database to show the user the performance visualization of the network. We can however, still look into using PCA and Multidimensional Scaling to further enhance the visualization tool for the. This web visualization tool should be able to cater for all the stake holders interested in the performance of the network and as mentioned earlier these are the ISps and end-users.

6. Discussion

We have presented in our review different research focusing on networks, network measurement platforms and visualization tools all in attempts to examine how other monitoring systems are built or how other aspects of monitoring systems are built. We looked a diverse types of networks like community networks and broadband networks [2, 6] which was done in attempts to examine if the different tools for the different network types can be adapted for the other. For example tools for Mobile broadband tools being adapted for community networks. We also took the approach to examine all networks and not just community networks to get familiar with research done under networking field.

In order to improve the Quality of Service for the end-user there is need to collect measurements from the network and analyze the collected measurements. We have thus looked at systems to collect these measurements from the simple ones like OOKLA speedtest [2] more complicated ones like MONROE AND M-Lab [2, 9]. MONROE and M-LAB are both measurement platforms but have differences. Monroe was presented as an open source project for collecting network measurements for broadband networks[2]. M-Lab on the hand is not just tied to a particular network type and comes with tools that enable users of M-Lab perform different kinds of measurements [5, 9]. Such a platform will be useful to have in attempts to come up with a monitoring systems for community networks. The fact M-Lab and one of its tool Network Diagnostic Tool where used by [5] in their paper where they Analyzed and of end-user QoE in community networks means that the platform has already been tested with community networks and thus can be used for a monitoring system for community networks.

We however noticed that there is few research that focused on the storage of the data collected from the measurements of these networks. [2] gives an overview into their system and how they stored data but still does not tell us why they went with that approach. We however have [8] who mention the fact that they used Cassandra database as it is fully distributed and lacks a single point of error. We feel that we can still explore a study into finding the best way to store data to optimize analysis and searching performed on the data by looking into other databases and seeing how they compare to Cassandra. More specifically we fell further investigation can look into how we can create databases that measure network data from different devices at different network layers so that they can be easily process by applying machine learning algorithms or easily queried for viewing by different devices.

7. Conclusion

In this review, we have looked into community networks by examining their make up and some of their properties. We then looked into network measurement systems and payed more more attention into the Livelab [22] in-device logger that collected and logged different

network measurements while mitigating issues like privacy and power challenges and also MONROE [2]a network measurement platform that provides nodes that are constantly collecting network measurements from the network aswell as a testbed for running network experiments We then identified how we can explore techniques from Livelab [22] and MONROE platform [2] to come up with a measurement platform for collecting measurement data from community networks. We feel the next step is to look into the best ways to store network recorded data from different devices for use by different applications and different groups of people.

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