An Evaluation of the Performance of the University of Limpopo TVWS Trial Network

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Abstract. A comparative study of the performance of the TV White space (TVWS) network and WiFi is presented. The Software Defined Radios and Cognitive Network Technology have presented many opportunities and possibilities, which advances the wireless technology. This paper investigates the effectiveness of the TVWS technology in comparison with the legacy broadband WiFi technology. The TVWS technology utilizes the spectrum holes in the broadcasting frequency bands. The vacant frequencies can be used opportunistically by the TVWS technology in providing broadband solutions to rural areas among other areas. It is therefore imperative to investigate the effectiveness of this technology and its performance in relation to existing technologies. The comparative study of TVWS and WiFi is therefore presented. For this study, performance-monitoring techniques were employed to analyze the basic performance metrics such as throughput and latency of the TVWS and WiFi technologies. To evaluate the performance of the technologies, two-performance analysis tools were used, Internet performance open group (Iperf) and Java Performance/Scalability Testing Framework (jperf) tool. Speedtest was also used as an additional tool. The performance data were gathered and analyzed. The results show that the performance of the TVWS of the University of Limpopo trial network still requires significant improvement for it to at least match the performance of the legacy technologies such as WiFi.

Keywords: Cognitive Networks · Software Defined Radios · TVWS

1 Background

The lack of broadband technologies in rural areas is widening the digital divide. The current technologies can not be deployed in rural areas due to a number of reasons. For example, it is not cost effective for telecommunication operators to deploy broadband technologies in rural areas given the terrain, barriers, density, sparsely populated communities with no disposable incomes. There is therefore a need for cost effective technology, which can be deployed in rural communities. Wireless technologies have emerged as promising rural technologies and are attracting significant research attention [1]. The TV White Spaces (TVWS) technology is one such technology, which is

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envisioned as a potential rural technology [2]. However, there is a need to investigate its performance in remote rural communities.

The TVWS technology is considered a rural technology largely because of its good signal penetration and efficiency. It also offers better coverage however, at the cost of low information content. Lastly, the technology does not require any new spectrum and it addresses the spectrum scarcity challenge through the utilization of the licensed TV channels opportunistically, for broadband communications. The University of Limpopo (UL) in collaboration with Microsoft, Multisource and Council for Scientific and Industrial Research (CSIR) implemented a trial TVWS network which connects five (5) rural schools. The UL trail project is the second such a trail project in South Africa after the Cape Town project [3]. The Cape Town project was implemented in an urban area while the UL one was deployed in a rural setting.

The term TVWS refers to "part of the spectrum, available for a radio-communication application (service, system) at a given time in a given geographical area on a noninterfering/non-protected basis with regard to primary and other services" [4]. The TV broadcast bands, between 450 and 700 MHz can be utilized for broadband communication [5]. The vacant or unused portions of the radio spectrum can be used as an alternative for wireless broadband communication and access in both rural communities and urban centres [5].

In [6] white space spectrum is defined as "frequencies that are not being used by existing licensees at all times or at all locations". The TVWS technology utilizes the unused or unassigned frequency opportunistically for wireless broadband communications. It is envisioned that the TVWS technology will address the underutilization of the licensed spectrum and the overcrowding of unlicensed spectrum against the backdrop of ever-increasing number of wireless devices requiring wireless spectrum bands for communications. The advert of the TVWS technology and the deployment of the trail projects in South Africa will benefit the growing economy if they succeed [3].

2 Related Work

TVWS is yet to be implemented as an operational network however, a number of trial networks have been deployed. The performance analysis of the technology still requires further investigation. There are many wireless technologies that exist namely 2G, 3G, IEEE 802.11 and 4G however; our research is a comparative study of the performance the UL trial TVWS network and WiFi. The study focuses on the performance of these two technologies in terms of bandwidth, jitter, and latency. This study is significant in the light of the observation in [7], which concluded that the availability rural broadband technologies are hardly compared to urban technologies. The success of teaching and learning depends largely on the access to the broadband technology and these broadband technologies are not deployed in rural areas. The TVWS technology however, addresses this digital divide for the benefit of the rural communities.

Malawi - Performance Assessment of TV White Spaces Technology
There are a number of performance analyses on TV White Spaces technology that have been conducted. The study in [8] conducted a preliminary performance assessment of TVWS technology in Malawi after a successful deployment of the technology. In addition to the monitoring and analysing the performance of the network, they also evaluated the performance the network through simulations. However, for the scope of this paper, we focus on the monitoring and performance of the technology.

The results [8] of the performance were based on the students accessing contents or material availed through the electronic system of the university library. Students also use the services of the network to interact with the university faculty. The evaluation of the performance was to ascertain the usability of the technology. The evaluation was also designed to inform the industry regarding the capability of the technology including its effective coverage and bandwidth. However, the evaluation did not present results, which relate to the experiences of the end users in terms of downloading and uploading rates. In this case, a learner may want to download study material and lecturers may want to upload notes and reading material. Our study takes into consideration the end user experiences.

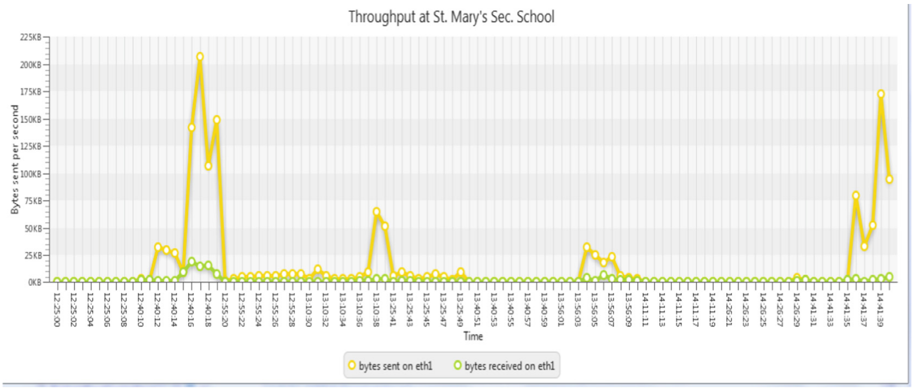

Fig. 1. Achieved end to end throughput at St. Mary's School [8]

The results of the preliminary measurements of throughput and latency were generated. The results are presented in Fig. 1.

The measurement were done for a period of two hours and the maximum throughput achieved was 2 Mb/s. The results show that the technology offers reasonable connection speeds; however, large buffers and higher connection speeds are required for large files and multimedia files. A 2 Mbps connection may be sufficient for voice and may be a challenge in rural areas due to fading, attenuation, shadowing effects and distance. The average latency of the network was also generated and the results are presented in Fig. 2.

Latency, the delay between an input being processed and corresponding output has a negative impact on time bounded data such as voice and video data.

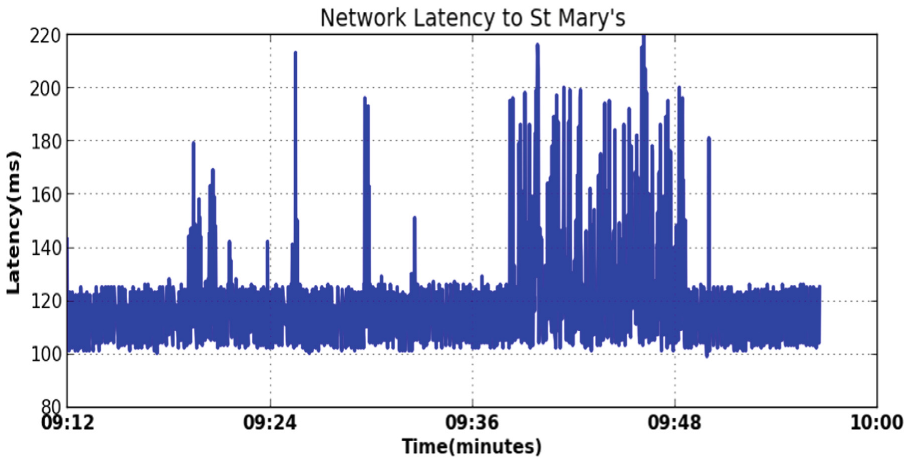

Fig. 2. Latency at St. Mary's School [8]

Cape Town Trial

The study in [3] made a contribution in TVWS in South Africa by deploying a trail network. The trial network is based in Cape Town and was launched on 25 March 2013. It was deployed to explore the capability of TVWS technology in widening network access.

The trial network established that TVWS can provide a fast broadband solution that is reliable at bit rates in the order of Mbps for distances up to 6.5 km.

Cape Town was selected as the host for this trial because it has the highest number of players utilizing the broadcasting spectrum in South Africa with high likelihood of interference. The trial was conducted to demonstrate that TVWS technology can deliver low-cost broadband services without interfering with the TV reception.

The trail network has multiple base stations located at Stellenbosch University's Faculty of Medicine and Health Sciences in Tygerberg, Cape Town. The network provides connectivity to ten schools located within a radius of ten kilometers. The links to each school have a capacity of 2.5 Mbps. The schools are equipped with Carlos Wireless RuralConnect TVWS radios with a backup ADSL line.

The results show an uplink peak of 4 Mbps while the downlink peak speed was 12 Mbps. The results show the great potential of the technology. However, the latency results show that the technology still requires improvement. High latency is largely caused by the Software Defined Radio. This study presents similar performance results of the UL trail network which provides connectivity to five rural schools [9, 10]. However, in contrast with the Cape Town trail network, the UL trial network's evaluation is based on data gathered over longer durations.

The Extension of LTE Operation Mode over TV White Spaces

The work in [3] extended LTE to TVWS. The motivation of their work was the digital switch over which releases Ultra High Frequency to be used for TVWS technology. Network simulations were employed to evaluate the scheme. The simulation framework modeled an urban scenario. The results of the simulation are presented in Figs. 3 and 4. The results compare the performance of the LTE with TVWS.

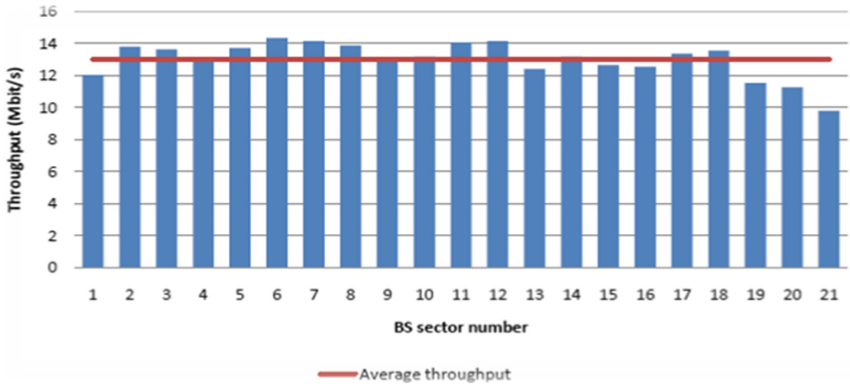

Fig. 3. Legacy carrier

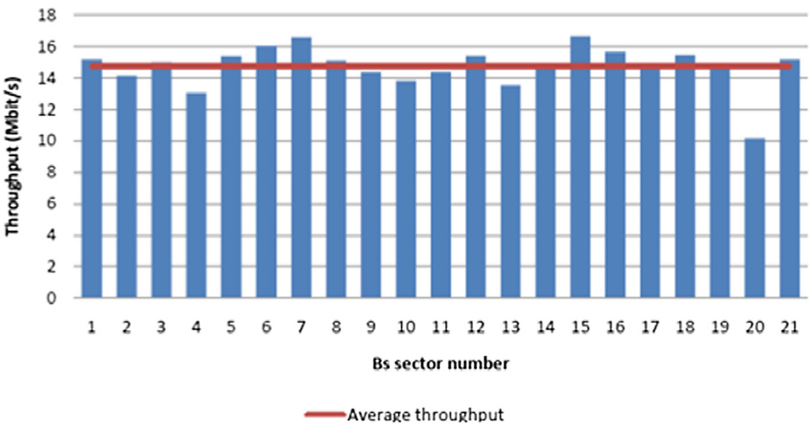

Fig. 4. TVWS carrier

The results show that the TVWS outperformed the LTE in terms of coverage and achievable throughput. The TVWS offered a wider coverage than the LTE technology. The TVWS also achieved higher throughput in all the sectors. The adoption of TVWS is motivated by its characteristics, and its good coverage.

A number of TVWS trail projects have been implemented elsewhere. For example in Cambridge [11], Kenya [12], and EI, Dorado County [13]. The implementation of cognitive radios has gained popularity since 1999 when Mitola [14] proposed it. As a result, specifications of TVWS has been recommended in [15] and [16]. In [17], a number of spectrum access algorithms were reviewed and the technology is presented as a candidate of the next generation networks. Lastly, studies [5, 18–24] either present the TVWS as a possible rural technology or as a promising alternative technology to existing technologies.

3 Methodology

Active monitoring method has been adopted for this study. It involved the collected of data between two end points in the TVWS network. The tool used for the monitoring was Internet Performance Working Group tools (Iperf) which collected bandwidth, delay jitter, and loss measurements. The monitoring was conducted on different days during the week when there was high traffic in the network. The data was collected for a minimum of 12 h during the week on different days.

The throughput was measured using Iperf. Iperf was configured using command lines. The tool was used to test the point to point bandwidth. Three computers were configured and were placed at different locations and measured the performance of the network between endpoints. The experiment was designed to monitor TVWS network at three sites, specially three schools, namely Mamabudusha, Doasha and Mapeloana.

A clock was used to measure the file transmission speed. TCP and UDP traffic was generated to measure the performance of the network. The network was evaluated using the jitter, bandwidth, and the latency metrics.

Jperf was used to collect WiFi data. Two computers were configured as a server and the other as a client. The speedtest was used as well to test the upload and download rate, as well as the latency of the WiFi network.

4 Results

The goal of this research was to compare the performance of TVWS with the existing technologies such as WiFi. The data was collected using three different network analysis tools namely, Iperf, Java Performance/Scalability Testing Framework (Jperf), and speedtest. Figure 5 presents the bandwidth results of the WiFi network.

Figure 5 represents the end user's experience on WiFi network. The measurement results between the 170 and 200 s are presented. The results show that from 170 s the bandwidth was less than 0.5 Mbps. It remained under 0.5 Mbps until it peaked momentarily to 6 Mbps after 195 s before dropping to 2.5 Mbps. At the time of the measurements, there were few active users, which accounted for low bandwidth. The results also show that when active users reduce, the bandwidth for a given user increases. The users received more bandwidth after 195 s largely because some users had to close their sessions in preparation for the next class. Around this time of the measurement, students move from one lecture to the next. Students tend to have short sessions during these breaks to access emails, messages, the learning management systems, and other applications. Figure 6 presents more bandwidth results. The results were gathered approximately six seconds after the results in Fig. 5.

Figure 6 shows that users were consuming less than 0.7 Mbps on the Wi-Fi network. It only reached the highest pick of 0.7 mbps. The bandwidth usage later dropped

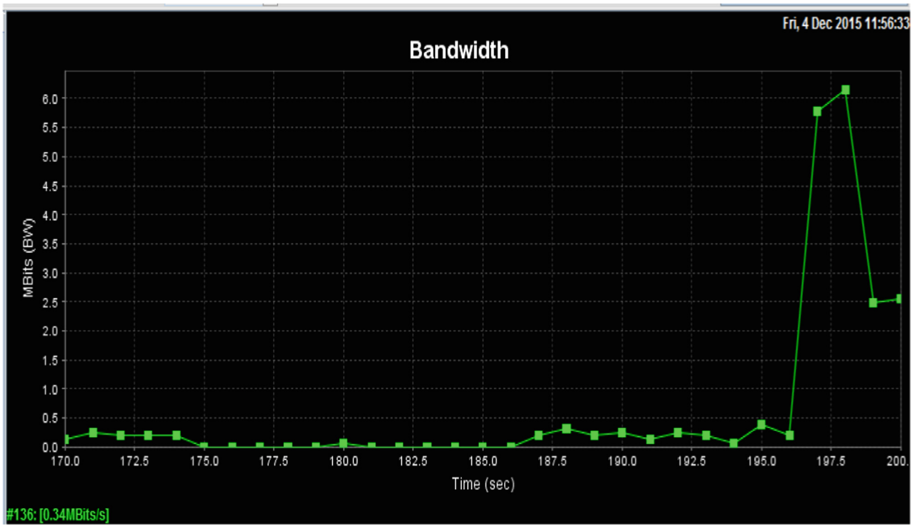

Fig. 5. WiFi bandwidth

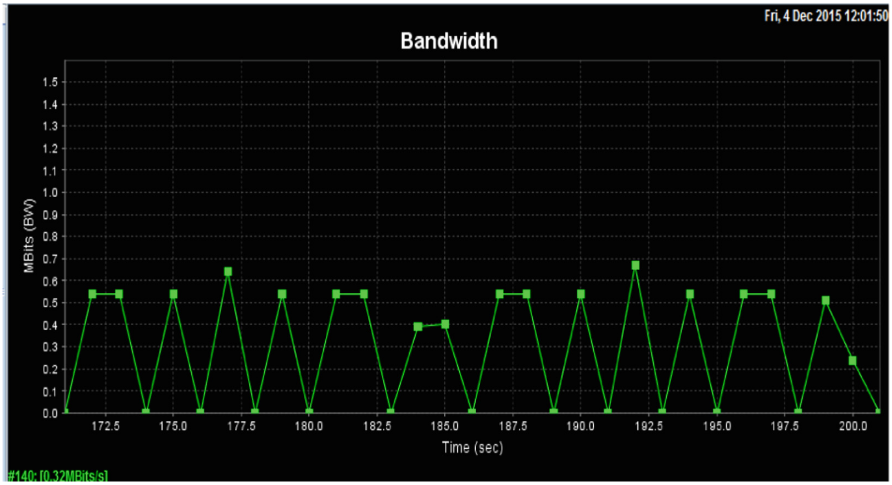

Fig. 6. More WiFi bandwidth

to as low as 0.2 mbps. This shows bandwidth increased when active users closed their sessions and thereafter it began degrading as new users began accessing the Internet after the lectures. The jitter results are presented in Fig. 7 together with the bandwidth results.

Figure 7 represents both bandwidth and jitter. According to the results, there was no observed delay and jitter in the performance of the network. The TVWS technology requires more improvement in delay and jitter. The technology cannot guarantee the

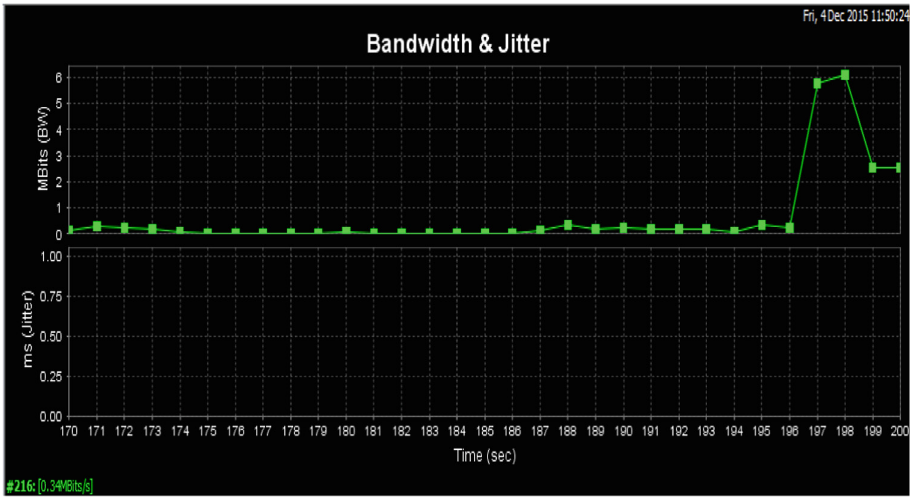

Fig. 7. WiFi bandwidth and jitter

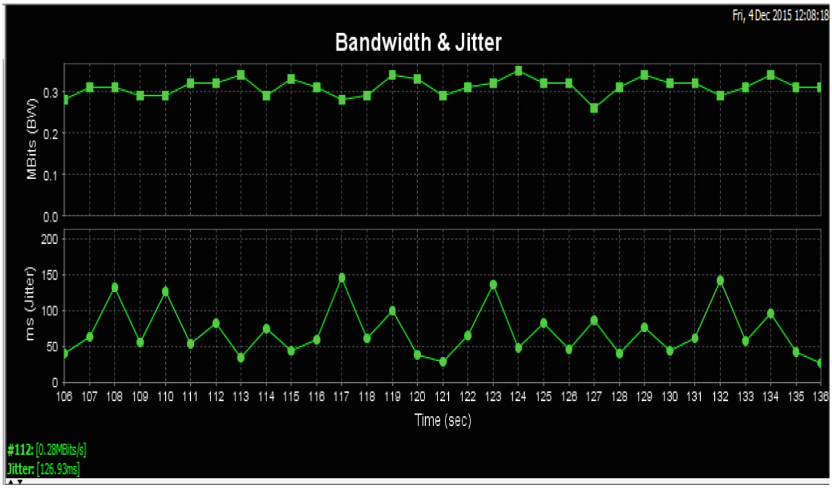

Fig. 8. WiFi bandwidth and jitter

QoS requirements due to jitter and delay. Figure 8 presents more jitter and bandwidth results.

Figure 8 shows both jitter and bandwidth. The jitter reached the highest pick of 150 ms which shows a lot of delays of packet transition on the Wi-Fi network. The network was degraded by many active users. Figure 9 presents more bandwidth and jitter results.

The jitter results show that when the number of active users reduces, jitter improves. The jitter results reached a maximum of 100 ms, which delays packets on

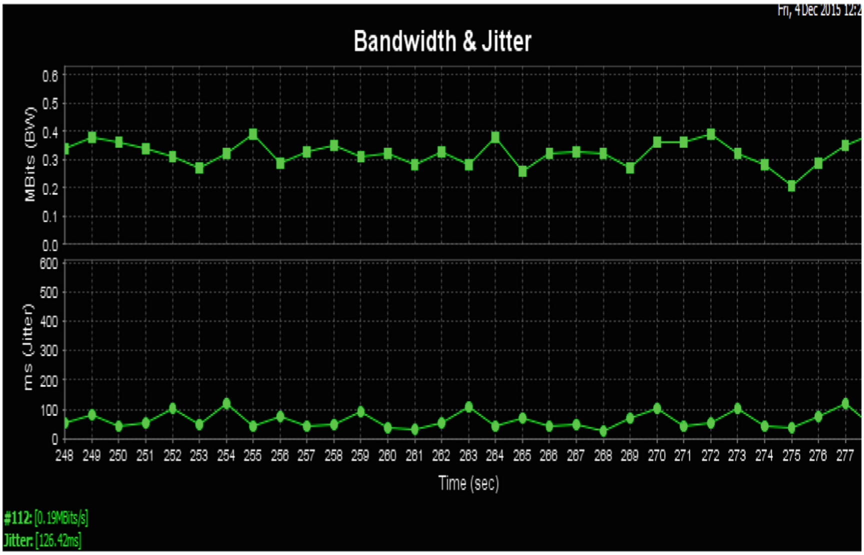

Fig. 9. WiFi bandwidth and jitter

the network while the bandwidth was ranging between 0.2 Mbps and 0.4 Mbps. The jitter was less than 100 ms while bandwidth increased marginally.

In Fig. 10, we present the TVWS results and compare them to the results of the WiFi technology. The WiFi had more active users compared to the TVWS network.

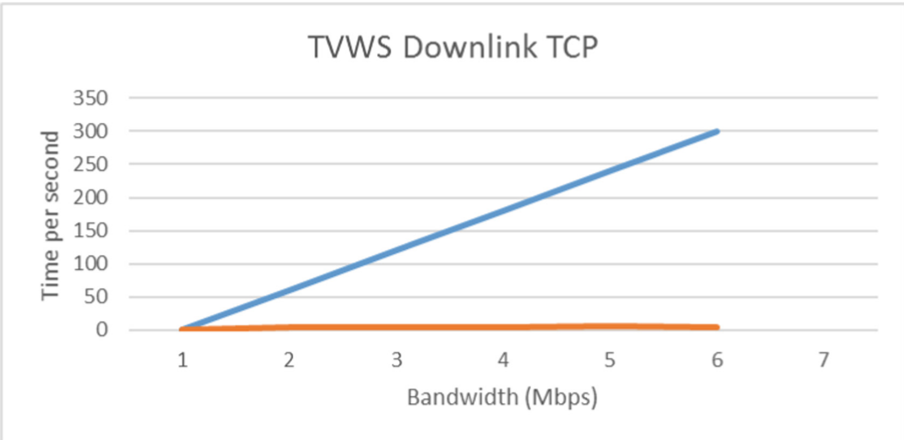

Fig. 10. TVWS downlink

The TVWS downlink results depicted in Fig. 10 show a steady increase in bandwidth from 1 Mbps to 6 Mbps. The measurement results for a five minutes duration were extracted and reported on. During this period, the achievable throughput increased steadily. Figure 11 depicts the latency results for an uplink.

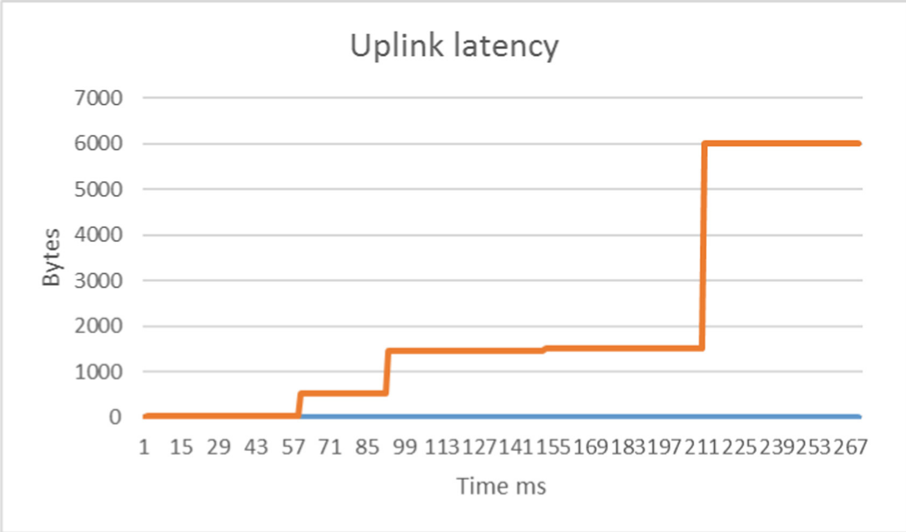

Fig. 11. Uplink latency on TVWS

The latency results show that in TVWS technology an increase in traffic increases latency. They also show that the TVWS in its current performance level cannot meet the QoS of time bounded data. The TVWS UDP jitter results are presented in Fig. 12.

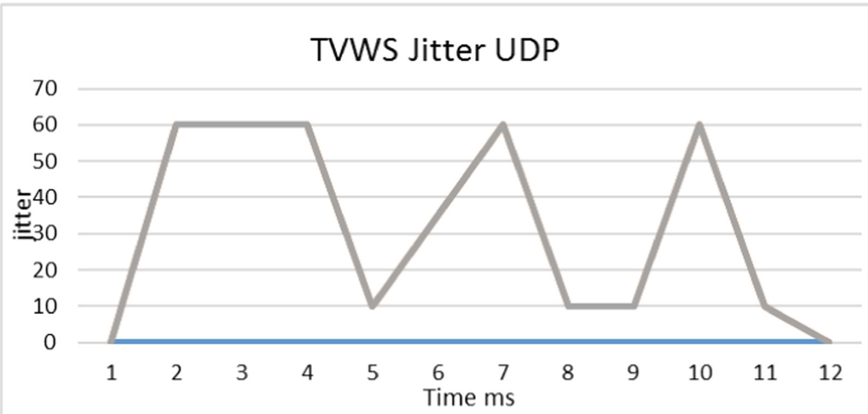

Fig. 12. TVWS jitter

The TVWS technology outperformed the WiFi in terms of jitter results. The number of active users can be the cause of this good performance. There were many active users in the WiFi network as compared to the TVWS network. The TVWS jitter results are significantly lower than the Wi-Fi jitter results. The Wi-Fi jitter was over 100 ms whereas the TVWS jitter is less than 70 ms. The TVWS delay results are also reasonable and can be tolerated by the client. The jitter results, in general, they vary in the network, fluctuating between 10 ms and 60 ms. The performance of the TVWS network was also monitored for a longer duration in Fig. 13.

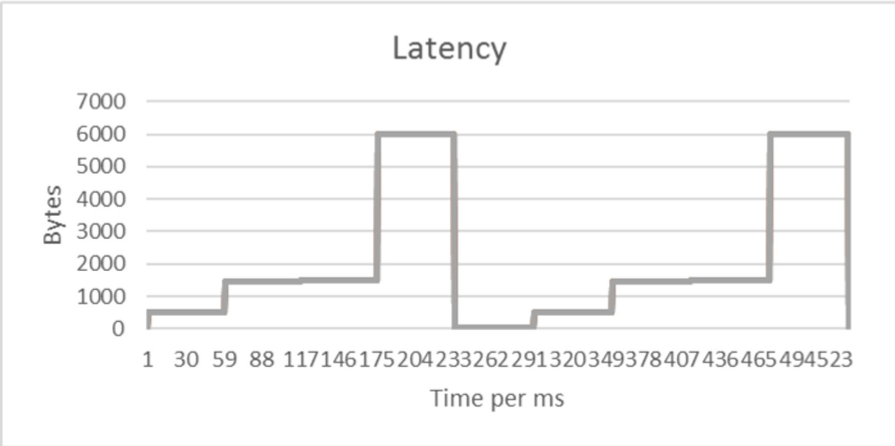

Fig. 13. TVWS latency results

The latency results were generated which depicts that technology is not performing well with regards to latency. Figure 14 presents additional results of the TVWS network in which the uplink speed was measured.

These tests show that 120 bytes were transferred in 116 s. The curve increased as the bytes transferred rate increased. Figure 15 presents the speedtest results of the WiFi network.

The speedtest used to gather performance results shows that the network was able to reach 4.99 Mbps of download speed and 8.52 Mbps upload speed. The WiFi offers higher uploading and downloading speeds compared to the TVWS technology. The speed results show that the TVWS seemed to be performing well due to the fact that it had fewer active users.

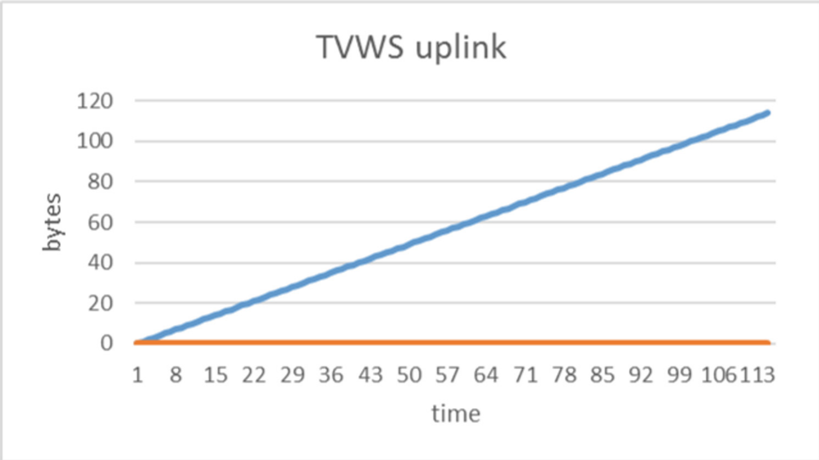

Fig. 14. TVWS uplink speed

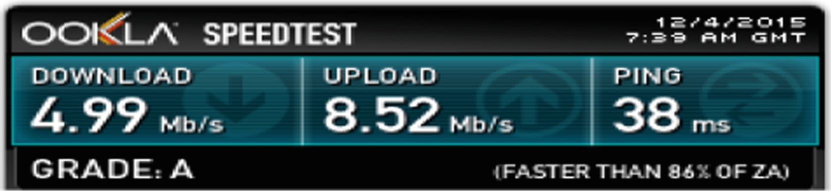

Fig. 15. Speedtest results on Wi-Fi network

5 Conclusion

The results of this study in relation to the literature provide insights to the future research directions in TVWS. In general, the characteristics of TVWS that makes it attractive to broadband access. Attributes such as its capabilities to cover long distances, and to penetrate walls and hard substances clearly show that TVWS is a promising technology. However, the performance of the technology still requires in-depth investigation. Most of the studies do not perform through performance analysis of the technology.

This study contributes to the need for further investigation by presenting practical results based on a trial network. It also presented comparative results of the TVWS and WiFi networks.

The research findings of this study are consistent with the findings of several performance related studies in the evaluation of TVWS technology. This study extended the existing evaluations by presenting comparative results of TVWS and WiFi technologies in a rural setup. An efficient broadband technology customized for rural areas is sought after. This study and the related work show that TVWS can be successfully deployed in the rural areas. Though in our study, TVWS outperformed the

WiFi network there is need for further investigation of the technology in more scalable, robust, large, and heavily loaded TVWS networks offering many multi hop links in a mesh like topology.

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