TV White Space Usage in Education: An Overview of GTUC TV White Space Network in Accra, Ghana

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Abstract: This paper introduces the Ghana Technology University College (GTUC) television white space (TVWS) network deployed in Accra, Ghana. The network, which is still work-in-progress, provides Internet connectivity to six Senior High Schools and the GTUC Abeka campus using two sub-networks built using White Space devices from two different manufacturers. After introducing the GTUC TVWS network, the paper then presents the preliminary results as well as few challenges facing the network. The ultimate results of the GTUC TVWS network will be interesting given that the regulator in Ghana, the National Communications Authority (NCA) has proceeded to issue a commercial license to operate on TVWS while the regulations are not finalised.

Keywords: Television White Spaces, Wireless Networks

1. Introduction

A growing number of the population in developing countries are without affordable access to Internet connectivity in spite of the numerous benefits that can be derived from its availability and appropriate usage. The International Telecommunication Union (ITU) reports that, broadband penetration in Africa continues to rise steadily but lags behind the rest of the world. The global internet penetration statistics for 2015 rates Africa’s penetration at 20.7% compared to the world’s average of 43.4%.[1] This low rate of Internet penetration on the continent is largely attributable to the deficit in fixed-line telecommunication infrastructure in most African countries. The cost of investing in fixed-line telecommunication infrastructure is expensive and this cost continues to rise nonetheless. The situation has compounded the Internet connectivity problem in developing countries and limiting the citizenry’s participation in the global digital economy.

According to Lysko, *et al* [2], wireless communications has been considered one of the most cost effective solutions to providing Internet access to areas where fixed-line telecommunications infrastructure does not exist, hence, focus has been placed on the exploitation of unused radio frequency (RF) spectrum in the television band, known as Television White Space (TVWS), to provide affordable wireless broadband connectivity to people in underserved areas. Saeed and Shellhammer [3] argues that the TVWS spectrum provides a much better RF propagation than the systems deployed in the Industrial, Scientific and Medical (ISM) bands, allowing for a reliable, cost-effective, and better coverage in rural areas and metropolitan applications, such as intelligent transportation, emergency and public safety, and smart grid.

A 2014 social indicator data from the United Nation Statistical Division reveals that about 46.6% of Ghana's population live in rural communities [4], and these communities lack investment in telecommunication infrastructure. This is due to perceived lower average income per head compared to urban communities, narrow skills base, less developed service sector, and geographical characteristics such as thick vegetation and sparsely distributed population and settlements. Connecting these areas by means of fixed-line infrastructure is capital intensive and a cheaper alternative may be in the deployment of affordable cutting-edge wireless communication technologies. The motivation is therefore in the provisioning of last-mile broadband network infrastructure and access through TVWS technology to those in areas which are unserved or underserved, difficult to reach (terrain challenges), or socio-economically marginalized but can be elevated through technology-driven and the knowledge economy.

The purpose of this research is to investigate the feasibility of using TVWS enabled by a geo-location spectrum database to provide wireless broadband connectivity to inner-city public schools and finding solutions to the likely signal interference problems that will arise due to competing transmissions in the allocated TV bands/spectra with primary users (PU) in the city. The study also seeks to extend the lessons learned in inner-city experiments to schools in rural communities by providing TVWS wireless network access that links them to the commodity Internet in support of education, e-commerce activities, and rural industry development.

Based on the above purpose, this research paper aims to achieve the following objectives:

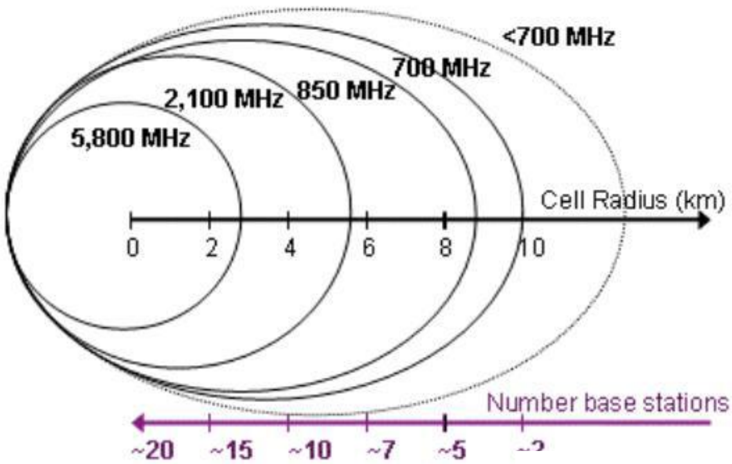
- **Improved Education to Rural Schools:**
  - The network will be used to expand software technologies research in distributed content sharing of educational software artefacts such as e-books distribution platform at the primary and secondary levels of education in geographically challenged communities, so that pupils in these areas will have untethered access to broadband connectivity to access the wealth of educational resources abound on the Internet.

- **Influencing the Regulator to Open up TVWS access**:
  - Regulations for TVWS access are not yet defined across the African continent. The outcomes from the TVWS trials will play an important part in supporting the regulator in Ghana, (i.e. the NCA) in making informed regulatory decisions on how to allow TV spectrum sharing between broadcasting and broadband communication.

The remainder of this paper is presented as follows. Section 2 provides a high level overview of TVWS, related works around the use of TVWS in other African countries and the regulatory status of TVWS in Ghana. Section 3 presents the Ghana Technology University College (GTUC) TVWS network and the description of the network nodes. The preliminary results of the GTUC TVWS network are presented and discussed in Section 4. Section 5 concludes the paper with a mention of ongoing and future works.

2. Television White Spaces for Broadband Access

The TVWSs offer favourable propagation characteristics which makes more cost effective when it comes to rolling-out the network. The term “white space” refers to portions of radio spectrum that are allocated for licensed use but are not assigned to a particular licensee or are allocated and assigned for licensed use but are not utilized by the licensees at all times or across all geographical locations [5]. As shown in Figure 1 below, the number of base stations (BS) required to provide wireless coverage increases as the RF spectrum band moves from few hundred MHz to GHz.



Source: BBC R&D

Figure 1: Propagation characteristics of radio frequency spectrum

2.1 TVWS Networks: Related Work

There are a number of TVWS trial networks deployed across the world of which some are completed and some are still ongoing [6]. The Cambridge White Spaces Trial in UK [7] included a number of scenarios, such as city centre, rural, and machine-to-machine (M2M) connectivity. In 2013, a commercial pilot study started in Singapore [8] which considered a variety of commercial services that could be deployed using TVWS technology in a terrain where traditional wireless deployment would be difficult. Such service included various monitoring applications and video surveillance.

The NICT in Japan with support from King's College London [9] recently launched a trial network under the auspices of the Ofcom TV White Spaces Pilots [10], [11]. The IEEE 802.11af system established a 3.7km point-to-point link using one TV channel, achieving a downlink throughput of over 2 Mbps.

In Africa, the TVWS trials have been deployed in SA [12], [13], in Tanzania [12], in Malawi [14], in Kenya [15], in Namibia [6] and in Ghana [6]. Cape Town trial [12] is the first large scale TVWS trial in Africa. The trial was set up to demonstrate that TVWS is a viable technology for providing alternative means of reliable high speed wireless connectivity, and that it can coexist with TV broadcasting – the primary user (PU) of the band. The trial utilized TV channels adjacent to the operational TV broadcasting channels. Despite this, no interference was reported for both analogue and digital TV reception. These results have prompted the regulator in SA to prepare for public discussions on TVWS legislation.

The Namibian trial network with coverage of 9,424 km² is currently the largest in the world [12]. The network covers several regional councils and a number of schools in the northern part of Namibia. The trial in Kenya has demonstrated the technical viability of this model of delivery, using point to multi-point TVWS base stations with coverage of up to 14 km at 2.5W Effective Isotropic Radiated Power (EIRP) [15], the base stations can achieve up to 16 Mbps on a single 8 MHz TV channel.

2.2 TVWS Regulation: A case of Ghana

Currently there are no rules regulating the use of TVWS in Africa. Despite a number of TVWS trials, several regulators are playing a wait and see approach in order to decide on how to regulate these valuable RF spectrum bands. As such, any form of TVWS usage is such countries is based on trial or research licenses issued by the regulators, for example, the Independent Communications Authority of South Africa (ICASA) issued a number of trial licenses to allow research and development on TVWS for the two separate TVWS trials in South Africa [12], [13].

The NCA in Ghana recognizes the need to innovatively increase spectrum supply and availability in the country and has issued a combination of commercial and trial licenses for the exploitation and research on TVWS. Microsoft 4Afrika Initiative reports on its website that together with Spectra Wireless (the first Africa company to offer a consumer broadband Internet access service leveraging TV white space technology), they “launched Africa's first commercial service network utilising TVWSs in Ghana [16], which will allow students to buy affordable, high speed internet bundles and devices”. According to the report, this commercial service “builds on the success of the initial TVWS pilot launched in May 2014”.

The issuance of a commercial licence to Spectra Wireless in partnership with Microsoft via the 4Afrika initiative [16] is one of the special cases in Africa. Through this initiative, the NCA has demonstrated that it does not intend to play catch up in regulating the TVWS ecosystem, but is determined to be miles ahead of other regulators on the continent and the world at large. To the best of our knowledge, there are no regulations or rules regulating the use of TVWSs in Ghana, and as such this decision might have some unintended consequences. For instance, if a number of independent operators are allowed to utilize TVWS, there is a possibility of creating interference among TVWS operators as well as to the TV viewers (primary users). However, the impact of NCA’s decision is yet to be seen since the TVWS network rolled-out in Accra and Koforidua are managed by a single operator, Spectra Wireless.

Chances for such interferences occurring seems to be high given the RF activities occupying the TV band (400 to 700 MHz) as shown in Figure 2. The RF spectrum scan results depicted in Figure 2 were conducted in Accra at GTUC-Abeka campus using a Rhode & Schwarz FSH4 spectrum analyser with a UHF omnidirectional antenna. The spectrum analyser was set to 30 kHz resolution bandwidth, 0 dB attenuation, RMS detect and clear/write trace. It is worth noting that the intention of these RF scans was not to conduct extensive RF spectrum measurements but to have a snapshot of TV band occupancy around the TVWS network deployment area.

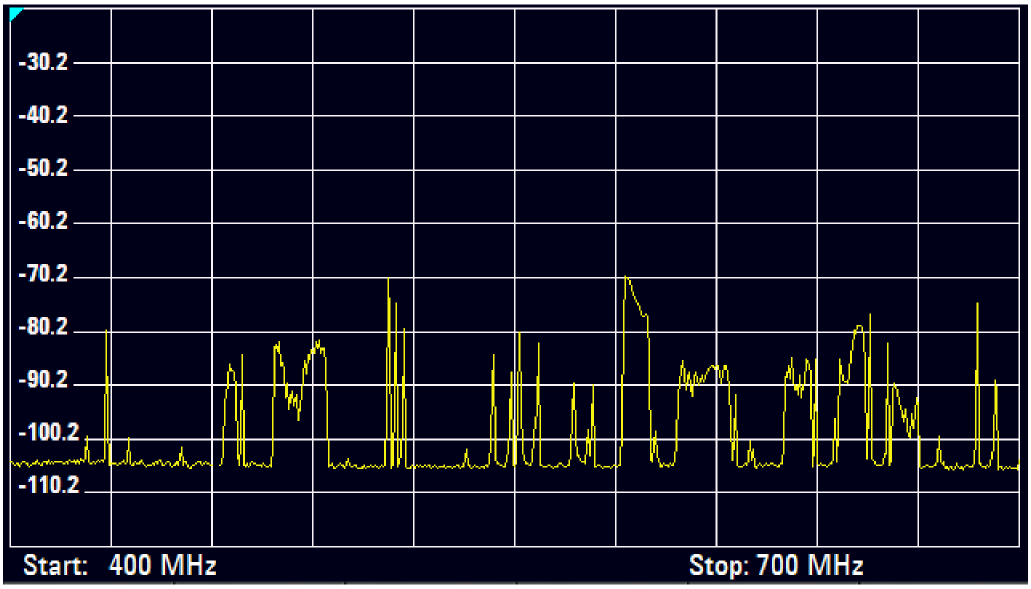


Figure 2: Snapshot of the UHF band showing spectrum occupancy in parts of Accra, Ghana

3 GTUC TV White Space Network

On the 19 June 2014, the Ghana Technology University College (GTUC) and the South African Council for Scientific and Industrial Research (CSIR) Meraka Institute signed a Memorandum of Understanding (MoU) for collaboration in the areas of Information Communications Technology (ICT), which includes collaboration in dynamic spectrum sharing and capacity building on TVWS ecosystem. An initial phase of the collaboration under the MoU focused on building the TVWS test-bed network to provide Internet connectivity to six Senior High Schools with two GTUC campuses in the Accra metropolis, Ghana. This section introduces the GTUC TVWS network.

3.1 GTUC TVWS Network Topology and Description

The GTUC TVWS network was deployed from March 2015 following an authorization by the NCA to conduct a pilot on TVWS in the frequency band 470MHz – 694MHz, and expected to be completed in June 2016. The network connects six public Senior High Schools (SHSs) and the GTUC – Abeka campus, all within 10km radius of the GTUC (main campus) in Tesano, Accra. The GTUC TVWS network was designed with the star topology concept and configured in a point-to-multipoint setup using White Space Devices (WSDs) from two separate manufacturers. Figure 3 below depicts the topology of the network. The Client Premise Equipment (CPE) sites were selected based on their distances from the BS which is within 10 km. The closest CPE is the GTUC – Abeka campus located at 1.5km from the BS, and the furthest at 9.1km is at St. Mary's Girls SHS.

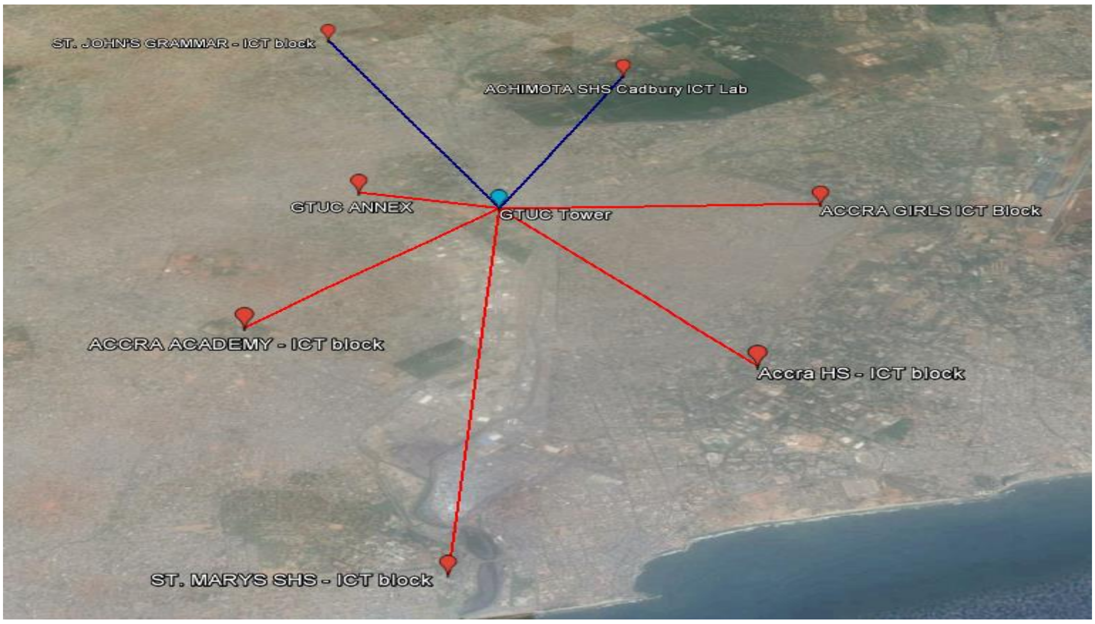


Figure 3: *Topology of the GTUC TVWS network in parts of Accra, Ghana*

The implementation of the network using WSDs from two different manufacturers meant the network was sub-divided into two sub-networks with each using a specific vendor’s WSD. *Sub-network A* connects the Base station (BS) in GTUC – Tesano with five CPE located in Accra Girl’s SHS, Accra High SHS, Accra Academy SHS, St. Mary’s Girls SHS and the GTUC – Abeka campus. Sub-network A is shown in Figure 4. *Sub-network A* BS uses an Omni-directional antenna which is positioned at 50 metres above the ground level whiles the CPEs Yagi antennas are positioned between 10 metres and 20 metres depending on the heights above ground level and the clearance. The BS of *Sub-network A* communicates with the CPEs on TV channel 26 (which occupies the frequency band: 510MHz-518MHz) with the transmission power of 20dBm.

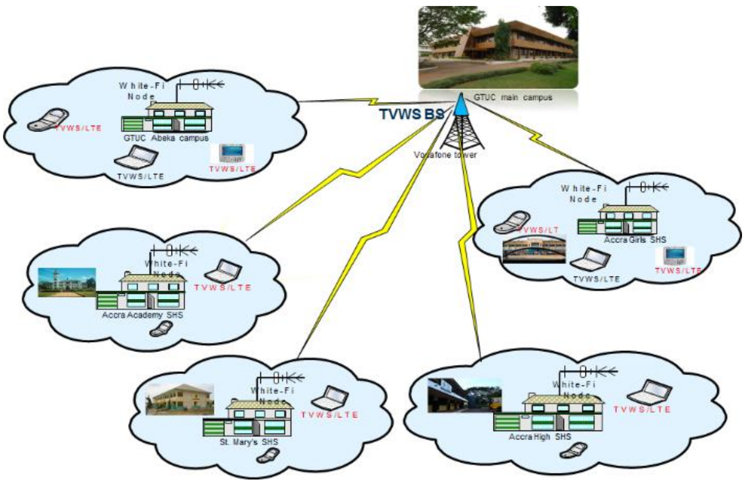


Figure 4: *Sub-network A of the GTUC TVWS network*

Sub-network B on the other hand, connects the BS (also in GTUC – Tesano) with two CPEs located in Achimota SHS and St. John’s Grammar SHS. Figure 5 depicts sub-network B. *Sub-network B*’s BS antenna, on the other hand, is a directional antenna and positioned at 70 metres above the ground linking the two CPE sites at 12 metres and approximately 20 metres respectively. Similar to sub-network A’s BS, s*ub-network B’s* BS operates at the transmission power of 20 dBm on TV channel 40 (which occupies the frequency band: 622MHz-630MHz).

The TVWS network is linked to the main GTUC network that provides a backhaul broadband Internet bandwidth of 2 Mbps to the BS with some assigned IPs to dynamically connect the client stations or CPEs.

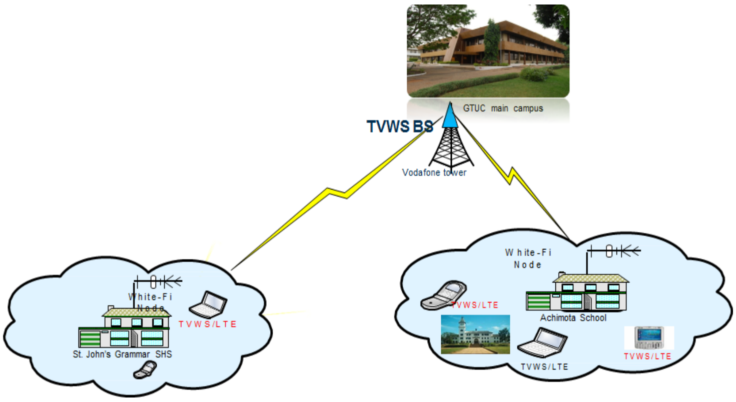


Figure 5: Sub-network B of the GTUC TVWS network

3.2 Participating Pilot Sites

The GTUC TVWS network will be used to expand GTUC's software technologies research in distributed sharing of software artefacts as well as e-book distribution platform at various levels of education, especially at the primary and secondary levels in the rural areas. While the ultimate goal of the TVWS project is to address the digital-divide in rural areas, the initial phase of the project is being deployed within the urban area (i.e. Accra) in order to develop necessary skills and capacity for GTUC to expand the network to rural areas. This will also support the Ministry of Education (MoE) and Ministry of Environment, Science, Technology and Innovation (MESTI) to achieve their goals under the One Laptop Per Child (OLPC) project. Below is a list of the participating pilot sites with some basic characteristic data.

Table 1: Basic Statistics on participating sites of the GTUC TVWS network

CPE Site Name	Distance from BS	Number of Student users	Number of Teacher users	Total user population	Number of User Devices in the Lab
St John's Grammar SHS	4.26 Km	1,652	81	1,733	40 PCs
Achimota SHS	3.7Km	1,825	121	1,946	80 PCs
Accra Girls SHS	3.32 Km	1,000	68	1,068	40 PCs
Accra High SHS	4.26Km	1,017	75	1,092	40 PCs
St Mary's Girls SHS	9.1 Km	510	37	547	40 PCs
Accra Academy SHS	3.42 Km	1,309	84	1,393	40 PCs
GTUC - Abeka Campus	1.5 Km	2,125	85	2,210	1,375PCs**

** This number includes student's own laptops, smartphones and other wireless-enabled devices

4 Preliminary Results and Discussions

In this section we present a selection of preliminary results on the performance of the GTUC TVWS network.

4.1 Network Performance Results Measured from BS

Figure 6 depicts the signal-to-noise (SNR) for the GTUC TVWS sub-network A as measured from the BS. In each of the plots in Figure 6, the x-axis represents the day of the month while the y-axis represent the SNR in dB. In our case, the measurements were conducted from the 26th November until the 2nd December 2015 for both downlink and uplink SNR. The highest downlink SNR (shown by the top plot) was recorded from GTUC Abeka campus (at 36 dB), followed by St Mary SHS at ~25 dB. Despite being the furthest site, St Mary SHS had good SNR because it is located on the hill with clear line-of-sight to the BS.

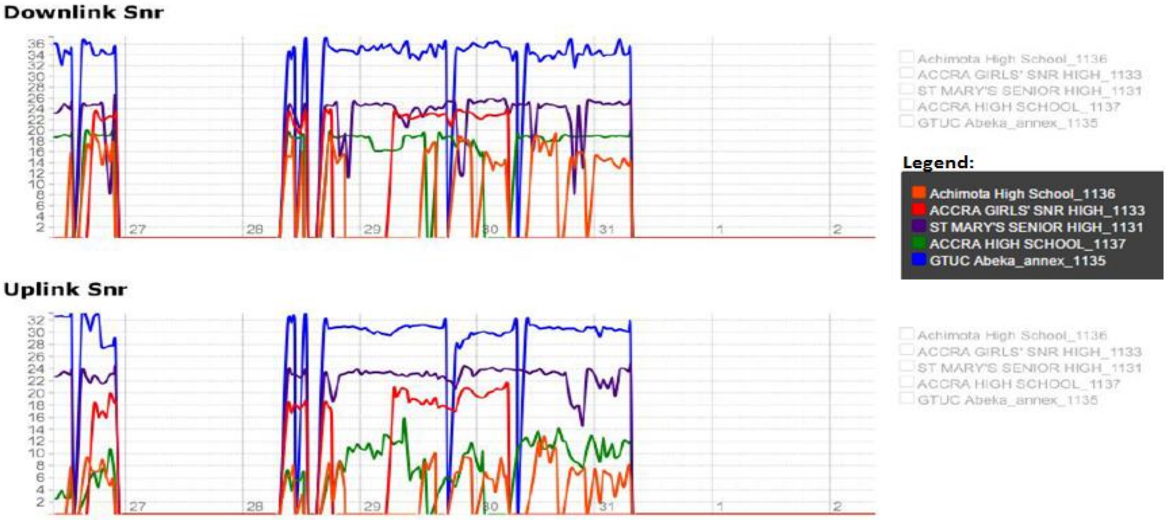


Figure 6: Signal to noise ratio for TVWS links as measured from the BS

4.2 Network Performance Results from CPE side

Table 2 presents the preliminary results collected from two CPE sites each belonging to a different sub-network. St John's Grammar SHS is served from sub-network B whilst GTUC Abeka campus is served by sub-network A. The upload and download speeds were measured using the Internet speed-test tool from http://www.speedtest.net/.

Table 2: Preliminary network performance results from CPE site

Parameters	St John's Grammar SHS	GTUC Abeka Campus
Sub-Network Type	B	A
Upload Speed (Average)	503 Kbps	300 Kbps
Download Speed (Average)	487 Kbps	100 Kbps
TV Channel Number	40 (622-630 MHz)	26 (510-518 MHz)
Link Distance	4.26 km	1.5 km
Received Signal Strength level	-99.5 dBm	-94.44 dBm
BS Antenna Type	Directional	Omnidirectional
BS Antenna Gain	6-11dB	5dBi
CPE Antenna Gain	6-11dB	2.8dBd

The above results show that WSD in sub-network B outperforms the WSDs deployed in sub-network A when it comes to upload and download speeds. WSDs from sub-network A provided very low speed (300 Kbps upload and 100 Kbps download) despite its shortened link distance (1.4 km) from the BS. Although this has not been investigated in any detail, there might be a number of possibilities for such a huge difference. One of the possibilities might be the high number of CPEs being served by sub-network A's BS, which is five compared to only two CPEs from sub-network B. Another possibility is that sub-network B used a directional antenna which has a higher gain of 6 – 11 dB compared to sub-network A's antenna which is omnidirectional with a gain of 5dBi.

While the above presents preliminary results, work is still on-going to collect more data and conduct comprehensive analysis. Different approaches for testing the link performance (such as using *iperf)* are also being considered in order to compare the results.

4.3 Main Challenges

Unlike other TVWS trial projects deployed in most African countries, the GTUC TVWS project is one of the first projects deployed in Africa without the direct support from multi-national organizations. Other than the limited project funding challenges, the following are some of the external challenges affecting the GTUC TVWS network:

- Lack of comprehensive analogue terrestrial TV primary user datasets: Such dataset is crucial for the geo-location spectrum database to accurately predict TVWS. As a result, at its current form, the GTUC TVWS network uses fixed or manual channel allocation instead of dynamic channel allocation or dynamic spectrum access (DSA). However, this challenge will be addressed once the country has completed its digital migration since the regulator will be in possession of accurate digital terrestrial TV primary user datasets.
- Like most African countries, one of the major challenges directly affecting the GTUC TVWS network is unreliable electricity power supply. Power cuts are common in Ghana, and this may last from few hours to days without electricity supply. GTUC is also involved in the solar energy research. In order to remedy this situation, we are investigating the use of solar power system.

5 Conclusions

In this paper we presented the GTUC TVWS network which is a trial network intended to provide Internet connectivity to benefit about 10 thousand users from six Senior High Schools and a GTUC campus around Accra in Ghana. The TVWS network is deployed using a blend of two different WSDs from two manufacturers. Since its deployment, the network experienced a number of prolonged electricity outages which affected the entire city of Accra. Such outages had negative impact on the overall project which affected the planned research activities on the network. Such activities include data usage by schools, data collection and analysis by researchers, as well as the implementation of a geo-location spectrum database. In order to deal with such electricity challenges, there are plans to introduce alternative power supply such as solar energy to a selected number of sites. Further work also include extensive RF spectrum measurements in order to assess the co-existence of GTUC TVWS network with other TVWS network deployed in Accra as well as the primary TV users, to study the actual performance of the network per link, to compare the performance of the two different types of WSDs, and to make use of geo-location spectrum database for dynamic spectrum access.

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