Successful deployment and key applications of Television White Space Networks (TVWS) in Malawi

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Abstract

Successful deployment and key applications with their social impact of the Malawi TVWS pilot project as of June 2014 is presented. The Malawi Television White Spaces (TVWS) Pilot Project was initiated due to the continually growing demand for spectrum. Utilization of service sharing within frequency bands is one of the alternatives that can be deployed for spectrum efficiency. The TVWS project is utilizing the free spectrum channels in the UHF TV band to provide broadband wireless connectivity. This is in line with Malawi Communications Regulatory Authority's motto of promoting universal ICT access in Malawi. The TVWS network has been deployed during the pilot phase of this project at the following selected sites; Saint Mary's Girls Secondary School, Pirimiti Rural Community Hospital, Malawi Defense Force Airwing and Gelogical Survey department. These sites were chosen because of their national importance on education, security, natural disaster preparedness and health. The results indicate that the TVWS can be used for broadband connectivity in rural and underserved areas even when the broadcasting spectrum is already used. Typical applications that support remote access of e-library resources from a rural secondary school and significant impact to pilot institutions in areas of health, national security and disaster preparedness have been demonstrated. Network performance metrics like latency, SNR, throughput have been further analyzed using path loss empirical models. Additionally, this paper presents key Malawi TVWS project achievements, challenges encountered and recommendations.

Keywords: SNR, UHF, Latency, TVWS, Malawi

1. Introduction

The Malawi Television White Spaces (TVWS) Pilot Project was initiated due to the continually growing demand for spectrum as well as the need to conduct Research and Development activities. Spectrum is a scarce resource and utilization of service sharing within frequency bands is one of the alternatives that can be deployed for spectrum efficiency. The TVWS project is utilizing the free spectrum channels in the UHF TV band to provide broadband wireless connectivity. This is in line with Malawi Communications Regulatory Authority (MACRA's) motto of promoting universal Information and

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Communications Technology (ICT) access in Malawi. Various TVWS networks have been deployed across the globe (Mfupe et al., 2014, Yang A., 2014, Baykas, T. et al, 2014) In Malawi, a TVWS pilot network that provides broadband Internet to a secondary school, a rural community hospital, the Malawi Defense Force Airwing and the Department of Geological Survey was deployed in September 2013(Ghosh C., et al, 2011 n, N. et al., 2008, Aulakh I.K, 2009). While it is true that Malawi has a relatively low number of primary TV spectrum users, and hence more TV white spaces (Aulakh I.K, 2009), the move to allow secondary access in the TVWS may result in interference between the secondary users. With MACRA's intention to release TVWS regulations and keen interest of commercial pilot deployments from various telecommunication operators; a need to have an interference mitigation strategy is of paramount importance.

2. Network design

The TVWS network was designed based on star topology utilising single UHF channel 31 (554 MHz) meant for digital Television broadcasting. Find the network diagram shown in Fig. 1 with the longest site having a distance of 18.57 km from the Base station.

Fig.1 showing the TVWS network diagram deployed in Zomba district

Taking into account that a single frequency was deployed in this network, new boundary condition for inter-device interference was computed . This is the interference within the TVWS network and specifically among the White Spaces Devices (WSDs). We have four WSDs also called Client Premise Equipment (CPEs). These sites were chosen because of their national importance on education, security, natural disaster preparedness and health.

3. Interference Calculation

We consider a region shown in Figure 2 where we have 21 available channels by regulation (MACRA implementation of the GE-06 channel arrangement). In the same region as of May, 2014 there are 10 UHF transmitters (ATV, DTV and DTT for the digital migration signal testing). Considering the following definitions; m for the available channels to the secondary user, given that the 10 current UHF transmitters (primary users) have selected n channels each from a pool of 21 available channels in the specified region, the following mathematical relationship applies.

$m=21-10n$...........................(1)

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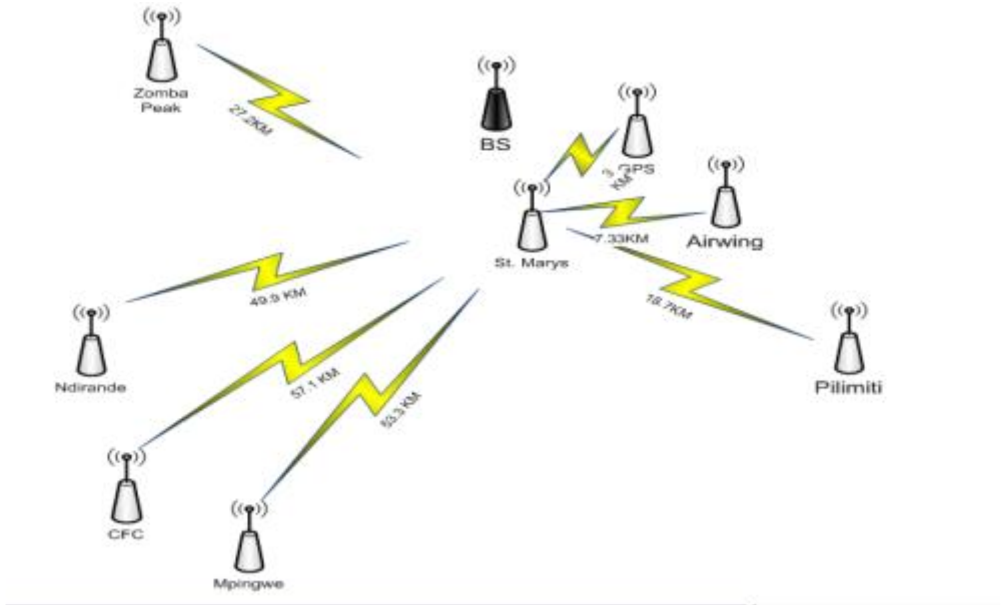

Fig. 2: UHF and TVWS network. The network covers the following districts; Zomba, Chiradzulu, Blantyre, Machinga, Mwanza and Phalombe covering a total area of 9,870 km^2

In this case, two principal sources of interference under consideration include: primary to secondary user interference and interference between secondary users (inter-device interference).

3.1 Primary to Secondary User Interference

Channel information is obtained from the following relationship from (1), where *m* are the free channels available for secondary user, *21* is the number of available channels in a given location or region, *10* is the number of primary users (UHF transmitters) and *n* is the possible number of channels selected by each primary user.

It is therefore obvious that though, primary to secondary user interference is critical; it is non-existent in our network shown in Fig 2. Additionally, Fig. 3 clearly shows that all the primary users have selected their preferred channels and for the boundary case, a single channel has been left for the secondary user(s).

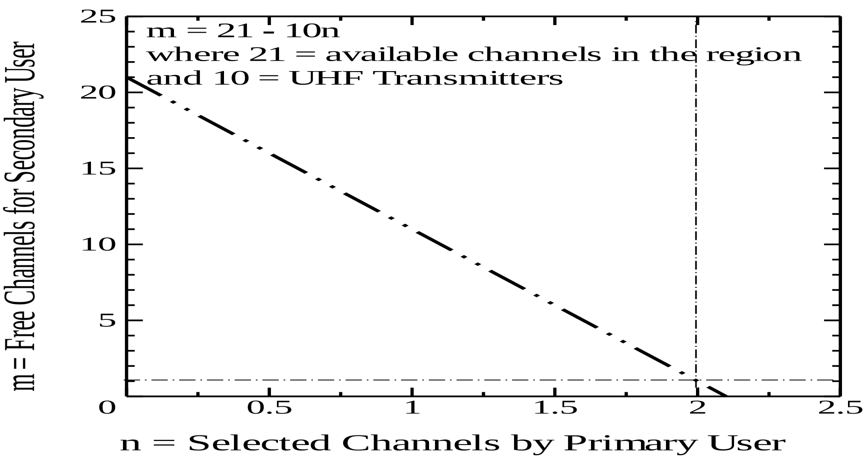

Fig. 3: Chomora boundary condition at m = 1

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3.2 Inter-device Interference

This is the interference within the TVWS network and specifically among the WSDs. We have four WSDs and from Mfupe, L. et al. (2014), we could specify that k = 4. Therefore, with respect to Fig. 3, where the Chomora boundary condition allows for m = 1; we have as a result, k > m which is the necessary condition to warrant inter-device interference. The obvious implication here is that all the four WSDs will scramble for the single channel and we are using channel 31 (554 MHz) as shown in Table 1. The constraint to use a single channel has been imposed due to the RuralConnect Carlson Base Station that we are using which can allocate only 1 channel in a given instance. Future improvements shall consider multi-channel allocation.

3.3 Results and Discussion

Based on Laska J.N.,(2014), we computed the inter-device interference power, P_{ij} as follows.

$$P_{ij}=P_jG_jG_i\{\lambda/(4\pi d_{ji}))\}^2/L \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where from actual WSDs parameters in the operational network, P_i= 0.5 Watts, $G_j = G_i$ = 15 Watts and $\lambda = 554 \times 10^3 / 3 \times 10^8 = 1.846667 \times 10^{-3}$ m and $L = 1$.

The four WSDs also called Client Premise Equipment (CPEs) in our TVWS experiment are named as follows: St. Marys, GPS, Airwing and Pirimiti. All these connect to one Base Station named Malawi TVWS BS (at GPS coordinates of LON: 35.3182564, LAT: -15.376415).

We arbitrarily selected St. Marys to be our ith WSD node, implying that from (2), j represents GPS, Pirimiti and Airwing. The final computed inter-device interference is shown in Table 1.

Table 1: Inter-device interference power

Pij	$P_{i\text{- }GPS}$	$P_{i\text{-}Airwing}$	$P_{i\text{-}Pirimiti}$
Parameters			
d_{ij}(km)	3.0	7.33	18.7
Watts(W)	0.27×10^{-12}	4.5×10^{-12}	6.95×10^{-15}
DBm	-70.38	-80.31	-96.12

The results show that the interference level increases with a decrease in inter-device distance. Each WSD has an adaptive modulation scheme which offers the capability to increase the radio's receiver sensitivity. From the current operation, the WSD receiver sensitivity is -93 dBm for 10^{-6} BER using QPSK ½, -86 dBm for 10^{-6} BER using 16QAM ½ and -80 dBm for 10^{-6} BER using 16QAM. Relating the receiver sensitivity to the inter-device interference, raises an alarm especially for $P_{i\text{-}GPS}$ and $P_{i\text{-}Airwing}$where the receiver is overwhelmed with interference and could not pick the desired signal. However, the situation is not worse as it appears in these figures because the radiation pattern of the Yagi-Uda

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antenna used for each WSD has its broadside directed to the Base Station, thereby reducing the effect of inter-device interference by spatial arrangement of the radiating elements.

For purposes of the proposed interference mitigation systems (IMS), it will be necessary to compute the total network interference which in this case is simply the sum of all Pij. Furthermore, to invoke and run the Simulated Annealing algorithm in the decision making optimizer, it is imperative to compute the average of the total network interference and minimize it.

While we have solved for the inter-device interference in the current TVWS network, we are also aware of the possible occurrence of multiple access interference (MAI) considering a situation where all the WSDs are accessing the base station while using a single channel. Multiple access interference arises naturally in several access systems due to the effects such as multipath or non-ideal frequency channelization in general. Unlike other noise sources, MAI is structured and therefore could be modeled and propagated using appropriate receiver techniques collectively termed as multiuser detection (MUD). The effect of MAI is experienced on both the uplink and downlink channels. In this scenario, the maximum number of WSDs accessing the Base Station is set at 4; hence the issue of MAI can only arise where the WSD power varies among the deployed WSDs with respect to the distance from the Base Station. The average interference threshold and the minimum transmission power will thus have to be set in the proposed interference mitigation system (IMS).

4. Network Performance Analysis

Performance status of the Malawi TVWS pilot is further presented. Basic performance metrics like throughput, latency, SNR have been analyzed using known path loss empirical models like Hata, Asset and Friis. Typically, for the tested link at 7.5km from the BS, an average SNR = 24.7dB, data-rate of 420kbps and latency of 118ms were observed using the collected data. The important results in this paper are on the throughput and latency. Throughput and latency are computed averages from the measured data over one month at station premises.

1.1 Performance Graphs

The downstream throughput (blue line) and upstream throughput (black line) are shown in Fig. 4 below.

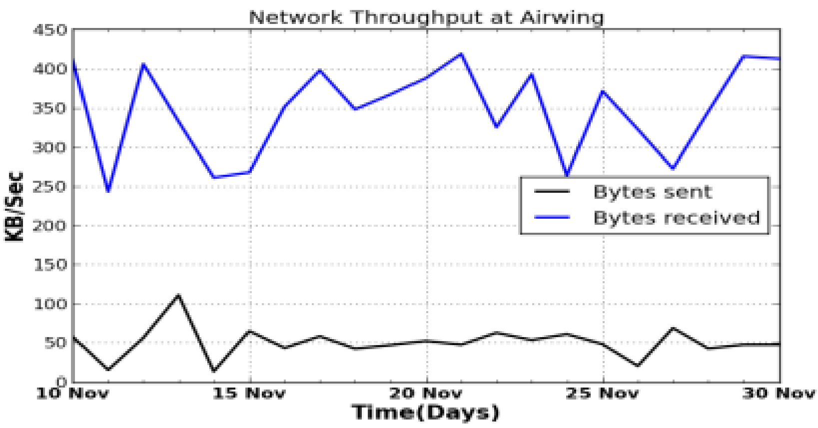

Fig. 4: Average downstream throuput at Airwing TVWS station (7.5 km from BS).

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The average latency in milliseconds (ms) for 3rd December,2013 in an hour study is shown in Fig. 5 below.

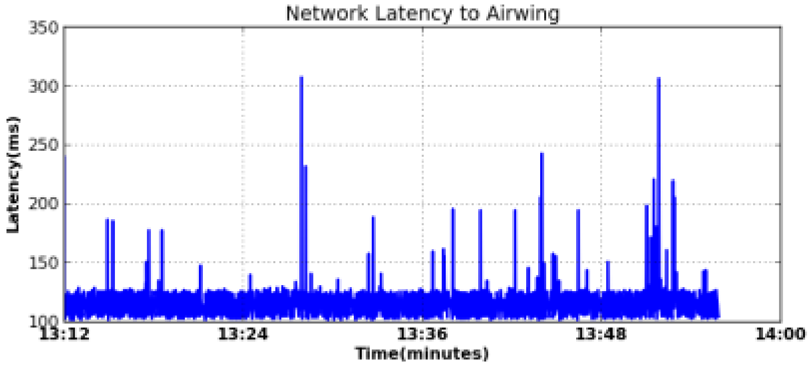

Fig. 5: One hour latency measurement at AirWing station

5. Typical application of TVWS at Seismology Section-Geological Survey

The science revolving around seismology involves constraining of earthquake source parameters and disseminating such information to the general public. Such information is also used by the construction industry where civil engineers are guided on best structural designs that can withstand a certain ground motion due to earthquakes. To achieve this, an efficient data acquisition and analysis platform has to be put in place so as to be ready to disseminate information to public within 2-30 minutes of an earthquake occurrence and on demand through production of bulletins. Connectivity between the Data Centre and the remote seismic station has to be established in order to access data on real-time or near real-time. As it is the case with TVWS Project, the pilot connectivity program at the Seismology Section of the Geological Survey Department commenced with hooking up online a Continuous Global Positioning System (cGPS) where it transfers data to a local computer (server) ready to be uploaded to a remote server at UNAVCO in the USA on regular basis. Currently, the internet provided through TVWS is working well and has improved the data transfer and availability between the cGPS unit and local server.

6. Conclusion

This paper proposes a new boundary condition that eliminates the possibility for primary to secondary user interference or vice versa. Instead, the condition introduces inter-device interference that is a function of inter-device distance, maintaining all other factors constant. The closer the distance between two white space devices (WSDs), the greater is the interfering power and for distances less than 7 km, it has been shown that a reference WSD could be overwhelmed, since the receiver sensitivity is nearly equal to or less than the interfering power. As a rule, we could advise that for a TVWS base station operating in the UHF band, transmitting at 4 W to WSDs which transmit at 0.5 W, and having adaptive modulation schemes from QPSK to 16QAM; the modulation scheme should be increased to achieve the best receiver sensitivity and at the same time, the distance between WSDs should be greater than 7 km, to reduce or eliminate the effect of inter-device interference. Additionally, the use of adaptive radiation pattern reconfiguration for the WSD antenna could be used as a spatial interference mitigation strategy while an interference mitigation engine co-operating with a database as proposed in this paper could be used as a temporal (real-time, lightweight adaptive solution) for inter-device interference.

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Biographies

Jonathan Pinifolo holds an MSc Degree in Wireless Communication Systems passed with Distinction from Oxford Brookes University in the United Kingdom. He also holds an MBA from ESAMI. He is a PhD student in Electrical and Electronic Engineering at University of Johannesburg, South Africa and currently working as Deputy Director of Spectrum Management with Malawi Communications Regulatory Authority. He has got fourteen years of high level experience in telecom, gained at management level as well as technical operation in the field. His PhD research work is on design of Spectrum re-use system.

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Chomora Mikeka is a Senior Lecturer in the Physics Department at Chancellor College Campus of the University of Malawi in Zomba. He is also the Director for the Malawi White Spaces Project in partnership with the Malawi Communications Regulatory Authority (MACRA) and Marconi Wireless T/ICT4D Laboratory in Trieste, Italy. Chomora Mikeka holds a PhD from the Division of Physics, Electrical and Computer Engineering at Yokohama National University, Japan. His PhD research was about power autonomous sensor radio based on cellular and digital TV RF energy harvesting.

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Lloyd –Leyd Momba received his BSc in Electrical Engineering from Malawi Polytechnic. He also holds an MSc in Wireless Communications System with distinction from Oxford Brookes University (UK) and he is a registered with Malawi Institute of Engineers. He is currently working with Malawi Communications Regulatory Authority as Director of Telecommunications and has over 13 years experience in the sector. He got an award from the IEEE UK & RI Communcations Chapter on the best Telecommunications MSc. Project. He currently serves as the coordinator for Malawi TVWS project and he has been instrumental in the Malawi Spectrum Audit and refarming project.