 ISSN: 2244-2146

TV White Space Field Tests in the Philippines Using the IEEE 802.11af - compliant Prototype

Alberto S. Bañacia[1], Rosana J. Jumarito[2], Antonio C. Montejo III[1], Felicito Caluyo[2], Hirokazu Sawada[3], Kentaro Ishizu[3], Kazuo Ibuka[3], Takeshi Matsumura[3], Fumihide Kojima[3]
[1]Dept. of Electrical & Electronics Engineering, [2]School of Engineering, University of San Carlos, Cebu City Philippines
[3]National Institute of Information and Communications Technology (NICT), Kanagawa, 239-0847 Japan
asbanacia@usc.edu.ph

Abstract—This paper presents an overview of the experimental results obtained in deploying a Television white space (TVWS) technology in the Philippines under varying radio frequency (RF) environmental conditions using an IEEE 802.11af - compliant prototype devices developed by the National Institute of Information and Communications Technology (NICT) of Japan. The primary objectives were to address the Philippines' needs of providing broadband connectivity to an estimated 50 million non-internet user-Filipinos especially those in unserved and underserved areas and the country's need for an Information and Communications Technology (ICT) infrastructure that could serve as a reliable and readily deployable communications link in times of disasters. In a suburban hilly environment in a University campus in Cebu City, where the presence of buildings and vegetation served as obstructions between the access point (AP) and station (STA), a deployed multihop network centered at 593 MHz attained a maximum uplink throughput of 4.81 Mbps and 4.93 Mbps for downlink at a combined distance of 600 meters. In another experiment conducted in one of the rural villages in Surigao del Norte, Philippines, the TVWS technology was able to provide internet connectivity in a single link to a public elementary school (STA) roughly 530 meters away from the source (AP) located at the village hall despite Non-line-of-sight (NLOS) conditions providing a maximum downlink and uplink throughput of 3.43 Mbps and 3.38 Mbps, respectively. In the same locality, a 2 - hop deployment using a different carrier for each hop was also tested to connect an area isolated by the damaged bridge that collapsed due to a 6.7 magnitude earthquake. A maximum throughput of 3.25 Mbps and 3.16 Mbps for downlink and uplink, respectively, were obtained up to a combined distance of 1290 meters. Based on the aforementioned results, TV white space technology utilizing the IEEE 802.11af-based network can indeed provide internet connectivity even in the presence of NLOS conditions and extend internet coverage via a multihop network implementation obtaining throughput that can successfully support voice and data transmission and reception.

Index Terms—IEEE 802.11af, TV white space, Multihop Network

I. Introduction

Due to the misfortune of having been geographically located in the Pacific Ring of Fire along the typhoon belt, the Philippines has endured some of the world's worst natural disasters such as the 2013 7.2-magnitude strong earthquake in Bohol and the devastating super typhoon Haiyan in Central Philippines costing billions of pesos of damages to life and properties [1]. On both occurrences, almost all forms of communication networks including mobile phones were down and unusable for days and even for weeks making emergency and relief efforts difficult.

On the other hand, a World Bank studies suggest that a 10% increase in broadband penetration in developing countries like the Philippines is correlated with a 1.35% increase in Gross Domestic Product (GDP) [2]. But according to the study on Measuring Digital Development Facts and Figures released by the United Nation's International Telecommunications Union (ITU) in 2019, while global internet penetration grew from 16.8% in 2005 to 53.6% in 2019, there still exists barriers that billions were still not connected to the internet and will remain so unless there is a concerted action to address the barriers to connectivity mainly related to issues on availability and affordability [3]. In the Philippines, data shows almost 45 percent (46 million) of Filipino citizens, and 74 percent (34,500) public schools do not have access to the Internet [4]. This is rather particularly alarming given the Philippine educational system's tremendous need for broadband connectivity for online learning due to the Covid19 pandemic. Among the reasons cited for such sorry state were the high cost of getting broadband connectivity not being commensurate with the low speed internet connection it offers, and in remote and urban areas, the high cost of setting up ICT infrastructure for that purpose does not guarantee immediate and sufficient return of investment.

To address these problems, an information communication technology (ICT) infrastructure that is robust, flexible and easily deployable must be put in place. One of the key wireless communications technology that emerges in the last few years to provide broadband connectivity to unserved and underserved areas is the TV white space technology. The current fixed spectrum allocation scheme, especially in TV broadcasting, results in heavy underutilization or inefficient utilization of frequency spectrum. Measurements performed at various locations worldwide showed that the actual spectrum

ISSN: 2244-2146

utilization is only about 5% to 25%. Occupancy measurements performed in Singapore showed only 4.54% overall usage [5] while the same quantitative analysis in Auckland yielded 6.2% [6]. A relatively higher spectral occupancy was measured in Chicago at 17.4% [7] and Barcelona at 22.57% [8]. These open the door for possible utilization of these unoccupied spectrum opportunistically or through a dynamic spectrum sharing .

The Institute of Electrical and Electronics Engineers (IEEE) has formed several working groups to develop standards in the field of TV white space. These standards and its key features are summarized in [9]. Each IEEE standard operating in TV white space has different demands on system design and implementation to address the needs for a particular application scenario or usage model (UM). For example, majority of the challenges in enabling Wifi systems in TVWS (IEEE 802.11af) mainly come from regulations since specifications in IEEE 802.11af must ensure that legacy IEEE 802.11 WLAN system can still legally operate in the TV white spaces given the necessity of protecting existing primary services. The IEEE 802.11af standard or the Wireless Local Area Network (WLAN) in TV white space was completed in 2013 [10]. The IEEE 802.11af standard defines the physical (PHY) layer and medium access control (MAC) sublayer that allow legacy IEEE 802.11 systems to operate in TVWS but expected to cover longer distance and better resiliency to obstacles as compared to the current WLAN standard using higher frequency operating at 2.4 GHz and 5 GHz ISM band. However, unlike legacy IEEE 802.11 system, the operation of IEEE 802.11af system depends on a geolocation database (GDB) to ensure protection of the primary users (PUs) from the white space devices acting like secondary users (SUs). In [11], the IEEE 802.11af standard, which defines international specifications for spectrum sharing among unlicensed white space devices (WSDs) and licensed services in the TV white space band was presented. A geolocation database was used to regulate spectrum sharing among unlicensed WSDs, the implementation of which varies among regulatory domains.

Based on records, there had been field trials and successful deployments of TV white space technology since February 2013 in the Philippines through the ICT office that was then under the Department of Science and Technology (DOST) but none has so far utilized an IEEE 802.11af-compliant device much less implement a multihop network utilizing this type of TV white space technology [12] [13] until a study in [14] was made.

In December 2016, the University of San Carlos in Cebu City, Philippines has signed a Collaborative Research Agreement (CRA) with MIMOS BERHAD, Malaysia and the National University of Malaysia, and the National Institute of Information and Communications Technology (NICT), Japan under the auspices of the ICT Virtual Organization of ASEAN Institutes and NICT (ASEAN IVO) with the primary objective of conducting field evaluation of TV white space systems for social deployment. This bodes well with the Philippines given that it is an archipelagic country with no less than 7000 islands. Providing an affordable, reliable, adaptable and resilient broadband connectivity is indeed a challenge especially in remote and rural areas. The resolve to conduct field trials in the country especially in extending internet connectivity through multihopping was further boosted by the Department of ICT's unveiling of National Broadband Plan (NBP) identifying TV white space technology as one of the emerging wireless technologies that can be tapped to provide broadband internet access in the countryside [15].

This paper presents an overview of TV White Space field tests in the Philippines conducted using the IEEE 802.11af - compliant prototype developed by NICT. The said prototype meets the European Telecommunication Standards Institute (ETSI) regulation on transmission spectrum. The experiments were conducted in a hilly, suburban University campus in Cebu city and in a relatively flat rural environment in one of the villages in Surigao del Norte to demonstrate two different environmental RF scenarios. Results of the experiments have so far shown the ability of the IEEE 802.11af-based network to provide internet connectivity even in the presence of NLOS conditions and extend internet coverage via a multihop network implementation obtaining throughput that successfully supported voice and data transmission and reception.

The primary contributions of this paper were as follows: (1) it was able to conduct the first outdoor field tests on single-hop and multihop IEEE 802.11af-based network successfully; and (2) was able to demonstrate the better propagation and wider coverage characteristics of IEEE 802.11af devices than typical Wifi operating in the 2.4 GHz and 5 GHz bands.

The rest of the paper is arranged as follows: section II presents related works; section III outlines the experimental sites and measurement set-up; results and discussion of the deployment in two separate RF environments are contained in section IV while section V concludes the study.

II. Related Works

Recent research and development worldwide in TV white space technology has demonstrated its capacity to bridge digital divide and ensure easy access to affordable internet broadband especially in underserved and unserved communities. The global initiatives for trials and deployment of the TV white space networks have cut across almost all continents in the world with diverse applications ranging from providing a link to connect a remote health village in Bhutan(Asia-Pacific) to a quality healthcare; to using the TV white space technology to stream daily live footage of zoo animals to YouTube in a London zoo (Europe); to delivering broadband internet service to some schools within a 10 -

ISSN: 2244-2146

kilometer radius without causing interference to licensed spectrum holders in Cape Town, South Africa (Africa) [12].

In the Philippines, the limited availability of broadband frequencies prompted the government to harness unused TVWS or the so-called “Super WiFi” nationwide. As early as February 7, 2013, the Department of Science and Technology (DOST) through the Information and Communications Technology Office (ICTO) has already studied the use of TV white space technology to increase Internet access in the country, particularly in areas that remain unserved by Internet [16]. Successful pilot testing of the TVWS technology had already been conducted by DOST in partnership with TVWS pioneering Filipino-Singaporean firm Nityo Infotech with the fishermen in Bohol as the first beneficiaries of the technology [17]. The technology was able to provide internet connectivity in Bohol and Tacloban City when both localities were hit by a strong 7.2 magnitude earthquake and Super typhoon Haiyan, respectively, demonstrating its ability to immediately provide a deployable and reliable ICT infrastructure in times of disasters [13]. A study conducted in [18] showed availability of 46% to 62% TVWS in urban areas and 60% to 80% TVWS availability in rural areas in the Philippines.

Among the standards developed by the IEEE for TV white space were IEEE 802.22 and IEEE 802.11af. Published in September 2011, the IEEE 802.22 specifies Wireless Regional Area Network (WRAN) operation in TVWS in long-distance communications while the IEEE 802.11af, which was published in February 2014, specifies Wireless Local Area Network (WLAN) in TVWS in short-to-middle range distance communications. These two TVWS technologies were used in [19]. In the said study conducted by Ishizu et al, a field experiment was conducted using IEEE 802.22 system as a backbone to connect Tono City to Takashimizu which was about 12.7 Km apart and used IEEE 802.11af system as a means to further extend connection of Takashimizu to Sadato located about 6.3 Km away. This multihop implementation using two different TVWS standards were touted to be the world’s first throughput, distance, and application testing. The IEEE 802.22 system achieved a throughput of 4.5 Mbps and 5.2 Mbps for uplink and downlink, respectively while a throughput of 15.5 Mbps for downlink and 9.0 Mbps for uplink was achieved over 6.3 km using an IEEE 802.11af system that used an aggregate bandwidth of two discontinuous TV channels. The study also demonstrated that applications such as web browsing, video streaming and video talk were feasible in a multihop network covering a total distance of approximately 19 Km. This makes feasible the use of the TVWS technology as a robust, flexible and reliable ICT infrastructure in times of disasters.

To the best of the authors’ knowledge, the study conducted in [14] was the first in the world to have demonstrated the feasibility of a multi-hop network based on IEEE 802.11af standard. Other than successfully implementing a single frequency at 593 MHz for both hops; adjacent, co-channel and intermodulation issues experienced in the conduct of the implementation were also addressed in this study of Montejo et al. Some of the relevant results were again presented and discussed in this present study as they served as the take off point for further study of multihop based on the IEEE 802.11af standard.

III. Experimental sites and Measurement setup

There were two sites considered in this study each representing a different RF environmental condition. In both cases, the radio equipment used was an IEEE 802.111af prototypes developed by NICT with specifications listed in Table I.

In each experimental site, the RF environment was scanned using a portable ATTI PSA6005 RF spectrum analyzer to ensure that the carrier frequencies used in the study were not being utilized at the time of the experiment, thus avoiding undue interference to existing primary users. With a resolution and video bandwidth ranging from 300 Hz to 10 MHz and a built-in battery capable of 4 hours uninterrupted operation, the analyzer can scan from 10 MHz to 6000 MHz when equipped with a whip antenna with a 2.2 dBi gain.

Figure 1 shows the radio equipment used in this experiment both as a transmitter (Access Point or AP) and a receiver (Station or STA). It has a maximum RF output of 20 dBm and a physical dimensions of 30 x 23 x 20 cu. cm. The modulation and coding scheme (MCS) is from MCS 0 to MCS 7 each with a corresponding data rate. The System Architecture adopted in this study is illustrated in Figure 2. The Master Device (MD) used as either an AP or STA was connected to an external ring Yagi antenna via SMA connector. At the designated headquarters, the AP was connected to a 12-element ring Yagi antenna having a gain of 11.8 dBd. It communicates with the relay node over TV white space UHF frequencies via the same 12-element ring Yagi antenna. As can be seen, the over-the-air connection between the relay node and the end node (designated as disaster site) was made possible over TVWS utilizing a pair of 3-element ring Yagi antenna with a gain of 5.5 dBd.

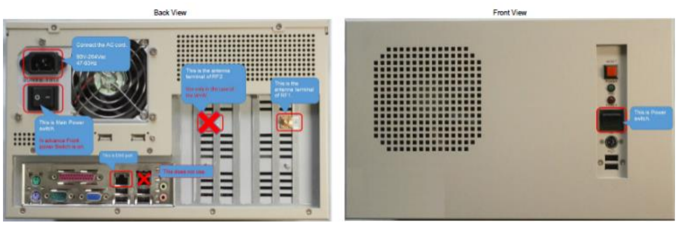

Fig.1 IEEE 802.11af Prototype developed by NICT

Table 1
Specifications of IEEE 802.11AF System

 ISSN: 2244-2146

System	IEEE 802.11af PHY/MAC
Carrier frequency	470 - 710 MHz
Channel bandwidth	6 MHz
Signal bandwidth	4.83 MHz
Tx power	100 mW
Modulation	BPSK, QPSK, 16-QAM, 64-QAM
Error correcting code	Convolutional code (coding rate: 1/2, 2/3,3/4,5/6)
Multiple access	CSMA/CA
Multiplexing	OFDM
FFT size/clock	128 points/5.33 MHz

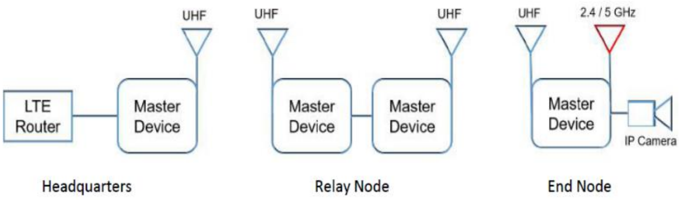

Fig. 2 System Architecture

A. Experimental Site 1: A hilly suburban University Campus in Cebu city, Philippines


Fig. 3. Aerial View of the University of San Carlos Talamban Campus

The first site of the experiment was located inside the Talamban Campus of the University of San Carlos in Cebu City located in Cenral Visayas, Philippines. The campus was about 83 hectares consisting of a few 15 m- to 20 m - high buildings made mostly of concrete frame, glass windows and wooden doors. In between buildings are a 10m to 15m - wide concrete pavement. Trees and vegetation flourished inside the hilly campus terrain (Figure 3).

The presence of a concrete building on top of a hill made it difficult to establish a point-to-point (PtP) link between the AP and STA. Using Google map, it was possible to connect an AP located at the Communication and Broadcasting Engineering Laboratory (CBELS) of the Bunzel Building to the library as the end node even if there was no direct Line-of-sight (LOS) between them by putting a relay station or node at the rooftop of College and Arts and Science Building (CAS). This created a multihop network consisting of about a 400 - m hop 1 from CBELS AP to CAS relay station and another 200 - m hop 2 to finally connect CBELS AP to the STA located at the library via the CAS relay station. The multi-hop scenario is depicted in Figure 4.

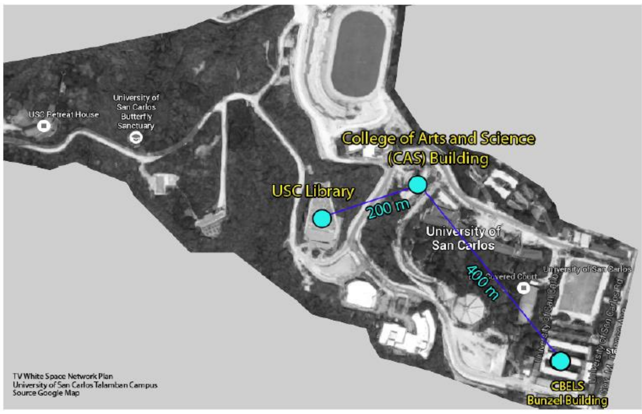

Fig. 4. Overview of the Multihop Network in Site 1

B. Experimental Site 2: A relatively flat rural villages in Surigao del Norte, Philippines

In this part of the study, there were two use cases considered : (1) the TV white space devices were used to establish an internet coverage via point-to-point wireless connection (PtMP); and (2) the same prototype devices were used to establish a multihop network.

Use Case 1: Point - to - multipoint

The IEEE 802.11af prototype was used to establish a TVWS network between Bgy. Diaz Hall towards Bgy. Diaz Elementary School, both situated at the municipality of San Francisco, Surigao del Norte, Philippines. The TVWS network was used in order to provide internet connectivity to the 250 pupils of the school which aid them in their lessons and research. Moreover, the 9 teachers used the internet access to send emails towards their main office. Figures 5 and 6 show the topography and the elevation profile of the PtMP network, respectively.

The AP was situated at the Bgy. Diaz Hall where an internet connection is available. Moreover, as shown in Figure 4, there were two stations (STAs) installed at Diaz Elementary school: (1) Principal's Office (STA1) and (2) Computer Room (STA2). The distance between the AP and STA located at the Principal's office is about 531 meters. The separation distance of the two STAs is only about 12 meters. The deployed PtMP network was a non-line-of-sight scenario with a hilly topography (Figure 6) and high vegetation in between (Figure 5). The operating frequency was set at 659 MHz for both communication links.

A vertically polarized 12-element ring Yagi antenna with a height of 8 meters were used at the AP side (Figure 7). On the other hand, two vertically polarized 3-element ring Yagi antennas with an antenna height of 5 meters were used for both STAs (Figure 8). The gains of these antennas were noted to be 11.8 dBd and 5.5 dBd for the 12-element and 3-element ring Yagi, respectively

ISSN: 2244-2146

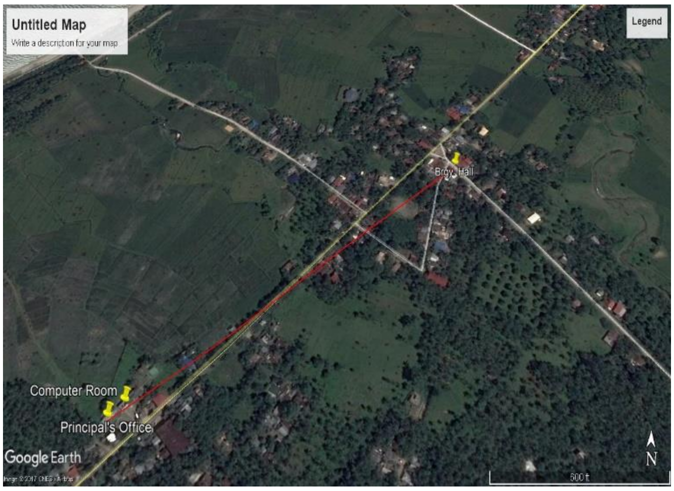

Fig. 5. Topography of the PtMP Network

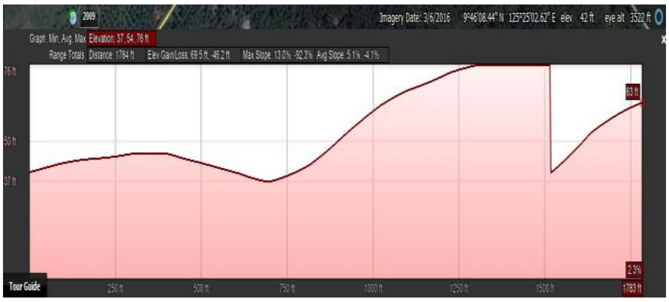

Fig. 6. Elevation Profile between the AP (Bgy. Hall) to STA1 (Principal's Office)

Fig. 7. Configuring the AP inside the Brgy. Hall and placement of the 12-element antenna at the floor just outside where the team has installed the AP.

Fig. 8. Location of the two 3-element antennas for STA1 and STA2 at Diaz Elementary School

Use Case 2: Multihop Deployment

In order to extend the coverage area and possibly reroute the radio link when the system is installed around the presence of high obstruction, a multi-hop network was examined using the TVWS. The multi-hop network was implemented over a total distance 1,295 meters. The AP was still installed at Diaz Bgy Hall while the relay station is situated 835 meters away. Moreover, the distance between the relay station and the end station is about 409 meters apart. The specific placement of the AP, relay and end station is intentionally selected in order to establish a communication link between isolated barangays due to the then damaged Anao-aon bridge. Figures 9, 10 & 11 show the topography and elevation profile of the multihop network.

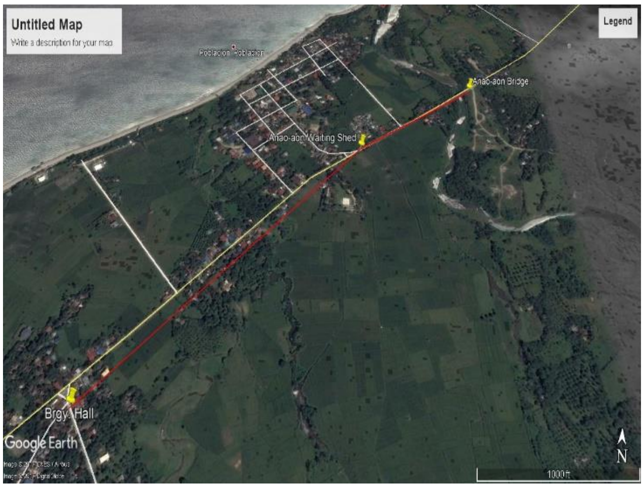

Fig. 9. Topography between the AP and the relay station and the end node

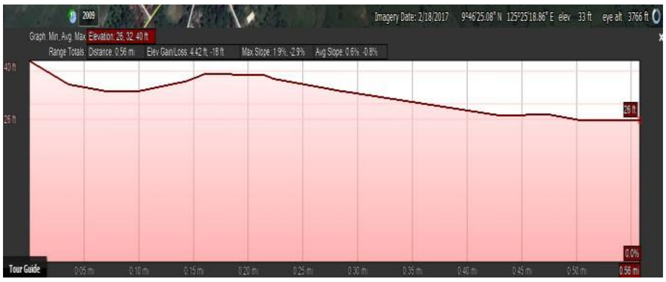

Fig. 10. Elevation profile between the AP and the relay station

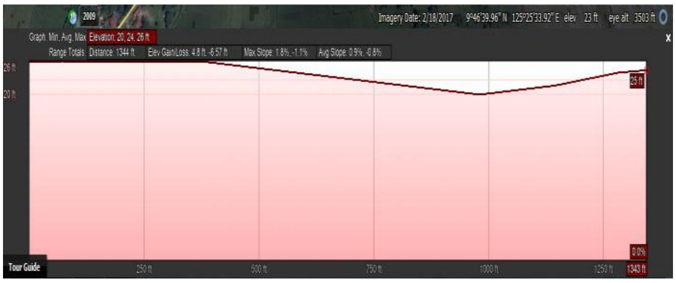

Fig. 11. Elevation Profile between the relay station and the end station

A vertically polarized 12-element ring Yagi antenna were used for the connection between the AP and relay station (hop 1). On the other hand, a vertically polarized 3-element ring Yagi antenna were utilized to forge a connection between the relay station and the end station (hop 2). Furthermore, hop 1 used 659 MHz center frequency while hop 2 utilized 593 center frequency. Same with the previous section, the throughput performance was examined as the transmit power and MCS settings were varied. Lastly, the radio link of hop 1 was hampered by high vegetation while hop 2 has a line-of-sight situation.

IV. Results and Discussion

A. Experimental Site 1: A hilly suburban University Campus in Cebu city, Philippines

Table 2
Maximum Throughput Performance at Different TX Power and MCS Values

Tx Power (dBm)	MCS Value	Total Uplink (Mbps)	Total Downlink (Mbps)
20	7	4.81	4.93
15	5	3.34	4.00
10	4	2.75	2.09
5	2	1.98	1.86
0	2	2.21	1.72

During the initial run of the experiment, two separate frequencies were used for hop 1 (Ch 45 659 MHz) and hop 2 (Ch 46 665 MHz). These two frequencies were supposedly unoccupied as shown by the scanning of the RF environment prior to the experiment. However, a nearby transmission coming from Channel 47 caused Adjacent Channel Interference to the IEEE 802.11af network resulting to a failure in establishing link in hop 2. While the use of a single channel for both hops could be a viable option, this however, could potentially lead to Co-channel interference (CCI). To remedy this, the 12 -ring and 3-ring antennas located at the CAS relay station were isolated from one another by a concrete wall and horizontally by a 15-m distance. Further, the last channel at the UHF band, Ch 34 (593 MHz) was utilized to solve as well the problem of intermodulation. Table I summarizes the maximum throughput performance of the multihop network for varying transmit power and MCS values. The uplink and downlink throughput values were obtained using a networking tool known as *Iperf* that measures on a point-to-point (PtP) basis the throughput, but for a multihop network, it considers the overall throughput of the network as that pertains to the weakest link. *Iperf* measures throughput on the basis of the UDP packets.

B. Experimental Site 2: A relatively flat rural villages in Surigao del Norte, Philippines

Use Case 1: Point - to - multipoint

This experiment recorded the throughput performance of the system while the transmit power and the MCS settings were varied. Table III shows the PtMP performance of the deployed system.

Table 3
Maximum PtMP Throughput Performance at Different TX Power and MCS Values

Station 1: Principal's Office				
Antenna: 3-element				
Tx Power (dBm)	**MCS**	**RSSI (dBm)**	**Downlink (Mbps)**	**Uplink (Mbps)**
20	0	-87	1.46	1.27
20	3	-89	3.43	3.38

Station 2: Computer Room				
Antenna: 3-element				
Tx Power (dBm)	**MCS**	**RSSI (dBm)**	**Downlink (Mbps)**	**Uplink (Mbps)**
20	0	-88	1.22	0.764
20	3	-89	3.56	0.235

The result shows that in an NLOS scenario, with a total antenna gain of 17. 3 dBd (GTx + GRx), a maximum downlink and uplink throughput of 3.43 Mbps and 3.38 Mbps can be achieved at STA1. Based on table III, a 20 dBm transmit power and an MCS 3 settings, the system can attain its maximum throughput performance. However, it can also be noted that at the same settings, the uplink performance of STA2 was only about 235 Kbps as compared to the 3.38 Mbps recorded at the STA1. Furthermore, the same phenomena can be observed using MCS 0 wherein the uplink performance STA2 was only 764 Kbps, way below than the 1.27 Mbps performance of the STA1. This inconsistency in performance is expected as both

ISSN: 2244-2146

channels (AP to STA1 and AP to STA2) utilized a single frequency which can contribute to co-channel interference in between them. It is important to note that such poor performance was only experience when the packets were sent from the STAs towards the AP. In such scenario, it is of high probability that the packets undergo collision upon arrival at the AP side. Lastly, it is evident that due to the topography, a power of at least 20 dBm is necessary in order to establish a communication link for both channels.

Fig. 12. Learning with the aid of internet connectivity

Bgy. Diaz Elementary School is a recipient of the Department of Education Computerization Program (DCP) which aims to provide public schools with technologies to enhance information and communication technology (ICT) skills of the students. E-classroom is the specific program intended for primary students which provides, aside from projector, printer, and UPS, a shared computing technology using desktop virtualization kit. In this setup, one (1) host PC controlled by the teacher is shared among the six (6) users as shown in Figure 6. The host PC was run by windows multipoint server as its operating system. However, the e-classroom model can be further enhanced through the integration of internet connectivity.

Table 4
Multihop Throughput Performance at Different TX Power and MCS Values
User Case II

Tx Power (dBm)	MCS Value	Hop 1			Hop 2			Total Downlink (Mbps)	Total Uplink (Mbps)
		RSSI (dBm)	Downlink (Mbps)	Uplink (Mbps)	RSSI (dBm)	Downlink (Mbps)	Uplink (Mbps)		
20	0	-86	1.36	1.31	-72	1.41	1.36	1.36	1.31
20	3	-86	3.25	3.16	-72	3.66	3.55	3.25	3.16

Using the developed PtMP network in the TVWS, the school campus was connected to the internet. A Wi-Fi dongle connects the host PC to the IEEE 802.11n Wi-Fi router which was wired to the IEEE 802.11af prototype. In the aforementioned setup, some network constraint has been experienced during the actual implementation as the users cannot directly access the internet. In this scenario, the host PC needs to switch from one network (*connecting the six (6) users*) to the IEEE 802.11n router in order to access the internet. Thus, simultaneous network connectivity between the internet and the local network was not possible. Overall, the internet access was still viewed important as the teacher can now download materials online and shared it to the local network thereafter.

Use Case 2: Multihop Deployment

Table IV summarizes the performance of the system in a multi-hop network. The throughput performance of the multi-hop network was tested by conducting *Iperf* test on each hop; as analogous to a chain, the weakest link represents the maximum throughput of the system. As shown in Table IV, the multi-hop network can only reach a peak rate of 3.25 Mbps and 3.16 Mbps for downlink and uplink, respectively, using a transmit power of 20 dBm and an MCS 3 setting. Furthermore, as we try to increase the MCS setting and lower the transmit power, an erratic performance was experienced. It was also noted that during the experiment, with a transmit power of 15 dBm, though a near expected uplink rate were attained (MCS 0 & MCS 3), its downlink rate is way below. In addition, the problem worsens for lower transmit power, in this scenario, a total communication breakdown between the AP and STA was experienced. The obtained results shown in this part of the study is in correlation with the radio environment which has a dense vegetation. Also, the over 800 m in separation distance of hop 1 contributed to unstable connection which became evident when using a transmit power of 10 dBm and below. At 10 dBm, the throughput of hop 1 has only peaked at 118 Kbps using MCS 0, a high variance as compared to the expected throughput of over 1 Mbps for MCS 0. On the contrary, with the lesser separation distance of hop 2, the actual throughput reconciles with the theoretical. With a transmit power set at 10 dBm using MCS 3, both uplink and downlink rate still attained over 3 Mbps of data rate. In a nutshell, the terrain conditions greatly affect the radio propagation of the IEEE 802.11af system operating in the UHF band – hop 1 with dense vegetation as an obstacle has worst performance than the LOS situation of hop 2.

V. Conclusions

This paper presents an overview of the experimental results obtained in deploying a Television white space technology in the Philippines under varying RF environmental conditions using an IEEE 802.11af - compliant prototype devices. In a suburban hilly environment in a University campus in Cebu

ISSN: 2244-2146

City, a deployed multihop network centered at 593 MHz attained a maximum uplink throughput of 4.81 Mbps and 4.93 Mbps for downlink at a combined distance of 600 meters. In another experiment conducted in one of the rural villages in Surigao del Norte, Philippines, the TVWS technology was able to provide internet connectivity in a single link to a public elementary school (STA) roughly 530 meters away from the source (AP) located at the village hall despite Non-line-of-sight (NLOS) conditions providing a maximum downlink and uplink throughput of 3.43 Mbps and 3.38 Mbps, respectively, but only at STA1. In STA2 having the same set-up or parameters with STA1, the uplink throughput was recorded to be low and expectedly caused by packet collisions. In the same locality, a 2 - hop deployment using a different carrier for each hop was also tested to connect an area isolated by the damaged bridge that collapsed due to a 6.7 magnitude earthquake. A maximum throughput of 3.25 Mbps and 3.16 Mbps for downlink and uplink, respectively, were obtained up to a combined distance of 1290 meters. Based on the aforementioned results, the use of the TV white space technology utilizing the IEEE 802.11af-based network can indeed address digital divide through connectivity and provide an alternative ICT infrastructure in times of disasters.

ACKNOWLEDGMENT

This research was made possible under the auspices of the ICT Virtual Organization of ASEAN Institutes and NICT (ASEAN IVO) project on “TV White Space (TVWS) Experimental for Application in Remote Area.” The authors are likewise grateful to the the Department of Science and Technology (DOST) of the Philippines through its Engineering Research and Development for Technology (ERDT) Scholarship grant, the Commission on Higher Education (CHED), and the Office of Research, Development, Extension and Publication Office (RDEPO) of the University of San Carlos, Cebu City, Philippines for providing the technical and funding support.

REFERENCES.

[1] Republic of the Philippines National Disaster Risk Reduction and Management Council, “Final Report: Effects of Typhoon Yolanda”, December 2015

[2] Does broadband Internet access actually spur economic growth? Available at http://www.eecs.berkeley.edu/~rcs/classes/ictd

[3] Measuring Digital Development Facts and Figures. International Telecommunications Union, Geneva, Switzerland 2019.

[4] https://asiafoundation.org/wpcontent/uploads/2019/03/CfC-Reform-Story-11-Improving-Internet-Access-in-the-Philippines.pdf.

[5] M. Islam et. al, “Spectrum survey in Singapore: Occupancy Measurements and Analyses,” in Proc. of 3rd Intl. Conference on Cognitive Radio Oriented Wireless Networks and Communications, May 2008, pp. 1-7.

[6] R. Chiang, G. Rowe, and K. Sowerby, “A Quantitative Analysis of Spectral Occupancy Measurements for Cognitive Radio,” in Proc. of IEEE 65th Vehicular Technology Conference, Apr. 2007, pp. 3016-3020.

[7] M. McHenry et. al, “Chicago Spectrum Occupancy Measurements & analysis and a Long-term Studies Proposal,” in Proc. of the ACM 1st Intl. Wkshp. on Tech. and Policy for Accessing Spectrum, Aug. 2006, pp. 1-12.

[8] M. Lopez-Benitez, A. Umbert, and F. Casadevall. “Evaluation of Spectrum Occupancy in Spain for Cognitive Radio Applications,” in Proc. Of IEEE 69th Vehicular Technology Conference, Apr. 2009, pp. 1-5.

[9] C. S. Sum et al., "Cognitive communication in TV white spaces: An overview of regulations, standards, and technology [Accepted From Open Call]," in IEEE Communications Magazine, vol. 51, no. 7, pp. 138-145, July 2013

[10] IEEE Std 802.11af-2013, IEEE Standard for Information technology - Telecommunications and information exchange between systems - Local and metropolitan area networks - Specific requirement - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Spec-ifications Amendment 5: Television White Spaces (TVWS) Operation, published in February 2014.

[11] A.B. Flores, R. E. Guerra, E. W. Knightly, P. Ecclesine and S. Pandey, "IEEE 802.11af: a standard for TV white space spectrum sharing," in IEEE Communications Magazine, vol. 51, no. 10, pp. 92-100, October 2013.

[12] Dynamic Spectrum Alliance :Worldwide Commercial Pilots, Deployments & Trials http://www.dynamicspectrumalliance.org/.

[13] The State of Broadband 2014: broadband for all. A report by the Broadband Commission for Digital Development, September 2014 (ITU – UNESCO)

[14] Antonio Montejo III et. Al, “Implementation of a Multi-hop Network at the University Campus Using an IEEE 802.11af - compliant Network”, The 20th IEEE International Symposium on Wireless Personal Multimedia Communications (2017 WPMC) pp 173 - 180, Bali, Indonesia, December 17-20, 2017

[15] J.C. Lim, “ DICT launches National Broadband Plan, ” Business World Online, 24 June 2017

[16] Helen Flores, “DOST eyes new technology to increase Internet access,” The Philippine Star, February 7, 2013

[17] J. M. Tuazon, "Bohol fisherfolk are first beneficiaries of Philippines’ ‘Super Wi-Fi’ tech," Interaksyon: The Online News Portal of TV5, p. 1, 30 July 2013.

[18] Warren A. Nunez˜ and Alberto S. Banacia,˜ Simulation and FPGA Implementation of Television White Space Sensing Using Energy Detection for Cognitive Radio, 7th IEEE International Conference HNICEM IEEE – Philippine Section 12-16 Hotel Centro, Puerto Princesa, Palawan Philippines, November 2013

[19] Kentaro Ishizu et. al, “Field Experiment of Long Distance Broadband Communications in TV White Space Using IEEE 802.22 and IEEE 802.11af”, 7th International Symposium on Wireless Personal Multimedia Communications pp 468-473, Sydney, New South Wales, Australia, September 2014

