Final Project Report
Detailed Form

I. Title of Proposed Project: TV White Space (TVWS) Experimental for Application in Remote Area

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III. Project Members:

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Alberto S. Bañacia	Faculty Member	University of San Carlos, Philippines	abanacia1201@gmail.com
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IV. Project Report

This document provides final report for the ASEAN IVO Project entitled "TV White Space (TVWS) Experimental for Application in Remote Area".

i) Introduction

TV white space (TVWS) is a portion of the spectrum in ultra-high frequency (UHF) and very-high frequency bands, which is not utilised by primary users in specific time and location. The regulators in the USA and in the UK have given approval for companies to operate new communication systems with the capability of utilising TVWS spectrum. This project focuses on experimental test bed for TVWS implementation for applications in rural areas. In particular, we have demonstrated the effectiveness of TVWS for natural disaster emergency network.

ii) Project Activities

(1) Development and Implement

Experimental sites
Specific location for the implementation for this project have been identified in Malaysia and Philippines for TVWS experimental, namely Chini Lake (Malaysia) and Surigao (Philippines). For the implementation in the Philippines, the location has been be changed from Bogo, Cebu to San Farncisco, Surigao del Norte. This is due for the following reason: the location in Surigao was just hit by a strong 6.7 magnitude earthquake.

TVWS equipment by NICT
TVWS equipment was design and build by NICT Japan. The device are ready for deployment in Philippines and Malaysia. These equipment units are compliant with the IEEE 802.11af standard with the following specifications:

Frequency bands: 470-710 MHz
Channel spacing: 6 MHz (center freq. can be set in 1 MHz step.)
Bandwidth: 5/10/20 MHz
Data rate: Up to 6 MHz depending on MCS
Modulation: BPSK/QPSK/16QAM/64QAM (QPSK or 16QAM is recommended for stability)
Rx sensitivity: around -78 dBm
User interface ports: Ethernet Base station
RF transmit power: 100mW or 1W depending on unit CPE terminal
RF transmit power: same as BS (same unit)

Face-to-face meeting
Two meetings was held in Japan and Malaysia on 21-22 Nov 2016 and 29-30 Mar 2017, respectively. The agenda and participants for the meetings are described in the following text.

Face-to-face meeting #1: 21-22 Nov 2016 in Japan

Date	Agenda (Academic Event at NICT Japan)	Venue
Nov 21, 2016 (Monday)	*Morning:* General meeting and presentation by project members; - Presentation by NICT - Presentation by MIMOS - Presentation by USC - Presentation by UKM *Afternoon:* Discussion on project plan and legal related matters.	Meeting venue: NICT, Yokosuka, Japan
Nov 22, 2016 (Tuesday)	*Morning:* Training on NICT TVWS equipments. *Afternoon:* Discussion on project implementation issues at Bogo City and Tasik Chini.	Meeting venue: NICT, Yokosuka, Japan

Participants: There are seven (7) project members who will be involved in the academic event at NICT, Yokosuka, Japan. These are the composition of the project members by country;

- Three (3) members from Malaysia
- One (1) member from Philippines
- Four (4) members from NICT, Japan

Participants from Malaysia and Philippines:

Name	Position	Department, Institution, Country
Dr. Hafizal Mohamad	Senior Staff Researcher	Wireless Innovation, MIMOS Berhad, Malaysia
Dr. Nordin Ramli	Senior Staff Researcher	Wireless Innovation, MIMOS Berhad, Malaysia
Dr. Rosdiadee Nordin	Associate Professor	Universiti Kebangsaan Malaysia (UKM), Malaysia
Alberto S. Bañacia	Faculty Member	University of San Carlos (USC), Philippines

Participants from NICT, Japan:

Name	Position	Department, Institution, Country
Dr. Kentaro Ishizu	Research Manager	Smart Wireless Laboratory, NICT, Japan
Dr. Fumihide Kojima	Director	Smart Wireless Laboratory, NICT, Japan
Dr. Hirokazu Sawada	Senior Researcher	Smart Wireless Laboratory, NICT, Japan
Dr. Kazuo Ibuka	Researcher	Smart Wireless Laboratory, NICT, Japan

Figure 1: Project members with TVWS equipment during F2F meeting in Japan on 22 Nov 2016.

Face-to-face meeting #2: 29-30 Mar 2017 in Malaysia

The main objectives are as follow:

- Day 1 (Mar 29, 2017)
  - To conduct site visit to Chini Lake which is the location of the implementation site for this project. This is 1-day trip using a chartered coach and the travelling time is about 3.5 to 4 hours (one way)
- Day 2 (Mar 30, 2017)
  - To present project progress update from each project members
  - To report on the project implementation plan, timeline, finalize budget and equipment list and discuss outstanding issues

Date	Time	Agenda	Venue
Mar 29, 2017 (Wed)	8:30 12:00 13:00 15:00 19:00	Start travelling from Kuala Lumpur Arrive at Chini and lunch Site study Depart from Chini Arrive at Kuala Lumpur	Chini Lake, Pahang

Mar 30, 2017 (Thur)	9.00 10.00 10.30 11.00 11.30 12.15 14.00 15.30 17.00	General meeting and presentation; - project update by NICT - project update by MIMOS - project update by USC - project update by UKM Lunch break Discussion on project timeline, finalize budget and equipment list. Discussion about outstanding issues. Tea break End of discussion	Le'meridien, Putrajaya

Participants List: Total = 11 persons. These are the composition of the project members by country;

- Five (5) members from Malaysia
- Two (2) member from Philippines
- Four (4) members from NICT, Japan

Name	Position	Department, Institution, Country
Dr. Hafizal Mohamad	Sr Staff Researcher	MIMOS Berhad, Malaysia
Dr. Nordin Ramli	Sr Staff Researcher	MIMOS Berhad, Malaysia
Dr. Rosdiadee Nordin	Associate Professor	Univ. Kebangsaan Malaysia (UKM), Malaysia
Dr. Mahamod Ismail	Professor	Univ. Kebangsaan Malaysia (UKM), Malaysia
Anabi Hilary Kelechi	PhD Student	Univ. Kebangsaan Malaysia (UKM), Malaysia
Alberto S. Bañacia	Faculty Member	University of San Carlos (USC), Philippines
Antonio C. Montejo III	Master Student	University of San Carlos (USC), Philippines
Dr. Kentaro Ishizu	Research Manager	Wireless Systems Laboratory, NICT, Japan
Hoang Vinh Dien	Researcher	Wireless Systems Laboratory, NICT, Japan
Dr. Hiroshi EMOTO	Manager	NICT, Japan
Nobuyuki Asai	Expert	NICT Asia Center, Thailand


Figure 2: Project members at Tasik Chini Meeting Room on 29 Mar 2017.

Discussion with regulators and stakeholders

In Malaysia, the formal application for TVWS experimental implementation at Tasik Chini was submitted to MCMC on July 2016. Several round of discussions were held with the Radio Spectrum Assignment Department, Licensing and Assignment Division, Malaysian Communications and Multimedia Commission (MCMC). Project members from MIMOS and UKM have also presented the spectrum sensing findings on the available (unutilized) TV spectrum at Tasik Chini to the MCMC officers. However, in February 2017 we received a notification from MCMC about the status and appeal for our application to obtain TVWS license for experimental trial in Tasik Chini. Our TVWS license application was not approved by MCMC. This is very unfortunately after having numerous rounds of discussion and presentation of spectrum measurement etc. These are the reason given by MCMC: "Currently we are in midst of migrating analogue to digital TV in the requested band, nationwide. In view of this situation and in order to avoid disruption to this migration process, we cannot consider any trial for TV White Space."

Philippines is undergoing analog to digital TV transition adopting the Japanese ISDB - T standard. This has been so since 2013 but late last year and this year, the Philippines government has been aggressively pushing for it. USC has filed an appeal application on November 2016 and met some of the NTC officers. The project members from USC has also presented the spectrum sensing study conducted throughout Cebu indicating that the available channels (Ch. 45 and Ch 46) that were practically not being utilized and by the time our study is completed. Contact and discussion was also made with ICT Office (ICTO) of Cebu for a MOA on July 2016. ICTO used to be under the Dept. of Science and Technology (DOST) but with the change of Philippines administration last June and with the creation of a new Dept. of ICT last July, ICTO is now under DICT. ICTO is the lead agency of the Phil. government in conducting TVWS trials and deployments. To date, they've deployed in at least 4 provinces (out of about 80) but covering only roughly 10 municipalities (out of hundreds) which has fallen short of the ICT original roadmap of full TVWS deployment by 2015. USC's MOA with ICTO Cebu was finally signed and completed only last January 2017. This allows us to share ICTO's experimental license frequencies (Ch.45, 46, 49) for our own experiment. However, last February 9, USC representative was invited to attend a public consultation in NTC Cebu to discuss Digital TV planning with ISDB-T Corporate Director and in-charge of Phil. Cebu NTC Director has arranged a meeting with NTC Manila's in-charge of Broadcasting and Special License Division with USC to talk about our pending appeal for an experimental license. It was decided that all activities pertaining to TVWS activities have to be temporarily halted to avoid any potential interference or problem it might caused during the transition.

(2) Leveraged Resources and Participants

TV white space (TVWS) has gain a lot of attention due to its potential to address current wireless connectivity challenges and can be used to help augment existing broadband networks, extend broadband access to rural areas and allow other applications such as disaster recovery and machine-to-machine communications. A number of regulators such as FCC in the US and Ofcom in the UK are working on technical measures that will allow the use of this spectrum without interfering with incumbent licensed users. Researchers at NICT have been involved in numerous projects related to dynamic spectrum access and TV white space (please refer to Reference list). They have been contributed for many standardization activities such as IEEE 802.15.4g, IEEE 802.15.4m, IEEE 1900.4, IEEE1900.6, and 802.11af.

For this IVO program, we have identified researchers from three countries (Malaysia, Japan and Philippine) to work together for TVWS experimental implementation. This project aims to demonstrate the effectiveness of TVWS which is applicable for at last one of the following applications; hydrological quality monitoring in rural area and natural disaster emergency network.

Project coordination has been managed through Skype communication, email exchange and face-to-face meeting. Technical milestones of the project such as radio propagation study and spectrum measurement has been achieved successfully. Implementation in Philippines will be carried out at San Francisco, Surigao del Norte as experimental site for disaster response network using TVWS technology. Arrangement for the equipment and logistic has been successfully made.

In February 2017, based on the update from regulator in Malaysia on TVWS restriction, we are now considering alternative wireless systems such as Wi-SUN and LoRa for implementation in Malaysia due to regulation of TVWS restriction. The term Wi-SUN is the short form of Wireless Smart Utility Network, which is a good alternative technology. For LoRa, frequency assignment in Malaysia is 919-923 MHz. Experimentation for LoRa and Wi-SUN has been conducted.

NICT has strong research in TVWS and has developed prototype hardware for TVWS communications. Philippine government and researcher have strong interest in TVWS and one of the important applications for the country is natural disaster management. Through this join work with University of San Carlos, Philippines, an experimental implementation has be deployed. This IVO project provides opportunity for researchers from MIMOS and UKM to discuss TVWS to stakeholders in Malaysia. Numerous research work and finding have been published by NICT, MIMOS, University of San Carlos and UKM.

NICT has loaned the TVWS transceivers and to provide assistance for the experimental work. MIMOS and UKM has conducted the propagation study at the experimental location and to setup the ICT solution for smart environmental monitoring. USC has been involved in connectivity implementation at the identified location and obtained TVWS trial license.

Existing Facilities

- Research laboratories at MIMOS, NICT, University of San Carlos and UKM
- Meeting venues at MIMOS, NICT and University of San Carlos
- Biodiversity Monitoring Centre at Chini Lake (UKM, Malaysia)

Equipment

- TVWS communication transceivers from NICT
- PC/computing hardware and software from MIMOS and University of San Carlos

Resources

- Researchers from MIMOS, NICT, University of San Carlos and UKM, including supporting research assistants relevant to this project.

(3) Findings and Outcomes

Radio propagation study at Chini Lake and USC Campus

<u>Site #1 (Malaysia)</u>: Chini Lake is a fresh water lake near the Pahang River in central Pahang, Malaysia. The lakeshores are inhabited by the Jakun branch of the Orang Asli (indigenous people). Chini Lake is located at Pahang State, approximately 243km on the east side of Kuala Lumpur as depicted in Figure 4. The 12,565 acres (5,026 hectares) Chini Lake is the second largest fresh water lake in Malaysia and is made up of a series of 12 lakes. Chini River, which drains from the lake, flows into Pahang River. Chini Lake is one of the UNESCO Biosphere Reserve status sites in Malaysia. The location of seven (7) water quality stations are shown in Figure 5.

The simulated results for link budget and elevated path between Sg. Chini station and monitoring lab are shown in Figure 6. The simulated results indicate that the signal can received signal strength is -77dBm for the transmission distance of 2.78km. This means a communication link can be established between the water station (at Sg. Chini) and the monitoring lab (PPTC). The lake system lies between 3°22´30" to 3°28´00" N and 102°52´40" to 102°58´10" E.

The exact location of the water stations are as follow;

PPTC	= Lat 3°25'35" Long 102°55'37"
Melai	= Lat 3 24’26” Long 102 54’ 52”
Merapoh	= Lat 3 24’23” Long 102 54’ 37”
Jemberau	= Lat 3 25’10” Long 102 55’ 51”
Sg. Chini	= Lat 3 26’36” Long 102 54’ 32”
Kura-kura	= Lat 3 25’58” Long 102 55’ 53”
Gumum	= Lat 3°26'13" Long 102°55' 45"

Jerangking = Lat 3 26’45” Long 102 54’ 54”

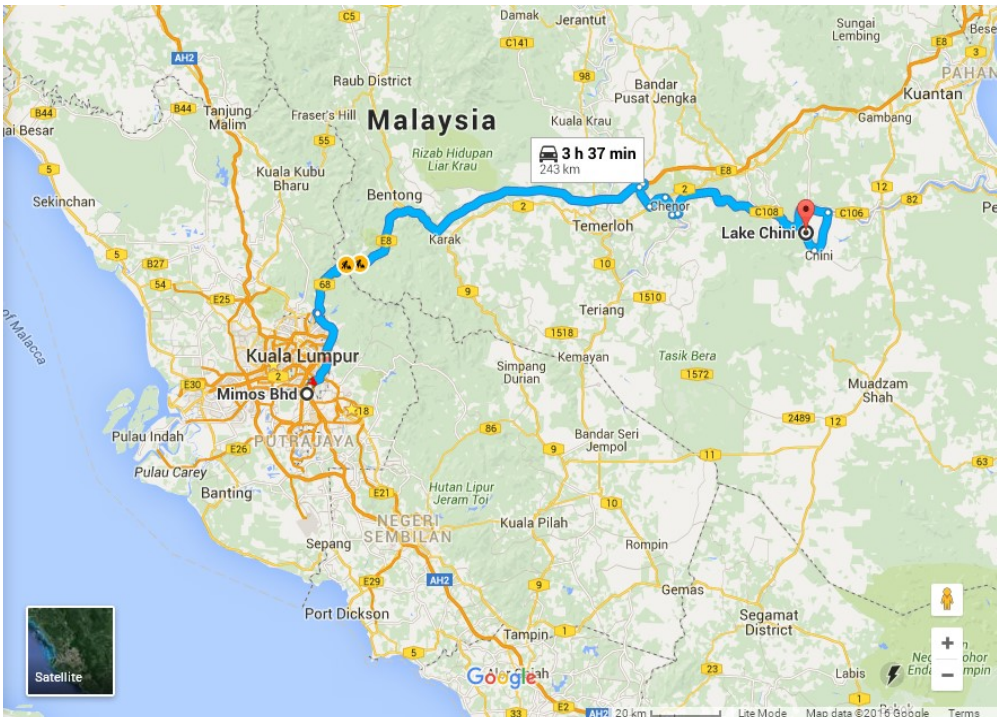


Figure 4: Distance between Tasik Chini and Kuala Lumpur

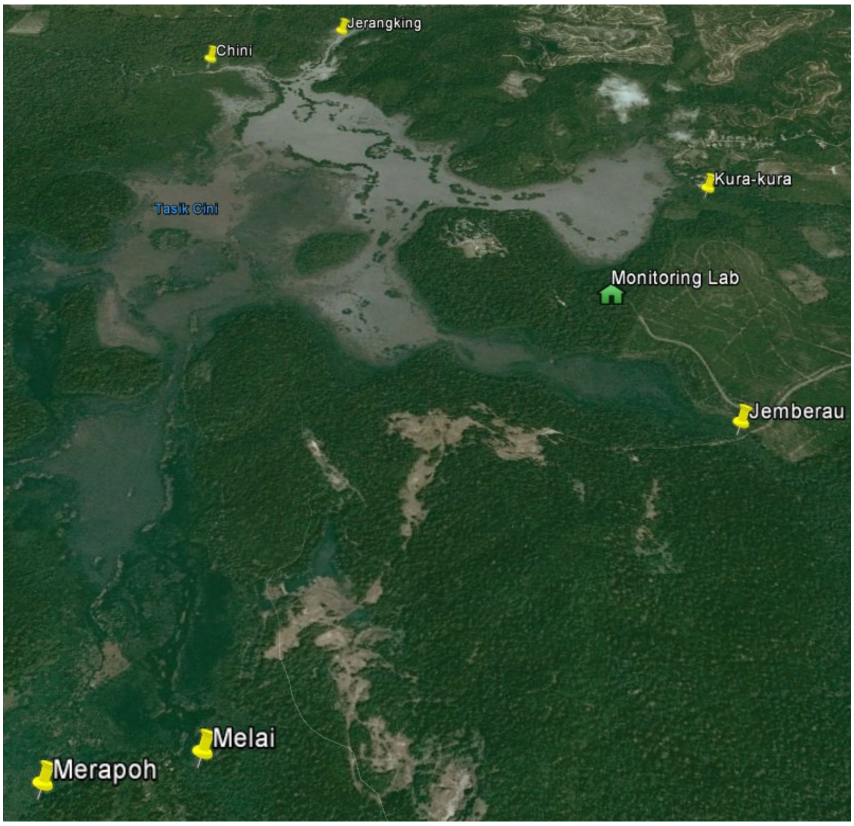
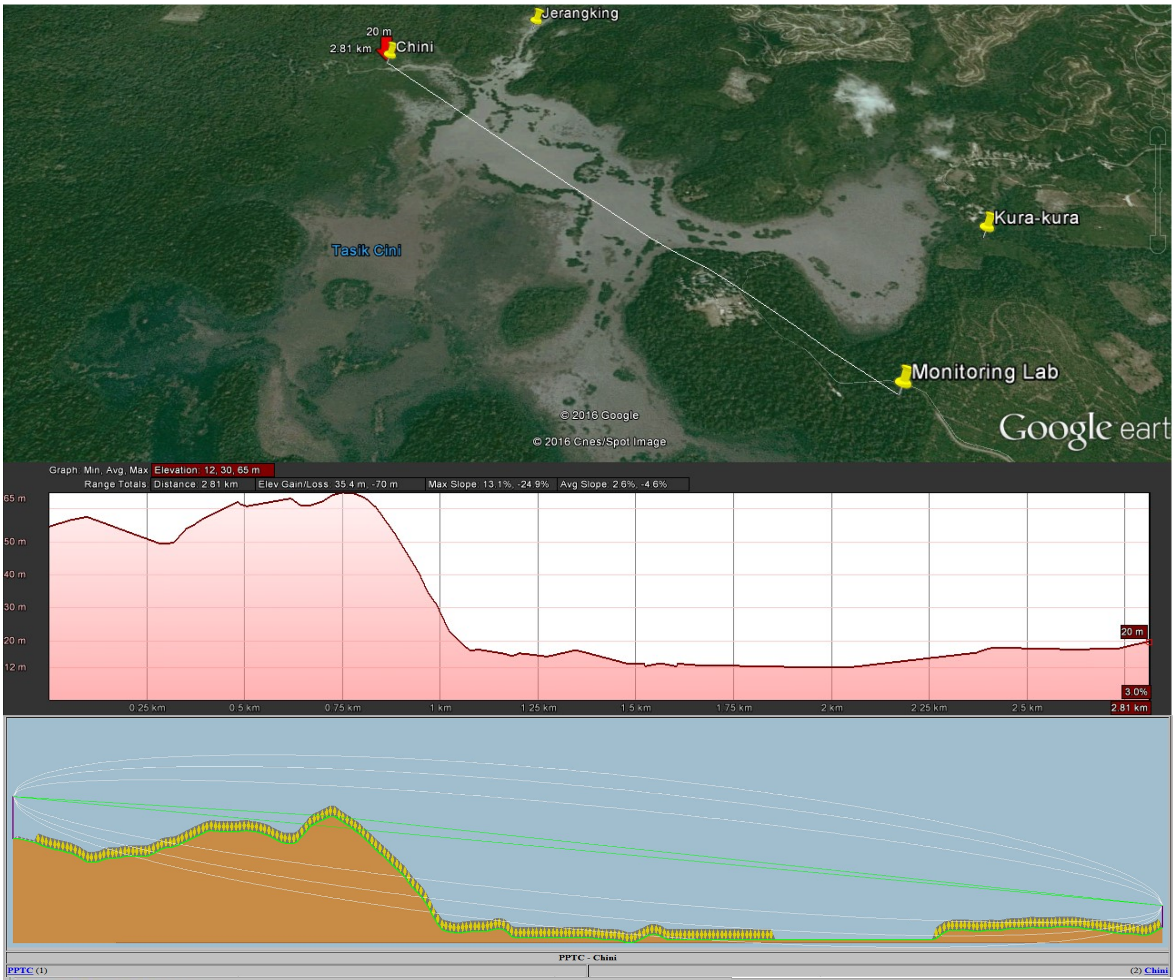


Figure 5: Exact location of the monitoring lab and water stations in Tasik Chini, Pahang



Performance	
Distance	2.783 km
Precision	10.0 m
Frequency	450.000 MHz
Equivalent Isotropically Radiated Power	6.310 W
System gain	142.68 dB
Required reliability	90.000 %
Received Signal	-77.11 dBm
Received Signal	31.23 µV
Fade Margin	**18.07 dB**

Figure 6: Link budget and elevated path between Sg. Chini station and monitoring lab

Site #2 (Philippines): Initial site in our proposal is Bogo City, which was one of the cities and provinces badly hit by Super typhoon Haiyan last November 8, 2013. Located in the northeastern coast of Cebu province, the city is 101 kilometers (63 mi) from Cebu City and is accessible by land and sea and has an area of 103.5 square kilometers (40.0 sq. mi). However, the location has been be changed from Bogo, Cebu to San Farncisco, Surigao del Norte. This is due for the following reason: the location in Surigao was just hit by a strong 6.7 magnitude earthquake recently.

For the purpose of experimentation, initial test has been conducted at USC in Talamban

Campus, Cebu City, whereby the campus photo is shown in Figure 7. Simulation results for 649MHz frequency is depicted in Figure 8.

Figure 7: Initial test site - University of San Carlos Talamban Campus, Cebu City

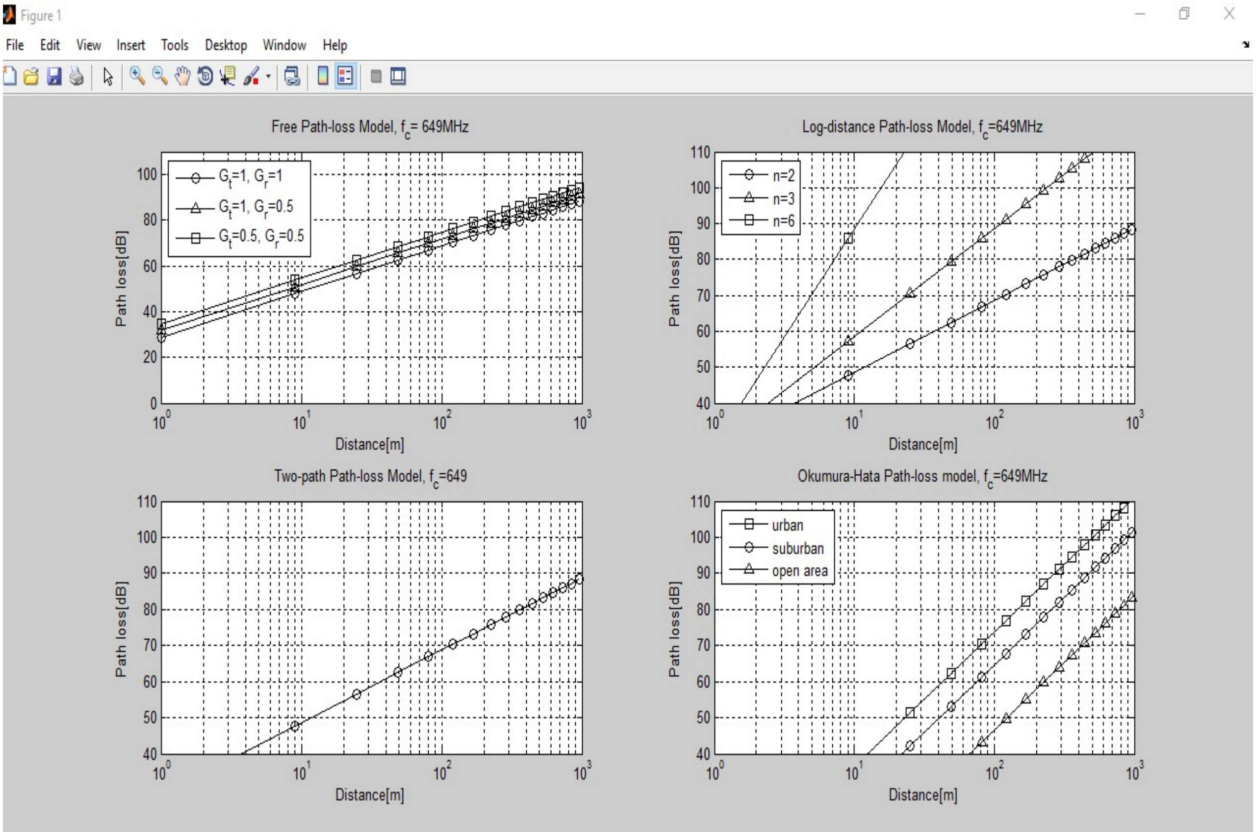


Figure 8: Path loss simulation for TVWS spectrum

3.2. Spectrum measurement at Chini Lake

Spectrum measurement campaigns are providing the much-needed response to the validation that most of the Sub 1GHz licensed spectrum utilization are heavily under-utilized in temporal and spatial dimensions. Hence, there are lots of spectrum holes/gaps, often referred as White Spaces especially in TV channels that need to be exploited for the provisioning of broadband services for wireless consumption. This section provides findings on TVWS availability in Tasik Chini - Pahang using RF explorer.

RF explorer is a fully functional unit with a standalone capability and does not require PC to be used. Since our measurement was considered as a static test, which does not require mobility and driving, there is no need for GPS module as our locations are known. In addition, the RF explorer GUI provided an easy approach for selecting the start and stop frequencies. Thus, eliminating the need for writing script batch file to automatization of the spectrum measurement campaign.

The measurement campaign was conducted from October 14th to 15th 2016, using a car and a boat. Car was deployed to access offshore measurement site and boat for the onshore site. The RF Explorer was placed on top of the car/boat to obtain clean UHF signal. The RF Explorer was connected to the laptop via a USB cable which facilitates easy spectrum measurement configuration. The spectrum span of approximately 100 MHz was chosen as it enabled easy UHF spectrum band measurement as: 400-496 (400 MHz band), 500-596 (500 MHz band), 600-696 (600 MHz band), 700-796 (700 MHz band) and 800-896 (800 MHz band). The design of the experiment for the land and lake spectrum measurement campaign with the RF Explorer is shown in Figure 9.

Figure 9. Measurement setup on the Tasik Chini.

The measured data of the four locations under test were recorded and plotted as graphs shown in Figures 10 to 14. For the purpose of discussions, the received signal strength were categorized as high with threshold values of -87 dBm (Level 1 shown in the figures) and -97.5 dBm (Level 2 shown in the figures). The selected threshold is based on The European Conference of Postal and Telecommunication Admissions (CEPT) ECC SE43 Draft Report (Saeed and Shellhammer, 2012). Furthermore, the similar threshold was used in the Malawi spectrum measurement (Zennaro et.al, 2013). For the signal strength in Figures 4 to 8:

- Above Level 1: 'high'
- Below Level 1 but above Level 2: 'low'
- Below Level 2: noise floor.

Values with strength below Level 2 are considered the noise floor they are below the receiver sensitivity of most radios and well beyond the level required for adequate decoding of a TV signal. Therefore, signals below Level 2 are considered as TV White Spaces.

The signal Level 1 can be further investigated to infer if they are actually assigned by the spectrum regulators (MCMC). In Figure 10, high signal levels are reported in 413MHz to 422MHz, 476MHz to 485MHz, 486MHz to 499MHz in Chini. The MCMC spectrum assignment chart indicates that 470MHz to 502 MHz are assigned to Channels 21-25 for TV broadcast. Apart from TV broadcast, Mobile Cellular Service for Code Division Multiple Access in Band 450MHz (CDMA450) is also active. The CDMA 450 is characterized as having Upper band: 462.090MHz to 466.360MHz and Lower band: 452.090MHz to 456.360MHz. Furthermore, there is a need for MCMC to investigate why there is high power from 413MHz to 422MHz. at 465 MHz. In the MCMC spectrum chart currently in use, the band 460—470 MHz is not allocated. However, a high signal was captured.

Based on ITU regulations, this band is reserved for Fixed Mobile or Meteorological-Satellite (Space-to-Earth).

In Figure 11, the start and end of 500MHz to 599MHz shows high signal level indicating TV broadcast are high especially from 500MHz to 512MHz representing TV Channels of 25 and 26 respectively. Spectrum frequency of 550MHz and 580MHz representing Channels 31-34 are active in PPTC location.

TV spectrum band from 600MHz to 699MHz is generally considered the most actively engaged based on Figure 12. With the exception of 630MHz to 660MHz and 664MHz to 670MHz, every other spectrum band is active. Hence, this band will be the least considered for implementation of TVWS technology. In another case, it can be selected to showcase the proof of concept that TVWS technology causes negligible interference to other licensed bands.

The 700MHz to 799MHz as shown in Figure 13 is the least active bands in all the measured spectrum bands and can be considered as the desired frequency range. Though TV spectrum channels in Malaysia are from 470MHz to 798MHz, this study extended the measurement campaign to the 800MHz to 899 MHz GSM bands as shown in Figure 14. Clearly, the GSM bands are highly active in all the locations.

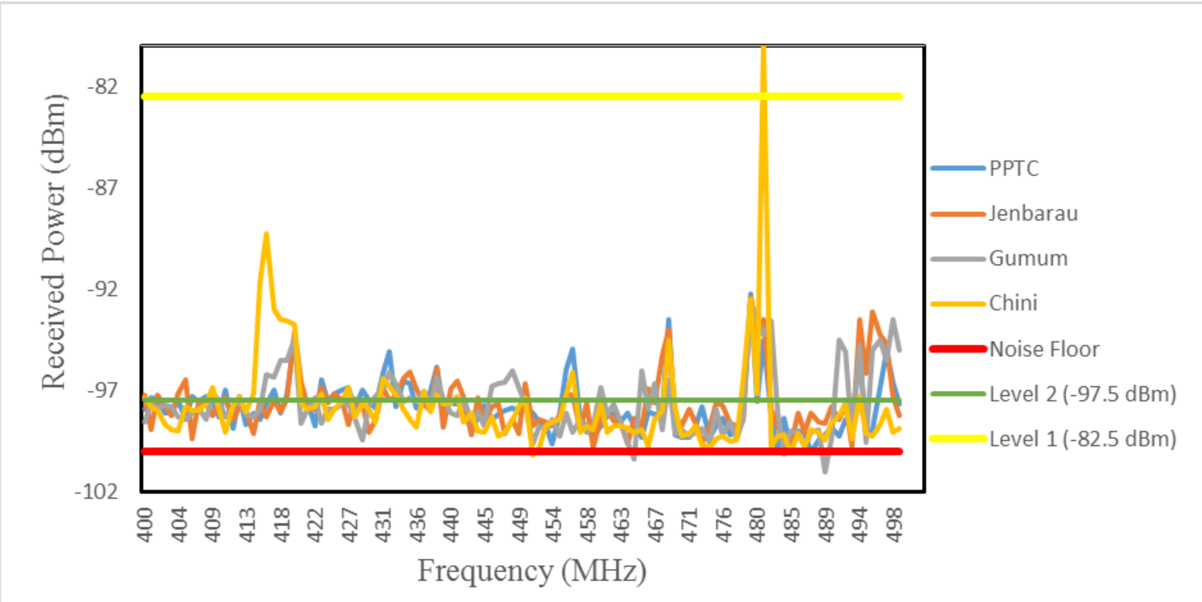


Figure 10. Measurement from 400MHz to 499MHz.

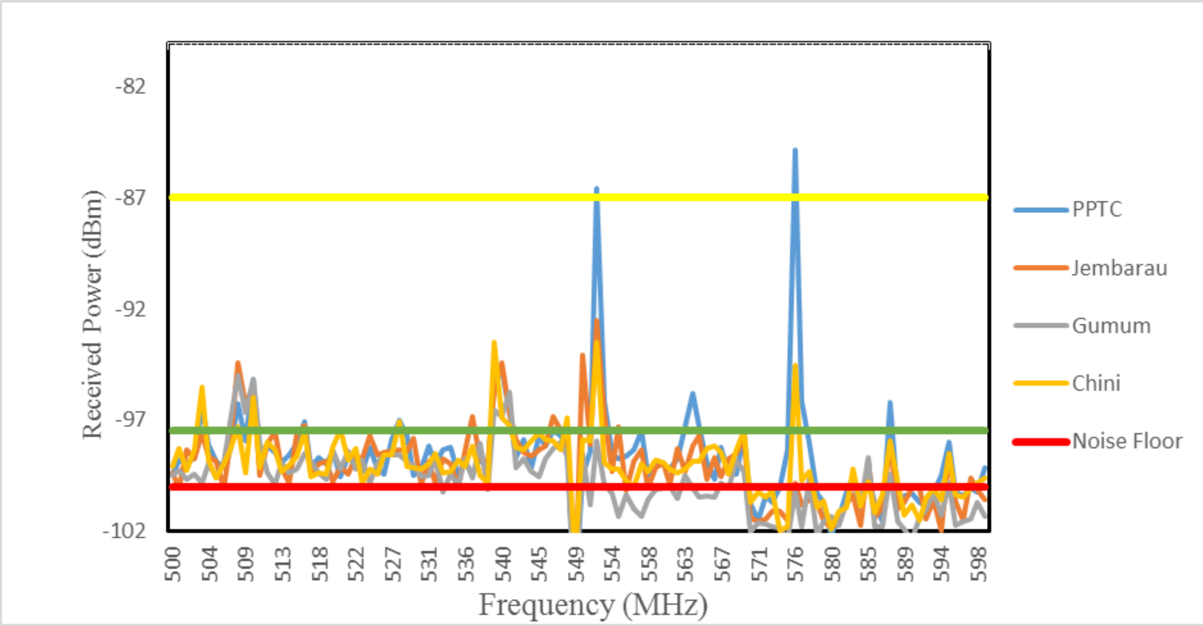


Figure 11. Measurement from 500MHz to 599MHz.

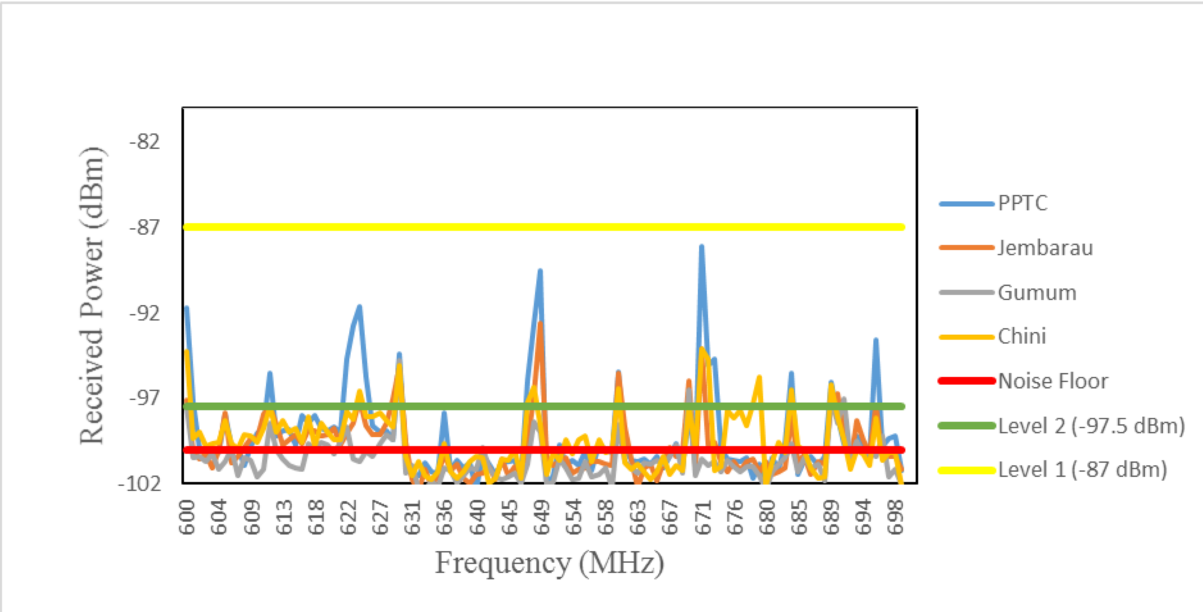


Figure 12. Measurement from 600MHz to 699MHz.

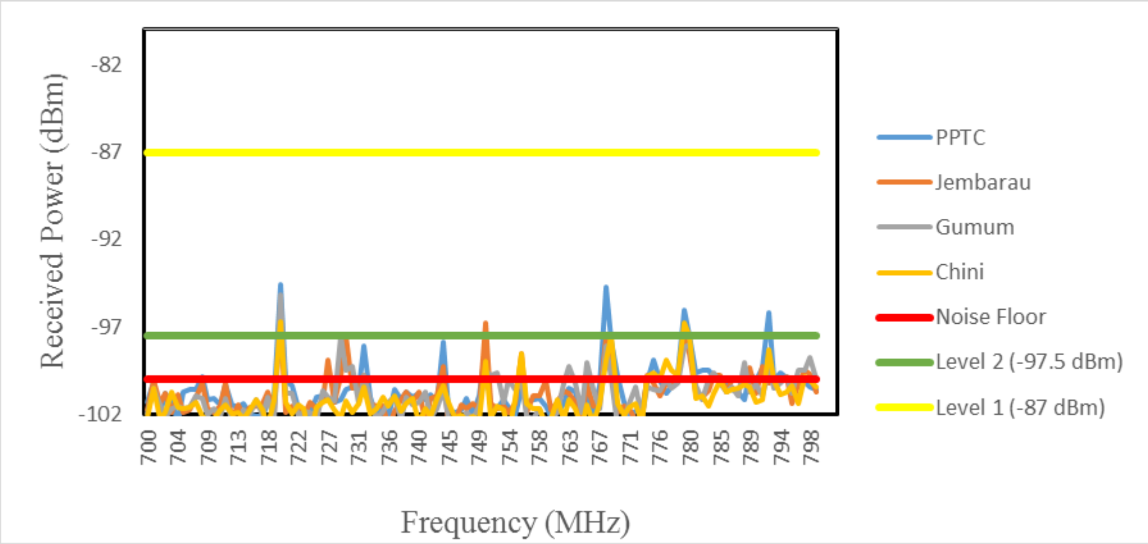


Figure 13. Measurement from 700MHz to 799MHz.

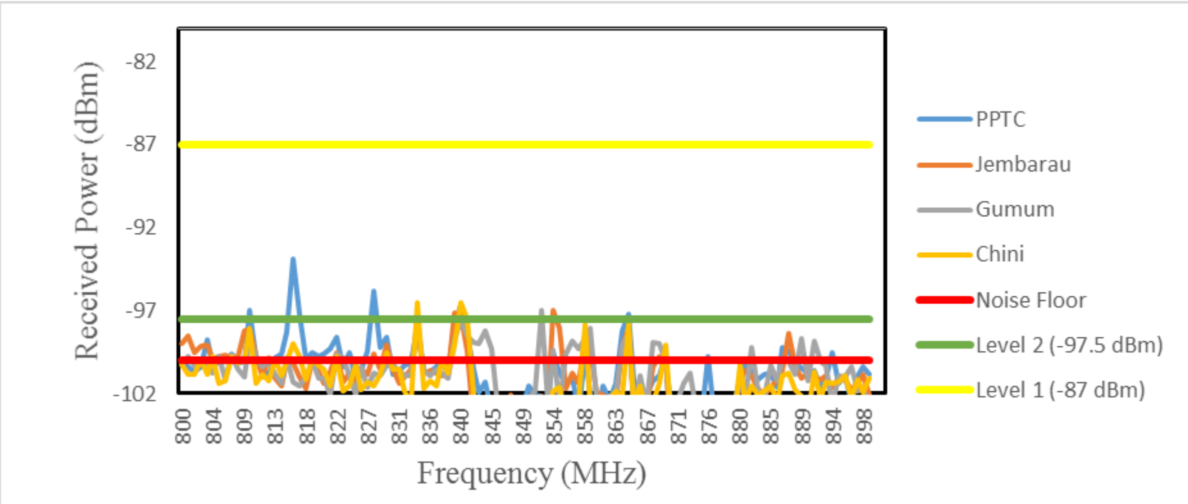


Figure 14. Measurement from 800MHz to 899MHz.

An important discovery made in this study indicates on the average that spectrum bands between 700-742 MHz bands are less busy and can be deployed for the TVWS technology pilot trial projects. This conclusion was arrived based on the fact that the measured received signal powers between 700-742 MHz bands were below -94 dBm.

Table 1: Recommendation of available UHF channels surrounding Tasik Chini

Frequency Range (MHz)	**Avg RSS**	**Avail. frequency**	**TV Channel No**
400-500	-98 dBm	470MHz – 478MHz	Channel 21
500-600	-98 dBm -99 dBm	510MHz – 518MHz 518MHz – 526MHz	Channel 26 Channel 27

	-99 dBm	526MHz – 534MHz	Channel 28
600-700	-101 dBm -101 dBm	630MHz – 638MHz 638MHz – 646MHz	Channel 40 Channel 41
700-800	-102 dBm -102 dBm -102 dBm -102 dBm	702MHz – 710MHz 710MHz – 718MHz 726MHz – 734MHz 734MHz – 742MHz	Channel 50 Channel 51 Channel 53 Channel 54

WiSUN and LoRa Experimenatal Work at Tasik Chini, Malaysia

Tasik Chini is the second largest natural fresh-water lake in Malaysia after Tasik Bera. It is located in the state of Pahang, Malaysia. The lake area is approximately 202 hectares of water bodies and 700 acres of freshwater wetlands and swamp forests around. The lake area is rich in wetlands biodiversity, and ecological capitals. According to the Malaysian Nature Society, this area is richly endowed with biological resources and some 288 species of plants, 21 species of aquatic plants, 92 species of birds, and 144 species of freshwater fish.

Moreover, Tasik Chini is home to the Jakun tribe (Orang Asli), one of the major aborigines' groups in Malaysia. Residing in and within the surrounding area of the watershed, the Jakun forms a total six kampung (small villages). Altogether, 80 families or approximately 500 members stay in this sensitive area. The mainstay economy is mainly forest-based and agriculture-based activities (i.e. rubber tapping, rattan, and palm oil plantations). They also use the lake as a source of sustenance and the source of their water supply.

Nevertheless, the unplanned development, illegal mining, and the monsoon flood are some of the hazards causing negative impacts on the lake's ecosystem and Orang Asli's community. Hence, Tasik Chini must be maintained as an important legacy for the country and the coming generations, where its loss is permanent and cannot be replaced. In this regard, Chini Lake Research Center, or in a local language as Pusat Penyelidikan Tasik Chini (PPTC), which is near the lake, was established under the auspices of the Faculty of Science and Technology (FST) of Universiti Kebangsaan Malaysia (UKM). PPTC designated to carry out research, field work, environmental awareness and dissemination of information on lake management integrated into society.

Tasik Chini is awarded UNESCO biosphere reserve status. With the biosphere status, Tasik Chini is expected to fulfill major functions, such as strictly protected ecosystem for natural conservation, buffer zones and practices ecologically sustainable economy and human development.

To preserve the natural ecosystem of the lake, seven HMS were established around the lake. The stations are used for sampling/measuring water quality, climate changes, and water level. According to the importance of measured data, the data should be collected based on a specific hourly schedule. It should be mentioned, that since the stations are located around the lake and some of them are quite remote, it is difficult or impossible to travel by boat and collect the data manually at the HMS. In this regard, a wireless system is vital to transfer the collected data from the HMSs to the PPTC monitoring lab.

Monitoring Stations

Figure 15 shows the approximate location of the seven HMSs, PPTC monitoring lab, and the only cellular Base Station (BS) that provides coverage surrounding the Tasik Chini area. Figure 16 depicts the current wireless network connectivity between one of the HMSs and the monitoring lab at PPTC. According to the Figure 15, each HMS is equipped with 15 sensors (includes water quality, climatology, and water level sensors), one data logger and one GSM Modem. The sensors are digital and analog, where connected to the data logger via wires. Data logger is a configurable and programmable device that based on a schedule reads measured data from the sensors, converts and analyzes the collected data to understand the useful data, prepares the analyzed data as a readable file format (i.e. *.csv), prepare the GSM modem for data transmissions, and transfer the data to the GSM modem via RS 232 cable. The data logger also supports multiple connection interfaces, which makes it extendable for several wireless technologies, which in this case NB-IoT. GSM modem is a configurable modem that is used for wirelessly transmitting the data from HMS to the PPTC monitoring station. Moreover, the GSM modem is equipped with one prepaid SIM card and a high gain Yagi antenna.

On the other side, the PPTC monitoring lab is equipped with a GSM modem and one desktop computer (act as a server). The tasks of GSM modem at the PPTC server are; (i) dialing the contact number of GSM modem at each HMS (based on a scheduler) and establishing a connection between two ends based on the Point to Point Protocol (PPP) and File Transfer Protocol (FTP), and (ii) receiving the transmitted data from the cellular BS and transferring to the PC Server for future usage by the researchers.

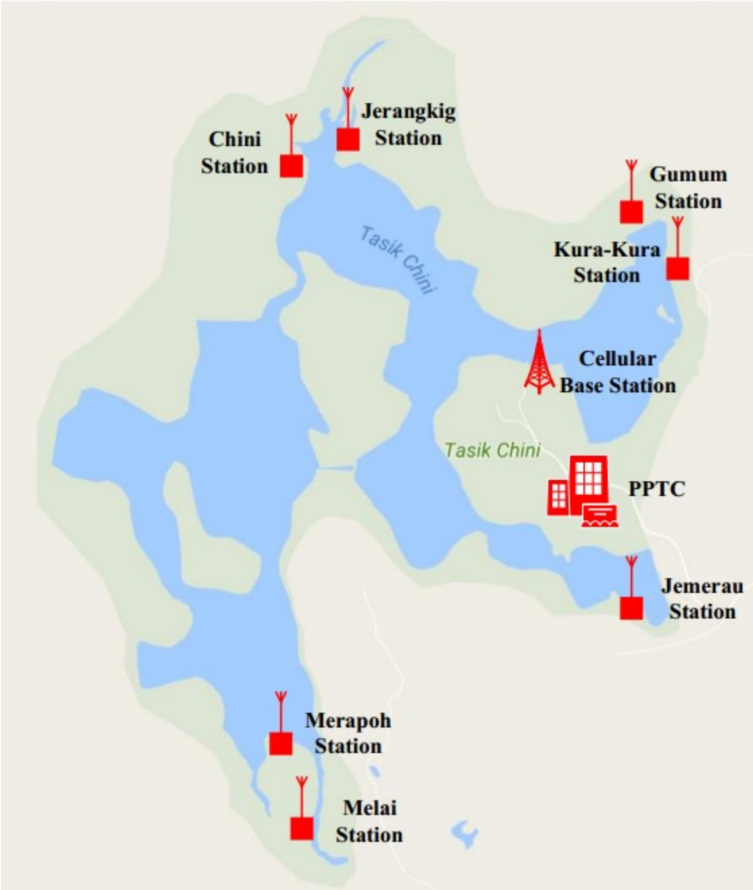


Fig. 15: Geographical position of HMSs, PPTC monitoring lab, and cellular BS at Tasik Chini

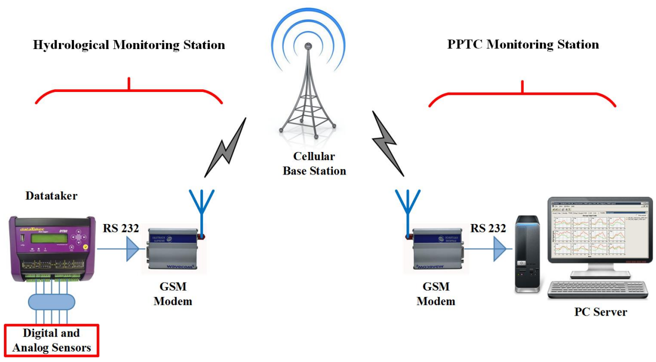


Fig. 16: Cellular network connectivity between HMSs and PPTC monitoring lab

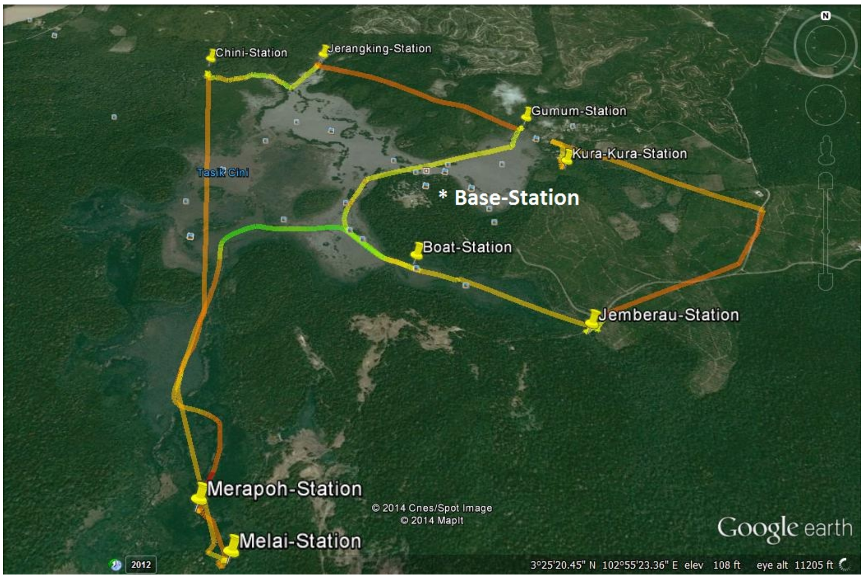


Fig. 17: Measured RSS of seven HMSs surrounding Chini Lake

Beyond the problems of 2G communications, another challenging aspect of wireless data transmission in Tasik Chini is its remote location, which causes limited coverage through the lake due to irregular terrain environment (Non-Line of Sight communications). In this regard, we investigated and measured the radio-related parameters at the Tasik Chini, HMSs, and the PPTC. The following presents the observed measurements in Tasik Chini.

To measure the received-signal-strength (RSS) of cellular networks the RF Signal Tracker has been used, which is an open source Android application. Three cellular operators have been examined, which named; DiGi, CelCom, and Maxis. Figure 17 depicts the measured RSS of all seven HMSs based on Maxis network service. The color of lines represents the quality of received signal, from Red (no signal) to Green (excellent).

Figure 18 represents the measured RSS of the seven HMSs, where three different operators are examined. From the results, the strength of the received signal depends on the utilized network-operator. However, only the RSS of four HMSs (Gumum, Chini, Jemberau, and Kura-Kura) are in 'Good' level, especially with Celcom, while, the other three HMSs working within a 'Poor' cellular coverage. There are different reasons for this poor coverage:

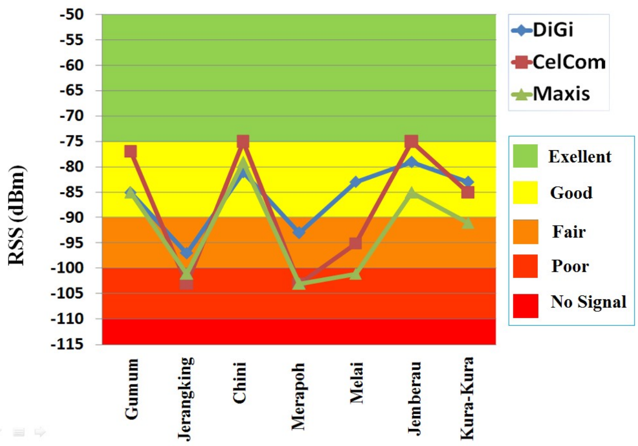


Fig. 18: RSS of seven HMSs, where three different operators are examined

i. Poor telecommunication penetration. Since the lake is located in a rural and remote area, there is only one cellular tower and the three different cellular operators installed their equipment there. Economically not feasible for a cellular operator to increase their coverage & traffic in a remote area due to size of the population, and

ii. Non-line of Sight (NLoS) communication, due to irregular terrain environment, trees, and foliage, which severely weakens the signal strength due to shadowing, diffraction and absorption. According to the high elevation profile between the HMSs, PPTC, and BS, practically it is not feasible to establish a line of sight link between them. However, as a solution to enhance the RSS at the HMSs, we utilized high gain Yagi antennas at the HMS sides, and installed at a high elevation, where the antenna direction has been adjusted and tilted by utilizing spectrum analyzer that can maximize the receive gain from the antenna.

The drive test result provides valuable information on the best network operator that can be installed with the SIM card for each of the station. As examples, the cellular connection is reliable with Celcom SIM at Chini and Jemberau station. While for the HMSs that fall under 'poor' or 'no signal' (such as Merapoh and Melai), this is where the use of non-cellular network infrastructure is attractive, albeit several technical challenges need to be addressed in this research. For this paper, the use of LoRA wireless technology will be tested.

Low-Power Wide-Area Network (LPWAN) is designed to enable long range communications with low power utilization. It has received much attention as it is appealing for sensor and Internet of Things (IoT) applications. One such LPWAN technology is known as LoRa (Long Range). LoRa is the physical layer or the wireless modulation utilized to create the long range communication link. LoRa is based on chirp spread spectrum modulation, which operates at low power while significantly increases the communication range. LoRaWAN defines the communication protocol and system architecture for the network. The protocol and network architecture have the most influence in determining the battery lifetime of a node, the network capacity, the quality of service, the security, and the variety of applications served by the network.

Fig. 19: Elevation profile between PPTC (left) and Melai station (right).

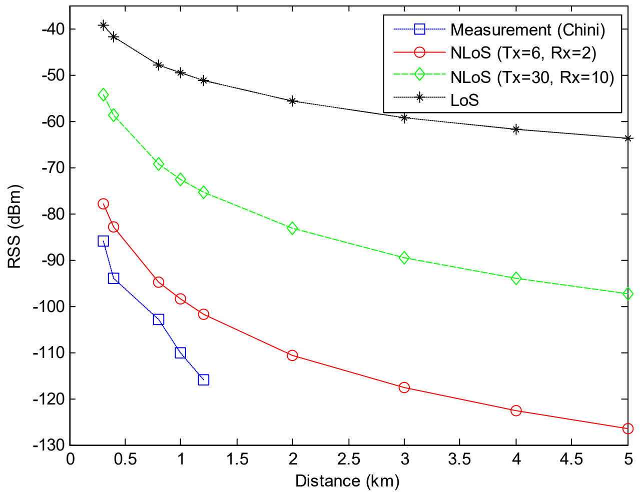


Fig. 20: Received power at seven different HMSs based on simulation and measurement

LoRaWAN performance evaluation has been conducted at Tasik Chini involving the following activities; installation of four sensor nodes, one gateway and server. The gateway is fixed at PPTC, while the sensor nodes are moved to evaluate the received signal strength (RSS) at various locations around Tasik Chini for different node-gateway separation distance. A boat has been used to move the nodes from one location (water station) to another water station. The data from sensor nodes are transmitted using 922 MHz frequency to the server at every 10 seconds.

The collected RSS data indicate that the transmission signal could reach Gumum (1.3km) and Kura-kura (1.1km) stations. However, the signal could not reach Sg Chini (3km) and Melai (2.5km) stations due to challenging propagation environment, as shown in Figure 19. Furthermore, the gateway was located at a relatively low height of 6 meters above the ground.

Comparison of RSS for actual measurement at Tasik Chini and different propagation models is shown Figure 20. The Line of Sight (LoS) model represents an ideal propagation condition, whereby there is no obstruction between the node and gateway. This is plotted for the purpose of comparison only and it is not the actual scenario in Tasik Chini, as the PPTC are surrounded by large trees and difficult to obtain LoS. NLoS propagation model based on Hata Model is given in Figure 19 for different transmitter (Tx) and receiver (Rx) height. Green diamond markers and red square markers represent the simulated configuration for Tx = 30m & Rx = 10m, and Tx = 6m & Rx = 2m, respectively. Both scenarios represent two potential deployment scenario that will be implemented in the near future for the LoRa network at the water stations. From the simulated results, the signal propagates better for high transmitter and receiver placements, whereby an improvement of around 25dBm could be achieved if the Tx and Rx heights are increased from Tx = 6m & Rx = 2m to Tx = 30m & Rx = 10m. Finally, from our experimental work, it is observed that the actual measurement at Tasik Chini is worse than NLoS Hata model for Tx = 6 & Rx = 2.

This study has successfully analyzed the limitations of 2G-powered HMS. It is found out the 2G wireless link is not reliable and is characterized by numerous technical issues, especially in rural area. Therefore, there is a need to migrate from 2G to 3G or Long Term

Evolution (LTE) network infrastructure. 3G/LTE focus around the TCP/IP protocol suite with the capability of supporting EWS, rural telemedicine and rural eco-tourism. There is also the various alternative wireless backbone for Tasik Chini hydrological center to be explored.

(4) Broader Impact

The impact of this project is useful in the context of enabling opportunistic use of the unutilized TV spectrum for rural and remote area communications. This will also directly increase the spectrum utilization efficiency. This project has demonstrated of emergency networking system utilizing TVWS to support more connected devices in the future and spectrum scarcity issue. Based on this TVWS experimental, we have evaluated propagation studies quantifying the effect of vegetation for TVWS spectrum.These applications are useful for people in rural areas as their daily life will be affected by any problem related to natural disaster. The implemented system provides ICT solutions to protect the environment and saves human lives.

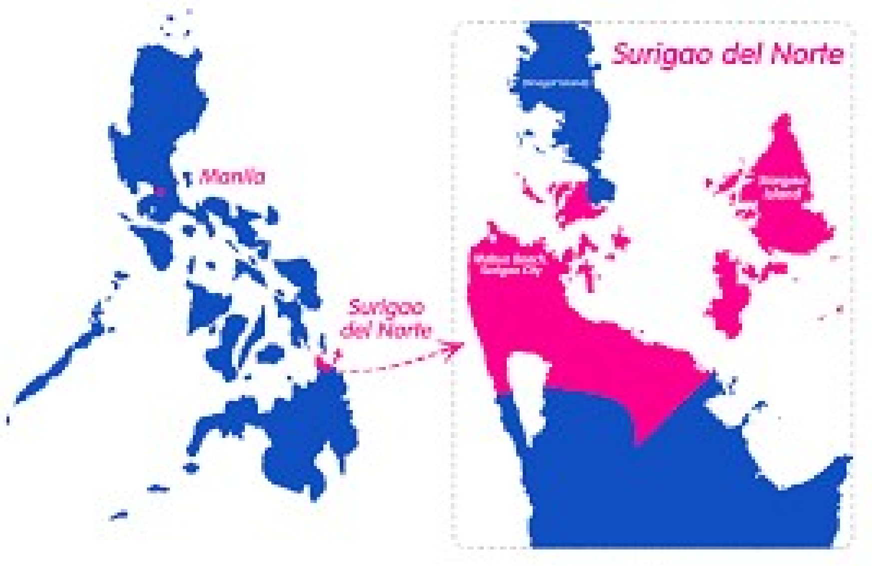
In the following, we will describe the measurements and activities that we have conducted to demonstrate the capability of TVWS technology to provide internet connectivity to remote area and as an emergency network during disasters.
Site: Bgy. Diaz Elementary School and other premises of San Francisco, Surigao del Norte
Duration: August 14 – 20, 2017

Surigao in general is said to be an earthquake hazard due to Philippine Trench and nearby active faults. Hence, the choice of the place as an experimental site for demonstrating the capability of TV white space for providing an immediately deployable and resilient form of ICT infrastructure. For this experiment, the NICT IEEE 802.11af prototypes will be used either as a single-hop or multi-hop network.

The specific experimental site is the town of San Francisco, a fifth class municipality in the province of Surigao del Norte, Philippines located about 731 kilometers from Manila. Based on the 2015 census, it has a population of 14,552 people. On 10 February 2017 at 10:03 PM Philippine Standard Time (PST), a magnitude 6.7 earthquake struck the Province of Surigao del Norte in northeastern Mindanao. Using the data from the Philippine Seismic Network (PSN) of the Philippine Institute of Volcanology and Seismology - Department of Science and Technology (PHIVOLCS-DOST), the epicenter was located in Surigao Strait at 9.80° N and 125.35° E or 16 km offshore northwest of Surigao City at a shallow depth of 10 km.

The earthquake was generated by the movement of the Philippine Fault - Surigao segment. The ground shaking was felt at PHIVOLCS Earthquake Intensity Scale (PEIS) VII (very strong) in Surigao City and San Francisco. This earthquake generated a 4.3 km surface-rupture that was mapped in Brgy. Ipil in Surigao City and Brgys. Poblacion, Honrado and Macopa in the Municipality of San Francisco, Surigao del Norte.

The following figures show some of the damage caused by the earthquake to the city of Surigao and municipality of San Francisco.


Manila
Surigao
del Norte
Surigao del Norte

In this experiment, two user case scenarios were considered: (1) Providing internet connectivity to a public elementary school via a point – to multipoint set – up and (2) extending internet coverage or connectivity utilizing the IEEE 802.11af technology via multi-hop set-up.

Experiment Setup, Results and Discussion

I. POINT-TO-MULTIPOINT CONNECTION (PtMp)

The IEEE 802.11af prototype developed by NICT Japan was used to establish a TVWS network between Brgy. Diaz Hall towards 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. Figure 21 and 22 show the topography and the elevation profile of the PtMp network, respectively.

The access point (AP) was situated at the Bgy. Diaz Hall where an internet connection is available (Figure 23). Moreover, as shown in Figure 24, 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. Moreover, the separation distance of the two STAs is about 12 meters. The developed PtMp network was a non-line-of-sight scenario with a hilly topography and high vegetation in between.

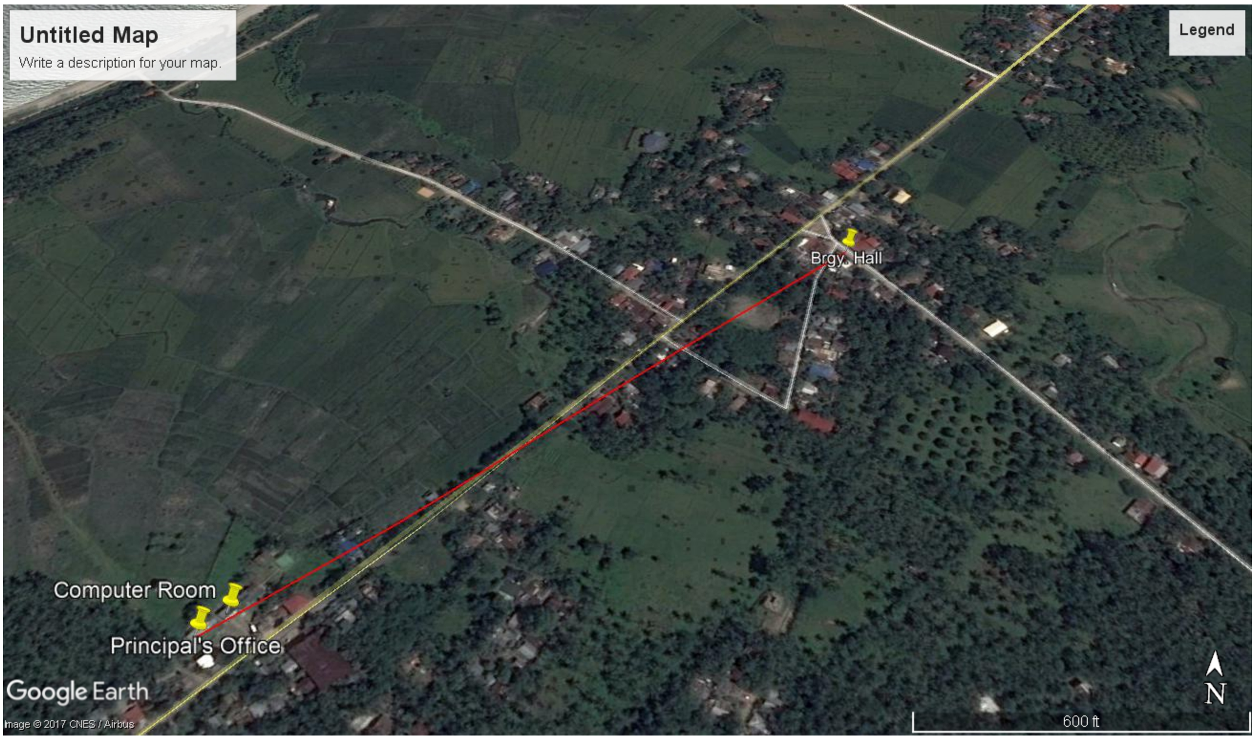


Figure 21. Topography of the PtMp Network

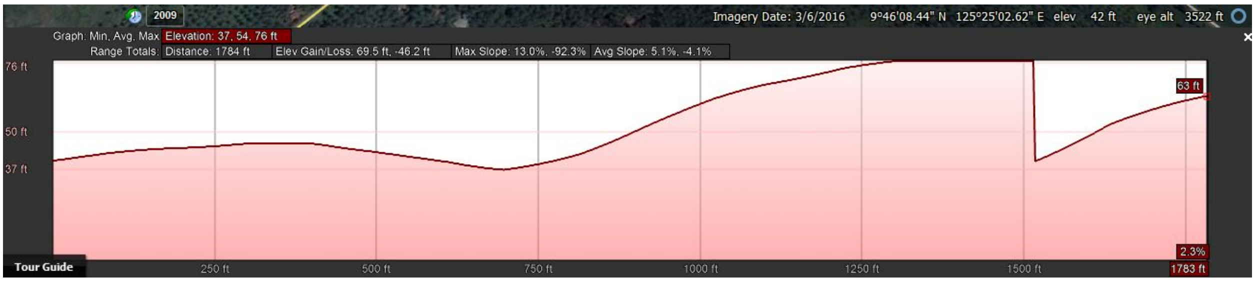


Figure 22. Elevation Profile between the AP (Brgy. Hall) to STA1 (Principal's Office)

A vertically polarized 12-element ring Yagi antenna with a height of 8 meters were used at the AP side (Figure 23). 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 24). The gains of these antennas were recorded to be 11.8 dBd and 5.5 dBd for the

12-element and 3-element ring Yagi, respectively.

Figure 23. Configuring the AP inside the Bgy. Hall and placement of the 12-element antenna at the floor just outside where the team has installed the AP.

Figure 24. Location of the two 3-element antennas for STA1 and STA2 at Diaz Elementary School

The experiment recorded the throughput performance of the system while the transmit power and the MCS settings were varied. Table 2 shows the PtMp performance of the developed system.

Table 2. 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
15	0	-92	0	0

20	3	-89	3.43	3.38
15	3	-91	0	0
20	5	-87	0	0
Station 2: Computer Room				
Antenna: 3-element				
Tx Power (dBm)	MCS	RSSI (dBm)	Downlink (dBm)	Uplink (dBm)
20	0	-88	1.22	0.764
15	0	-91	0	0
20	3	-89	3.56	0.235
15	3	-91	0	0
20	5	-89	0	0

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 STA 1. Based on the table, 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 STA 2 was only about 235 Kbps as compared to the 3.38 Mbps recorded at the STA 1. Furthermore, the same phenomena can be observed using MCS 0 wherein the uplink performance STA 2 was only 764 Kbps, way below than the 1.27 Mbps performance of the STA 1.

This inconsistency in performance is expected as both channels (AP to STA 1 and AP to STA 2) 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 experienced 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.

Figure 25. Showing connectivity between AP (Bgy. Hall) and STA1 (Principal's Office)

Brgy. 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 26. The host PC was run by windows multipoint server as its operating system. However, the e-classroom model can be further enhance through the integration of internet connectivity.

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.

Figure 26. Learning with the aid of internet connectivity

II. POINT-TO-POINT CONNECTION (PtP) (Multihop)

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 of 1,295 meters. The AP was still installed at Brgy Diaz 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 27 and 28 show the topography and elevation profile of the multi-hop network.

Figure 27. Topography between the AP and the relay station and the end station

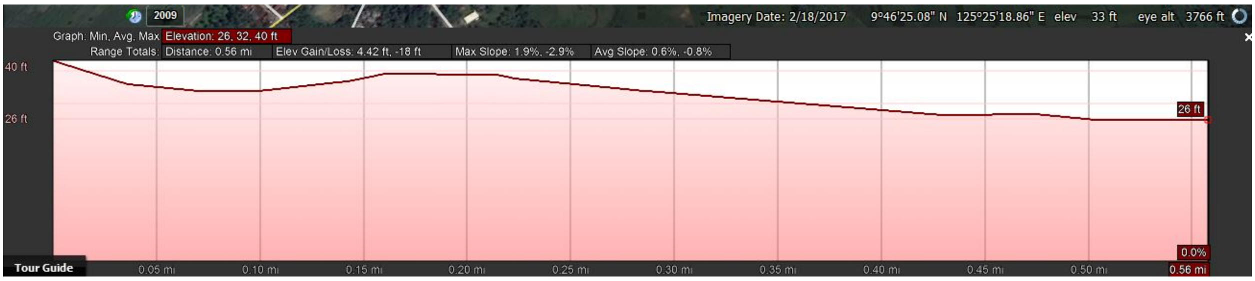


Figure 28. Elevation profile between the AP and the relay station

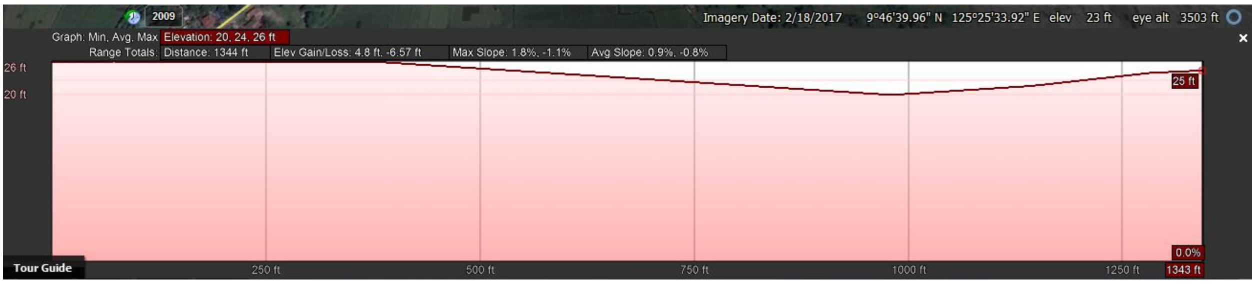


Figure 29. Elevation Profile between the relay station and the end station

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 were 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. The following table shows the performance of the system in a multi-hop network.

Table 3. PtP Througput Performance of the multi-hop network at different Tx power and MCS values

Tx Power (dBm)	MCS	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
20	5	-86	1.07	0	-72	4.92	4.61	1.07	0
15	0	-89	1.21	0.706	-76	1.39	1.35	1.21	0.706
15	3	-89	2.89	0.376	-76	3.6	3.36	2.89	0.376
15	5	-89	0	0	-77	0.47	0.423	0	0
10	0	-93	0.095	0.118	-85	1.43	1.32	0.095	0.118
10	3	-93	0	0	-85	3.5	3.55	0	0
10	5	no connection			-85	2.69	1.41	0	0
5	0	no connection			-88	1.36	0.811	0	0
5	3	no connection			-88	3.46	1.92	0	0
5	5	no connection			-89	0	0	0	0
0	0	no connection			-91	0.388	0.106	0	0
0	3	no connection			-92	0.188	0	0	0
0	5	no connection			-92	0	0	0	0

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 3, 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. The table shows that 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 Table 3 is in correlation with the radio environment which has a dense vegetation. Also, the over 1 km separation distance of hop 1 contributed to unstable connection as evident in the data with transmit power of 5 dBm and below.

Figure 30. Relay Station about 800 meters away from AP and about 400 m away from End Node

(5) Future Developments

Based on our previous experiments, we found that the main challenges are to address the thick foliage and various terrain profile that obstruct the propagation of the EM waves in the remote jungle area. These challenges limit the penetration and coverage to reach the water sampling stations that scattered across the lake area. In other words, higher elevation is the key to solve variable terrains & tall trees in rural wireless communications. The next plan is to increase the tower height or be innovative such as to experiment the use of the unmanned aerial vehicle (UAV), or drones.

Currently, UKM has applied for the research fund for an extension related to the use of UAV for rural wireless communication. The fund is under the Ministry of Higher Education (MoHE) and the decision is expected by the end of June, 2018. The next plan is to apply for an international fund, under the Ministry of Science, Technology & Innovation (MOSTI) to pursue further the idea of using UAV focusing on specific energy efficiency approaches to prolong the life of the UAV. To make sure the application for international fund a success, UKM and MIMOS still require commitment from NICT as the research collaborator. This can be done under the current Contract Research Agreement (CRA), which currently under extension by legal office.

The TV White Space technology (IEEE 802.11af) has so far been tested successfully in providing internet connectivity through multihopping (1) in a hilly terrain covering a distance of about 600 meters obtaining a maximum throughput of 4.81 Mbps and 4.93 Mbps for uplink and downlink, respectively, with a transmit power of 20 dBm and MCS 7 setting; and (2) in a relatively flat terrain that further extends distance coverage to a total of about 1200 meters with a maximum downlink throughput of 3.25 Mbps and 3.16 Mbps for uplink at a maximum power of 20 dBm and using MCS 3. The success has so far encouraged further deployment and testing of the prototypes to applications in vehicle – to – vehicle communications in semi-urban areas and the development of models for indoor and outdoor propagations. Moreover, a video conference software which supports local server setting, as opposed to cloud server based Skype, is needed to test the network when internet access is not available as the absence of internet and all forms of communications are actually a natural consequence of strong typhoons and earthquake thereby making the network indeed suited for such disaster scenario as envisioned to be one of the main applications of TV white space. The results of the study have so far been disseminated in a form or oral presentations both in and outside the Philippines.

iii) Social Contribution

This project has produced the following academic papers which was presented at international conference as well as invited papers:

- R. Nordin, H. Mohamad, M. Behjati, A. Kelechi, N. Ramli, K. Ishizu, F. Kojima, M. Ismail & M. Idris, "The World-First Deployment of Narrowband IoT for Rural Hydrological Monitoring in UNESCO Biosphere Environment," International Conference on Smart Instrumentation, Measurement and Application 2017 (ICSIMA), Nov 2017
- A.S. Bañacia & A. Montejo, "Implementation of a Multihop Network at the University Campus Using an IEEE 802.11af Compliant Network," International Symposium on Wireless Personal Multimedia Communications (WPMC), Dec 2017
- R. Nordin, H. Mohamad, M. Behjati, A. Kelechi, N. Ramli, K. Ishizu, F. Kojima, M. Ismail & M. Idris, "Internet of Things for Rural Hydrological Monitoring in UNESCO Biosphere Environment," International Symposium on Wireless Personal Multimedia Communications (WPMC), Dec 2017
- R. Nordin, H. Mohamad, N. Ramli, K. Ishizu, F. Kojima, M. Ismail & M. Idris, "Internet of Things for Water Quality Monitoring Application," IEICE Tech. Rep., vol. 117, no. 457, SR2017-116, pp. 31-34, Feb. 2018.

This project has also created awareness for stakeholders in Malaysia and the Phillipines about the benefit of TVWS for applications in rural areas, whereby the aim of this project is to enable positive social impact specifically focusing on environmental preservation and disaster communications.