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Project factsheet information

Project title	Long range community based hybrid wireless network in the Himalaya Region: TV White Space, Wi-Fi and VHF deployment and testing
Grant recipient	Nepal Wireless / E-Networking Research and Development (ENRD) Shivabhakta Marg 304, Lazimpat, Kathmandu Nepal Phone/fax: 977-1-4428090 Website: http://www.nepalwireless.net
Dates covered by this report	15 – 05 – 2015 / 30– 04 – 2017
Report submission date	30 – 04– 2017
Country where project was implemented	Nepal
Project leader name	Mahabir Pun, mahabir@nepalwireless.net
Team members (list)	Girish Adhikari (girish.adh@gmail.com), Niraj Acharya (niraj@nren.net,np)
Partner organizations	World Link Communication Pvt. Ltd., Hitachi Kokusai Electric Inc Japan, Asia Pacific Telecommunity, and the communities of Gorakha, Myagdi and Janakpur
Total budget approved	AUD29,050
Project summary	The project deployed a long-range hybrid wireless network in the villages near Manaslu Himalaya region of Nepal using Wi-Fi (2.4 GHz and 5.8 GHz), TV White Space (472 MHz to 698 MHz) and VHF (192.5 MHz to 202.5 MHz) band spectrums to bring broadband Internet for the villagers. This hybrid approached addressed limitations from each technology, such as clear Line of Sight (LoS), for example, in the case of Wi-Fi or tree obstruction, cloudy weather, among other variables. Nepal Wireless proposed to build a network using a combination of Wi-Fi, VHF and TVWS technology and use the experience to develop a comparative study among the three technologies regarding coverage, throughput, performance etc. The network is providing Internet access for telemedicine at community clinics and online education at community schools, as well as providing community access in the villages through hotspots. The project was delayed as the initially proposed sites were very close to the epicentre of the 25 April 2015 earthquake that hit Nepal and destroyed most of the schools and settlements where the project was going to take place and also because of the delays to be granted permission from the Nepali Authorities to use VHF and TVWS frequencies and import the necessary equipment. The project was completed in April 2017.

Table of Contents

Background and Justification

Even in the most developed countries broadband Internet is not available in many remote areas, so it is not surprising to know that is the case in Nepal. E-Networking Research and Development (ENRD) has been involved in building community wireless networks in the Himalayan villages of Nepal since 2002 after successfully connecting one village using simple indoor Wi-Fi routers and home built antennas. These activities were conducted under the Nepal Wireless Networking Project (NWNP) or Nepal Wireless for short. The initial goal was to use the community wireless network to use Voice over IP (VoIP) and navigate the Internet. There was not a single telephone available in those days in any of the rural areas of Nepal. Since then, we have learned step by step, how to use the network for other purposes such as for education, health, and local e-commerce purposes. Our initial plan was to connect only 10 mountain villages but as the demand grew, the wireless network has been extended to more than 175 villages of 15 districts of Nepal and we are still building community wireless networks.

Due to the very rugged nature of terrain and no road access to remote areas, optical fiber links are not economically feasible, only viable in densely populated urban areas. Wireless for rural connectivity is by far more affordable and the best option to get sparsely populated rural areas connected to broadband. That applies not only for Nepal but also for any remote rural area around the world.

Due to high costs associated with 3G/4G spectrum licenses and equipment, Nepal Wireless has been using unlicensed 2.4 GHz for the last mile connectivity and 5.8 GHz band for Point to Point (P2P) back haul link. Equipment for these bands is readily available locally and at much cheaper prices. Despite the affordability advantage, unlicensed bands have some limitations and disadvantages. Wi-Fi requires clear Line of Sight (LoS) so if there are is a tree, a hill or bad weather along the path of these radio waves, the signal strength decreases drastically. There are also limitations to the maximum distance for P2P links (around 60 KM for good connection). As more repeater stations were required to connect long range wireless link using 2.4 GHz and 5.8 GHz bands, the cost for building the infrastructure of community wireless network increases.

As we became aware of projects experimenting with TV White Space (TVWS) technology in rural areas in Africa, the United Kingdom and the United States, the idea of using TVWS in Nepal for solving the problems we are facing using unlicensed bands started to take shape, hoping that it would have better coverage and penetration in the sparsely populated mountain villages. TVWS refers to the unused broadcasting frequencies previously used by analog TV stations. Because most of the analog TV stations have moved to digital broadcasting system, the spectrum is becoming available. TVWS uses lower level frequencies, so theoretically it should have better penetration and wider coverage than the unlicensed spectrum. For this project, we are granted permission to use 460 MHz to 478 MHz on TVWS and 192.5 MHz to 202.5 MHz on VHF spectrum.

This report presents the findings of the pilot project that Nepal Wireless did in rural Nepal for rural connectivity to bring broadband Internet in remote villages. The project was completed in April 2017.

Project Objectives

The original objective of the project was to examine what could be achieved through the combined use of TVWS and Wi-Fi technology. Through the pilot project we had decided to do comparative analysis of Wi-Fi and TVWS to learn how effective and feasible the hybrid wireless network would be in terms of performance, power consumption, cost and coverage in remote and high mountainous region to bring Internet. As part of its impact, the project team planned to provide Internet to the villagers:

- to provide health services through e-learning and e-health services in the community schools
- to create job opportunities for the local population by promoting tourism in the region and by providing Internet in the lodges and along the trekking trails by creating hotspots along the trekking trails
- to provide Internet for the safety of the trekkers using tracking system

As equipment to use VHF bands became available to Nepal Wireless, the project was adjusted to include it in the deployment.

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Project Narrative

Nepal Wireless specializes in connecting remote villages of the Himalayan region of Nepal, located several walking days from the nearest city and highways. There are no commercial companies providing Internet services in any of those rural areas. Nepal Wireless first Wi-Fi deployment in the Manaslu region of Gorakha district was in 2013, although it has been the most challenging project with signal lost and not good coverage due to the narrow, windy and rugged valleys of the region. Two repeater stations were built. One at 4,200m in Dhorjung and a second one at 3,800m in Chaunrikharka. Around 15 villages in that region are indeed very difficult to connect with wireless links, and so the area was chose for the hybrid network deployment. The project team took a very yet practical approach for the project implementation, as follows.

Get advice from experts

As Nepal Wireless team knowledge about TVWS technology was very limited, the team discussed with several technical experts of wireless technology working in different countries around the world, with whom Nepal Wireless regularly exchanges information since mid 2000s. Expert contacted were Sebastian Büttrich (Research Lab Manager, IT University of Copenhagen); Steve Song (Network Startup Resource Center - NSRC); Ermanno Pietrosemoli (International Center for Theoretical Physics – ICTP); Gaurab Upaddhyaya (Limelight Networks, also Technical Director at ENRD) and Jonathan Brewer (Telco2/NSRC). They all offered valuable advice regarding the equipment available in the market, training required as well as sources to improve knowledge about implementation based on their own experiences.

Select the right equipment for the project

As TVWS technology is an emerging technology, and although there are companies producing the equipment, it is not widely available at a scale that makes it affordable. Nepal Wireless conducted an analysis and review of different equipment available that has been already tested in different parts of the world, in order to select the equipment for the project.

The decision was based on the advice from the experts above, availability, price and technical support available. Four TVWS equipment manufacturers were contacted and the specifications of their equipment reviewed: 6harmonics[1], Carlson Wireless Technologies[2]; Doodlelab[3]; Saankhya Labs[4]. It was decided to use TVWS equipment produced by Carlson Wireless Technologies.

During the review process, the team was also interested in a VHF Band Wireless radio unit produced by the Japanese manufacturer Hitachi Kokusai Inc. that uses the 172.5 MHz to 202.5 MHz band and has been tested it in Indonesia. Nepal Wireless received the equipment as a donation from Hitachi Kokusai Electric Inc. Specifications of the equipment are presented in Figure 1 and 2 below.

Partnership with other organizations

Nepal Wireless is working with many technical partners as well as receiving financial support to implement ICT projects and service rural areas. Partnerships are listed below:

[1] 6harmonics http://6harmonics.com/ Last accessed 30 April 2017
[2] Carlson Wireless http://www.carlsonwireless.com/ Last accessed 30 April 2017
[3] Doodle Lab http://www.doodlelabs.com/products/licensed-band-radio-transceivers Last accessed 30 April 2017
[4] Saankya Labs http://www.saankhyalabs.com/products/white-space-base-station Last accessed 30 April 2017

CarlsonWireless.com

CARLSON WIRELESS TECHNOLOGIES — BROADBAND AND VOICE PRODUCTS

RuralConnect® TV White Space Radio

FASTER SPEED, BETTER COVERAGE and LOWER COST
TV WHITE SPACE BROADBAND RADIO

Imagine rural broadband where it's never been before, bringing telemedicine, distance learning and residential connectivity to last-mile locations. RuralConnect uses vacant TV frequencies (TV White Space Spectrum : 470 to 698 Mhz domesically | 470 to 790 Mhz internationally) to bring wireless broadband to homes, businesses, and municipal sites. TV frequencies penetrate foliage and weave around hills and other barriers that render microwave or Wi-Fi inoperable.

FCC-Approved

The Federal Communications Commission (FCC) has certified the RuralConnect TV White Space (TVWS) radio system for use with the Spectrum Bridge TV White Wpaces database. This FCC certification brings to market an unparalleled ability to provide truly affordable long distance, non line of sight (NLOS) high speed wireless connectivity.

CLIENT STATION

BASE STATION

APPLICATIONS:

- Rural Broadband Internet Access
- Community Hotspot Backhaul
- Nomadic Broadband
- NLOS backhaul and middle mile
- VoIP/SIP Networks
- Video Surveillance & Security
- Mobile Command Unit
- Home Networks
- M2M SCADA Communications:
  - Smart Grid & Metering
  - Traffic Signal Communications
  - Oil & Gas Well and Pipeline Monitoring
  - Wind Farms

BASE MODEL NO.
6MHz : SRCIP-AP-RM-UHF-F
8MHz : SRCIP-AP-RM-UHF-F-8

SPLIT BASE MODEL NO.
6MHz : SRCIP-AP-ODU-UHF-F
8MHz : SRCIP-AP-ODU-UHF-F-8

CLIENT MODEL NO.
6MHz : SRCIP-CS-ODU-UHF-F
8MHz : SRCIP-CS-ODU-UHF-F-8

FEATURES:

The Beachfront Spectrum Advantage
The RuralConnect is a software-defined radio designed to support access to vacant television bands. In 2010, the FCC made these unoccupied TV channels available for unlicensed broad-band with range and propagation superior to microwave.

Greater Throughput, Lower Latency and Higher Reliability
With data speeds up to 20 Mb/s (16 Mb/s US) OTA, the RuralConnect offers the throughput necessary for today's Internet needs. Advanced receiver technology blocks nearby high-power cellular TV signals from interfering. Examples of different distances and modulation settings to show thoughputs and link margin are shown on a chart on the back.

Multiple Applications
The RuralConnect can be used to create point-to-point and point-to-multipoint networks.

Remote Management and Diagnostics
The RuralConnect is operated over an easy-to-use, comprehensive browser-based GUI management system that provides a centralized platform for efficient and securely managed network operations.

Better than 900MHz
TV White Space offers up to 220MHz of new spectrum to help alleviate the advance of 900MHz smart meters.

Base Available with Indoor or Split Mount Cabinetry
All indoor: Typically installed in building or outdoor cabinet, this model incorporates the radio in the rack mountable enclosure. This a typical configuration for backhaul radios.

Split mount option: To eliminate RF cable loss, a split base option is available. This includes a pole-mountable ODU and a rack mount cabinet. This special configuration is beneficial because it shortens the distance from antenna to radio through the RF Coax Cable, which increases throughput.

Split Mount Configuration
Omni Antenna
RF Coax Cable
Radio
Ethernet Cable
Base Station

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2700 Foster Avenue
Arcata, CA 95521 USA

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F: +1 707.822.7030
E: info@carlsonwireless.com

Hitachi Kokusai Electric Inc.
32, Miyuki-cho, Kodaira-shi, Tokyo 187-8511, Japan
Tel: +81-50-3383-3482 Fax: +81-42-322-3270

1. Product specifications

Item No.	Item	Specifications	Comments
1	System standard	ARIB STD-T103	To be included in IEEE802.22b
2	Range of available frequencies	VHF 172.5~202.5MHz	
3	Channel bandwidth	5MHz	
4	Occupied bandwidth	4.9MHz	
5	FFT size	1024	
6	Subcarrier spacing	5.47kHz	
7	Multiple access / Duplex	OFDMA / TDD	
8	Frame duration	10msec	
9	Modulation method	QPSK, 16QAM, 64QAM	
10	Coding scheme	Convolutional Turbo Code	
11	Coding rate	1/2, 2/3, 3/4	
12	Maximum throughput	Uplink: 8.0Mbps	Obtained by setting higher priority to uplink.
		Downlink: 10Mbps	Obtained by setting higher priority to downlink.
13	Antenna interface	Type-N connector (impedance: nominal 50Ω)	
14	Transmission power	≤1W	
15	Diversity function	Receiver diversity (maximal ratio combining)	
16	Dimensions (mm)	Approx. 240(W) x 300(H) x 130(D)	
17	Weight	≤6kg	
18	LAN interface	100BASE-TX	
19	Cooling system	Natural air cooling	
20	Power supply	DC13.8V±10%	
21	Power consumption	≤80W	
22	Range of ambient temperature	-10°C~+50°C	
23	Ambient humidity	90% (25°C)	
24	Vibration	JIS C60068-2-6 Standard	
25	Waterproof	JIS C0920-2003 IPX4 Standard	
26	Display function	Status indication with external LED	

Figure 1 and 2. Technical specifications of equipment selected

- Nepal Wireless has been working with Open Learning Exchange Nepal[5] since 2008 to develop interactive educational content and a digital library in Nepali language that benefit community schools in the villages. Mahabir Pun, Nepal Wireless leader, is a founder member of the organization.

- Collaboration with the Public Health Concern Trust[6] started in 2004, to deliver health programs that cover e-learning and deliver e-health services to schools and clinics that are part of this pilot project as well.

- World Link Communication Pvt. Ltd is one of the largest Internet Service Providers in urban areas in Nepal. They are lon standing technical partners of Nepal Wireless providing bandwidth at a discounted rate, as well as technical support. For this pilot project, the connection to the Internet is established through their POP in Gorakha Bazaar.

- Hitachi Kokusai Electric Inc. donated the VHF band equipment for use in the range of 172.5 MHz to 202.5 MHz as well as the shipping costs, valued at US$33,000. They also provided technical support with two engineers onsite to assist during the testing. Nepal Wireless paid for customs and duties to import the equipment. They were interested to continue testing their equipment, as they had successfully used the equipment in Japan as well as in Indonesia in non-Line of Sight environments.

[5] Open Learning Exchange Nepal. http://www.olenepal.org Last accessed 30 April 2017.
[6] Public Health Concern Trust. http://phectnepal.org Last accessed 30 April 2017.

- Nepal Wireless received a grant from the Asia Pacific Telecommunity (APT) to build community wireless networks using Wi-Fi and TVWS technology in some of the villages of Gorakha, Dhading and Sindhupalchok districts, and the project is currently underway, building on the results of the ISIF Asia grant. The APT grant focuses on the deployment of Wi-Fi hotspots where the ISIF Asia grant supported the deployment of TVWS base stations. APT grant will also support more testing on TVWS technologies and to expand the network to about 15 villages. ENRD is an affiliate member of the Asia Pacific Telecommunity.

Build infrastructure for testing

Nepal Wireless built the following infrastructure in the Laprak valley area of Gorakha, Sindhupalchok and Myagdi for testing TVWS links in the villages.

a. To bring Internet from the nearest city (back haul) of Gorakha Bazar, three relay stations were built on the top of the mountains at Bhachek, Gumsipakha, and Yamgaun of Gorakha district, and Nagarkot of Bhaktapur using 5.8 GHz bands for Point to Point links. The back haul link to Gorakha to Mohare of Myagdi using 5.8 GHz was already in place when the project started.

b. Base stations for testing TVWS in different terrains (mountains as well as in plains) were built at Mohare (Myagdi district); Yamgaun (Gorakha district) and Janakpur city in the southern plain area of Nepal. From the Mohare TVWS base station the technical team of Jiban Phagami and Pritam Pun tested the links to Thaban village, Aula village, Rima Village, Chinar village, Nangi village, in none line of sight (nLoS) and LoS environment. The base station was set up at Mohare at an elevation of 3,310m and the villages were located in the range of from 1,500m to 2,300m. The summary of test results is as follows.

Test Result of Carlson TVWS Link Testing In Mohare (Myagdi district)							
Test Site No.		Name of the Site	Coordinates	Elevation (m)	Aerial Distance (KM)	Link Result	Remark
S.N.	Base Station	Mohare	28.371386°, 83.678978°	3,310	0	Signal Status	
1	Test1	Aula School	28.413590°, 83.615316°	1,550	7.78	No Link, 1 led light on	Non LoS
2	Test2	House Above Aula Village	28.414926°, 83.615619°	1,635	7.85	No Link, 3 led lights on	Near LoS
3	Test3	Rima WiFi Relay	28.409542°, 83.630078°	1,920	6.39	Linked, Internet received	LoS
4	Test4	House Above Rima School	28.407742°, 83.630061°	1,837	6.26	Linked, Internet received	Near LoS
5	Test5	Rima School	28.406862°, 83.629072°	1,734	6.25	No Link, Only 2 led lights on	Non LoS
6	Test6	Karpakeli Temple	28.394744°, 83.615997°	2,331	6.70	No Link, Only 2 led lights on	Near LoS
7	Test7	Chinar Village	28.391182°, 83.619651°	2,360	6.23	Linked, Internet received	LoS
8	Test8	Thaban Village	28.372710°, 83.651312°	2,209	2.73	No Link, Only 2 led lights on	Near LoS
9	Test9	Nangi Lodge	28.370936°, 83.639444°	2,335	3.88	Linked, Internet received	LoS
10	Test10	Pakha, Nangi	28.370138°, 83.639653°	2,330	3.95	No Link, Only 3 led lights on	Near LoS
11	Test11	Aunte, Nangi	28.363930°, 83.636642°	2,256	4.24	No Link, No led lights on	Non LoS

From the Yamgaun TVWS base station, the team of Surya Subedi, Niraj Acharya, and Sherbahadur tested the links to Khoralabensi, Machhakhola, Khanigaun, and Lapu villages in none line of sight (nLoS) and LoS environment. The summary of the test results has been given in the following table.

Test Result of Carlson TVWS Link Testing in Yamgaun (Gorakha district)							
Test Site No.		Name of the Site	Coordinates	Elevation (m)	Aerial Distance (KM)	Link Result	Remark
Base Station Yamgaun			28.203461, 84.854615	1,960	0.00		
1	Test1	Machhakhola-Near School	28.2292, 84.873195	870	3.50	No link light, no signal reception	Non LoS
2	Test2	Machhakhola- Budhigandaki Pari	28.2314667, 84.874511	845	3.80	No link light, no signal reception	Non LoS
3	Test3	Khorlagaun, Saatkanya School	28.243784, 84.867408	1,644	4.70	No link light, no signal reception	Non LoS
4	Test4	Khorlabesi, near Tatopani School	28.255020, 84.884015	896	6.40	Linked, One RSSI glow, and 2nd one blinked, Network received	LoS
5	Test5	Lapubesi, Prabhat Kiran School	28.183681, 84.877764	820	3.17	No Link, Only 1 RSSI blinked.	Non LoS
6	Test6	Khanigaun, Gorkhkali School	28.194691, 84.858156	1,570	1.00	Linked, All four RSSI lights on. Network was accessed from CPE	LoS
7	Test7	Lapugaun, Kaalratri School	28.181709, 84.858397	1,787	2.44	Linked, Two RSSI on and 3rd was blinking, Network was established.	LoS
8	Test8	Lapsibot1, School	28.212780, 84.861707	1,706	1.16	No link, only one RSSI on.	Near LoS
9	Test9	Lapsibot2, near to School	28.212540, 84.859621	1,689	1.15	No link, 2 RSSI on.	Near LoS
10	Test10	Lapsibot3, near to School	28.212147, 84.859429	1,700	1.16	Linked, 3 RSSI on and network was accessed from CPE	LoS
11	Test11	Gumda School	28.194603, 84.823197	2,273	3.33	No link light, no signal reception	Non LoS

From the initial test results of the performance of Carlson TVWS devices collected from Myagdi and Gorakha districts, it has been found that the performance is good in Line of Sight environment. However, the reception of the signals is poor in near Line of Sight (near LoS) situation. The test show there was almost no reception in none Line of Sight environment.


Backhaul Link in Laprak from Bhackek


Lapsibot Base Station of Carlson TVWS


Carlson Omni Antenna in Mohare


Carlson Base Station in Kholara


Carlson Base Station in Janakpur


Carlson CPE Station in Babhangawa

The following table shows the test results done in plain area of Janakpur city, where the test in plain terrain was conducted. The elevation of the area is below 100m but there are lots of trees.

Test Result of Carlson TVWS Link Testing in Janakpur city (Plain Areas)						
Test Site No.	**Name of the site**	**Coordinate**	**Aerial Distance (KM)**	**Elevation (m)**	**Link**	**Remark**
Test Site 1	Bhanuchok / Bench test				Linked with Station. Found all RSSI of all Radios illuminated	
	Base Station(Sita Chok, Janakpur City)	26.734526, 85.934983	0	80		
Test Site 2	Belahi Health Clinic	26.75969, 86.02049	9	90	Poor link, Single RSSI Led Illuminated, could not connected to another modulation	Near LoS
Test Site 3	Laliya School		10	96	Linked with very poor link. Found one RSSI illuminated	Near LoS
Test Site 4	Baghchura	26.76062, 85.99614	8.3	88	Found one RSSI illuminated and second one was blinking	Near LoS
Test Site 5	Belahi Health Clinic	26.75969, 86.02049	9	98	No signal found after reinstalling the antenna as Carlson Team suggested	Near LoS
Test Site 6	Babangawa		4	76	Found two RSSI illuminated and third one was blinking	LoS

From the above test results in Janakpur, the performance of the devices was not as good as we had expected. Our assumption was that the reception at the CPE site would be much better in the plain areas than in the mountain terrain because of the low vertical altitude difference between base station and CPE in the plains. Testing is continuously being conducted, to tweak equipment and setting to improve performance. Carlson devices were also tested in Kathmandu, which is a city with dense population and large buildings. The following are the pictures of the base stations set up and some of the tests done in Janakpur.

Carlson CPE at Janakpur

Carlson CPE at Bagchauda

Carlson CPE being raised at Bagchauda

Carlson CPE at Belhi

Carlson Base Station Set up at Kathmandu

Carlson COE set up at Laliya School

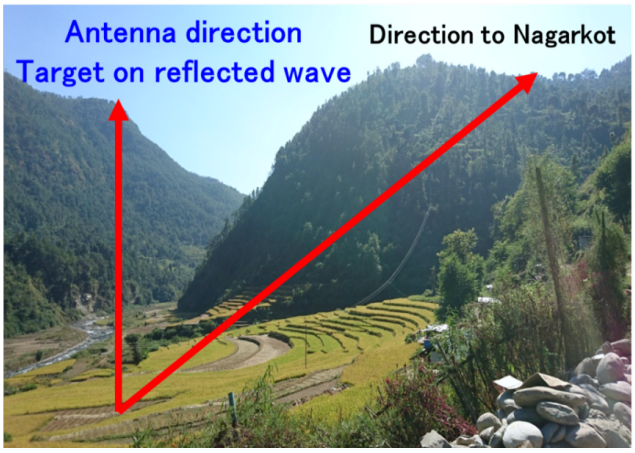
c. A base station at Nagarkot was built to test the VHF equipment and establish the link to Jholunge village (Sindhupalchok district). The following table shows the statistics of radio connection. By setting the modulation and coding scheme (MCS) as QPSK 1/2, the throughput of uplink and downlink was obtained at 2 Mbps and 400 kbps, respectively, which enabled the network access.

Statistics of VHF radio connection from Nagarkot to Jholunge			
	Items	Downlink	Uplink
1	Burst RSSI [dBm]	-71	
42	Throughout [kbps]	2217.14	18.76
53	CINR [dB]	9	6
64	MCS and Coding rate	QPSK 1/2	QPSK 1/2

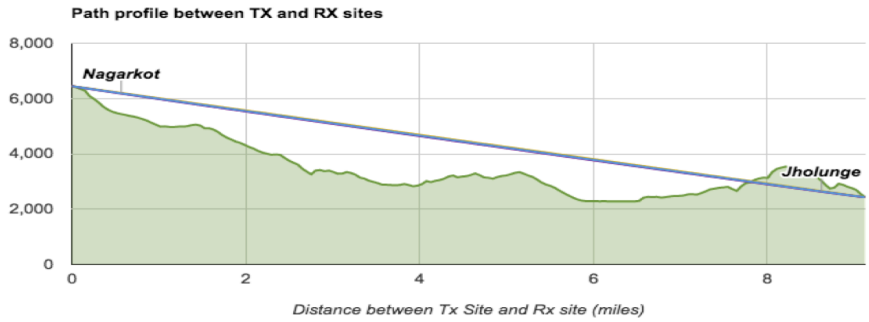
Also the following photo shows how the VHF signals were received even in none LoS situation, by pointing the antenna toward the hill on the left of Jholunge, demonstrating that the Hitachi VHF equipment also works for none line of sight connection as well. After testing the link for two months in Jholunge, we have moved the base

station at Golabhanjyang (Dhading district) and establish the link to Lapu and Ree village (Gorakha district) to continue testing with very good results.

Hitachi VHF Set up in Nagarkot



Hitachi Receiver at Jholunge showing path



Path Profile between Nagarkot and Jholunge

Community involvement

Nepal Wireless knows from a decade of experience how important is to get the beneficiaries of a project involved from the very beginning. This is a key aspect that guarantees smooth operation and long-term benefit. Their involvement is required to achieve both technical and financial sustainability. For the network to be technically sustainable, it is necessary to train local people for repairing and maintaining the local network. For financial sustainability, a network management committee must be in place, fully responsible for operating the network, covering maintenance and operation costs.

The beneficiaries of the pilot project are students, teachers, health workers as well as the farmers of the villages. During the implementation period, villagers were required to engage people interested to learn and install wireless equipment. They were trained on how to configure, install and operate wireless equipment including Wi-Fi routers, access points and hotspots as well as the solar power backup system. We also train them how to protect the devices from lightening or power surge.

During the implementation period, the project team did not identified or received reports about any gender or ethnic discrimination regarding the project activities that prevented anyone from benefitting of the technology

installed. However, there is going to be generation gap for sure. It is mostly the younger generation, who are excited much more than the older generation to have the Internet in their villages. The project team is composed by only men, and no women participated in the technical deployment of the project.

Main challenges for project implementation

There were two main challenges – the earthquake and the delayed permission from the government to use and import the TVWS equipment.

Nepal was hit by earthquake of 7.8 magnitudes on April 25, 2015. The epicenter of the earthquake was just 10 Km from the proposed sites of Manasalu region of Gorakha district where we had planned to implement the project. Then, landslides all over the trails and monsoon rain make the villages impossible to reach. Reconstruction has been slow and it was dangerous to travel with the equipment and other accessories in some parts of the trail. Therefore, Nepal Wireless had to change some of the proposed sites of the project implementation. Two years have passed, and most of the villagers are still living in temporary shelters, with schools and health clinics in that region running in temporarily buildings.

The Telecommunication Authority of Nepal was in the process of reviewing their national broadband policy when we had applied for permission to use VHF and TVWS frequencies. Only after the policy was finalized, we were able to apply for the permission and it took more than six months to get the permission to use 460 MHz to 478 MHz band of TVWS and 192.5 MHz to 202.5 MHz of VHF band. Once that was granted, a few more weeks were required to get permission from the Ministry of Commerce to import the equipment. This is the first time, TVWS technology has been used in Nepal.

Indicators

Due to earthquake, remoteness, and weather locations for testing were changed. The original plan was to test the TVWS in Nubri and Chung valley of Gorakha. After the earthquake, we changed the plan and decided to do in Laprak valley of Gorakha and Mohare region of Myagdi. We decided to do the link testing in different mountain terrains and environment as well as in the plain areas in the southern part of Nepal. We also planned to connect more villages, do more testing and built Wi-Fi hotspots after we got additional funding from APT to provide Internet access to some more earthquake hit areas.

Indicators	Baseline	Status	Assessment	Course of action
Back haul connections establish to link pilot project locations to the Internet.	No broadband connection. Partial mobile coverage.	Completed.	Back haul link using 5.8 GHz radios to bring Internet from Gorakha bazaar to Bhachek established in four months, completed by November 2016.	Testing and use.
The maximum distance TVWS devices will cover for Point to Point and Point to Multi Point link.	No TVWS equipment in use on the selected locations.	Maximum distance in P2P environment was about 10KM in mountain areas. Distance covered in plain areas with lots of trees was around 5 KM.	TVWS base station built in Mohare. Tested link to Thaban, Rima, Kaphhaldanda and Aula villages completed in January 2017. Poor performance in non-LoS environment. Out of 7 villages in Laprak valley tested, TVWS+WiFi link successful to 4 (Singla, Khorla, Lapu, and Kanshigaun) in LoS environments with 6KM in coverage. Completed in March 2017. TVWS link tested (plain areas) Janakpur district completed in April 2017. Signals received at a distance of 10Km but no Internet connection established.	Testing and use.
The coverage in diameter TVWS devices will have in non-Line of Sight environment.	No TVWS equipment in use on the selected locations.	The coverage in near non-Line of Sight environment was about 5KM. No link in any non-Line of Sight environment.		Testing and use.
The maximum numbers of users one TVWS Access Point can have in Line of Sight and non-Line of Sight environment.	No TVWS equipment in use on the selected locations.	Tested four links per one base station. The links were good in LoS, not so good in near LoS and no Link in non-LoS environment.		Testing and use.
The coverage of VHF band for point to point link in non-Line of sight environment.	No VHF equipment in use.	Completed.	Test link from Jholunge village of Sindhupalchok using VHF devices in by November 2016.	Testing and use.

Project implementation

Project activities	Input	Outputs	Timeline	Status
Technical team visited Sirdibas, Philim, Bihi and Nubri villages. After the earthquake, villages in lower parts of Gorakha in Laprak region were visited to discuss with the villages for need assessment.	Collected information about existing situation of the villages and contact information of village leaders to engage	Villagers were supportive to work with the implementation of the project as they were interested to get Internet connectivity	Initial site visits conducted April 2015. Postponed after the earthquake and remaining visits conducted in November 2015	Communication discontinued due to the earthquake. Temporary trail was built in November 2015 that allowed limited access.
Selection of equipment for TVWS and VHF	Experts helped to identify and assess TVWS devices in the market, to find pros and cons and supported decision-making. A study visit to Hitachi Kokusai Electric Inc. in Tokyo Japan (wireless radios VHF band 170.5 MHz to 192.5 MHz) lead to a cooperation agreement signed.	Decision to use Carlson Wireless equipment was reached. Hitachi Kokusai Electric Inc. donated equipment worth US$33,000 and technical support by two engineers that travel to Nepal to train project team.	Between June 2015 to September 2016	Carlson equipment bought, imported and installed in Nepal during Q1 2017. Training received in Q1 2017. Hitachi Kokusai Electric Inc. equipment dispatched, imported and installed in Nepal in Q3 2016.
Requests to Ministry of Information and Communication and Nepal Telecommunication Authority for permission to use TVWS and VHF devices for the pilot project.	Submitted formal application requesting the government for permission to use the TVWS technology in Nepal.	Permission to use 460 MHz to 478 MHz of the TVWS and 192.5 MHz to 202.5 MHz was received.	Applied in February 2016 and received permission in September 2016.	Permission to use the TVWS and VHF frequencies were granted during the pilot project period.
Required equipment import permission from the Ministry of Commerce.	Went through the official process to get the permission to import equipment and ordered equipment.	Received the permission to import the equipment	September 2016	The equipment ordered after the paper works were done.
Hitachi prepared shipment of donated VHF equipment.	Equipment was shipped by cargo to Nepal.	Freight charge paid by Hitachi. Nepal Wireless paid custom and duties.	October 2016	Equipment received and cleared from customs.
Import Carlson TVWS equipment.	Carlson shipped equipment to Nepal	Carlson equipment arrived in Nepal.	October 2016	Equipment received and cleared from customs.
Training on VHF and TVWS for Nepali engineers planned in Kathmandu.	Training scheduled, and team members selected to receive training.	Seven team members trained in Kathmandu.	November, 2016	Training completed.
Construction of base station for Hitachi VHF link in Nagarkot and receiver link in Jholunge.	Nepal Wireless and Hitachi technical team travel with equipment.	Set up base station in Nagarkot and receiver station in Jholunge.	November 2016	Link between Nagarkot and Jholunge (VHF) established and testing successfull for two months.
Construction of base station for Carlson's TVWS devices in Myagdi, Gorakha and Janakpur.	Built TVWS base stations in Mohare of Myagdi, Yamgaun of Gorakha and Janakpur	Tested TVWS links from Mohare of Myagdi, Yamgaun of Gorakha.	In February. March, April, 2017	Carlson TVWS deployment completed and underway.
VHF link in Dhading district.	Built base station at Golbhanjyang of Dhading.	Link test done to Lapu village.	March 2017	Testing underway.

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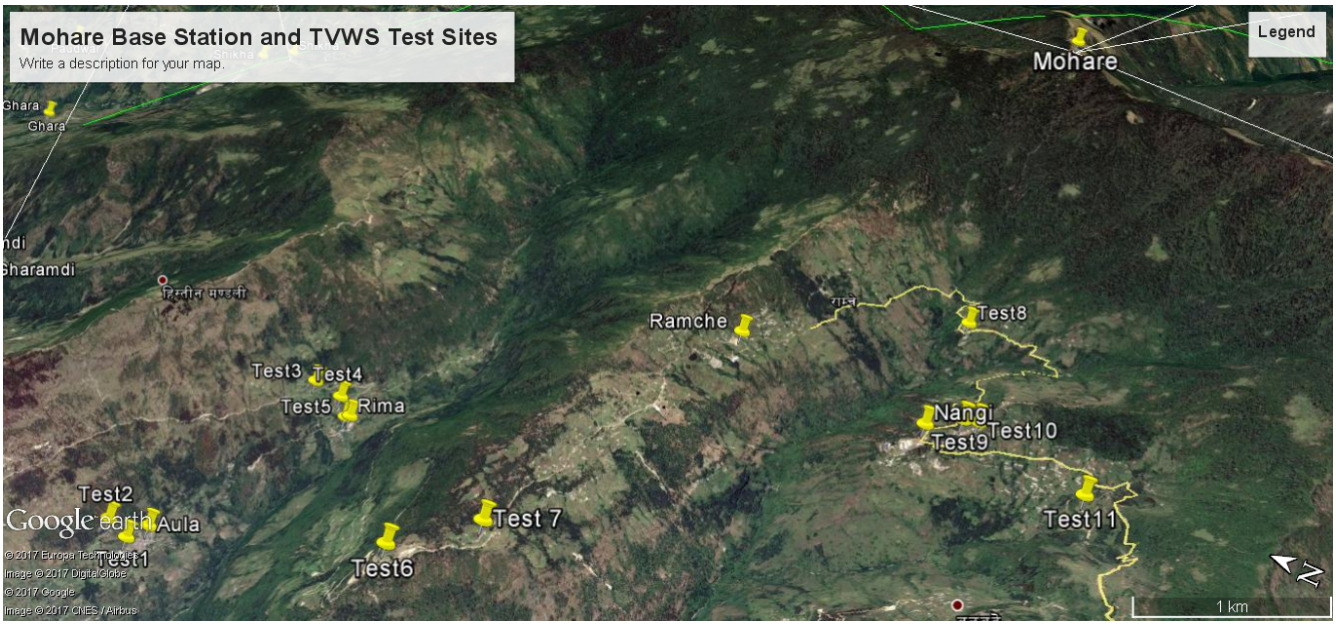

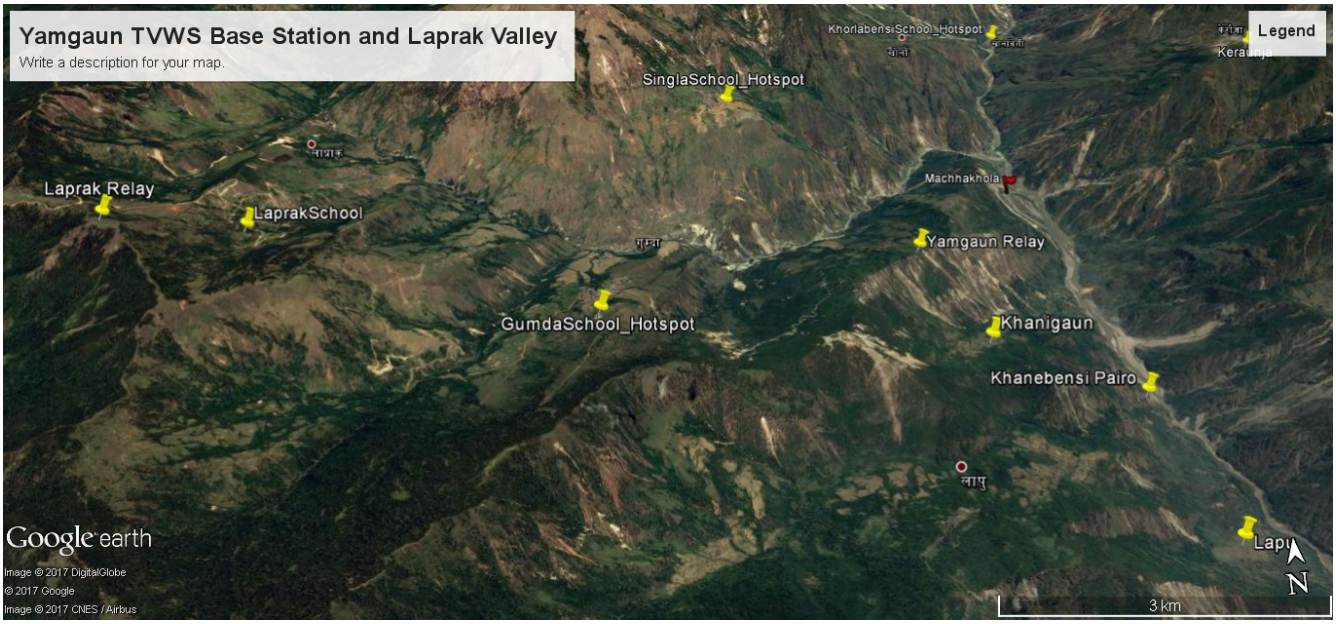

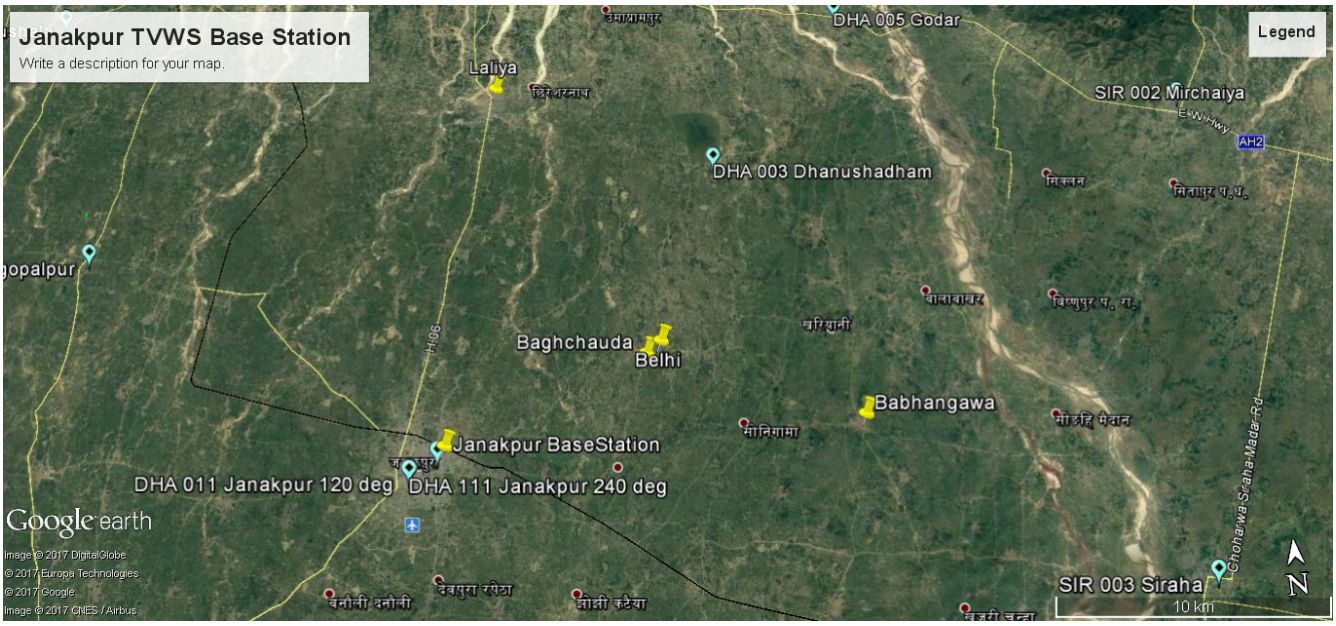

Communication and dissemination

Most of the area that Nepal Wireless serves is rural and remote, where most of the people are subsistent farmers from different ethnic backgrounds, marginalized and disadvantaged. Those that have been able to secure jobs and generate income most times migrate to the larger cities in Nepal or migrate overseas. As a result, the majority of the people staying in the villages are school age children, women, and older people who are left behind.

Conscious of that situation, Nepal Wireless has traditionally disseminate information, examples and ideas about how the people in this isolated, rural and remote communities can benefit from information and communication technologies, increasing awareness. The villagers want their children to get access to a better education, so they are supportive of the work we are doing to bring Internet in their villages. Once we bring Internet in one village, the news spread very fast and people from the neighbouring villages also come asking for help to bring Internet in their village. Based upon our experience, we can tell that communicating with the villagers and disseminating the benefits of the technology is not difficult. In most cases they are already motivated and are ready to provide support for the project.

Nepal Wireless strategy with the younger generation uses Facebook, Viber, and Skype as well as email. Nepal Wireless also teaches students and teachers how to search and retrieve educational materials from the Internet and provide training for the villagers of Gorakha in the area of e-education, e-health and e-commerce.

Project Management and Sustainability

Deployment of the wireless network is much easier than managing it and making it sustainable. For the technical implementation and management of the project, Nepal Wireless has a core technical team of eight people, that have a minimum of two years working at Nepal Wireless, who has deployed several Wi-Fi networks in the past. The technical team ensure for the technical sustainability of the project. Lead by Mahabir Pun, Girish Adhikari is the network and system engineer that oversees Nepal Wireless projects. The names and responsibility of rest of the technical team are as follows. All team members are males.

1. Prabal Lama, Field Supervisor (responsible for maintenance)
2. Pritam Pun, Network installation, solar power installation, maintenance
3. Surya Subedi, Site monitoring, system administration

4. Niraj Acharya, Network technician
5. Sherbahadur Pun, Technical Assistant
6. Jiban Phagami, Network technician

Besides this core technical team, Nepal Wireless has the support of local technicians living in the communities served, trained by our technical team and capable of troubleshooting and performing maintenance tasks.

Nepal Wireless supported Girish Adhikari to receive TVWS training in Tokyo (Japan) in November 2016. The training program was provided for three weeks by Japan Telecommunications Engineering and Consulting Service (JTEC). Upon his return, he was able to to train other team members on how to use the new technology. During the first semester of 2017, Carlson Wireless send an engineer to Nepal to expand on the knowledge for the team and the local technicians around their equipment, and troubleshooting.

Hitachi Kokusai Electric Inc. sent three engineers in November 2016 to Nepal to provide training for three days to our engineers on the VHF devices. The Japanese engineers also went to Jholunge village to make the first link from Nagarkot with VHF devices.

Regarding the sustainability of the project, it is important to highlight that the reason why there is no presence of broadband Internet Service Providers in rural areas, is simply because the investment needed to build the physical infrastructure to bring Internet in sparsely populated area to a limited number of users does not make the financial returns the companies are expected to have so they cannot justify the investment.
In this scenario sustainability is the most important issue any rural Internet service provider like Nepal Wireless has to maintain. Otherwise, the community networks in the rural area would collapse after some time due to the lack of financial resources. However, it is not an easy task to make rural community networks keep sustaining for a long time.

ENRD has learned how to make rural Internet services sustainable in its own way. The key is that the rural wireless network has to be owned and managed by the local communities. ENRD has more than 10 years of experiences for building wireless network in rural areas to bring Internet and make it sustainable. In order to pay for the operation and maintenance cost, the community centers, individual users, local businesses, rural schools and rural clinics are paying reasonable monthly connectivity cost of about USD10 to USD30 per month depending upon the bandwidth they use. The monthly fee will be used to pay for the Internet bandwidth cost and to provide incentive to the technical support team. Most of the local technical support teams come from the rural areas whom we have trained to troubleshoot and maintain the network.

The same idea as mentioned here is implemented in the new pilot project to build community based wireless network and make the project sustainable.

Project Outcomes and Impact

It has been already explained that affordability was the main reason why Nepal Wireless has been using unlicensed spectrums. As mentioned earlier, the major limitation is that 2.4 GHz and 5.8 GHz requires clear Line of Sight (LoS) for connectivity. If there is a small obstruction such as trees, houses, etc, the wireless signal gets interrupted to the device at the other cannot connect. To explore ways to overcome these problems, this pilot project was set to build a community base hybrid wireless network using TVWS and Wi-Fi spectrum. Later, VHF spectrum was also added, as equipment was donated. The expectation was that the TVWS and lower level frequencies would have better penetration than the 2.4 GHz and 5.8 GHz bands making the rural broadband connectivity better.

The results so far are not considered final, as testing is still been conducted and it is too early to tell how effective TVWS and VHF bands are for rural broadband connectivity, as TVWS is an emerging technology. The following are some early test results as the outcome of this pilot project:

1. This is the first time that the Nepal government granted permission to use TVWS spectrum, although it was a lengthy and frustrating process, it will open a new window of opportunities for wireless Internet Service Providers in the rural areas of Nepal. Although the permission has been granted for limited time to Nepal Wireless, we continue to lobby with the government to make the spectrum available for all rural Internet Service Providers as TVWS technology continues to develop.

2. Nepal Wireless technical engineers received training about TVWS and VHF technology and were able to deploy it for testing to provide rural connectivity. As the testing continues in different locations, practical learning required for implementation and deployment continues as well.

3. The performance of VHF broadband technology developed by Hitachi Kokusai Electric Inc was quite impressive because we could establish links even with a hill in between two points. The signal was actually reflected by a mountain slope. The results were similar is two tests conducted in two different locations.

4. The initial test result of the Carlson devices using TVWS frequencies in the range of 460 MHz and 478 MHz were not as good as what we had expected. In most cases we could make good link in the Line of Sight (LoS) environment, however, the quality of the link was found not good even with some obstructions on the path of the signals. However, it will be too early to conclude that the penetration of TVWS technology is no good for rural broadband. We will have to do a few more rounds of testing for longer time in different geographical locations to draw a conclusion.

5. We were able to build a hybrid community network serving the community using a combination of Wi-Fi and TVWS to bring broadband internet in Laprak valley of Gorakha distinct.

There are large companies like Microsoft and Google investing heavily to develop TVWS technology and testing it in different parts of the world. So, in time, lessons learned from this project can contribute TVWS impact in the future. Based upon the outcomes of the pilot project, Nepal Wireless is going to lobby with the government to open 460 MHz to 478 MHz of TVWS spectrum and make it unlicensed band for public use.

Overall Assessment

Through the pilot project we did comparative analysis of Wi-Fi and TVWS to learn how effective and feasible the hybrid wireless network would be in terms of performance, power consumption, cost and coverage in remote and high mountainous region to bring Internet. While we were doing testing in the mountains, we also conducted testing in flat plains of the southern parts of Nepal and in a big city environment of Kathmandu Based upon the testing done after building the TVWS base stations and testing the connectivity, we have made some overall assessment of the benefits of TVWS technology.

During the initial testing, we have found that the TVWS signals have better penetration through trees and dry walls than Wi-Fi signal. It has been found that the radio signals are available in near Line of Sight environment as well but the links could not be made in none Line of Sight environment. As we had hoped, the technology is helpful to connect the villages located in difficult terrains and narrow mountainous valleys of the Himalayas. It is also good in the plain areas with lots of trees around. We have found that it is good to connect the villages more easily than using 2.4 and 5.8 GHz equipment. During the pilot, we found that TVWS signals can also travel in near Line of Sight environments.

As for comparing the VHF and TVWS technology, we have found that signals from VHF spectrum works much better than TVWS spectrums in terms of penetration and coverage. It has been found that VHF signals can be received in none Line of sight environment as well.

However, the technology is still under improvement. The equipment is not mass produced yet. That is why the cost of the equipment is much higher and is not affordable by community network operators in rural areas. We will have to wait for some more time to conclude whether TVWS technology is really good options for bringing broadband internet services in rural area. We can see that there is a lot of potential for TVWS technology for broadband provision.

Recommendations and Use of Findings

From the preliminary test results, we can clearly see that TVWS works better than Wi-Fi in terms of coverage and connectivity in difficult terrains. If the TVWS technology is improved, the future users of the TVWS technology will be the small community wireless network operators that are providing Internet services in rural areas. Therefore, our recommendation to International Communication Union (ITU) and governments around the world is that at least 20 MHz band in TVWS spectrum should be made freely available for public use and for encouraging rural Internet service providers to connect the unconnected. That will build on the experience gained to make Wi-Fi so popular, thanks to unlicensed spectrum at 2.4 GHz and 5.8 GHz: because it was unlicensed for public use, Wi-Fi technology had developed so fast.

In the same manner, if some bands in TVWS are unlicensed just like Wi-Fi was made unlicensed, the technology will be improved and produced on commercial scale. That way it will be more affordable. It will be cheaper to build wireless infrastructure and the coverage will be better than that of normal unlicensed Wi-Fi bands. That is the best option to reach billions of people who are not connected to the Internet yet.

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