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Feasibility Study of a Reconfigurable Fiber-Wireless Testbed Using Universal Software Radio Peripheral

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Abstract

Fiber-wireless (FiWi) network is still improved ongoingly and there are a number of testbeds for the FiWi network available nowadays. However, most of them are hardware-based, making them not easy to reconfigure to perform architecture or protocol studies. This paper first proposes a reconfigurable FiWi testbed using software-defined radio, particularly universal software radio peripheral (USRP) with LabVIEW as the simulation platform. To evaluate the testbed, wireless range and power output were tested to optimize the best output for the USRP. With the range of 100 m, it was found that the best output power is 30 dB. Then, the study evaluated the performance of the upstream FiWi testbed transmission in terms of throughput, transmission time, and jitter. To test the testbed reconfigurability, the testbed architecture and transmission type were altered, and the performance was scrutinised. The experimental results indicate that USRP is suitable for a reconfigurable FiWi testbed.

Keywords: fiber wireless, testbed, reconfigurable, USRP

1. Introduction

The Internet has now evolved from luxury to necessity. The sudden increment of Internet subscribers combined with bandwidth-hungry applications are observed worldwide. Besides, the needs of having smooth Internet connections on-the-go caused mobility to be high on demand. The integration of fiber optics with wireless link creates a fiber wireless (FiWi) network that provides an architecture for the next generation network that can support higher data rate and overcome mobility issues in the current access network [1].

FiWi is deployed using Passive Optical Network (PON) architecture. PON begins at the optical line terminal (OLT) which is connected to the optical network units (ONUs) via a fiber link. The back end wirelessly connects the ONUs to the gateways [2]. Technologies such as time-division multiplexing PON (TDM PON) and wavelength-division multiplexing PON (WDM PON) are used as FiWi multiplexing techniques. TDM PON has the simplest architecture and cost effective while WDM PON supports point-to-point optical network with simple maintenance and upgradation. Wireless front-end uses technologies such as wireless fidelity (WiFi), worldwide interoperability for microwave access (WiMAX), long term evolution (LTE) or wireless mesh network (WMN) [3].

Two approaches are used to transmit large amount of FiWi delay-sensitive data, namely through radio over fiber (RoF) and radio and fiber (R&F) [4]. RoF is a technique where radio frequency (RF) signals are converted into optical signals

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using a converter and it is propagated over a fiber link from OLT to remote antenna units (RAUs) and transmitted to clients wirelessly [5]. All the RoF controls are centralised in the OLT. Hence, OLT is regarded as an intelligence network center while RAUs are only responsible for signal conversion. RoF has advantage that it only requires minimal modification at the base stations since RF signals are transmitted to a remote antenna as it is.

Meanwhile, Radio and Fiber (R&F) uses different media access control (MAC) protocols for both wireless and fiber links [6]. R&F has advantage in terms of its ability to solve the MAC protocol major performance due to the insertion of optical distribution system in wireless networks since R&F uses different protocol for different link.

To date, FiWi network is still emerging and improving. Numerous FiWi testbeds are developed for various purposes. Among them is by Chen et al. [7] that propose a W-band fiber-wireless-fiber (Fi-Wi-Fi) transmission which uses directly prove that DML is a simple and cost-effective converter to be used in the proposed Fi-Wi-Fi testbed.

Shaddad et al. [8] also propose a FiWi network system based on WDM/TDM PON for optical backhaul and WiFi-WiMAX wireless front end. The proposed FiWi system is simulated and analysed via a testbed that consists of laser diode, photodiode, low past filter with decoder, arrayed-waveguide-grating router and passive optical splitter. The testbed achieves 2.5 Gbps for up-and-downlink for fiber backhaul as well as 54 Mbps and 30 Mbps for wireless front-end in the distance of 50 m and 5 km respectively.

Zhang et al. [9] propose a full-duplex FiWi testbed equipped with optical I/Q modulator, two parallel Mach Zehnder modulators, phase shifter, optical local oscillator and tuneable laser. This paper has demonstrated the feasibility of the proposed full-duplex link to integrate wired and wireless networks in the future.

Although the testbed [7-9] meets the objectives, they are all hardware-based. Hardware-based testbed requires tedious hardware setups that is hard to configure, making it less suitable for architecture and protocol testing. As FiWi technology is still developing, the best architecture and protocol are scrutinised to improve the network overall performance. Therefore, it is essential to develop a reconfigurable testbed to observe the performance of various FiWi networks in terms of architecture and protocol.

The use of a programmable radio is one of the best solutions in developing testbed. Radio has the ability to transfer digital data from transmitter to receiver. There are two types of programmable radio, they are software-controlled radio (SCR) and software-defined radio (SDR). SDR is a radio system where all signal processing, modulations and demodulations are implemented within a computer. It is software-defined where any technology is implemented in the radio via programming. SDR utilises digital signal processing techniques to achieve reconfigurability, modulation and coding encryption with RF front-end characteristic. The main difference between SDR and SCR is that SDR is reprogrammable for different functionality as compared to SCR.

In this paper, for the first time to the best of our knowledge, universal software radio peripheral (USRP) is used to develop a reconfigurable FiWi testbed for architecture and protocol testing. USRP is a programmable SDR manufactured by National Instruments (NI). USRP has the advantage of being easy to reprogramme and operate using the license ISM bands, between 2.4 and 2.5 GHz. The USRP-based FiWi testbed will be analysed in a real and controlled environment. This paper is organised as follows; the FiWi testbed design is introduced in Section 2, performance evaluation is discussed in Section 3, results and discussion are presented in Section 4 whereas conclusion is summarised in Section 5.

Modulated laser (DML) to convert electrical to optical signals. The DML is tested using a testbed that consists of devices such as external cavity laser, I/Q modulator, Erbium-doped fiber amplifier and optical attenuator. Chen et al. successfully.

2. The Proposed FiWi Testbed Design

In this section, a FiWi testbed design that has both USRP and LabVIEW advantages is proposed. USRP is a computer-hosted RF transceiver that can transmit and receive RF signals of different bands. It runs on Gigabit Ethernet (CAT 6) cable to connect to a host computer where signal processing and modulated signals stream to the USRP.

There are many USRPs available in the market such as the standard one, USRP RIO and FlexRIO. The standard USRPs are subdivided into USRP-292x and USRP-293x. USRP-293x series are equipped with global positioning system (GPS), which at the moment is not required for the FiWi testbed. With that, USRP-292x series was chosen for the proposed testbed, particularly USRP-2922, since the focus is for 2.5GHz frequency transmission. The comparison between standard USRPs is shown in Table 1. The USRP-2920 offers a narrower frequency range and USRP-2921 does not offer a simultaneous transmit/receive feature, hence this justifies the use of USRP-2922 in the FiWi testbed. The basic USRP-2922 specifications are shown in Table 2.

Table 1 Comparison between NI-USRP models [10]

Model	Frequency Range	Instantaneous Bandwidth	Simultaneous RX/TX	Oscillator Type
USRP-2920	50 MHz–2.2 GHz	Up to 20 MHz	Yes	TCXO
USRP-2921	2.4 GHz–2.5 GHz and 4.9 GHz–5.9 GHz	Up to 20 MHz	No	TCXO
USRP-2922	400 MHz–4.4 GHz	Up to 20 MHz	Yes	TCXO
USRP-2930	50 MHz–2.2 GHz	Up to 20 MHz	Yes	GPS-Disciplined OCXO
USRP-2932	400 MHz–4.4 GHz	Up to 20 MHz	Yes	GPS-Disciplined OCXO

Table 2 Specifications of USRP-2922 [11]

Maximum output power	15-20 dBm
Transmit output gain	0-31 dB
Real time bandwidth	40 MHz for 8 bit samples
Maximum input power	0 dBm
DAC	2 channels, 400 MS/s, 16 bit samples
ADC	2 channels, 100 MS/s, 14 bit samples

Four sets of USRP-2922, namely SDR 1, SDR2, SDR3 and SDR 4 are used for the proposed FiWi network testbed. SDR 1 represents the OLT, while SDR 2 and SDR 3 represent ONU 1 and ONU 2 respectively, whereas SDR 4 represents the end-user where the hardware setup is illustrated in Fig 1. Each SDR is connected to a computer, equipped with graphical user interface (GUI) for testbed configuration and monitoring. The main simulation platform is programmed using LabVIEW. The architecture uses a ratio of 1:2:1 (one OLT, two ONUs and one end-user), but with minimal hardware rearrangement, the architecture can be modified to 1:1:2 or others.

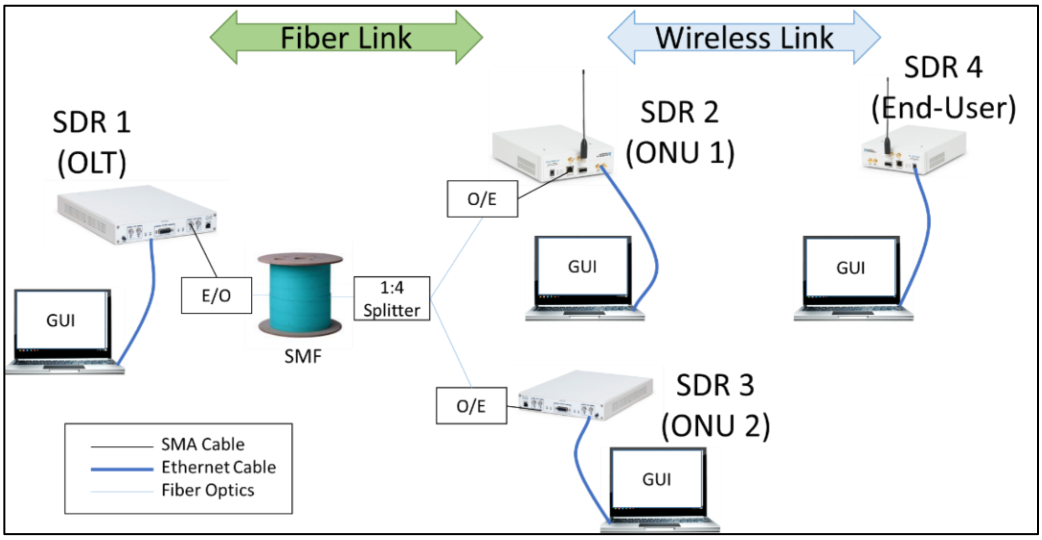


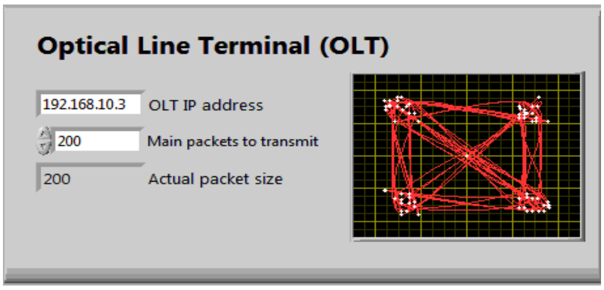
Fig. 1 Hardware setup for the proposed FiWi testbed

SDR 1 is first connected to the electrical to optical (E/O) converter via SubMiniature Version A (SMA) cable. E/O and optical to electrical (O/E) converters are important for the testbed where their function is to convert RF signal to optical signal and vice versa. A 3GHz E/O and O/E of the RF Optics is used to transmit frequency below 2.5 GHz. This is because the frequency between 2.4 and 2.5 GHz is for home and commercial business. E/O converts the RF signals generated from USRP to optical signals so that the signals can travel through a single mode fiber (SMF) cable. The signals are then split to SDR 2 and SDR 3 using optical splitter.

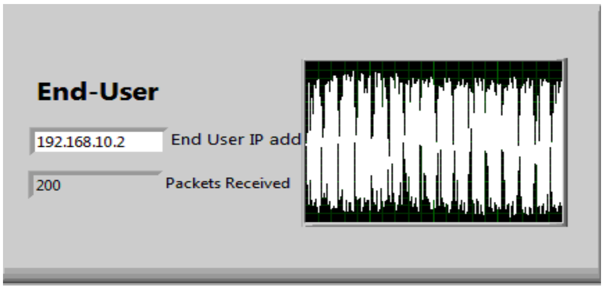
Then, the optical signals are reverted back to RF signals via the O/E. The data received via SDR 2 and SDR 3 will be downconverted, sampled and streamed to the computer via 1 Gb Ethernet cable. SDR 2 will further transmit the signal wirelessly to SDR 4 without any converter as USRP works directly with the wireless link. SDR 3 then converts the data back to represent a number of packets

In this study, USRP is integrated with LabVIEW in the form of data source, signal processing and modulation of the testbed. The proposed testbed allows user to key in any data and the data are automatically converted into packets. For user-friendly purpose, the data to be transmitted are translated to a number of packets where user can choose a range of packets from 1000, with 1000 increment.

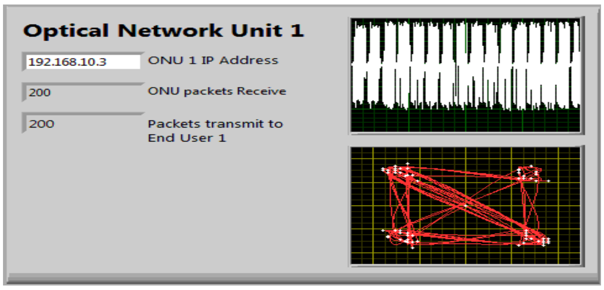
The user interfaces for OLT, ONU and end-user are shown in Fig. 2. The OLT's GUI consists of two inputs with the size of packets for transmission and ONU address. A red constellation graph displaying the GUI represents the USRP I/Q output signals. The ONU address is predefined by user using the USRP utility driver provided by NI. Each user interface comes with two light emitting diode (LED) indicators to monitor transmission. The white waveform graph indicates the data received by the SDR. With only one button pressed in the OLT's user interface, the FiWi downstream transmission is automatically performed. The user does not need to modify any ONU's and end-user's interfaces, save for the Internet Protocol (IP) addresses.



(a) User interface for OLT



(b) User interface for end-user



(c) User interface for ONU

Fig. 2 User interfaces

The receive and transmit parameters and modulation type can be altered in the user interface. From Fig. 3, the sampling rate, gain and frequency are adjustable, depending on the research objectives, making this testbed easy-to-use, without having to perform the tedious hardware reconfiguration. The types of modulation are included together with the USRP modulation toolkit that is included by NI. The modulation tools are ready to use and the inputs for a specific modulation type are available.

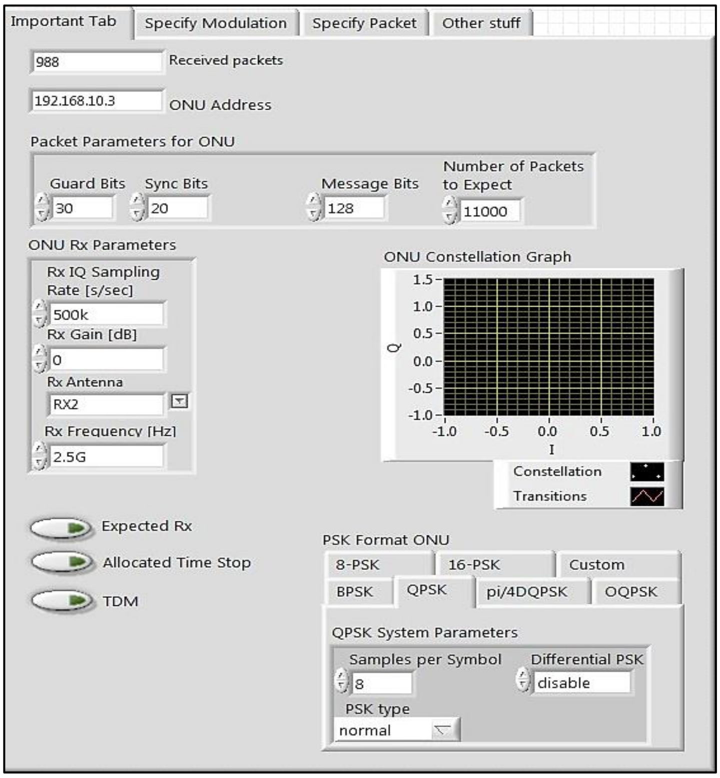
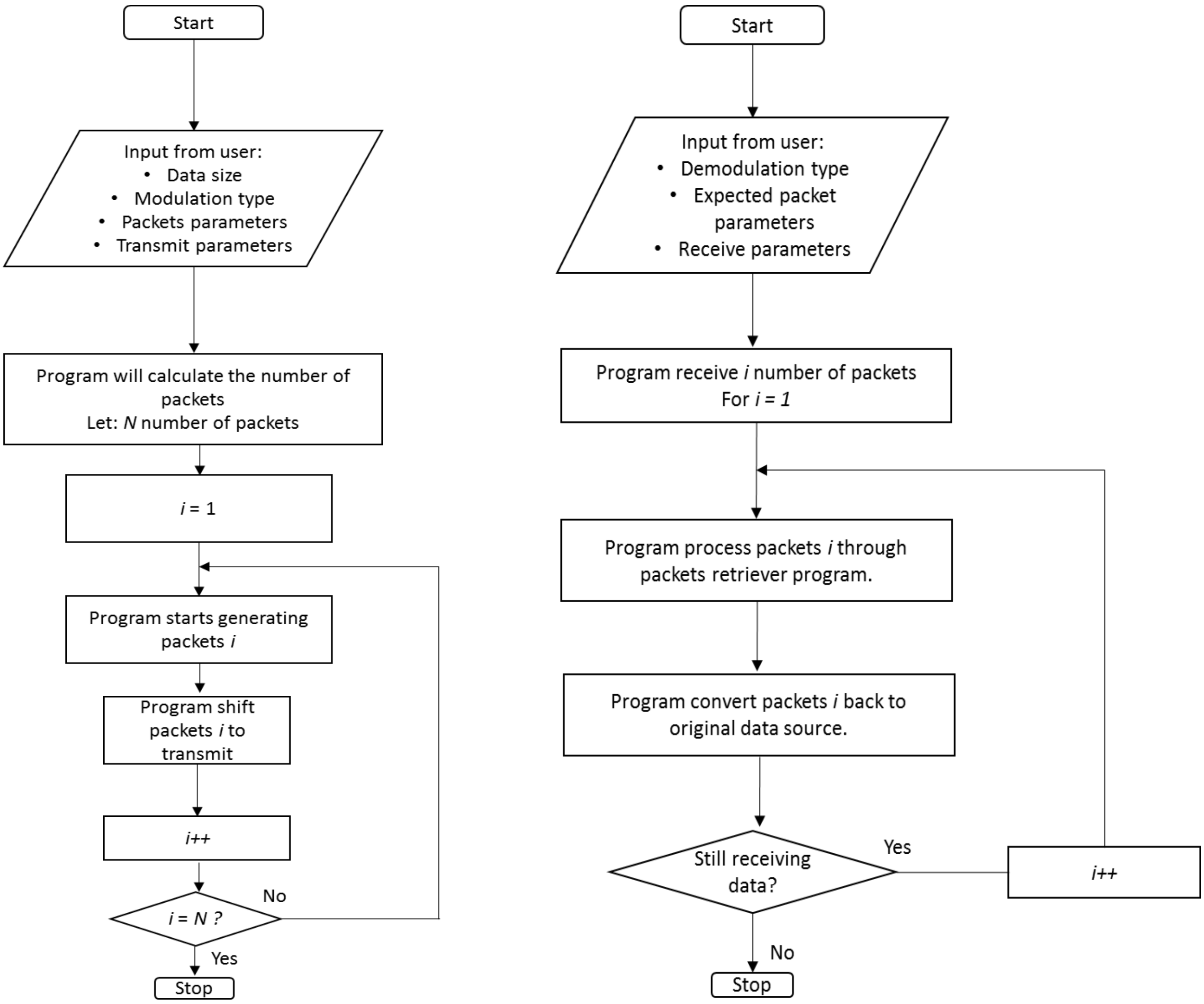


Fig. 3 User interface for receive parameters



(a) transmit program (b) receive program

Fig. 4 Flowchart

Fig. 4 (a) shows the transmit program flowchart. For transmission, the user is required to key in data size, modulation type, packet parameters and transmit parameters. When the program starts, the data will calculate the total number of packets, which is denoted by *N*. The program will then generate the first packet, a packet is denoted by *i*. The program will shift the packet *i* to the USRP for transmission. Then, the program will generate the next packets until *i* is equivalent to *N*, then the program stops.

3. Performance Evaluation of the Testbed

This section discusses the performance evaluation of the proposed FiWi testbed in three areas. The first is the preliminary study to determine the output power for specific wireless range between the USRPs. The second is the performance evaluation in terms of throughput, transmission time and jitter. The final part is to test the FiWi testbed reconfigurability.

3.1. Preliminary study

Since NI does not state the maximum USRP wireless range (due to its dependency in the surrounding interference) and output power required for a specific range, this is essential prior to the evaluation of the testbed performance. For the wireless range test, two USRPs are used, one as transmitter while another as receiver. The distance between the USRPs was first set to 10 m, with 10 m increment for each iteration until the receiver USRP no longer receives data transmitted by the transmitter USRP. The experiment took place indoor where there is no wireless activity that shares similar transmission frequency (between 2.4 and 2.5 GHz) to the USRP, such as WiFi network. The wireless range test is repeated using packets ranging from 1000 to 11000, and the average packets were recorded. A successful transmission occurs when the packets are transmitted from the transmitter USRP are received by the receiver USRP without any packet loss.

The relationship between wireless distance and USRP output power is summarised in Table 3, where the greater the distance, the higher the output power required by the USRP to transmit data. From the experiment, when the maximum wireless distance is 100 m, the required output power is 30 dB. It shows that for the wireless range lesser than 20 m, the required output power is 10 dB. Meanwhile, for a distance between 20 and 50 m, the output power required is 15 dB whereas for a distance between 50 and 100 m, the power output required is at its maximum, which is 30 dB.

Table 3 USRP output power for different wireless range

Output power (dB)	Wireless Range (m)
10	<20 m
15	20 m – 50 m
30	50 m – 100 m

To study the relationship between power output, distance and packets received in detail, an experiment for wireless range was set up, as shown in Fig 5. The transmitter is placed at the displacement of 0 m and three receivers are placed at the displacements of 10, 50 and 100 m. The wireless coverage between the transmitter and receivers was reviewed by varying the distance and power output.

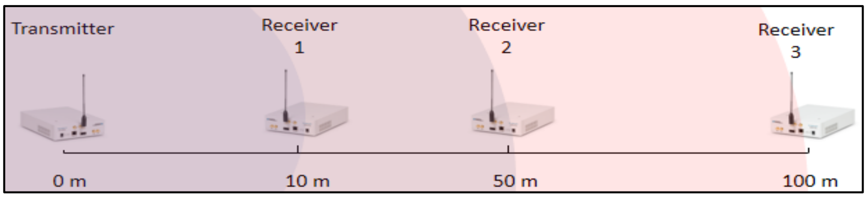


Fig. 5 Experimental setup for wireless range test

The results are shown in Fig 6. The plot in Figure 6 validates the results in Table 3 where the greater the distance, the higher the output power required by the USRP. The green area under the graph shows the USRP coverage area, for the output power between 0 and 30 dB. It is proven that the best output power for wireless range of 100 m is 30dB. The 100 m wireless range is selected as it is typical WiFi network range, as stated in the IEEE Standard 802.11a.

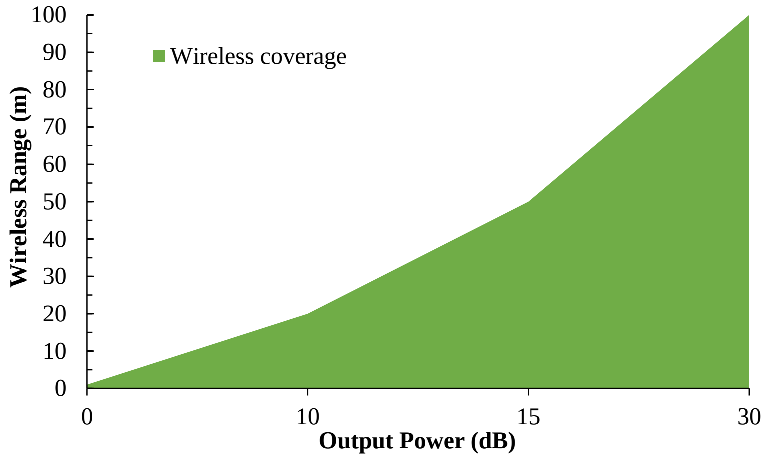


Fig. 6 Wireless range versus output power

3.2. Performance evaluation

After the suitable output power for 100 m distance between the USRPs was identified, the FiWi testbed throughput, transmission time and jitter in upstream transmission were determined. Upstream transmission is the transmission from the end-user to the OLT. In this case, end-user acts as the transmitter, OLT as the receiver while ONUs work both ways. To minimise interruption, the computer that simulates the ONU program requires higher memory and processing speed.

Throughput is defined as the amount of packets received in a specific period of time. In this study, the offered load varies between 0 and 1 Gbps, with 0.1 Gbps increment as demonstrated in Fig 7. It is shown that OLT receives all packets sent by the end-user. When the offered load is 1 Gbps, the throughput is also 1 Gbps, proving that the testbed works well without any packet loss, which is an ideal condition for the FiWi testbed.

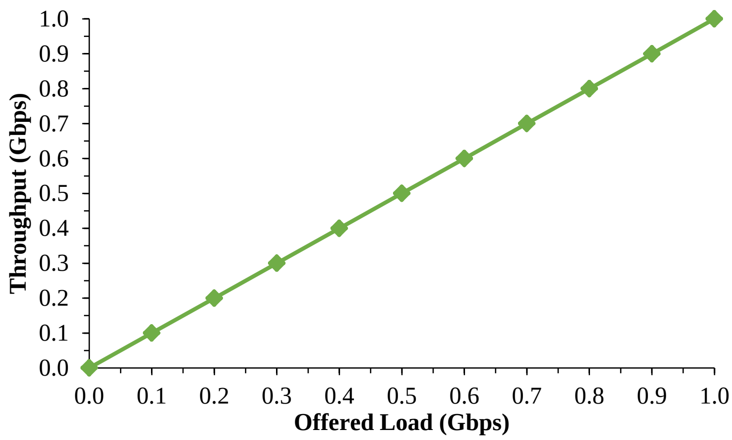


Fig. 7 Throughput versus offered load for the upstream transmission of FiWi testbed

Transmission time is defined as the total time taken for a complete transmission from end-user to the OLT, as depicted in Fig 8. As the offered load increases, the transmission time also increases where at 0.75 Gbps, the transmission time increases to 5.75 ms.

The jitter, J is calculated by using Eq. 1 [12], in which PDV refers to the packet transmission time which is derived from Eq. 2 [12]. D_i is the delay of transmission i, in transmitter j and N_p is the total number of receiving packets. D_{ave} is the average delay of transmission i in transmitter j, which is obtained using Eq. 3 [12]. Jitter is influenced by the transmission time, where greater transmission time causes greater delay which leads to higher jitter. The results are illustrated in Fig 9;

when the offered load is 0.1 Gbps, the jitter is 52.5 μs. As the offered load increases, the jitter also increases, demonstrating the FiWi network concept [13].

$$Jitter\ (J) = \sqrt{PDV} \tag{1}$$

$$PDV = \frac{\sum_{c=1}^{Np}(D_{i,j} - D_{ave})^2}{Np} \tag{2}$$

$$D_{ave} = \frac{\sum_{c=1}^{Np} D_{i,j}}{N_p} \tag{3}$$

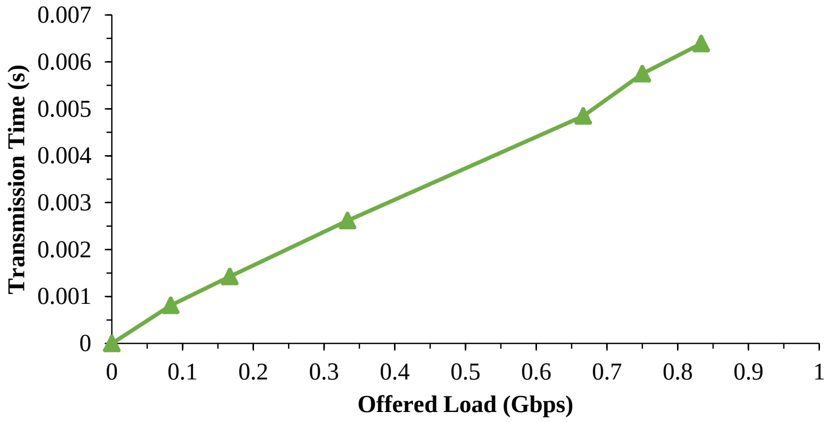


Fig. 8 Transmission time versus offered load for the upstream transmission of FiWi testbed

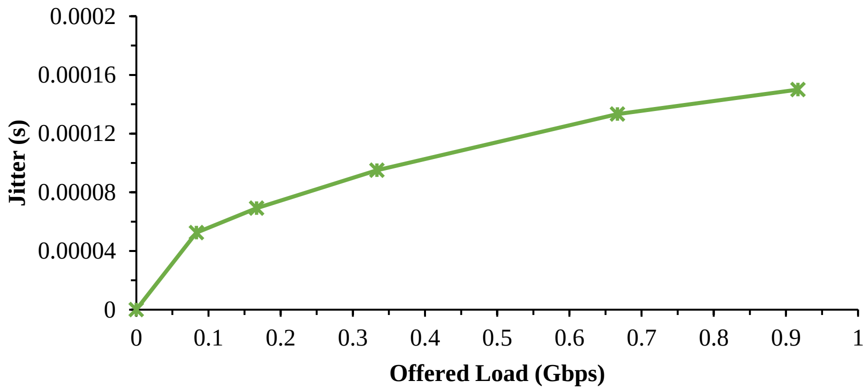


Fig. 9 Jitter versus offered load for the upstream transmission of FiWi testbed

3.3. Testbed reconfigurability

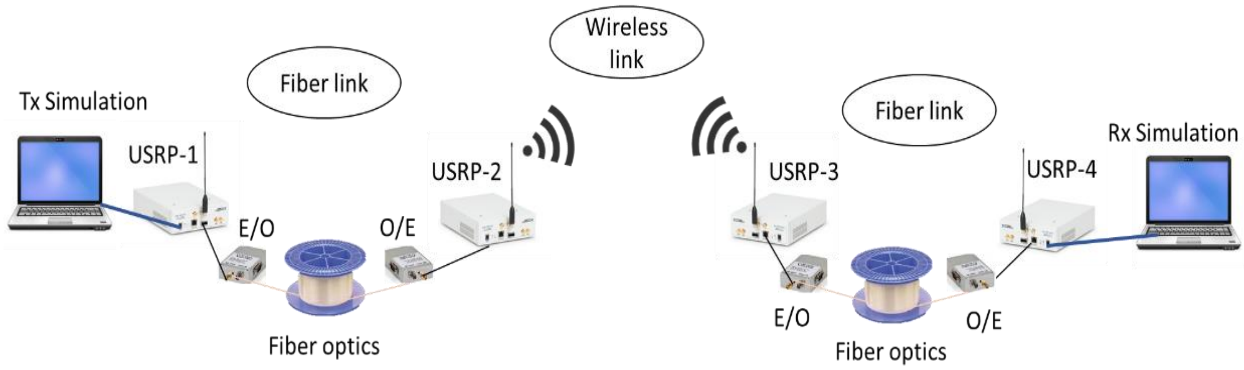


Fig. 10 Fi-Wi-Fi topology using USRP

To prove the testbed reconfigurability, the testbed was altered using different topology and other type of transmission type, with slight modification. Fi-Wi-Fi topology is useful when the optical network is not deployable from one point to another due to geographical constraint such as the presence of a river. Hence, a wireless link is used to overcome the constraint. Fi-Wi-Fi testbed is first developed by Xu et al. [14] and it was utilised in the proposed USRP testbed, as depicted in Fig. 10. It is shown that USRP 1 is connected to USRP 2 via fiber link while USRP 2 is further connected to USRP 3 via wireless link. Meanwhile, USRP 3 is connected to USRP 4 via fiber link again.

The Fi-Wi-Fi topology performance using USRP is evaluated in terms of number of packets received, transmission time and jitter. Since the FiWi network performance in the upstream transmission had been tested before, this section now focuses on the downstream transmission. Hence, the data were recorded starting from USRP 1, until all were transmitted and received by the USRP 4. There is no packet loss in the Fi-Wi-Fi transmission, as shown in Fig. 11. When the number of packets transmitted by USRP 1 is 11000, USRP 4 also receives 11000 packets. This indicates that the testbed works fine for other topology and transmission type.

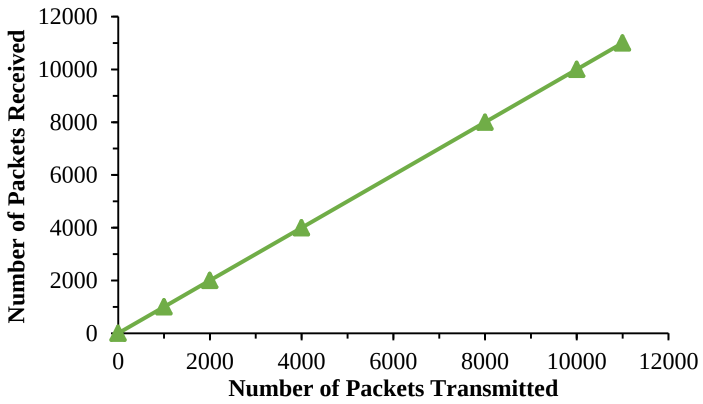


Fig. 11 Number of packets received versus number of packets transmitted for the Fi-Wi-Fi topology

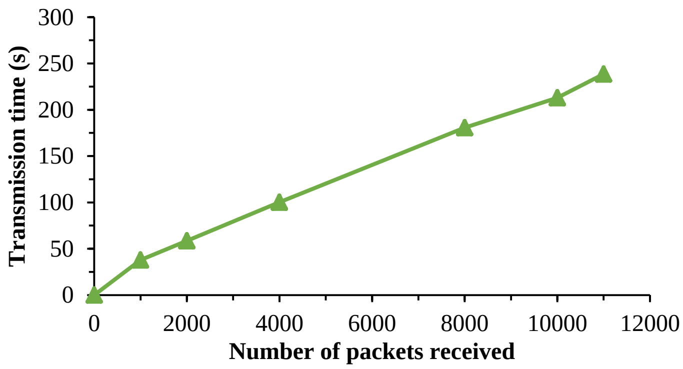


Fig. 12 Transmission time versus number of packets received for Fi-Wi-Fi topology

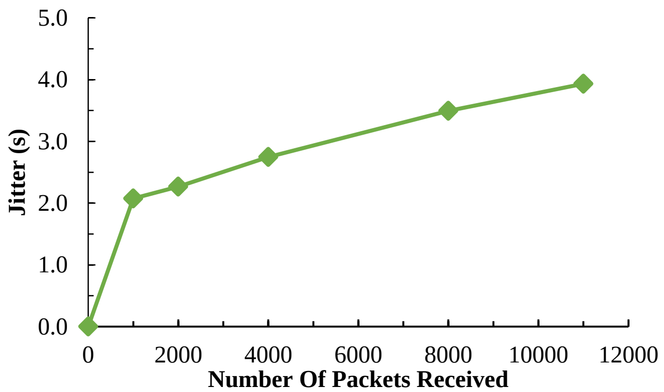


Fig. 13 Jitter versus number of packets received for the Fi-Wi-Fi topology

The results of transmission time is shown in Fig. 12. Due to the extended architecture, as expected, the time taken to complete the transmission from USRP 1 to USRP 4 also increases significantly. The increase in the number of packets received leads to higher transmission time. As it gets to 11000 packets, the transmission time increases to 238.5 s.

Higher transmission time leads to higher jitter, as shown in Fig. 13. As the number of packets received increases, jitter also increases, until it gets to 4s when the number of packets received is 11000. Although it takes longer to receive, this shows that the testbed is working for different topology and transmission type, proving that the testbed is reconfigurable.

4. Conclusion

The feasibility of NI-USRP which is the main radio of the proposed FiWi testbed had been presented in this paper. Besides transmiting data via wireless link, USRP can also transmit data via fiber link using RoF technology. With simple channeling of RF signals via E/O or O/E, the RF signals can be modulated into optical signals. In this study, the suitable output power and maximum wireless distance to be used between USRPs were determined. The maximum wireless distance between USRPs is identified to be 100 m, similar to the typical WiFi netwok, with maximum output power of 30dB. The performance of the proposed FiWi network in terms of throughput, transmission time and jitter for the upstream transmission was reviewed. The results confirm the FiWi concept and its reconfigurability was further evaluated. By changing the topology to Fi-Wi-Fi testbed and transmission type to downstream, it is proven that the testbed can be reconfigured for further FiWi studies.

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