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Full-Duplex Transmission using Passive Optical Network and Optical Wireless Communication

[1]M. Samayaraj Murali Kishanlal and [2]A. Jawahar
[1]St. Joseph's Institute of Technology,
[2]Sri Sivasubramaniya Nadar College of Engineering, Chennai, India

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Corresponding Author:
M. Samayaraj Murali Kishanlal
St. Joseph's Institute of Technology, College of Engineering, Chennai, India

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Abstract: This research is of combining Passive Optical Network (PON) with Optical Wireless Communication (OWC) using Wavelength Division Multiplexing (WDM) transmitter for PON. For optical wireless communication, Light Emitting Diode (LED) and converging lens with Positive Intrinsic Negative Photo Detector (PIN-PD) is combined. To enable high speed transmission, low attenuation and flexible multiple access with simplified Optical Network Unit (ONU) intensity modulation is used with operating wavelength of 1550 nm. The system successfully delivers a distance of 500 cm wirelessly indoor after transmitting over a span of 25 km using a standard Single Mode Fiber (SMF) together with eight wired users. To overcome the distortion that occurs when the signal travels over a long distance, low pass Bessel filter and 3R-Regenerator is used to reshape the distorted signal. The 1×8 optical splitter is used to support eight users. This system can achieve a maximum data rate of 622 Mbps at each direction. The measured Bit Error Ratios (BERs) for each user are all smaller than the 7% pre-Forward-Error-Correction (pre-FEC) limit of 3.8×10-3 which shows the promising potential and feasibility of this proposal to extend multiple services from metro areas to suburban areas.

INTRODUCTION

During the past few years, the demand for high-speed wired and wireless access is increasing rapidly, especially in building environments, fueled by the rising popularity of multimedia applications such as online games, high-definition video and broadband internet[1-7]. Gbps wired speed can be obtained based on the wide deployment of Passive Optical Networks (PONs) which can be used to feed fixed terminals. But as for wireless access, the data rate is still a main technical limitation. The capacity of widely used Wi-Fi and WiMax is mainly limited to 400 Mbps[1]. As for radio over fiber, there is only 7 GHz license-free bandwidth in the 60 GHz frequency region, still resulting in a limited maximum bit rate. As a promising alternative and complementary to microwave systems, Optical Wireless Communication (OWC) including infrared communication and Visible Light Communication (VLC) has attracted more and more attention, motivated by the dramatic development ofLight-Emitting Diode (LED) technologies and the scarce spectrum resources[8-10,2,3]. It can provide about 400 THz license-free spectra. Widespread, application, cost effectiveness, high brightness and larger bandwidth compared with other typical radio frequency-based devices make it the most promising candidate for simultaneous illumination and communication, especially in some specific areas like hospitals, aircraft, underwater and high-security requirement environments. For VLC, it can not only simultaneously provide communication and illumination at the strong illuminance level but also provide merely communication in the weak case for short-distance applications such as electronic payment. Many research efforts have been dedicated to increasing the capacity of VLC.

The highest data rate of a wavelength division multiplexing VLC system can be up to 4.22 Gbps using commercial LEDs[11]. By implementing visible laser diodes an access data rate in excess of 100 Gbps is possible[12]. However, the intrabuilding network considering OWC is commonly neglected.

In this research, we propose a full-duplex integrated PON and indoor OWC system. For the PON part, considering the transmission capacity demands and upgradation, WDM transmitter is used as the optical source with input power of 7 dBm for the downlink and uplink respectively. WDM transmitter consist of continuous wave LASER for Intensity Modulation (IM).

The OWC subsystem employs a LED operating at the optical frequency of 193.1 THz for downlink and uplink respectively. The LED can provide simultaneous communication and illumination. Generally, speaking, the bandwidth of an LED is merely several megahertz.

The information at downlink and uplink are successfully transmitted over a span of 25 km Single Mode Fiber (SMF). At the ONU, the seven subb and PON signals are fed to seven different wired users and the OWC signals are transmitted a further indoor distance of 5 m to a wireless consumer's device. As a proof of concept, a symmetrical bidirectional integrated system with 622 Mbps at each direction for eight wired users and one wireless user is successfully achieved with the measured Bit Error Rate (BERs) for all wired users at downlink is achieved as 0 (no error) and for uplink user at the Central Office (CO), it is achieved as 4.05×10^{-8} which shows the promising potential and feasibility of this proposal to extend multiple services from metro areas to suburban areas. The BER for wireless user is achieved as 4.37×10^{-5}.

MATERIALS AND METHODS

Architecture of full-duplex hybrid pon and OWC system: Multiple services with a variety of different standards should be hosted in the converged indoor network including wireless and wired services. Figure 1 illustrates the configuration of such a network based on PON and OWC. Different terminals can be hooked up via this network architecture. The wired users can be connected by fiber and the wireless users can be connected by visible LED or IR LED. As the visible light ranging from 380-780 nm and infrared light located at 850 nm cannot penetrate walls, they are totally confined to a single room without interference from adjacent rooms. Each single room can be regarded as a picocell which can provide high capacity per user[1]. The interfacing of the indoor network with the access network such as an optical

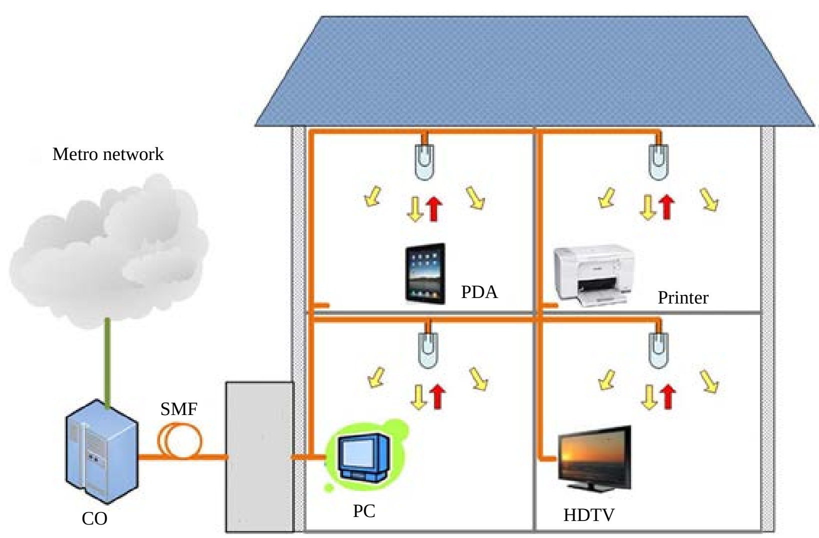


Fig. 1: Schematic diagram of integrated PON and OWC network (Personal computer)

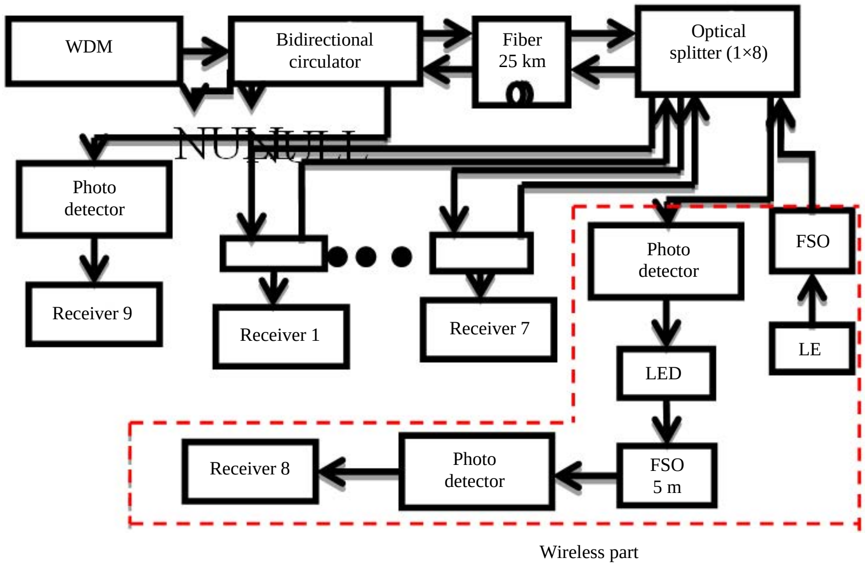


Fig. 2: Block diagram of fullduplex integrated passive optical network and optical wireless communication

fiber network, can take place via the residential gateway proposed by Koonen and Tangdiongga[13] which contains media converters and possibly additional intelligence.

In the upstream direction PON is a multipoint-to-point network. One of such problems is upstream traffic synchronization. Because distance from central office to every network unit is different if every unit will transmit in its own time slot, due to differences in propagation delays, data will collide in the point where fibers from different network units join together. Four 155 PONs shared by 32 subscribers each versus One 622 PON shared by 32 subscribers High-speed justified only if IP video or high-speed data services. Technology alone does not make deployment.

PON gained a lot of attention as a possible solution to the broadband local access network. PON may be deployed as a bus, ring or tree topology. While it is a very cost-effective solution, it has some unique problems, not found in backbone or metropolitan networks.

The simulation of integrated PON and OWC for multiple users is shown in Fig. 2. At the CO for downlink WDM transmitter which consists of CW LASER with input power of 7 dBm (4.9 mW) 100 GHz frequency spacing, linewidth of 4 MHz and extinction ratio of 15 dB is used for modulating the generated signals with light by intensity modulation. Then the optical signal is passed, through 25 km SMF after passing through bidirectional circulator. The optical signals are operated at wavelength of 1550 nm with a bit rate of 622 Mbps. Thus, the SMF has 0.2 dB km^{-1} attenuation. The optical signals are detected by PIN photo diode at other end after passing through 1x8 optical splitter such that seven for wired and one for wireless user (Fig. 3).

For wired user, at ONU the light information is converted into electrical information using Photo Diode (PD). This electrical signal is passed into Bessel LPF with the cut-off frequency of 466.6 MHz. Finally, it is amplified using 3R-Regenerator and the information is made to access by seven wired users. In wireless branch,thesplitted light information is given as the input to the LED operating at 193.1 THz frequency. The output of LED is made to travel in free space of 5 m range with 0.2 dB km^{-1} attenuation. Since, LED is omni-directional source, at the receiver converging lens will be placed. This light signal is converted to electrical signal using PD and passed into Bessel LPF with cut-off frequency of 466.6 MHz. This signal is amplified using 3R-Regenerator and made to access by one wireless user.

In wireless branch for uplink transmission the electrical signal generated by using RZ pulse generator operating at 0.25 duty cycle is intensity modulated and converted to light signals by using LED operating at 193.1 THz. These signals are then transmitted in free space with 0.2 dB km^{-1} attenuation. These optical signals are directly fed into bidirectional SMF by using converging lens at the other end. This signal gets multiplexed with wired signals from seven users before passing, through bidirectional SMF.

The information for seven wired users at upstream is generated by using WDM transmitter which performs intensity modulation with continuous wave LASER. This information is multiplexed using power splitter. This light information is transmitted over bidirectional optical fiber of length 25 km and bidirectional circulator. The output of bidirectional circulator is passed in PD in order to convert light signal into electrical signal. This signal is amplified and made to access by the user at the CO (uplink user). The third port (input) of circulator is made null, so that, the information will not be interfered.

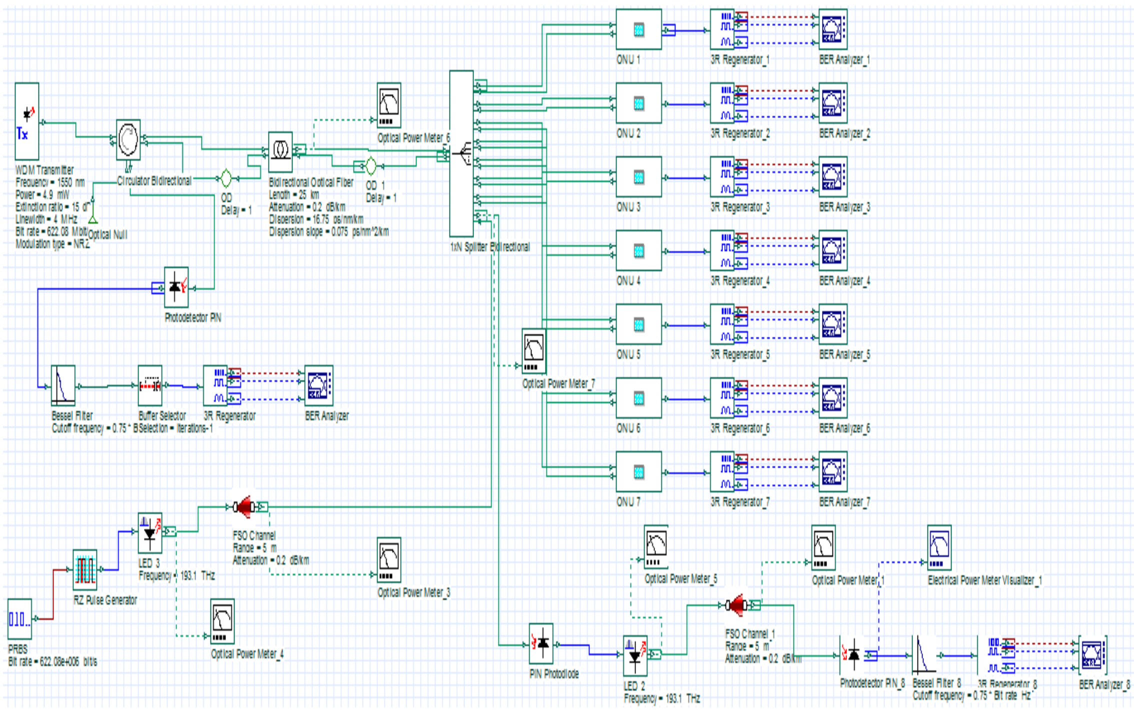
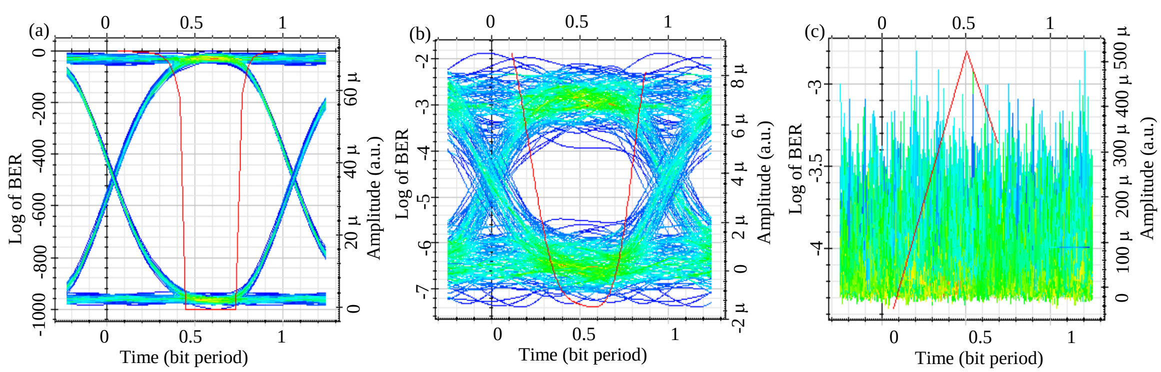


Fig. 3: Full duplex transmission using PON and OWC



Max. Q factor	54.0118
Min. BER	0
Eye height	6.32403e-005
Threshold	2.66396e-005
Decision inst.	0.542553

Max. Q factor	5.36492
Min. BER	4.04773e-008
Eye height	3.00451e-006
Threshold	3.78781e-006
Decision inst.	0.579634

Max. Q factor	3.75273
Min. BER	4.36881e-005
Eye height	3.83213e-005
Threshold	0.000200847
Decision inst.	0.0704961

Fig. 4(a-c): Eye diagram of 7 wired users (a), Eye diagram of uplink user (b) and Eye diagram of wireless user (c)

RESULTS AND DISCUSSION

Simulation and results: Figure 4a shows the eye diagram of seven wired users with BER of 0 and Q factor of 54.0118 which is determined using BER analyser. Figure 4b shows the eye diagram of one user at CO with BER of 4.04773×10^{-8} and Q factor of 5.36492. Figure 4c shows the eye diagram of wireless user with BER of 4.36881×10^{-5} and Q factor of 3.75273.

Figure 5a shows the BER analysis made for various input power and Fig. 5b shows the BER analysis made for uplink user located at CO (USER9) (Fig. 6).

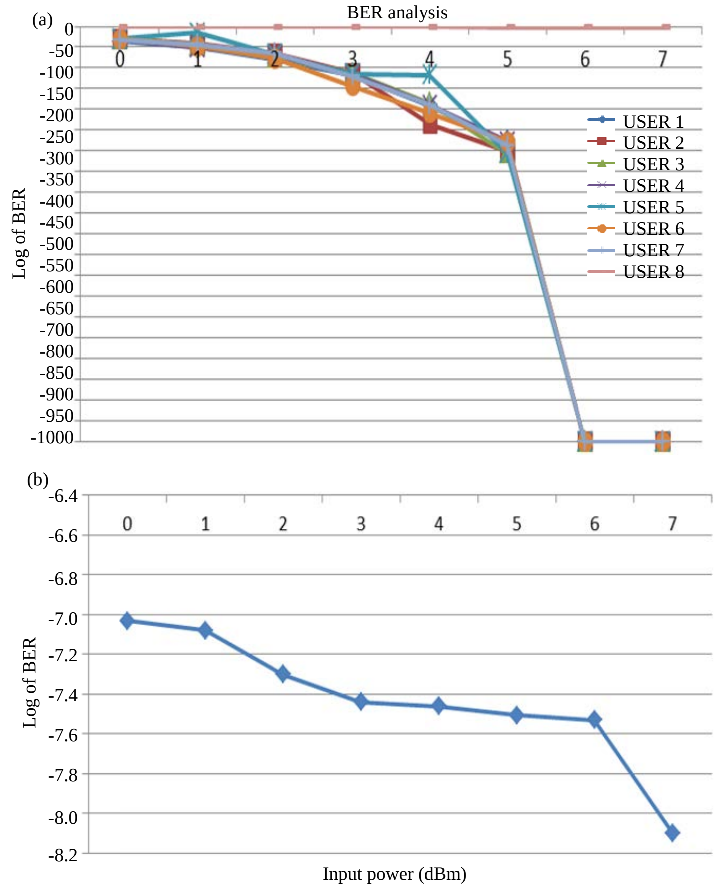


Fig. 5(a, b): BER analysis for various input power for various users and (b) BER analysis for various input power for uplink user

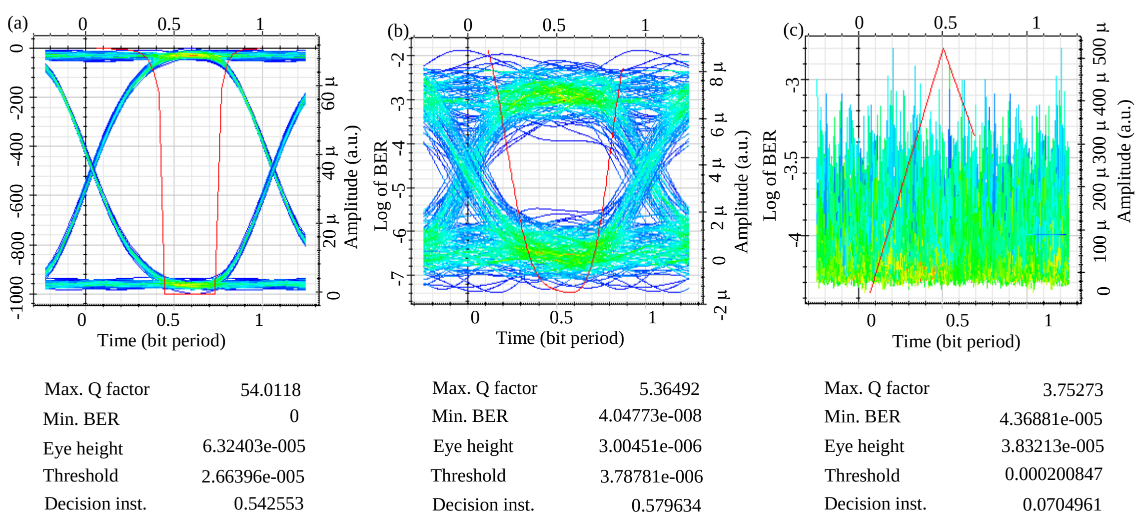


Fig. 6(a, b): Received optical power at FSO output and (b) Received optical power for various length of the fiber

USER 1-7 mentioned in above figure are wired users at downlink and USER 8 mentioned is the wireless user at downlink. From both the graph, low BER value is achieved for the input power of 7 dBm, hence, it is considered as the optimum power for transmission. The graphs are plotted using MS Excel. Figure 6a shows the received optical power performance in dBm obtained at FSO output for various wireless distances for each fiber lengths with input power as 7 dBm. BTB in the figure indicates Back-To-Back connected fiber, i.e., 0 km fiber (no fiber).

As the length of the fiber and free space medium increases the power linearly decreases. The graph infers that optimum FSO distance for optical wireless communication is till 5 m. Figure 6b shows the received optical power in dBm for wired and wireless users. Since, the power for wireless transmission is not below -30 dBm the transmitted signal could be recovered with acceptable BER. The low received power for wireless user compared to wired is due to background artificial light acting as loss. Both the graphs are plotted using MS Excel.

CONCLUSION

In conclusion, we have proposed a full-duplex hybrid PON and in-door OWC network architecture which can provide multiple services to one wireless and seven wired users originating from the CO with one user. The data rate of 622 Mbps for both PON and OWC systems are achieved for fiber length of 25 km and free space range of 5 m for both uplink and downlink. The optical power for various fiber length and FSO range is analysed such that wireless optical communication is supported to an optimum distance of 5 m. The measured BERs for downlink and uplink for all users are both under 4.36881×10^{-5}. The proposed architecture is shown to be a brilliant one to integrate a PON and short-distance OWC home area network.

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