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Simultaneous Upstream and Inter Optical Network Unit Communication for Next Generation PON †

Saba Ahmed *, Rizwan Aslam Butt and Muhammad Imran Aslam

Department of Telecommunications Engineering, NED University of Engineering and Technology, Karachi 75270, Pakistan; rizwan.aslam@neduet.edu.pk (R.A.B.); iaslam@neduet.edu.pk (M.I.A.)
* Correspondence: sabaa@neduet.edu.pk

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Abstract: In traditional passive optical network (PON) neighboring, optical network units (ONUs) cannot communicate directly but through optical line terminals, resulting in propagation delays, security hazards and unnecessary use of upstream and downstream bandwidth. Inter optical network unit communication (IOC) can be a promising solution for these problems. IOC is mostly demonstrated with the help of dedicated or tunable transceivers increasing the cost of the system and making it complex. Transceiver sharing is also demonstrated in the literature but this will be a bandwidth-inefficient technique. In our paper, the simultaneous transmission of IOC signal and upstream signal is demonstrated in a time-division-multiplexed PON using single transmitter and self-phase modulation-based wavelength convertor at each ONU that converts the upstream wavelength of 1310 nm to 1310.6 nm when IOC signal is being transmitted by that ONU; at the same time another ONU can transmit the upstream data at 1310 nm which results in efficient bandwidth utilization with less delays compared to the traditional PON. In our proposed design the IOC signal is reflected back by a Uniform Fiber Bragg Grating and the upstream signal is transmitted through it. This design supports a data rate of 25 Giga bits/sec.

Keywords: bandwidth efficiency; inter optical network unit communication; self-phase modulation

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1. Introduction

In recent years the passive optical network (PON) has become the most widely used technology for fiber to home networks because of its low maintenance and cost efficiency [1]. In mobile fronthaul, for bandwidth efficiency the transmission of multiple mobile channels over optical fronthaul link has become a highly desirable approach [2,3]. PON has also become the best option for mobile backhaul and all optical virtual private networks [4,5]. Therefore, PON has wide range of applications. In a traditional PON the optical line terminal (OLT) is connected to the ONU via the optical distribution network (ODN) and remote node (RN). ONUs cannot communicate with each other directly but via OLT which results in greater delay, losses, security hazards and unnecessary use of upstream and downstream bandwidth. These effects can be minimized if ONUs can communicate with each other directly, without involving the OLT, known as inter ONU communication (IOC). IOC has also become important because of services such as peer to peer file sharing, interactive gaming, and cloud computing among users in the same PON. If the PON is used for mobile fronthaul then the propagation delay can be up to 200 micro seconds while the allowed delay for 5G is 250 micro seconds [6], so to reduce latency IOC can be used for mobile fronthaul. The same latency issues exist when PON is used for 5G mobile backhaul, which can be resolved if inter base station communication is implemented using IOC [7]. Therefore, we can say that IOC can be used in many different scenarios. Many schemes for IOC have been proposed in which IOC is achieved using broadcast and select mechanisms [8,9]. Schemes have also been proposed which are secured but have complexity or greater latency [10]. IOC can be implemented using transceiver sharing [11,12], but this effects the upstream and downstream communication. Numbers of transmitters can be reduced by using tunable transmitters or other complex designs [13]. In short, simultaneous transmission has been proposed but with dedicated or tunable transmitters and receivers [14,15]. Numbers of transmitters can also be reduced by using wavelength convertors at ONUs. Wavelength conversion is mostly used in wavelength-division-multiplexed networks for wavelength routing. Most popular methods of wavelength conversion are self-phase modulation (SPM), cross gain modulation (XGM), cross phase modulation (XPM) and four wave mixing (FWM). XGM, FWM and XPM mostly use semiconductor optical amplifiers (SOA) for achieving wavelength conversion, which is a costly component and requires dedicated laser pump. On the other hand SPM occurs due to the property of fiber at a certain power level and length; if the parameters are correctly selected then wavelength conversion at desired wavelength can be achieved.

We have demonstrated IOC using SPM at ONU for wavelength conversion. In case of IOC signal transmission, the IOC signal is reflected back through uniform Fiber Bragg Grating (FBG) and broadcasted to the neighboring ONU without affecting the normal upstream and downstream communication; single identical transmitters have been used at each ONU for simultaneous transmission of the IOC and upstream data from two different ONUs, resulting in better bandwidth utilization

2. System Model for Simultaneous IOC and Upstream Communication

In our system model shown in Figure 1, two ONUs are considered for simultaneous transmission of IOC and upstream data, having identical transmitters that can be connected to either one of the available paths as shown in Figure 2—that is the IOC signal transmission path or the upstream signal transmission path—based on the type of the data transmitted by that ONU. The transmitter generates a return-to-zero (RZ) format optical Gaussian pulse at 1310 nm with a bit rate of 25 Giga bits/sec and 1watt power. For upstream transmission the generated signal passes through an attenuator before coupling at a remote node, and for IOC signal transmission the generated pulse passes through a single mode fiber of a length of 12 km, which results in SPM, generating peaks at two wavelengths as shown in Figure 3. We filtered the 1310.6 nm wavelength by passing it through a bandpass Butterworth filter with a 1 nm bandwidth. This signal is coupled with an upstream signal generated by another ONU, at the remote node. The coupled signal is passed through FBG that reflects back the IOC signal, which is at 1310.6 nm, and transmits the upstream signal, which is at 1310 nm.

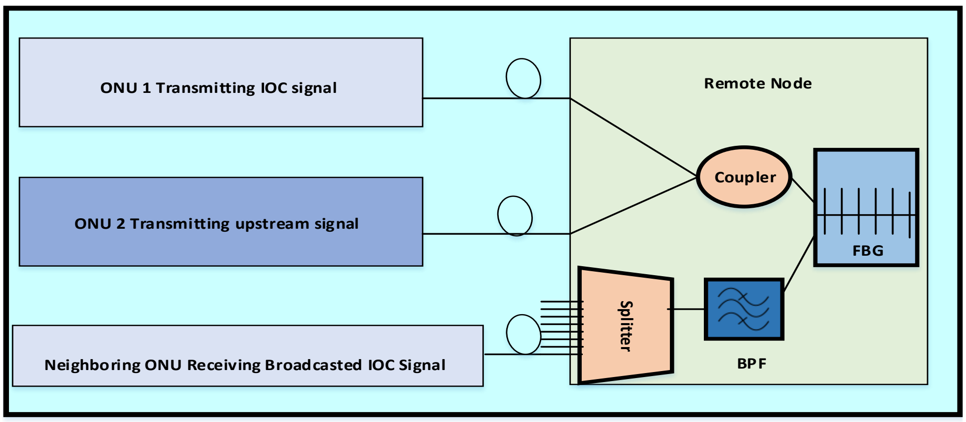

Figure 1. System model for simultaneous IOC and upstream communication.

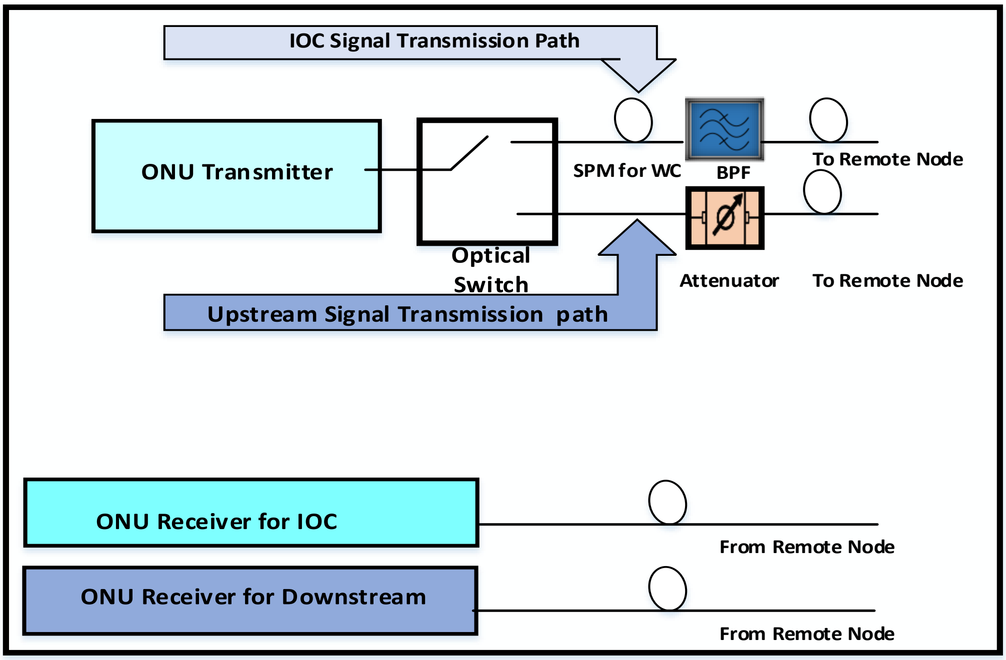

Figure 2. ONU block diagram showing two different paths for signal transmission.

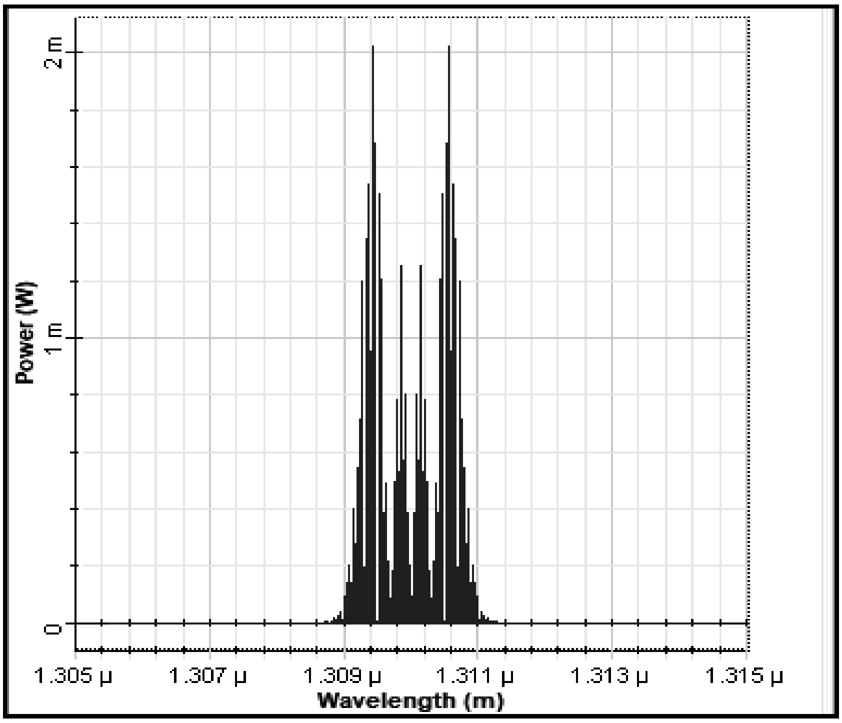

Figure 3. Spectrum after SPM showing two peaks at 1309.4 nm and 1310.6 nm.

Every ONU has two dedicated receivers for IOC and downstream reception, respectively. The reflected signal from FBG is passed through a bandpass filter centered at 1310.6 nm with a bandwidth of 0.5 nm for further suppression of residual upstream components. This signal is then passed through a 1:8 splitter for broadcasting to the neighboring ONUs. The received IOC signal is converted into an electrical signal using a photo-detector, lowpass filter (LPF) and 3R regenerator (Re-amplification, Re-shaping, Re-timing regenerator) and analyzed with a bit error rate (BER) analyzer.

3. Results and Discussion

The performance of the proposed IOC system was evaluated on the complete two-way IOC link for variable distances between ONUs and the remote node in the range of 2 to 5 km, with a differential end-to-end reach of 20 km. The main simulation parameters are shown in Table 1:

Table 1. IOC link simulation parameters.

Simulation Parameter	Value
Bit Rate	25 Gbps
US Wavelength	1310 nm
Fiber Bragg Grating Reflectivity	99%
Bandwidth of Fiber Bragg Grating	0.8 nm
Modulation	RZ

The performance is gauged in terms of the BER, Q factor and Eye diagram as the function of different distances between remote node and ONU, shown in Table 2 and Figure 4. The results show that the BER increases with increasing distance which is logical. However, the observed BER value for the maximum distance of 5 km is also in the acceptable range, which should be less than 10^{-12} as per the ITU- T G.987.1 specification, which shows satisfactory performance of the proposed system. Q factor is also one of the parameters to gauge performance of any optical network as it indicates the optical signal-to-noise ratio (OSNR) at the receiver. In PONs a Q factor of 7 or above is acceptable, in our proposed system the minimum Q factor is 22.3, which is also higher than the minimum acceptable range. The eye diagram is mostly used in optical communication to gauge error-free transmission; the greater the eye opening, the greater the Q factor and the lesser the BER will be. Eye pattern can also provide information about dispersion in the medium, the more overlapping the samples the lesser the dispersion will be. Figure 4 shows the eye diagram at different distances from the remote node, and it can be observed that the eye opening is wide and samples are overlapping, hence the dispersion is less and the BER is also very good.

Table 2. BER at different distances from the remote node.

Distance from Remote Node	Min BER	Q Factor
2 km	4.13×10^{-142}	25.3
3 km	2.60×10^{-132}	24.4
4 km	1.45×10^{-125}	23.8
5 km	6.43×10^{-111}	22.3

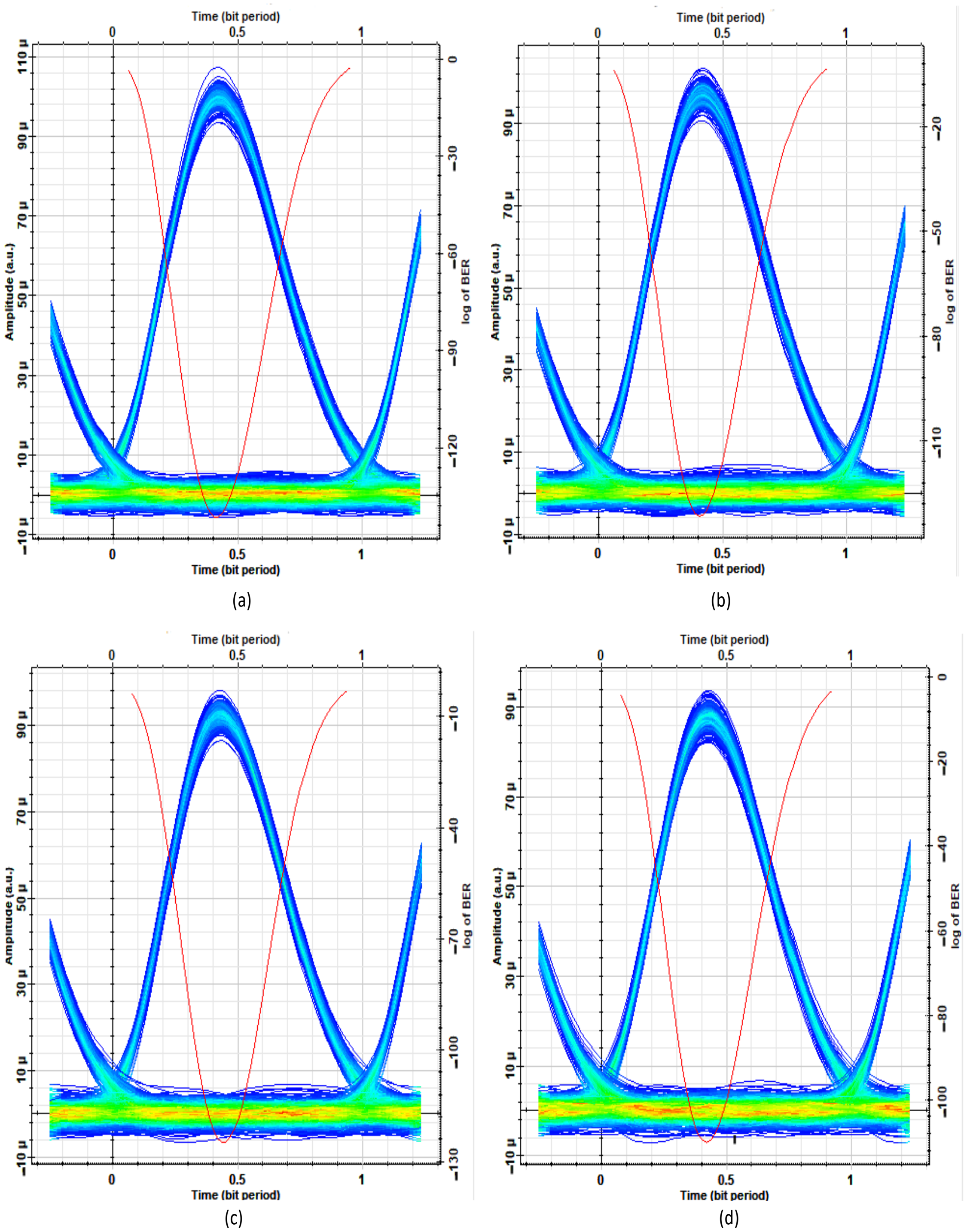

Figure 4. Eye Diagram at (**a**) 2 km (**b**) 3 km (**c**) 4 km (**d**) 5 km distance between the ONU and remote node.

4. Conclusions

The simultaneous transmission of upstream and IOC signals has been demonstrated successfully. Two ONUs transmit the IOC and US signal at the same time, but at different wavelengths, to the remote node where FBG reflects back the IOC signal at 1310.6 nm, which passes through the bandpass filter before broadcasting to the neighboring ONUs to suppress the residual US component. The eye diagram, BER and Q factor have been observed at one of the neighboring ONUs as a function of different distances between the ONU and remote node. A minimum Q factor of 22.3 is achieved at 5 km, which is higher than the acceptable range. Maximum BER is also observed at the same distance and is of the order 10^{-111}, which is much lower than the acceptable BER of 10^{-12} as per the ITU-T G.987. 1 specification. Hence, it can be concluded that IOC can be achieved using single transmitters and SPM without affecting upstream and downstream communication.

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References

1. Horvath, T.; Munster, P.; Oujezsky, V.; Bao, N.-H. Passive Optical Networks Progress: A Tutorial. *Electronics* **2020**, *9*, 1081. [CrossRef]
2. Torres-Ferrera, P.; Straullu, S.; Abrate, S.; Gaudino, R. Upstream and Downstream Analysis of an Optical Fronthaul System Based on DSP-Assisted Channel Aggregation. *J. Opt. Commun. Netw.* **2017**, *9*, 1191–1201. [CrossRef]
3. Li, H.; Yang, Q.; Fu, S.; Luo, M.; Li, X.; He, Z.; Jiang, P.; Liu, Y.; Yu, S. Digital Code-Division Multiplexing Channel Aggregation for Mobile Fronthaul Architecture With Low Complexity. *IEEE Photon- J.* **2018**, *10*, 7902710. [CrossRef]
4. Orphanoudakis, T.; Kosmatos, E.; Angelopoulos, J.; Stavdas, A. Exploiting PONs for mobile backhaul. *IEEE Commun. Mag.* **2013**, *51*, S27–S34. [CrossRef]
5. Mallette, E. Mobile Backhaul for PON: A Case Study. In Proceedings of the OFC/NFOEC, Los Angeles, CA, USA, 4–8 March 2012; pp. 1–3. [CrossRef]
6. Zhong, Z.; Jin, W.; Jiang, S.; He, J.; Chang, D.; Hong, Y.; Giddings, R.P.; Jin, X.; O'Sullivan, M.; Durrant, T.; et al. Concurrent Inter-ONU Communications for Next Generation Mobile Fronthauls Based on IMDD Hybrid SSB OFDM-DFMA PONs. *J. Light Technol.* **2021**, *39*, 7360–7369. [CrossRef]
7. Li, J.; Chen, J. Passive Optical Network Based Mobile Backhaul Enabling Ultra-Low Latency for Communications Among Base Stations. *J. Opt. Commun. Netw.* **2017**, *9*, 855. [CrossRef]
8. Garg, A.K.; Janyani, V. Overall/ Subgroup ONU Intercommunication based on Two Stage Flexible PON Network. In Proceedings of the 13th International Conference on Fiber Optics and Photonics, Kanpur, India, 4–8 December 2016; p. W3A.1. [CrossRef]
9. Li, Y.; Wang, J.; Qiao, C.; Gumaste, A.; Xu, Y.; Xu, Y. Integrated Fiber-Wireless (FiWi) Access Networks Supporting Inter-ONU Communications. *J. Light Technol.* **2010**, *28*, 714–724.
10. Gharaei, M.; Cordette, S.; Gallion, P.; Lepers, C.; Fsaifes, I. Enabling internetworking among ONUs in EPON using OCDMA technique. In Proceedings of the 2009 3rd International Conference on Signals, Circuits and Systems (SCS), Medenine, Tunisia, 6–8 November 2009. [CrossRef]
11. Lu, Y.; Deng, H.; Hu, L.; Cao, L.; Luo, Y.; Wang, J.; Zhai, Y. Inter-ONU-communication for future PON based on PAM4 physical-layer network coding. *Opt. Commun.* **2021**, *497*, 127162. [CrossRef]
12. Lu, Y.; Bi, M.; Qian, Z.; Hu, M.; Wei, Y.; Yang, G.; Li, Q. Inter-ONU-communication over different wavelength group in next generation pon based on physical-layer network coding. *Microw. Opt. Technol. Lett.* **2017**, *59*, 1068–1071. [CrossRef]
13. Bharti, M. Performance Enhancement in Colorless WDM–PON Using SSB-SC. *J. Opt. Commun.* **2022**, *43*, 353–361. [CrossRef]
14. Guo, Y.; Gan, C.; Zhan, N. Cost-effective WDM-PON for flexible ONU-communication featuring high wavelength utilization and low latency. *Opt. Fiber Technol.* **2021**, *67*, 102709. [CrossRef]
15. Jyoti; Sharma, D.P. ONU-Internetworking in Passive Optical Networks: Proposal of a New Strategy for High Bandwidth. *Int. Res. J. Eng. Technol.* **2021**, *8*, 657–663.