Paper

# SAC-OCDMA over Hybrid FTTx Free Space Optical Communication Networks

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**Abstract—This paper presents an investigation of Spectral Amplitude Coding Optical Code Division Multiple Access (SAC-OCDMA) over hybrid Fiber-to-the-x (FTTx) Free Space Optical (FSO) link under different weather conditions. FTTx and FSO are the last mile technologies that complement each other in delivering secure and high speed communication to customers' residence or office. SAC-OCDMA is one of the potential multiplexing techniques that has become a research area of interest in optical communications and considered a promising technique for FTTx access networks. It is based on Khazani-Syed (KS) code with Spectral Direct Decoding (SDD) technique. All the components involved in the network were specified according to the available market product in order to simulate the actual environment as close as possible. The result shows that for bit error rate (BER) of $10^{-9}$, the network is able to perform with 20 km Single Mode Fiber (SMF) spanning from the central office (CO) and 1.48 km FSO range with transmission rate of 1.25 Gb/s during heavy rain.**

*Keywords—Hybrid FTTx Free Space Optical, Khazani-Syed code, SAC-OCDMA, Spectral Direct Decoding.*

## 1. Introduction

The tremendous growth of the Internet, broadband services, and the World Wide Web contents has encouraged the presence of fiber optics in last-mile access networks. FTTx is a description of the Passive Optical Networks (PONs) based broadband access network technology that uses optical fiber running all the way from the local exchange (central office) to the customers, based on the location of the fiber's termination point. The FTTx can be described as a fiber-to-the-home (FTTH), fiber-to-the-building (FTTB), fiber-to-the-curb (FTTC), or fiber-to-the-cabinet (FTTCab). Fiber-to-the-x (FTTx) based PON represents an attractive solution for providing high bandwidth and support various types of signals [1]. In optical access networks, multiplexing is desirable in order to reduce cost and to make use of the optical fiber's huge bandwidth. Although Wavelength Division Multiplexing (WDM) is the current favorite multiplexing technique in long haul communication [2], Optical Code Division Multiple Access (OCDMA) is seen to have great potential for large scale deployment in all optical communication fields due to its ability to support asynchronous and simultaneous multiple user access with high level of security [3]. Spectral Amplitude Coding (SAC) OCDMA is the most suitable technique for optical multi-access networks over other OCDMA techniques because of its ability to eliminate the Multiple Access Interference (MAI) [4].

In this paper, SAC-OCDMA using the Khazani-Syed (KS) [4] code with Spectral Direct Decoding (SDD) [3] detection technique is proposed. The advantages of KS-code include its ability to cancel the MAI, support larger number of users, simple code construction and encoder-decoder design, existence for every natural number, ideal cross correlation and high signal-to-noise ratio (SNR) [4].

One interesting approach in order to realize future multiservice access networks is to integrate optical access networks such as FTTx and free space optics (FSOs). FSOs are increasingly being considered as a suitable alternative approach for optical networks, especially in areas where the deployment of fiber optic is not feasible and in underserved rural areas lacking broadband network connectivity. The advantages of FSO are wide bandwidth, free license, deployment cost at one-fifth of optical fiber installation, ease of deployment and high security [5]. Based on the merits of FTTx and FSO, it is hypothesized that the proposed hybrid FTTx-FSO based KS-code can be taken advantage of towards enhancing the high-speed broadband access networks.

In this paper, the simulation of the proposed architecture is studied. The proposed architecture is presented in the subsequence sections. The simulative setup description of the proposed hybrid FTTx-FSO is reported in Section 3, followed by the simulation results under various weather conditions. The conclusion drawn from the simulation results is presented in Section 5 of the paper.

## 2. System Implementation

In this section, the principle operations of FTTx and FSO technologies are explained, followed by the architecture of the proposed hybrid system.

### *2.1. Technology of FTTx and FSO*

FTTx is a generic term for various optical fiber delivery topologies that are classified according to where the fiber terminates. The expectation is that the fiber would get much closer to the subscriber. This technology brings fiber from the central office (CO) down to a fiber-terminating node called optical network unit (ONU). For the case where ONUs serve a few homes or buildings, this can be thought as FTTC or FTTB. Coaxial or twisted pair copper cable is used to carry data into the buildings. Generally, FTTx can be divided into two categories which are point-to-point (P2P) system and point-to-multipoint (P2MP) system. These are shown in Fig. 1. In the P2P architecture, a dedicated fiber runs from the local exchange to each subscriber. When the number of subscribers increases, the number of fibers and fiber terminals required in the local exchange are also increases. Thus the system cost is also increases. In the P2MP architecture, a single fiber carries all signals to the passive optical power splitter that feeds the individual short branching fibers to the end users. These splitters do not require any power supply and the optical signals are divided into 32, 64 or even 128 shared connections [6]. In this architecture, the cost rise slower than the P2P architecture as more fiber is needed only in the branches. Therefore, it has become popular for deployment in access networks, and widely known as PON.

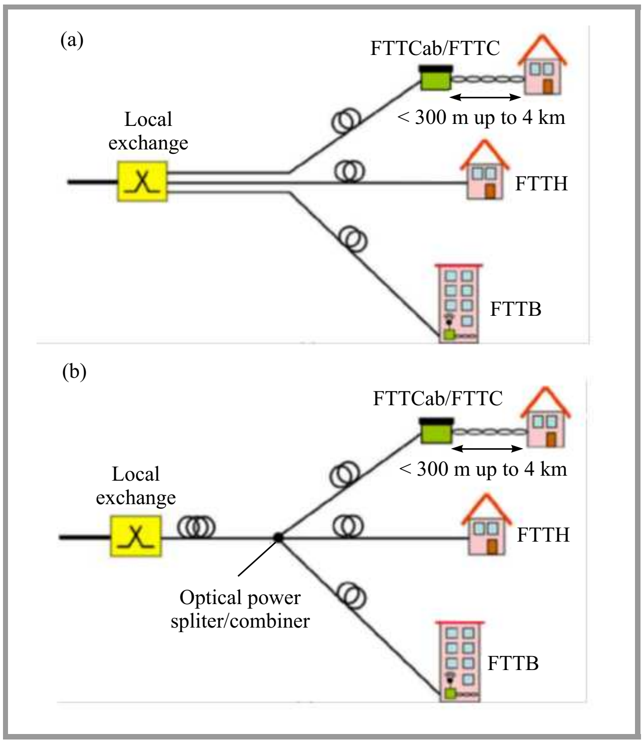


*Fig. 1.* FTTx architecture: (a) P2P, (b) P2MP using passive optical fiber splitter.

PONs were the first FTTx technology being developed into several standards [7]. The first standard developed was asynchronous transfer mode over PON (APON), followed by Broadband PON (BPON), Ethernet over PON (EPON), and gigabit PON (GPON). GPON was the latest developed PON that based on G.984 series of the ITU-T recommendations, and it supports upstream rate up to 1.25 Gb/s while downstream rate up to 2.5 Gb/s [7].

FSO is a wireless optical technology that enables optical data transmission through the air based on the use of the free space as transmission medium and low power lasers as light sources. The interest in FSO continues mainly for two reasons:

– identification as an attractive alternative to complement existing microwave and radio frequency (RF) communication links,

– being a broadband wireless solution for the "last mile" connectivity in metropolitan networks to connect the "backbone" to the clients (Last-Mile-Access) by providing significantly high data rates in P2P and P2MP link configurations [8].

However, rain attenuation does cause a significant effect to the FSO system performance with signal frequency above 10 GHz [9]. The international visibility code for various weather conditions is depicted in Table 1 [10].

Table 1
International visibility code

| Weather condition | Amount [mm/h] | Visibility [km] | Attenuation [dB/km] |
|---|---|---|---|
| Storm | 100 | 0.5–0.77 | 18.3 |
| Heavy rain | 25 | 0.77–1.9 | 6.9 |
| Medium rain | 12.5 | 2–4 | 4.6 |
| Light rain | 2.5 | 4–10 | 2 |
| Drizzle | 0.25 | 10–20 | 0.6 |

### *2.2. Hybrid FTTx-FSO Network Architecture*

The hybrid FTTx-FSO network has the potential to overcome the last mile bottleneck issue since both technologies can support high capacity and high security in optical network. Besides that, FSO can contribute to overcome the geographical area problem where there are difficulties of fiber deployment. Figure 2 depicts a general architecture of hybrid FTTx-FSO network. This general architecture shows an optical access networks from CO to the end users. This is where the ONU is located. These end users could be homes, office buildings, curbs or cabinets. Signals from the optical line terminal (OLT) that located at the CO, are combined with the amplified video signal using wavelength selective coupler (WSC). Signals from OLT and video are transmitted at 1490 nm and 1550 nm wavelength, respectively. Due to the high signal quality demand, a pre-amplifier is used for video signals. Thus, the transmit power for that particular application is increased. These downstream signals propagate through a Single Mode Fiber (SMF) and FSO transmission link. After the

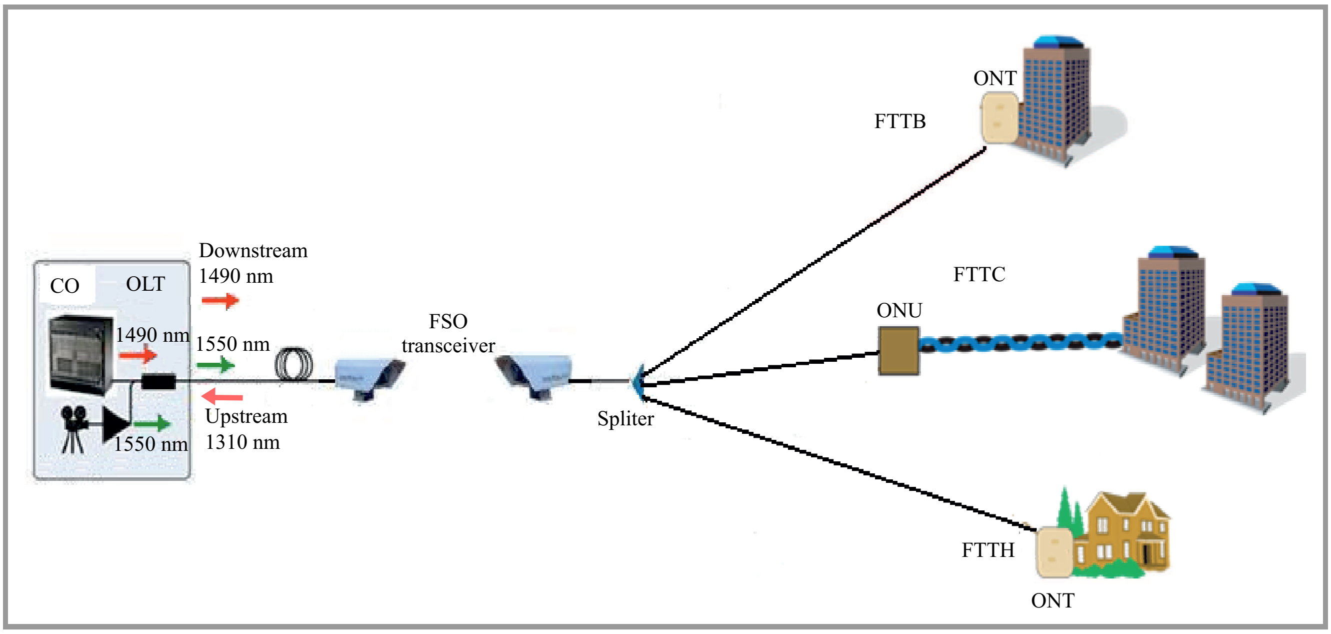


*Fig. 2.* Hybrid FTTx-FSO architecture.

FSO receiver, these downstream signals propagate through a passive splitter of N branches. After the splitter, the downstream signals are transmitted to the ONU of the intended receiver. The function of ONU is to convert the optical signal to electrical signal. The electrical signals are carried by different cables such as RJ-11, RJ-45, and video cable for voice, data, and video signals, respectively.

## 3. System Design

### *3.1. Setup Description*

The proposed hybrid FTTx-FSO based KS-code was simulated using commercial package, Optisystem v. 9.0. All components in the proposed system were specified according to the typical industry values to simulate the actual environment as close as possible. Table 2 illustrates the parameters used in the simulation.

Only downstream performance is reported in this article with the assumption that signals are transmitted at the wavelength of 1550 nm. Generally, FSO systems operating at 1550 nm are 70 times more eye-safe, in terms of maximum permitted exposure, than FSO systems operating below 1000 nm [11]. This attribute makes the decision to use 1550 nm more feasible in the majority of cases. It is also suitable for video transmission and amplification as required for FTTx implementation. Figure 3 shows the block diagram of the proposed SAC-OCDMA over hybrid FTTx-FSO communication network.

At the transmitter, the Non-Return-to-Zero (NRZ) data at 1.25 Gb/s transmission rate were optically modulated onto a code sequence of KS code using Mach Zehnder Modulator (MZM). Then $n$ modulated code sequences were combined together and amplified using an FTTx-customized erbium-doped fiber amplifier (EDFA) with 30 dB gain and 6 dB noise figure. The amplified signal was 33 dBm at the wavelength of 1550 nm. The EDFA's technical specifications were based on Greatway Technology GWA3530

Table 2
Parameters used in the simulation

| Parameter | Value |
|---|---|
| KS Code weight | 4 |
| Detection method | SDD |
| Input power | 6.3 dBm |
| Transmission rate | 1.25 Gb/s |
| Atmospheric attenuation | Heavy rain, 10 dB |
| G.652 Fiber | |
| Attenuation | 0.25 dB/km |
| Chromatic dispersion | 17 ps/nm/km |
| Polarization mode dispersion | 0.1 ps/km |
| Fiber length | 20 km |
| FSO | |
| Transmitter aperture diameter | 0.025 m |
| Receiver aperture diameter | 0.08 m |
| Beam divergence | 3 mrad |
| Transmitter loss | 3 dB |
| Receiver loss | 3 dB |
| Additional loss | 1 dB |
| EDFA | |
| Gain | 30 dB |
| Noise figure | 6 dB |
| APD | |
| Gain | 10 |
| Responsivity | 10.1 A/W |
| Dark current | 165 nA |

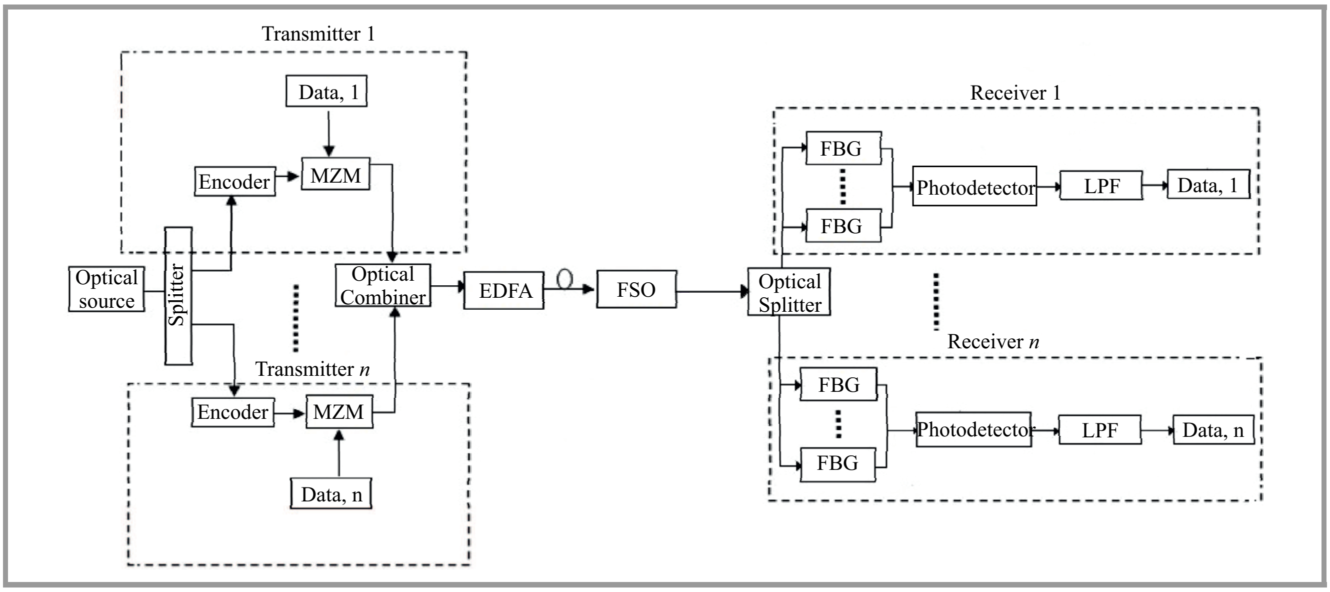


***Fig. 3.*** Block diagram of SAC-OCDMA over hybrid FTTx-FSO communication network.

series 1550 nm fiber amplifier. The modulated signals were then transmitted through a 20 km SMF. The attenuation coefficient and chromatic dispersion were set at 0.25 dB/km and 17 ps/nm/km, respectively. Then the signals were transmitted through the FSO transmission link. The FSO transceiver specifications were based on SONAbeam 1250-M product. Geometric losses depend on the transmitter and receiver aperture diameters, which were 0.025 m and 0.08 m, respectively, and the beam divergence was 3 mrads [12]. The losses for the transmitter and receiver, and the pointing loss of the FSO link in order to simulate the real environment as close as possible were 6 dB [13] and 1 dB [14], respectively. Considering these two major losses, the received power used in this study is given by [15]:

$$P_{RX} = P_{TX} - 20\log\left(\frac{d_2}{d_1 + (DR)}\right) - \alpha R, \qquad (1)$$

where: $P_{TX}$ – transmitted power [dBm], $P_{RX}$ – received power [dBm], $d_1$ – diameter of transmit aperture [m], $d_2$ – diameter of receive aperture [m], $D$ – beam divergence [m], $R$ – range [km], $\alpha$ – atmospheric attenuation factor [dB/km].

The second and third terms in the right-hand side of Eq. (1) represent the geometric losses and atmospheric attenuation at a particular distance, respectively.

At the receiver, an optical splitter was used to separate the different modulated code sequences. The received signal were decoded based on SDD detection technique by using the fiber Bragg grating (FBG) which functions to extract the non-overlapping chips. Meanwhile the overlapping chips were not filtered as it may cause interference at the receiver. Then, the decoded signal was detected by the photodetector. Avalanche photodiodes were used in this simulation. In order to recover the original transmitted data, the detected signal was electrically filtered with a 0.75 GHz Bessel electrical low-pass filter (LPF).

The scope in this study is focused on the EPON standard, based on the P2MP topology with bit rate of 1.25 Gb/s. A 20 km SMF was used to connect OLT and FSO transceiver. A passive optical splitter was used at the receiver whereby the decoded signals were sent to the ONUs. The atmospheric attenuation of the FSO link, $\alpha$ was varied to represent various weather conditions. The values are as shown in Table 1. However attenuation of 10 dB was used to represent heavy rain based on typical Malaysia weather. The reason is that Malaysia typical rain amount is more than 25 mm/h when it is observed through whole year [16]. The distance of the FSO link was varied to observe the proposed hybrid network performance.

## 4. Results and Discussion

The performances of the proposed hybrid system were characterized by referring to the bit error rate (BER) against

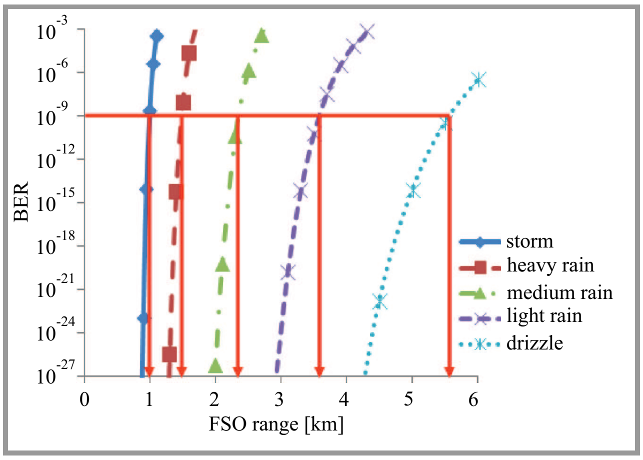


***Fig. 4.*** BER versus FSO range for storm, heavy rain, medium rain, light rain and drizzle.

FSO range and received optical power (ROP). Figure 4 depicts the performance of the hybrid system for various weather conditions. It can be seen that under drizzle weather, the system still achieve acceptable BER of $10^{-9}$ until 5.56 km of FSO range. For light and medium rain, the FSO ranges at acceptable BER performance are 3.6 km and 2.33 km, respectively. However, for heavy rain and storm the acceptable BER are achieved at 1.48 km and 1 km, respectively. The FSO range is directly related to the atmospheric attenuation associated with the respective weather condition. The results are considered good enough as the proposed SAC-OCDMA FTTx-FSO is capable of transmitting 1.25 Gb/s data over FSO link under various weather conditions after propagating through 20 km SMF, optical splitter and decoders.

Figure 5 depicts the relationship between the proposed hybrid system performance and the ROP. It can be seen that at BER of $10^{-9}$, the ROP for heavy rain and medium rain are –41.7 dBm and –41 dBm, respectively. It shows that approximately 0.7 dB power penalty is introduced. The power penalty may be attributed to the effects from heavy rain whereby signals are prone to be diffracted by the bigger-sized and closer-spaced rain particles.

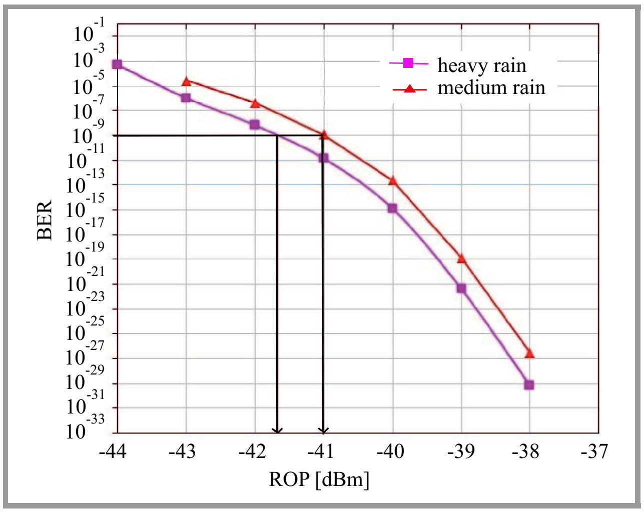


*Fig. 5.* BER versus ROP for heavy and medium rain.

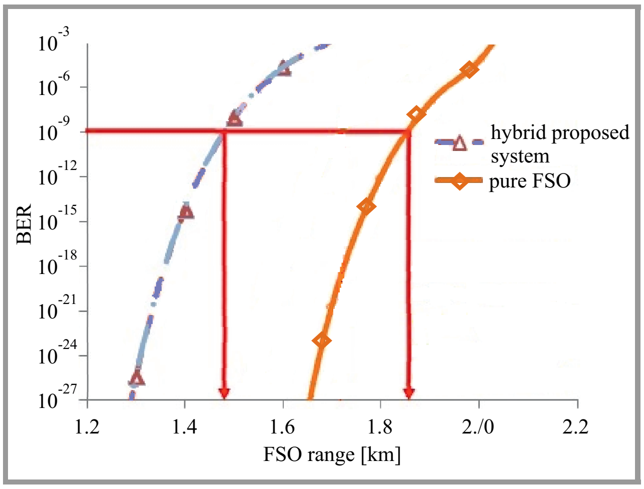


*Fig. 6.* BER versus FSO range for hybrid FTTx-FSO and pure FSO systems.

Figure 6 depicts the comparison between SAC-OCDMA over hybrid FTTx-FSO system and the SAC-OCDMA over FSO system. It can be observed that the pure FSO system has a maximum FSO range of 1.85 km while hybrid FTTx-FSO system has a maximum FSO range of 1.48 km under the same weather condition at the acceptable BER threshold. It denotes that the pure FSO system exceeds by 0.37 km of FSO range of the hybrid FTTx-FSO system. Consequently, although hybrid FTTx-FSO system has shorter FSO range than the pure FSO system, the total transmission link for the proposed hybrid FTTx-FSO system is 21.48 km (20 km fiber + 1.48 km of FSO distance).

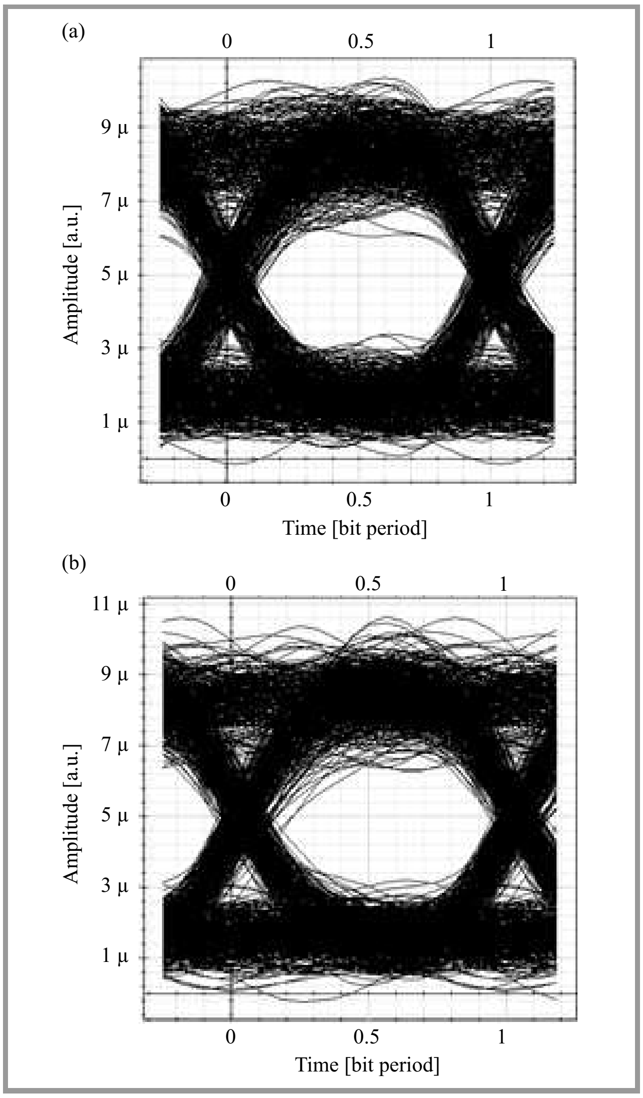


*Fig. 7.* Eye diagrams for heavy rain at BER threshold: (a) hybrid FTTx-FSO system at FSO range of 1.48 km, BER of $4.2 \times 10^{-9}$, (b) pure FSO system at FSO range of 1.85 km, BER of $1.4 \times 10^{-9}$.

Eye diagrams at acceptable BER of $10^{-9}$ are illustrated in Fig. 7a, where represents hybrid FTTx-FSO system during heavy rain at 1.48 km of FSO range with BER of $4.2 \times 10^{-9}$, and in Fig. 7b represents pure FSO system during heavy rain at 1.85 km of FSO range with BER of $1.4 \times 10^{-9}$.

## 5. Conclusion

In this paper, the FTTx part was designed based on the EPON technology. The performance of SAC-OCDMA over the hybrid of FTTx-FSO network for the last mile users with various weather conditions were presented. The results reveal that the proposed SAC-OCDMA FTTx-FSO could support the maximum FSO range of 5.56, 3.6, 2.33, and 1.48 km for drizzle, light rain, medium rain and heavy rain, respectively, at the acceptable BER of $10^{-9}$. These information are useful for the system engineer to locate the FSO transceivers based on the geographical influence and rain tabulation. Obviously, the proposed SAC-OCDMA over the hybrid of FTTx-FSO network presents an appealing performance and can provide a feasible solution for last mile access problem.

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