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Random weather phenomena in free-space optical - FTTx communication system

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ABSTRACT

In the last few decades, optical wireless communication became an essential technology in various applications. Researchers have paid more attention to achieving high bandwidth and low loss. However, the random weather phenomena cause attenuation of optical signals, thus will decrease the bandwidth in optical wireless communication. In this article, we investigate a hybrid free-space optical (FSO) and fiber-to-the-x (FTTx) communications link based on wavelength-division multiple access (WDMA) over different random weather phenomena that operate over different wavelengths. The performance of the hybrid FSO-FTTx system is evaluated under clear sky weather phenomena, heavy rain weather phenomena, and heavy haze weather phenomena based on BER and Q-Factor measurements. The results show that we can transmit 140 Gbit/s data over 9650 meters a hybrid link under the clear sky and heavy rain weather phenomena, 3950 meters over. Additionally, the transmission of 140 Gbit/s data can be achieved for 1450 meters under the heavy haze weather phenomenon.

Keywords: WDMA, FSO, FTTx, LAN, WAN, Weather phenomena, Geographical phenomena

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1. Introduction

Various improvement on broadband wireless communication systems have been done to fulfill the demand for larger bandwidth and high mobility.In optical fiber communication, a huge number of works have been conducted to achieve high capacity, low loss, and further BW in both the local area network (LAN) and wide area network (WAN) [1-8]. According to the Cisco report [9], there is a rapid increasing in demand for the internet. The report anticipated that by 2022, more IP traffic would cross global networks than in all prior (the 32 years since the internet started). Furthermore, the report expected that the number of internet users would reach 60% of the global population. Moreover, 28 billion connections will be online, and multimedia files will make up eighty two percent of all IP traffic. To overcome the demand of the internet, the development of wireless optical communication technology stands out as one of the significant phenomena in the communication systems [7, 10-12]. The main goal of the proliferation of wireless optical communication is to improve both capacities and bandwidth [13, 14]. Today, the highest available carrier frequencies are provided by optical wireless communication systems. In this respect, FSO is considered as a lower-cost in compare with the communication links that are based on conventional fiber-optic cable. FSO is more attractive in the urban area due to the establishment and maintenance easiness, which can vary from $200K to $1M per mile (according to the metropolitan environment)[15]. It is well known that different random weather phenomena affect bandwidth. Because of certain phenomena, the interactions of optical radiation with the atmosphere happen, which rely on its conformation. Several molecular species Existing in the atmosphere in addition to small particles like aerosols (e.g., forest, fog, dust, exudates, sea-salt particles, particulate, volcano debris, smog, pollutants, and smoke), water droplets and ice particles. Consequently, attenuation of optical signals at the atmosphere caused by scattering, absorption and scintillation[16]. Furthermore, in practice, time and geographical location are crucial in wireless optical communication. Therefore, there are three diverse disturbance impacts: 1) beam wander; 2) beam spreading; and 3) scintillation. For instance, the scintillation is most important for FSO links that cause inconstancy in the intensity at the receiver surface[2, 16-19]. In the literature, researchers have applied different techniques to improve the bandwidth and noise in the communication system. In 2015, the authors in [20], studied the transmission of a bidirectional long-haul optical fiber. In their design, as an application in outdoor environments such as bridges, 10-Gb/s hybrid optical fiber (HOF), and free-space optics (FSO) link was transmitted as part of a bidirectional long-haul optical fiber transmission. In contrast to traditional FSO systems, the new generation aimed to be more transparent to an optical fiber by maintaining high data rates, protocols and high signal bandwidths. Over a 100 m link, it was demonstrated a high speed outdoor full-optical FSO system experimentally. In our previous work [19], we proposed a system consists of a comb generator and a flexible multiformat transmitter. Over photonics networks, the implementation of next-generation 5G mobile networks was demonstrated in 2017. In previous work [21], using photonic technology, the concept of generating and transmitting a Millimeter-Wave wave (MMW) wireless signal has been demonstrated successfully. Furthermore, the authors studied three transmission medium/segments where the measures of Error Vector Magnitude (EVM) and BER showed successful communication over 10 Km-SMF, 1meter-RF channels, and 6.5meter-FSO. Moreover, the BER was found to be below the FEC limit of $3.8x10^{-3}$. Over wavelength-division multiplexing passive optical network (WDM-PON), the authors in work published 2017 examined the HOF/FSO design a backhaul downlink [22, 23], Besides, the hybrid backhaul architecture can maintain flexibility, quick deployment in addition to providing high-data-rate. Additionally, over a four-wavelength WDM-PON, the evaluation was conducted for HOF/FSO backhaul downlink under the effect of four-wave mixing. Very recently, in different weather conditions, we investigated 10-channels of mode division multiplexer (MDM) over hybrid free-space optics (FSO) link. The aim of the design concerns of achieving the maximum possible medium-range and fiber to the home (FTTH) for high bandwidth access networks. Accordingly, by using MDM over hybrid FSO-FTTH, the System capacity has effectively improved [14, 24]. The author applied compensation for atmospheric turbulence and modal dispersion in optical communication systems. Over FSO link under different weather conditions and few-mode fiber (FMF) based on linear Bessel filter, we investigated 12-channel Spatial Division Multiplexing (SDM). The experiments demonstrated that the system capacity increases effectively by using SDM over hybrid FSO- fiber to the home (FTTH) that operates at 1550 nm wavelength [17, 25]. It is worth mentioning that the Wavelength-division multiple access (WDMA) is one of the powerful multiplexing and the key feature of a modern communication system. This technology was applied to divide and combine different wavelength channels with improving the bandwidth and capacity of existing optical communications [26][13][27]. Furthermore, hybrid system FSO links and optical fiber-based on WDMA is to improve the bandwidth and increase the capacity of the communication system for fiber to the home access network. The remainder of the paper is structured as follows. The system model is explained in Section 2. The results of the hybrid system simulation are discussed in Section 3. Finally, Section 4 concludes the paper.

2. System model

As illustrated in Figure 1, our system model is a hybrid FSO and the FTTx (FSO-FTTx) link based on WDMA consists of a 14-channel optical transmitter and a 14-channel optical receiver. The system has been designed and simulated by using optical-system software [8, 25, 28-31]. The optical transmitter is used to transmit data signals over the hybrid FSO-FTTx. The transmitted fourteen-channel WDMA over our system that has separated based on the ITU grid are as follows: 192.00 THz, 192.20 THz, 192.40 THz, 192.60 THz, 192.80 THz, 193.00 THz, 193.20 THz, 193.40 THz, 193.60 THz, 193.80 THz, 194.00 THz, 194.20 THz, 194.40 THz and 194.60 THz). The optical transmitter consists of fourteen channels, where each channel includes the following parts:

1. The generator of the Pseudorandom bit sequence at 10 Gbps (140 Gbps is total capacity).
2. The generator of NRZ pulse.
3. Laser and multiplexer, different channels can multiplex at 1 dBm transmission power.

As demonstrated in Table 1, the optical signal is attenuated in different weather phenomena that rich over different distance FSO channels. Then, a de-multiplexer is found to restore the signals from the FSO to fourteen different fiber. The WDMA signals are then propagated through a 450 meters single-mode fiber.

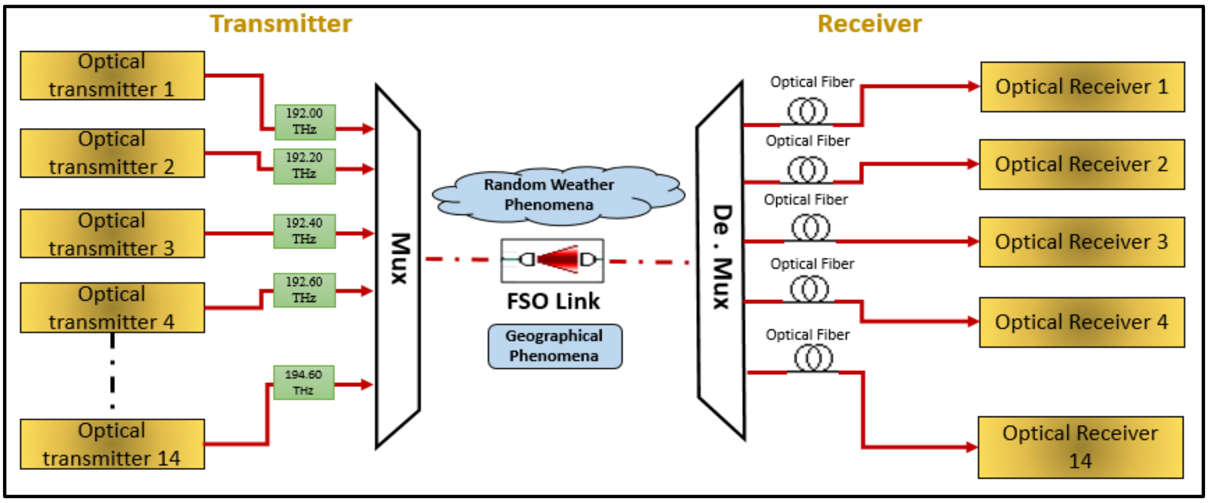

Figure 1. hybrid FSO-FTTx under the effect of random weather phenomena and geographical phenomena

The parameters of the receiver apertures set to 20 cm, and transmitter apertures are set to 30 cm, and beam divergence is one μrad [24, 32]. Finally, the receiver comprises a fourteen-channel optical receiver, an electrical filter, and a performance analyzer.

Table 1. Adopted phenomena and attenuations in our system

Phenomenon	Attenuation (dB-Km)
Very clear air	0.15
Clear sky	0.299
Light rain	0.61
Heavy rain	2.62
Light haze	6.80
Heavy haze	19.77

3. Results and discussion

We evaluated the random weather phenomena and geographical phenomenon over hybrid FSO and FTTx under the effect of the phenomena listed in Table 1. In the evaluation, we measured the Q-Factor and BER of our system based on WDMA in Figures 2-7. In the beginning, as shown in Figures 2 and 3, we calculated system performance in terms of BER and Q-Factor in clear sky weather phenomena, respectively. In the evaluation, we selected six distances (1650 m, 3650 m, 5650 m, 7650 m, 9650 m, and 11650) for each channel (from channel 1 to channel 14).

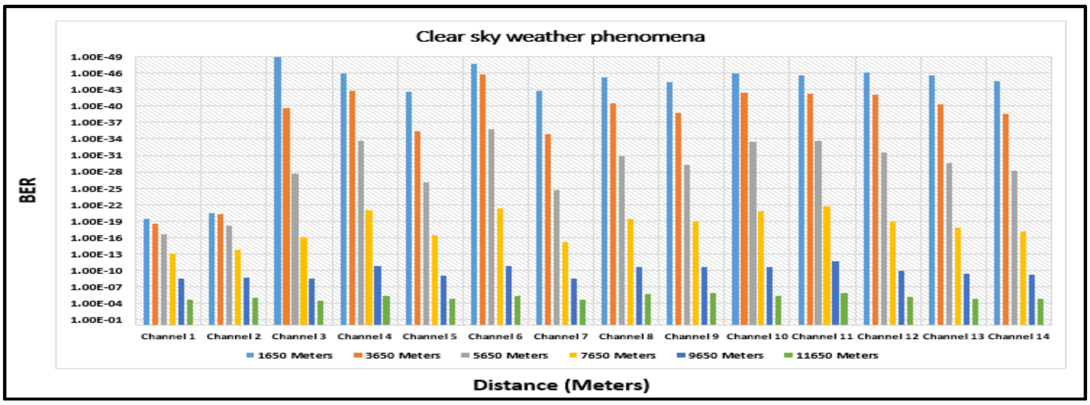

Figure 2. BER results under (clear sky weather phenomenon)

From the findings, we see that transmitting data over hybrid link under the clear sky weather phenomenon in the distances (1650 m to 9650 m) are acceptable. However, the results of the transmission over 11650 m is not enough to be accepted. In the second experiment, as illustrated in Figures 4 and 5, we calculated system performance in terms of Q-Factor and BER in heavy rain weather phenomena, respectively. In the evaluation, we selected six distances (1150 m, 1850 m, 2550 m, 3250 m, 3950 m, and 4650) for each channel (from channel 1 to channel 14). The findings demonstrated that transmitting data over hybrid link under the heavy rain weather phenomenon from the distances (1150 m to 3950 m) are acceptable results. However, the result of the transmitting at a distance of 4650 m is not acceptable.

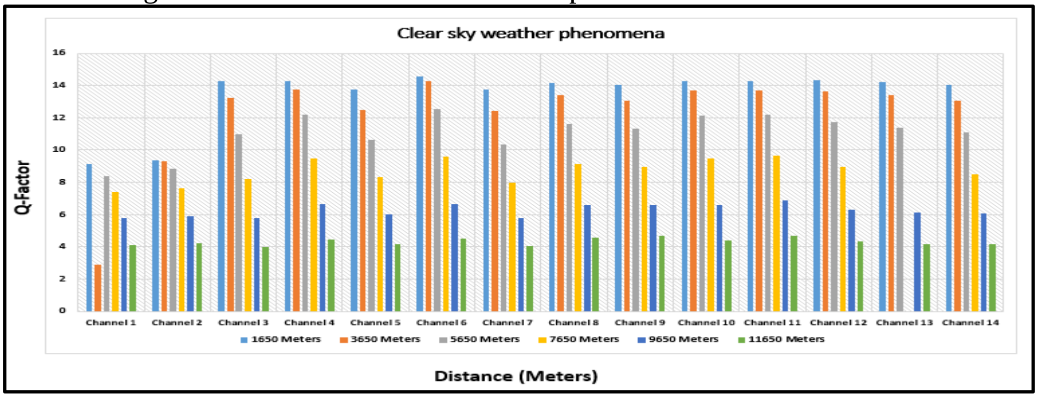

Figure 3. Q-Factor results under (clear sky weather phenomenon)

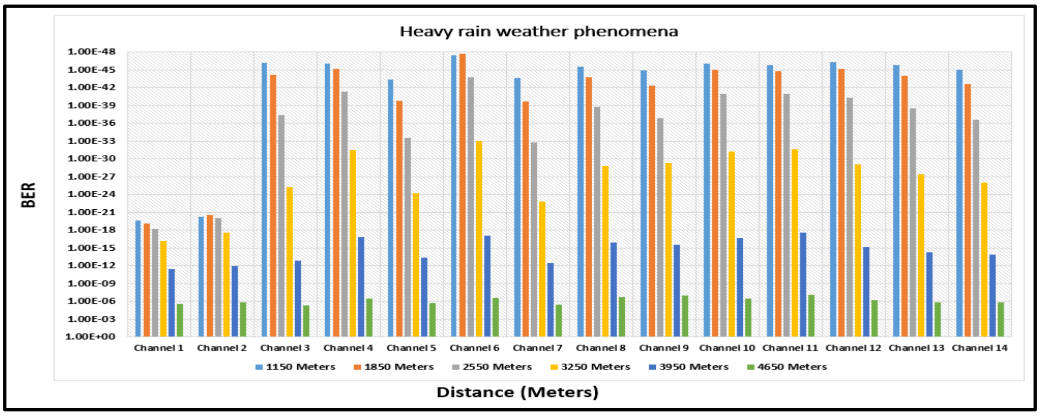

Figure 4. BER results under (heavy rain weather phenomenon)

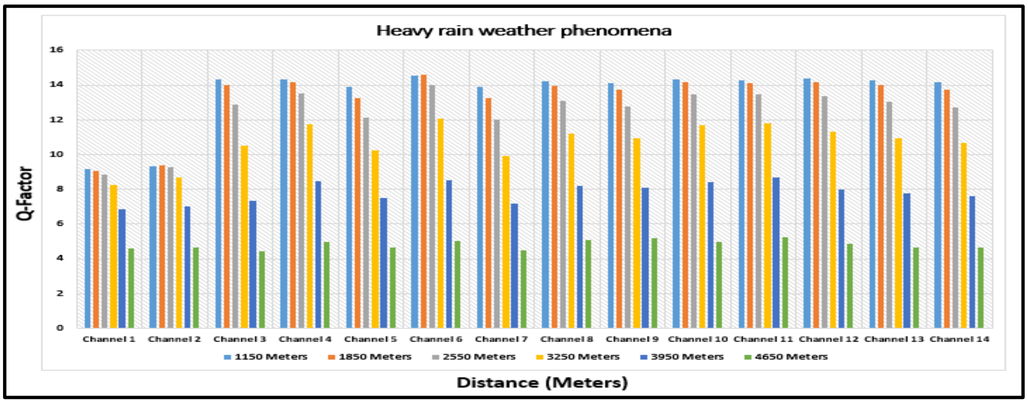

Figure 5. Q-Factor results under (heavy rain weather phenomenon)

In the last experiments, as illustrated in Figures 6 and 7, we calculated system performance in terms of Q-Factor and BER in heavy haze weather phenomena, respectively. Similar to previous tests, in the evaluation, we selected six distances (850 m, 1000 m, 1150m, 1300 m, 1450 m, and 1600 m) for each channel (from channel 1 to channel 14). The findings demonstrated that transmitting data over hybrid link under the heavy haze weather phenomenon from the distances (850 m to 1450 m) are acceptable results. However, the results of the transmitting at a distance of 1600 m is not acceptable.

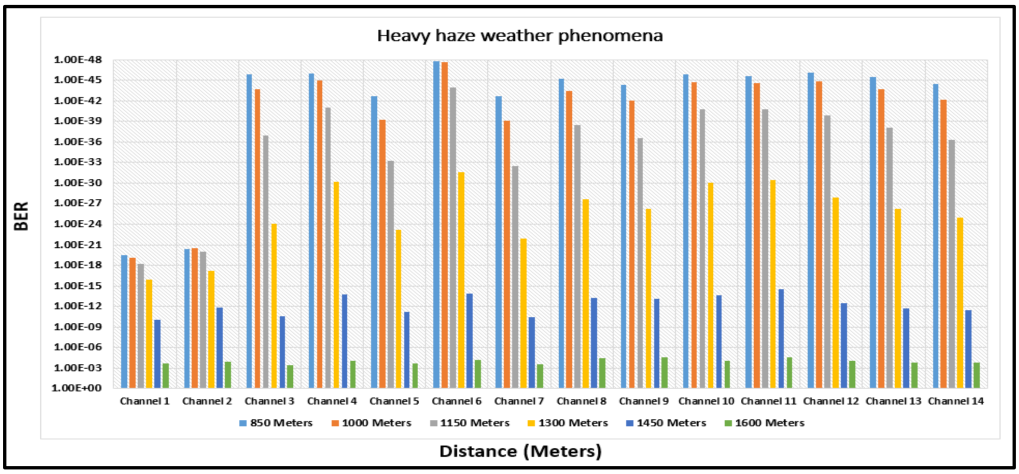

Figure 6. BER results under (heavy haze weather phenomenon)

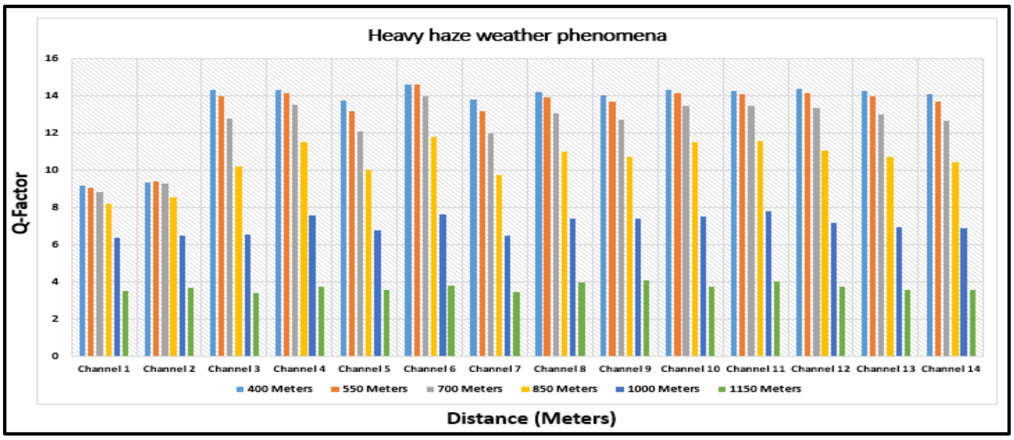

Figure 7. Q-Factor results under (heavy haze weather phenomenon)

4. CONCLUSION

In this article, we proposed a hybrid FSO-FTTx communications link based on WDMA over different random weather phenomena. We transmitted 140 Gbit/s different random weather phenomena that operate over fourteen wavelengths based on the electrical filter. The simulation revealed that we achieved 140 Gbit/s data transmission over 9650 meters over hybrid link under the clear sky and heavy rain weather phenomena. Additionally, 140 Gbit/s data transmission was achieved over 1450 meters over hybrid link under the heavy haze weather phenomenon.

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