Free Space Passive Optical Network

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Abstract. This paper proposes free space passive optical network (FSPON) as a potential candidate of high data rate access network based on optical wireless transmission. FSPON could be considered for indoor as well as outdoor deployments. Pending the progress in FSO range, it is appropriate for short range communication network. The system architecture and network architecture are depicted. A key component for the deployment success is the alignment of the remote terminal equipment's with the free space optical splitter (FSOS). The main advantages and performances of a user terminal station are discussed. The performance comparison has been made with a simple point to point free space optical link. The FSPON capacity is limited to 6 users at the cost of low modulation scheme and high signal to noise ratio.

Keywords: Free space optics · FSO · Passive optical network · PON · FSPON

1 Introduction

Developments in optical transmission have revolutionized the lives of users of information and communications technology [1, 2]. The advent of the fiber and the latest innovations enable transmission of ten order to hundreds of terabits data rates. This is possible through wavelength division multiplexing technology (WDM) [3, 4]. WDM technique by reducing the gap between two adjacent wavelengths provides the ability to simultaneously send information in parallel by occupation of the available spectrum. Thus, each forwarded data stream throughput is maximized in order to optimize the transmission capacity of the fiber. The limitations of the fiber from a technical point of view have been greatly improved from the moment where it is introduced into the access network. This leads to a successful user experience of on provided services. The fiber comes and replace the copper overwhelmed by the growing demand of bandwidth. Actually, the desire to satisfy the needs of users has generated increasingly bandwidth-intensive with network applications or software. Several implementation architecture solutions of the fiber in the access network have been proposed. The first simplest solutions were the Point -to- Point architecture. The high cost of deployment of these solutions has contributed to its gradual shift except for wholesale customers to loop solution and more recently in passive optical networks. Passive optical networks are currently the types of networks whose architecture seems the most economical and best suited for certain types of customers and localities. The first generations of PON solutions offered

C. M. F. Kebe et al. (Eds.): InterSol 2017/CNRIA 2017, LNICST 204, pp. 304–311, 2018.
https://doi.org/10.1007/978-3-319-72965-7_28

capacity in the order of hundreds of megabits shared among thirty-two or sixty-four users. The capabilities of these systems have gradually evolved gigabit and offers on market performance of 40 Gbps. All these solutions have confirmed beyond doubt that the fiber is a necessity to resolve transmission capacity needs. This makes it a complementary solution to satellites that are designed to solve real problems of distance in a network or between continents. Satellites proven with Broadcast solutions like television. What hinder the more the deployment of optical fiber-based solutions is the deployment cost of which at least half goes in the civil works. To this is also added the long delays in implementation and the multitude of permissions issues related to the crucible and operation of certain arteries. A possibility to maintain the performance provided by the fiber while minimizing the above mentioned limitations led to the introduction of optical transmission over space [5–11]. Optical transmission solutions over space called free space optic (FSO) are now a hope for operators and ISPs. It gives the advantage of providing long delays and especially the reduction of investment costs which directly or indirectly augment the benefit to be earned. Different types of FSO equipment with varying data rates could be find in the market. These equipment's used in the case of terrestrial transmission are limited by distance. Explanations found thanks to the different research includes among others the turbulence phenomenon in the light propagation path. Turbulence partially amends the path of the luminous flux. It randomness is actually the real problem that still causes additional work in research. The proposed interim solutions are the use of more efficient coding in combination of multiple antenna systems known as MIMO [9]. Work was also carried out for the optimization of the size of the receiving antenna to recover the maximum possible transmitted photon. Some researchers have addressed the use of repeater systems to overcome these difficulties but this also compromise an additional cost.

Pending progress in the near future to increase the range of FSO systems, we propose in this paper a study of the optical free space transmission version of passive optical network (PON) as an equivalent image of the wireless local loop (WLL). One could also call a type of optical wireless local loop (OWLL). Clear advantages of OWLL are speed of deployment, low-cost solution very skilled broadband today. Immediate applications of this approach can be justified by the multiple interests both indoor in a large room and external environment on reasonable ranges for outdoor applications. Indoor video application for example. In premises or campus areas, the free space passive optical network (FSPON) also provides a faster and cheaper solution for the deployment of a broadband network.

The rest of this paper is organized as follows. Section 2 presents the FSPON architecture. Section 3 is dedicated to the study of the performance of this system for more appropriate modulation scenarios fashionable compared to an initial system point to point. The last section is the conclusion.

2 FSPON System Architecture Description

The Fig. 1 below shows three main parts of the proposed network architecture. The part at the operator's central office side depicts an OLT equipped with a free space optical transceiver called free space optical line terminal (FSOLT).

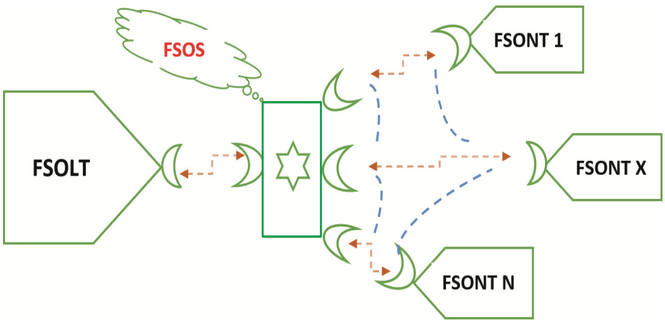

Fig. 1. Free space passive optical network architecture. This shows a figure consisting of a free space optical line terminal (FSOLT), a free space optical splitter (FSOS) and "N" free space optical network terminals (FSONT).

The FSOLT is linked over free space to the second part denoted as splitter is adapted to receive and split in downstream the optical signal to the end users terminals known as optical network terminal (ONT).

The appropriate version of splitter and ONT in our context are called FSOS (free space optical splitter) and FSONT (free space optical network terminal). The passive optical splitter is provided with an antenna in charge of collecting the optical downstream signal from the FSOLT and many other antennas at the customer side. The subscribers of the same cell are allocated a set of antennas at the FSOS. This optical splitter induced considering its imperfection local loss and misalignment loss that does not include losses related to splitting the signal. Customers at their end also have stations in charge of transmitting and receiving as with ONT in the case of the conventional PON. Coordinating the transmission between the FSOS and the multiple FSONT requires a delicate adjustment to minimize interference and pointing offsets.

Figure 2 describes the main components of the FSOLT. The extra part of the FSOLT in comparison to classic OLT is the FSO transceiver which exempts the use of fiber. FSOLT is equipped with application servers and FSO transceivers interconnected thanks to a router. Application servers configured depend on the profile of the equipment sold by the network operators. One of the router interfaces is connected to the driver. The driver has to adapt the incoming signal to low and high tensions that could change the state of the external modulator depending on the nature of the binary data. The modulator receives a constant light power from a laser. Variation of the light power at the output of the Antenna is due to the behavior of the modulator influenced by the transmitted data.

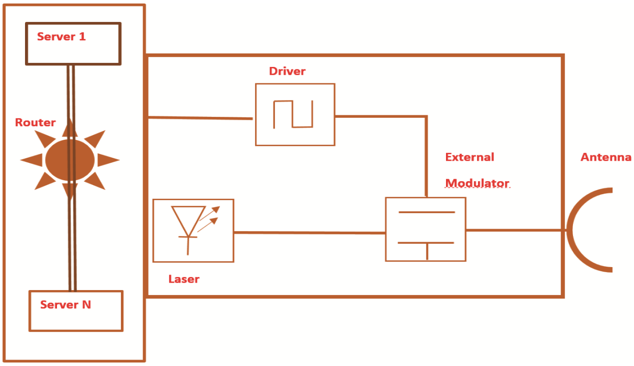

Fig. 2. Free space optical line terminal (FSOLT) system architecture. The FSOLT is located at central office.

Figure 3 details the components of the FSONT. An antenna in charge of collecting the optical signal dispersed over the space feeds a photodiode. The photodiode transforms the optical signal into electrical and its output is connected to a pre-amplifier which delivers a more powered electrical signal. The resulted signal of the filter is post processed in order to detect the user transmitted data to be dispatched by the switch according to the service port.

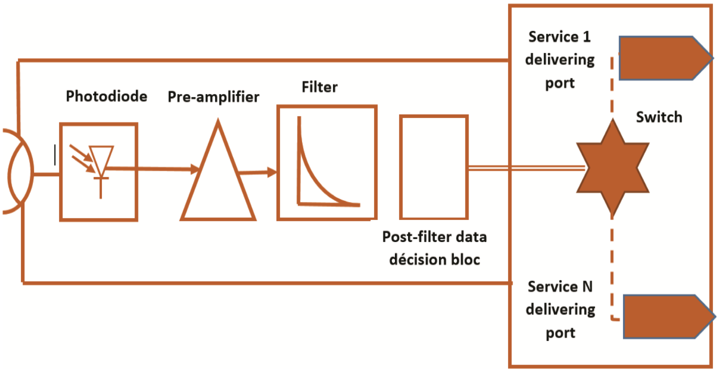

Fig. 3. Free space optical network terminal (FSONT). This shows a figure composed of the classic ONT at the back side liked to an FSO transceivers.

As discussed in the previous section, the main limitation of the FSPON is the range. The range limitation is due to turbulence in addition to attenuation phenomena. In the propagation path, the temperature of the weather may vary. This variation affects the refraction index of the local environment.

$$n_1 \sin i_1 = n_2 \sin i_2 \tag{1}$$

Since Snell Descartes discovery, it is established that a different refraction index may change the light path direction (1).

The received optical signal can be expressed as follows:

$$y = (P)^{1/2} h.x + n \tag{2}$$

P is the average transmitted power, h is the channel gain,
y and x are respectively the received and transmitted data,
n is the noise.

3 Simulation Results

All the FSPON performances have been simulated with MATLAB. Low turbulent channel, short ranges up to 600 m, wavl = 850×10^{-9} and Cn = 0.75×10^{-16} have been considered. The modulation were pulse position modulation (PPM) of 8 states and 2 PPM. The number of end users were limited to a maximum of 6 because of the performance degradation based on the simulation results.

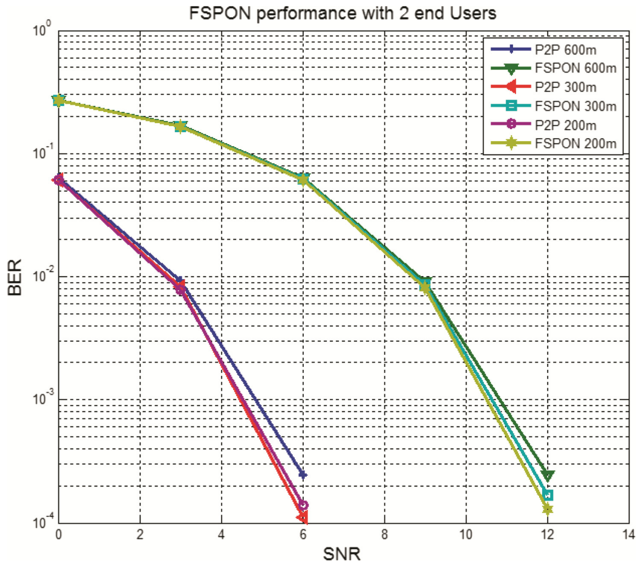

Fig. 4. FSPON performance with 2 end users, 8 PPM and splitter at half-way

In Fig. 4 a user communication link were simulated for a maximum of 2 end users capacity of the FSPON. Comparison were done with a simple point to point FSO link. An idle splitter without any other additional loss in each case is placed at half-way. An 8 PPM modulation were simulated. Even if the performance improves for shorter range, it can be seen that the variation of distance is not the important limitation factor since 600 m, 300 m and 200 m have approximately the same link performance while the other parameters does not change. The simulation results present a gap of 3 dB at a BER of 10^{-3} obtained with a SNR = 9 dB for FSPON.

Figure 5 shows the simulation results for a double number of user in comparison to the simulation in Fig. 4.

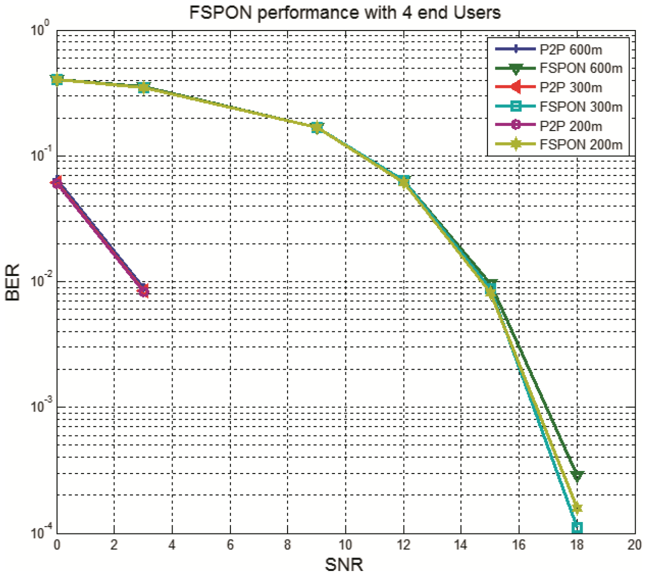

Fig. 5. FSPON performance with 4 end users, 8 PPM

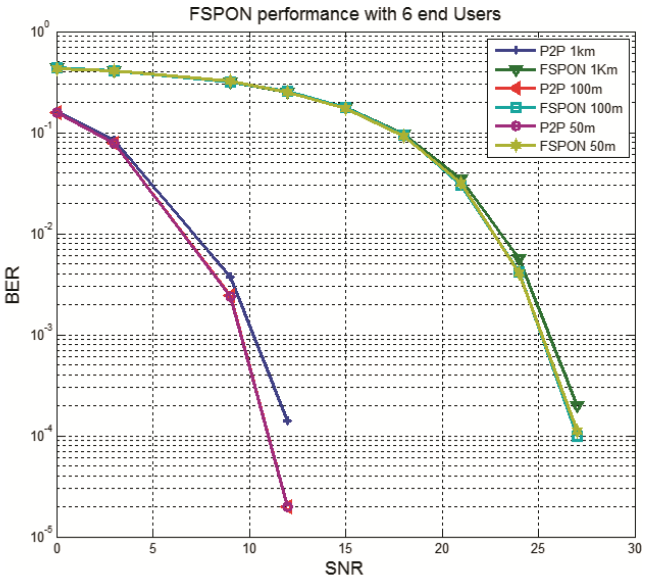

Fig. 6. FSPON performance with 6 end users with 2 PPM, the splitter is at half-way.

In order to support more user a lower modulation scheme might be set. It is the reason why the simulations performed in Figs. 6 and 7 focused on 2 PPM.

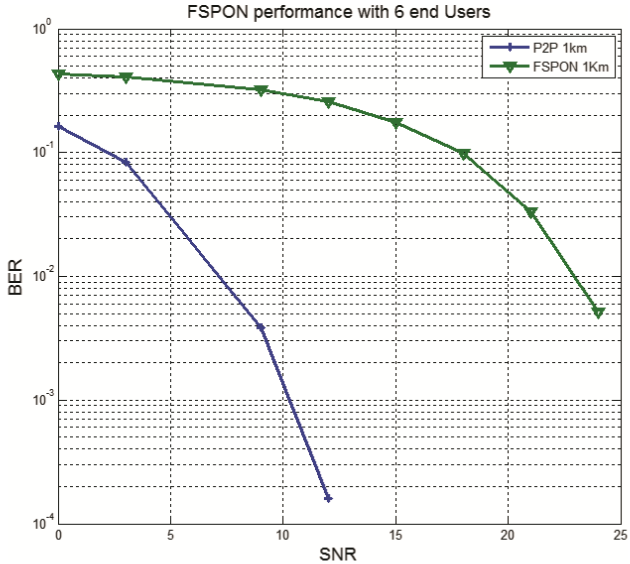

Fig. 7. FSPON performance with 6 end users, 2 PPM, splitter at 250 m of the end users.

Figures 6 and 7 present simulation results performed for a 6 users FSPON with a modulation scheme of 2 PPM but the position of the splitter were changed. In Fig. 6, the splitter were half-way but the splitter were ¼ way from the end users in Fig. 7. The performances show the low impact of distance for full range and also for the position of the splitter. There is a gap of about 16 dB in comparison to point to point optical link in both cases at a BER of 4×10^{-3}.

Our simulations clearly show in the case of low turbulence the great impact of the supported number of user which degrades the FSPON link performance in comparison to the distance. Six users could be supported in the simulated conditions at the cost of low modulation scheme (2 PPM).

4 Conclusion

Free space passive optical network (FSPON) has been presented. The increasing needs of bandwidth constitutes an opportunity for a low cost and fast deployment of FSPON. The difficulty is the channel behavior leading to attenuation and deviation of the optical signal because of turbulence. Splitting the optical signal cost higher bit error rate performance and shorter range. The maximum number of user in comparison to a simple point to point wireless optical is limited to approximately 6 and this depends on the signal to noise ratio and considered modulation scheme.

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