Performance Analysis of Two Way All Optical Relay Assisted PM-FSO over Different Weather Conditions

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This paper proposes a novel method of relaying in Polarization Multiplexing (PM) in Free Space Optical (FSO) networks using amplify and forward and decode and forward relays with and without fixed gain. The idea of multiplexing scheme combined with relay helps in improving the channel capacity and the link distance. To mitigate the inter channel crosstalk that occurs in Wavelength Division Multiplexing, PM is proposed. To avoid the degrading performance of the system due to atmospheric turbulence, QAM modulation scheme is used. The performance of the system is analyzed by considering various parameters like BER, link distance and the transmitted and received power. Monte Carlo simulations are used to validate the results.

Key words: free space Optical communication (FSO); bit error rate(BER); serial and parallel relays; amplify and forward (AF); decode and forward (DF); gamma gamma channel

DOI: 10.20535/RADAP.2018.74.30-35

Introduction

FSO is the trending technology to be used in communication networks for its ease of deployment and availability of license free spectrum, and bandwidth [1, 2]. Many researches are already available to increase the capacity of FSO networks, to meet the growing demands of communication and multimedia applications where WDM is the major focus of interest [3–5]. Since WDM offers extensive capacity increase in terabits/s, this offers a solution the demand in global digital communication. The major problem with WDM in FSO is the inter channel crosstalk, which degrade the system performance more when combined with the turbulence characteristics of atmosphere [5]. WDM is a technology where we need a different wavelength for each transmitted channel. For last mile applications, it becomes costly if we add more number of sources for each transmitted channel. But WDM is imposed of inter channel cross talks and hence PM is proposed in this paper. PM offers a solution that, it allows multiplexing of two channels with same carrier wavelength by separating them into different polarizing beams [6]. To increase the link distance relays are introduced.

The major contribution of this paper can be detailed as follows: in section II, PM in FSO network with amplitude and forward relay is proposed. This offers a cost effective network with easy deployment. This can be combined with RF or Fiber based networks to provide connectivity where RF and fiber solutions are not possible.

In section III, Channel model is explained and QAM is proposed as the modulation scheme which provides the constellation with uniform probability and higher spectral efficiency but with shorter distance.

In Section IV, BER is analyzed.

In Section V, we discussed the results by including all types of noises due to atmospheric turbulences. Gamma Gamma channel model is assumed as the propagation model for simulating the results.

1 System Model: PM–FSO with Relays

The existing WDM FSO with relay assisted system as in [7] is shown in Fig. 1. It consists of single and two hop relays. Inter channel crosstalk is the major issue with WDM and it is dealt with the OOK modulation in [8] and M-PPM in [7]. The existing system uses a multihop WDM FSO with relay nodes to increase the distance.

The system proposed M-PPM as the modulation scheme which is more complex for real time implementation and also it requires a large bandwidth. The multiplexing method used in existing system is WDM which imposes a set of two different laser sources to send two channels which increases the cost of the system.

The proposed system uses single Laser source with the transmitted optical beam is split into two polarized beams which can be used for two channels. The proposed system is shown in Fig. 2.

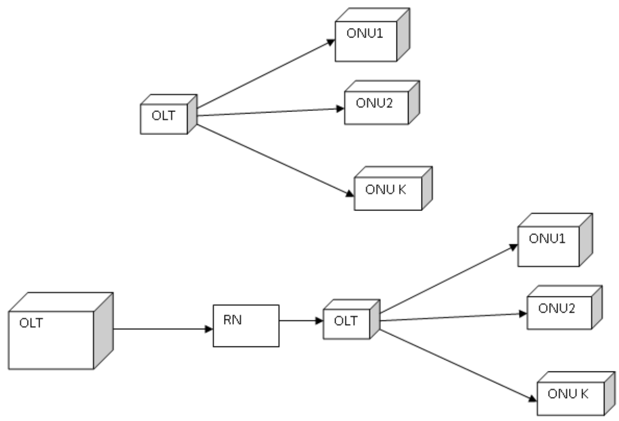


Fig. 1. Existing System WDM/FSO with Relay nodes

Figure 2b shows the remote nodes to provide two way transmissions. The system provides two way communications both upstream and downstream between users at different locations. The total distance transmitted is increased using relay nodes which are at LOS distance from transmitter and receiver.

In this proposed model, we have considered a single Laser source with wavelength λ which is split into E_x and E_y components using a PBS (Polarization Beam Splitter). The two beams are useful in carrying the data for two different channels. The transmitted beams are multiplexed using PBC (Polarization Beam Combiner) instead of WDM MUX.

Each transmitted optical beam enters the relay node which amplifies the received signal and retransmits it. The receiver section detects the optical signal, convert it to electrical signal and demodulate it to original signal.

In existing system, inter channel crosstalk is prominent in the DEMUX due to the imperfections present in it and also it becomes severe if atmospheric turbulence is also considered. Hence the received signal may suffer severe degradations.

In the proposed system, each polarized beam is QAM modulated where each polarized beam is again split into two carriers differ in phase by 90 degrees (I and Q signal). Before sending into the free space, both the signals are combined and transmitted. At the receiver end, for demodulation the carriers are separated and the information bits are recovered.

2 Channel Model: Gamma-Gamma Atmospheric Turbulence Model

We adopted gamma gamma channel model to describe the characteristics of atmospheric turbulences [8]. In our proposed system, as shown in Fig. 2, the source node (S) communicates with the destination node (D) via an intermediate relay node (R). Both the two hop communication uses FSO links. The Relay uses Amplify and Forward Scheme where the incoming signal is multiplied with a fixed gain using EDFA amplifier. The signal received is modeled as

$$Y_{SR} = h_{SR}X + n_{SR}. \tag{1}$$

Where Y defines the received signal at the relay and X is the transmitted signal and n defines the noise introduced in the system. h is the channel matrix defined by gamma gamma model. The signal received at the receiver is modeled as

$$Y_{RD} = h_{RD}G\eta(Y_{SR}) + n_{RD}. \tag{2}$$

The instantaneous SNR at the destination is defined in [8] given by

$$SNR_{SD} = \frac{h_{RD}^2 G^2 \eta^2 h_{SR}^2}{h_{RD}^2 G^2 \eta^2 \sigma_{SR}^2 + \sigma_{RD}^2}. \tag{3}$$

The normalized received irradiance I is defined in [7] as the product of two statistically independent random processes I_x and I_y defined by the equation (4):

$$I = I_x I_y, \tag{4}$$

where I_x and I_y are the large-scale and small-scale turbulent eddies, respectively.

Their probability density function are given by the equations (5) and (6)

$$p(I_x) = \frac{\alpha(\alpha I_x)^{\alpha-1}}{\Gamma(\alpha)}\exp(-\alpha I_x); \tag{5}$$

$$p(I_y) = \frac{\beta(\beta I_y)^{\beta-1}}{\Gamma(\beta)}\exp(-\beta I_y). \tag{6}$$

Gamma gamma irradiance fluctuation is given by equation (7) and (8)

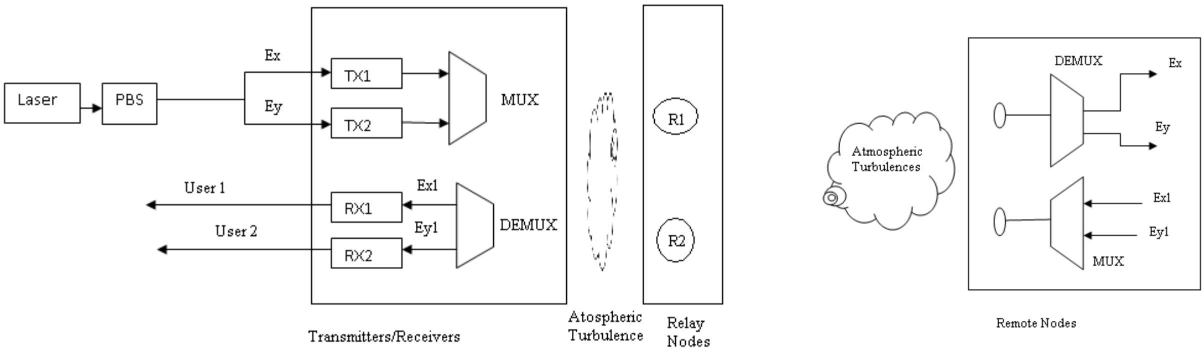
$$p(I) = \int_0^\infty p\left(\frac{I}{I_x}\right)p(I_x)dI_x; \tag{7}$$

$$= \frac{2\alpha\beta^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\alpha+\frac{\beta}{2})-1} K_{\alpha-\beta}\left(2\sqrt{\alpha\beta I}\right), \tag{8}$$

where $I > 0$; α and β represents small scale and large scale eddies of the scattering process. $K(.)$ is modiefied Bessel function of second kind of order n, $\Gamma(.)$ represents gamma function. α and β values are given by the equations (9) and (10) as

$$\alpha = \left[\exp\left(\frac{0.49\sigma_l^2}{(1+1.11\sigma_l^{\frac{2}{5}})^{\frac{7}{6}}}\right) - 1\right]^{-1}, \tag{9}$$

$$\beta = \left[\exp\left(\frac{0.51\sigma_l^2}{\left(1+0.69\sigma_l^{\frac{12}{5}}\right)^{\frac{5}{6}}}\right) - 1\right]^{-1}, \tag{10}$$



(a) (b)

Fig. 2. (a) Transmitters/Receivers at the OLT and Receiver Nodes (b) Remote nodes with MUX and DEMUX

where σ_l^2 is the Rytov variance, defined as

$$\sigma_l^2 = 1.23\left(\frac{2\pi}{\lambda}\right)^{7/6} C_n^2 d^{11/6}, \qquad (11)$$

where λ is the wavelength used, [9] and C_n^2 varies from 10^{-13} m$^{-2/3}$ to 10^{-17} m$^{-2/3}$ and is defined in [10].

3 BER Analysis

Our proposed 32-QAM signal constellation scheme is expressed as the sequence of two unconstrained 8 PAM signals. The Bit Error rate of QAM (12) can be derived from analyzing PAM signals.

$$BER(QAM) = \frac{1}{\log_2(8X4(PAM)} \cdot \left(\sum_{k=1}^{\log_2 8} P_8(k) + \sum_{l=1}^{\log_2 4} P_4(l)\right). \qquad (12)$$

In the system developed in [10], the upstream transmission considers signal and interferer travel distinct paths and in downstream, the signal and interferer is assumed to experience same atmospheric turbulence; crosstalk is assumed as interferer and the probability is calculated. In our proposed model, since the signal of different wavelengths travel with different polarization, it doesn't experience the turbulence effects of interferer. Thus it provides better system performance when compared to WDM FSO.

3.1 Performance Analysis in Upstream and Downstream Transmission

The mathematical model for FSO channel is derived for single parallel relay placed between the source node and destination node. The distance between the source node and destination node is varied and the performance is analyzed. The channel is assumed to be independent and randomly varying due to atmospheric turbulences. We consider three loss factors: attenuation due to absorption and scattering (hs - Rayleigh scattering is considered for simulation), attenuation due to geometric properties like beam divergence (hg) and attenuation due to pointing errors (hp) which are caused by building sway.

The channel between the source and relay node and relay to destination is represented as (13)

$$h_i = h^s h^g h^p. \qquad (13)$$

The probability of error can be written as

$$P_e \leqslant \frac{N-1}{2}\int_0^\infty h_1 \int_0^\infty h_2\, erfc\left(\sqrt{\frac{SNR}{2}}\right), \qquad (14)$$

where h_1 is the channel from source to relay node and h_2 is the channel from relay to destination node. SNR for QAM is already defined in equation (3).

4 Results and Discussions

The simulation parameters used in this work are tabulated in table 1.

Табл. 1 FSO Simulation Parameters

Name	Numerical Value
Load resistance	75 Ω
Electron Charge	1.6×10^{-19} C
Relay minimum spacing	500 m
Relay maximum spacing	2.5 km
Optical wavelength used	1550 nm
Aperture diameter	20 cm
Beam Divergence	2 mrad
Photo detector responsivity	1 A/W

Fig. 3 shows the BER for dual-hop FSO systems with single relay placed between the transmitter and receiver using QAM modulation. The figure is obtained by keeping the distance between the relay and receiver is constant and varying the distance of the relay node from 0.5 km to 2.5 km under clear weather conditions. We obtained better results till 2 km and after 2.5 km, no signal is received.

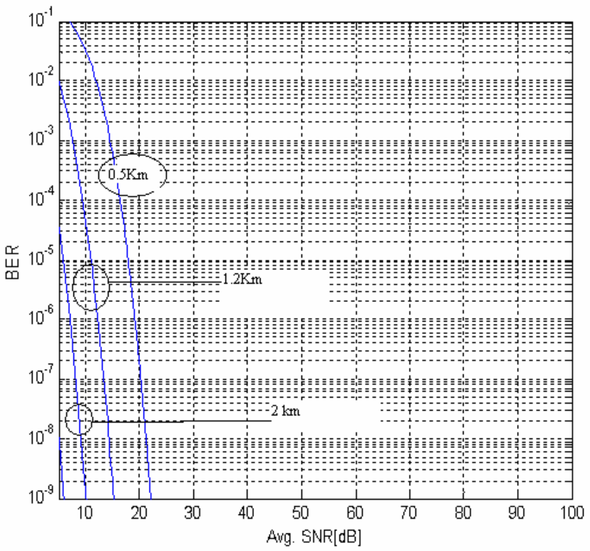


Fig. 3. Avg. SNR Vs BER for dual-hop FSO system

Fig. 4 shows the BER for with two relays placed in FSO systems between the transmitter and receiver using QAM modulation. The figure is obtained by keeping the distance between the second relay and receiver is constant and varying the distance of the first relay node from 0.5 km to 2.5 km under light Fog Conditions. We obtained better results till 1.8 km and after 2 km, no signal is received.

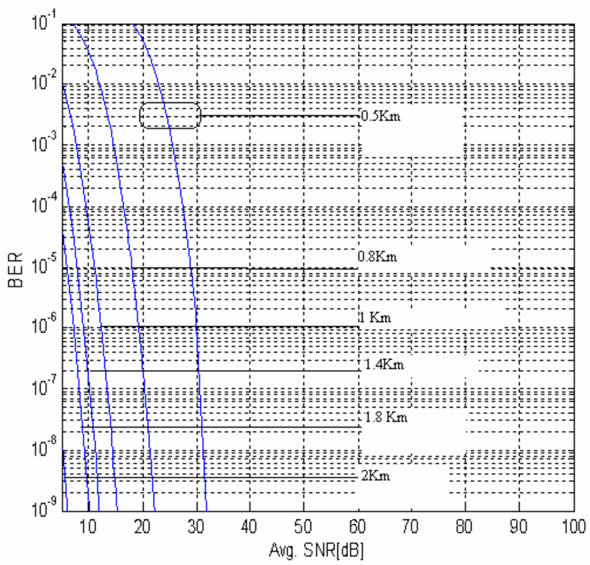


Fig. 4. Avg. SNR Vs BER for Multi-hop (with 2 relays) FSO system

Fig. 5 shows the BER for with two relays placed in FSO systems between the transmitter and receiver using QAM modulation. The figure is obtained by keeping the distance between the first relay and receiver is constant and varying the distance of the second relay node from 0.5 km to 1.8 km under clear weather Conditions. We obtained better results till 0.8 km and after 1.2 km, no signal is received.

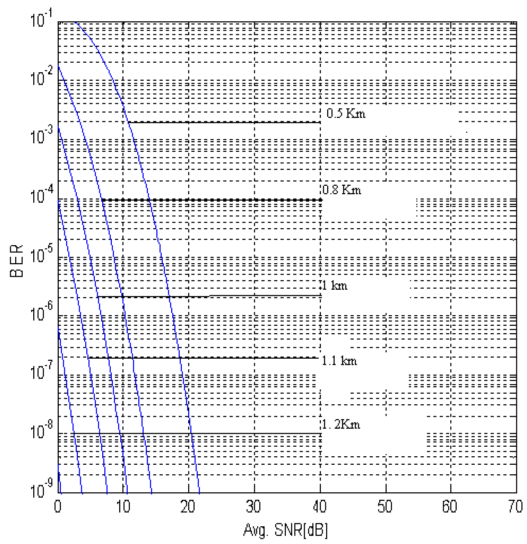


Fig. 5. Avg. SNR Vs BER for Multi-hop (with 2 relays) FSO system under clear weather conditions

Fig. 6 shows the BER for with two relays placed in FSO systems between the transmitter and receiver using QAM modulation. The figure is obtained by varying simultaneously the distance between the first relay from 0.5 km to 1.2 km and the second relay node from 0.5 km to 1.5 km under clear weather Conditions. We obtained better results when we keep 0.5 km for the first relay and 1 km for the second relay.

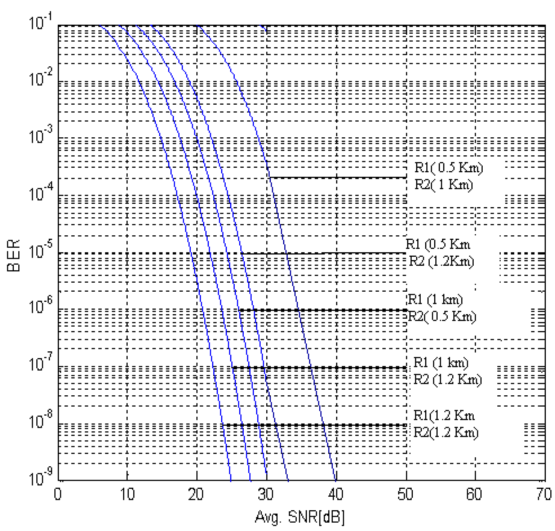


Fig. 6. Avg. SNR Vs BER for Multi-hop (with 2 relays with varying distance) FSO system under clear weather conditions

Fig. 7 shows the outage probability for various gamma distribution values for both AF and DF relays. Here we considered a single parallel relay placed between the source and destination nodes. The distance between the relay and source is 1.3 km and between the relay and destination is 1 km. Figure shows better performance for AF relays than DF relays.

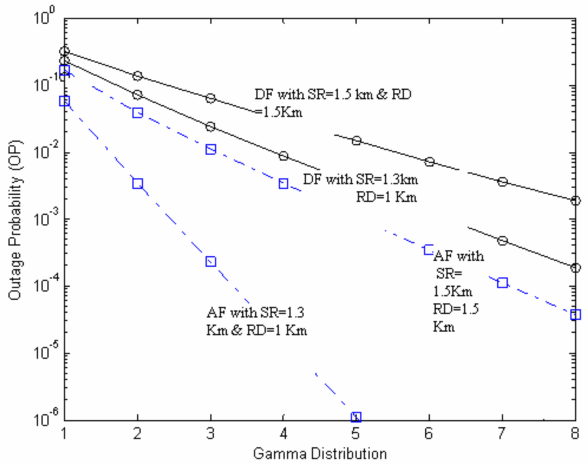


Fig. 7. Gamma Distribution Vs Outage Probability

Fig. 8 shows the outage probability for Avg. SNR for both fixed and variable gain AF and DF relays. Here also, we considered a single parallel relay placed between the source and destination nodes. The distance between the relay and source is 1.2 km and between the relay and destination is 0.8 km. Figure shows better performance for AF relays than DF relays. For fixed gain both AF and DF shows similar performance but for variable gain DF shows better performance than the system with AF relays.

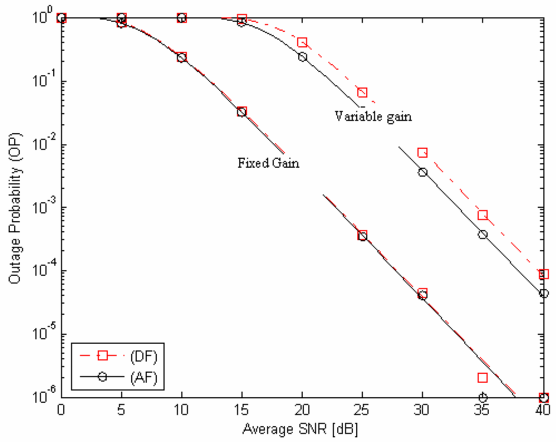


Fig. 8. Avg. SNR Vs Outage Probability (Fixed and Variable Gain)

Conclusion

This paper analyzed a method of relaying in Polarization Multiplexing (PM) in Free Space optical (FSO) networks using amplify and forward and decode and forward relays with and without fixed gain. The effect of different atmospheric conditions for the relays with single and dual relay nodes is analyzed and graphs are plotted by varying the link distance. The analysis of the system shows a different aspect of multiplexing the data using PM without using WDM which gives satisfactory results. The PM provides a way to increase the capacity of the system whereas relays provide a way to enhance the link distance.

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Аналіз продуктивності дуплексної оптичної передачі даних з PM-FSO за різних погодних умов

Джаярані Д., Кумар Д. Ш.

У статті пропонується новий метод ретрансляції в оптичних мережах вільного простору з поляризаційним мультиплексуванням (ПМ) з використанням реле фіксованим підсиленням і без нього. Ідея схеми мультиплексування в поєднанні з реле допомагає поліпшити пропускну здатність каналу і відстань між лініями. Для зменшення міжканальних перехресних перешкод, що виникають у разі використання мультиплексування за поділом по довжині хвилі, пропонується ПМ. Для уникнення погіршення продуктивності системи через атмосферну турбулентність використовується квадратурна амплітудна модуляція (КАМ). Продуктивність системи проаналізована з урахуванням різних параметрів, таких як BER, відстань зв'язку, потужність передавача і чутливість приймача. Для підтвердження результатів використано метод Монте-Карло.

Ключові слова: оптичний зв'язок у вільному просторі; ймовірність бітової помилки; BER; послідовні і паралельні реле; підсилення; декодування; гамма-гамма канал

Анализ производительности дуплексной оптической передачи данных с PM-FSO в различных погодных условиях

Джаярани Д., Кумар Д. Ш.

В статье предлагается новый метод ретрансляции с поляризационным мультиплексированием (ПМ) в оптических сетях свободного пространства (ОССП) с использованием реле с фиксированным усилением и без него. Идея схемы мультиплексирования в сочетании с реле помогает улучшить пропускную способность канала и расстояние между линиями. Для уменьшения межканальных перекрестных помех, возникающих при мультиплексировании с разделением по длине волны, предлагается ПМ. Для избежания ухудшения производительности системы из-за атмосферной турбулентности, используется схема модуляции КАМ. Производительность системы проанализирована с учетом различных параметров, таких как BER, расстояние связи, мощность передатчика и чувствительность приемника. Для подтверждения результатов использован метод Монте-Карло.

Ключевые слова: оптическая связь в свободном пространстве; вероятность битовой ошибки; BER; последовательные и параллельные реле; усиление; декодирование; гамма-гамма канал