Reduction in BER in FSO Using Amplify and Forward Relaying Techniques

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Abstract- **Multihop free space optical (FSO) system using optical amplify-and-forward (OAF) relaying technique combine with wavelength division multiplexing (WDM) is proposed for all-optical access networks. The proposed system can provide a low cost, flexible, and high-bandwidth access network for multiple users. To investigate the system performance, we consider a special case of dual-hop WDM-FSO system taking into account the effects of all noises, inter channel crosstalk, as well as path loss and geometric spreading of optical beam over atmospheric turbulence channels. In addition, pulse position modulation (PPM)is employed for improving the overall performance. Our results show that OAF technique combined with PPM scheme can be a good solution for mitigating the effect of atmospheric turbulence. Moreover, the required amplifier gain corresponding to a specific value of BER, transmission distance, and turbulence strength is quantitatively discussed. Finally, the adverse effect of inter channel crosstalk in the upstream transmission is also evaluated.**

I. INTRODUCTION

Free Space Optical Link

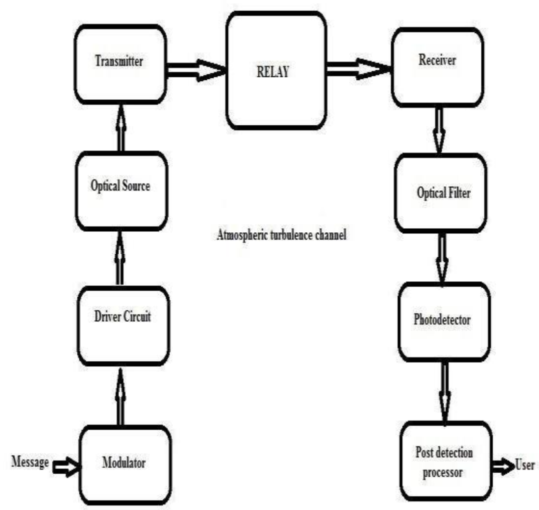
Free Space Optics (FSO) is a communication technology that uses light as a carrier and free space as medium to transfer information between two terminals.. This technique is widely known as Optical Wireless Communication (OWC). With increase in number of users, demand for bandwidth in communication is increasing significantly. Applications like mobile, video conferencing etc. requires large amount of bandwidth, so the coming communication technology must be able to handle such higher data rates. Current technologies have lots of limitations and cannot handle such applications efficiently. Performance of technologies like copper/coaxial cables, RF (microwave) and optical fiber is limited because of problems like congested spectrum, lower data rate, expensive licensing, security issues and high cost of installation. Relay-assisted FSO transmission which was introduced in context of the radio frequency (RF) cooperative relaying protocols, has been popularly used as a fading mitigation tool. In the cooperative RF systems, the source broadcasts information to multiple relays, which forward the information to the destination. However, unlike the RF counterpart, the FSO systems are non-broadcasting in nature. Hence, the source needs to be equipped with a multi-laser transmitter for each relay node, with the total source power divided amongst the multiple source-relay links.

II. SYSTEM MODEL

The object of the communication system is to transfer data or information from a transmitter at one point to a receiver at another point through the atmospheric channel within acceptable error rate while providing high reliability. The FSO link comprises of three basic subsystems - transmitter, channel and receiver Alternative transmission protocols which can be applied to relay-assisted FSO systems with no LOS between the source and the destination.

For the signaling rates of interest, the atmospheric channel does not vary within one packet. Thus, channel state information (CSI) can be easily obtained for all or for some of the involved links. Capitalizing on this fact, the presented protocols select only a single relay to take part in the communication in every transmission slot, thus avoiding the need for synchronization between the relays. It should be noted that similar relay selection protocols have been also proposed in the context of radio-frequency relaying systems.

Today's FSO systems use either lasers or LEDs (light emit- ting diodes) to transmit a modulated beam of visible/infrared light .These systems are license-free with high-bandwidth capacity providing a cost-effective and easy-to-install alternative to fiber optics. They further provide an inherent security due to the nature of their 6 directional and narrow beams which make eavesdropping and jamming nearly impossible. With its unique features, FSO communication is appealing for a number of applications including last-mile access, fiber back-up, back-haul for wireless cellular networks, and disaster recovery.



III TRANSMITTER

The primary function of the transmitter is to modulate the information onto the optical carrier which then propagates and reaches the receiver after propagating through the atmosphere. Optical transmitter essentially consists of (a) modulator, (b) driver circuit that stabilizes the optical radiation from the optical source in case of fluctuations in temperature and (c) telescope, that collects the radiation, collimates it and finally directs it towards the receiver. The most widely used modulation is the intensity modulation (IM) in which the source data is modulated on the irradiance/intensity of the optical signal. The main idea behind cooperative diversity is based on the observation that in a wireless RF channel, the signal transmitted by the source node is overheard by other nodes, which can be defined as partners or relays. The source and its partners can jointly process and transmit their information, creating a virtual antenna array although each of them is equipped with only one antenna The main idea behind cooperative diversity is based on the observation that in a wireless RF channel, the signal transmitted by the source node is overheard by other nodes, which can be defined as partners or relays. The source and its partners can jointly process and transmit their information, creating a virtual antenna array although each of them is equipped with only one antenna.

Multihop transmission is an alternative relay-assisted transmission scheme which employs the relays in a serial configuration Such schemes are typically used to broaden the signal coverage for limited- power transmitters and do not offer performance improvement against fading effects in wireless RF environments, i.e., it does not increase the diversity order.

IV RECEIVER

The primary function of the receiver is to recover the transmitted data from the incident optical radiation. It consists of a receiver telescope, optical filter, photo-detector and a demodulator. The receiver telescope collects and focuses the incoming optical radiation onto the photo-detector. The optical filter reduces the level of background radiation and directs the signal onto the photo-detector that converts the incident optical signal into an electrical signal.

V OPTICAL AMPLIFY-AND-FORWARD RELAYING TECHNIQUE

multihop FSO communications using all-optical components is studied.The distance dependence of atmospheric turbulence and path loss limits thetotal communicating distance in FSO systems. Using relaying techniques, "FSO transmissionis possible over longer distances. High-bandwidth, short-distance free-spaceoptical tranceivers, e.g 10Gbps TereScope TS-10GE, encourages replacement of electricalrelaying processors by optical elements in all relays. In this chapter, it is shownthat by using all-optical relaying techniques, longer communicating distances can beachieved in FSO systems while taking advantage of high-rate optical transmissions.

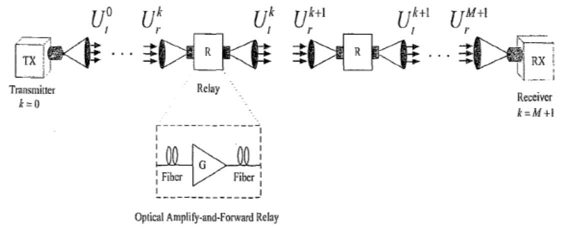


Fig:-1 An All-Optical multihop FSO Communication System

VI. OAF RELAY STRUCTURE

In OAF relaying, there is at least one optical amplifier which amplifies the receivedoptical field and retransmits it to the next relay. The structure of a typical OAF relayis simply shown in Fig.1 As mentioned, there is a converging lens at the beginningof each relay that collects and focuses the incident light onto the back focal plane ofthe lens, a plane normal to the lens axis placed at distance f_{focal} behind the lens. The complex amplitude distribution of the field in the focal plane of the lens is the Fraunhofer diffraction pattern of the field incident on the lens. This field distributionis projected onto a single mode fiber (SMF).

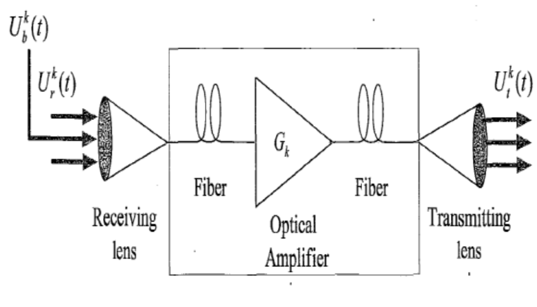


Figure-2 Structure of OAF Relays

The SMF is connected to the optical amplifier that is mathematically modeled as

$$U_t^k(t) = \sqrt{G_k}U_T^k(t) + U_{ASE}^k(t), \qquad (1)$$

where $U_T^k(t)$ and $U_t^k(t)$ are the received and transmitted signals at the k^{th} relay respectively, G is the k^{th} amplifier gain and $U_{ASE}^k(t)$ is the amplified spontaneous emission (ASE) noise of thek^{th}amplifier. The ASE noise is modeled as an additive zero-mean white Gaussian noise. The spectral density of ASE noise is given by .

$$N_0^k = \bar{h}f(G_k - 1)n_{sp}, \qquad (2)$$

VII OPTIMAL RELAYING CONFIGURATION

relays are placed at fixed stations between the source and destination nodes. It is important to arrange relays such that the best system performance is achieved at the receiver. In this section, the performance of the system is analyzed in terms of the average optical signal-to-noise ratio (SNR) at the receiver. In the considered multihop system, relays are consecutively placed between the source (k =0) and destination (k = M+ 1) nodes. Figure-3 shows an optical Amplify-and- Forward multihop system with M relays, where OAF relays are typically shown as amplifiers. The hop distance, L_k ,which is the length ofthe link connecting the (k-1)thnode to the k^{th}node varies for different relays. Let U_t^0 denotes the transmitted signal at

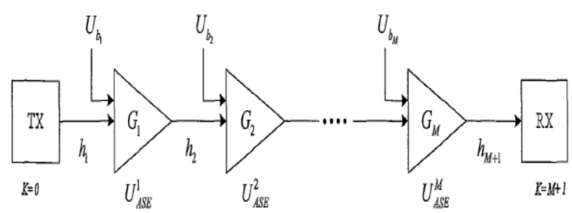


Figure:3 Optical Amplify-and-Forwardmultihop FSO Systems

the source, the received field at the j^{th}relay,, j = 1,2....M + 1, is expressed as

$$U_r^j = \left(\prod_{k=1}^{j-1}\sqrt{G_k}h_k\right)h_j U_t^0 + \left(U_b^j + \sum_{i=1}^{j-1}\prod_{k=i}^{j-1}\sqrt{G_k}h_{k+1}U_b^i\right) + \left(h_j U_{ASE}^{j-1} + \sum_{i=1}^{j-2}\prod_{k=i+1}^{j-1}\sqrt{G_k}h_k h_j U_{ASE}^i\right) \quad (3)$$

Assuming that the signal, background noise, ASE noise and fading are all independent, the average received power at the receiver (j = M+ 1) is

$$P_r^{M+1} = \left(\prod_{k=1}^{M} G_k h_k\right) g_{M+1} + \left(1 + \sum_{i=1}^{M}\prod_{k=i}^{M} G_k g_{k+1}\right) P_b + \left(g_{M+1}P_{ASE}^M + \sum_{i=1}^{M-1}\prod_{k=i+1}^{M} G_k g_k g_{M+} P_{ASE}^i\right) \quad (4)$$

In order to analyze variations of the data signal power and noise during the channel, the average optical SNR is defined as the ratio of the average data signal power to the average total noise power. From Eq.(4), the average optical SNR at the receiveris obtained as

$$\mathrm{SNR}^{M+1} = \frac{\left(\prod_{k=1}^{M} G_k g_k\right) g_{M+1} P_t}{\left(1+\sum_{i=1}^{M}\prod_{k=i}^{M} G_k g_{k+1}\right)P_b + \left(G_{M+1} P_{ASE}^{M} + \sum_{i=1}^{M}\prod_{k=i1}^{M} G_k g_k g_{M+1} P_{ASE}^{i}\right)P_b} \quad (5)$$

Typically amplifier spontaneous emission noise PASE is negligible with respect to data power $P_t$and background noise power P_b, therefore Eq.(5) can be approximated as

$$\mathrm{SNR}^{M+1} \approx \frac{\left(\prod_{k=1}^{M} G_k g_k\right) g_{M+1} P_t}{\left(1+\sum_{i=1}^{M}\prod_{k=i}^{M} G_k g_{k+1}\right)P_b} \quad (6)$$

By substituting euations, and performing some simplifications, the average optical SNR is expressed as

$$\mathrm{SNR}^{M+1} = \frac{1}{\left[\prod_{k=1}^{M+1}\left(1+\mathrm{SNR}_k^{-1}\right)\right]-1} \quad (7)$$

WhereSNR_k is the average receive SNR at the receiver of a direct FSO link (where there is no relay between transmitter and receiver) with length L_k :

$$\mathrm{SNR}_k = g_k\, \mathrm{SNR}_0 \quad (8)$$

The path loss $g_k$depends on the hop distance L_k .Now,SNR^{M+l} must be optimized with respect to L_k'S. Consider the optimization problem

$$\max_{L_k} \mathrm{SNR}^{M+1}$$
$$\text{s.t } \sum_{k=1}^{M+1} L_k = L_T \quad (9)$$

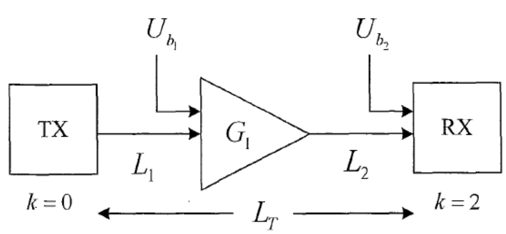


Figure:4 An OAF multihop FSO System with M= 1

VII.FIXED TOTAL COMMUNICATING DISTANCE

Consider an FSO system where the some and destination nodes are placed at a total communicating distance of L_T= 3 km from each other. In this section, by placing a different number of relays (different M) between the source and destinationnodes, the significant role of relaying technique in improving the performance of thesystem is justified. In order to simulate the FSO system in the slowly-varying optical channel, 10^7 bits are transmitted per channel state. At both bit rates, 64 samplesper bit interval are provided. In the presence of atmospheric turbulence, the BER is averaged over N^T= 1000 different fading conditions to reasonably simulate the slow-fading turbulence channel.

The overall performance of the system for different number of relays, M, placedbetween the source and destination is analyzed by plotting the BER versus the transmit signal-to-noise ratio $\mathrm{SNR}_0 = P_t/P_b$.Fig.5 and 6 correspond to the systems working at bit rates BR= 1.25 Gbps andBR= 10 Gbps respectively. The turbulence fading effects are not considered in these plots. Table 1 summarizes the configuration, i.e., number of relays and hop distance, of the systems considered in these figures.

The overall performance of the system only depends on the average transmit SNR_0 and the relaying configurations, g_k. By comparing two figures,

Table 1: Different system configurations for L_T= 3 km.

Marker	hop Distance . L_k(km)	Number of Relays M
⊖	3	0
×	1.5	1
□	1	2
●	0.75	3
✳	0.6	4
▽	0.5	5

it is justified that for a given SNR_o the system performance for a specific configuration is nearly the same at both bit rates. Since the amount of background power is relative to the optical bandwidth or equivalently optical bit rate, the noise power collected at each relay (or receiver) in 10 Gbps system is more than the noise power in 1.25 Gbps system. Therefore, In order to gain relatively similar performance at both bit rates, almost 9dB more power must be transmitted by the system operating at 10 Gbps. The maximum average power transmitted by the state-of-the-art FSO transceivers is on the order of hundreds of miliwatts, SONAbeam™ 1250-M transceiver sends P_t= 640 mW power via focus transmitters each sending 160 mW. By assuming P_t= 640 mWas the maximum available transmit power, the maximum achievable SNR_0 at BR= 1.25 Gps and BR= 10 Gbps is about 39 dB and 30 dB respectively.

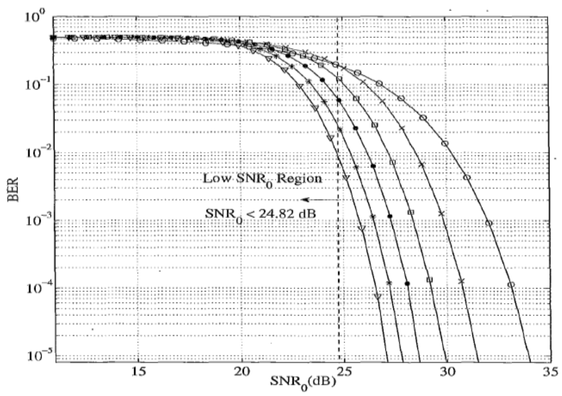


Figure :5 BER versus SNR_0 for a 3 km link and different number of relays M at BR= 1.25 Gbps, no fading effect is considered.

At both bit rates, for a given SNR0, by shortening the hop distances via inserting more relays between communicating nodes (increasing M), BER at the destination node decreases. its shown in Fig.5 and 6, inserting one relay at the middle of a3 km link gains 2.49 dB improvement at BER = 10-5Here the effects of atmosphericfading are not considered. Thus this gain mainly comes from the reduction in pathloss achieved by shortening the hop distances.

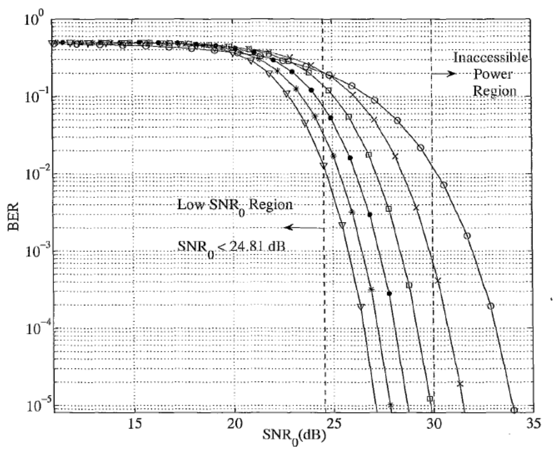


Figure:6 BER versus SNR_0 for a 3 km link and different number of relays M at BR= 10 Gbps, no fading effect is considered.

Simulation

In this Paper the major objective that we have discussed

1) Mitigation of atmospheric turbulence by more no of relays

2) Comparison of the FSO signal transmission with and without AF RELAYING which we can clearly observe reduction into BER

3) Large bandwidth signal can also propagate through AF relaying technique

4) If no of relays has been increase then more reduction in BER occur

This paper presents new optical relaying techniques to mitigate atmospheric turbulence induced fading effects and eliminate background noise in free space optical (FSO) communication systems. The main contributions of the thesis are proposing all-optical amplify-and-forward (OAF) relaying technique and applying them to relay assisted FSO systems. In order to define an all optical relay-assisted FSO system, a new channel model is developed which characterizes the variations of intensity and phase of the optical signal during wave propagation. An additive AWGN channel is assumed in which background illumination is the dominant source of noise. Three primary factors have been considered to model the free space channel effects:

1) Atmospheric attenuation which includes both absorption and scattering contributions

2) log-normal fading under weak atmospheric turbulence conditions

3) Propagation loss due to optical beam spreading through optical channel. The Beers-Lambert law is modified to find the atmospheric attenuation factor applied to the optical field envelope. Since the optical field envelope is analyzed, both amplitude and phase of atmospheric-induced fading are statistically modeled and new definition for propagation loss is defined.

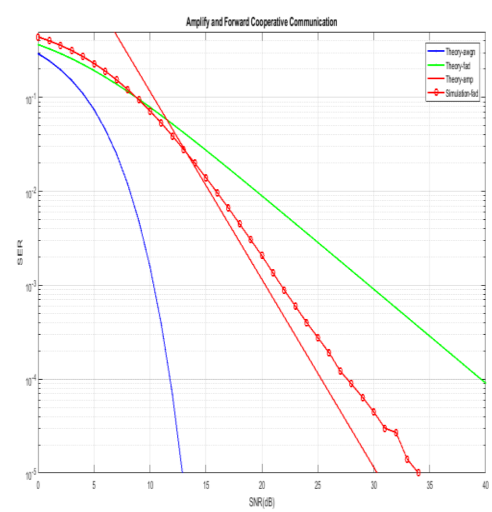


Fig:-7comparison of BER with and without relay when Pt =1mW

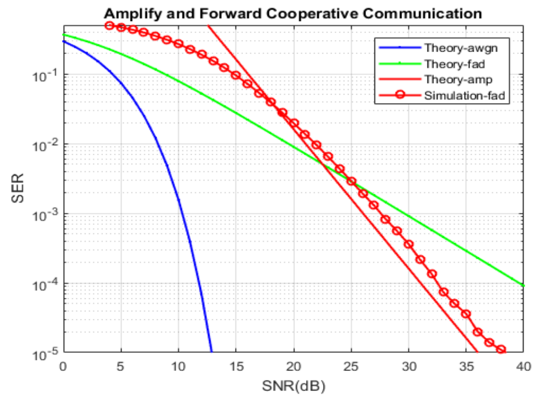


Fig:8 comparison of BER when Pt =100 mW

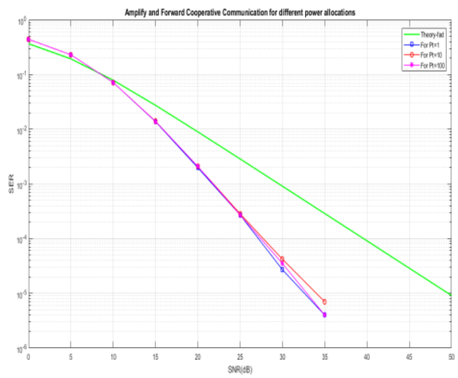


Fig:9comparison of BER with and without relay when Pt =1,10,100 miliwatt

The numerical results show that the new model for propagation loss is close to the conventional model (geometric loss), however, the proposed model provides more accurate estimation of beam propagation loss especially over short ranges (a few hundred meters). The OAF relaying technique is proposed as a powerful technique for mitigating the atmospheric turbulence-induced fading while all relaying processes, e.g. amplification, filtering (as needed) etc. are performed in optical domain.

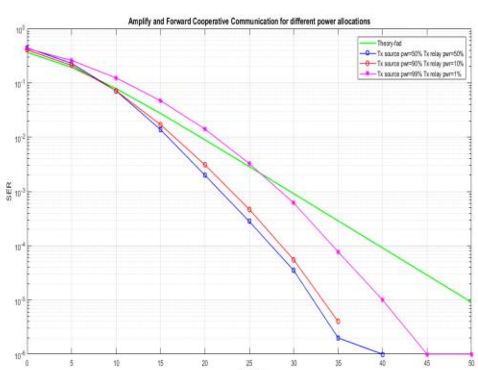


Fig-10 BER if total transmit power distribution for different percentage to source and relay (source have more power compare to relay)

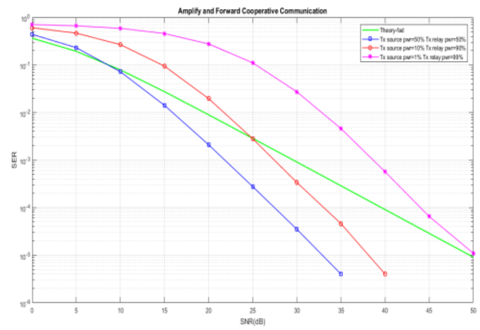


Fig:-11BER if total transmit power distribution for different percentage to source and relay (source have less power compare to relay)

It is numerically shown that by increasing the number of relays between source and destination, hop distances decrease and consequently distance-dependent atmospheric-induced fading is mitigated. In fact by employing more OAF relays, longer communicating distances are accessible for a given average transmit power. FSO communication systems suffer extensively from atmospheric turbulence and background noise.

IV. CONCLUSIONS

We investigated transmission protocols for relay-assistedFSO systems Increasing the number of relays is accompanied by collecting more additive background noise at relays that degrades the system performance. Therefore, to reach a specific communicating distance at a given BER, a tradeoff is compromised between the average transmit power and the number of relays. Since the average transmit power is limited due to eye-safety regulations, the number of relays determines the maximum communicating distance. By increasing the number of relays, besides the total communicating distance, the background noise also increases so that the distance improvement reduces. Although the OAF relaying technique reduces the effects of atmospheric fading, background noise still remains as a limiting factor in FSO communication systems. An optical regenerative relaying method using non-linear optics is developed to reduce the background noise effects and increase the communication distance coverage.

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