Spatial Diversity and Multi Hop in FSO Communication Over Turbulence Channels

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Abstract

Free-space optical (FSO) communication systems have high data rate and perfect end-user communication solutions. On the other hand, FSO bit error rate (BER) performance degrades with the atmospheric turbulence and the weather attenuation. Spatial diversity and relay assisted techniques have been proposed in literature as a solution for these problems. However, authors concentrate on the comparison between either spatial diversity and single-input single-output (SISO) or relay assisted techniques and SISO. In this paper, comparisons between a multi hop decode and forward (DF) relay and a multiple-input single-output (MISO) system are driven under different turbulence and weather conditions. Our results show that multi hop DF relay outperforms MISO, with number of transmitters equal to the number of hops, using repetition codes for correlated case in the BER performance under different conditions.

Keywords: *Free-space optical communications; atmospheric turbulence; spatial diversity; repetition Codes (RCs); decode and forward (DF) relay.*

1- Introduction

Nowadays, free-space optical (FSO) communication systems have gained a lot of attention due to its high data rate and its advantage in end-user communication solution. FSO face a lot of challenges as atmospheric turbulence and weather attenuation effects. Atmospheric turbulence is the main reason of fading in FSO. Weather attenuation results from rain, snow, dust, fog or haze [1, 2]. Spatial diversity using intensity modulation with direct detection (IM/DD) as a cheap and simple technique is proposed [3–7] to mitigate the atmospheric turbulence.

In [8, 9], three methods are used based on orthogonal space time block codes (OSTBCs), repetition codes (RCs) and transmit laser selection (TLS). Simulation results show that RCs outperform OSTBCs [8], however lack of synchronization leads to make asynchronous OSTBCs better than RCs [10]. Also, the authors of [9] show that TLS perform better than RCs. However, TLS is more complex and it requires channel state information. RCs and OSTBCs in wireless optical communications using IM/DD is different than radio frequency (RF).

In fact, while RCs send the same information simultaneously from all transmitters. OSTBCs is quite different from standard OSTBCs by using IM/DD only positive signals can be transmitted so the negative part of signals is represented by its 1’s complement [8]. Relay assisted techniques can be a perfect tool in mitigation atmospheric turbulence as turbulence is directly proportional with distance. Using relay assisted, the distance will decrease so the turbulence effect will be also reduced.

Relay assisted techniques can be classified as amplify and forward (AF) (i.e., the signal and the noise are amplified at the relay) and decode and forward (DF) (i.e., the signal is regenerated at the relay so the noise is not amplified). DF system is more complex and suffers from delay time. Relay assisted techniques can be classified according to two types of connections: parallel (cooperative) or multi hop (serial). Parallel connection can be with or without direct link [11, 12].

To the best of our knowledge, only [13–16], discussed the comparison of BER performance on relay assisted diversity networks with spatial diversity in FSO communication systems. In [13], a parallel optical AF is employed where the received signal consists of two parts: one from the direct path and the other from the relay. The authors of [13], considered log-normal channel and different weather attenuation.

Their results show that optical AF has better BER performance than 2 x 1 multiple-input single-output (MISO) using RCs especially when the source destination link is long or the attenuation factor is high. In [14], cooperative FSO communications with one relay DF and equal gain combining (EGC) at the receiver side using IM/DD is investigated. Rayleigh and log-normal channels are assumed. According to [14] the cooperative techniques outperform 2x1 MISO using RCs if the correlation between transmitters is considered.

In [15], with the same cooperative scheme of [14] gamma-gamma model and misalignment channel are considered. They achieve a BER performance better than two transmitter following TLS under certain relay location. In [16], the authors introduce three modified types of parallel DF: bit detect and forward (BDF), adaptive bit detect and forward (ABDF) and adaptive decode and forward (ADF). To evaluate the performance of the three proposed models the authors assume that the link quality between source and destination similar to the link quality among cooperative paths.

This assumption means that BDF and ABDF have no considerable gains over direct link at moderate signal to noise ratios (SNRs), but ADF approximately has the same performance as that of the case of two transmitters. In this paper, we consider a multi hop DF relays with equal hop length for IM/DD FSO systems in log-normal channel taken into consideration different weather attenuation effects. This multi hop model is compared with IM/DD MISO using RCs with and without the correlation effects among the transmitters.

Our results show that the proposed multi hop model outperforms the correlated MISO system for different turbulence and weather attenuation losses especially when the link attenuation is high.

2 - System Description

a. *Single-Input Single-Output (SISO)*

Figure 1 illustrates the SISO scheme connection. On-off keying (OOK) signals are transmitted through laser over a log-normal channel which suffers from path loss due to weather effects and an additive white Gaussian noise (AWGN), *n(t),* result from background noise limited receiver [8].
where *x(t)* is the transmitted information bits, *L* is the propagation distance, *r(t)* is the received signal and $\hat{x}(t)$ is the estimated received bits.

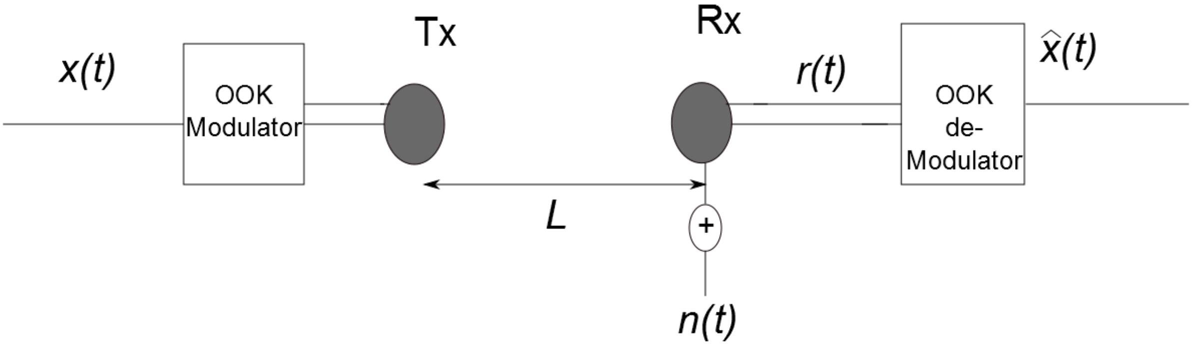

Fig. 1: SISO scheme.

b. MISO Using RCs

Figure 2 illustrates the MISO scheme connection using RCs. OOK signals are transmitted simultaneously through N_t lasers over a correlated log-normal channel which suffers from path loss due to weather effects and an AWGN. At the receiver the photodetector combines the multiple signals with the same weight as the received irradiance are real and positive [8]. Correlation effect, ρ, is a function of the separation distance *d* among transmitters, Please note that for fair comparison the total power must be divided among the transmitters.

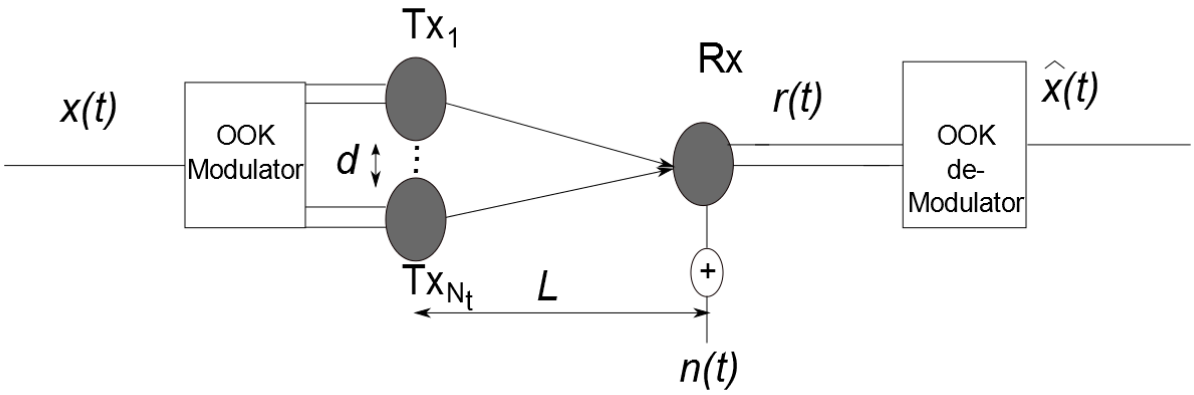

Fig. 2: MISO scheme using RCs.

c. Multi Hop DF Relay

The multi hop DF relay scheme connection is illustrated in Fig. 3. This scheme transmits information in N_h hops. Each hop is considered as a SISO link with equal and short distance. Where every relay receives the signal, regenerates it (no accumulative AWGN) and send it again either to the next relay or to the final destination. Because the link will be shorter both turbulence effect and weather attenuation effect will be decreased.

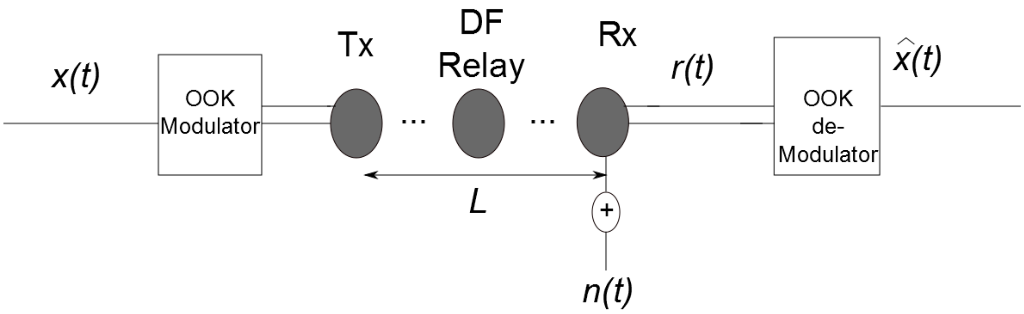

Fig. 3: Multi hop DF relay scheme.

3 - Numerical Results and Discussions

According to [17], the target BER for FSO is 10^{-9}, wavelength λ = 1550 nm, *L* = 1200 m, C_n^2 = 1.7 x 10^{-14} $m^{-2/3}$ and α = 20 dB/km for light fog attenuation in the morning, C_n^2 = 5 x 10^{-14} $m^{-2/3}$ and α = 0.43 dB/km for clear weather condition on strong sunlight condition, ρ = {0, 0.3} and hops lengths are equal.

In Fig. 4, the direct link distance is about 1200 m and the relay is fixed in the middle distance. Light fog is considered with low turbulence as fog does not happen in strong sunshine. Exact and approximated BER for multi hop techniques have perfect match. Our simulations show that DF dual hop relay required less SNR at the target BER than dual transmitters using RCs with ρ = 0.3 and SISO by 22.7 dB and 26.5 dB, respectively.

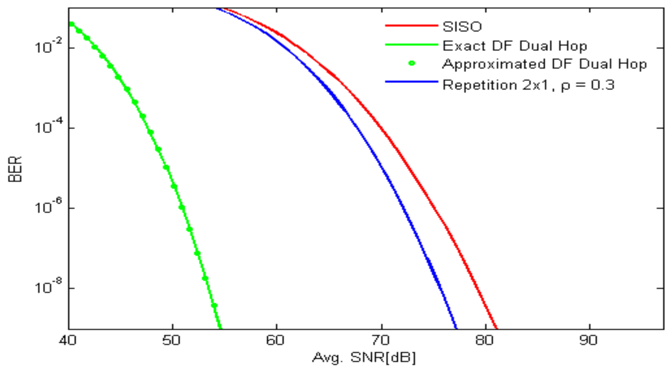

Fig. 4: BER of FSO in log-normal fading channel and light fog (C_n^2 = 1.7 x 10^{-14} $m^{-2/3}$; α = 20 dB/km). Distance between source and destination = 1200 m and distance between hops is 600 m.

In Fig. 5, the similar parameter set of Fig. 4 is employed but in clear weather condition. The superior advantages of multi hop scheme are reduced as it only results from mitigation of turbulence. We observe that DF dual hop relay required less SNR at the target BER than dual transmitters using RCs with ρ = 0.3, dual transmitters using RCs with ρ = 0 and SISO by 4.5 dB, 0.75 dB and 11.3 dB, respectively. Multi hop scheme has worser BER performance in low SNR than SISO and correlated MISO.

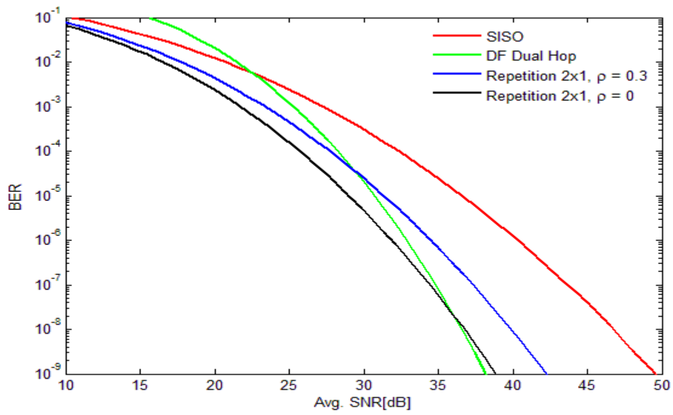

Fig. 5: BER of FSO in log-normal fading channel and light fog (C_n^2 = 5 x 10^{-14} $m^{-2/3}$; α = 0.43 dB/km). Distance between source and destination = 1200 m and distance between hops is 600 m.

In Fig. 6, the direct link distance is 1200 m and two relays are fixed in the middle distance. Light fog is considered with low turbulence. In this case, we noticed that DF triple hop relay required less SNR at the target BER than triple transmitters using RCs with ρ = 0.3 and SISO by 28.3 dB and 33.9 dB, respectively. This means that triple hop outperforms dual hop by 7 dB. On the other hand, increasing the number of transmitter to three will enhance the performance only by 1.4 dB. The gap of spatial diversity does not mitigate weather attenuation effects.

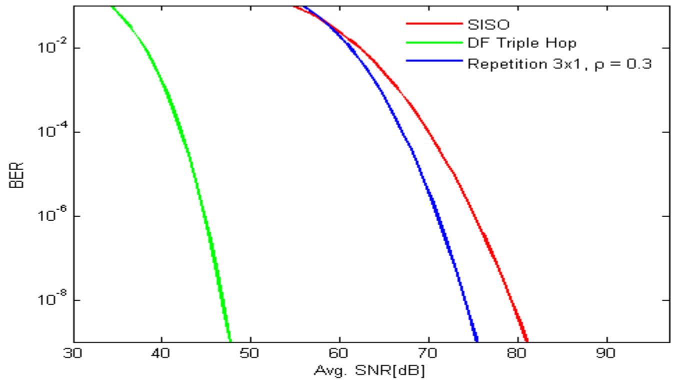

Fig. 6: BER of FSO in log-normal fading channel and light fog ($C_n^2 = 1.7 \times 10^{-14}$ $m^{-2/3}$; α = 20 dB/km). Distance between source and destination = 1200 m and distance between hops is 400 m.

In Fig. 7, similar conditions to Fig. 6 are employed but in clear weather condition. Results show that DF triple hop relay required less SNR at the target BER than triple transmitters using RCs with ρ = 0.3 and SISO by 2.4 dB and 13 dB, respectively. It is worth noticing that triple transmitters using RCs with ρ = 0 outperforms DF with triple hops by 1.6 dB however, uncorrelated case cannot exist in real applications due to limited space for transmitter units. We should add that multi hop scheme has low BER performance in low and medium SNR under clear weather condition.

Finally, comparing dual hop DF with correlated 3 x 1 MISO shows that multi hop scheme has better performance for both clear and light fog attenuations by 0.3 dB and 21.2 dB, respectively.

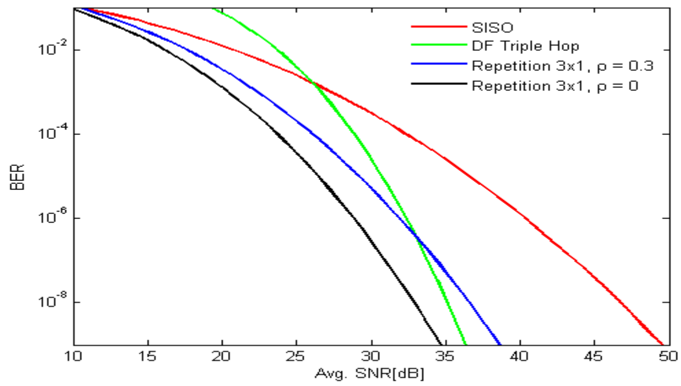

Fig. 7: BER of FSO in log-normal fading channel and light fog ($C_n^2 = 5 \times 10^{-14}$ $m^{-2/3}$; a = 0.43 dB/km). Distance between source and destination = 1200 m and distance between hops is 400 m.

4-Conclusions

In this manuscript, multi hop DF relay and MISO system are investigated under different turbulence and weather conditions. Our results show that multi hop DF is more reliable than MISO using repetition codes under correlation effect at BER = 10^{-9}. Different atmospheric challenges are simulated with the same link power for the sake of this comparison.

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