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Optimum transmission distance for relay-assisted free-space optical communication systems

Arif Basgumus [a,*], Bahadir Hicdurmaz [a], Hasan Temurtas [c], Mustafa Namdar [a], Ahmet Altuncu [a], Gunes Yilmaz [b]

[a] Dumlupinar University, Department of Electrical & Electronics Engineering, 43100 Kutahya, Turkey
[b] Uludag University, Department of Electrical & Electronics Engineering, 16059 Bursa, Turkey
[c] Dumlupinar University, Department of Computer Engineering, 43100 Kutahya, Turkey

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ABSTRACT

In this paper, optimum transmission distances are obtained for different relay nodes in the serial and parallel decode-and-forward relaying schemes by using differential evolution algorithm in free-space optical communication systems. The transmission distances are investigated by optimizing the place of the relay nodes at a target outage probability of 10^{-6}. In this study, the numerical results reveal that the optimum transmission distances are increased for both the whole power margins and different number of relay nodes with the help of the proposed optimization technique.

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1. Introduction

Free-space optical (FSO) communication is one of the key technologies for very high speed and large capacity line-of-sight optical transmission through the earth's atmosphere. In the last quarter-century, FSO systems have become attractive as an adjunct or alternative to radio frequency communication. Although FSO communication has many advantages such as high bandwidth capacity, unlicensed spectrum, electromagnetic interference immunity and the ease of installation, atmospheric turbulence-induced fading becomes a major performance limiting factor for the links longer than 1 km [1].

System limitations imposed by atmospheric turbulence-induced fading has established an important research area. Djordjevic et al. [2] proposed different techniques for the coded multi-input multi-output (MIMO) FSO communication. In their works, they achieved about 20 dB gain by using low-density parity-check (LDPC) coded MIMO configuration with four photodetectors over single-input single-output (SISO) configuration at a bit error rate (BER) of 10^{-6}. In Ref. [3], the authors considered the advantages of spatial diversity in terms of BER performance in the FSO systems. They analyzed the results of multi-input single-output (MISO) system with three transmitters obtained 110 dB gain as compared to SISO system at a BER of 10^{-9}. The sequence detection techniques in MIMO FSO systems are investigated in Ref. [4]. They attained the performance

* Corresponding author.
E-mail addresses: arif.basgumus@dpu.edu.tr (A. Basgumus), bahadir.hicdurmaz@dpu.edu.tr (B. Hicdurmaz), htemurtas@dpu.edu.tr (H. Temurtas), mustafa.namdar@ieee.org (M. Namdar), altuncu@dpu.edu.tr (A. Altuncu), gunesy@uludag.edu.tr (G. Yilmaz).

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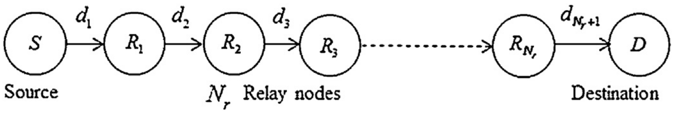

Fig. 1. Serial relaying scheme.

improvement of about 0.3 dB by using sequence detector based on expectation-maximization algorithm (EMA) compared to the maximum-likelihood sequence detection (MLSD) at a BER of 10^{-4}.

Recently, relay-assisted (RA)-FSO communication systems have been studied as a powerful technique for the fading mitigation [5–10]. The concept of RA-FSO was introduced by Ref. [11] for the first time. Then, the coverage area of RA-FSO is expanded. Kashani et al. studied the outage probability performance and diversity analysis for different number of nodes in the serial and parallel decode-and-forward (DF) relaying [9]. Kashani and Uysal improved this work by adding different multi-hop parallel relaying schemes [10]. The authors in Ref. [12] investigated the medium-short distance FSO communication with optical amplification by using simulations. To the best of the authors' knowledge, optimum transmission distances for RA-FSO systems are not available in the literature.

In our study, with the help of differential evolution algorithm (DEA), the transmission distance and the place of each individual relay nodes are optimized for different number of relays in the serial and parallel DF relaying at an outage probability of 10^{-6} which is an acceptable bound.

2. System model

In this paper, we assumed that FSO communication system uses binary pulse position modulation (BPPM) [5,9,10]. Two different systems, including serial and parallel DF relaying are investigated, as shown in Figs. 1 and 2, respectively [5].

In the channel model, atmospheric turbulence-induced log-normal fading and path loss are taken into consideration. The normalized path loss is given [13] by

$$L(d) = \frac{\ell(d)}{\ell\left(d_{S,D}\right)} = \left(\frac{d_{S,D}}{d}\right)^2 e^{\sigma\left(d_{S,D}-d\right)} \tag{1}$$

where $\ell(d)$ and $\ell\left(d_{S,D}\right)$ are the path losses in the distance of d and in the distance from source (S) to destination (D), respectively. In Eq. (1), σ represents the atmospheric attenuation coefficient. The outage probabilities of the serial and parallel DF relaying are given [5] as follows:

$$P_{out,serial} = 1 - \prod_{i=1}^{N_r+1}\left(1 - Q\left(\frac{\ln\left(\frac{L(d_i)P_M}{N_r+1}\right) + 2\mu_\chi(d_i)}{2\sigma_\chi(d_i)}\right)\right), \tag{2}$$

Table 1
Optimization results for the serial relaying with 1–5 relay nodes at a target outage probability of 10^{-6}.

P_M (dB)	$N_r = 1$		$N_r = 2$		$N_r = 3$		$N_r = 4$		$N_r = 5$	
	Optimum $d_{S,D}$ (km)	Optimum Relay Locations	Optimum $d_{S,D}$ (km)	Optimum Inter-Relay Locations	Optimum $d_{S,D}$ (km)	Optimum Inter-Relay Locations	Optimum $d_{S,D}$ (km)	Optimum Inter-Relay Locations	Optimum $d_{S,D}$ (km)	Optimum Inter-Relay Locations
0	0.9964	0.5	2.6147	0.333	4.8260	0.25	7.7162	0.2	11.4482	0.167
1	1.3574	0.5	3.2070	0.333	5.6879	0.25	8.8976	0.2	13.0138	0.167
2	1.7234	0.5	3.8033	0.333	6.5527	0.25	10.0800	0.2	14.5765	0.167
3	2.0929	0.5	4.4022	0.333	7.4187	0.25	11.2614	0.2	16.1344	0.167
4	2.4646	0.5	5.0025	0.333	8.2849	0.25	12.4407	0.2	17.6858	0.167
5	2.8377	0.5	5.6034	0.333	9.1503	0.25	13.6165	0.2	19.2298	0.167
6	3.2117	0.5	6.2042	0.333	10.0141	0.25	14.7882	0.2	20.7652	0.167
7	3.5861	0.5	6.8045	0.333	10.8757	0.25	15.9552	0.2	22.2916	0.167
8	3.9605	0.5	7.4038	0.333	11.7348	0.25	17.1168	0.2	23.8084	0.167
9	4.3346	0.5	8.0019	0.333	12.5908	0.25	18.2727	0.2	25.3152	0.167
10	4.7083	0.5	8.5984	0.333	13.4436	0.25	19.4227	0.2	26.8117	0.167
11	5.0814	0.5	9.1932	0.333	14.2929	0.25	20.5665	0.2	28.2979	0.167
12	5.4537	0.5	9.7860	0.333	15.1385	0.25	21.7039	0.2	29.7738	0.167
13	5.8251	0.5	10.3769	0.333	15.9805	0.25	22.8349	0.2	31.2390	0.167
14	6.1955	0.5	10.9656	0.333	16.8183	0.25	23.9590	0.2	32.6935	0.167
15	6.5648	0.5	11.5520	0.333	17.6522	0.25	25.0768	0.2	34.1376	0.167

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