Performance Comparison of the Differential Evolution and Particle Swarm Optimization Algorithms in Free-Space Optical Communications Systems

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Abstract—**In this comparative study we evaluate the performance of Differential Evolution (DE) and Particle Swarm Optimization (PSO) algorithms in free space optical communications systems. In particular we obtain the optimal transmission distances for different relay nodes in the parallel decode-and-forward relaying schemes by optimizing the relay placements. We analyze that the cost functions are suitably minimized. Then we investigate the execution time and the stability of the DE and PSO algorithms for decode-and-forward relay-assisted free space optical links. The simulation results demonstrate that the PSO algorithm outperforms DE algorithm in terms of the minimization of the cost function. Furthermore the results indicate that we get the similar performance for the execution-time and optimization results in the DE and PSO algorithms.**

Index Terms—**communication systems, cooperative systems, distance measurement, evolutionary computation, particle swarm optimization.**

I. Introduction

Free space optical (FSO) communications has been proposed as a solution for the various applications including fiber back-up, and back-haul for wireless communications networks [1]. Despite the fact that the usage of FSO communications is widespread in major applications for wireless communications, the performance limitation for long-range links due to the atmospheric turbulence-induced fading, has had profound impacts in FSO communications systems. The method used for relay-assisted FSO transmission links is one of the fading mitigation technique has attracted significant attentions recently in FSO communications networks [1-4]. In [1] the authors consider relay-assisted free space optical communications, and investigate the outage performance under serial and parallel scheme with amplify-and-forward (AF), and decode-and-forward (DF) relaying models. The authors in [2] consider a cooperative free space communications via optical AF relay, and investigate the Bit Error Probability (BEP) performance. Bit error rate (BER) analysis of cooperative systems in FSO networks is presented in [3]. The outage performance analysis of FSO communications is presented in both [4] and [5]. Kashani et al. in [6] consider the diversity gain analysis and determine the optimal relay locations for both the serial and parallel relaying schemes. Although cooperative transmissions have greatly been considered in the above manuscripts, as far as we know there has not been any notable research on the optimal transmission distances for the relay-assisted FSO communications systems.

In our study the locations of each individual relay nodes and the transmission distances are optimized for the parallel DF relaying scheme. To the best of the authors' knowledge, none of the previous studies provide a comparison between Differential Evolution (DE) and Particle Swarm Optimization (PSO) algorithms when applied for FSO systems. To fill the research gap, in this paper, we investigate the performance comparison of these two algorithms for the parallel DF relaying in respect to the execution time, cost and stability analysis. With the help of the simulations we obtained accurate optimal transmission distances and optimal relay locations for different number of relays at a target outage probability of 10^{-6} for both algorithms.

The rest of the paper is organized as follows: The DE and PSO algorithms are introduced in Section II. In Section III, the system model and problem statements are discussed. Section IV provides the numerical results. Finally, the concluding remarks are given in Section V.

II. Optimization Algorithms

The aim of the optimization is to provide the best-suited solution to a problem under the given constraints. The optimization algorithms have recently been much attention and gained significant importance in plenty of engineering problems [7-12].

DE is a simple evolutionary algorithm introduced by Storn and Price [13]. The main objective of the DE algorithm is to generate a new position for an individual, based on the calculation of the vector differences, between the members of the population [15-17].

PSO is a population based iterative optimization algorithm inspired by the collective behavior of the bird flocks and fish schools, firstly developed by Eberhart and Kennedy [14-17].

Many literatures have been devoted to compare the mentioned optimization algorithms to each other [18-22]. But, this paper is the first to compare DE and PSO

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algorithms for the parallel DF relaying scheme in FSO communications networks. In addition, as far as we know, there is not any study which obtained the optimal transmission distances between the source node and destination node.

III. System Model And Problem Statements

This section presents the system model for FSO communications networks with parallel DF cooperative relaying protocol shown in Figure 1. We assume that FSO communications network uses binary pulse position modulation [1], [5], and [6]. We consider that the FSO links between the source-to-relay $\left(S \rightarrow R_j,\, j=1,2,...,M\right)$ and relay-to-destination $\left(R_j \rightarrow D\right)$ are subject to atmospheric turbulence-induced log-normal fading [1]. Here, the j index refers to the number of the relay nodes, where the maximum number of relay nodes $\left(R_j\right)$ is defined with M $\left(j=1,2,...,M\right)$ as shown in Figure 1. Besides, the normalized path loss can be expressed as $L(d)=\frac{\ell(d)}{\ell\left(d_{S,D}\right)}=\left(\frac{d_{S,D}}{d}\right)^2 e^{\sigma\left(d_{S,D}-d\right)}$ where $\ell(d)$ and $\ell\left(d_{S,D}\right)$ are defined as the path losses for the distance of d and for the distance between $S \rightarrow D$ $\left(d_{S,D}\right)$ respectively [5-6]. Here, σ is the atmospheric attenuation coefficient. In the same figure below, d_{S,R_j} is the distance between the source and the $j-th$ decoding relay, and $d_{R_j,D}$ is the direct link distance between the $j-th$ relay and the destination where the relay nodes are placed on the straight line connecting the source and the destination.

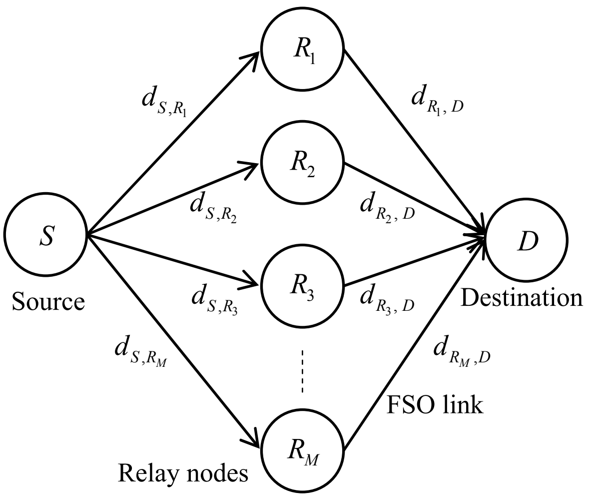

Figure 1. System model for parallel relaying

In [6] the outage probability for the parallel DF relaying is expressed as

$$P_{out}=\sum_{i=1}^{2^M}\left[\prod_{j\in W(i)}\left(1-Q\left(\frac{\ln\left(\frac{L\left(d_{S,R_j}\right)P}{2M}\right)+2\mu_\chi\left(d_{S,R_j}\right)}{2\sigma_\chi\left(d_{S,R_j}\right)}\right)\right)\times\prod_{j\notin W(i)}Q\left(\frac{\ln\left(\frac{L\left(d_{S,R_j}\right)P}{2M}\right)+2\mu_\chi\left(d_{S,R_j}\right)}{2\sigma_\chi\left(d_{S,R_j}\right)}\right)\right]Q\left(\frac{\ln\left(\frac{Pe^{\mu_\xi}}{2M}\right)}{\sigma_\xi\left(\bar{d}_{W(i)}\right)}\right) \tag{1}$$

where $Q(x)=\frac{1}{\sqrt{2\pi}}\int_x^\infty \exp\left(-\frac{u^2}{2}\right)du$ is the Q function, M is the relay number. Here, P is the power margin and defined by $P=\left(P_T/P_{th}\right)$, where P_T is the total transmitted power, and P_{th} is the threshold value for the transmit power in case of no outage is available. P_T is expressed as $P_T=P_S+\sum_{j=1}^{M}P_j$, where P_S is the source power, and P_j is the power of the $j-th$ relay [1]. In (1), the variance of the fading log-amplitude, χ is defined by $\sigma_\chi^2(d)=min\left\{0.124k^{(7/6)}C_n^2 d^{(11/6)},\ 0.5\right\}$, where $k=\left(2\pi/\lambda\right)$ is the wave number, and $C_n^2=10^{-14}m^{2/3}$ is the refractive index structure constant [6]. Here, $\ln(.)$ is the natural logarithm operator and λ is the wavelength [2]. The mean value of the fading log-amplitude is modeled as $\mu_\chi=-\sigma_\chi^2$ [3].

In the outage probability of the parallel DF relaying scheme, there are 2^M possibilities for decoding the signal between $S \rightarrow R_j$. In (1) the i index refers to the number of possible combinations where the $i-th$ possible set is defined by $W(i)$, and the possible set of distances between the relays and destination is given by $\bar{d}_{W(i)}$. μ_ξ is the mean value, and σ_ξ is the variance of the log-amplitude factor, also given in [1], [6].

For the optimization problem, a function is employed to minimize the outage probability for the parallel DF relaying, can be written as $\min\left\{P_{out}\right\}=\min\left\{f(d_{S,R_1},d_{S,R_2},...,d_{S,R_M})\right\}$ where $0<d_{S,R_j}<d_{S,D}$ for $j=1,2,....,M$. Optimal transmission distance is maximized by optimizing the locations of the relays, at an outage probability of 10^{-6} as modelled as follows:

$$\max\left\{d_{S,D}\right\}=f\left(\min\left\{\left|\min\left\{P_{out}\right\}-10^{-6}\right|\right\}\right). \tag{2}$$

IV. Numerical Results

In this section, numerical results are presented. For the optimization algorithms, the parameters $\lambda = 1550\, nm$, $C_n^2 = 10^{-14} m^{2/3}$, $\sigma = 0.1$, $P = 9$ dB are used, and totally 4 relays are evaluated.

The cost function analysis is illustrated in Figure 2, for the DE and PSO algorithms in terms of the iteration number. It can be observed from the simulation results in Figure 2 that the cost function for the PSO algorithm is minimized for the small number of iterations as compare to the DE algorithm. This result indicates that PSO outperforms DE in terms of the cost function. Here, the iteration number is set to 40, and the execution number is taken as 50.

Figure 3 shows the optimal $d_{S,D}$ for the aforementioned algorithms. While 4 relays are used, $d_{S,D} = 6.0547$ km is calculated. For the each execution, PSO algorithm gives almost the same result. Therefore, it is obvious that PSO is more stable than the DE algorithm under the same setup.

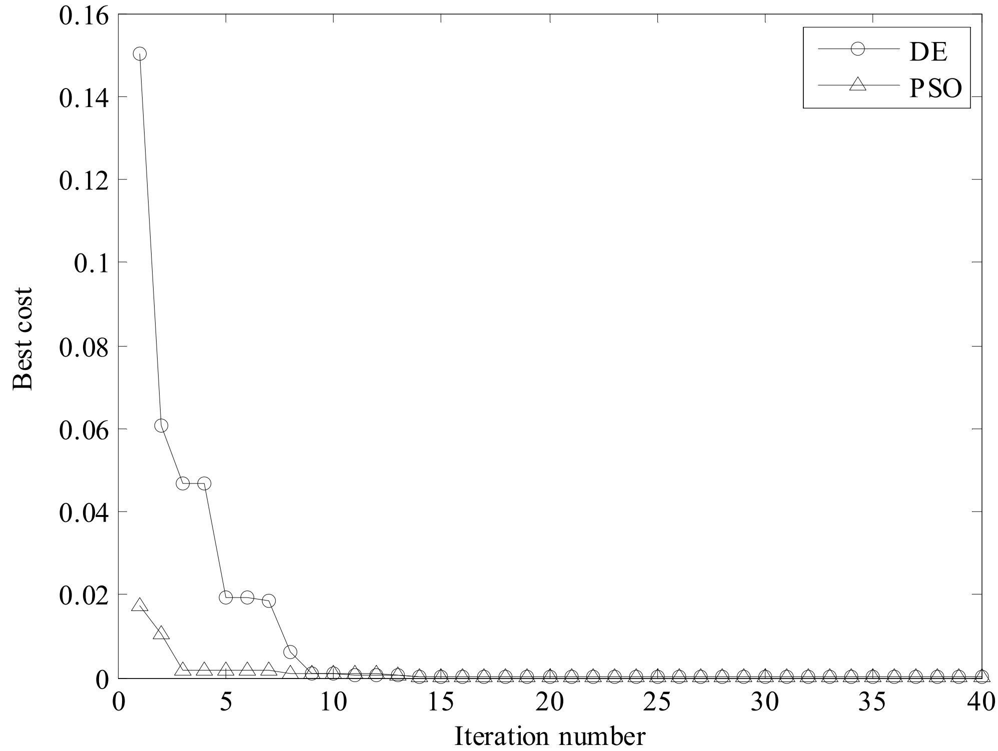

Figure 2. Cost function for 40 iterations

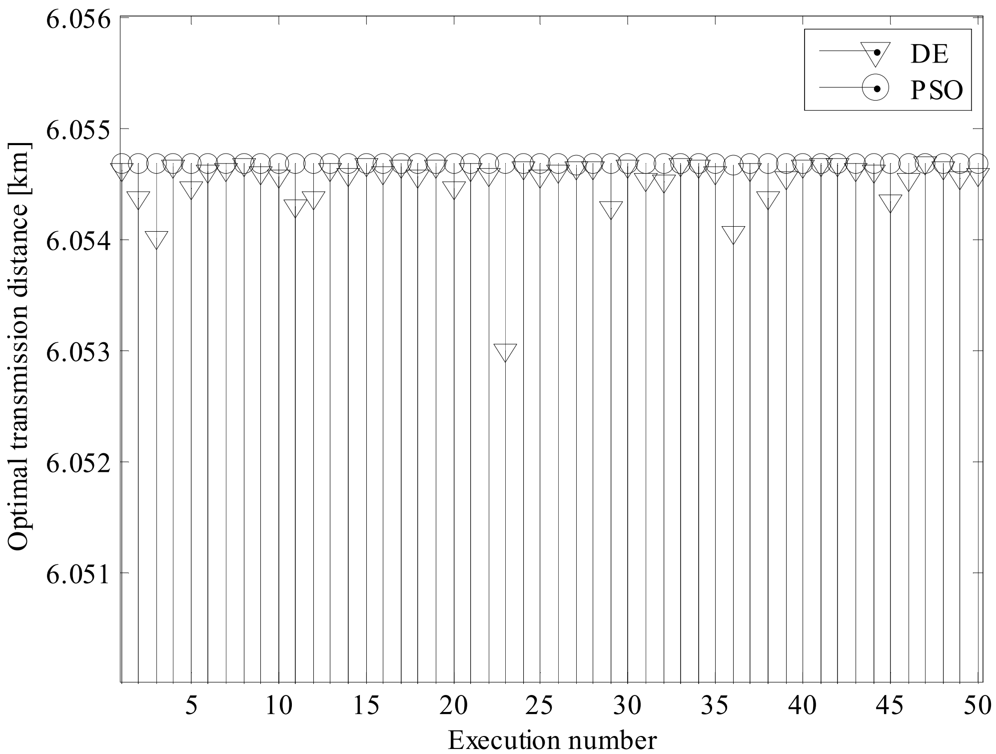

Figure 3. Optimal $d_{S,D}$ vs. execution number for the DE and PSO algorithms

It can be noticed from Figure 4 that the execution time for the PSO algorithm closely matches with the execution time of the DE algorithm for different number of relays.

Figure 5 shows the optimization results for the locations of each individual relay nodes. Accurate relay placements are obtained for $P = 9$ dB and 4 relays $\left(R_j,\ j = 1,2,3,4\right)$. The optimization results indicate that if the places of each individual relay nodes are similar, regardless of the relay number and the P value, better performance is achieved. Figure 5 clearly shows that the optimal places of the relay nodes for both algorithms are calculated as $d_{S,R_j} \approx 2,607$ km, after the number of iterations, which confirms the accuracy of the employed optimization algorithms. In addition, this results show that both algorithms seem to be the better optimization algorithms in providing the reliable and the rapid results.

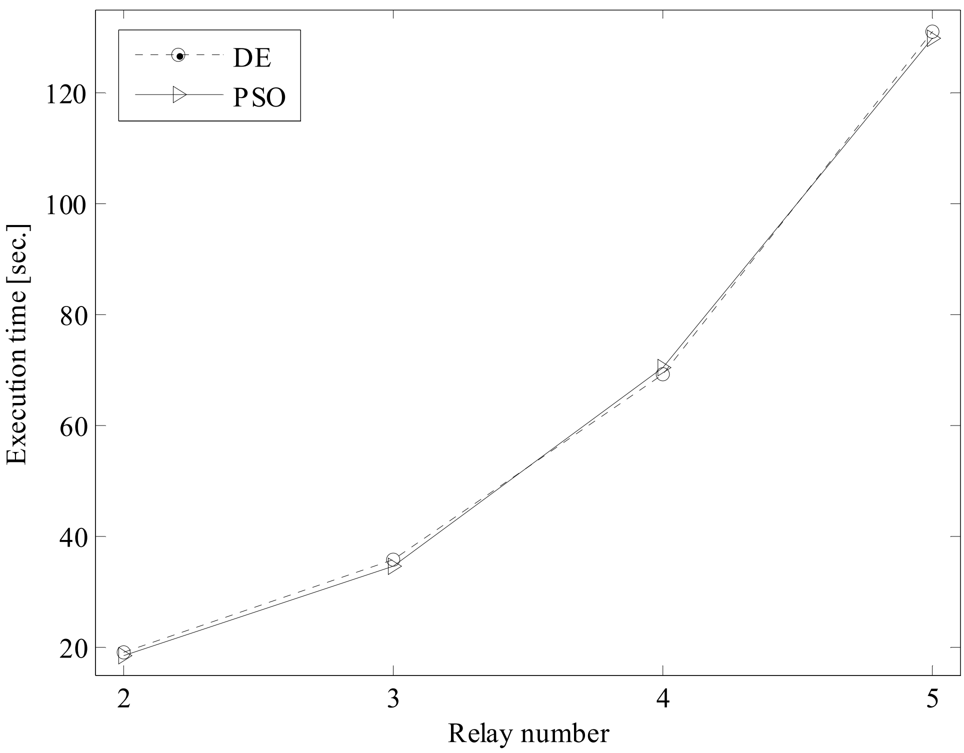

Figure 4. Execution time vs. relay number for the DE and PSO algorithms

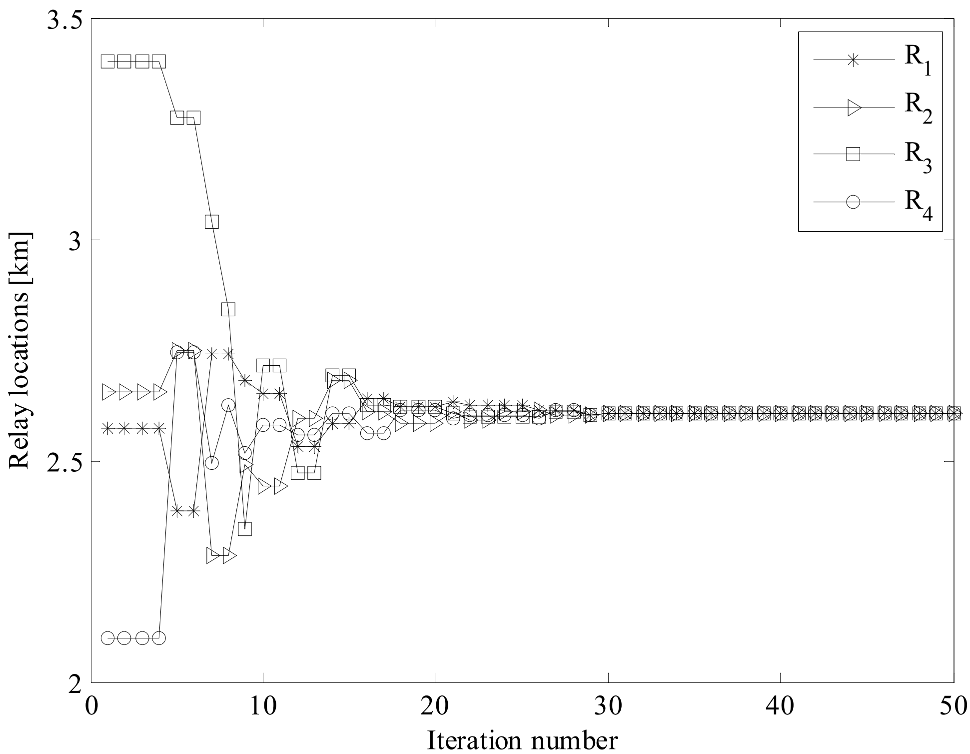

Figure 5. Relay location vs. iteration number for $R_j,\ j = 1,..,4$

Finally the impact of the varying P on the optimal transmission distance for the DE and PSO algorithms is depicted in Figure 6. It can be seen from the below figure that the optimal transmission distance increases with P and the results for both algorithms closely match with each other for all P values.

The detailed optimization results with the DE and PSO algorithms for DF parallel relaying scheme are given in Table I. Here, the results for the optimal transmission distances and optimal relay locations are listed for various P values, where $d_{S,D}$ is the distance between the source-to-destination $(S \to D)$ and d_{S,R_j} is the distance between the source and the $j-th$ relay $\left(S \to R_j,\, j = 1,2,...,M\right)$. Based on the numerical optimization results provided in Table I, while the number of relays is increased, the relays are obliged to get close up to the source, and the distance between the source-to-destination is shortened in low P region, as expected [23].

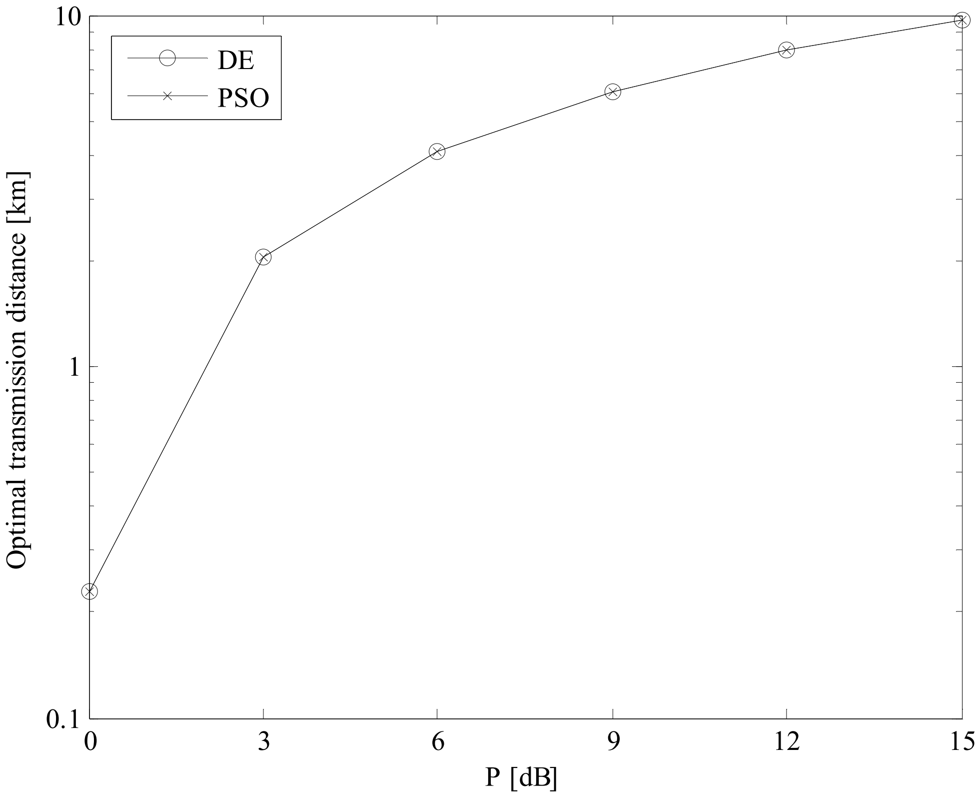

Figure 6. Optimal $d_{S,D}$ with varying P

TABLE I. OPTIMIZATION RESULTS FOR THE PARALLEL DF RELAYING WITH DIFFERENT NUMBER OF NODES

P [dB]	**2 Relays**				**3 Relays**				**4 Relays**				**5 Relays**			
	DE		**PSO**		**DE**		**PSO**		**DE**		**PSO**		**DE**		**PSO**	
	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]	Opt. $d_{S,D}$ [km]	Opt. d_{S,R_j} [km]
0	0,6323	0,2608	0,6323	0,2608	0,4017	0,1464	0,4016	0,1463	0,2276	0,0756	0,2276	0,0756	0,0888	0,0274	0,0888	0,0274
3	2,0304	0,8562	2,0304	0,8562	2,0453	0,7813	2,0453	0,7813	2,0541	0,7280	2,0541	0,7280	2,0547	0,6832	2,0547	0,6832
6	3,5568	1,5653	3,5568	1,5653	3,8708	1,6044	3,8708	1,6044	4,0930	1,6114	4,0930	1,6114	4,2558	1,6006	4,2558	1,6006
9	5,1021	2,3490	5,1021	2,3490	5,6697	2,5207	5,6697	2,5207	6,0547	2,6065	6,0547	2,6072	6,3361	2,6542	6,3361	2,6542
12	6,6391	3,1868	6,6392	3,1868	7,4014	3,4801	7,4014	3,4801	7,9173	3,6665	7,9173	3,6665	8,2927	3,7939	8,2927	3,7939
15	8,1326	4,0077	8,1326	4,0077	9,0656	4,4476	9,0656	4,4476	9,6952	4,7477	9,6952	4,7477	10,1544	4,9665	10,1544	4,9665

V. CONCLUSIONS

In this paper, we present a comprehensive performance comparison of the DE and PSO algorithms in FSO communications systems. We investigate the optimal transmission distances for different number of nodes and P values in the parallel DF relaying scheme. Moreover, we analyze the cost function and the execution time for the DE and PSO algorithms. We demonstrate that the cost functions are suitably minimized proving the accuracy of the employed optimization algorithms. We find out that both algorithms have similar execution time, besides PSO is more stable than the DE algorithm. Furthermore, the PSO algorithm outperforms DE algorithm with regard to the cost function. It should be emphasized that both optimization algorithms are reliable and can be used for the applications in the FSO communications systems.

REFERENCES

[1] M. Safari and M. Uysal, “Relay-assisted free-space optical communication,” IEEE Trans. Wireless Commun., vol. 7, no. 12, pp. 5441-5449, Dec. 2008. [Online]. Available: http://dx.doi.org/10.1109/T-WC.2008.071352

[2] M. Karimi and M. Nasiri-Kenari, “Free space optical communications via optical amplify-and-forward relaying,” J. Lightwave Technol., vol. 29, no. 2, pp. 242-248, Jan. 2011. [Online]. Available: http://dx.doi.org/10.1109/JLT.2010.2102003

[3] M. Karimi and M. Nasiri-Kenari, “BER analysis of cooperative systems in free-space optical networks,” J. Lightwave Technol., vol. 27, no. 24, pp. 5639-5647, Dec. 2009. [Online]. Available: http://dx.doi.org/10.1109/JLT.2009.2032789

[4] M. Karimi and M. Nasiri-Kenari, “Outage analysis of relay-assisted free space optical communications,” IET Commun., vol. 4, no. 12, pp. 1423-1432, Aug. 2010. [Online]. Available: http://dx.doi.org/10.1049/iet-com.2009.0335

[5] M.A. Kashani and M. Uysal, “Outage performance and diversity gain analysis of free-space optical multi-hop parallel relaying,” J. Opt. Commun. Netw., vol. 5, no. 8, pp. 901-909, Aug. 2013. [Online]. Available: http://dx.doi.org/10.1364/JOCN.5.000901

[6] M.A. Kashani, M. Safari and M. Uysal, “Optimal relay placement and diversity analysis of relay- assisted free-space optical communications systems,” J. Opt. Commun. Netw., vol. 5, no. 1, pp. 37-47, Jan. 2013. [Online]. Available: http://dx.doi.org/10.1364/JOCN.5.000037

[7] C. Knievel, and P. A. Hoeher, "On Particle Swarm Optimization for MIMO Channel Estimation," Journal of Electrical and Computer Engineering, vol. 2012, doi:10.1155/2012/614384, 10pp., Dec. 2011. [Online]. Available: http://dx.doi.org/10.1155/2012/614384

[8] L. Su, P. Wang, and F. Liu, "Particle swarm optimization based resource block allocation algorithm for downlink LTE systems," IEEE 18th Asia-Pacific Conference on Communications, pp. 970-974, Jeju Island, Oct. 2012. [Online]. Available: http://dx.doi.org/10.1109/APCC.2012.6388227

[9] F. R. Dunand, and T. Abrao, "Energy-Efficient Power Allocation for WDM/OCDM Networks With Particle Swarm Optimization," J. Opt. Commun. Netw., vol. 5, no. 5, pp. 512-523, May 2013. [Online]. Available: http://dx.doi.org/10.1364/JOCN.5.000512

[10] D. Manickavelu, and R. U. Vaidyanathan, "Particle swarm optimization (PSO)-based node and link lifetime prediction algorithm for route recovery in MANET," Eurosip Journal on Wireless Communications and Networking, vol. 2014, no. 107, pp. 1-10, Jul. 2014. [Online]. Available: http://dx.doi.org/10.1186/1687-1499-2014-107

[11] A. Omidvar, and K. Mohammadi, "Particle swarm optimization in intelligent routing of delay-tolerant network routing," Eurosip Journal on Wireless Communications and Networking, vol. 2014, no. 147, pp. 1-8, Sep. 2014. [Online]. Available: http://dx.doi.org/10.1186/1687-1499-2014-147

[12] L. Xiang, L. Ximing, M. F. Ercan, and Z. Yi, "A New Hybrid Algorithm Based on Collaborative Line Search and Particle Swarm Optimization," IEEE 4th International Conference on Autonomous Robots and Agents, pp. 486-489, Wellington, Feb. 2009. [Online]. Available: http://dx.doi.org/10.1109/ICARA.2000.4803909

[13] R. Storn, and K. Price, “Differential evolution: A Simple and Efficient Adaptive Scheme for Global Optimization over Continuous Spaces,” Technical report, TR-95-012, International Computer Science Institute, Germany, Mar. 1995

[14] R. Eberhart, and J. Kennedy, "Particle swarm optimization," In Proceedings of IEEE International Conference on Neural Networks, vol. 4, pp. 1942–1948, Perth, WA, Dec. 1995. [Online]. Available: http://dx.doi.org/10.1109/ICNN.1995.488968

[15] M. Zhang, W. Zhangi, and Y. Sun, "Chaotic Co-evolutionary Algorithm Based on Differential Evolution and Particle Swarm Optimization," IEEE International Conference on Automation and Logistics, pp. 885-889, Shenyang, Aug. 2009. [Online]. Available: http://dx.doi.org/10.1109/ICAL.2009.5262798

[16] I. Ahmed, S. Sadeque, and S. Pervin, "Margin Adaptive Resource Allocation for Multiuser OFDM Systems by Modified Particle Swarm Optimization and Differential Evolution," IEEE 21st International Conference on Electrical Communications and Computers, pp. 227-231, San Andres Cholula, Mar. 2011. [Online]. Available: http://dx.doi.org/10.1109/CONIELECOMP.2011.5749365

[17] J. Zhang, S. Chen, X. Mu, and L. Hanzo,"Evolutionary-Algorithm-Assisted Joint Channel Estimation and Turbo Multiuser Detection/Decoding for OFDM/SDMA," IEEE Transactions on Vehicular Technology, vol. 63, no. 3, pp. 1204-1222, Mar. 2014. [Online]. Available: http://dx.doi.org/10.1109/TVT.2013.2283069

[18] X. Xu, and Y. Li, "Comparison between Particle Swarm Optimization, Differential Evolution and Multi-parents Crossover," IEEE International Conference on Computational Intelligence and Security, pp. 124-127, Harbin, Dec. 2007. [Online]. Available: http://dx.doi.org/10.1109/CIS.2007.37

[19] S. K. Goudos, Z. D. Zaharis, K. B. Baltzis, C. L. Hilas and, J. N. Sahalos, “A Comparative Study of Particle Swarm Optimization and Differential Evolution on Radar Absorbing Materials Design for EMC Applications," IEEE International Symposium on Electromagnetic Compatibility, pp. 1-4, Athens, Jun. 2009. [Online]. Available: http://dx.doi.org/10.1109/EMCEUROPE.2009.5189697

[20] B. Basu, and G. K. Mahanti, "A Comparative Study of Modified Particle Swarm Optimization, Differential Evolution and Artificial Bees Colony Optimization in Synthesis of Circular Array," IEEE International Conference on Power, Control and Embedded Systems, pp. 1-5, Allahabad, Dec. 2010. [Online]. Available: http://dx.doi.org/10.1109/ICPCES.2010.5698614

[21] V. Roberge, M. Tarbouchi, and G. Labonte, "Comparison of Parallel Genetic Algorithm and Particle Swarm Optimization for Real-Time UAV Path Planning," IEEE Transactions on Industrial Infirmatics, vol. 9, no. 1, pp. 132-141. Feb. 2013. [Online]. Available: http://dx.doi.org/10.1109/TII.2012.2198665

[22] A. Deb, J. S. Roy, and B. Gupta, "Performance Comparison of Differential Evolution, Particle Swarm Optimization and Genetic Algorithm in the Design of Circularly Polarized Microstrip Antennas," IEEE Transactions on Antennas and Propagation, vol. 62, no. 8, pp. 3920-3928, May. 2014. [Online]. Available: http://dx.doi.org/10.1109/TAP.2014.2322880

[23] A.S. Avestimehr, D.N.C. Tse, "Outage-optimal relaying in the low SNR regime," Proceedings of the IEEE International Symposium on Information Theory, pp. 941-45, Adelaide, SA, 2005. [Online]. Available: http://dx.doi.org/10.1109/ISIT.2005.1523476