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Research Article

Hybrid Differential Evolution (HDE) Algorithm Based Optimization Technique for Relay Assisting Wireless Optical Communication

[1]A. Jabeena and [2]T. Jayabarathi
School of Electronics Engineering, VIT University, Vellore, Tamil Nadu 632014, India

Abstract: Wireless Optical Communications (WOC) systems are advantageous over other competing technologies and are attractive to provide broadband services due to their inherent wide bandwidth, easy deployment and no license requirement. A Hybrid Differential Evolutionary (HDE) algorithm, in which both trial vector generation strategies and their associated control parameter values are gradually self-adapted by learning from their previous experiences in generating promising solutions is introduced to determine optimal relay locations in serial and parallel WOC relaying so as to minimize the outage probability and then quantify performance improvements obtained through optimal relay placement. The effect of wavelength on the performance of a WOC link has been evaluated and the variation of outage probability has been compared with the power margin P_m of the WOC link.

Keywords: (HDE) algorithm, hybrid differential evolutionary, optimal relay, outage probability, power margin, wireless optical systems

INTRODUCTION

Albeit their attractive features, wireless optical communications suffer from several challenges in practical deployment, a majority of them is fading. Multiple Input Multiple Output (MIMO) and cooperative techniques have been recommended for overcoming such limitations. Here, we have considered a relay-based WOC communication and investigate the outage performance of the well-known cooperative protocol, Decode and Forward (DF), for the parallel relaying system. The performance comparison of the different cooperative WOC is analyzed and it's found that relay-assisted techniques can be used for WOC communication to achieve spatial diversity. Wireless Optical Communication (WOC), which has attracted significant attention recently, is a cost-effective access technique with considerable properties (Kedar and Arnon, 2003; Strickland *et al*., 1999; Willebrand and Ghuman, 2002; Andrews *et al*., 2001). Large bandwidth, unlicensed spectrum, excellent security and quick. And inexpensive setup is among its most attractive features (Willebrand and Ghuman, 2002; Andrews *et al*., 2001). It is also a promising solution for the 'last mile' problem. WOC is now common for point-to-point communications between fixed locations on land and is also used for communications between moving platforms on land, the surface of the sea and in the air. Despite the major advantages, of WO communications, there are several challenges in a practical deployment. Aerosol scattering, caused by rain, snow and fog, leads to performance degradation, (Strickland *et al*., 1999). Another possible impairment over WOC links is building-sway as a result of wind loads, thermal expansion and weak earthquakes (Kedar and Arnon, 2003). But the major problem is that WOC links suffer from atmospheric turbulence because of in-homogeneities in the index of refraction known as scintillation, which leads to stochastic amplitude (and power) fluctuations (Andrews *et al*., 2001; Zhu and Kahn, 2002; Kim *et al*., 1998). This phenomenon, which is known as fading or scintillation, degrades the link performance, particularly for distances of 1 km and above (Andrews *et al*., 2001). To overcome such limitations, both error control coding (Zhu and Kahn, 2003) and Multiple Input Multiple Output (MIMO) techniques have been proposed for WOC systems (Lee and Chan, 2004; Wilson *et al*., 2005; Navidpour *et al*., 2007). The latter has been shown to significantly improve the performance in spatially uncorrelated channels by creating additional degrees of freedom via spatial diversity (Lee and Chan, 2004; Wilson *et al*., 2005; Navidpour *et al*., 2007). The spatial diversity of the MIMO systems overcomes the degradation of the performance caused by fading. Owing to the size, cost and hardware limitations, a wireless device may not always be able to support multiple transmit antennas. To overcome this limitation, a new form of space diversity, known as user cooperation diversity, has been recently proposed (Sendonaris *et al*., 2003a; Laneman *et al*., 2004). This new technique takes the advantage of the broadcast nature of the radio channel allowing (single-antenna) terminals in a multiuser environment to share their physical resources in order to create a

Corresponding Author: A. Jabeena, School of Electronics Engineering, VIT University, Vellore, Tamil Nadu 632014, India

virtual transmit and/or receive array through distributed transmissions and signal processing., Cooperative transmission can dramatically improve the performance by creating diversity using the antennas available at the other nodes of the network. It has been shown that the node cooperation is an effective way of providing diversity in wireless fading networks proposed (Sendonaris *et al*., 2003b; Laneman *et al*., 2004). Although the promising effects of cooperative transmissions have greatly been considered in RF communications, there has not been any notable research on cooperative diversity in WOC. The authors in Safari and Uysal (2008a) have investigated the performance of cooperative diversity schemes over log-normal fading channels, but they have not considered the WOC links and their constraints in special. In Safari and Uysal (2008b), both serial (multi-hop transmission) and parallel (i.e., Cooperative transmission) relaying encoupled with Amplify-and-Forward (AF) and Decode-and-Forward (DF) schemes have been studied.

Differential evolutionary algorithm: The DE algorithm was introduced by Storn and Price (1995). The algorithm is quite good and "DE can rightfully be regarded as an excellent first choice", according to Vesterstrom and Thomsen (2008). Furthermore, DE has been used in the filter design problems which are described in Storn (1996) and Storn (2005) In DE, the weighted difference between the two population vectors is added to a third vector and optimized using selection, crossover and mutation operators as in GA. Fitness of both the parent and the offspring is then calculated and the offspring is selected for the next generation only if it has a better fitness than the parent (Karaboga, 2005). The most recent improvement by Jeyakumar and Shanmugavelayutham (2011) proposed to solve unconstrained global optimization problems. They have chosen fourteen functions to implement and analyzed for thirty dimensions.

The results suggest that the best performing variants are faster in converging to the solution. The worst performing variants were found to have less probability of convergence and hence they were slow in convergence. So, DE using parallel programming has emerged. In spite of the fairly good algorithms for DE, some people want to increase its performance using parallel programming. It was invented by Kozlov and Samsonov (2006) who are developing the Combined Optimization Technique (COT) for biological data fitting and performing experiments in the context of one biological system. In that work, they introduced a new migration scheme for the Parallel DE that is going to be used as an alternative for the SA at the first stage of COT.

In the result, the new migration scheme for Parallel DE has shown that the speeds of convergence on the test problem have been increased. But, there is a problem about the population because it could not exceed three hundred. That is the reason why Weber *et al*. (2011) did their scheme by updating the Parallel DE for Large Scale Optimization. They stated that if they double the dimensionality of a problem they do not just double its difficulty. The resulting problem difficulty would increase by many times. The resulting algorithm behaves in a similar way to multi-start multiple searches and proved to be efficient for high dimensional problems. Therefore, while dimensionality grows, the proposed algorithm appears to be more capable to handle the fitness landscapes and for the set of most multi-variable problems displays a significantly better performance.

OPTIMIZATION OF RELAY LOCATION AND MINIMIZATION OF OUTAGE PROBABILITY

Serial relaying: In serial relaying the optimized relay placement will be an equidistant relay placement for all the relays (Safari and Uysal, 2008b). Therefore, to find the optimized relay placement, we can directly divide the distance between source and destination with the number of relays. So we can say, $d_{0,1} = d_{1,2} = d_{2,3} = \ldots\ldots = d_{N,N+1}$.

Outage analysis: Atmospheric turbulence results in a very slowly-varying fading in FSO systems. The channel coherence time is about 1-100 msec, therefore fading remains constant over hundreds of thousands up to millions of consecutive bits for typical transmission rates. For such quasi-static channels where the errors caused by fading are no longer independent, outage probability is a suitable metric to evaluate the system performance. Denote C (α') as the instantaneous capacity corresponding to a channel realization $\alpha = \alpha'$ which is a function of instantaneous electrical SNR $\acute{g}$. For a Gaussian channel where the mean of received signal components for the signal and non-signal slots are given by m^s and m^n and, we have:

$$\acute{g}^s \sim N(m^s, \sigma_n^2/2) \text{ and } \acute{g}^n \sim N(m^n, \sigma_n^2/2) \qquad (1)$$

Instantaneous electrical SNR can be then defined as:

$$\acute{g} = \frac{(m^s - m^n)^2}{\sigma_n^2}$$

The outage probability at the transmission rate r_0 is given by:

$$P_{out}(r_0) = P_r(C(\acute{g}) < r_0) \qquad (2)$$

Since C (·) is monotonically increasing with respect to ǵ, can be rewritten as:

$$P_{out}(r_0) = P_r(\acute{g} < \acute{g}_{th}) \qquad (3)$$

where, $\acute{g}_{th} = C^{-1}(r_0)$ is the threshold SNR. If SNR exceeds $\acute{g}_{th}$, no outage happens and signal can be decoded with arbitrarily low error probability at the receiver. It should be noted that in DF relaying, outage of each intermediate link may lead to the outage of the relaying scheme (Safari and Uysal, 2008b). Therefore, the calculation of outage probability for each intermediate link is required to evaluate the end-to-end performance. At first the outage probability of an intermediate SISO (Single-Input Single-Output) link which is the building block of serial is calculated.

The received electrical SNR for the intermediate SISO link connecting i^{th} and j^{th} nodes can be obtained as:

$$\acute{g} = \frac{R^2 T_b^2 P^2 g_{i,j}^2}{K_0} \tag{4}$$

Comparing Eq. (4) and (3), we can obtain the outage probability of the SISO link is:

$$P_{out,SISO} = P_r(g_{i,j} < \sqrt{\frac{\acute{g}_{th} K_0}{R^2 T_b^2 P^2}}) \tag{5}$$

But $g_{i,j} = \alpha_{i,j}^2 L_{i,j}$ and P_M denotes power margin and is defined as $P_M = P_T/P_{Th}$ where P_{Th} denotes a threshold transmit power required to guarantee that no outage happens in a direct fading-free transmission from the source to the destination (Safari and Uysal, 2008b).
Thus the power margin can be expressed as:

$$P_M = \sqrt{P_T^2 R^2 T_b^2 / K_0\, \acute{g}_{th}} \tag{6}$$

$$P_{out,SISO}(d_{i,j}) = P_r\left(\alpha_{i,j}^2 < \frac{1}{L_{i,j}} \frac{K'}{P_M}\right) \tag{7}$$

where, $K' = K + 1$ for serial relaying and $K' = 2K$.

Forparallel relaying. Here $\alpha_{i,j}^2$ is a log normal random variable with mean and variance $4\sigma_\chi^2(d_{i,j})$. Therefore the outage probability can be written using the Cumulative Distribution Function (CDF) of the log-normal distribution as:

$$P_{o,(SISO)}(d_{i,j}) = Q(\frac{\ln(L_{i,j} P_M / K') + 2\mu_\chi(d_{i,j})}{2\sigma_\chi(d_{i,j})}) \tag{8}$$

where,

$$Q(x) = (1/\sqrt{2\pi}) \int_x^\infty \exp\left(-u^2/2\right) du$$

Once the outage probability of the SISO link is obtained, we need to find an end-to-end outage probability for serial and parallel relaying. In serial relaying, an outage occurs, when any of the intermediate SISO links fails. Hence the outage probability for the end-to-end scheme can be given as:

$$P_o = P_r\left(\cup_{i=0}^{K} \{\acute{g}_i < \acute{g}_{th}\}\right) \tag{9}$$

where, $\acute{g}_0, \acute{g}_1, \dots \acute{g}_N$ are the SNRs of the intermediate SISO channels with the lengths of $d_{0,1}, d_{1,2}, \dots .\, d_{K,K+1}$. The Eq. (9) can be rewritten as:

$$P_o = 1 - P_r\left(\cap_{i=0}^{K} \{\acute{g}_{i_i} > \acute{g}_{th}\}\right) \tag{10}$$

Then, the end-to-end outage probability for the serial relaying scheme is obtained as:

$$P_o = 1 - \prod_{i=1}^{K+1} \left(1 - Q\left(\frac{\ln\left(\frac{L(d_i) P_M}{K+1}\right) + 2\mu_X(d_i)}{2\sigma_X(d_i)}\right)\right) \tag{11}$$

The log amplitude variance is given by $\sigma_X^2(d) = \min\{0.124 k^{7/6} C_n^2 d^{11/6}, 0.5\}$.

where,
k = The wave number
C_n^2 = The refractive index structure constant

Also log normal mean $\mu_X = -\sigma_X^2$. This ensures that the fading does not attenuate or amplify the average power. The Eq. (11) is the outage probability which is used to find out the performance of the serial relaying technique over direct transmission. Let $L(d) = l(d)/l(d_{S,d})$ denotes the normalized path loss with respect to the distance of the direct link between the source and the destination, $d_{S,D}$:

$$l(d) = e^{-\sigma d} A_{TX} A_{RX} / (\lambda d)^2$$

where, A_{TX}, A_{RX}, λ and σ is the transmitter aperture area, the receiver aperture area, the optical wavelength and the attenuation coefficient, respectively. Let d_1, d_2 and d_{K+1} denote these lengths to be optimized and define the following functions:

$$h(d_1, d_2, \dots, d_{K+1}) \stackrel{\text{def}}{=} \prod_{i=1}^{K+1} \emptyset\left(f(d_i)\right) \tag{12}$$

$$g(d_1, d_2, \dots, d_{K+1}) \stackrel{\text{def}}{=} \sum_{i=1}^{K+1} d_i \tag{13}$$

where, $\emptyset(x) = 1 - Q(x)$ is the cumulative distribution function of the normal Gaussian distribution:

$$\emptyset(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(\frac{-t^2}{2}\right) dt \tag{14}$$

Also $f(d_i)$ is defined as:

$$f(d_i) = (\ln\left(L(d_i) P_M / (K+1)\right) + 2\mu_X(d_i)) / 2\sigma_X(d_i) \tag{15}$$

By optimizing the above objective function, we conclude that the outage probability is minimized when the consecutive nodes are placed equidistant along the path from the source to the destination.

Parallel relaying and outage analysis: In parallel relay placement technique the relays are placed randomly between source to destination (Safari and Uysal, 2008b). To optimize the relay placement, we use the hybrid differential algorithm which uses the technique of mutation. The objective function is optimized as the following functions:

$z(d_{S,1}, d_{S,2}, \ldots, d_{S,K}, d_{1,D}, \ldots, d_{K,D}) \stackrel{\text{def}}{=} \sum_{i=1}^{2k} \Big[\prod_{j \in w(i)} \Big(1 -$
$Qu_{dS,j} j \notin w(i) Qu dS,j \times Qv d_{Wi}$
(16)

where,

$u(d_{S,j}) \stackrel{\text{def}}{=} \left(ln \left(\frac{L(d_{S,j}) P_M}{2K} \right) + 2\mu_X(dS, j) \right) / 2\sigma_X\,(d_{S,j}),$

$\text{v}(\bar{d}\text{W(i)} \stackrel{\text{def}}{=} ln \left(\frac{PMe^{\mu\varepsilon}}{2K} \right) / \sigma\varepsilon\,(\bar{d}W(i))$

Then the optimization problem can be stated as:

$$\min_{d_{S,j}, d_{j,D}, j = 1,2,\ldots K} z(d_{S,1}, d_{S,2}, \ldots, d_{S,K}, d1, D \ldots, dK, D)$$

$$\textit{Such that } d_{S,j} + d_{j,D} = d_{S,D}, j = 1,2, \ldots K$$

Based on the numerical optimization results, we further developed a heuristic expression through an interpolation of logarithmic functions. This expression for the optimum relay location is given by:

$$\text{dopt}\,(\text{P}_\text{M}, \text{d}_\text{S}, \text{D}, \text{N}) = 0.5\text{d}_{\text{S,D}} + \frac{\beta}{P_M} \ln\,(\varpi P_M^{\gamma} + \varphi), \text{N} \geq 2 \quad (17)$$

where,
P_M = Power margin
$d_{S,D}$ = Link range
K = Number of relays
λ = Optical wavelength
C_n^2 = Refractive index structure constant
σ = Atmospheric attenuation

$\beta, \varpi, \gamma, \varphi$ defined, respectively, as:

$$\beta = d_{S,D}(7 \times 10^{-6} d_{S,D} - 0.14 \ln(N) - 0.5)$$

$$\varpi = -2.7 \times 10^{-5} d_{S,D} + 0.1 ln(N) + 0.11$$

$$\gamma = -6.5 \times 10^{-6} d_{S,D} + 1.19$$

$$\varphi = 4.5 \times 10^{-5} d_{S,D} + 0.024N + 0.9$$

For parallel relaying, we have found out that all of the relays should be located at the same place closer to the source and the exact location of this place depends on the system and channel parameters.

Algorithm design: The algorithm used for optimization is a hybrid differential algorithm which is based on principle of mutation:

- It is a stochastic, population based, real-valued algorithm.
- Designed for challenging continuous problems (*f*: *X* _R*n*! R): where f may be non-differentiable, nonlinear and/or multimodal.
- The algorithm is easy to use (e.g., Few control parameters) and have good convergence properties.

Step 1: Mutation: For the mutation of DE, it separates the individual factor from each dimension. Then, it randomizes the value from each generation by using the mutation Equation (Fig. 1):

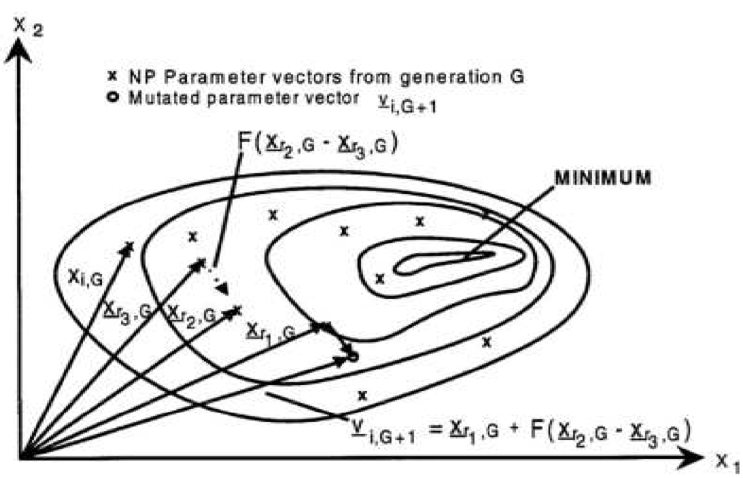

Fig. 1: Mutation process

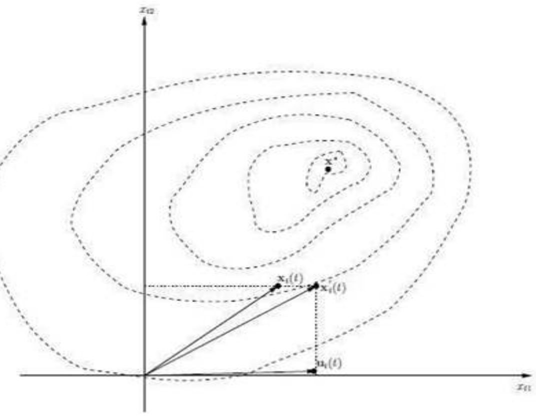

Fig. 2: Crossover process

$$G_{ij} = X[1]_{ij} + F\,(X\,[2]_{ij} + X\,[3]_{ij}) \tag{18}$$

The scaling factor F is a positive control parameter for scaling the difference vectors. Hence, X represents a string denoting the vector to be perturbed. Moreover, i and j are mutually different indexes of individuals.

Step2: Crossover: To increase the potential diversity of the population, a crossover operation plays an important role. After generating the vector through mutation, it changes the possibility and increases the opportunity to get the best fitness value. Crossover operation is implemented as mentioned below:

X'ij (t) = uij (t) ifj $\in$ population

X'ij (t) = xij (t) otherwise

where, x_{ij} (t) refers to the j^{th} element of the vector x_i (t), the crossover will change all of the values for every element until it finishes. This helps the population to get better fitness value (Fig. 2).

Step 3: Selection:

- Decide if trial vector u_i enters the population at G+1
- Trial vector u_i (G) is compared to target vector x_i (G)
- Use greedy criterion:

If u_i (G) is better than x_i (G) with u_i (G).
Otherwise x_i (G): "survives" and u_i is discarded.

METHODOLOGY

As WOC uses lasers for communication we require a direct line of sight which is not available in urban areas, we require placement of relays so that signal can be transmitted from source to destination. Relays are transceivers which can both transmit and receive a signal. It has two basic functions:

- To amplify and reshape the received distorted signal.
- To provide a link from source to destination when there is no direct line of sight.

It can be said that the more number of relays better the probability of receiving the signal. In this project, optimization of placement of relays in parallel format is done using a hybrid differential evolutionary algorithm. The placement of relays is based on outage probability function which determines whether the signal can be transmitted further without any outage. Since our objective function is a continuous time function of path loss, power margin and number of relays so we can easily optimize it using HDE.

The implementation of the parallel WOC relaying is done using the HDE algorithm. So we first form a mathematical model of parallel DF relaying.

Let $d_{S,\,j}$ and $d_{j,\,D}$, $j = 1, 2 \ldots K$ respectively denote the distance of source-to-relay and relay-to-destination links. The end-to-end outage probability for parallel DF relaying is given by following equation:

$$P_{out} \overset{\text{def}}{=} \sum_{i=1}^{2^K} P_{out-p}(W(i)) = \sum_{i=1}^{2^K}\left[\prod_{j\in W(i)}\left(1-Q\left(\frac{\ln\left(\frac{L(d_{s,j})P_M}{2^k}\right)+2\mu_x(d_{s,j})}{2\sigma_x(d_{s,j})}\right)\right)\times \prod_{j\notin W(i)} Q\left(\frac{\ln\left(\frac{L(d_{s,j})P_M}{2^k}\right)+2\mu_x(d_{s,j})}{2\sigma_x(d_{s,j})}\right)\right] \tag{19}$$

which can be minimized with respect to $d_{S,j}$, $d_{j,D}$, $j = 1, 2, \ldots K$. It can be shown that, for performance optimization in parallel relaying, all the relays should be located along the direct path from the source to the destination.

Defining the following functions:

$$z\,(d_{S,1}, d_{S,2}, \ldots, d_{S,K}, d_{1,D}, \ldots, d_{K,D}) \overset{\text{def}}{=} \sum_{i=1}^{2^K}\left[\prod_{j\in W(i)}\left(1-Q\left(\frac{\ln\left(\frac{L(d_{s,j})P_M}{2^k}\right)+2\mu_x(d_{s,j})}{2\sigma_x(d_{s,j})}\right)\right)\times \prod_{j\notin W(i)} Q\left(\frac{\ln\left(\frac{L(d_{s,j})P_M}{2^k}\right)+2\mu_x(d_{s,j})}{2\sigma_x(d_{s,j})}\right)\right] \tag{20}$$

IMPLEMENTATION

Differential Evolution (DE) is a search heuristic that has a remarkable performance as a global optimization algorithm on continuous numerical minimization problems that have been extensively explored.

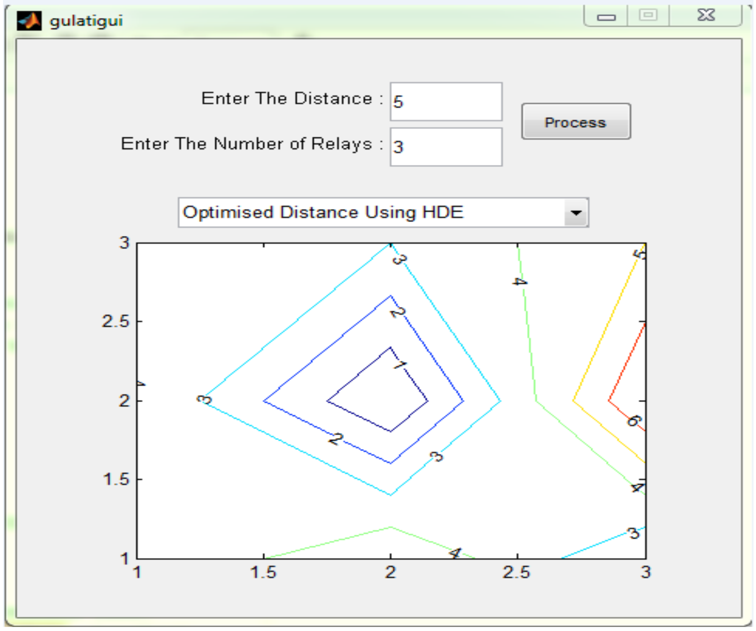

Fig.3: Graph for the optimized location of the relay

In order to discuss the quality and robustness of the proposed approach, it is necessary to verify the rate at which the algorithm is able to achieve optimal or near-optimal solutions, i.e., the convergence dynamics of the approach for each benchmark function.
Following are the steps of implementation:

Step 1: Define u $(d_{S,j})$ and v $(\bar{d}_{W(i)})$ given by Eq. (3) and (4).

Step 2: Define stigmatism which is a function of wavelength, number of relays and absolute temperature.

Step 3: Define normalized path loss L (d) with respect to the distance of the direct link between the source and the destination. Also, we define sigma epsilon which is a function of path loss.

Step 4: Finally, we define power margin P_M which defines the optimum power at a particular relay, which will not allow outage to occur.

Step 5: Now we find the optimized values of power margin, theta, gamma, beta and omega which are all the functions of path loss.

Step 6: To define our objective function, we require the above values of the functions so we call all of them in the objective function defined by Eq. (2).

Step 7: After defining the objective function, we need to optimize it using a hybrid differential evolutionary algorithm. For that we follow the next 4 steps.

Step 8: First, we decide a random population of the given size i.e., According to number of relays.

Step 9: Now we make the process of mutation which will make changes in random values generated according to a function defined in the study.

Step 10: After the process of mutation we make the process of crossover i.e., mixing of the current and the previous species since we want to preserve the characteristics of the previous species.

Step 11: Finally the process of selection is done in which we decide which species to keep according to the results which are better. After the execution of the code in MATLAB, we get the following results:

- The optimized location of the relay.
- The graphs for outage probability vs. Power margin.

Based on the above results we can say that the Placement of relay depends on the distance between the source and destination and also on the number of relays kept between the source and destination. Our results also include that the performance of the whole system is better if we have more number of relays, but as we know the placement of relays is costly, so we have to optimize their placement using this technique. Also, our results include that our algorithm gives the allowed, but not the exact placement of the and also gives very quick results.

It is inferred that for optimized results the relay should be placed near the source and the optimization also depends on the wavelength and power margin used. A large wavelength ensures less fading and mitigation. From Fig. 3, it can be understood that after numerous iterations, the objective function is converged so as to get a minima. it can be seen that that the minimum surface area determines the minima of the

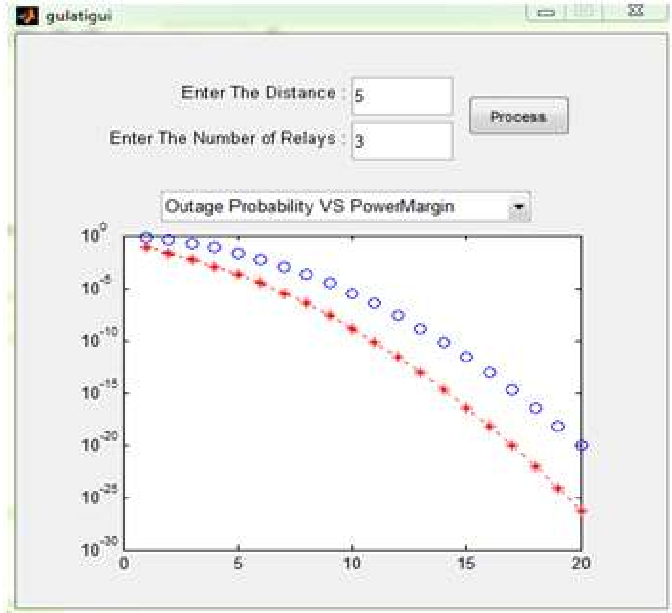

Fig. 4: Graph for outage probability vs. power margin

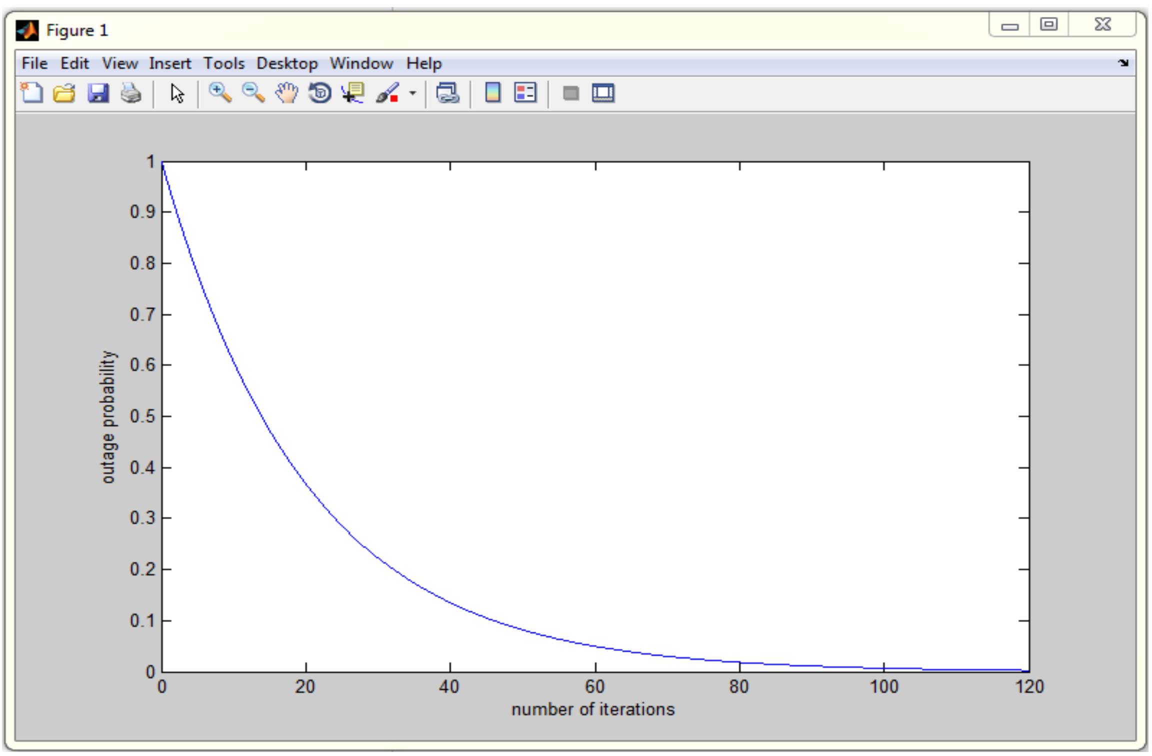

Fig. 5: Graph for P_{out} vs. number of iterations

function. Hence, for a distance of 5 km between the source and destination relay, the intermediate relays must be placed at a distance of 1 km from the source relay for minimum outage probability. Figure 4 depicts end to end outage probability of a WOC DF system for parallel relay scheme assuming the number of relays 3. It can be clearly seen that in the same power margin the outage probability for optimized relay positions is much less than un-optimized relay positions.

Figure 5 depicts that after a particular number of iterations the outage probability is minimized and the objective function is optimized (minimized in this case).Further increasing the iterations has no significant effect on outage probability.

CONCLUSION

The investigation on optimal relay placement for serial and parallel WOC relaying has been done. A Hybrid Differential Evolutionary (HDE) algorithm is applied to determine optimal relay locations in serial and parallel WOC relaying as to minimize the outage probability through optimal relay placement. It is clearly understood that equal distance relaying can be recommended for serial relaying and relays can be kept at the same point for parallel relaying. It can also be recommended to apply other evolutionary algorithms to determine optimal relay placement for wireless optical communication systems.

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