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OPTIMAL HYBRID RELAYING FOR WIRELESS OPTICAL COMMUNICATION USING METAHEURISTIC ALGORITHMS

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Abstract: Free space or wireless optical communication (WOC) is significantly better thanfiber optic communication. Since transmission is through free space, it will be faster than the other one.**Methods/Analysis:** Optical transceivers are used as relays for the effective performance of the WOC system. Relay assisted WOC communication recognizes the fact that atmospheric turbulence fading variance is dependent on the distance and gives significant performance gains by taking the shorter hops. **Findings:** A combined channel model can be used which considers both path-loss and turbulence-induced log-normal fading.The optimal relay locations as to reduce the outage probability in hybrid relaying technique have been analyzed and discussed by the application of metaheuristic algorithms such as firefly algorithm, invasive weed optimization algorithm, particle swarm optimization algorithm , shuffled frog leap algorithm etc.**Novelty /Improvement:**Weed Optimization is found to be the best technique among all applied algorithms.Hence it has been implemented to parallel relaying technique and then the output again considered as input to the serial relay placement. The outage probability vs power margin graph shows the result analysis of this hybrid structure.

Keywords : Atmospheric turbulence, fading channels, hybrid relaying, outage probability.

1. INTRODUCTION

Wireless optical communication has been becoming a part of modern life rapidly. In the past five years, there was a stable growth in the clients numbers who are using high capacity data communications, and demands in their data rates have been strikingly rising from hundreds of megabits to tens ofgigabits, per second. These customers include educational, businesses and recreational establishments, utilities and government offices. The high data rates required are gained with optical fiber communication.

The concept of WOC has been initially being developed by US military and NASA but now, also accessible to the public and works in a similar fashion to fibre optics, but without the use of fibre optic cables. The optical wireless unit (transceiver) is having the optical source with a lens that sends light via the atmosphere into the receiver of another unit. The transmissions don't experience interference and do not need RF license. Besides, the system is easily upgradable , no requirement of upgrade of security software and there is no need to install expensive fibre optic cables.The users will have greater mobility and flexibility than fibre optic system. This type of communication system will have the speed of fibre optics and currently capable of speeds of 1.25 GB per second and also has the future capability of speed as high as 10 GB per second. With its unique features, WOC is useful for a number of applications such as fibre backup, last-mile access, and back-haul for cellular networks. One of the original uses of WOCisnaval communicationbetween ship-to-ship [1]-[5]. The most important uses for the technology these days are in the private and public sectors. Many businesses and universities have problems getting connected because the fibre optic cables do not run all the way to the facility, but instead stop a mile or so away. That last mile is critical and hence the use of WOC applications can easily bridge that last mile and ensure that more users are able to connect and communicate. There are a number of entities that are able to take advantage of WOC, including educational institutions, health care facilities, the government,

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cities, and corporations.Building-to-building transmission within a confined area can easilybe made possible with WOC. Despite having major advantages, the widespread use of FSO has been limited by its rather disappointing performance for long-range links. For link ranges longer than 1 km, atmospheric turbulence-induced fading becomes a major performance limiting factor in WOCsystems[6]-[10]. To solve this issue, relay-assisted WOC systems have been proposed as a necessary method for the extension coverage and fading mitigation. One of the security risks of wireless transmissions is the interception of data. The broader the signal, the easier it is to intercept. WOC allows for a much narrower signal than traditional wireless methods of transmission and it stays narrow for the whole journey, which means there is a lower security risk. Another natural security feature of WOC is the need for an uninterrupted signal between units. If the signal becomes blocked for any reason, including by a detector, the transmission will automatically end. Thus the only way to pick up the signal that is being sent is to detect it behind the unit that is receiving the transmission. It is highly unlikely that this would be attempted, but the signal can be made to stop at the unit rather than extend past it and thus no one would be able to pick up the signal in that fashion.

2. TRANSMISSION AND SYSTEM MODEL

The WOC system is considered to utilize intensity modulation direct-detection (IM/DD) using binary pulse position modulation (BPPM). In such type of systems, an optical transmitter is "on" for half of the BPPM bit interval and is "off" during the other half. The receiver combines the received photocurrent from both the signal and non-signal slots of the BPPM pulse[11]-[15]. The BPPM signal from the transmitter is transmitted to the relay (transceiver) by a laser source or an LED. The placement of relay has two type of configurations such as serial and parallel. In serial relaying, the modulating signal from the transmitter is sent to the next relay placed along the direct link between the source and the receiver. The signal from the relay is forwarded to the next relay along the direct link and this process continues till the signal reaches the receiver. Also, there are two methods by which the signal can be forwarded among the relays: Amplify and Forward (AF) and Decode and Forward (DF). In AF relaying, the modulating signal which is received from the earlier node is amplified and then forwarded to the end node. In DF relaying approach, the received modulating signal has been decoded and then sent to the relay node. The same signal is transmitted to a predefined number of relay nodes and each relay, decodes and forwards the signal to the destination only if the received SNR exceeds a given decodingthresholdlevel.

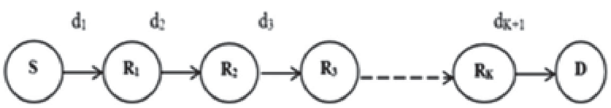

Figure 1 (a). WOC relaying serial relaying

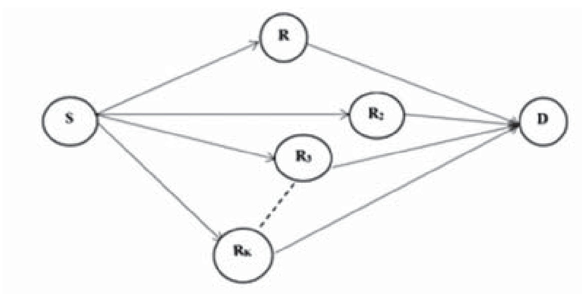

Figure 1 (b). WOC relaying parallel relaying

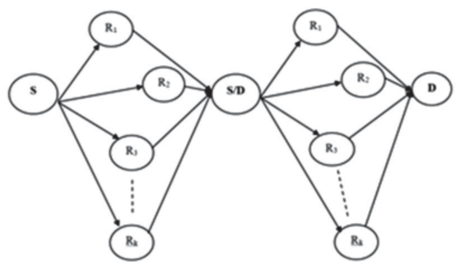

Figure 1 (c). WOC relaying hybrid relaying

An aggregated channel model is considered where both path loss and turbulence-induced log-normal fading are taken into considerations. The new concept of hybrid relaying system consists of both, the mixture of serial and parallel relaying. The parallel system is placed in series with another parallel system in order to make it a hybrid structure. Hybrid structure covers the individual drawbacks of both serial and parallel relaying.

3. OUTAGE PROBABILITY AND OUTAGE CONDITIONS FOR RELAYING SCHEMES

3.1 Outage Probability

The probability that an outage will occur within a specified time period is defined as the outage probability[12]-[15]. outage probability is a crude measure of performance. It is defined as the probability when mutual information is less than the given threshold. The importance of outage probability is that when an outage occurs, there is more probability to have decoding failure[16]-[20]. The outage probability (P_{out}) is denoted as

$$P_{out} \approx \sum_{i=1}^{2^n}\left[\prod_{j\in(t)}\left(1-Q\left(\frac{ln\left(\frac{L_{o,j}\mathrm{P_M}e^{2\mu x}}{2\mathrm{N}}\right)}{2\sigma_x\left(d_{o,j}\right)}\right)\right)\times\prod_{j\notin s(t)}Q\left(\frac{ln\left(\frac{L_{o,j}\mathrm{P_M}e^{2\mu x}}{2\mathrm{N}}\right)}{2\sigma_x\left(d_{o,j}\right)}\right)Q\left(\frac{ln\left(\frac{\mathrm{P_M}e^{2\mu\xi}}{2\mathrm{N}}\right)}{\sigma_\xi\left(d_{s,(i)}\right)}\right)\right.$$

And the optimal relay location is given as

$$d_{opt}\left(\mathrm{P_M}, d_{\mathrm{S,D}}, \mathrm{K}\right) = 0.5d_{\mathrm{S,D}} + \frac{\beta}{\mathrm{P_M}}\ln\left(\omega P_M^k + \varphi\right), K \geq 2$$

where β, ω ,k, and φ are defined as

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

$$\omega = -2.7 \times 1^{-5}\,d_{\mathrm{S,D}} + 0.1\ln(\mathrm{K}) + 0.11$$

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

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

3.2 Outage Conditions

Conditions for outage in parallel relaying are:

1. If the single relay does not exactly decodes the signal, for all the nodes.
2. Multiple inputs single output (MISO) links fail between the relay and the destination.

4. DESIGN APPROACH

Hybrid relay placement technique using metaheuristic algorithmssuch asfirefly algorithm, invasive weed optimization algorithm, particle swarm optimization and shuffled frog leap algorithm has been applied using matlabsimulations and then outage probability vs power margin have been analyzed.

4.1 Firefly algorithm

Three flashing characteristics of fireflies to develop firefly algorithm:

(a) As a matter of fact all fireflies are unisex, and they tend to move towards more attractive and brighter ones regardless of what their sex is.

(b) Attractiveness of each firefly is proportional to its brightness, so for any two flashing fireflies, the less bright firefly gets attracted to the brighter one and move towards it. Attractiveness and brightness of the firefly decreases as distance increases. If there is no more attractive firefly than a particular one, it will move randomly.

(c) The brightness of any firefly is determined by the value of the objective function. For maximization problems, brightness is proportional to the value of the objective function.

4.2 Invasive weed optimization algorithm

IWO was first designed and developed by Mehrabian and Lucas and it is a numerical stochastic optimization algorithm inspired from the colonization of invasive weeds. A weed is a plant growing where it is unwanted, any tree, vine, shrub, or herb may be classified as a weed in a specified geographical area, depending on situations. Weed has shown a very robust and adaptive nature that renders it undesirable plant in agriculture. In any *D*-dimensional search space, a weed which represents a potential solution of objective function is represented as $p = (p_1, p_2, p_3, \ldots, p_{N-1})$. At first, *p* weeds, called a population of plants, are initialized with random growth position of each weed, and then each weed produces seeds depending on its fitness and its colony's lowest fitness and highest fitness to simulate the natural survival of the fittest process. The number of seeds each plant produces increases linearly from minimum possible seed production to its maximum; the generated seeds are being distribution randomly in the search area by normal distribution with mean the equal to zero and a variance parameter decreasing over the number of iteration. By setting the mean parameter equal to zero, the seeds are distributed randomly such that they locate near the parent plant, and by decreasing the variance over time, the fitter plants are grouped together and inappropriate plants are eliminated over time.

4.3 Particle swarm optimization algorithm

In this algorithm, the population is called a *swarm* and the individuals are called *particles*. Resembling the social behaviour of a swarm of bees to search the location with the most flowers in a field, the optimization procedure of PSO is based on a population of particles which fly in the solution space with velocity dynamically adjusted according to its own flying experience and the flying experience of the best among the swarm. During the PSO process, each potential solution is represented as a particle with a position vector and a moving velocity represented as *x* and *v*, respectively.Thusfora *K*-dimensional optimization, the position and velocity of the *j*thparticlecanberepresented $sxj = (xj_1, xj_2, \ldots, xj_k)$ and $vj = (vj_1, vj_2, \ldots, vj_k)$. Like a GA, the PSO also begins by generating a population of particles at random. At each time step, an associated value for each particle is evaluated in accordance with a function called the *fitness function* which is critically defined and configured from a consideration of the search objective. The value normally called the *fitness* indicates the goodness of the solution. The position of the individual best fitness which the *i*th particle has been achieved so far; that of the highest fitness which has been obtained among all the particles in the population so far are known as the personal best (denoted as xbestj) and the global best (denoted as x^{best}), respectively, and both are stored to generate the new velocity of *j*th particle. During the process, each particle adjusts its velocity according to its own experience, and the position of the best of all particles moves toward the best solution. Personal best (*pbest)* position of a particle expresses the cognitive behavior of particle.It is defined as the best position found by the particle. It will be updated whenever the particle reaches a position with better fitness value than the fitness value of the previous personal best. Global best (*gbest*) position has been expressed as the social behavior. It is defined as the best position found by all the particles in the swarm. It will be updated whenever a particle reaches a position with better fitness value than the fitness value of the previous global best.

4.4 Shuffled frog leap algorithm

The shuffled frog leap algorithm (SFLA) is a metaheuristic technique to implement a heuristic search using a heuristic function to seek a solution of a combinatorial optimization problem. In SFLA, a population contains many frogs. Each frog represents a different solution. The population of frogs is divided into multiple subgroups. Every subgroup contains a certain number of frogs. The subgroup is called a memeplex (m).A different memeplex is considered as a unique group offrogs with a different value; thus, a local search can be implemented in each memeplex. Each frog has its own thought, which will be affected by other frogs. The memeplex is developed via a memetic algorithm. After a certain memetic development and jump process, the memeplexes are forced to mix, and memeplexes are formed through a shuffling process.This shuffling enhances the quality of the memes after they are infected by frogs from different regions of the swamp.

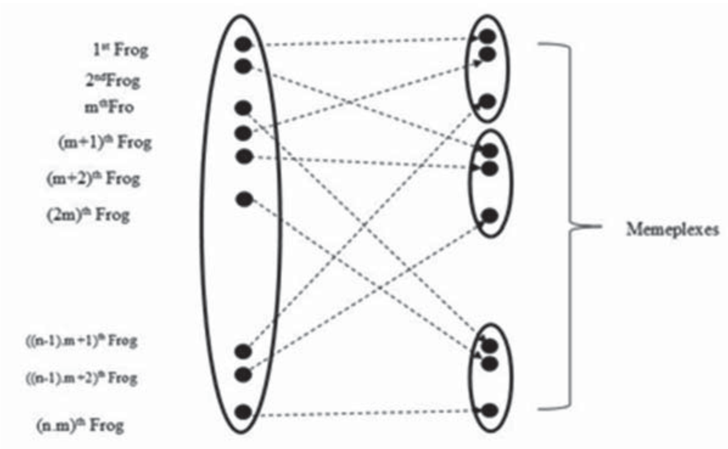

Figure 2 Dividingfrogs into memeplexes

The memetic development and jump process will not stop until the results meet the criteria or the maximum time of optimization has been reached.

5. RESULTS AND DISCUSSION

PSO ,Firefly, SFLA and IWO algorithms have been compared on the basis of outage probability i.e., so as to find out the best among them for determination of optimal relay location. Invasive weed optimization algorithm came out to be the best among five evolutionary algorithms that have been compared.

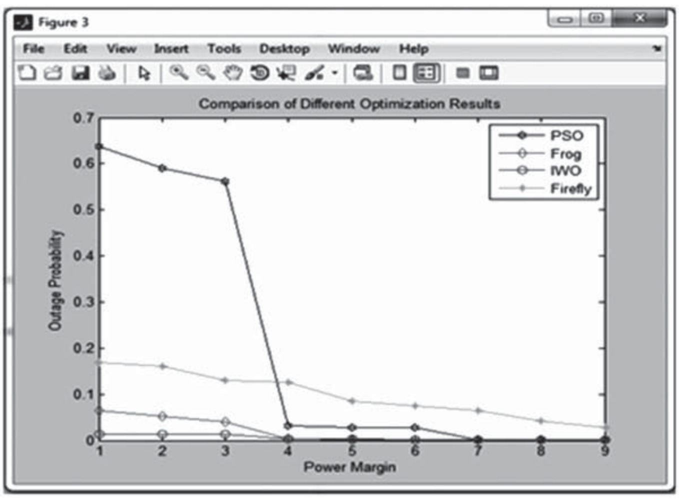

Figure 3. Outage probability vs power margin for all four algorithms

The outage probability of different optimization algorithms have been analysed with various power margins. Safari.,et al (2008) defined power margin (PM) as a ratio of transmitted power to threshold power, which denotes the threshold value of transmitted power needed for no promising link failure issues.All the above simulated results are obtained on the following specifications: Log normal distribution channel, laser source,: avalanche photodiodes detector, 2-6 relays, 1550 nm wavelength and 10mW of input power. The PSO and Firefly algorithms have required more power margin than the other two algorithms to achieve no outage probability. The Table 1 shows the obtained results for a link distance of 5 km and 3 number of relays. Finally, Fig. 3 has concluded that IWO will be the best among all four evolutionary algorithms as it has the least outage probability.

Table 1.
Outage Probability vs Power Margin

PM (dB)= 10 log (PT/P Th)	Outage probability K=3, dS,D = 5 km			
	PSO	SFLA	FIREFLY	IWO
1	0.65	0.08	0.18	0.01
2	0.59	0.06	0.17	0.01
3	0.58	0.04	0.16	0.01
4	0.05	0	0.15	0
5	0.05	0	0.12	0
6	0.05	0	0.1	0
7	0	0	0.09	0
8	0	0	0.08	0
9	0	0	0.04	0

Since SFLA and IWO performs well than other algorithms and this two algorithms are compared with number of iterations. It is found that IWO algorithm provides the best results with lesser computational time followed by all other algorithms. Hence, the Invasive weed algorithm has been recommended as the best preferred choice for practical implementation. Table 2 shows the normalized optimal relay locations obtained with three relays for all the four algorithms. It is considered as K as the number of relays and the normalized optimum relay position

Table 2.
Normalized Optimal Relay Locations Obtainedwith Three Relays

PM (dB)	Optimal relay locations K=3, dS,D =5km			
	Proposed or obtained results			
	PSO	SFLA	FIREFLY	IWO
0	0.3562	0.4658	0.3212	0.3454
5	0.3673	0.4517	0.3654	0.3687
10	0.3941	0.4483	0.3789	0.3898
15	0.3998	0.4591	0.4098	0.3974
20	0.4365	0.4882	0.4232	0.4273

as the ratio of distance between source to relay to distance between source and destination. For example, if the relay is kept at 1 km and total distance between source to destination is 3km, then Normalized optimal relay location will be 1/3= 0.33. Looking at this table 2, it can be clearly stated that IWO is the best optimization algorithm. For long range WOC, serial relaying has been preferred, but if a single link fails, the entire transmission will be disturbed. Parallel relaying has less chances of total link failure, but it is not suitable for long distance transmission.Hence, it has been recommended that a combination of both i.e. parallel relaying in serial by making it as hybrid relaying structure can be used for long distance links. The four algorithms such as PSO, firefly, SFLA and IWO algorithms are matched on the basis of outage probability, so as to find out the best among them. And then a hybrid structure has been made of the best algorithm, so as to minimize the effect of atmospheric turbulence in wireless optical communication.

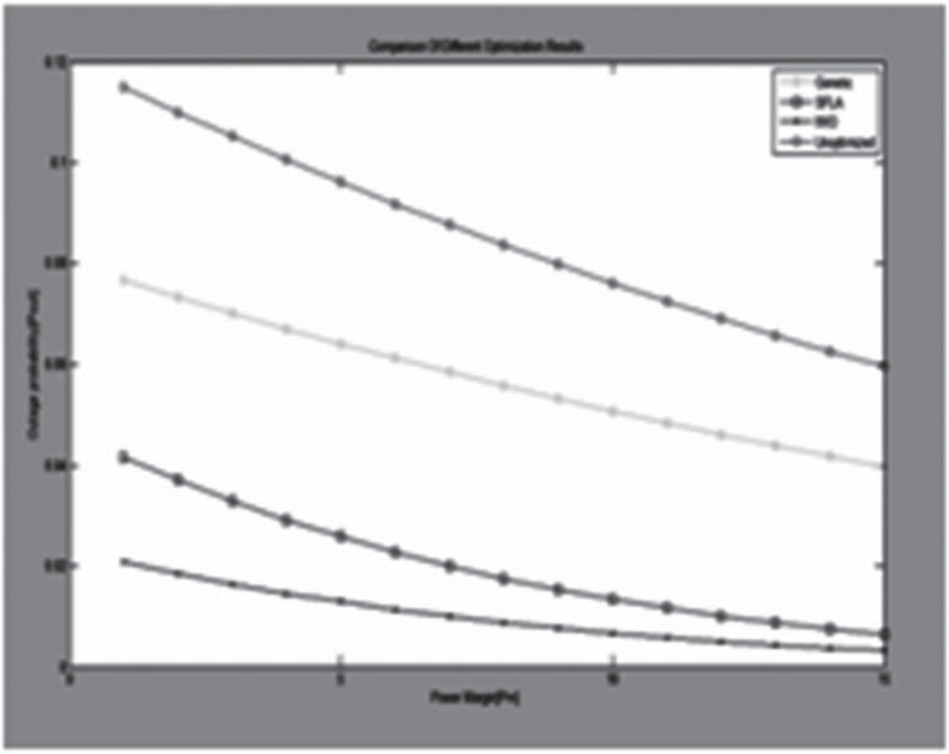

Figure 4. Comparison of outage probability vs power marginfor hybrid relaying technique

Invasive weed optimization algorithm came out to be the best among four evolutionary algorithms with comparing to all other algorithms used. And then the outage probability vs. power margin graph has been plotted for this hybrid relaying technique which is similar to the previous individual set up.Fig.4 shows the results of hybrid relaying technique with three number of relays. Thus, the same invasive weed optimization algorithm has given minimum outage with hybrid relaying technique, hence it has been recommended for long distance wireless communication system.

5. CONCLUSION

Revolutionary growth in WOC field and the computing methods enhanced the development leap continuously. The optimized output results of PSO, Firefly, SFLA and IWO algorithm have been considered for comparing with the un-optimized output. The optimized output of IWO algorithm provides the best result and the lesser computational time followed by all other algorithms, hence, the Invasive weed algorithm has been recommended as the best preferred choice for practical implementation. To overcome the limitations of serial and parallel relaying systems, a hybrid method of relaying which is parallel with serial combination technique has been recommended for the coverage of large distance optical links. If the variety of hop has been enhanced, the error activities will also be expanded by providing higher transmitting delay for every hop. Optimization of these errors with end-to-end transmitting delay for serial relaying situation has given an appealing issue for forthcoming developments. This liability of the results on the structure of the system with respect to the constraints leads to increase in price with improved complexity. This will be one of the fascinating or challenging issues in future for design considerations.

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