A Genetic Algorithm Method for Multi-spot Diffuse Infrared Wireless Communications

M Nikkar Esfahani and J M H Elmirghani†

†University of Leeds

Abstract: A genetic algorithm for improving the received SNR in multi-spot diffuse infrared communication systems is proposed. The technique aims to adjust the position and number of the spots on the ceiling as the receiver moves to different locations. It is shown that this algorithm can improve the signal to noise ratio across the room. This technique provides an upper bound on the SNR that can be achieved by spot-diffuse system such as LSMS[1] in a mobile scenario. In practice this algorithm provides an improvement of up to 8dB compared to LSMS at a cost of about 1% overhead.

1 Introduction

Indoor Infrared (IR) wireless communications have attracted considerable attention in recent years as they allow high-speed transmission free from electromagnetic interference and make use of inexpensive optoelectronic devices, such as light emitting diodes (LEDs) and silicon detectors [2]. However there are two major impairments that impede the optical wireless systems. The first is additive noise and the second is multipath dispersion associated with non-direct line of sight (NDLOS) infrared systems, which can result in significant inter-symbol interference [3]. A possible efficient technique that can improve SNR performance, mitigate the shadowing effect and reduce multipath dispersion is the multiple spot diffusing technique [4]. Systems that adopt this approach possess the advantages of the DLOS and overcome the drawbacks of diffuse links. A multi-beam transmitter is used to create the multiple diffusing spots pointed in different directions. Multiple diffusing spots can be created using a computer generated holographic optical element mounted on the transmitter[1]. Moreover, another technique that is effective in combating the destructive effects of multipath dispersion and ambient light interference is utilising angle diversity detection. In previous studies the mobility of the receiver is generally not included and hence the spots often take a uniform distribution on the ceiling. Mobile users will violate such a geometry arrangement, thus producing weak coverage in certain zones as the user moves. To reduce the performance degradation due to user mobility a number of solutions have previously been proposed [5], these techniques mainly concentrate on adjusting the power allocated to each spot to maximise the SNR at the receiver. In this paper we utilise the power of genetic algorithms to optimise the position and number of spots to maximise the receiver's SNR. Genetic algorithms (GAs) have previously been utilised to improve the quality of indoor infrared wireless communications but the aim has generally been to provide an even power distribution over the entire communication floor [6]. Our studies serve to provide an upper bound on the achieve SNR by the multi-spot diffuse systems and due to the acceptable level of computation cost is an attractive option for the practical systems.

2. Propagation environment

The propagation environment includes the transmitter radiation pattern, the transmission medium and the receiver characteristics

2.1 Simulation Set-up

To simulate the effects of multipath dispersion and ambient light noise and their impact on the received data in indoor wireless application, a rectangular room was chosen as the communication environment. The dimensions of the room are set to $8m \times 4m \times 3m$. Walls (including ceiling) and floor are modelled as Lambertian reflectors of the first order with reflectivity coefficients 0.8 and 0.3, respectively. Reflections from doors and windows are considered to be same as the reflections from walls. The transmitter is placed on the floor with a hologram mounted on it that can shape the beams. The receiver is set to move around the room on a plane positioned 1m above the floor. To simulate a more realistic environment the system was analysed in the presence of directive noise sources. Eight halogen spotlights, which result in one of the most stringent optical spectral corruptions to the received data stream have been chosen [5]. To evaluate the impact of ambient light, the background noise (BN) distribution pattern of an incandescent light was investigated. 'Philips PAR 38 Economic' (PAR38) emits a power of about 65W in a narrow beamwidth which is modelled as generalised Lambertian radiant intensity with order $n = 33.1$ which corresponds to a semiangle of 11.7°. The eight spotlights were equidistantly placed in the ceiling, 2m above the plane where the receiver is placed on; at coordinates (1,1,3), (1,3,3), (1,5,3), (1,7,3), (3,1,3), (3,3,3), (3,5,3) and (3,7,3) [7].

2.2 Transmitter Model

The multi-beam transmitter is assumed to produce N beams to form N spots on the ceiling with equal densities. In our simulations the total number of spots is varied to achieve the optimum receiver SNR. The transmitter is pointed upwards and emits 1W total optical power. The power incident on each reflecting element, either on the ceiling or walls, can be modeled as Lambertian.

2.3 Diversity Receiver

The proposed receiver was initially reported [8] with three detectors. The direction of each photo-detector is characterised by two major parameters: elevation angle (El) and orientation angle (Az). While the El angle remains at 35° for the photo-detectors placed on the slope sides, the El angle for the detector placed on the top remain at 90°. Alternatively, Az angles correspond to the truncated pyramid's face orientation angles and are fixed to $0^\circ, 0^\circ$ and 180°. Their FOVs have been chosen to achieve the best SNR; hence, two of them were restricted to 35°, whereas the detector that faced up was set to 20°.

2.4 SNR & Delay Spread Calculation

The bit rate for this system employing on-off keying is set at 50 Mbit/s. Assuming Gaussian statistics for the noise in the channel, the SNR can be calculated as

$$SNR = \left(\frac{R \times (P_{s1} - P_{s0})}{\sigma_{t0} + \sigma_{t1}} \right)^2 = \left(\frac{R \times (P_{s1} - P_{s0})}{\sigma_t} \right)^2 \qquad (1)$$

where P_{s0} and P_{s1} are power levels associated with the received signals for logic '0' and '1' respectively and R is the responsively of the receiver and is set as $0.5A/W$. The delay spread of an impulse response is expressed as a root-mean-square value by

$$D = \sqrt{\frac{\sum (t_i - \mu)^2 . P_{r_i}^2}{P_{r_i}^2}} \qquad \mu = \frac{\sum t_i . P_{r_i}^2}{\sum P_{r_i}^2} \qquad (2)$$

where t_i is the time delay of the received optical power (P_{r_i}).

3. The Genetic Algorithm

GAs should not be considered off the peg ready to use algorithms, but rather a general framework that need to be tailored to a specific problem [9]. This section explains the details of the genetic algorithm that is applied to find the optimum number and position of spots. To control the computation cost of the simulation, 200 uniformly scattered spot positions were considered on the ceiling with a maximum of 200 radiating spots at one time. Each chromosome consists of 200 genes that can take values of 0 or 1 corresponding to the state of that specific spot. In each generation 150 different chromosomes are produced and compete based on their fitness and this is repeated across 450 generations. This number was chosen as a balance between computation cost and diversity. It is assumed that the transmitter takes $0.1\mu s$ to adjust the hologram for each chromosome and $0.1\mu s$ to receive feedback on the relevant SNR. Therefore for each transmitter and receiver position the computation time associated with 150 chromosomes (150 individuals) and 450 generations is 13.5ms. At a typical pedestrian rate of 1m/s, the spot locations can be updated at 1 second intervals (1 meter transmitter or receiver displacement has little impact on SNR). The spot reconfiguration overhead time is therefore about 1%.

3.1 Fitness

While the genotype describes each individual chromosome, it is the phenotype that determines the fitness level and chances of the success of each individual in life. The GAs operators, such as reproduction work on genes level, hence the phenotypic properties will require evaluation for each generation. This evaluation is referred to as fitness or objective function which in the case of our simulations is the SNR induced at the receiver (after maximum ratio combining of the three incoming signals) due to that particular arrangement of spots.

3.2 Selection

The objective of the selection operator is to facilitate the survival of fitter individuals. This means individual with higher fitness value have a higher probability of contributing to the next generation. There are several methods for implementing this selection process. The easiest to implement is the Biased Roulette Wheel where each current string in the population has a roulette wheel slot sized in proportion to its fitness value. A target value is set, which is a random proportion of the sum of the fitnesses in the population. The population is stepped through until the target value is reached.

3.3 Reproduction

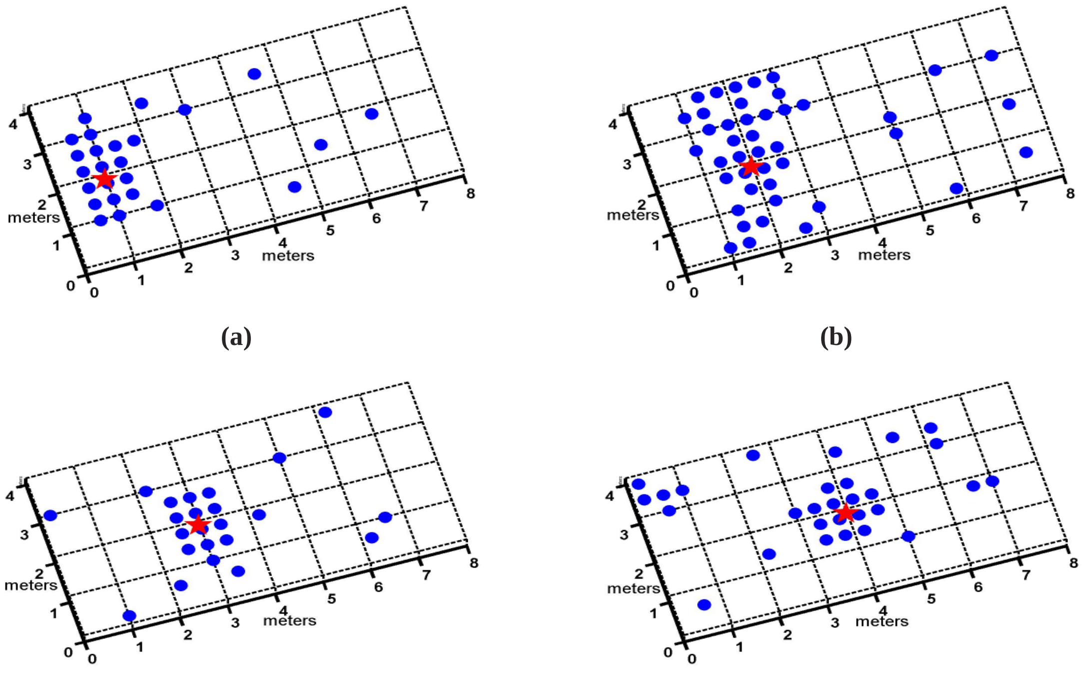
The natural phenomenon of reproduction is replicated by Crossover; this is applied with a probability of 0.8 to the pool of randomly selected individuals. In this paper we apply the simple single point crossover, in which the individuals are randomly paired and each pair of strings undergoes crossing over as follows: an integer position k along the string is selected uniformly at random between 1 and the string length less one $[1, l-1]$. Two new strings are created by swapping all character between $k+1$ and l inclusively [10].

3.4 Mutation

Random mutations alter a certain percentage of bits in the list of chromosomes. Mutation is the second way a GA explores a cost surface. It can introduce traits not in the original population and keeps the GA from converging too fast. The probability of mutation was set as 0.01 in this paper.

4. Results

To understand how the genetic algorithm would perform we simulated the system with receiver at different positions along the central line of the room $x = 2$, the improvement in the SNR and also the arrangement of spots in the fittest individual after 450 generation was studied. Figure 1(a) shows how the spots have converged when the receiver is positioned close to the side wall. As well as covering the area immediately above the receiver, which facilitates a LOS path between the spots and the receiver, the spots seem to form three lines in parallel to the side wall. The rays from these lines can reach the receiver by reflecting from the nearby wall. In Figure 1(b) where the receiver is positioned at equal distances from three different walls, we see that the number of the spots have increased to form lines along side the three walls as well directly over the



(a)

(b)

(c)

(d)

Figure 1 Arrangement of spots after the optimisation as the receiver is moved along the central line of the room (a) Receiver at (2, 1, 1), (b) Receiver at (2, 2, 2), (c) Receiver at (2, 3, 1), (d) Receiver at (2, 4, 1)

receiver. As can be seen when the receiver moves further from the walls, the contribution of the spots toward the received power is decreased and the number of the spots is considerably reduced, and they are positioned mainly above the receiver.

Figure 2, is a display of the trajectory of the optimization through the generations. It can be seen that there is an improvement in excess of 10 dB through the generations. In Figure 3 the new proposed system is compared against the line strip multi-spot diffuse system and conventional diffuse systems. Impressive SNR gain is evident compared to both systems and the delay spread results are superior compared to the diffuse system and are comparable with LSMS. The SNR gain of the new proposed system outweighs the loss of uniformity that is offered by the line-strip multisport systems. The SNR improvement offered by our proposed system is 8dB and 20 dB over LSMS and CDS respectively.

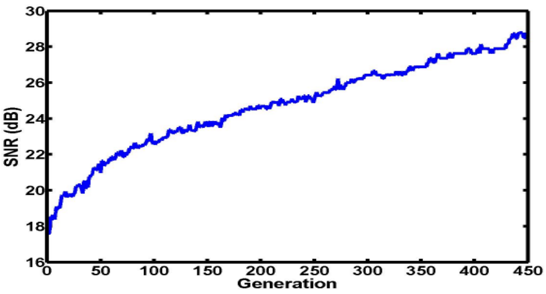


Figure 2: SNR improvement through the generations, receiver at (2, 4, 1)

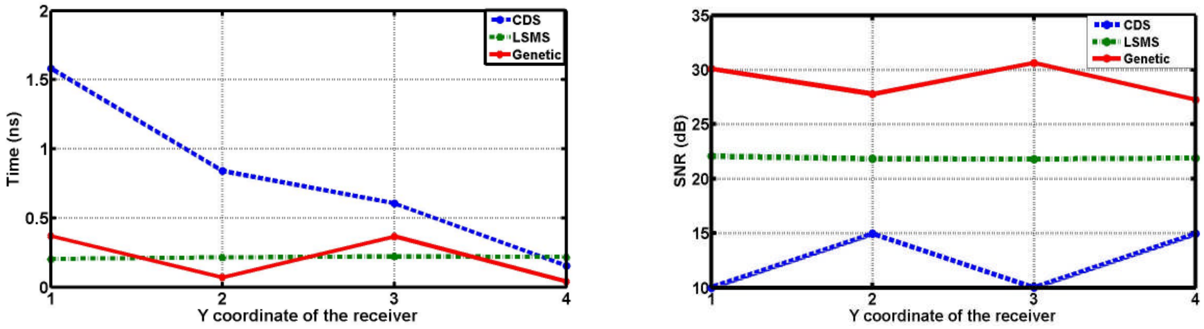


Figure 3: Delay spread and SNR comparison for Genetic optimised, LSMS and CDS (transmitter in center of the room) systems

5. Conclusions

This paper reports a novel approach using genetic algorithms to optimise the number and arrangement of spots in a multi-spot diffuse indoor infrared system. It has been demonstrated that this method can lead to significant improvement in the quality of the signal received at the receiver and can pave the way for more resilient high speed links. Our results act as an upper bound on the capabilities of spot-diffuse systems as the spot locations, number and power have been optimised. More computationally efficient genetic algorithms are the subject of our future work.

References

1. A.G. Al-Ghamdi, and J.M.H. Elmirghani, *Performance comparison of LSMS and conventional diffuse and hybrid optical wireless techniques in a real indoor environment* Optoelectronics, IEE Proceedings -, 2005. **152**(4): p. 230-238.
2. Gfeller, F.R. and U. Bapst, *Wireless in-house data communication via diffuse infrared radiation.* Proceedings of the IEEE, 1979. **67**(11): p. 1474-1486.
3. Kavehrad, M. and S. Jivkova, *Indoor broadband optical wireless communications: optical subsystems designs and their impact on channel characteristics.* Wireless Communications, IEEE, 2003. **10**(2): p. 30-35.
4. Al-Ghamdi, A.G. and J.M.H. Elmirghani, *Analysis of diffuse optical wireless channels employing spot-diffusing techniques, diversity receivers, and combining schemes.* Communications, IEEE Transactions on, 2004. **52**(10): p. 1622-1631.
5. Alattar, J.M. and J.M.H. Elmirghani. *Adaptive Beam Clustering Optical Wireless System for An Indoor Channel*. in *Communications, 2007. ICC '07. IEEE International Conference on*. 2007.
6. Higgins, M.D., *A Genetic Algorithm Method for Optical Wireless Channel Control.* Journal of Lightwave Technology, 2009. **27**: p. 760-772.
7. Al-Ghamdi, A. and J.M.H. Elmirghani, *Optimization of a triangular PFDR antenna in a fully diffuse OW system influenced by background noise and multipath propagation.* Communications, IEEE Transactions on, 2003. **51**(12): p. 2103-2114.
8. Al-Ghamdi, A.G. and J.M.H. Elmirghani, *Line strip spot-diffusing transmitter configuration for optical wireless systems influenced by background noise and multipath dispersion.* Communications, IEEE Transactions on, 2004. **52**(1): p. 37-45.
9. Thomas B¨ack, U.H., and Hans-Paul Schwefel, *Evolutionary Computation: Commentson the History and Current State.* IEEE Trans. Evolu. Comp., April 1997. **1**(1).
10. Goldberg, D.E., *Genetic Algorithms in search, optimization, and machine learning* 1989, Boston: Addison Wesley