Fair Optimal Transceivers Placement in Foggy Cooperative Dynamic FSO Networks

Abdallah S. Ghazy[1], **Hossam A. I. Selmy**[2], **and Hossam M. H. Shalaby**[1]

[1]*Egypt-Japan University of Science and Technology (E-JUST), Alexandria, Egypt.*[2]*Cairo University, Cairo, Egypt*

abdallah.gahzy@ejust.edu.eg, hossamselmy@yahoo.com, shalaby@ieee.org

Abstract: New optimal transceivers' placement scheme is proposed to improve the performance of fair resource allocation in foggy dynamic FSO networks. The scheme is formulated as bilevel-multi-objective-optimization problem. Results indicate the superior performance over random placements.

OCIS codes: Free space optics (FSO), Foggy link, placement.

1. Introduction

FSO is a promising solution for existing last mile connectivity problem. However, FSO channel is affected by various weather conditions. One of these conditions is the foggy weather which could absorb and scatter the transmitted optical signal [1]. To overcome this performance degradation and increase the network reliability, dynamic FSO networks has been proposed [2]. We have proposed in [3] a resource allocation scheme called Lex-Max-Min Fairness (LMMF) scheme, that aims to enhance the performance of cooperative dynamic networks against the atmospheric variation at given number and placement of FSO transceivers. In that work, the number of additional FSO transceivers at each FSO node is assumed to be fixed throughout the performance evaluation, i.e., the effect of changing transceivers' placement has not been investigated. In order to increase the number of alternative paths from/to each node and possibilities of network reconfigurations, the number of additional FSO transceivers must be increased. However, increasing number of additional transceivers without considering their optimal placement could significantly increase the network cost [4]. In this paper, optimal transceivers' placement scheme associated with fair resource allocation is proposed for cooperative dynamic FSO networks.

2. FSO Link Model

The FSO channel losses are accumulated from many sources [1]. In the considered networks, both fog and geometrical losses are assumed the dominating ones. Moreover, a homogeneous foggy weather is assumed over the entire network with equal visibility value. When the background radiation level is relatively high (e.g., outdoor), the thermal noise can be ignored and the receiver can be modeled as shot noise limited. On-off keying modulation is used in the transmission over FSO links.

3. Placement Vector Parameters

Generally, the cooperative FSO network consists of N nodes $(v_1, ..., v_N)$ with arbitrary geographical distribution in addition to the backbone node v_0. Normally, each FSO node is equipped with one optical transceiver to transmit/receive its own traffic to backbone node, which is equipped with N optical transceivers. In order to take the advantages of cooperative reconfigurable FSO network, additional w optical transceivers are implemented. Given w, the total number of optical transceivers at k^{th} node is $z_k \in \{1,2,\ldots,w+1\}$, where $k \in \{1,2,\ldots,N\}$. The number of nodes equipped with s transceivers is given by n_s where $s \in \{1,2,\ldots,w+1\}$. The number of feasible placement vectors is Λ and each vector is represented as $Z_a = (z_1, z_2, ..., z_k, ..., z_N)$ where $a \in \{1,2,...,\Lambda\}$. Also, all vectors can be summarized in matrix H with dimension $(N \times \Lambda)$ and Λ is upper bounded as: $\Lambda < N + \sum_{b=2}^{b=w-1} \binom{N}{b} \times (w-1)^b + \binom{N}{w}, w \leq N$. For each transceiver's placement vector Z_a, there is a number of feasible configurations β_a that could be realized with this placement, where β_a is upper bounded by: $\beta_a < \left[\sum_{ii=1}^{ii=N} \binom{N}{ii}\right] \times \prod_{s=1}^{s=w+1} \left[\sum_{jj=0}^{jj=s} \binom{N}{jj}\right]^{n_s}$. The overall total number of feasible configurations for all placements vectors is $\alpha < \left[\sum_{a=1}^{a=\Lambda} \beta_a\right]$. At a given visibility value V, the losses of all FSO links are summarized in γ matrix, $\gamma = (\gamma_{00}, \ldots, \gamma_{0N}; \ldots, \gamma_{ij}, \ldots; \gamma_{N0}, \ldots, \gamma_{NN})$, where γ_{ij} is the loss coefficient of link between transmitter of i^{th} node and receiver of j^{th} node. Clearly, $0 \leq \gamma_{ij} \leq 1$, γ_{ii}= 0 and $\gamma_{ij} = \gamma_{ji}$ for any $i, j \in \{0,1,\ldots,N\}$. Associated with each placement vector Z_a a number of feasible configurations β_a. The feasible d^{th} configuration, where $d \in \{1,2,\ldots,\beta_a\}$, is identified by binary connection matrix G_d. Moreover, a matrix G_a represents at set of β_a binary connection matrices that summarize the connections for all feasible configurations associate with placement vector Z_a. The connection status between network nodes in d^{th} configuration are summarized in connections matrix $G_d = (g_{d00},\ldots,g_{l0N};\ldots,g_{dij},\ldots;g_{dN0},\ldots,g_{dNN})$, where g_{dij} is the connection status between i^{th} and j^{th} nodes in configuration d and $g_{dij} \in \{0,1\}$. The connection between nodes i and j is established if $g_{dij} = 1$. Also, bidirectional links are assumed so that $g_{dij} = g_{dji}$ and $g_{dii} = 0$. Moreover, all FSO links are assumed to have the same average transmitted power, i.e., the power of optical link between nodes i and j is constant, $P_{dij} = P_0$. However, to increase link capacity and guarantee an error rate less than a specified maximum $BER_{dij} < BER_{max}$, the link between nodes i and j in configuration d adapts its transmission rate, T_{dij}, to be one of $q+1$ discrete values, where $T_{dij} \in \{0,x_1,x_2\ldots,x_q\}$ and $x_1 < x_2 < \ldots < x_q$. The transmission rate of node k in configuration d is denoted by T_{dk}, where $T_{dk} = \sum_{j=0}^{N} T_{dkj}$. The bit rate of node k (its own traffic) through connection to node j is denoted by R_{dkj}. The overall bit rate of node k is $R_{dk} = \sum_{j=0}^{N} R_{dkj}$. Obviously, $R_{dk} \leq T_{dk}$ and for practical implementation both R_{dk} and $T_{dk} \in \{0,x_1,x_2\ldots,x_q\}$. The end-to-end bit error rate of node k, BER_{dk}, is bounded by $BER_{dk} \leq BER_{max}$. The bit rates and bit-error rates associated with all nodes in the feasible configurations could be summarized in $(\beta_a \times N)$ matrices R_a and E_a, respectively. For the d^{th} configuration, the bit rates for all nodes are represented in vector r_d $(1\times N)$ and $r_d \in R_a$. Also, The bit-error rates are summarized in vector e_d $(1\times N)$ and $e_d \in E_a$. The network capacity associated with configuration d is $C_d = \sum_{k=1}^{N} R_{dk}$, and all capacities associated with all feasible configuration are summarized in vector $(\beta_a \times 1)$ C_a and $C_d \in C_a$.

4. Optimal Transceivers Placement scheme

In the proposed scheme, the optimization problem is formulated in two levels of multi-objective optimization. Each level optimizes different objectives with different priories. The highest priority objective is the reliability (in terms of non-zero bit rate node). The second objective is the fairness $F = \sum_{k=1}^{k=N} R_{dk}^2/(N \times \sum_{k=1}^{k=N} R_{dk}^2)$ [5], and the least priority one is the average error rate. In first level of the optimization problem, and for each Z_a, the scheme obtains the optimal configuration, $\bar{G}_a(:,:,m)$, at each visibility interval ΔV_{am}, $m \in \{1,2,..,M_a\}$. This could be achieved by optimizing r_d using sequential max-min that reduces number of dropped nodes and hence rises the fairness. If there are more than one solution (configuration) with the same max-min bit rate, the scheme proceeds to optimize e_d, using sequential min-max that reduces the error rates. The results of this optimization level are two matrices, $(M_a \times N)$ $\bar{R}_a$ and $(M_a \times N)$ $\bar{E}_a$, which are used in the next level of optimization as shown in (1). In the second level of the optimization problem, the optimal placement vector Z_{a^*} along with the associated optimal configuration $G_{a^*}(:,:,m)$ are obtained. The optimization aims to get the the optimal placement vector that minimizes number of dropped node at the entire range of visibility $\Omega_a^{\Re}$ then increase fairness Ω_a^f and finally decrease the average error rate Ω_a^e.

Step One : Optimal configurations

$$\underset{d}{\textbf{Lex-Max-Min}} : \{r_d = (R_{d1},...,R_{dN}) : r_d \in R_a\}$$

$$\underset{d}{\textbf{Lex-Min-Max}} : \{e_d = (BER_{d1},...,BER_{dN}) : e_d \in E_a\}$$

Subject to:

$$d \in \{1,2,3,...,\beta_a\}, z_k \in \{1,2,...,w+1\},$$

$$R_{dk} = \sum_{j=0}^{N} R_{dkj}\,,\; R_{dk} \leq T_{dk}\,,\; T_{dk} = \sum_{j=0}^{N} T_{dkj},$$

$$BER_{dk} \leq BER_{max}\,,\; BER_{dij} < BER_{max}\,, P_{dij} = P_0\,,$$

$$\{R_{dk}, R_{dkj}, T_{dk}, T_{dkj}\} \in \{0,x_1,x_2,\ldots,x_q\}\,,$$

$$T_{djj} = R_{djj} = 0\,,\; \{i,j\} \in \{0,1,2,3,...,N\}\,,\; j \neq i.$$

Step Two: Optimal Placement

$$\underset{a}{\textbf{Max}} \left\{ \Omega_a^{\Re} = \frac{1}{N} \sum_{m=1}^{m=M_a} P(\Delta V_{am})\,.\,\Delta V_{am} \cdot \sum_{k=1}^{k=N} \delta_{mk} \right\}$$

$$\delta_{mk} = \begin{cases} 1 & \bar{R}_{mk} > 0 \\ 0 & \bar{R}_{mk} = 0 \end{cases} : \bar{R}_{mk} \in \bar{R}_a,$$

$$\underset{a}{\textbf{Max}} \left\{ \Omega_a^f = \sum_{m=1}^{m=M_a} P(\Delta V_{am})\,.\,\Delta V_{am}\,.\,F_m : \bar{R}_{mk} \in \bar{R}_a \right\},$$

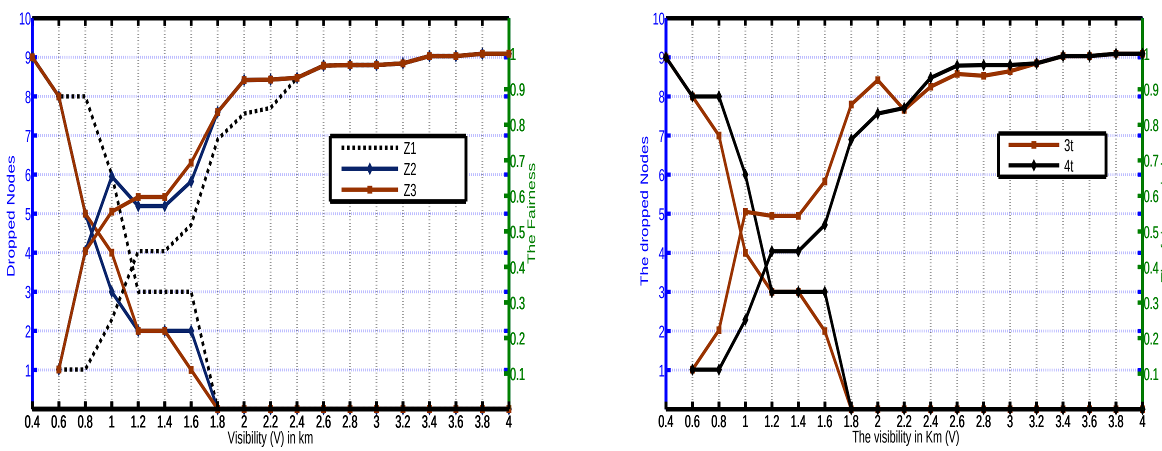
$$\underset{a}{\textbf{Min}} \left\{ \Omega_a^e = \sum_{m=1}^{m=M_a} P(\Delta V_{am})\,.\,\Delta V_{am} \cdot \sum_{k=1}^{k=N} \frac{\bar{R}_a(m,k)\,.\,\bar{E}_a(m,k)}{\bar{C}_a(m)} \right\}$$

Subject to:

$$a \in \{1,2,3,...,\Lambda\}\,.$$

Table 1: Simulation Parameters

Link parameters	Values	Link parameters	Values
Signal wavelength	1550 nm	Divergence angle	2 mrad/m
Average Transmitted Power	-12 dBm	Bit Rates in Gbps	1, 3/4, 2/3, 1/2, 1/3, 1/4, 0.
Diameter of Transmitter	4 cm	Average ambient noise	-49.6 dBm
Diameter of Receiver	20 cm	BER threshold	$1e-4$
Network area	4x4 km	Cell length	1x1 km



(a) Four additional transciveres.

(b) Four and three additional transciveres.

Fig. 1: Reliability and fairness for different networks.

5. Simulation and Numerical Results

The problem is solved numerically by using exhaustive search (ES) method to guarantee the optimal solutions. Table 1 shows the simulation parameters of the FSO links. The values are selected to be in the practical range. In these networks, the longest FSO link is 3.6 km and the shortest FSO link is 0.77 km. Also, the maximum bit rate is 1 Gbps and maximum allowable error-rate is 10^{-4}. At $N = 9$, two networks with $w = 3$ and $w = 4$ are evaluated. Figure 1a shows reliability and fairness performance of many placement vectors, Z_1, Z_2, and Z_3 at the entire range of visibility. Depending on the probability distribution $P(\Delta V_{am})$ of the visibility, one of Z_2 or Z_3 is the optimal placement. Figure 1b shows the superior performance of the optimal placement scheme with $w = 3$ over the performance of a misplacement network with $w = 4$.

References

1. A. Vavoulas, H. G. Sandalidis, and D. Varoutas, "Weather effects on fso network connectivity," *Journal of Optical Communications and Network*.
2. S. D. Milner, T.-H. Ho, I. I. Smolyaninov, S. Trisno, and C. C. Davis, "Free-space optical wireless links with topology control," in *International Symposium on Optical Science and Technology*, 2002.
3. A. S. Ghazy, H. A. I. Selmy, and H. M. H. Shalaby, "Reliable-fair resource allocation schemes for snowy cooperative free space optical networks," *ACP*, vol. 3, no. 6, pp. 278–300, 2015.
4. F. Ahdi and S. Subramaniam, "Optimal placement of fso relays for network disaster recovery," in *Communications (ICC), 2013 IEEE International Conference on*. IEEE, 2013, pp. 3921–3926.
5. R. Jain, D. Chiu, and W. Hawe, "A quantitative measure of fairness and discrimination for resource allocation in shared computer systems," *arXiv preprint cs/9809099*, 1998.