Basic Fundamental Optimized Topology Design For Free Space Optical Networks

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***Abstract*— Wireless mesh network addresses the last mile issue. This technology utilizes radio frequency (RF). The practical limitations and challenges of RF based communication networks have become increasingly apparent over the past decade, leading researchers to seek new hybrid communication approaches. One promising strategy that has been the subject of considerable interest is the augmentation of RF technology by Free Space Optical (FSO) networks. Using the strength of FSO communication technology it may be possible to overcome the limitations of RF. In this short paper we present an initial joint topology design in FSO networks.**

I. INTRODUCTION

Wireless mesh network (WMN) is a promising solution to address the last mile issue of the access networks. The advantages of using WMN come at the price of lower data rates mainly due to the wireless channel limitation. Most present day WMNs networks are deployed using only radio frequency (RF) channels, since these provide efficient support for radial signal broadcasting by each of the network's constituent nodes. The disadvantages of RF communication are by now well-known, including bandwidth scarcity, lack of security, high interference, and high bit error rates. These limitations make provisioning of scalable quality of service (QoS) support difficult, if not intractable. Faced with such daunting obstacles to QoS in RF-only networks, the use of Free Space Optical (FSO) for wireless communications was proposed. The FSO has THz of unregulated bandwidth, and characteristics that are distinct from that of radio. Together these media might provide a broad spectrum of channel characteristics and capabilities that radio alone would find it difficult to meet. FSO has many advantages, such as cost effectiveness, large transmission distance, free license, interference immunity, and high-bandwidth, among others [2]. FSO networks provide a promising solution to mitigating the scalability problem of wireless mesh networks [7]. In a FSO communication forms a high speed wireless optical communication that relies on pure line of sight (LOS) technology. Its performance strongly depends on the atmospheric conditions between the transmitter and receiver [1], [3]. The key applications of FSO communication include inter-and intra-chip communication, inter-satellite communication, alternative technology for optical fiber networks, temporary network installation and radio over FSO communications. To maximize the potential of FSO networks, the unique characteristics of FSO links should be considered, and the problems of topology design and routing of the traffic flows should be jointly considered and optimized [4], [5]. In this short paper (abstract), we present an initial joint topology design in FSO networks

II. FORMULATION

We adopted the *log-normal* model to characterize FSO link reliability under turbulent atmosphere [8]. The link reliability γ_{ij} is the probability that the intensity of received signal I exceeds a threshold I_{th}, which can be computed using the error function $erf(\cdot)$ as:

$$\gamma_{ij} = Pr\left\{I \geq I_{th}\right\} = \frac{1}{2} - \frac{1}{2} erf\left(\frac{ln(I_{th})/I_0}{2\sigma_x\sqrt{2}}\right) \tag{1}$$

where I_{th} is the threshold of the received signal intensity, and I_0 is the average received intensity. The standard deviation σ_x^2 is approximated by $\sigma_x^2 = 0.30545\left(2\pi/\lambda\right)^{7/6} C_n^2\left(h\right) l^{11/6}$, where λ is the wavelength, l is the transmission distance, and $C_n^2\left(h\right)$ is the is the index of refraction structure parameter with a constant altitude h which expresses the strength of the atmospheric turbulence. For an atmosphere channel near the ground, e.g., $h < 18.5m$, $C_n^2\left(h\right)$ ranges from 10^{-13} to 10^{-17} $m^{-2/3}$ for a strong to weak atmospheric turbulence. For a fixed ratio, I_{th}/I_0, the reliability of the link depends on the transmission distance and the weather turbulunce. We assume the set of edges satisfying $\gamma_{ij} \geq \gamma_{th}$ forms the candidate link set ξ_c for constructing the FSO networks topology.

We assume an *n x n* traffic matrix *F* that describes the traffic demand for the access network, where each element $f_{sd} = |F|_{sd}$ represents the mean data rate between each source and destination pair *s-d*. We characteristic each FSO link $e = (i,j) \in E$ with link capacity c_{ij}.

Network-wide Average Load: Multipath routing for load balancing, where a flow f_{sd} may be split into multiple subflows. Let f_{ij}^{sd} be the subflow passing through a link *(i, j)* with the following flow-conservation condition:

$$\sum_{j=1}^{n} f_{ij}^{sd} - \sum_{j=1}^{n} f_{ji}^{sd} = \begin{cases} f_{sd}, & i = s \\ -f_{sd}, & i = d \\ 0, & otherwise, i \in V \end{cases} \tag{2}$$

Considering all the *s-d* pairs, the average traffic load $\lambda_{ij} = \sum_{s,d\in V} f_{ij}^{sd}$ and the link utilization $\rho_{ij} = \lambda_{ij}/c_{ij} < 1, (i,j) \in E$.

Network-wide Average Delay: We modeled each link $(i,j) \in E$ as a general queueing system with average input rate λ_{ij} and services capacity c_{ij}. The average delay incurred at the link depends on the traffic. When the traffic constantly exhitbits short-range dependent (SRD) characteristics, we model the link queueing delay with an exponential distribution with parameter $c_{ij} - \lambda_{ij}$. Applying Little's formula [6], the network-wide average dalay T is computed as:

$$T \cong \frac{1}{\lambda} \sum_{(i,j)\in E} \left[\frac{\lambda_{ij}}{c_{ij} - \lambda_{ij}} \right] \tag{3}$$

The problem is that we must select m links from all candidate edges to form a mesh topology. In addition, we also determine multipath routing for the *s-d* flows, such that either the network-wide average load *L* or the network-wide average delay T is minimized. Define the following index variables for each link $(i, j) \in E$ as

$$y_{ij} = \begin{cases} 1, & \text{if } (i,j)\ is\ chosen \\ 0, & otherwise \end{cases} \tag{4}$$

The considered joint topology design and routing optimization for minimizing delay is presented as following.

$$\text{minimize } T$$

subject to:

$$\sum_{i=1}^{n} \sum_{j=1}^{n} y_{ij} = m \quad for\ i, j \in V \tag{5a}$$

$$y_{ij} = y_{ji} \quad for\ i, j \in V \tag{5b}$$

$$\sum_{j=1}^{n} y_{ij} \le d_i \quad for\ i \in V \tag{5c}$$

$$0 \le f_{ij}^{sd} \le y_{ij} f_{sd}, \quad for\ i, j, s, d \in V \tag{5d}$$

$$\lambda_{ij} = \sum_{(s,d)\in V} f_{ij}^{sd} \le c_{i,j} \quad for\ (i,j) \in E \tag{5e}$$

$$\text{flow conservation rule} \quad (2) \tag{5f}$$

The interpretation of the constraints is as follows:
(5a) Expresses that m links are selected from all candidate links.
(5b) Assures that if an arc is selected, the arc with the same end nodes but opposite direction should also be selected.
(5c) Makes sure that the transceivers installed in a nodes should not exceed certain value.
(5d) Makes sure that if there is a flow passing through arc *(i, j)*, then *(i, j)* should be selected.
(5e) Expresses the link load.

III. PRELIMINARY RESULTS

We will present the preliminary results of the proposed heuristic algorithm. The nodes were randomly deployed. The link connectivity was determined by the link reliability, which was derived using the FSO channel model given in Section II.

Then the y_{ij}'s were known and the candidate link set ξ_c is found. In Figure 1, the network-wide average traffic delays were plotted. We applied Little's formula from Equation (3) in order to obtain *T*, the average time spent in the network system. This depends on the of average time on the λ_{ij} in relation to c_{ij}. We assume $c_{ij} < \lambda_{ij}$. The behaviour was rather dramatic. As λ_{ij} approaches unity, the average time in the network system grew in an unbounded fashion[1]. When λ_{ij} approaches c_{ij} we can assume throughput decreases since packets are starting to get dropped. This is of course due to that the FSO wireless channels have reached full capacity.

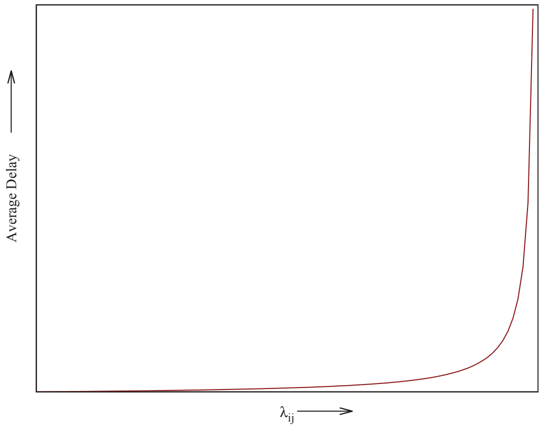

Fig. 1: *Network-wide Average Delay.*

IV. CONCLUSION

In this paper, we presented as simple heuristic algorithm for a joint optimization FSO network topology. In future work will examine long-range-dependent (LRD) traffic. Also more advance models should be investigated to achieve higher degree of resilience for when multiple FSO links fails due to rain, fog or snow.

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[1] We observed at $\lambda_{ij} = 1$, the system behaviour is unstable; this is not surprising since $c_{ij} < \lambda_{ij} \Rightarrow \rho_{ij} < 1$ was our condition for ergodicity.