Topology Control Schema for Better QoS in Hybrid RF/FSO Mesh Networks

Osama Awwad, Ala Al-Fuqaha, *Senior Member, IEEE*, Bilal Khan, and Ghassen Ben Brahim

***Abstract*—The practical limitations and challenges of radio frequency (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 Optics (FSO), using the strength of each communication technology to overcome the limitations of the other. In this article, we introduce a new scheme for controlling the topology in hybrid Radio-Frequency/Free Space Optics (RF/FSO) wireless mesh networks. Our scheme is based on adaptive adjustments to both transmission power (of RF and FSO transmitters) and the optical beam-width (of FSO transmitters) at individual nodes, with the objective of meeting specified Quality of Service (QoS) requirements, specifically end-to-end delay and throughput. We show how one can effectively encode the instantaneous objectives and constraints of the system as an instance of Integer Linear Programming (ILP). We demonstrate that the technique of Lagrangian Relaxation (LR), augmented with iterative repair heuristics, can be used to determine good (albeit sub-optimal) solutions for the ILP problem, making the approach feasible for mid-sized networks. We make the proposed scheme viable for large-scale networks in terms of number of nodes, number of transceivers, and number of source-destination pairs by solving the ILP problem using a Particle Swarm Optimization (PSO) implementation.**

***Index Terms*—Hybrid RF/FSO, topology control, QoS, linear programming, Lagrangian relaxation, MANETs, particle swarm optimization.**

I. Introduction

MOST present day wireless 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 providing 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 Optics (FSO) for wireless communications was proposed [6]. FSO technology enables the transmission of data using optical signals through free space (or air), and so has the potential to support higher link data rates than RF. The propagation of optical signals requires the use of specialized light sources [1], such as lasers (providing coherent light) and LEDs (providing non-coherent light). LEDs are better suited for wireless mesh networks, since they consume very little power, have wider beam-width compared with lasers, and overcome the safety issues that are a major concern with high-powered lasers. Recent developments in high-brightness LED technology has made it possible to deploy LED transmitters with a rate up to 2 Gbps, with transmission ranges of up to 104 miles [2]. In addition to high data rates, because FSO uses directed optical transmissions with adjustable channel beam-width, inter-FSO communication interference can be minimized. In addition, because FSO does not support radial broadcasting, it also provides some degree of security against malicious eavesdropping. The benefits of FSO do not come without a price, however. Most notable of these drawbacks is the need to maintain line of sight (LOS) between the transmitter and the receiver during the course of communication. In contrast, LOS is not a requirement for RF transmissions. The complementary strengths and weaknesses of RF and FSO make them ideal technologies to hybridize. A hybrid approach that uses both RF and FSO has the potential to overcome the weakness of each of the individual channel types. Several frameworks have been proposed for such hybrid networks [3], [4], [5], [23], [25] and a few prototypes have been implemented [7], [8], [24].

The dynamic nature of RF and FSO channel characteristics makes topology control a major issue in hybrid RF/FSO networks. Questions of topology control have already been studied extensively in traditional RF-only networks. In the RF-only context, the objective is to adjust the "microscopic" node-level parameter (e.g. transmission power levels) so as to achieve some "macroscopic" network-level property such as connectivity, minimal interference, or specified QoS requirements [9], [10], [17]. The newer questions of topology control in hybrid RF/FSO networks are much more challenging, and by comparison, relatively few solutions have been developed; here we survey some of the notable prior achievements. In [11], Kashyap et al. proposed a joint topology control and routing framework wherein the RF links serve to provide instantaneous backup to traffic in hybrid RF/FSO networks whenever FSO links become degraded. In another paper [12], the same authors studied the ability to provide topology reconfiguration in response to changes in links capacities and traffic demands in RF/FSO networks. The authors proposed a heuristic for finding a topology configuration with the minimum packet dropping rate.[1] We are not aware of any previous work which has explored the potential for optimization

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[1]The authors took the packet dropping rate to include both link congestion and packet drops that occur in the transient states occurring during a topology reconfiguration.

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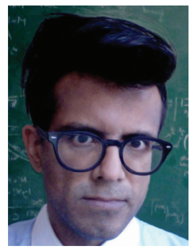

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