Bayesian-Based Game Theoretic Model to Guarantee Cooperativeness in Hybrid RF/FSO Mesh Networks

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***Abstract*—**In this paper we describe an effective new technique by which to guarantee cooperativeness in Hybrid Radio-Frequency/Free Space Optics (RF/FSO) networks. Our approach is based on a novel Bayesian game-theoretic model, and uses a pricing scheme in which each destination node pays some amount of virtual money to the source node in order to acquire a reliable connection. We describe both single-stage and multi-stage solutions for the game in terms of its Nash and Perfect Bayesian Equilibriums. Pure strategies are found when the required conditions are met; otherwise the game is played as a mixed-strategy. Our numerical results quantify the inherent tradeoffs involved in changing the game's parameters vis-a-vis the equilibrium player strategies and game's outcomes.

***Index Terms*— Hybrid RF/FSO, QoS, Reliable Routing, Game Theory, Nash Equilibrium, Bayesian Game.**

I. INTRODUCTION

Most wireless networks are deployed strictly in the radio frequency (RF) domain, since RF channels provide natural support for radial broadcast operations. However, the downside of RF channels is that they introduce many limiting externalities that make providing scalable quality of service (QoS) support difficult, if not intractable. These well-known technical challenges include bandwidth scarcity, lack of security, high interference, and high bit error rates.

Faced with such daunting obstacles to QoS, several researchers have recently proposed the use of Free Space Optics (FSO) for wireless communications [2-6]. First, FSO has the potential to support higher link data rates compared to present RF technology. Furthermore, because FSO uses directed optical transmissions in which channel beam-width is adjustable, inter-FSO communication interference can be limited. Finally, the avoidance of radial broadcasting also provides some degree of security against eavesdropping. The benefits of FSO do not come without a price, most notable of which is the need to maintain line of sight (LOS) between the transmitter and the receiver during the course of communication. Moreover, FSO link availability can be degraded by adverse weather conditions like fog, rain, snow, and haze. Finally, when link endpoints are mobile, maintaining stable LOS requires potentially sophisticated tracking technology.

Clearly, a hybrid approach that uses both RF and FSO is needed to overcome the shortcomings of each medium, which we have just described. The cost and structure of RF and FSO channels in a hybrid RF/FSO networks will depend on the channel conditions and the desired QoS, respectively. But deciding to use a hybrid model brings with it, its own set of unique problems, stemming in large part from the fact that nodes can choose between two *different* channels types—each with its own transmission characteristics. Given this, steps must be taken to prevent a relay node in a multi-hop connection from being tempted to behave selfishly by forwarding other nodes' packets using the less reliable channel type, thereby avoiding the individual opportunity cost that would be incurred by a "fairer" choice of allocating a high quality link. We address this problem of selfish behavior by formulating node decisions within a hybrid RF/FSO network in a Bayesian game-theoretic model that is designed specifically to guarantee optimal cooperativeness—this model, its formal analysis, and the experimental verification of its properties are the principal contributions of this paper.

We note that the application of game theory to resolving conflicts of interest between nodes in wireless networks is not new. In [10], for example, the authors recast the routing problem for ad hoc networks in terms of a pricing model, in which the destination node gives some amount of virtual money as payment to the source node for each packet of information that is delivered. While the authors of [10] were able to demonstrate a polynomial time modification of Dijkstra's algorithm that can compute a Nash equilibrium path, their model may not be realistic in some scenarios since it does not distinguish between selfish and cooperative nodes in the network. Most prior work that applies game theory to wireless networks assumes complete information among nodes, which is to say, all knowledge about all other players is

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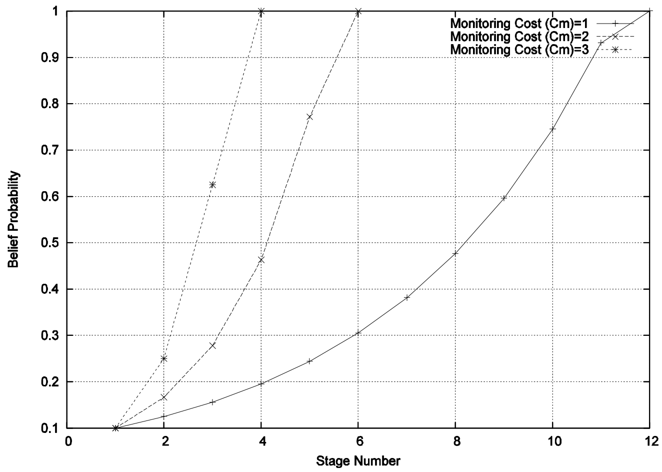

Figure 5: The effect of increasing the link monitoring cost C_m on the posterior belief convergence.

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