A Model for Cooperative Mobility and Budgeted QoS in MANETs with Heterogenous Autonomy Requirements

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***Abstract*— Modern mobile ad-hoc networks (MANETs) frequently consist of nodes which exhibit a wide range of autonomy needs. This is particularly true in the settings where MANETs are most compelling, i.e. battlefield, response & rescue, and contexts requiring rapid deployment of mobile users. The time-critical nature of the underlying circumstances frequently requires deployment of both manned and unmanned nodes, and a coordination structure which provides prioritized tasking to them. Unlike consumer MANETs, these settings bring with them a common group purpose, making inter-node cooperation plausible. In this paper, we focus on how cooperation can improve MANET communications. We begin by taxonomizing all prior approaches and noting that no existing approach adequately captures networks where nodes exhibit a wide range of autonomy with respect to their mobility. To this end we present a new Cooperative Mobility Model, developing a cost-benefit framework which enables us to explore the impact of cooperation in MANETs where nodes are, to varying extents, willing to move for the common good. In the second half of the paper, we describe the design of CoopSim, a platform for conducting simulation experiments to evaluate the impact of parameter, policy and algorithm choices on any system based on the proposed model. Finally, we present a small but illustrative case study and use the experimental evidence derived from it to give an initial evaluation of the merits of the proposed model and the efficacy of the CoopSim software.**

***Index Terms*— wireless ad-hoc networks, bit error rate, cooperative, QoS.**

I. Introduction

Mobile wireless ad-hoc networks (MANETs) are an important infrastructure building block, enabling the successful execution of both military and public safety operations. In the military setting, MANETs facilitate communication between mobile infantry units, command and control, field intelligence, aerial surveillance, etc. They can be built using Radio Frequency (RF) communication links both between and within infantry formations, ground armored vehicles (e.g., tanks), airborne units (e.g., fighters, bombers), and naval/amphibious platforms (e.g., destroyers, troop carriers). MANETs are particularly well-suited for rapid establishment of communications in battlefield and public safety settings, because they are comprised of mobile platforms that do not require a fixed infrastructure but rather operate over a shared wireless medium.

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The modern battlefield communications network is a MANET comprised of both manned and unmanned elements (e.g. UAVs [15]), the question remains as to the role of cooperation between nodes. Certainly, task-oriented cooperation is to be expected in such a setting, e.g. coordinating the activity of UAVs to achieve a joint objective like radio source localization [16]. Here, however, we pose a more fundamental question: What role can cooperation play in supporting *communication itself?*

Prior work on the question of how cooperation can benefit communication (e.g. See [9], [7], [12] and others) has approached the issue from the vantage point of a node's willingness to forward messages to the next hop (toward the intended destination) along a multi-hop path. Almost all prior work was colored by the consumer model in which node mobility is considered the sacrosanct domain of the user, autonomously determined and non-negotiable. While this is an appropriate conception of current consumer applications (e.g. cell phone and laptop users) it fails to leverage the unique opportunities present in battlefield MANETs. In the latter setting, mobility is a fundamental resource of every MANET node, and cooperative nodes can potentially contribute their mobility towards the common good vis-a-vis systemic objectives. In this paper, we develop a realistic model for cooperation in battlefield MANETs and evaluate the extent to which communications can be improved when constituent nodes are sometimes willing to *be moved.*

The remainder of the paper is organized as follows. In Section 2 we begin with a taxonomy of models for cooperation in MANETs. In Section 3 we use these models to motivate a novel Cooperative Mobility Model. In Section 4, we describe the design of the CoopSim platform that is used to evaluate and experiment with parameters of the proposed model. In section 5, we present a small case study to illustrate the richness of the model and the efficacy of the CoopSim platform. Finally, in Section 6 we draw conclusions and extrapolate the future trajectory of our research efforts.

II. A Taxonomy of Cooperative Communication Models

The notion of cooperative communication is itself quite old, appearing in the networking literature as early as the 1970's (e.g. papers on the relay channel model in information theory [5]). The phrase "cooperative communication" reflects the fact that each network node has two existential modalities:

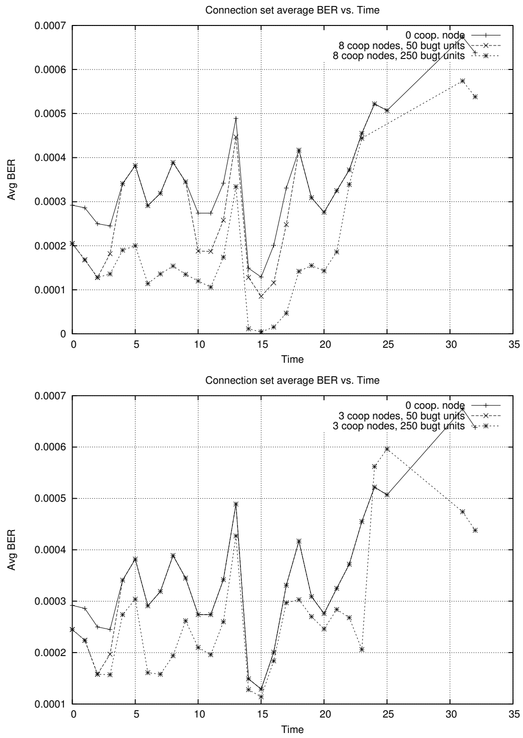

Fig. 2. The benefits of increasing the mobility budget.

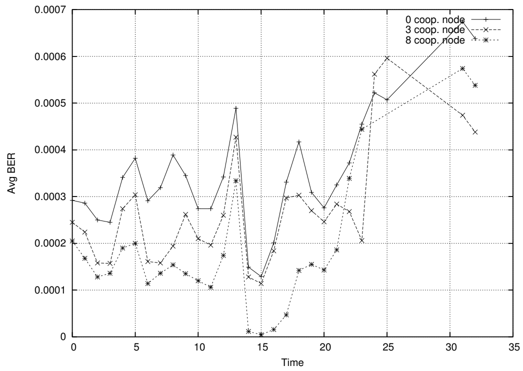

Fig. 3. The benefits of increasing the number of cooperative nodes.

The first experiment investigates the effects of increasing the total mobility budget while keeping the number of cooperative nodes fixed. The simulation setup for the top graph of Figure 2 consists of 15 autonomous nodes moving according to a Gauss-Markov process, and 8 cooperative nodes having mobility costs equal to one unit per meter. The graph shows the average BER of the 7 connections as a function of time. The results indicate that a mobility budget of 50 units permits the routing and optimization layer to lower average connection BER by almost 10%, and that increasing the mobility budget to 250 units permits more consistent BER reduction frequently in excess of 50%. The bottom graph in the same figure shows that if the number of cooperative nodes is decreased from 8 to 3, the Routing and Optimization Layer is not able to use cooperative mobility as effectively.

The second experiment investigates the effects of increasing the number of cooperative nodes while keeping the total mobility budget fixed. The simulation setup for the graph in Figure 3 consists of 15 autonomous nodes moving according to a Gauss-Markov process, and 0, 3 or 8 cooperative nodes having mobility cost equal to one unit per meter. The graph shows the average BER of these 7 connections as a function of time. The results indicate that having more cooperative nodes permits the Routing and Optimization Layer to better leverage cooperative mobility, even when the mobility budget is not increased proportionately.

VI. Conclusion and Future Work

The cost-benefit framework of the Cooperative Mobility Model is able to capture MANETs in which nodes exhibit a wide range of autonomy with respect to their mobility. Initial experiments show that with even modest mobility budgets and a few cooperative nodes, it is possible to leverage communication-reactive mobility control in a way that significantly improves MANET communications. Increasing mobility budgets increases the potential benefits of cooperation, while increasing the number of cooperative nodes improves the efficiency with which a mobility budget can be leveraged. Our results are a significant step towards improving MANET operations in battlefield, response & rescue, and contexts involving time-critical mission oriented deployments of mobile users.

In future work, we will conduct systematic investigations using the CoopSim platform. We will design robust distributed algorithms which leverage mobility in MANETs under the Cooperative Mobility Model, and evaluate the scalability and performance of these algorithms using both analytic techniques and realistic simulation experiments.

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