Using MILP for Optimal Movement Planning in MANETs with Cooperative Mobility

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***Abstract*— Rapid-deployment mobile ad-hoc networks (MANETs) are frequently characterized by common over-arching mission objectives which make it reasonable to expect some degree of cooperativeness on the part of their constituent nodes. In this article we demonstrate new strategies to improve MANET communications, based on inter-node cooperation with respect to node mobility. We present our model for cooperative mobility, and use this cost-benefit framework to explore the impact of cooperation in MANETs where nodes are—to varying extents—willing to be moved for the common good. We develop a Mixed-Integer Linear Programming (MILP) formulation of the model, accurately capturing its objectives and constraints. The MILP model is evaluated through simulations and found to be very effective, albeit for small networks. To make the proposed technique scale to large networks we develop a new technique for converting a large global MILP into a sequence of smaller local MILP optimizations, and demonstrate that the resulting approach is scalable and succeeds at efficiently moving cooperative nodes in a manner which optimizes connection bit error rates.**

***Index Terms*— wireless ad-hoc networks, bit error rate, cooperative, mixed-integer linear programming.**

I. Introduction

Technical challenges facing MANETs stem from their intrinsic limitations, specifically (i) bandwidth scarcity and high bit error rates of wireless RF channels, and (ii) limited battery capacities which mandate energy-awareness to extend the network lifetime. These limitations have hindered the development of truly scalable QoS-aware routing, and to cope with them much effort has been undertaken to leverage the power of *cooperation* between MANET nodes.

While prior work on the question of how cooperation can benefit communication (e.g. see [6], [4], [3], and others) has principally considered the node's willingness to forward messages as it's cooperative contribution, we explore the ramifications of treating a node's physical mobility as a contributable resource. The assumption, while not applicable in the consumer MANET setting, is quite reasonable in in MANETs where participants have a common (e.g. mission) objective; these rapid deployment settings are precisely the ones where MANETs are most compelling anyway.

II. Cooperative Mobility Model

We consider networks where mobility is a resource that can be used to ameliorate communication infrastructure. Our work begins with the model of Basu et al. [1], but rather than considering networks consisting of robots and non-robots, we consider the more general setting of *heterogenous* networks comprised of nodes which exhibit the entire spectrum of personalities: from defiant autonomy to self-sacrificial cooperativeness. We capture this viewpoint by adopting a cost model for mobility. To wit, every node is willing to move for the sake of the common good, but *for a price*. Each node is assigned a **movement cost** (proportional to distance moved)—this is the price it charges to be moved, say, per meter. Defiant autonomy is exhibited when a node declares this cost to be infinite; self-sacrificial cooperativeness is manifest when this cost is set to zero. The relative extent of cooperativeness exhibited by battlefield MANET nodes is reflected by the ratios of their associated movement costs.

We see mobility planning (for cooperative nodes) as a core function of the network routing layer, which becomes responsible for allocating a fixed (periodically renewed) **mobility budget** towards paying for the movement of cooperative nodes. The model assumes that a node will execute any mobility request that has been adequately funded by an allocation of the mobility budget; such requests are interpreted as being from higher-level supervisors whose objective is to maintain a communication network that best supports the overall mission requirements. Nodes that are autonomous (i.e. unwilling to be subjected to the movement requests of the routing layer) simply declare their movement costs to be infinite.

The central problem to be addressed then is how best to utilize the movement budgets of nodes to defray the cost of for moving them, in a way that leads to meeting the end-to-end QoS requirements of a set of connections. The QoS parameter we consider is bit error rate (BER) as it is gives a good estimate about the quality of the wireless connections. In short, if BER requirements are to be met, which nodes should be moved, and to where?

III. System model

We consider a wireless ad-hoc network consisting of n nodes equipped with omni-directional antennas with different transmition power. Wireless propagation suffers severe attenuation [2] If node i transmits with power P_t(i), the power of the signal received by node j is given by

$$P_{rcv}(j) = \frac{P_t(i)}{c \times d_{ij}^{\alpha}}, \tag{1}$$

where d_{ij} is the distance between nodes i and j. α and c are both constant, and usually $2 \leqslant \alpha \leqslant 4$ (See [2]).

Each wireless channel L between two nodes has a computable Bit Error Rate, $BER(L)$, that is the probability of

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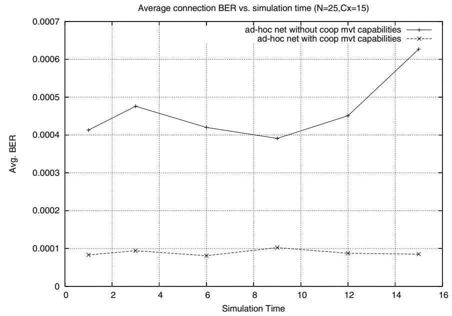

Fig. 6. Using localized MILPs to minize connection BER

The first experiment investigates the impact of the proposed scheme on improving the average BER of the connection set. The top curve in figure 6 represents the average BER of an ad-hoc network where the cooperative nodes remain stationary over time. The bottom curve represents the same measure in the presence of cooperative nodes manipulated according to the proposed MILP scheme. By looking at the *slope* of the bottom chart, we conclude that the routing and optimization scheme were able to maintain a fairly constant low connection set BER. By analyzing the difference of both curves, we conclude that with our proposed scheme, we were able to achieve an improvement of the overall connection set BER by almost 300%.

The second experiment investigates the effects of increasing the node mobility budget (from 20 to 50) and number of connections. By considering the *difference* between the curves curves of the top graph, we notice that for a higher node movement budget corresponds a better improvement in the overall percentage BER improvement. For example, for a connection set size, corresponds a 20% improvement when using 50 units of budget compared to the case where each node has only 20 units. Considering the *slope* of the curves in the top graph, we conclude that the average percentage BER improvement decreases as the connection set size increases.

The bottom graph of figure 7, illustrates the impact increasing the movement budget on the percentage of the connections that do not meet the BER requirement by the time the optimization terminates. By looking at the *slopes*, we conclude that this percentage increases as the connection set size increases. For example, 13% of the connections did not meet the BER requirement when the connection set size equals to 17. By considering the *difference* between both curves of the bottom graph, we conclude the percentage of connections that did not meet the BER requirement is much less in the case of higher movement budget available per node.

VIII. Conclusion and Future Work

In this paper, we consider how cooperation between nodes can improve communication in mobile ad-hoc networks (MANETs). We propose a new cooperative mobility model based on location management scheme under budget constraints aiming to the improvement of the QoS of a connection set. We propose an MILP formulation that accurately depicts the proposed cooperative model. Our formal description of this model describes both cases: (1) minimizing the movement budget used by all nodes while meeting the end-to-end QoS requirement of all connections, and (2) minimizing the BER of all connections under movement budget constraints. The MILP model was evaluated through simulations and found to be very effective, albeit for small networks. To make the proposed technique scale to large networks we developed a new technique for converting a large global MILP into a sequence of smaller local MILP optimizations. Simulation experiments indicate conclusively that the resulting approach is scalable and succeeds at efficiently moving cooperative nodes in a manner which optimizes connection bit error rates.

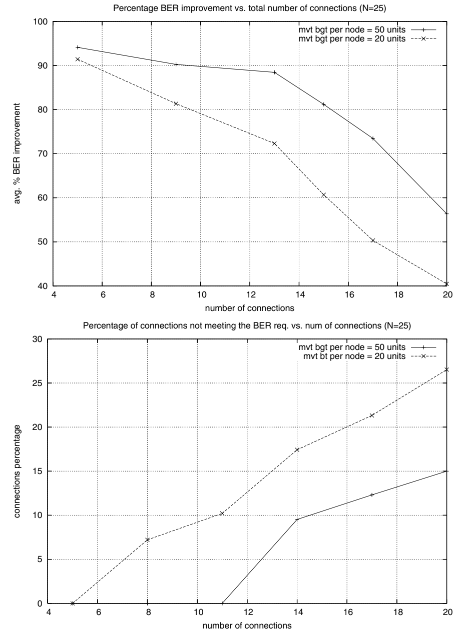

Fig. 7. The benefit of increasing the mobility budget

Unfortunately, the current solution formulation is not suitable for a decentralized implementation. In our future work, we will design new distributed schemes for mobility planning, and use the MILP formulation as a baseline by which to assess the relative performance.

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