The Effect of Mobility on Cooperation in Ad Hoc Networks

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1 Introduction

Ad hoc networks have the potential to increase the flexibility of wireless communication systems. They, however, also require novel operating principles. In particular, due to the absence of fixed infrastructure, most of the functions (routing, mobility management, in some cases even security) must rely on the cooperation between the nodes.

In civilian scenarios, the selfishness of the participants might be a motivation for non-cooperation. Over the last few years, several researchers have proposed incentive techniques to encourage nodes to collaborate, be it by making use of a reputation system [2, 6], or by relating the right to benefit from the network to the contribution to the common interest of a node provided thus far [3]. These proposals have been based on heuristics, and are therefore rather difficult to compare with each other. Srinivasan *et al.* [7] have proposed a formal framework, based on game theory, to study cooperation with the emphasis on energy-efficiency. They have identified the conditions under which cooperation is a Nash equilibrium[3]. Urpi *et al.* [8] propose a general framework for cooperation without any incentive mechanism. Their solution is based on the idea that each node monitors the behavior of other nodes in the neighborhood.

In our paper, we also study the case, where no incentive mechanisms are implemented in the nodes. Contrary to the previous solution by Urpi *et al.*, the nodes are not required to monitor all packets in their neighborhood. We identify the conditions for the existence of cooperation. Our main contribution is to show that cooperative Nash equilibria are much more likely to happen with mobile than with static nodes. In addition, we quantify how much "generosity" the nodes should grant in order to make these equilibria feasible. An extended version of the paper is provided in [5].

2 Model and results

We assume a network of N nodes. Each node uses an omni-directional antenna with the same radio range. Hence, there is a bi-directional communication link between two nodes if they reside within the radio range of each other.

We model packet forwarding as a game of infinite duration, where each node as a player interacts with the rest of the network. Inspired by [1], we call *Generous Tit-For-Tat (GTFT)* a strategy that overestimates the required contribution to the network. Thus, a node playing this strategy is *generous*, because it is willing to contribute more to the network than to benefit from it. If a node i plays the GTFT strategy, it uses the strategy constant g_i that stands for the *generosity* of the node.

We split up the time in discrete steps. At the end of each time step, each node evaluates the results of its interaction with the network. The length of the time step (meaning the evaluation period) is correlated with the amount of network change. The longer is the time step, the more mobility changes the network. Thus, we can use the length of the time step as a parameter to study the effect of mobility.

We simulated a realistic network as follows. First, we place 100 nodes with uniform probability in a toroid simulation area of $1.5km^2$. Then, we generate a connection for every node with the average

[3] In a *Nash equilibrium* none of the nodes can increase its utility by unilaterally changing its strategy.

number of relays $\bar{\ell}$. Then, we let every node send a packet on the connection for which it is the source. We repeat this procedure for the number of steps. We regenerate a new connection only if the old one breaks due to mobility. We apply the random waypoint mobility model with average speed of 10 m/s and average pause time of 10 s.

We investigate the effect of mobility on cooperation. We increase the step duration exponentially and we observe the required generosity level that ensures that 95 % of the simulations result in full cooperation (we call this value the *generosity threshold*). Figure 1 presents the generosity threshold as a function of the duration of a step (which represents the effect of mobility). We see that if the length of one step is small (meaning that mobility is small), then a higher generosity threshold is required. The higher the mobility is, the lower the generosity threshold is. This result is fully consistent with our previous work [4]: The absence of mobility is a major hurdle for "spontaneous" cooperation.

Generosity is needed for nodes that are relays in a high number of connections compared to the average number of relays in a connection. This situation represents the worst case for a node. If the duration of the step is small, then this worst case situation is valid for several steps and the node has to be more generous to cope with the cumulative effect of the situation. If mobility increases (meaning that the topology of the network changes more between the steps), then the duration of a worst case situation is shorter and less generosity is required to cope with its cumulative effect.

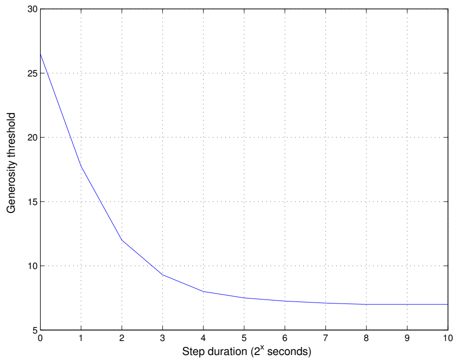

Figure 1. Generosity threshold ensuring full cooperation as a function of the duration of one step (i.e., the effect of mobility)

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