Poster: About the Impact of Co-operation Approaches for Ad Hoc Networks

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1. INTRODUCTION

Although the need for protocol extensions dealing with co-operation issues for ad hoc routing protocols is undoubtedly accepted, it is still a question of belief whether such protocol extensions really intensify participation within the ad hoc network and benefit the community. This statement is applicable to both motivation-based (e.g. [1], [2]) and detection-based approaches (e.g. [3], [4]). It is our intention to give a quantitative estimation of the added value of such co-operation based approaches. We present results based on two assumptions: First, the co-operation approach uses an underlying on-demand routing protocol (DSR, AODV, etc.) and in particular tries to combat malicious behavior of nodes in the forwarding phase. More precisely, although a node behaves well in the routing phase, it simply drops packets in the forwarding phase. Second, the network topology is low-densely filled with nodes, meaning that each node's transmission range does not reach more than a few other nodes (approximately four). In such topologies, the loss of one node often cannot be handled by diverting traffic.

This work particularly shows in which range any co-operation approach increases the probability of the destination to receive data addressed to it. Note, that for the measurement of the effect of a co-operation approach, it needs not to be shown how high participation is in the presence of it. It is instead required to evaluate the increase of throughput to the destination compared to solely communicating without such an approach.

The statistical participation model we imply is both simple and meaningful. It is suitable to evaluate the increase in participation in the presence of any co-operation approach. It is fully characterized by the ad hoc nodes' behavior:

1. For each 'transmission event', each node uniquely decides to either forward all traffic or to drop all traffic, i.e. if a node once decides to send a bundle of packets it indeed sends all these packets. 2. the ratio of forwarding or dropping traffic is uniformly distributed over all nodes of the ad hoc community and thus it is equal for all.

Note, that our participation model in particular includes the case where nodes may participate in the route discovery phase while dropping traffic in the forwarding phase. Our model also takes the nodes' internal states into account. We feel that such states are mainly driven by a device's remaining battery power but also by its owner's random behavior. Depending on its internal state, a node may at some point in time decide to forward data, whereas it drops packets at other times.

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2. EFFECT OF PARTICIPATION INTENSIFICATION

Let $\wp$ be the set of all current and future on-demand ad hoc routing protocols and $\wp'$ be the set of all *co-operation approaches* for on-demand ad hoc routing protocols. Let $p \in \wp$, $p' \in \wp'$. We define two events E_p^i, $E_{p,p'}^i$ and give a notation for the probability $Pr(E)$ that these events occur:

-$E_p^i \stackrel{def}{=}$ node i forwards in presence of p (without p')
-$Pr(E_p^i) \stackrel{def}{=} e$, and $e \in [0, 1]$
-$E_{p,p'}^i \stackrel{def}{=}$ node i forwards in presence of p and p'
-$Pr(E_{p,p'}^i) = e + \Delta e$, and $\Delta e \in [0, 1-e]$

So, Δe denotes the probability increase affected by fear based awareness or motivation at which an individual node increases its participation. Note, that the exact values of e and Δe (where Δe may vary for each $p' \in \wp'$) are not important for a first approximation.

Since the events are independent of each other, the probability that the final destination receives data in absence of p' over a pre-established path with n intermediate nodes is: $Pr(E_p^1 \wedge \ldots \wedge E_p^n) = e^n$. The same applies to $E_{p,p'}^i$ and in presence of p' we denote: $Pr(E_{p,p'}^1 \wedge \ldots \wedge E_{p,p'}^n) = (e + \Delta e)^n$. Thus, since $\lim_{n\to\infty}(e + \Delta e)^n = 0$ the absolute effect of any p' is neglectable for a 'large' number of n.[1]

To measure the impact of any p' at least for a limited number of involved intermediate nodes, we introduce a threshold T. T represents the ad hoc network's minimum necessary average end-to-end reliability and indicates from which moment the network's throughput to the final destination is unacceptable. Earlier work has shown that the minimum acceptable value of T for UDP traffic should not be less than 0.6.

The intersection of the throughput probability with the reliability threshold is indicative of the maximum number of intermediate nodes that may be involved in the forwarding process while maintaining a reasonable throughput. We denote $e^n = T$ and $(e + \Delta e)^n = T$ in absence or in presence

[1] We feel that the case $e + \Delta e = 1$ is not relevant in practice.

of p'. We used exemplary values $(e, \Delta e) = (0.7, 0.2)$ to illustrate the affect of selfish behavior with UDP traffic. For these values, in the absence of p', the intersection with T is at $n \approx 1.43$, whereas the presence of p' raises values to $n \approx 4.85$. Thus, at least for this value we feel that p' adds value to the network's overall reachability.

To get a general statement about the impact of co-operation approaches, we observe the relative effect of p' in terms of increased number of intermediate hops with still acceptable throughput. The equation $\Delta n_r = \frac{ln\ e}{ln(e+\Delta e)} - 1$ shows the *relative* gain when using co-operation approaches in terms of intermediate hops. Observing this equation, we derive that the relative effect of Δe on the overall reachability is *underproportional* for small Δe whereas it is *superproportional* for big Δe. The smaller e, the bigger needs to be Δe to affect the overall reachability in *superproportional* manner. Vice versa and more surprising, with an appropriate high e, even a small Δe *superproportionally* increases the reachability of the network.

3. SIMULATION

To confirm results of Section 2. we used the ns-2 simulator version 2.1b9. Nodes moved according to the random waypoint model on an $1000m^2$ area, using $100m$ radio range. In our scenarios, eight concurrent connections send five packets with 512 $bytes/s$. To understand the practical relevance of our results, we need to look at the occuring traffic. More precisely, the distribution of the traffic with respect to the required number of involved intermediate hops needs to be considered.

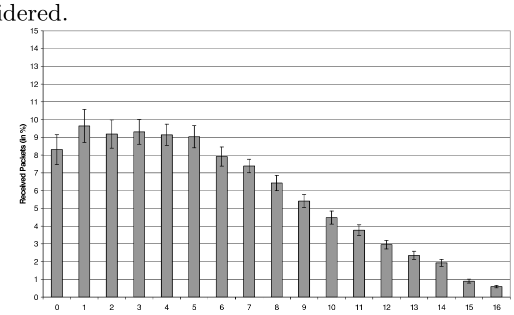

Figure 1: Traffic distribution per route length with all non-selfish nodes.

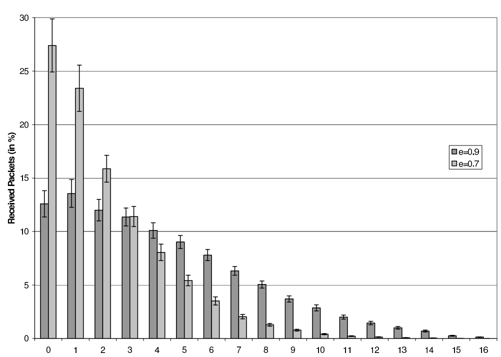

Figure 2: Distribution of successfully received traffic with selfish nodes either in presence or absence of p' and $(e, \Delta e) = (0.7, 0.2)$.

Figure 1 depicts such a distribution of traffic in a small-scaled ad hoc network with the idealized case that all nodes act in a non-selfish manner. It illustrates that nearly 50% of the occuring traffic is distributed uniformly between the first five hops. With the beginning of the sixth hop, the occuring traffic is getting smaller. With respect to our results and a more realistic exemplary selfish behavior ($e = 0.7$) and $T = 0.6$, only 17.95% of the traffic reaches the destination in absence of p'. In the presence of p' and a moderate exemplary $\Delta e = 0.2$, about 45.59% of the traffic reaches the destination.

Next, we evaluate the nominal results. In particular we substantiate that with an appropriate e, even a small Δe *superproportionally* increases the network's overall reachability. We started simulation with $(e, \Delta e) = (0.7, 0.0)$ and $(0.7, 0.2)$.

The histogram of figure 2 illustrates that in absence of p' most of the successfully received traffic (77.2%) runs along less or equal than three intermediate nodes. Vice versa this means, that only 22.8% of all successfully received traffic was forwarded over more than three intermediate nodes. This is an insufficient ratio, since the histogram in figure 1 illustrates that in case of all non-selfish nodes more than 60% of all traffic uses more than three intermediate nodes to successfully reach the destination. In presence of any p' which increases an individual's participation about e.g. $\Delta e = 0.2$, 75.8% of all successfully received traffic runs along 6 intermediate nodes, now covering 61.8% of the successfully received traffic of the idealized non-selfish scenario of figure 1.

We feel that these values emphasize our results of section 2. They indicate that in the presence of p', even when causing only small Δe but coming from an appropriate e, the network's overall reachability dramatically increases.

4. CONCLUSION

Even assuming a co-operation approach that strongly increases the individuals' participation, its effect for ad hoc networks with large average routes is rather low. However, for small ad hoc networks with short average route length a couple of values for $(e, \Delta e)$ exist that make co-operation approaches attractive. In particular those networks benefit for which even in absence of any co-operation approach the network's throughput is already acceptable for for short routes. Here, co-operation approaches add value, since they dramatically extend the network's overall reachability in terms of tolerable number of hops to an acceptable amount of data received at the final destination.

5. REFERENCES

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