Analysis of Co-operation Approaches in Ad Hoc Networks

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1. Introduction

In early September'02, some discussions came up on the IETF MANET working group's mailing list how to 'measure' security and co-operation in ad hoc networks. Although the necessity to secure ad hoc routing protocols is undoubtedly accepted, and although a couple of protocol extensions dealing with co-operation issues for ad hoc routing protocols were recently proposed, it is apparently 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, detection-based [1], [2], [3], [4] as well as motivation-based approaches [5], [6]. Both types try to intensify the nodes' foreign data forwarding participation within the ad hoc community.

- The co-operation approach uses an underlying on-demand routing protocol (DSR, AODV, etc.) and in particular tries to combat malicious behaviour of nodes in the forwarding phase. Although a node behaves well in the route request/response phase, it drops packets in the forwarding phase, and/or
- the network topology is low-dense filled with nodes. In such topologies the loss of one node many times cannot be handled by diverting traffic.

For high-dense filled ad hoc networks non-participation of some nodes is as long insignificant unless they have participated in the route discovery phase and afterwards stopped participation in the data forwarding phase. Generally, in high-dense filled networks, a totally inactive node appears as not existing without loss of the network's connectivity.

Our work particularly shows in which range any co-operation approach $p' \in P'$ of an ad hoc routing protocol p increases the probability for the destination to receive data destined to it. The protocol class P' includes all currently as well as all future co-operation approaches for on-demand ad hoc routing protocols $p \in P$.

2. Participation Model

The participation model we assume is both, simple and meaningful. It suits to infer participation increase in the presence of any co-operation approach p' e.g. [1], [2], [3], [4], [5], [6]. It is fully characterized by the ad hoc nodes' behaviour:

- For each 'transmission event' each node uniquely decides to either forward all traffic or to drop all traffic, e.g. if a node once decides to send a bundle of packets it indeed sends all these packets,
- 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 considers that nodes may participate in the route discovery phase whereas they may decide to drop traffic in the forwarding phase. The 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 behaviour.

3. Effect of Participation Intensification

We define two events E and give notation for their probability $Pr(E)$:

- E^i_p : node i forwards in presence of p but without p' *and* $Pr(E^i_p)=e$, with $e \in [0,1]$,
- $E^i_{p'}$: node i forwards in presence of p and p' *and* $Pr(E^i_{p'})=e+\Delta e$, with $\Delta e \in [0,1-e]$

So, Δe denotes the probability increase affected by fear based awareness or motivation of p' at which an individual node increases its participation. Note, that for a first approximation the exact values of e and Δe are not important.

Let us now consider how p' influences the final forwarding result of all nodes which∧ are involved into the payload forwarding process. Since the, E^i_p $(i=1,\ldots,n)$ are independent of each other, the probability that the final destination receives in absence of p' data over a pre-established path with n intermediate nodes is $Pr(E^1_p \wedge \ldots \wedge E^n_p) = e^n$. The same applies to $E^i_{p'}$ and in presence of p' we denote $Pr(E^1_{p'} \wedge \ldots \wedge E^n_{p'}) = (e+\Delta e)^n$. We are now prepared to give some quantitative estimation on the effect of intensifying participation in ad hoc networks with the help of any $p' \in P'$. For this, it is essential to understand the interdependencies of e, Δe, and, of course, n. This enables us to finally enclose practical relevant values for Δe. We start with some analytical discussion on the probability expressions, now understanding n as real and denote n^* as the largest integer less than or equal n. The convergence behaviour of functions e^n and $(e+\Delta e)^n$ is $lim_{n\rightarrow\infty} e^n = 0$ and $lim_{n\rightarrow\infty}(e+\Delta e)^n = 0$ for all permutations $(e,\Delta e)$ except $e=1$ for the first and $e+\Delta e=1$ for the latter equation. Thus, the absolute effect of any $p' \in P'$ (and obviously also the throughput in absence of p') is neglectable, if a 'large' number n^* of intermediate nodes needs to be involved to reach the destination. It is in particular insignificant which $\Delta e \in$ [0,1-e] the p' has caused (We feel that the exceptional and obviously idealized cases $e=1$ resp. $e+\Delta e = 1$ and $lim_{n\rightarrow\infty} e^n = 1$ or $lim_{n\rightarrow\infty}(e+\Delta e)^n = 1$ are not relevant in practice).

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To measure the value 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 for T should not fall below approximately 0.6 including selfish nodes' behaviour as well as loss rates on the wireless link [7]. This border suits for connection-less UDP traffic whereas for connection-oriented TCP over the wireless, reasonable T indeed is much higher. Taking T into account, next we show how Δe affects the maximum acceptable path length. More generally, we investigate if and how Δe affects the network's overall reachability.

We denote $e^n = T$ and $(e+\Delta e)^n = T$ in absence or in presence of p' and derive $n = \ln T/\ln e$ and $n = \ln T/\ln(e+\Delta e)$. We introduce values n_1 and n_2, where n_1 holds the first and n_2 holds the latter equation. Further, we introduce $\Delta n_a = n_2 - n_1$ believing that this is a reasonable measure for the *absolute* impact of p' in terms of increased number of intermediate hops with still acceptable throughput. Thus, Δn_a represents in absolute manner the increased reachability in the ad hoc network and we denote

$$\Delta n_a = \ln T/\ln(e+\Delta e) - \ln T/\ln e.$$

For completeness, the expression $\Delta n_r = (n_2 - n_1)/n_1$ shall also be taken into account, representing the *relative* reachability increase of the network:

$$\Delta n_r = (\ln T/\ln(e+\Delta e) - \ln T/\ln e)/(\ln T/\ln e)$$

We are satisfied by showing the impact of Δe on Δn_a resp. Δn_r by exemplary graphical illustrations (1-2). Fortunately remaining parameters, although generally variable, are fix and available for each particular ad hoc network. For illustration we choose $e=0.3$, $e=0.5$ and $e=0.7$ and again $T=0.6$. Note, that the first two cases represent scenarios where in absence of any p', the ad hoc network's reachability is even insufficient when using just a single involved intermediate node.

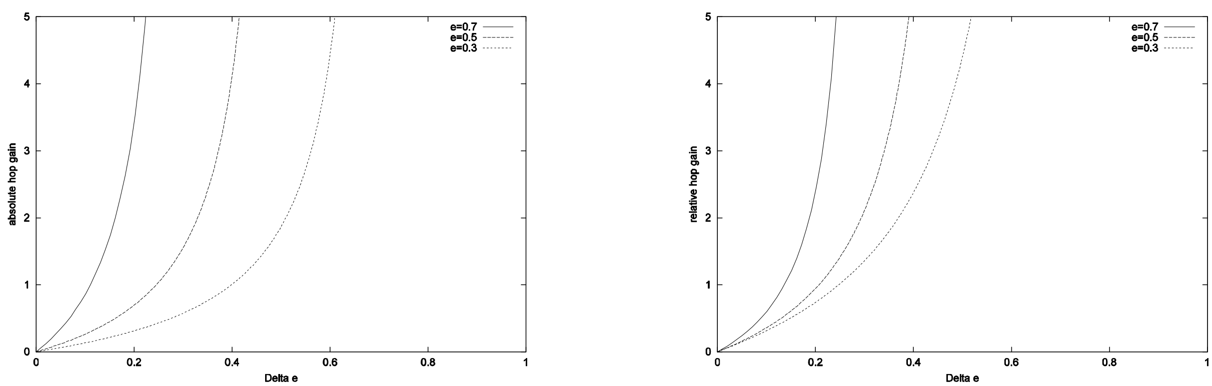

Fig. 1-2. Absolute and relative hop gain per Δe for various ad hoc networks' throughput probability e.

Conclusion

The above curves feed the statement that p' dramatically increases the network's reachability for all permutation $(e, \Delta e)$ where $e+\Delta e$ is greater 0.8. In particular this means that for small e the impact of Δe is only valuable if it rises an individuals throughput probability to that range. On the other hand, if e itself is high, even small Δe can cause significant benefit on the network's reachability. Thus, in cases where the network's throughput itself is already reasonable we feel that p' is most valuable for loose dense ad hoc networks. Here, p' dramatically improves the ad hoc network's overall reachability in terms of tolerable number of intermediate hops with still acceptable amount of data received at the final destination.

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