The Degree of Participation Concept in Ad Hoc Networks

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Abstract

The paper introduces the novel concept of Degree-of-Participation (DP) in mobile ad hoc networks. The Degree-of-Participation concept allows nodes in the ad hoc network to express the level of involvement they are willing to give to the forwarding process. The paper also introduces a DP-based routing scheme for mobile ad hoc networks. Performance evaluations show that the Degree-of-Participation allows a more resource-aware forwarding process.

1 Introduction

A Mobile Ad hoc Network (MANET) is an autonomous system of mobile hosts or nodes which are free to move arbitrarily. The nodes are equipped with wireless transmitters and receivers. At a given point in time, depending on the nodes' positions and the coverage patterns, transmission power and interference levels, a wireless connectivity in the form of a multihop graph exists between the nodes. This Ad hoc topology may change with time as the nodes move or adjust their transmission and reception parameters [2].

Many routing protocols have been developed for ad hoc networks and can be divided into two categories: table-driven routing and source-initiated on-demand routing. Examples of the first category of routing protocols are: DSDV (Destination-Sequenced Distance-Vector) routing [10]; CGSR (Clusterhead Gateway Switch Routing) [1]; and WRP (Wireless Routing Protocol) [7]. Examples of the second category of routing protocols are: AODV (Ad hoc On-Demand Distance Vector) routing [11]; DSR (Dynamic Source Routing) [5]; TORA (Temporally Ordered Routing Algorithm) [9]; ABR (Associativity Based Routing) [12]; and SSR (Signal Stability Routing) [3].
These and other recent works on Ad hoc networks [4, 8, 6] have mainly focused on routing issues with the assumption that every node has the same willingness to participate in the routing mechanism. However, a MANET node may decide not to participate in all or part of the forwarding mechanism. This can be driven by an energy saving policy for example. Special resource management schemes and policy-based routing are required to accommodate such node behaviors.

Existing routing algorithms for MANETs assume and require that all nodes in the MANET will participate in the forwarding process with the same level. In other words, independently of any resource related information (energy-level, number of processes asking for CPU time, etc.), a node is asked to participate fully in the forwarding process. However, in MANETs, nodes do not necessarily have the same amount of available resources for the forwarding process. A node may have a short life-time battery, while another one may have a longer life-time battery. A node may be overloaded by user processes, while an other node may be idle. A node may simply not want to participate in the forwarding process, if it does not use it.

The idea of degree of participation is based on the following statement: "Instead of forcing nodes to participate in the forwarding process regardless of their resource availability state, why not give nodes a way to define their levels of involvement in the forwarding process, achieving this way more fairness and avoiding unnecessary resource consumption from nodes with low available resources".

The rest of the paper is structured as follows: section 2 introduces the concept of Degree of Participation . Section 3 presents a Degree-of-Participation-based routing algorithm for mobile ad hoc networks. In section 4 a performance evaluation of the proposed algorithm is presented. Finally section 5 concludes the paper.

2 Degree of Participation Concept

The degree of participation concept is a totally new approach to routing in mobile ad hoc networks which captures well the spirit of nodes in ad hoc networks. At the difference from wired networks where routers are their to serve hosts by forwarding their packets, nodes in MANETs have other goals. They have to face the difficult choice between using the available resources to forward other nodes' packets and

Proceedings of the Eighth IEEE International Symposium on Computers and Communication (ISCC'03)
1530-1346/03 $17.00 © 2003 IEEE

between using the resources to perform the user requested tasks. In traditional networks, routers are their to forward packets, so to a certain extent, there is no need to take into consideration their resources when routing. In ad hoc networks, a new approach is needed. The nodes have to have a say in the routing mechanism. So, we need a way to let the nodes define their degree of involvement, and this is exactly what the degree of participation concept is all about.

The Degree of Participation value may be function of several parameters such as:

- Power level
- Number of processes running
- Memory levels
- Node capabilities
- Security
- Internal resource management policies

The values taken by the DP are between 0% and 100% and represents the node's percentage of participation in the forwarding process.
A value of 50% for example, means that the node is not willing to handle more than 50% of what it can handle in the normal situation.

One of the drawbacks of assuming that all nodes will fully participate in the forwarding process (an assumption maid by all existing routing protocols), is to push low energy terminals to consume their scarce energy, while it may be possible to use another route that will be well served by other high-level energy terminals.

The Degree of Participation approach can be seen as a perpendicular dimension to routing in ad hoc networks and can be used in conjunction with the already proposed routing mechanisms.

In the following, we will present a Degree-of-Participation-based routing scheme for mobile ad hoc networks. However, the idea of Degree of Participation in ad hoc networks is more general and can be used as a basis for other routing schemes.

3 DP-Based Routing

In the following, we assume that every node in the MANET has a Degree of Participation (DP) that defines its involvement in the forwarding process. The node may change its DP according to its internal resource management policies. The precise definition of these policies is out of the scope of this paper and will be handled in future works. Periodically, each node exchanges its DP value with its neighbors. These DP values are used in the forwarding process.

3.1 Overview

The Degree of Participation Based Routing (DPBR) builds routes on-demand[1]. When a route is required but no information to the destination is known, the source floods the ROUTE REQUEST packet to discover a route. The source includes in this message the minimal allowed DP in the route, a target DP value for the route and a threshold value. The minimal DP value can not be higher than the source's DP. The other parameters will be explained later.

When a node other than the destination receives a non-duplicate ROUTE REQUEST with a minimal DP lower than its DP, it builds a route entry for the <source, destination> pair and records the previous hop to that entry. This previous node information is needed later to relay the ROUTE REPLY packet back to the source of the route. If a ROUTE REPLY packet is not received, the entry will timeout and be removed from the route table. The node then attaches its DP information and forwards the ROUTE REQUEST packet to its neighbors that has a DP value higher than the minimal allowed DP specified in the ROUTE REQUEST . This has the advantage of limiting the flooding to only those nodes that are able to offer this minimal DP, hence reducing the overhead. If the minimal DP is higher than the node's DP the ROUTE REQUEST message is discarded.

After receiving the first ROUTE REQUEST packet, the destination waits for an appropriate amount of time to learn all possible routes. In order to learn all the routes and their quality, the destination node accepts duplicate ROUTE REQUESTS received from different previous nodes. The destination then chooses the best route and sends a ROUTE REPLY packet back to the source via the selected route[2]. The selection process is describe in section 3.2.

Along with the ROUTE REQUEST , the source includes a parameter REPLY_FROM_CACHE that will indicate if the source allows or prohibits intermediate nodes from replying to ROUTE REQUESTS if they already have in their cache a route to the destination satisfying the minimal allowed DP. A source that allows intermediate nodes to reply to ROUTE REQUESTS will be able to rapidly find a route to the destination, but the discovered route may not be the best possible one or may not exist anymore. A source that prohibits intermediate nodes from replying to ROUTE REQUESTS will need to wait longer for the route discovery, but will allow the destination to choose the best possible route. The decision of the source will depend on many parameters like the type of application, the QoS needed, the urgency of the communication and its duration.

Another parameter included in the ROUTE REQUEST

[1]The Degree of Participation concept can also be integrated in table-driven routing schemes for ad hoc networks by including the Degree of Participation value in the used metric.

[2]The degree of participation concept can also be used in networks with unidirectional links, but this is left for future work

message, is ONLY_TOTAL_RECONSTRUCTION . This parameter tells intermediate nodes, if the source prefers a partial or total route reconstruction in case of a link failure (or a DP that goes below the minimal allowed value). Table 1 shows the added parameters of the ROUTE REQUEST message and their possible values.

Parameter	Possible Value
DP_{min} ($\leq DP_{Source}$)	$0\% - 100\%$
Target DP ($\geq DP_{min}$) and ($\leq DP_{Source}$)	$0\% - 100\%$
Threshold	≥ 0
REPLY_FROM_CACHE	True/False
ONLY_TOTAL_RECONSTRUCTION	True/False

Table 1. ROUTE REQUEST message parameters

3.2 Route Selection

To each DP_N of a particular node N, we associate the value $\Delta_N = 100\% - DP_N + \alpha$ that we call abstention ($\alpha > 0$ will be explained later).
If the minimal DP is higher than the destination DP, the destination node chooses the right route and then sends a ROUTE REPLY with the NEW minimal DP. Nodes along the path will update their parameters' values accordingly. The source will have the choice to accept or refuse this new value.

If the minimal DP is lower than the destination's DP, the destination node adds the values of abstention Δ of each intermediate node and selects the route with the least sum. If there is a tie, the destination selects the route with the shortest hop distance. When there are still multiple routes that have the least abstention and hop distance, the path that is taken by the packet arrived at the destination the earliest between them is chosen.

The parameter α represents the tradeoff between a path with several nodes with high DP values and a shorter path with nodes with low DP values. This is a parameter of the algorithm that is chosen to give the best performance. To understand the effect of this parameter, lets take the following example: assume that there are 4 paths between a source S and a destination D as follows (see figure 1):

- P1 S-100-80-D: two nodes between the source and the destination with DP values of 100% and 80% respectively.
- P2 S-80-D: one node between the source and the destination with a DP value of 80%
- P3 S-100-100-D: two nodes between the source and the destination with DP values of 100%
- P4 S-100-100-100-D: three nodes between the source and the destination with DP values of 100%

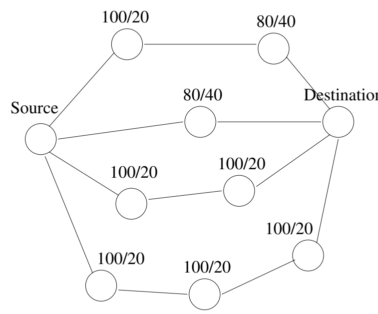

Figure 1. Example network. Each node N is labeled with its DP_N/Δ_N and $\alpha = 20\%$

α	$\sum\Delta$ for P1	for P2	for P3	for P4	Chosen path
10	40	30	20	30	P3
20	60	40	40	60	P2 or P3
30	80	50	60	90	P2

Table 2. $\sum\Delta$ of the four paths according to α

Table 2 shows the sum of abstention Δ for each of the four paths according to the value of α. It also shows the paths that can be chosen by the routing algorithm. If $\alpha = 10\%$, DPBR prefers to take path P3 with two nodes (100% DP each) than taking the shorter path P2 with one node (80% DP). If $\alpha = 30\%$, DPBR prefers to take path P2 rather than P3. If $\alpha = 20\%$, P2 and P3 have the same sum of nodes' abstention, and P1 and P4 have also the same sum of nodes' abstention.

By choosing α carefully, we can make a tradeoff between longer paths with high DP values and shorter path with low DP values.

During the active data session, intermediate nodes periodically (or when a node changes its DP) piggyback their DP information on data packets. Destination node can thus monitor the status of the route.

The destination monitors the number of nodes in the path with a DP value lower than the target DP value specified in the ROUTE REQUEST message. If the number of these nodes is above the threshold value specified in the ROUTE REQUEST message, a new and better route is selected to replace the old path. The process of building new routes is similar to the initial route discovery process except that the destination floods the packet to the source of the route, instead of the source flooding to the destination. The source, upon receiving ROUTE REQUEST packets, selects the best route in the same manner as the destination. The source does not need to send a ROUTE REPLY , and simply sends the next data packet using the newly discovered route.

3.2.1 Route Selection Algorithm

When the destination receives a set of routes, it uses the following algorithm to choose between them:

1. Let DP_{min} be the minimum of DP_{Source}, $DP_{Destination}$ and DP_{min} specified in the RREQ.
2. Remove any route having any of its node's DP lower than DP_{min}
3. For each route R, do the following:
   - For each node N of R do the following: $\Delta_N = 100 - DP_N + \alpha$
4. Choose the route R with the minimum $\sum_N \Delta_N$

3.3 Route Maintenance

A node can detect a link break by receiving a link layer feedback signal from the MAC protocol, not receiving passive acknowledgment, or not receiving hello packets for a certain period of time. When a route is disconnected, then two situations may occur according to the value of the ONLY_TOTAL_RECONSTRUCTION parameter.

if the parameter ONLY_TOTAL_RECONSTRUCTION is set (i.e. True), the immediate upstream node of the broken link sends a ROUTE ERROR message to the source of the route to notify the route invalidation. Nodes along the path to the source remove the route entry upon receiving this message and relay it to the source. The source reconstructs a route by flooding a ROUTE REQUEST when informed of a route disconnection.

If the parameter ONLY_TOTAL_RECONSTRUCTION is not set (i.e. False), the node performs a partial path reconstruction by sending a ROUTE REQUEST to its neighbors with the values of minimal DP, target DP, threshold, REPLY_FROM_CACHE and ONLY_TOTAL_RECONSTRUCTION parameters copied from the initial ROUTE REQUEST sent by the source.

Route maintenance is needed in two cases: If one link along the path is broken, or if a node along the path has changed its DP value. In the former case, a partial or total path reconstruction will take place as described above depending on the value of the ONLY_TOTAL_RECONSTRUCTION parameter. In the later case (i.e. a node along the path changed its DP value), two situations may occur:

1. The DP of a node gets higher: in this case, no processing is needed.
2. The DP of a node gets lower: in this case, there are two possibilities:
   (a) The new DP value is higher than the minimal allowed DP for the path. In this case a notification message is sent to the destination. When receiving this message, the destination may initiate a route reconstruction depending on the target value and the threshold value for the path.
   (b) The new DP value is lower than the minimal allowed DP for the path. In this case a route reconstruction is initiated according to the ONLY_TOTAL_RECONSTRUCTION parameter.

In the case of Source or Destination's DP change, the parameters of the ROUTE REQUEST message are updated accordingly.

4 Performance Evaluation

4.1 The Simulation

To evaluate the performance of our Degree-of-Participation-based routing protocol, we constructed a connection-level simulator which allowed us to observe and measure the protocol's performance under a variety of conditions. In particular, the simulator allowed us to vary certain environmental factors such as the number of mobile hosts, the pattern and speed of host movement, and the distribution of the hosts in space. The main goal of the conducted simulations is to show that the proposed algorithm reduces the load experienced by nodes with low Degree of Participation.

Our simulation modeled a network of 50 mobile hosts placed randomly within 1000 meter $\times$ 1000 meter area. Each node has a radio propagation range of 250 meters. Each run executed for 300 seconds of simulation time. 100 connections were established at the beginning of each simulation. We assume that all connections have the same traffic load. The sources and the destinations are randomly selected with uniform probabilities. The mobility model used is the random waypoint model [5]. The minimum and the maximum speeds were set to zero and 30 m/s, respectively. The main goal is to assess the amount of load reduction experienced by low level DP nodes. To remove the influence of the nodes' location on the results, we make the nodes change their DP value each second. The new DP values are chosen randomly between 1% and 100%. DP_{min} was set to 0% for all nodes, and the target DP and the threshold values were set for all nodes to 0% and 50 respectively.

We compare our algorithm to a routing algorithm that uses the number of hops as a metric (i.e. shortest path). The two routing schemes were compared under exactly the same circumstances.

4.2 Simulation Results

4.2.1 Impact on Nodes' Load

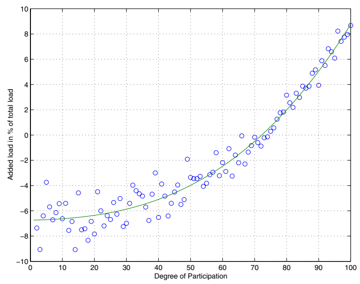

Figure 2. The amount of load difference according to the Degree of Participation

Figure 2 depicts the average difference in load (in percentage of total load) according to the Degree of Participation of the nodes. The X-axis represents the value of the degree of participation. The Y-axis represents the amount of added load to each node. The value is represented as a percentage of the total load in the system. For example, a value of 4% means that the node incurred an additional load equal to 4% of the total system load. Clearly, the DP-based routing scheme reduces the load experienced by low level DP nodes. All nodes with a DP value below 70% have their load reduced in average. Of course, this load is added to high level DP nodes (above 70%). The figure also shows the curve that approximate the data found. It is a strictly increasing function, which indicates that low level DP nodes benefit most of the load reduction.

Figure 3 shows the average difference in load (in percentage of total load) according to the node's load when using the shortest-path-based routing scheme. The X-axis represents the value of the load incurred by the nodes in the system when using the shortest-path-based routing scheme. The value is represented as a percentage of the total load in the system. The Y-axis is as in figure 2. According to this figure, the nodes that have their load increased are those who are less loaded, while the nodes that have their load reduced are those who are more loaded. In other words, the figure shows that not only that the DP-based routing scheme reduces the load of low level DP nodes but also the high loaded of them. Also, the nodes that have their load increased are those who are less loaded.

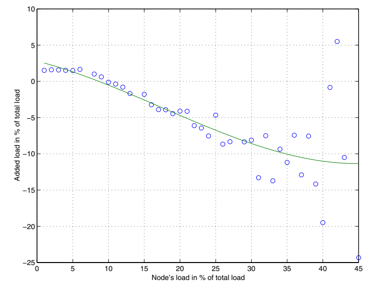

Figure 3. The amount of load difference according to the node's load

4.2.2 Impact on Paths' Length

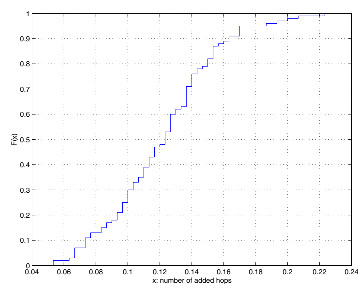

Figure 4. Cumulative Distribution Function of the difference in paths' length

An important aspect of the routing algorithm that should be investigated is its impact on the paths' length. Figure 4 shows the cumulative distribution function of the difference in path length for each connection established. It shows that the average increase in length experienced by the connections is 0.14 hop, which is 14% of a hop. The maximum increase observed was 24% of a hop. This is a very low increase. This shows that there is virtually no increase in terms of number of hops between paths chosen by the DP-based routing scheme and those chosen by the shortest path algorithm.

We have conducted several other simulations with different parameter values (e.g. number of nodes, number of connections established, longer simulation time...) and we have observed the same results, namely, a reduction of the load of nodes with low DP values and a very negligible increase in path lengths (always below 30% of a hop).

5 Conclusion

This paper introduces the new concept of Degree of Participation in mobile ad hoc networks. The Degree of Participation concept allows nodes in the ad hoc network to express the level of involvement they are willing to give to the forwarding process. This was not possible before. The paper also describes a Degree-of-Participation-based routing scheme. Performance evaluation shows that nodes with low Degree of Participation value incur lower load than when using a non-DP-based routing scheme. The simulations show also that there is virtually no penalty in terms of length of the chosen paths.

In future work, we intend to conduct packet-level simulations to assess the performance in terms of packet loss and end-to-end delay.

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