Pre-fetching protocol in mobile ad-hoc networks performance evaluation

Roxana ZOICAN*, Ph.D.,
Sorin ZOICAN*, Ph.D.,
Dan GALATCHI*, Ph.D.

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Abstract. This paper evaluates the performance of a new proposed protocol for finding the routes in mobile ad-hoc networks based on pre-fetching of information. For this protocol the predictability of the location is a key point because only the nodes placed in the near of the current node will be pre-fetched. The article proposes an algorithm that computes the probability that a node is placed in the neighbor of the current node. This algorithm involves a Gauss –Markov model for the mobility of each node. The pre-fetch protocol reduces the route discovery up to 10 times comparing with classical protocols.

1. Introduction

Finding the routes in mobile ad-hoc networks (MANET) is a difficult task. A node moves to a new location and it has to discover a route to the destination from this new location. The protocols proposed for route discovery has latency. This latency can be minimized by pre-fetching the routing information present in the nodes that will neighbor the current node. Of course, the memory requirements will be increased and some techniques for cache memory will be applied.

In the literature [1], the following MANET protocols are proposed:

– Distance-sequenced distance-vector (DSDV) protocol requires each mobile node to advertise, to each of its current neighbors, its own route table. There is considerable delay due to the advertisement of each node to its neighboring nodes.

– Dynamic Source Routing (DSR) protocol is composed of the two mechanisms of route discovery and route maintenance, which work together to allow nodes to discover and maintain source routes to arbitrary destinations in the ad-hoc networks. Route request and reply process of DSR may gives rise to a significant amount of routing delay.

– Ad Hoc On-Demand Distance-Vector (AODV) routing protocol broadcasts a route request when
a node needs a route to a destination. Any nodes with a current route to that destination can unicast a route reply back to the source node. Each node in its route table maintains route information.

– Zone Routing Protocol (ZRP) allows a node to recognize all its neighboring nodes within a fixed radius. However, the route request and reply process still incurs delay.

– Location-Aided Routing (LAR) protocol assumes that the average speed and position at a particular time of each node is known. With this information, LAR finds a destination node.

All the protocols outlined above require time for route discovery incurring a delay. A new self-configuring protocol for MANET that reduces the communication delay among nodes by pre-fetching of routing tables was proposed [2].

2. Pre-fetching Protocol for Route Discovery

We assume that the location of each node is known and each node has cache memory to hold the table structure. The location of the nodes will be computed as will be indicated in section 3. Assume a mobile node $X$ is communicating to a remote node $Y$ through a neighboring node $A$. When the signal from node $A$ becomes weak it will be replaced with other node, $Z$ from routing table of node $X$. If the node $Z$ is already placed in the cache memory of node $X$ the latency is reduced very much. The only problem here is to decide which nodes from $X$ node routing table will be pre-fetched. That is because not all the nodes in the routing table will be able to ensure the communications with node $X$ at a given moment of time.

The existing protocols impose a latency penalty if there is a break in the communications link due the lack of a pre-fetching and the routing information will be loaded from node $Z$ not from cache of node $X$.

Figure 1 presents the nodes mobility. We assume- as an example- that are 6 nodes (1, 2, 6) and the current nodes is node 6. The rest of the nodes form the routing table for node 6. We define a radius, $R$ called acceptance radius. All the nodes placed within the circle with radius $R$ will be pre-fetched in the cache memory of node 6 in order to be used when the signal become weak.

Some of the nodes in the routing table might have higher possibility to be selected as a pre-fetching node. The access probability will be defined as the probability that a node to be placed within the circle of radius $R$ and the centre in the position of the current node.

This probability will be computed based on the mobility model of the nodes as it shown in section 3. The access probability depends on the following factors: the speed of mobile, probability to change the direction and the distance between nodes. All of these factors it take into consideration if a probabilistic model for node mobility is assumed.

The table 1 indicates how the pre-fetch protocol works in time.
Table 1

<table>
<thead>
<tr>
<th>Time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_0$</td>
<td>Node $X$ (node 6 in figure 1) is communicating to the destination node $Y$ through node $A$ (the nodes $Y$ and $A$ are one of the nodes 1 to 5 in figure 1)</td>
</tr>
<tr>
<td>$t_1$</td>
<td>$A$ is on the edges of the communication range of $X$ (signal from $A$ is getting weak) Pre-fetching is invoked $X$ pre-fetches routing records used by $D$ (a node within the circle of radius $R$, node 4 in figure 1)</td>
</tr>
<tr>
<td>$t_2$</td>
<td>$X$ can communicate with node $D$ $X$ has sufficient routing information to route packets through node $D$ immediately (when the link with $A$ will be broken). This will be achieved without a executing a route discovery resulting in low latency.</td>
</tr>
</tbody>
</table>

We define the processing cost as $c_p$ and the cost incurred due to transmission time be $c_t$. The total cost will be: $c_ps + c_tt_t + c_tt_p$ where $s$ is the size of the routing table to be processed, $t_q$ is the transmission time for the route request message and $t_p$ is the transmission time for the route reply message. Assuming that request and reply transmissions times are the same time $t$ the total cost is: $T_p = c_p s + 2c_t t$.

In the other MANET protocols, a route discovery request is broadcast. This may involve on average broadcasting requests to $n$ nodes each time. There is a delay and break in communications while a new route is being discovered. Therefore, there is the delay or latency cost $c_d$ for route discovery and route reply messages. We assume transmission time for each hop is $t$. The average total cost for route discovery (route request broadcasts and route reply messages) is $T_{np} = P + R + D$, where $P$ is the cost for route request messages and processing, $R$ is the cost for route reply messages; $D$ is the cost due to the delay or break in communications while a new route is being found. The parameters $P$, $R$ and $D$ can computed as follows:

$$P = \sum_i \left[ c_p s_i + c_t t_i \right], \quad R = \sum_i c_t t_i, \quad D = \sum_i c_d d_i.$$ 

The cost to process the route request (accessing and searching the routing tables) in the pre-fetching protocol is the time taken for route discovery and the transmission time for the route request sent out by node $X$ and the route reply by a probable node.

$$P = \sum_i \left[ c_p s_i + c_t t_i \right], \quad R = \sum_i c_t t_i, \quad D = \sum_i c_d d_i.$$ 

The cost for route discovery is computed as follows: if access probability is greater than a minimum threshold then the cost is $T_p$ (and the node will be pre-fetched) else the cost is $T_{np}$.

Two problems must be resolved: how the weak-link is detected and how the distance between current node and the node witch is getting weak is determined.

Both above problems can be solved using a probabilistic mobility model (presented in section 3).

This mobility model estimates the position of each node in the MANET. Based on the propagation model we can estimate a maximum distance, $d_{max}$, between two nodes from they can communicate. When this distance exceeds a threshold, $T_c$ then the communication becomes weak.

The same mobility model can be used in order to determine the nodes within in the circle with radius $R$ witch will be pre-fetch when the communication getting weak.
3. Gauss Markov Model Mobility

A mobile is moving to a final destination and their velocity changes are limited due to physical restrictions. The current mobile’s velocity and positions are correlated with the past velocity and locations. A Gauss Markov process can be used as a model of the behavior of a mobile terminal in an ad-hoc network [4].

The mobile velocity, \( v_n \), is described as a Gauss Markov process as follows [3]:

\[
  v_n = \alpha v_{n-1} - 1 + (1 - \alpha) \mu_x + \sigma \sqrt{1 - \alpha_x^2} w_{n-1}
\]  \hspace{1cm} (1)

where \( \alpha \) represents the degree of memory in the process, \( \mu_x \) is the process mean and \( \sigma \) is its variance. The variable \( w_n \) is an uncorrelated Gaussian process with zero mean and unit variance and independent of \( v_n \).

The equation (1) covers a wide range of mobility patterns that include the two extreme cases: the random walk model (\( \alpha = 0 \)) and the constant velocity (\( \alpha = 1 \)).

The equation (1) may be expanded for two dimensional cases. Therefore we will define the velocity as vector \( \bar{v} = (v_n^x, v_n^y) \). The equations (2) and (3) illustrate the two dimensional model of mobile velocity:

\[
  v_n^x = \alpha_x v_{n-1}^x - 1 + (1 - \alpha_x) \mu_x + \sigma \sqrt{1 - \alpha_x^2} w_{n-1}^x
\]  \hspace{1cm} (2)

\[
  v_n^y = \alpha_y v_{n-1}^y - 1 + (1 - \alpha_y) \mu_y + \sigma \sqrt{1 - \alpha_y^2} w_{n-1}^y
\]  \hspace{1cm} (3)

This model takes into consideration the speed and the changes of the speed at every moment.

The mobile position \( \bar{p} = (p_n^x, p_n^y) \) can be estimated with maximum likelihood as follows [3]:

\[
  p_n^x = \frac{1 - \alpha_x}{1 - \alpha_x} v_0^x + (1 - \frac{1 - \alpha_x}{1 - \alpha_x}) \mu_x
\]  \hspace{1cm} (4)

\[
  p_n^y = \frac{1 - \alpha_y}{1 - \alpha_y} v_0^y + (1 - \frac{1 - \alpha_y}{1 - \alpha_y}) \mu_y
\]  \hspace{1cm} (5)

where \( v_0^x \) and \( v_0^y \) represent the initial velocities on x and y axes. The parameters \( \mu_x \) and \( \mu_y \) will be estimated as the average velocity on x and y directions, respectively as indicated in equation (6):

\[
  \mu = \frac{1}{N} \sum_{i=1}^{N} v_i
\]  \hspace{1cm} (6)

with \( v_i \) - the measured velocity at moment \( i \).

The parameters \( \alpha_x \) and \( \alpha_y \) will be estimated as follows [3]:

\[
  \alpha = 1, \text{ if } \sigma \approx 0
\]

and \( \alpha = \max \left( 0, \frac{\lambda^2}{\sigma^2} \right) \), otherwise \hspace{1cm} (7)

For simplicity in equation (6), (7), (8) and (9) we do not write the indices \( x \) and \( y \).

The parameters \( \sigma \) and \( \lambda \) are estimated as in relations (8) and (9):

\[
  \sigma^2 = \frac{1}{N} \sum_{i=1}^{N} (v_i - \mu)^2
\]  \hspace{1cm} (8)

\[
  \lambda^2 = \frac{1}{N} \sum_{i=1}^{N-1} (v_i - \mu)(v_{i+1} - \mu)
\]  \hspace{1cm} (9)

Based on equations (4) and (5) the relative distance between any two mobile nodes 1 and 2, can be estimated as:

\[
  d(1,2) = \sqrt{(p_1^x - p_2^x)^2 + (p_1^y - p_2^y)^2}
\]  \hspace{1cm} (10)

The access probability will be computed as a frequency of the time moments when the condition \( d(a,x) < R \) is fulfilled (\( x \) is the current
node and $a$ is a pre-fetch candidate from routing table of node $x$).

4. Experimental results

The pre-fetch protocol was simulated in the following condition: 5 nodes in the routing table of the current node, with the non pre-fetching costs (in cost units): 100, 50, 200, 150, 75 and pre-fetching costs (in cost units): 10, 5, 2, 15, and 25. The node 6 is the current node (which pre-fetch the rest of five nodes). The initial velocities of the mobiles was considered: $v^x = [10, 20, -30, 40, -50, 60]$ and $v^y = [1, -20, 10, -35, 10, -5]$. The node 2 change twice its velocity as follows: at iteration 50 $v = [-80, 0]$ and at iteration 100, $v = [60, 0]$. The measured velocities, $v_j$ has estimated as random variables with mean equal with the initial velocity. The access probability threshold for pre-fetch was imposed to 0.4.

The flowchart of the pre-fetch protocol (including the weak link detection) is illustrated in the figure 2. First, the weakness of node A is determined (that is, if the distance between node X and node A is less than a imposed threshold, $d_{max}$, then node A is weak).

![Flowchart](image)

Fig. 2. The pre-fetch protocol flow chart.

Secondly, the distance between each node in the routing table for node X (noted by node D) and current node (X) is computed. If the node D is in circle of radius $R$, then its routing information is pre-fetched and will be use by node X when the communication with node A will be interrupted. The figures 3, 4, 5 and 6 illustrated the main results: access probability, average number of pre-fetch nodes, route discovery cost.
Fig. 3. The access probability.

Fig. 4. The average number of pre-fetch nodes.
Fig. 5. The route discovery cost (with pre-fetch).

Fig. 6. The route discovery cost (with no pre-fetch).
We can observe from figure 5 and figure 6 that the pre-fetch protocol reduces the route discovery up to 10 times comparing with classical protocols. The computation time is greater for the pre-fetch protocol, but this is not a real problem for the router if the velocity of the mobiles is reasonable. The radius $R$ and $d_{\text{max}}$, are very important parameters to a proper function of this protocol. In our simulations $R = 100$ and $d_{\text{max}} = 150$.

5. Conclusion

The paper illustrated an approach to implement the pre-fetch protocol in order to reduce the latency in route discovery in MANET. The pre-fetching will improve significantly the performance of the network and the selected model for mobility of nodes can cover various situations from random walk to constant speed. The pre-fetching algorithm has good tracking proprieties (that is, at velocity changes the access probabilities is modified fast).

6. References