The Evaluation of Ad Hoc Network Node Density Influence on Routing Performance*

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Abstract. A mobile Ad Hoc network is made of mobile nodes connected to each other via wireless links. The nodes function both as routers and as host devices. As nodes are moving, the network density varies. Routing protocols are responsible for re-establishing network routes that break off due to topology changes. The evaluation of Ad Hoc network node density influence on routing performance is presented in this paper. Evaluation is made by simulating routing algorithms in different scenarios of the shrinking and expanding network.

Keywords: Ad Hoc networks, density influence evaluation, flooding-based routing, location-based routing, signal strength assisted routing.

1 Introduction

A mobile Ad Hoc network (MANET) is made of mobile nodes that self-organize into a network and communicate via wireless links as hosts sending and receiving data packets and as routers performing packet routing. Any routing protocol generates the additional stream of route request and reply packets – the overhead, which temporarily overloads the network. Different routing protocols are being constantly developed, that are capable of minimizing the routing overhead.

The applications of Ad Hoc networks can include corporate, home and personal area networking, sensor networks, voice communication services, emergency services, military communications and etc. Depending on the application networks can be more sparse or dense. As network nodes are moving the network can take different topology and the density of nodes varies.

It is important to choose the suitable routing algorithm for different MANET applications. A review of different flooding-based, location-based and signal level assisted routing algorithms is made in Section 2 of the paper. The related work on routing algorithm performance evaluations in dense and sparse networks and the new approach of the shrinking and expanding network model are presented in Section 3. The evaluation of Ad Hoc network node density influence on routing performance has been made. The simulation results, followed by their interpretations are presented in Section 4 of the paper. The final conclusions and recommendations for the routing algorithm usage are made in Section 5.

2 A review of routing algorithms used in simulations

Two main definitions: request zone and response zone should be emphasized when talking about routing for Ad Hoc networks [1]. Request zone is a space within wireless signal transmission range of the node. Response zone is a space, where nodes send response packets or forward route request packets further to the network. Request zones are not controlled during the routing process. Some routing algorithms control response zones to reduce the routing overhead.

2.1 Flooding-based routing algorithms

Ad-Hoc On Demand Distance Vector (AODV) algorithm [2] and Dynamic Source Routing (DSR) algorithm [3] are based on on-demand routing for Ad Hoc networks that operate by broadcasting route request (Rreq) packets in all directions over the network. Each intermediate node forwards Rreq packets to other nodes so that the entire network is flooded by Rreq packets. When the route to the destination node M_d is found, it is made available by unicasting a route reply (Rrep) packet back to the source along the circuit of intermediate nodes. DSR algorithm is based on source routing, i.e. route to the destination node M_d information is stored in data packet headers. Flooding-based routing generates a big network routing overhead, as the response zones are not controlled and are the same as the request zones.

2.2 Location-based routing algorithms

There are a number of routing algorithms proposed, seeking to achieve efficient routing by decreasing the overhead of route discovery. Some of these routing algorithms use network node location information to find

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the route – Location-aided Routing (LAR-1, LAR-2) [4], Modified Location-aided Routing (MLAR-1) [1], No-Beacon Geographic Distance (NB-GEDIR) [5] etc. Each network node has to know the current locations of all other network nodes. LAR-1 algorithm operates by flooding a fixed rectangular response zone with \(R_{req}\) packets. The nodes inside the response zone forward the \(R_{req}\) packets to other nodes, while nodes outside the response zone ignore the \(R_{req}\) packets. MLAR-1 is a modification of LAR-1 routing algorithm, where each node sending \(R_{req}\) packet, recalculates rectangular response zone, which decreases when nodes are closer to the destination. In LAR-2 routing algorithm the response zone contains only the nodes that are closer to the destination node \(M_d\) than the node from which they received the \(R_{req}\) packet. When NB-GEDIR routing algorithm is used, the source node \(M_s\) or some intermediate node requests location information from neighbour nodes by sending the location request (Lreq) packet. The nodes in the response zone respond by sending their coordinates to the requesting node in location reply (Lrep) packets. The source (or intermediate) node determines its next-hop node with the minimum distance to the destination \(M_d\). Location-based routing algorithms use node location information to reduce the response zone and perform directional routing.

### 2.3 Signal strength assisted routing algorithms

When the network nodes are distributed in an open space without surrounding obstacles and every Ad Hoc network node has the same transmitter power, receiver sensitivity and antennas, the request zone of a node \(M_s\) is a circle around the node with the radius \(R\). However, often there are cases when terrain, transceiver and antenna diversity have a significant impact on the actual request zone of a particular network node, so the request zone can become irregularly-shaped. Therefore, location-based routing towards the shortest distance to a destination is not always the best choice, as it may lead to choosing the next-hop node with weak signal level.

Signal strength assisted routing algorithms control the size of response zones to reduce the routing overhead. The received signal strength values are used in the location-based Dynamic Response Zone Routing (DRZR) [6] algorithm to avoid routing to the network nodes with low quality radio links. DRZR routing algorithm has been created by the authors of this paper. It operates by dynamically changing the response zone in separate steps of the routing process. The response zone is set by applying the signal strength range \([S_k; s_k]\), where \(S_{k,\text{min}} \leq S_k < s_k\) and \(k\) is the current network node. \(S_{k,\text{min}}\) is the marginal signal strength value, corresponding to the request zone, i.e. the lowest signal strength possible for successful radio communication. The source and destination node coordinates and signal strength range values \([S_0; s_0]\) are inserted into the Lreq packet. Nodes in the request zone make decisions of either being in a response zone or not, by evaluating the received signal strength levels of the sending node. The nodes in the response zone send their coordinates to the requesting node in the Lrep packet. As in the NB-GEDIR algorithm case, after receiving the Lrep packets, the source (or intermediate) node determines its next-hop node with the minimum distance to the destination \(M_d\) and the routing process continues. If there are no nodes sending reply packets, the signal strength limit value \(s_0\) is increased and set to some new value \(s_0 = s_1\), where \(s_1 > s_0\).

The flooding-based Signal level Restricted Flooding (SRF) [7] routing algorithm operates without location information and also makes response zone size restrictions by specifying signal strength ranges, which are included into \(R_{req}\) packets. SRF routing algorithm has been also created by the authors of this paper. As network node location information is not used for limiting the response zone, the routing is performed in all directions. The same schemes for SRF algorithm routing dynamics can be used as in DRZR algorithm case.

### 3 Routing algorithm performance evaluations in dense and sparse networks

The density of an Ad Hoc network is understood as the number of nodes in some network area \([X x Y]\). In most sources, ex. [8–10] routing simulations are made on network area model with a specified number of nodes randomly moving inside the area. The traffic is generated for numerous pairs of connections and such metrics as – data delivery ratio, routing overhead, end to end latency and other – are measured during the simulation. When simulations need to be done on a denser network, a higher number of network nodes are included into the network model. Therefore, when \(R\) increases, it can be assumed, that all the nodes are evenly getting closer to each other. The simulations have been performed using such network model and results are presented in Section 4 of this paper.
4 Simulation and evaluation of routing algorithms

Most of MANET research is made by simulating Ad Hoc network routing protocols with ns-2 [11], ns-3 [12], OPNET Modeler [13] or other simulation software. Routing protocols have to be implemented with all protocol specific data, such as packet headers, routing tables, routing algorithms, wireless link maintenance procedures and etc. The authors of routing protocols present their simulation results in papers and source codes are not accessible in public. Therefore, it is not possible to correctly repeat the exact implementations of routing protocols themselves. However, as we were analysing only the algorithms of the routing protocols, the simulation programs have been written using MatLab. The operation of flooding-based (AODV, DSR), location-based (LAR-1, LAR-2, MLAR-1, NB-GEDIR), and signal level assisted (DRZR, SRF) routing algorithms has been implemented according to their authors [1–7]. The purpose of the research was to perform routing algorithm simulations on the Ad Hoc network model in order to analyze the routing overhead \((Rreq+Rrep+Lreq+Lrep)\) dependence on network node density. The number of steps needed to find the route has been also analyzed for different network node density cases.

The simulations were made on a randomly generated network model with 400 network nodes. This model is created from the rectangular grid \([100 \times 100]\) network by disabling 96% of grid elements using uniformly distributed pseudorandom numbers [6]. The distances among adjacent rectangular grid elements in perpendicular directions are equal to \(U\). The simulations have been performed at the request zone size range varying from \(R=10U\) to \(R=80U\), by using the step of \(2.5U\). The bigger request zone size \(R\), the higher the network density. In our simulations we considered a low density network within the interval of \(R [10U; 30U]\) and a high density network with \(R \) above \(30U\).

The simulations of routing algorithms mentioned have been performed using the destination node \(M_D\) in network grid element \((1; 100)\) and two cases of source node locations in the same network model. In the first case, the source node \(M_S\) is in the network grid element \((50; 51)\), and the simulation results are presented in Figure 1 and Figure 3. In the second case, the source node \(M_S\) is in the network grid element \((100; 1)\), and the simulation results are presented in Figure 2. The diagrams in Figure 1 and Figure 2 show the number of routing overhead packets \((Rreq+Rrep+Lreq+Lrep)\) generated during the single route search process (from node \(M_S\) to node \(M_D\)), depending on the network density. The diagrams in Figure 3 show the number of steps needed to find the route during the single route search process (from node \(M_S\) to node \(M_D\)), depending on the network density.

There are two schemes of DRZR algorithm operation that were used in simulations. The initial signal strength value \(s_1\) is used to narrow the response zone from the inside. The DRZR \(\{s=(s_1)\rightarrow (P)\}\) algorithm scheme has one step changing the response zone – the signal strength limit value \(s\) is set to \(P\) in case of failure in getting any \(Lrep\) packets. The DRZR \(\{s=(s_1)\leftrightarrow(s_1+6)\leftrightarrow(s_1+12)\leftrightarrow(P)\}\) algorithm scheme changes the response zone in multiple steps: the \(s\) is being doubled (+6dB) in case of failure in getting any \(Lrep\) packets, and \(s\) is being decreased backwards in case of a successful receipt of any \(Lrep\) packet. Therefore, the algorithm seeks to maintain the narrowest response zone possible by decreasing \(s\) value after it has been increased in the previous step of the routing process. The illustration of signal strength value dynamic usage is presented in Figure 3 upper right corner.

![Figure 1. Routing overhead at different network density, when \(M_S (50; 51)\) and \(M_D (1; 100)\)](image-url)
In both locations of source node (50; 51 and 100; 1) flooding-based routing algorithms AODV and DSR performed equally: \( R_{req} = 400 \) packets and \( R_{rep} = 1 \) packet are generated. These algorithms generate the biggest routing overhead comparing with any other routing algorithm. As location information is not used for flooding-based routing, \( L_{req} = 0 \) and \( L_{rep} = 0 \).

LAR-1, LAR-2 and MLAR-1 algorithms avoid global flooding of the network when source and destination nodes are in grid elements (50; 51) and (1; 100), because they use location information to perform route search process towards the destination node (Figure 1). As seen in Figure 2, they are not efficient to find the routes when source and destination nodes are in grid elements (100; 1) and (1; 100), as they perform the same route search process as flooding-based algorithms (AODV and DSR). NB-GEDIR algorithm is efficient mostly in sparse networks; otherwise too many \( L_{rep} \) packets are being generated by the nodes in the response zone, as well as \( R_{req} \) packets are also sent after the election of the next-hop node.

![Figure 2. Routing overhead at different network density, when \( M_S (100; 1) \) and \( M_D (1; 100) \)](image)

The routing overhead of the DRZR algorithm \((R_{req}+1+L_{req}+L_{rep})\) in all cases was smaller than any other algorithm, because the response zone was reduced by the use of location information and signal strength restrictions together. It can be clearly seen from Figure 1 and Figure 2 that the efficiency of DRZR algorithm is fairly similar in different network density cases. However, it is desirable to use such DRZR algorithm case, where the response zone was kept as narrow as possible in every step of the route search process.

![Figure 3. Number of route search steps at different network density, when \( M_S (50; 51) \) and \( M_D (1; 100) \)](image)
The routing overhead of the SRF algorithm \((Rreq+1+0+0)\) highly depends on the location of source and destination nodes as well as the density of the network. SRF algorithm has good performance in high density networks as well as in many cases of low density networks. Although SRF is a flooding-based algorithm, it operates by reducing the response zone during route search process. Therefore, SRF routing simulation results (Figure 1 and Figure 2) indicate the significant reduction of the routing overhead, comparing with common flooding-based algorithms. The biggest advantage of SRF algorithm is that it makes response zone size restrictions without the use of location information. Therefore, it is most efficient in such Ad Hoc network scenarios, where network nodes are not equipped with positioning devices or location services are not available in the network.

The simulation results of routing steps needed to find the route are presented in Figure 3. According to the diagrams, two separate groups of routing algorithms can be defined, depending on their origin. The first group contains AODV, DSR, LAR-1, MLAR-1, LAR-2 and SRF algorithms that perform faster routing, because \(Rreq\) packets are immediately broadcasted in the entire response zone instead of waiting for \(Lrep\) packets to arrive. Another group: NB-GEDIR and DRZR algorithms operate slower especially in low density network areas, because \(Lreq\) and \(Lrep\) packets are sent at every step of the route search process and \(Rreq\) packet is sent to the next-hop node with the minimum distance. In case of failure to receive \(Lrep\) packets in DRZR algorithm, the \(Lreq\) packets are re-sent causing additional overhead and route search latency.

5 Conclusions

Different flooding-based, location-based and signal level assisted routing algorithms have been implemented in the simulation software. The simulations have been made on the network grid model, where network nodes are randomly scattered in grid elements.

The network node density affects the routing overhead and route search time. When flooding-based routing algorithms are used, every network node sends request packets that generate the biggest routing overhead. However, the route search process is fast, as every node does not wait for response packets to arrive from the nodes in the response zone.

In the networks with low node density the routing algorithms have small impact on the routing overhead. In high node density networks the differences between overhead of different routing algorithms are significant and reach up to 30 times, when the source node is in the centre of the network grid. When the source node is at the border of the network, the difference is about 5-10 times.

In the networks with high node density the routing process of different flooding-based, location-based and signal level assisted routing algorithms is fast. In low node density network the DRZR and NB-GEDIR algorithms have the slowest routing search process, because location request and reply packets are sent at every step of the route search process. LAR-1, LAR-2, MLAR-1, AODV, DSR and SRF algorithms have the fastest route search process, as the nodes do not wait for response packets to arrive from the nodes in the response zone. In low node density network the differences between route search times are about 3-4 times. These differences reach about 1.5 times in high node density network.

In the network cases with heterogeneous node density the SRF routing algorithm is a good choice to use. In SRF the response zone is restricted by applying the signal strength range. The response zone size is varied depending on the network density, so the algorithm adapts to the network topology changes.

Future work is going to be made on the SRF algorithm development into the routing protocol. The simulations of the newly created SRF routing protocol as well as the flooding-based AODV routing protocol are going be made by using the ns-3 network simulator. The Ad Hoc network with Random Waypoint Mobility model is going to be used for simulations. Different cases of network density and node speed are going to be evaluated.

References


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