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The effect of mobility on connectivity in MANETs

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Abstract

MANET - Mobile Ad Hoc Network is a network topology deprived of any supporting structure. Each node in the network acts as both host and router. In order for the network to work, a routing protocol like AODV (Ad hoc On-demand Distance Vector) has to be used to deliver packets. The main assumption of MANET is its mobility. In this paper AODV, the protocol responsible for transferring data in the network will be tested, compared and analysed under different working conditions using the NS-3 network simulator.

Keywords: MANET, throughput, topology, mobility, AODV, NS-3, simulation, round-trip time.

1. Introduction

MANETs or Mobile Ad Hoc Networks significantly different from other networking solutions in that it is a decentralised infrastructure-less network, composed of autonomous, wireless nodes. In comparison “traditional wireless communication networks, namely cellular and satellite networks, require a fixed infrastructure over which communication takes place” [7]. In MANET there is no fixed infrastructure, or backbone, in the network responsible for supervising it, the nodes are responsible for everything; they have to cooperate in order to transfer data from source to destination. MANETs are multi-hop wireless networks because the destination node is usually out of the transmission range of the source node. Therefore, the packets reach the destination after some hops over the intermediate nodes between the source and destination [6]. To fulfil the task, each node, depending on need, can act as both router and as host. As the name of the network suggests, nodes can be move; each node is a mobile device (laptop, phone, etc) and with movement of the nodes the topology of the network is in constant alteration.

This type of network can have great advantage over popular networks in places with difficult geographical conditions or inaccessible regions and could be used by army, scientists, medical services, etc. Unfortunately, despite many evident advantages, MANET is still a relatively under-explored field and therefore it struggles with a number of problems which have limited its adoption, including life expectancy (mobile devices require battery to function properly), bandwidth and unpredictable performance due to the constantly changing topology of the network. The mobility of the nodes is a MANET’s greatest advantage as well as a disadvantage. Thanks to mobility MANET is considered
self-organising and self-configurable network, but due to constant movement and changes in topology the routes are prone to frequent breaks which reduce the throughput of the network compared to wired or cellular networks [6] and increased time for data to find its destination.

In order to work properly MANETs need to use routing protocols to instruct each node how to deliver packets on multi-hop journeys. There are many different protocols – AODV, DSR, SAODV and more. One of the most popular is AODV - Ad hoc On-demand Distance Vector Routing. In order to achieve up-to-date information sequence numbers are used to guarantee loop freedom. To find the best path to a destination, each source node broadcasts RREQ (route request) messages (Figure 1) to all its neighbours. When one of the nodes receives packet, as long as it does not have fresher route saved, it sets the sender of the message in the reverse route. Duplicated RREQ messages are dropped, as only the one which arrived the fastest will dictate the best route. A destination node, upon receiving an RREQ message, sends an RREP (route reply) back to source node along the reverse route (Figure 2). The source device, after receiving an RREP is ready to send data to its neighbour from which it received first RREP packet. HELLO messages are periodically sent between nodes to detect route breakages. If any of the nodes leaves the network or breaks (by moving out of range) its upstream neighbour notifies all of it other upstream neighbours with another message RERR (route error) message [1, 2].

This type of network can be useful in the future in areas where setting up infrastructure is difficult or impractical task. It is therefore needed to know all limitations and complications that might be encountered along the way for the network to work as efficiently as possible. In this paper a series of tests will be performed in order to investigate how MANET performance and connectivity is influenced by mobility under AODV.
2. Simulation setup

Performing tests on networks, especially networks consisting of many standalone devices can be difficult (expensive and/or time consuming) and sometimes not possible to perform at all. NS-3 has been developed to study behaviour of network systems in a controlled and reproducible environment. NS-3 is an open source network simulator with research and educational use set as primary targets. NS-3 is designed as a set of libraries and can be used
with several external animators and other tools. Most of the configuration of the actual simulation is done in either in C++ or Python [4]. The animator used for tests performed in this document is called NetAnim [5] which uses XML files produced during the simulation run to perform visual representation and animation of network and network movement. For example, Figure 3 shows the transfer of RREQ packet from node 64 to nodes 49, 59 and 62 (broadcast to all neighbours), and it can be observed that source node’s IP is 10.0.0.55 (node 54) and destination node’s IP is 10.0.0.25 (node 24). This provides an easier way to read details of all transferred packets (Figure 4 and Figure 5). All Figures (Figure 3-5) present transfer of packets between nodes and Figure 3 and Figure 5 present the same message. NS-3 provides samples for different types of network with different settings, including AODV for MANETs. The sample setting is a simple network of 10 nodes 100 meters apart from each other, aligned in a single row, static, simulating behaviour of the network for 10 seconds – sending packets from first to last node. For the purposes of this paper, the sample file has been adjusted as follows:

- Running time for each test set to 180 seconds to obtain more data for comparison.
- Number of nodes increased to 100.
- Area of testing has been set to 1000m x 1000m.
- Nodes are being generated in random positions (used current time as seed for node generation, which prevents duplicate values).
- Generating of XML file used for animation has been enabled (not for all tests)
- Packet metadata and route tracking have been enabled to obtain more details during animation.
- Default removal of middle node (network loosing connectivity) has been disabled
- Initial initialisation of the nodes restricted to (depending on test) square of size: 1000m x 1000m and 500m x 500m.
- Nodes (depending on test) are set to move in random direction on X and Y axis by minimum 0 m/s (nodes are static) and maximum 30 m/s on each axis, restricted by area 1000m x 1000m.
- The remaining the settings are left unchanged from the defaults.

All the nodes in the network are considered to be identical; they transmit data with the same speed, none of them is malicious and none of them breaks at any time during the simulation. Energy consumption is not considered in this paper as in few initial tests performed with and without implementation of energy consumption model there was no visible difference between the results over these relatively short runtimes.

3. Simulation

Considering the fact that nodes are initialised in random positions with every new simulation, sending packets from first node to the last one will always produce different outputs as they are always generated and moved with random values. In order to perform accurate evaluation of node mobility, running the simulation even for 180 seconds would not be even close to unbiased evaluation. There needs to be certain amount of random
generations, as in some cases network generations are created in such a way, that no
transfer is possible even after 180 seconds of running a simulation and those simulations
cannot be omitted. They have to be taken into consideration as well to provide results as
accurate as possible. In order to achieve this, tests have been run in total of 280 times with
14 different settings. To do this simple script has been written to automate the work. The
differences between each run are as follows:

- Initial area of initialisation of nodes 1000m x 1000m
  - Speed of nodes set to 0 m/s, 5 m/s, 10 m/s, 15 m/s, 20 m/s, 25 m/s and 30
    m/s

- Initial area of initialisation of nodes 500m x 500m (Figure 6 represents this
  particular network visualised in NetAnim)
  - Speed of nodes set to 0 m/s, 5 m/s, 10 m/s, 15 m/s, 20 m/s, 25 m/s and 30
    m/s

Therefore, there are two main comparisons performed between different initial area used
for network, but with the same maximum area that nodes are restricted by during their
movement – 1000m x 1000m. Bigger area was taken into consideration, but after few tests
it has been clear that packet loss is too significant for only 100 devices to perform those
tests and evaluate them.

Figure 7 represents sample output from one of the simulations. From there a great amount
of important information can be obtained about the quality of service and data travelling in
the network. Every second, node with IP 10.0.0.1 pings node with IP 10.0.0.100 56 bytes of
data (real packets will be 28 bytes longer as 8 bytes are required for ICMP - The Internet
Control Message Protocol and 20 bytes are for IP) and below are listed all
acknowledgements that successfully arrived back to the source with round-trip-delay (time
necessary for a source to send a packet and receive acknowledgement, that transmission
was successful). There is also information about packets received and lost in the network during whole simulation and minimum/maximum/average/standard deviation of RTT in simulation. All that information is really important for evaluation of the AODV protocol in this network.

4. Evaluation

A number of metrics of interest were used in this evaluation:

- Throughput – The number of data bits delivered to the application layer of destination node together with data bits of reply delivered to the application layer of source node in unit time measured in bps
- RTT average – Round-trip time is the average length of time it takes for a message to be transmitted to destination and average length of time for acknowledgement of that message to be received
- RTT mdev – average of how far each ping RTT is from mean RTT.
- Lack of transmission (or unavailability) – percentage of all tests that did not succeed in transmitting even a single packet during 180 seconds of simulation

All the data presented in document for each setting has been calculated as average of 20 independent tests for each node speed.

<table>
<thead>
<tr>
<th>Node speed m/s</th>
<th>Throughput bp/s</th>
<th>Lack of transmission %</th>
<th>RTT average ms</th>
<th>RTT mdev ms</th>
</tr>
</thead>
<tbody>
<tr>
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<td>50</td>
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<td>200.3</td>
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<td>381.98</td>
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<td>82.88</td>
<td>30</td>
<td>296.27</td>
<td>475.46</td>
</tr>
</tbody>
</table>

Figure 8 Mean results from tests of initial area 1000m x 1000m
Table: Initial area 500m x 500m

<table>
<thead>
<tr>
<th>Node speed m/s</th>
<th>Throughput bp/s</th>
<th>Lack of transmission %</th>
<th>RTT average ms</th>
<th>RTT mdev ms</th>
</tr>
</thead>
<tbody>
<tr>
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<td>0</td>
<td>167.43</td>
<td>356.47</td>
</tr>
</tbody>
</table>

Figure 9: Mean results from tests of initial area 500m x 500m

Figure 10: Mobility versus throughput (higher = better)

Figure 10 compares the throughput of the same number of nodes (100) under different settings for each size of network area. It can be easily observed that initially (when nodes are static) the smaller area shows higher throughput. Considering that nodes are generated in a much smaller area it is logical to assume that messages will arrive quickly with fewer hops and there is less chance that TTL (time to live) of the packet will expire. Clearly in the larger area nodes are more spread out and so there is more chance of breaks in the network, even when there is little or no mobility. When mobility of the nodes is increased to 5 m/s, decrease in throughput can be noticed in both cases, but more significantly in the smaller area. The decrease must be caused by route breakage caused by mobility while packets are being transmitted or while source node is anticipating acknowledgement. On the other hand, such a small movement can be advantageous in some scenarios. From this point decrease in throughput while mobility is increased to 10 m/s is not as drastic as before, but it still appears and the smaller area again has greater decrease in throughput. Interesting observation at this point is that throughput decreases its value really slowly while increasing mobility to 15 and 20 m/s. The propagation speed of nodes between 20 m/s and
10 m/s does not make too much of a difference to introduce more route breakages than at slower speeds. When there the speed of nodes is at its maximum there is little difference in throughput between the different area sizes and we conclude that mobility, rather than area is the dominant factor here and successful transmission is likely to be mostly coincidental single hop. The minimum throughput is observed when the speed is 20 m/s for the larger area, although the difference between the throughput here and at 30 m/s is not large and this minimum may be due to experimental noise or possibly beyond 20 m/s the speed becomes so fast that connectivity is more a case of random collisions. We will observe other interesting results when the speed is 20 m/s.

Figure 11 shows the percentage of tests in each speed setting (20 runs each speed) that was not able to receive an acknowledgement during all 180 seconds of network simulation. Nodes generated in the smaller area were able to successfully perform transfer of at least one packet during simulation for speeds 0, 5 and 10 m/s. The speed here is too low to cause constant route breakages and density of nodes was high enough to guarantee that there will always be a connection between some source and destination. There was small increase in simulations with no successful packet transfer when speed was increased to 15 m/s and the peak of unsuccessful transfers was reached for simulations with speed 20 m/s. Afterwards with higher speeds, there were no completely unsuccessful simulations, which again may be due to random meetings at high speed or possibly experimental noise. For a network generated in larger area the ratio of unsuccessful simulations in much higher. 50% of cases show a lack of transmission, even when nodes are static. This is caused by the large initial area, where sometimes are no connections between source and destination and the lack of mobility prevents the nodes from finding alternative route. The moment nodes are able to change their position slightly is the best moment in the aspect of successful connection between devices; at least some packets were delivered and source received confirmation of it. Increasing speed of nodes further gradually increases percentage of complete lack of transmission, which once again reaches its peak at the speed of the nodes set to 20 m/s, just

![Figure 11 Mobility versus Lack of any transmission (lower = better)](image-url)
like in case of networks generated in smaller area. Speeding nodes up to 30 m/s, gradually decreases the failure of transfers.

Figure 12 presents how mobility affects average round-trip time. The higher RTT, the longer it takes for message to reach destination and for the sender to receive confirmation that message successfully travelled through the network of nodes. In this case, while nodes are static RTT is low and really similar for both cases, there is only a slight difference; the

Figure 13 Standard deviation round-trip time (lower = better)
nodes in the smaller area have a slightly lower RTT than nodes generated in the large area. What needs to be taken into consideration is the fact that in the case of the network generated in greater area, there are many simulations/packets that are not transmitted at all (Figure 11) and they are not taken into consideration while calculating RTT, that is the reason why it is so low – only successful transfers are taken into account and as it has been already established, static nodes as long as they are generated in good arrangement, they will transfer packets through the network and they will remember route for later, without mobility route is always the same. That is the reason for such a small RTT for static nodes (both in Figure 12 and 13). Disparity starts to grow alongside increasing mobility. A major cause would probably again be the difference in the distance between nodes. The ones generated in smaller area transfer data faster as it takes a while for nodes to traverse through network and even then there should be some safe routes saved for data to transfer. As for larger area, nodes are already spread far away they do not have enough neighbours which causes longer waiting times for data transfer (route discovery). RTT reaches its peak, in both cases (red chart might be difficult to observe, look Figure 9) again when speed of the nodes is equal to 20 m/s. Afterwards it starts gradually decreasing and difference between both charts is growing smaller. Worth observing is definitely almost the same RTT value for blue chart for node speeds equal to 10, 15 and 25 m/s. Figure 13 presents changes in standard deviation in RTT. High standard deviation might introduce speed issues with bulk transfers. Transfers will take longer time and sender will have to wait long time for acknowledgements. As in average RTT (Figure 12), in this example, while nodes are static RTT is low and almost the same in both charts, again red chart has slightly lower RTT. For both charts RTT grows together with increased mobility of nodes. In case of red chart, it is basically constant for both speeds 5 m/s and 10 m/s, but afterwards it grows much more rapidly than in case of nodes generated in large area. Both charts again reach their peak when nodes are set to 20 m/s. Blue chart afterwards linearly decreases RTT. Red chart on the other hand does it rapidly and there is almost no change in RTT between 25 and 30 m/s. Difference in RTT between red and blue chart grows smaller at the speed of 30 m/s. Movement speed probably causes nodes generated in smaller area to propagate fast enough to fill almost all, if not all available area, therefore results are getting closer to the ones produced by network represented by blue chart.

After assessing all the charts (Figure 10, 11, 12, 13) few observations can be made. Ad hoc On-demand Distance Vector Routing is definitely most efficient when the network is static. Smaller operating area equals to better overall results – throughput, RTT and general functioning of the network. Increasing the area on which network is supposed to work, without enough nodes to properly populate it, might end up with only partially functioning network, with “gaps” in area that are not possible to overcome as nodes are too far away from each other. If there appear node in a network that cannot transmit data to different node, it only means that network like that cannot be considered as functioning one. There has to always be a route between any two nodes. Nodes operating on bigger area, might gain from slow movement. Despite the fact that throughput and RTT might loose on performance, the overall functionality of network might be improved. If there is a “gap” in network, with the help of low mobility of devices, it can be fixed, by creating new routes. It is directly connected with small throughput decrease and RTT increase as some of currently
working routes might be broken, nevertheless it can be considered as minor disadvantage, over huge advantage of self “fixing” network. This advantage in smaller areas, with high density of nodes per square meter will be considered as disadvantage, as there is high chance there will not be any “gaps” in the network and movement will only decrease performance of network, by destroying current routes. In case of nodes working in larger area or in smaller area it can be observed that nodes perform the best up to the speed of 10 m/s. Above that in range 10-25 m/s performance of the network decreases drastically and it is not worth having nodes with such a speed. Network gains on performance again in range 25-30 m/s and it is applicable to both types of areas that were tested. The most interesting observation is worst performance of the network under mobility of nodes equal to 20 m/s. When nodes move with previously mentioned speed throughput, average RTT, standard deviation RTT and even “gap” appearance (ability to transfer at least one packet during whole simulation) or just really poor connection, which requires a lot of hops – time-to-live reaches its expiration - are all achieving worst results. Therefore, speed of nodes equal to 20 m/s should be avoided by all means, if network is supposed to work efficiently.

5. Conclusions and further work

In this paper MANET and Ad hoc On-demand Distance Vector Routing has been analysed under influence of different node mobility and area on which network is generated and is operating on. Network behaviour has been simulated and animated using NS-3 network simulator to study throughput, round-trip time, network efficiency and general dependability. From performed tests advantages and disadvantages of each network setting were noted, quite clearly stating which network features should be essential when creating MANET. Clearly mobility affects both performance and predictability – both in terms of high variability in RTT and percentage on non-delivery. Although the best throughput is when nodes are static, this should not be considered as permanent solution as a key characteristic of MANETs is mobility. It is also clear by now that node mobility of speed 20 m/s should be avoided as it results in drastic decrease in network stability and performance in every possible aspect. In general, the closer the nodes are to each other and the slower they are, the better performance can be achieved and higher chance of packets arriving in destination.

There is huge window of opportunity for future work trying to evaluate AODV under different circumstances, with different nodes behaviour to know how to utilise most of what MANET promises to provide. In particular it should be noted that the random waypoint mobility employed here and many other studies is often far from realistic. One would not expect pedestrians or vehicles to instantly disperse in random directions at the same speed. Hence it may be that the negative effect of relative mobility may be much reduced in many practical situations. This remains an issue for future work.

References