Performance of Mobile Ad Hoc Network in Constrained Mobility Pattern

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Abstract—Mobile Ad Hoc Networks (MANET) performance is affected by a number of factors, eg. speed, node density. In this paper we will focus on the effect of constrained mobility on the performance of the MANET protocol. Experiments were carried out to measure the performance of MANET protocols in two mobility patterns: random waypoint and Metropolitan Grid (M-Grid). The latter reflects the mobility pattern that would be encountered in inter-vehicle communication system. Our results show that MANET performance in the M-Grid mobility pattern is reduced considerably as compared to random waypoint. A parameter called coverage density index was proposed to normalize mobility patterns coverage and thus its connectivity. The probability of connectivity and route length provides an indication of the performance of MANET protocols given the mobility pattern.

1. INTRODUCTION

MANET is a dynamic multi-hop wireless infrastructure, where nodes take on the additional function of routing of packets across the infrastructure. The dynamic and multi-hop nature of the network has provided researchers with major challenges.

The MANET IETF community has been working aggressively on the standardization of MANET protocols. Two protocols that are receiving much attention are AODV [7] and DSR [8]. Both are reactive protocols, in which the path to the destination is discovered on demand. A number of studies have been carried out to assess the performance of the protocols and the factors affect the performance, eg. caching, mobility.

Although initially the main application of the technology is in the military, there is a growing deployment of the technology in the commercial world, especially in Inter-Vehicular communication systems (IVCS). Examples of applications and implementations of IVCS had been shown in FleetNet [1], VICS [2], CarNet [3], etc.

While MANET routing protocols seem to work well in scenarios where nodes are basically random and mobile, the same could not be applied to IVCS as vehicular travel are often restricted by the roads and traffic patterns. The performance of MANET would be greatly affected by the mobility pattern. Investigation into the effect of the mobility pattern on MANET would further our understanding the deployment of MANET for IVCS.

The rest of the paper is organized as follows. Section 2 describes two mobility patterns: random waypoint and Metropolitan grid. Section 3 will introduce the parameter known as Coverage density index. Section 4 will show the simulation results of running both MANET protocols using the two mobility patterns. Section 5 concludes the paper.

2. MOBILITY PATTERNS

Mobility pattern refers to the movement of the nodes in the environment. Two well known and at the same time representing extreme mobility pattern models are used in our simulations, random waypoint and Metropolitan Grid (M-Grid).

2.1 Random waypoint

Random waypoint is the most commonly used mobility pattern. For this mobility pattern, the nodes are moving in a random manner. The parameters for its movement are as follows: speed, pause time, destination. A node will pick a random speed and destination. Once it is chosen, the node will move towards the destination. On reaching the destination it will pause for a fix time period, after which it will pick a new destination and speed and start moving to the new destination. High node mobility is simulated by increasing speed and reducing the pause time.
2.2 Metropolitan GRID

The M-GRID[6] basically models a typical metropolitan environment that consists of roads and junctions made up of square grids. Nodes must travel on the grid lines, which represent the roads, at constant speeds. A random function is used to select the speed. Each grid intersection is treated as a junction where the vehicle would stop for a fix period of time, junction pause time, before it proceeds in the next random direction and at a newly chosen speed.

3. COVERAGE DENSITY INDEX

One of the issues in comparing the performance of MANET protocol in different mobility pattern is to find a common base for comparison. Comparison based on number of nodes is an unfair comparison as the effective coverage area of the wireless transceiver for different mobility pattern are different. To quantify the coverage obtained from the different mobility pattern, a new parameter Coverage Density Index(CDI) is proposed. It is defined as the average number of overlapping wireless coverage. In the case of the random waypoint the CDI is approximated by

\[ \text{CDI} = \frac{(\pi R^2 N)}{\text{Total area}} \]

where \( R \) is the transmission range of the node and \( N \) is the number of nodes.

In the case of M-GRID the CDI is calculated differently as given by

\[ \text{CDI} = \frac{C_{\text{ave}} \times N}{\text{Total length of path along the grid}} \]

where \( C_{\text{ave}} \) is the average effective coverage of a node as it moves along the grid path.

Taking the example of a M-Grid with 400 m between junctions, when a node moves from one junction to the middle is as shown in figure 2. As seen in the plot the effective coverage, \( C_{\text{node}} \), initially decreases followed by a sinusoidal increase while random waypoint is a constant. The plot from 200 to 400 meters is a mirror image of the plot form 0 to 200 meters. With a transmission range of 350 m the average effective coverage, \( C_{\text{ave}} \) is 1662 m.

4. PERFORMANCE MEASUREMENT

The constraint mobility pattern, M-GRID, affects two major parameters that will influence the performance of MANET protocols:

- Connectivity between nodes. This would affect the probability of detecting the destination in route discovery as well as when there is a break in the link.
- Path length between nodes. Longer path length would results in a higher probability of break in link.

where “x” is the distance from the junction and \( C_{\text{node}} \) refers to the effective wireless coverage of the node at an instance in time. The effective coverage areas are only along the path. Thus \( C_{\text{ave}} \) for M-Grid is

\[ C_{\text{ave}} = \frac{\int_0^{200} C_{\text{node}} \, dx}{200} \]

The two extreme scenarios, when \( x=0 \) and \( x=200 \) m, are shown in figure 1. The circle represents the wireless coverage of the node while the straight line, vertical and horizontal lines, represent the grid path along which a node moves. The straight lines that are within the circle represent the effective coverage of the node.

![Figure 1: Effective wireless coverage of node for M-GRID](image)

The effective coverage of a node in M-GRID, plotted using the formula above, as it moves from one junction to the middle is as shown in figure 2. As seen in the plot the effective coverage, \( C_{\text{node}} \), initially decreases followed by a sinusoidal increase while random waypoint is a constant. The plot from 200 to 400 meters is a mirror image of the plot form 0 to 200 meters. With a transmission range of 350 m the average effective coverage, \( C_{\text{ave}} \) is 1662 m.
A program was written to determine the above static characteristics for different mobility pattern model.

### 4.1 Connectivity analysis

Figure 3 shows the connectivity for Random Waypoint mobility pattern. The figures show good connectivity between nodes. This means that all the nodes are inter-connected most of the time. The non-restricted movements also allow the nodes in the random waypoint scenario to be more evenly distributed. Thus clusters are usually large with connecting intermediate nodes between each cluster. Large clusters generally improve the delivery ratio of packets, as there is a higher possibility that the source and destination node belongs to the same source. Furthermore, there are more connections between nodes.

Figure 4 shows snapshots of the connectivity of nodes in M-GRID. Unlike the random waypoint scenario, movement of the nodes in the M-GRID is constrained by roads and junctions. These restrictions, as can be seen from the connectivity diagrams in Figure 4, are the main reasons contributing to the partitioning of the nodes. More clustering are also observed in the M-GRID and these clusters are generally smaller than that in the random-waypoint scenario. Thus each cluster also has a smaller area of coverage. The lack of intermediate nodes to link up the clusters causes more partitioning in the M-GRID than in random waypoint.

To further understand the relationship between mobility pattern and connectivity, a program was written to measure the probability of connectivity. Connectivity of the scenarios was investigated by the generation of 100,000 different snapshots of the connectivity diagrams for each scenario, which shows nodes being randomly placed in each snapshot, taking into consideration the restrictions of the M-GRID. The connectivity between pair of node was checked. Large numbers of samples are obtained to find the probability of connectivity, and results shown that the probability has converged. Thus it is not necessary to do an exhaustive search.

Figure 5 shows the results obtained from the program. The results of the investigation show that in the random-waypoint scenario, the probability of connectivity is much higher than M-Grid scenario for a given number of nodes.

Figure 6 shows the results of plotting the probability of connectivity against coverage density index. In this case the two plots, Random waypoint and M-GRID, are almost the same. Thus, we can predict the connectivity performance of different mobility pattern given its coverage density index. As indicated in the plot, the connectivity increases with higher coverage density index. For coverage density index less than 10, the changes of partitioning are high. Thus affect the packet delivery.

The performance of the protocols, with density up to around 7, is determined by the connectivity. However, for environment where the density index is higher than 10, the performance will be hampered by congestion. Thus, for MANET protocol, we would expect the performance to improve as the density increases until a point where congestion comes into play and the performance will deteriorate.

### 4.2 Path Length

Another factor that a constrained mobility affects is the path length. The path length, in terms of number of hops, affects the stability of the link. The longer the path length, the higher is the probability of a break in the link.

As observed in figure 7, the path length goes through a number of stages. The path length is low when the density index is low because those nodes that it can successfully communicate with each other are usually close by and thus shorter path length. As
Figure 3: Random-Waypoint

Figure 4: M-GRID

Figure 5: Probability of connectivity verses Number of nodes

Figure 6: Probability of connectivity verses Coverage density index
the density increase the chances of longer path is increased. The path length will peaks and reduces slightly as there is higher probability of connection with nearer nodes.

The path length for M-Grid is longer than random waypoint. This is to be expected, as the nodes and thus the communication path are force to move along the grid. In actual fact the increase in the path length of M-Grid compared to random waypoint is by approximately the same factor as sum of the perpendicular edges versus the diagonal distance.

![Density vs Path Length](image)

Figure 7: Path length for different mobility pattern

### 4.3 MANET protocol

NS-2 network simulator [9], which has the AODV extension, was used as the simulation environment. The simulation parameters for the mobility pattern are as follows:

<table>
<thead>
<tr>
<th>Table 1: Simulation set-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
</tr>
<tr>
<td>Transceiver range (m)</td>
</tr>
<tr>
<td>Layout</td>
</tr>
<tr>
<td>Random Waypoint</td>
</tr>
<tr>
<td>Speed (m/sec.)</td>
</tr>
<tr>
<td>Pause Time (sec.)</td>
</tr>
<tr>
<td>M-GRID</td>
</tr>
<tr>
<td>Speed (m/sec.)</td>
</tr>
<tr>
<td>Grid Size (m)</td>
</tr>
<tr>
<td>Junction pause Time (sec.)</td>
</tr>
<tr>
<td>Simulation duration (sec.)</td>
</tr>
</tbody>
</table>

In this analysis we are evaluating the AODV MANET protocol mainly in terms of the following:

- **a. Data Delivery Percentage**: This represents the total number of packets delivered over the total number of packets sent.
- **b. End-to-End delay**: This represents the total delay incurred by the successfully delivered control packets over the number of successfully delivered packets.

<table>
<thead>
<tr>
<th>Table 2: Performance of MANET protocols</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility pattern</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Random</td>
</tr>
<tr>
<td>M-Grid</td>
</tr>
<tr>
<td>Random waypoint</td>
</tr>
<tr>
<td>M-Grid</td>
</tr>
</tbody>
</table>

Each of the results shown in Table 2, represents the average value obtained from 10 models. The delivery ratio for random waypoint mobility is similar to the connectivity results of figure 6 when the CDI is moderate, ie approximately CDI = 6. However, the delivery ratio drops below the probability of connectivity when the CDI approximately 14.4. After a close analysis of the data, it was found that majority of the lost packets in our simulation is due to “Noroute”, ie due to congestion. This means that when the CDI is moderate, the major factor affecting the delivery ratio is the probability of connectivity. However, when the CDI is high, congestion becomes a major factor affecting the delivery ratio.

From the simulations, it is shown that the average delivery percentage of M-GRID is approximately 20% less than the random waypoint at the same CDI. This drop in the delivery ratio performance in M-Grid environment, is due to main factors:

- Path length. Longer path length is equivalent to higher probability of breaks.
- Tunneling effect. From examination on the path, it was found that the packets are funnel along the path causing congestions.

### 5. Conclusion

In this paper, we have explored the issue of connectivity in a MANET environment for constraint mobility pattern, M-GRID, which is commonly encountered in IVCS. We have successfully shown that using our proposed coverage density index, we could normalize the
coverage and map the probability of connectivity value back to results obtained from random waypoint mobility pattern. This helps to make a fairer comparison between different mobility patterns as well as to predict the performance of constraint mobility pattern.

Our experiment of the probability of connectivity also provides an indication of the performance in terms of packet delivery ratio for the AODV MANET protocols in random waypoint mobility pattern. However, the performance for M-Grid is also affected by the path length, which is longer, and the tunneling effect where causes congestion.

Our future work would involve quantifying and prediction of MANET protocol performance for different mobility pattern. We hope to study the effect of other factors, eg. Speed, cache, and how these factors interact with each other to affect on the performance of MANET protocols.

REFERENCES


