Impact of propagation loss and mobility on the performance of AODV & DSR in ad-hoc networks

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Abstract—Network simulation tools are commonly used to analyze the performance of Mobile Ad-hoc Networks (MANETS) protocols and their applications. The radio propagation models used for these simulations strongly influence the produced results. While the Two Ray Ground (TRG) model is the most widely used path loss model in reported MANETS performance analysis studies, it is not a realistic model for use in urban areas. In this study, we compare the performance of two widely used routing strategies for MANETS, i.e. Adhoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR). Using the ns-2 simulator, a variety of mobility models are incorporated in the same scenario (e.g., two group movements and three random mobility patterns) to analyze the performance of an ad-hoc network with 100 nodes. Two new propagation loss models (i.e. Green-Obaidat Adhoc LoS model (GOA-LoS) and ITU-LoS in street canyons (ITU-LoS)) were incorporated into ns-2 and the results from there were then compared with those produced using the TRG path loss model. The network performance was determined on the basis of Packet Delivery Ratio (PDR), Normalized Routing Load (NRL) and mean end-to-end delay with the effects of changing pause time. The results indicate that the PDR is better if the communication channel behaves like TRG model for AODV and DSR protocols with varying pause time. This study verifies that underestimating physical layer in MANETS may lead to more optimistic rather than realistic network performance.

VII. INTRODUCTION

Mobile ad-hoc networks consist of wireless mobile nodes that form a communication network on demand without prior configuration, or infrastructure. Due to node mobility, the network topology changes frequently and thus requires a good routing strategy. Due to the high cost involved in realization of a real ad-hoc network, simulation is a research tool of choice for majority of the MANET research community. Network simulator ns-2 [1] has been used for the evaluation of routing protocols and network performance in the majority of the reported MANET studies [2]. Furthermore, a majority of routing protocol studies has used simplistic radio propagation models for simulation analysis of network performance [3]. In an urban area, where MANET applications are most likely to be deployed, using a simplistic propagation model may not represent the real wireless channel effects caused by reflection, diffraction, scattering and shadowing phenomena.

In this study, we integrate two more accurate (for urban structures) path loss models (i.e. Green-Obaidat Adhoc LoS model (GOA-LoS) [4] and ITU-LoS in street canyons (ITU-LoS) [5] into ns-2, and compare the performance of two routing strategies, i.e. the Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR). A multi mobility environment is used for an ad-hoc network of 100 nodes divided equally in 5 different mobility patterns such as Random WayPoint (RWP), Random Direction (RD), Levy Walk (LW), Reference Point Group Mobility (RPGM) and String model (SM). The analysis is undertaken in a fixed rectangular area of 1600x1000 meters varying the pause time of nodes from 0 sec to 500 sec in steps of 100. The resulting network performance is then compared with other studies, which used simplistic radio propagation models [6][7]. To the best of our knowledge, no other study has analysed outdoor MANETS performance with ITU-LoS and GOA-LoS propagation loss models.

VIII. OVERVIEW OF ROUTING PROTOCOLS

i. Dynamic Source routing (DSR)

DSR uses source routing and caching [8] where the sender node includes the complete hop-by-hop route to the destination node in the packet header and routes are stored in a route cache. When a node wants to communicate with another node to which it does not know the route, it initiates a route discovery process with a flooding request of route request (RREQ) packets. Each node receiving the RREQ packets retransmits it unless it is the target node or it knows the route to the destination from its cache. Such a node replies to the RREQ message with a route reply (RREP) packet. The RREP packet takes the traverse path back to the source node established by the RREQ packet. This route is stored in the source node cache for future communication. If any link of this route is broken, the source node is informed by a route error (RERR) packet and this route is discarded from cache. Intermediate nodes store the source route in their cache for possible future use.

ii. Ad-hoc On-Demand Distance Vector Routing (AODV)

AODV is a destination based reactive protocol [9]. This protocol inherits the feature of route discovery from DSR. However, AODV resolves the problem of large headers found in DSR. This problem can cause significant performance degradation especially when the actual data contents are small. AODV maintains routing tables on the nodes instead of including a header in the data packet. The source node initiates the route discovery process in the same way as in DSR. An intermediate node may reply with a route reply (RREP) only if it knows a more recent path than the one known by the sender node to the destination. A destination sequence number is used to indicate how recent the path is as follows. A new route request generated by the sender node is tagged with a higher sequence number and an intermediate node that knows the route to the destination with a smaller sequence number cannot send the RREP message. Forward links are setup when a RREP travels back
along the path taken by RREQ. So the routing table entries are used to forward the data packet and the route is not included in the packet header. If an intermediate node is unable to forward the packet to the next hop or destination due to link failures, it generates the route error (RERR) message by tagging it with a higher destination sequence number. When the sender node receives the RERR message, it initiates a new route discovery for the destination node.

IX. PROPAGATION LOSS MODELS

Radio propagation models considerably influence the performance of wireless communication networks. Radio propagation loss models are used in simulations to estimate the received signal strength of each packet received by a node. NS-2 uses the threshold values (i.e., CS and RX threshold), which defines the minimum possible value of the received signal strength indicator by which a node is still able to communicate successfully. If the value is smaller than the threshold, ns2 consider that the receiving node did not receive the packet successfully. The following section presents the deterministic propagation models used in our simulation scenarios.

Two Ray Ground reflection model: This model takes into consideration both direct and indirect paths between the transmitting and receiving node [10]. This is an empirical model, which uses the following equation to calculate the received power in watts.

\[ P_r(d) = \frac{P_G \cdot G_t \cdot h_t^2 \cdot h_r^2}{d^4 \cdot L} \]  

(1)

Where \( P_t \) is transmitted signal power, \( G_t \) and \( G_r \) are the transmitter and receiver antenna gains respectively, \( d \) is the distance between two communicating nodes, \( h_t \) and \( h_r \) are the transmitter and receiver antenna heights respectively, and \( L \) (\( L \geq 1 \)) is the system loss due to various sources. This model is readily available in ns-2 and was implemented by the Monarch group.

Green-Obaidat Adhoc LoS model: This model was first described by green & obaidat [4] in 2002. This model considers the path loss accounting due to Fresnel zone with near earth antenna height (i.e. typically between 1 and 2 meters) more accurately [4]. The proposed path loss for near ground antennas is as follows.

\[ P_{loss} = 40\log_{10} d + 20\log_{10} f - 20\log_{10} h_t h_r \ldots (2) \]

This equation can further be simplified for use in 2.4 GHz IEEE 802.11 frequency as

\[ P_{loss} = 7.6 + 40\log_{10} f - 20\log_{10} h_t h_r \ldots (3) \]

ITU-LoS model in street canyons: This path loss model is recommended by ITU [5] for typical urban areas. This model describes the path loss situation in street canyons where there is a line of sight (LoS) exists between transmitter and receiver. This model describes the path loss measurements in two limits (i.e. lower and upper bounds). In the UHF frequency range, the basic transmission loss can be characterized by two slopes and a single breakpoint [5]. An approximate lower bound is given by

\[ L_{\text{loss}, L} = L_{bp} + \begin{cases} \frac{20\log_{10} d}{\log_{10} R_{bp}} & ; d \leq R_{bp} \\ \frac{40\log_{10} d}{\log_{10} R_{bp}} & ; d > R_{bp} \end{cases} \]

(4)

Where \( R_{bp} \) is the breakpoint distance and is given by

\[ R_{bp} = \frac{4h_t h_m}{\lambda} \]

\( \lambda \) is the wavelength in meters, \( h_t \) and \( h_m \) are the base and mobile antenna heights respectively. The approximation upper bound is given by

\[ L_{\text{loss}, U} = L_{bp} + 20 + \begin{cases} \frac{25\log_{10} d}{\log_{10} R_{bp}} & ; d \leq R_{bp} \\ \frac{40\log_{10} d}{\log_{10} R_{bp}} & ; d > R_{bp} \end{cases} \]

(5)

\( L_{bp} \) is the value for the basic transmission loss at the breakpoint, defined as

\[ L_{bp} = 20\log_{10} \left( \frac{\lambda^2}{2\pi h_t h_m} \right) \]

The path loss (i.e., \( L_{\text{loss}, L} \) & \( L_{\text{loss}, U} \)) which represents the signal attenuation as a positive quantity (measured in dB) was subtracted from the transmitted power (then converted into watts for ns-2) in order to achieve the received signal strength. We implemented these two equations as a single model into ns-2 by calculating the mean path loss value for all communication distances. This model incorporates fading margins due to multipaths (i.e., reflection, diffraction and scattering) typically found in urban street canyons environment.

Figure 1 shows the received signal strength plot with varying communication range among nodes.

![Fig1: Received signal strength (dBm) vs communication distance](image)

With -84.5 dBm receiver sensitivity threshold used in our simulation, the communication range extends highest with TRG model (i.e. 250 meters) and lowest for ITU-UHF urban LoS model (about 110 meters). This is expected as there are extra losses have been added into ITU-LoS model due to fading conditions found in urban structures.

X. MOBILITY MODELS

Mobility plays an important role in network stability in MANETS. Routes between communicating nodes can change rapidly due to mobility. The mobility can affect not
only the communicating nodes but also the intermediate nodes and thus can have a significant influence on the network’s topology and hence the performance of routing protocols. The classification of mobility and mobility models can be done on the basis of controllability and model construction [11]. In synthetic mobility models, nodes move according to a random probabilistic process whereas the trace based mobility models are based on mobility patterns that are observed experimentally. Trace-based models have problems with scalability and are generally difficult to implement so synthetic models are frequently used in MANET simulations. This study employs the following five different mobility models in a single environment.

**Random WayPoint mobility model:** The Random waypoint (RWP) mobility model is the simplest and most widely used model for MANET studies [12]. In this mobility model, the nodes choose a random destination anywhere in the network area and start moving towards it with a velocity chosen from a speed vector \([0, V_{\text{max}}]\). After reaching the destination, the node stops at the destination for a duration specified by the ‘pause time’ parameter, which is same for all nodes. All nodes repeat this process until the simulation ends. This model has some known characteristics such as non-uniform node distribution and speed decay. These characteristics have a strong influence on routing protocol performance and many variations have been suggested by researchers to cope with these issues [13].

**Random Direction model:** This model is capable of overcoming the non-uniform spatial distribution problems typically found in Random Waypoint mobility model. In this model [14], a node randomly chooses a direction to move along until it reaches the boundary of simulation field. After reaching the boundary, it stops with a pause time and then it chooses another direction to travel. In this way, nodes are uniformly distributed within the network field [13].

**Levy walk model:** A levy walk is a random walk in which the walk times (flight times) have a power-law distribution \([15]\). In this model, each motion has four attributes, i.e. \(l, \theta, \Delta_t, \Delta_\theta\). Each node takes a random direction \(\theta\) and a flight time \(l\). \(\Delta_t\) indicates the flight duration, which is chosen for each flight from a probability distribution \(p(l)\). Using the values of \(\Delta_\theta\) and \(l\), the model calculates the speed of flight. \(\Delta_\theta\) indicates the pause time duration taken by nodes after each movement. In [16], Brockmann et al have analyzed human travelling patterns in the scale of several hundred to thousand kilometers and show that human long distance travelling patterns show levy walk patterns. In [17], the author has mentioned that human travelling patterns are not of random levy walk because it does not make sense that humans move in a pure random fashion. From literature survey [17,18], it can be considered that this model is more realistic than other random models for human travelling patterns.

**Reference Point Group Mobility model:** In this model, which was first described by [19], nodes are divided into groups each with a group leader. In the standard RPGM model, the leader’s mobility is based on the Random Waypoint [12] model and the group members follow the movement of the respective group leaders closely. So, there is a virtual centre to each group and the nodes move randomly around the virtual centre. The movements in groups can be characterized as follows.

\[
\begin{align*}
V_{\text{member}}(t) &= |V_{\text{leader}}(t)| + \text{random()} \times SDR \times \text{maxspeed} \\
\theta_{\text{member}}(t) &= |\theta_{\text{leader}}(t)| + \text{random()} \times ADR \times \text{maxangle}
\end{align*}
\]

The Speed Deviation Ratio (SDR) and Angle Deviation Ratio (ADR) parameters are used to control the deviation of the velocity (magnitude and direction) of group members from that of the leader. Since follower nodes chase their cluster heads within each group, the mobility pattern adopted by head nodes strongly influences the overall mobility behaviour observed in this model. We have chosen the following four random mobility patterns for leader’s motion.

**String Model:** This is a variation of RPGM model. In this model, nodes move in group as well but follow their respective group leaders in a row rather than being randomly around group leader as in case of RPGM model.

![Fig 2: Snapshots of mobility models with a) 20 nodes for individual models and b) 100 nodes for multi mobility model (actually used in simulation).](image)

Example node distributions for each model used in our simulation are given in Figure 2. We used a multi mobility environment with 100 nodes dividing equally in five mobility models for our simulation. Fig 2 shows the movement behavior of nodes under individual models and the mix mobility environment (bottom right) used for simulation. These snapshots were taken during the middle of a 500 sec simulation run for all models using mobsim tool [20]. It is evident that RWP exhibits non-uniformity of node distribution within the network area with high clustering in the centre. In case of RD, nodes are more scattered in the simulation field. Where as with LW pattern, nodes tend to stay in certain parts of the simulation area. With RPGM and SM mobility behaviors, nodes strictly follow the motion of their respective group leaders in two different manners.

**Traffic model:** Random traffic connections of constant bit rate (CBR) were setup between mobile nodes using cbrgen.tcl script, a utility provided by network simulator (ns-2). For this simulation, traffic models were generated.
with 100 nodes and with CBR traffic sources, with a maximum of 16 connections and a rate of 8 packets sec$^{-1}$ with a packet size of 512 bytes.

XI. NETWORK PERFORMANCE ANALYSIS

The following three quantitative performance metrics are used for this study.
1. Packet delivery ratio: This is the ratio of data packets successfully delivered to the number of data packets sent by the CBR sources.
2. Normalized Routing load: This is the total number of routing packets generated during the entire simulation run.
3. Mean end-to-end delay: The delays caused by latency, buffering, queuing, retransmission and route discovery are all included in this performance analysis. This delay is measured in seconds.

XII. METHODOLOGY:

The main aim of this study was to analyse the impact of propagation loss in a multi mobility environment on routing performance for an ad-hoc network. To evaluate the performance of two protocols, we took the following scenario; we changed the nodal pause time (i.e. mobility level) from 0 sec (i.e. continuous motion) to 500 sec in steps of 100 for a pedestrian environment. We used Mobisim tool [20] to generate mobility files for different mobility patterns in a fixed rectangular area of 1600 X 1000 meters. Mobile nodes were initially distributed randomly on the simulation field with boundary reflection attribute (i.e. nodes will stay in the simulation area during the whole simulation period). A cutoff period of 1000 secs was used to stabilize mobility behaviour of nodes. We generated ten mobility files for each mobility scenario. Each result is an average of ten simulation runs with identical input parameters but with a different random seed. We used IEEE 802.11b equipped radios with Omni directional antennas (height of 1.5m) and a receiver threshold of -84.5 dBm with a maximum transmission power of 4.7 dBm at 11 Mbits/s data rate.

XIII. RESULTS AND DISCUSSION

Some of the simulation parameters are given in Table 1.

Table 1: Simulation parameters with varying pause time

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation time</td>
<td>500 sec</td>
</tr>
<tr>
<td>Area size</td>
<td>1600x1000 m</td>
</tr>
<tr>
<td>Mean speed</td>
<td>1.5 m/sec</td>
</tr>
<tr>
<td>Traffic type</td>
<td>CBR</td>
</tr>
<tr>
<td>Packet size</td>
<td>512 bytes</td>
</tr>
<tr>
<td>No. Of Max. Traffic sources</td>
<td>16</td>
</tr>
<tr>
<td>Rate</td>
<td>8 pkts/sec</td>
</tr>
<tr>
<td>Channel frequency</td>
<td>2.412 GHz</td>
</tr>
<tr>
<td>Mobility environment</td>
<td>Multi mobility (5 sub models)</td>
</tr>
<tr>
<td>No. of nodes</td>
<td>100 (divided equally in 5 sub models)</td>
</tr>
<tr>
<td>Pause time</td>
<td>0, 100, 200, 300, 400, 500 (sec)</td>
</tr>
<tr>
<td>Transmitter power</td>
<td>4.7 dBm</td>
</tr>
<tr>
<td>Tx and Tr antenna Gain (Gt=Gr)</td>
<td>1</td>
</tr>
<tr>
<td>Rx and CS Threshold</td>
<td>-84.5 dBm</td>
</tr>
<tr>
<td>CP Threshold (Signal to interference ratio)</td>
<td>10 dB</td>
</tr>
</tbody>
</table>

Figure 3 shows the PDR under various propagation conditions for AODV and DSR with standard deviation values. The PDR for AODV and DSR is better when the channel behaves like TRG model. AODV performs better than DSR under different propagation loss situations. This is mainly due to the node density issues related with DSR [21]. The performance of AODV is generally poor if the communication channel acts like ITU-LoS model. This is largely because of the extra loss incorporated into this model due to multipath effects typically found in urban environments. This is significant as most of the protocol performance evaluation studies ignore the real channel fading environment and produce over-optimistic results.

From Figure 4, it can be readily observed that AODV and DSR suffers with considerably higher routing load under ITU-LoS and GOA-LoS propagation conditions with zero pause time (i.e. high mobility). Under poor transmission conditions (i.e. high propagation loss environment), most of the packets are dropped because interface queue is full when the transmitting node is waiting for an available route. Due to the random power fluctuations in the signal level caused by multipath propagation effects, a route found in a route discovery process may not remain a valid route. Also with broadcast nature of AODV and DSR for new route discovery, neighbouring nodes tend to receive multiple copies of same Route Request and thus increase the routing load sharply. Mobility causes more frequent topology changes and hence network suffers with high routing load. This is critical as higher PDR and lower routing load is always desirable in a bandwidth and battery power constraint environment.

From Figure 5, it is evident that the mean delay is very high when the radio channel behaves like an ITU-LoS or GOA-LoS environment for DSR protocol. Generally new route requests are more common in AODV (i.e. only one route per destination available in route table) as DSR uses aggressive caching technique and usually multiple routes are available to destination in the node cache. But due to poor physical layer conditions (i.e. ITU-LoS or GOA-LoS environment), the benefit of cache seems to have been lost as DSR tries it full cache before initiating a new route discovery and this property of DSR increases mean delay significantly. With higher routing load and mean delay, the network performance is significantly poor if the channel conditions are like ITU-LoS model for AODV and DSR.

Figure 3: packet delivery ratio vs. pause time

STD. AODV-PDR: min: 4% max:9% STD. DSR-PDR: min: 5% max:12%
This paper focuses on the importance of appropriate physical layer modelling and its crucial impact on the performance of AODV and DSR with a multi mobility scenario. This study verifies that physical layer modelling can have significant impact on the routing performance in MANETS. A detailed ITU recommended propagation loss models (i.e. ITU-LoS within street canyons) along with green-obaidat Adhoc LoS model were embedded into ns2 and the results from there were then compared with TRG model. The network performance was analysed with varying pause time. Results suggest that the network performance is generally better if the communication channel behaves like TRG path loss model. Fading conditions strongly impairs the network performance in urban scenarios. With increasing pause time (i.e. changing mobility level), DSR experiences significantly higher routing load and mean delay if the channel acts like GOA-LoS or ITU-Urban LoS model. This is predominantly due to node density issues related with DSR as node movements, network congestion and propagation loss effects mainly invalidate the routes. Although DSR uses route caching technique, but the benefit of this seems to have been lost due to high mobility level. This study compares the produced results with the AODV and DSR performance analysed with TRG channel environment and confirms that simplistic radio propagation modelling can overestimate the protocol performance but may not produce realistic results for a heavily built up area. Mobility models have significant role in the analysis of protocol evaluation in MANETS. In future, this study will investigate and analyse the impact of wireless channel on MANET applications in indoor multi story building environment.

REFERENCES