

# Scalability in MANETs Under the Influence of Dynamic Propagation Loss Models

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**Abstract:** Simulation based performance analysis studies for very large (i.e. up to thousands of nodes) Mobile Adhoc NETWORKS (MANETs) have considered simplistic radio propagation environment (i.e. for urban structures) such as Free Space or Two Ray Ground (TRG) path loss models resulting in over optimistic network performance. This study covers the aspect of scalability with a famous routing approach (i.e. Adhoc On-demand Distance Vector Routing AODV) under dynamic propagation loss conditions (i.e. Line of Sight LoS or Non Line of Sight NLoS environment) for ITU propagation models and compares the results with Network Simulator 2 (ns-2) based simulation analysis for TRG model. Results indicate that there is a significant difference in network performance if the propagation environment behaves like ITU path loss models.

**Keywords:** MANETs, Dynamic Propagation

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## I. Introduction

Recent advances in the size, power and hardware resources of wireless devices have resulted in proliferation of these devices. As the number of users continues to grow, scalable routing protocols will be in demand to facilitate the large population of nodes. Furthermore the widespread use of wireless devices and development of new applications for wireless networks will lead to the development of large adhoc networks. For example, in a conference room MANET scenario, there may be hundreds of participants joining the same adhoc network and hence nodes must be capable of configuring and establishing routes. There have been many unicast protocols that have been developed in this context such as Adhoc Ondemand Distance Vector Routing (AODV) [1] & Dynamic Source Routing (DSR) [2]. Other approaches like clustering and hierarchical addressing have also been developed to enhance the scalability of routing protocols in MANETS [3]. Furthermore, 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. While ns- 2 [4] remains the first choice as a simulation tool among MANETS research community [5], it has been noticed that majority of the published result (using ns-2 tool) have relied upon default propagation model (i.e. TRG model) for wireless channel selection. Through literature survey, it has been observed that the majority if not all the published work in MANET routing scalability have either ignored or have used simplified physical layer modelling. 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. Typically, multipath propagation and hence fading is very important for the urban case. Since fading can affect whether a node can communicate with adjacent nodes, this can have a significant effect on network performance. For example, Lee et al [3] have discussed the issue of scalability of AODV and simulation results have been presented for up to 10,000 nodes in a Free Space propagation environment using GlomoSim simulator. GlomoSim [6] is a scalable simulation environment for wireless networks that uses parallel discrete-event simulation capability. However the authors do not address the critical analysis of propagation layer in this context. Kuan et al [7] cover the simulation results for AODV and DSDV protocols for up to 200 nodes and using Free Space propagation model that may reduce the effect of packet collisions but may not be very realistic in urban mobile scenarios. There is still a need to look upon the scalability issues in a more realistic propagation environment. The scope of this chapter is to address this issue by analysing the MANET performance under ITU propagation models for urban environment.

There have been various studies conducted considering the scalability issues in wireless networks. Hamida et al [8] describes the importance of PHY layer and scalability issue (using their proprietary simulator WSnet) for static wireless sensor networks using up to 1500 nodes. Valery and Thomas [9] describe the techniques to enhance the scalability for AODV and DSR protocols and present the simulation results for up to 550 nodes using ns-2. However, the propagation model used for simulation analysis has not been described. David [10] simulates AODV for 1000 nodes using Qualnet simulator and the PDR for 1000 nodes remains above 90%. However, the simulation analysis carried out in our research only gets a PDR of 96% using 200 nodes with TRG propagation model. Increasing nodes (i.e. up to 1000) drops PDR to just 15% (8 traffic sources), which is not even worth to configure a reliable network. The performance degrades even further if the channel behaves like the ITU-R models. This huge difference makes important to analyze the MANET scalability in presence of a realistic wireless propagation scenario. This chapter covers the performance of AODV with varying node density (i.e. increasing the number of nodes in two fixed areas) and scalability by increasing the terrain size but for same node density.

## II. OVERVIEW OF ROUTING PROTOCOLS

MANET routing protocols are broadly divided into proactive and reactive categories. In MANETS, the network topology changes arbitrarily making routing information obsolete in time and space. A routing strategy must be able to adapt to these changes. Proactive protocols are often expensive, consuming network resources (such as battery power, buffer space, channel capacity etc) but provide a quality of service routing with lower latency than with reactive protocols. This resource utilization is more significant with increasing network size and mobility in proactive protocols. These are well known issues related with the proactive approach [11]. We have used a state of the art (i.e. AODV) reactive protocol for simulation analysis mainly because this is widely accepted by the research community and is also standardised by IETF MANET working group [12]. As the core of this research consists of extensive simulation analysis of routing with effect of mobility and propagation environment, other routing protocols are expected to perform in a similar way.

### 2.1. *Ad-hoc On-Demand Distance Vector Routing (AODV)*

This protocol was first described by [1] in 1998. Since then, this has been studied extensively and many variations have been suggested in literature [13 & 14]. AODV is a destination based reactive routing protocol. When an arbitrary node 'A' wants to communicate with another node 'B' then it initiates a Route Request (RREQ) message in the network. When the RREQ message reaches the intended node, it replies with a Route Reply (RREP) message, which travels reversely through the path along which RREQ has travelled. An intermediate node can generate a RREP message if it knows the route to the destination from a previous communication with a sequence number. The concept of sequence number is used in order to

determine the freshness of route by the middle nodes. 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. An example of the AODV routing mechanism is illustrated in Fig. 1. When a source node (i.e. N1) initiates a route discovery process (RREQ) for a destination node N8, it propagates through all available links, however RREP takes the shortest path (i.e. N8-N5-N2-N1) back to the source node.

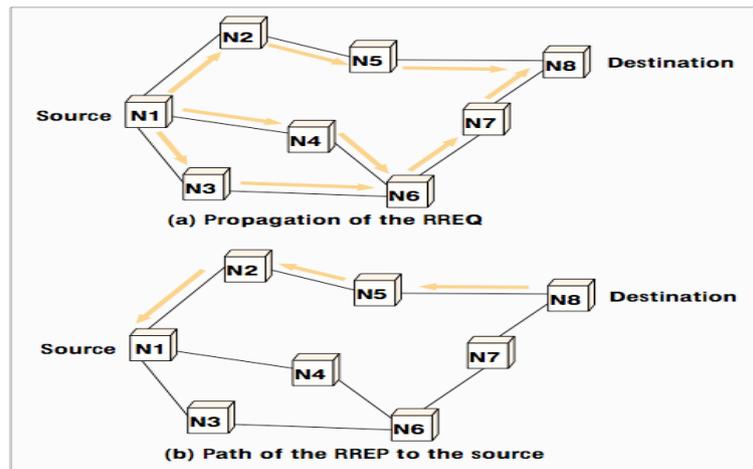


Figure 1. AODV route discovery process (from [14])

### III. MOBILITY MODELS

Mobility models should attempt to simulate the mobility behaviour of nodes in real life scenario. Synthetic mobility models are generally used for simulation analysis of MANETS mainly due to ease of use and higher scalability features in comparison with trace based mobility patterns. In this research, synthetic mobility models are used largely due to the following reasons.

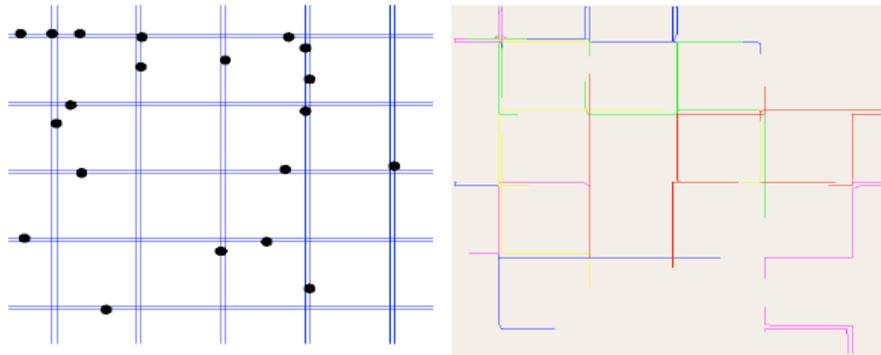
1. There are very few traces of human mobility available in the public domain. Some of the available mobility databases such as CRAWDAD [15] that are collected using Bluetooth and WiFi AP connectivity, have certain limitations. For example, the data collected in [16] was from the users in the same WiFi AP areas. So, two or more users (being in communication range of each other but using different AP) were linked to separate groups. Furthermore, the data collected represents the usage pattern while users being stationary in different AP areas. So although it is a real data, it does not completely reflect the real world mobility scenario with respect to communication range of nodes.
2. Mobile telecommunication companies record the mobility pattern of users for analysis however they do not share it publically due to data privacy and competitive advantage over other companies.
3. Most of the available real data sets have been recorded in specific scenarios such as campus or conference scenarios [15] and that makes it difficult for their generalized use.
4. Real data sets have certain limitations that cannot be altered such as node speed, node density and scalability, which are key elements in the analysis of routing algorithms performance.

In this research, we have used Manhattan Grid mobility models as it closely mimics the street/lane movement scenarios typically found in European/American cities. The following section further explains

the mobility model that is used in our research.

### 3.1. Manhattan Grid (MG) mobility model

In this model [17], nodes move in predefined pathways, e.g. nodes move in horizontal rows and vertical columns, while at the intersections nodes can turn either left or right or can carry on straight ahead. The probability of going straight is 0.5 and the probabilities of turning left or right are each 0.25. The speed of a mobile node at a given time slot is dependent on its speed at the previous time slot. A node's velocity is restricted by the velocity of the node preceding it on the same lane. So, this model imposes high spatial and temporal dependencies on nodes. This model is used in urban area scenario study as the columns and rows can simulate the effects of roads and pathways. Fig. 2 shows a snapshot and mobility trace for 250 secs with a sample of 20 nodes (i.e. fairly small network size) following MG mobility pattern. As nodes move in restricted lanes, resulting in scattered movements, there is more possibility of link breakages in MG mobility model.



**Figure 2.** Plots of (left) 20 nodes randomly distributed by MG model and (right) footprints of nodes Maximum velocity: 2m s<sup>-1</sup>, grid size: 500x500m, simulation time: 250 sec, zero pause time (continuous motion)

## IV. PROPAGATION 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. Carrier Sense (*CS\_Threshold*) and Receiver (*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, *ns-2* considers that the receiving node did not receive the packet successfully. The following section present the deterministic and probabilistic propagation models used in our simulation scenarios.

### 4.1. Two Ray Ground Path Loss Model

This model takes into consideration of both direct and indirect paths between the transmitting and receiving node. This model shows better performance than free space path loss model [18] for longer distances [19]. This is an empirical model, which uses the following equation to calculate the approximate received power.

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \quad (1)$$

Where  $P_t$  is the transmission power in watts,  $G_t$  and  $G_r$  the transmitter and receiver antenna gain and  $h_t$  and  $h_r$  are the transmitter and receiver antenna heights respectively,  $d$  is the communication distance and  $L$  is the

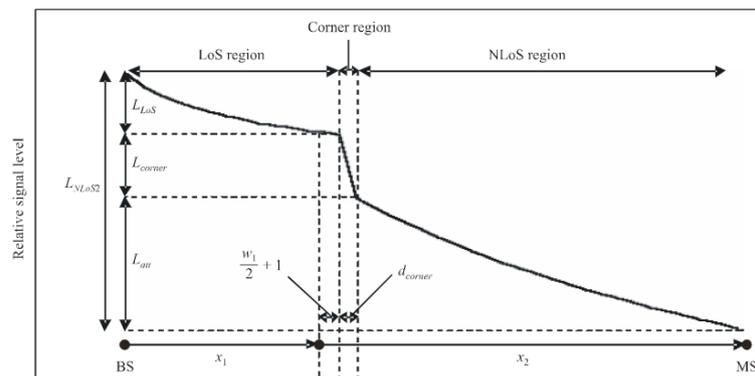
system loss. The two-ray model does not give a good result for a short distance due to oscillation caused by the constructive and destructive combination of the two rays. Free space model is a better choice for smaller distances. *ns-2* simulator uses a cross over distance  $d_c$  when this model is used. If  $d < d_c$ , pathloss is calculated with Friss equation and if  $d > d_c$ , TRG model is used. At the cross over distance, both equations produce the same results, so  $d_c$  can be calculated as

$$d_c = \frac{(4\pi h_t h_r)}{\lambda} \quad (2)$$

This model has been found reasonably accurate for predicting the large-scale signal strength over distances of several kilometres for mobile radio systems that use tall towers (i.e. height which exceed 50 m), as well as for LoS microcell channels in urban environments [20]. However, this is not a typical case in MANET scenarios (i.e. infrastructure less environment). This model is readily available in *ns-2* and was implemented by the Monarch group. We have modified this model in such a way that if there is an obstacle (i.e. wall) exists in between communicating nodes, the model subtracts the 6dB power (i.e. attenuation due to brick walls [19]) from the received signal strength.

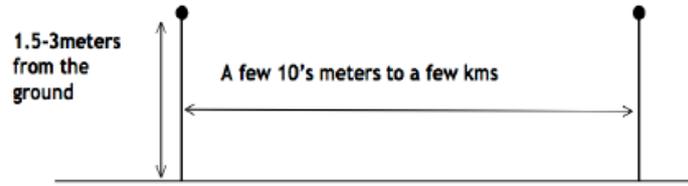
#### 4.2. ITU LoS-NLoS model in street canyons

This path loss model is recommended by ITU-R [21] for typical urban areas. This is a statistical model that calculates the path loss in LoS and NLoS regions and models the sharp decrease in signal strength in transition distance (i.e. going from the LoS to the NLoS region) known as the corner loss (see Fig.3).



**Figure 3.** Typical trend of propagation along street canyons with low base station height for frequency range from 2 to 16 GHz (from [21]).

This model was originally developed by an ofcom project [22] based upon measurements taken in two cities (i.e. London and Reading) in U.K. The model was called “Low Height Model” with the aim of developing a model for propagation between low-height terminals (see Fig. 4) where both terminals are located within clutter (primarily, but not exclusively, urban and suburban clutter) [22]. Although the multihop communication scenarios were not implemented during the development of this propagation model, this model seems to be the most suitable model for MANETS where nominal antenna height of transmitter and receiver is in between 1 to 1.5 meters (i.e. similar to human height).



**Figure 4.** Illustration of the required ranges for height and distance between the terminals (from [17])

Firstly, the LoS (median) loss is calculated between  $T_x$  and  $R_x$ .

$$L_{LoS}^{median}(d) = 32.45 + 20\log_{10}f + 20\log_{10}(d/1000) \quad (3)$$

Where  $d$  (m) is the distance between  $T_x$  and  $R_x$  and  $f$  (MHz) is the operating frequency. For the required location percentage,  $p$  (%), this model calculates the LoS location correction factor by using the following Rayleigh cumulative distribution function.

$$\Delta L_{LoS}(p) = 1.5624\sigma \left( \sqrt{-2\ln(1-p/100)} - 1.1774 \right) \quad (4)$$

where  $\sigma$  is the standard deviation (sd) recommended as 7dB through measurements. Now the total loss is calculated as

$$L_{LoS}(d, p) = L_{LoS}^{median}(d) + \Delta L_{LoS}(p) \quad (5)$$

The NLoS loss is calculated as

$$L_{NLoS}^{median}(d) = 9.5 + 45\log_{10}f + 40\log_{10}(d/1000) + L_{urban} \quad (6)$$

$L_{urban}$  depends upon the urban category and is 0 dB for suburban, 6.8 dB for urban and 23 dB for dense urban region. The required location percentage for NLoS location correction is calculated as

$$\Delta L_{NLoS}(p) = \sigma N^{-1}(p/100) \quad (7)$$

Where  $\sigma$  is recommended as 7dB and  $N^{-1}(\cdot)$  is the inverse normal cumulative distribution function. The total NLoS loss can be calculated as

$$L_{NLoS}(d, p) = L_{NLoS}^{median}(d) + \Delta L_{NLoS}(p) \quad (8)$$

For the required location percentage, ( $p$  %), the distance  $d_{LoS}$  for which the LoS fraction  $F_{LoS}$  equals  $p$  is calculated as

$$d_{LoS}(p) = \begin{cases} 212[\log_{10}(p/100)]^2 - 64\log_{10}(p/100) & \text{if } p < 45 \\ 79.2 - 70(p/100) & \text{otherwise} \end{cases} \quad (9)$$

This model suggests that if the mobile node's distance from the corner is known then  $d_{LoS(p)}$  is set to that distance [21].

Finally the path loss at distance  $d$  is calculated by the following three conditions.

- a) if  $d < d_{LoS}$ , then  $L(d, p) = L_{LoS}(d, p)$
- b) if  $d > d_{LoS} + w$ , then  $L(d, p) = L_{NLoS}(d, p)$
- c) Otherwise the loss is linearly interpolated between the following values

$$\begin{aligned}
 L_{LoS} &= L_{LoS}(d_{LoS}, p) \\
 L_{NLoS} &= L_{NLoS}(d_{LoS} + w, p) \\
 L(d, p) &= L_{LoS} + (L_{NLoS} - L_{LoS})(d - d_{LoS}) / w
 \end{aligned}$$

Where width  $w$  is the street width that introduces a transition region between LoS and NLoS conditions and is typically recommended as  $w=20m$  [21]. We have implemented this model into  $ns-2$  in a hybrid way. Depending upon the location of Tx and Rx in the simulation field (i.e. in a lane movement scenario see Figure 3),  $ns-2$  selects appropriate path loss model.

## V. 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 Constant Bit Rate (CBR) traffic sources.
2. Normalized routing load: This is the ratio of the total number of routing packets generated to the number of data packets successfully delivered to destination.
3. Packet collisions: This is the total number of packets, dropped due to collisions at the MAC layer (considering the impact of physical layer).

## VI. METHODOLOGY

$ns-2$  simulator has been used for all analysis. MG mobility model was used for two rectangular areas (i.e. 1000x1500 m & 2000x3000 m terrain sizes). MG mobility model was selected in order to have more scattered movement of nodes and to mimic a typical street movement scenario. This model can mimic more realistic mobility and propagation conditions (i.e. considering corner loss scenarios) for urban areas MANETS analysis. All blocks were equally apart in both terrain sizes (i.e. 75 meters gap between lanes). The simulation analysis was carried out by changing the number of nodes but keeping the node density same in both simulation environments. Each result is an average of five simulation runs. Table 1 summarizes the terrain sizes and No. of nodes in each scenario. The No. of nodes under 2000x3000 m terrain size were increased as to keep the average connectivity (neighbourhood) among nodes common for both terrains. The purpose of this study is two fold; one is to analyze the effect of node density under same terrain size and second is to analyze the impact of scalability by increasing the terrain size and network traffic but keeping the node density common for both scenarios.

**Table 1.** Summary of node density and terrain sizes

Terrain Size	and	No. of Nodes	
1000x1500 m		2000x3000 m	Average Neighbourhood
50		200	6.54
100		400	13.08

150	600	19.63
200	800	26.17
250	1000	32.72

The simulation tests have been conducted in a challenging environment with zero pause time and varying random traffic sources from 4 to 8. Some of the common simulation parameters are described in Table 2.

**Table 2.** Simulation Parameters with different terrain sizes

Parameter	Value
Simulation time	500 secs
Area size	1000x1500 m & 2000x3000 m
Mean speed	1.5 m sec-1
Traffic type	CBR
Packet size	512 bytes
Connection rate	8 pkts sec-1
No. of Traffic Sources	4 & 8
Propagation Models	ITU-LoS&NLoS TRG
Transmitter power	8.6 dBm
Tx and Tr antenna Gain (Gt=Gr)	1
Received power threshold (RXThreshold)	-84.5 dBm
Carrier sense threshold (CSThreshold)	-84.5 dBm

## VII. RESULTS & DISCUSSION

This section covers the discussion about produces results. The analysis is done for the performance metrics such as PDR, NRL and No. of packet collisions.

### 7.1. Packet Delivery Ratio

Fig. 5 shows the effect of node density, scalability and traffic load on the performance of AODV under TRG and ITU models. It is evident that node density and scalability affects adversely the network performance for AODV under ITU and TRG models. However the effect of ITU on the performance of AODV is more significant than TRG. Network suffers with significantly lower PDR if the channel behaves like ITU propagation model. As more nodes get into neighbourhood of each other, this causes congestion and decreases the PDR considerably. Generally, as the network area grows, there are more longer communication paths experienced by nodes which results in more link breaks and eventually degrades the performance.

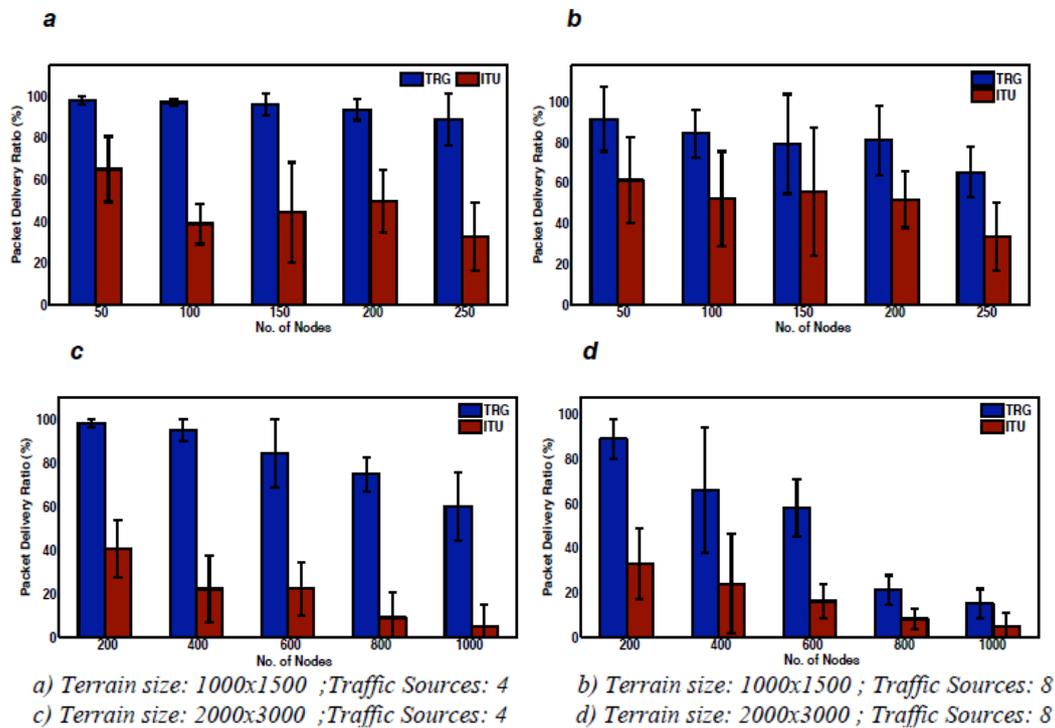


Figure 5. PDR vs No. of Nodes

### 7.1. Normalized Routing Load

NRL is the most important performance parameter with regard to network scalability. The routing load evaluates the internal efficiency of a routing protocol. Higher routing load will lead to more power and bandwidth consumption in a resource-constrained environment. A higher routing load will also cause congestion leading to packet collisions in large adhoc networks. Fig. 6 shows the NRL for changing node density, scalability and traffic load effects for AODV. It is apparent that network suffers with extremely high NRL if the wireless channel conditions are like ITU propagation model. Also there is higher fluctuation (i.e. high std. deviation) observed in network performance with ITU model. With 10 dB capture threshold value (default SIR ratio in ns-2), it is clear that increasing node density and scalability increases NRL significantly. Due to mobility and poor channel conditions experienced by nodes in ITU model, there are more link breaks among nodes, which leads to more RREQ attempts by nodes during simulation. As RREQ messages are broadcasted which causes flooding in the network and hence increases the routing load significantly. The impact of flooding is limited in a relatively small network (i.e. few tens of nodes). However as the network size grows it influences the routing load drastically. On the other hand, as the terrain size increases, there are longer communication paths between nodes, which also affect the NRL significantly. In an urban area, the presence of obstacles and objects causes multipaths, which results in higher fluctuation in received signal strength and leads to frequent RREQs. Reducing the NRL is still a challenge for larger MANETS as higher routing load results in lower PDR and higher Mean Delay. Comparing equal node density effect with reference to area (i.e. 50 nodes to 200 nodes & 250 to 1000 nodes), there is a much higher increase in NRL with ITU model than with TRG model. However the increase in ratio is 61 & 160 (for 4 traffic sources, see Fig. 6- a & c) and 95 & 52 (for 8 traffic source, see Fig. 6-b & d) with TRG and ITU models respectively. It can be said that the effect of node density (with higher traffic) is more severe with TRG model than with ITU model. Also, the effect of scalability is more significant on the performance of AODV with ITU model. In a smaller network, AODV performs well with higher PDR and lower NRL if the channel is like TRG model. As simulation environment get stressed (i.e. caused by increase in number of nodes, network traffic, mobility trace or poor channel conditions), the simulation results show higher fluctuations.

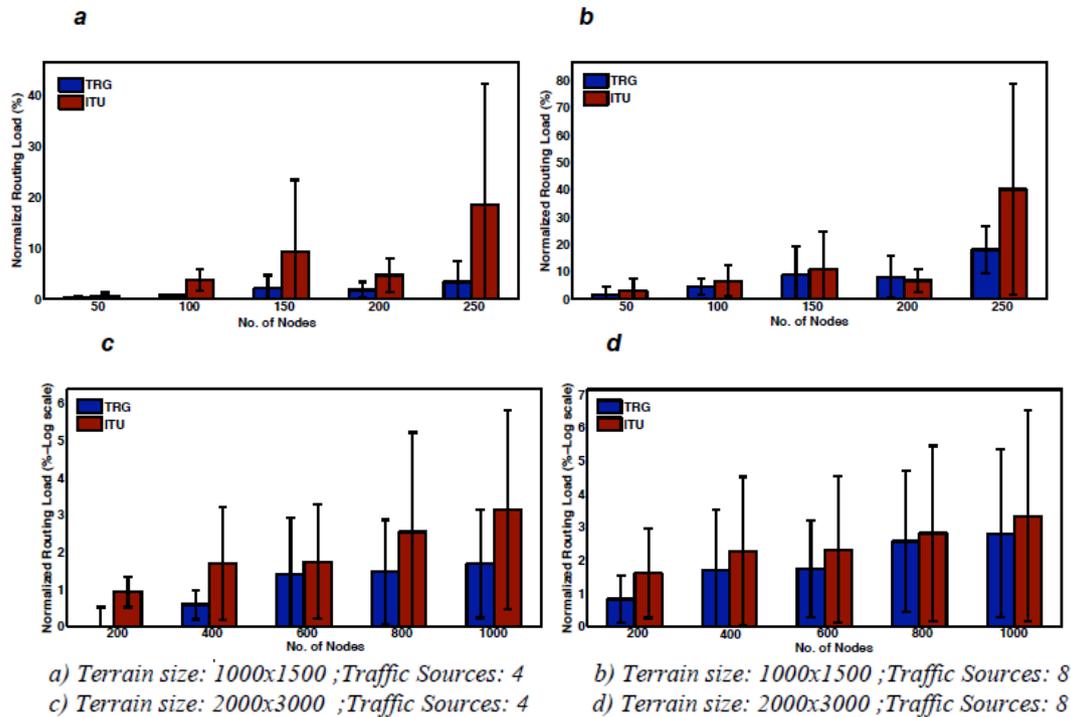


Figure 6. NRL vs No. of Nodes

### 7.3. Packet Collisions

Fig. 7 shows the occurrence of packet collisions with increasing node density, network and traffic size. Collision occurs when two or more nodes within neighbourhood of each other try to transmit at the same time. It can be said that the probability of packet collision increases with the number of nodes in the same area. More nodes will try to send which increases the coinciding simultaneous transmissions and hence the No. of packet collisions. Fewer nodes in the same area results in less probability of collisions. Also with poor channel conditions, there are more retransmission attempts that leads to congestion and hence increases packet collisions. It is evident from the results that the network experiences many more packet collisions with the ITU-R model for AODV, because with the ITU-R model, there are more RREQs generated (i.e. higher routing load see Fig. 6) which results in more broadcast packets and hence increases the No. of packet collisions. Increasing network size on a bigger terrain also increases the collision occurrences significantly in the presence of weaker propagation condition.

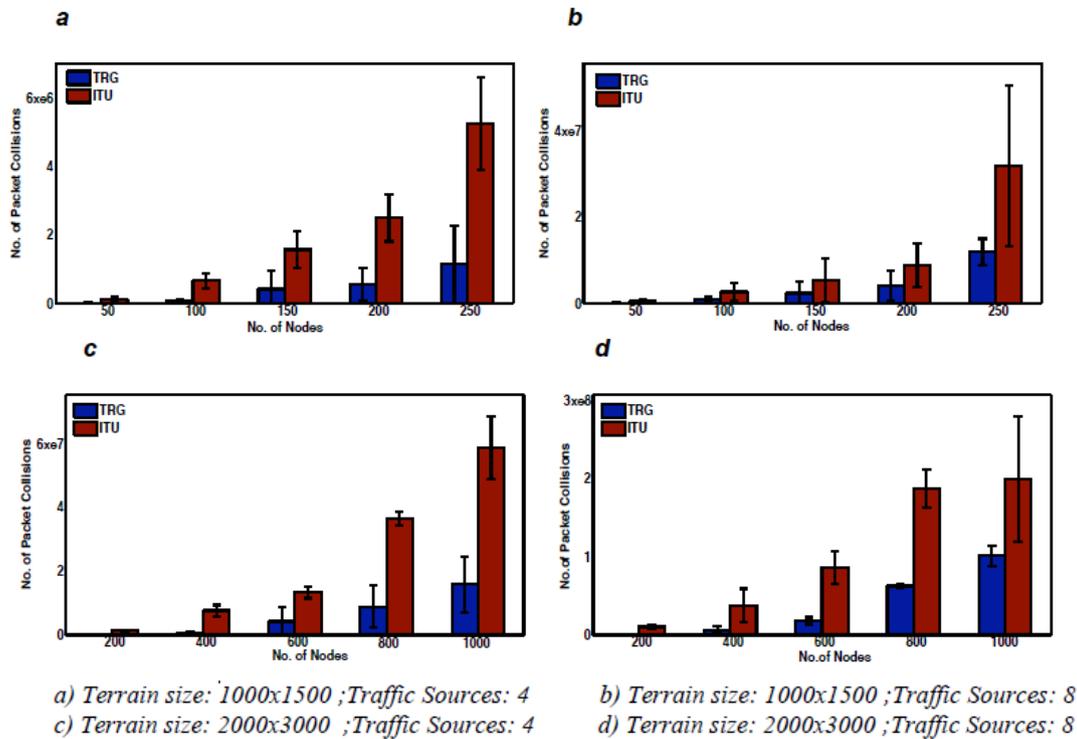


Figure 7. Packet collisions vs No. of Nodes for

## VIII. CONCLUSION

This study covers the analysis of AODV in scalable environment with the effect of ITU-R propagation models. Many reported studies about routing scalability neglect the physical layer and use simplistic models such as the Free Space model. However using a more realistic propagation model has a significant impact on AODV performance. By simulation results, it has been observed that the network performance declines sharply with increase in node density and network size if the channel conditions are poor. MG mobility model was used for all simulation analysis in order to analyze the LoS and NLoS propagation impact on AODV routing performance. The effect of terrain size is more significant with TRG than with ITU propagation models on AODV performance. With increasing AODV scalability, the degree of change in routing load is 3 to 4 times higher if the wireless channel behaves like TRG model. In order to have confidence in simulation results, this study shows that the correct modelling of PHY layer in MANET simulation environment is crucial.

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