A 3D signal obstruction model for realistic mobility models in Mobile Ad Hoc Networks

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Abstract

The study of mobile ad hoc networks depends on understanding protocols from simulations before applying them in a real-world setting. The production of a real-world environment within which an ad hoc network can be formed among a set of nodes requires the development of a realistic, generic, and comprehensive mobility model to replace random models. Realistic mobility models consist of three sub-models. One of these sub-model is signal obstruction sub-model. Realistic mobility model have previously been proposed and include the Obstacle Mobility Model and the Pathway Mobility Model. These models consider 2D pathways and obstacles that constrain node movements and their signals. In this paper, a new signal obstruction sub-model is proposed that can be used in all realistic mobility models. Proposed model can consider all obstacles of environment in 3D and simulate obstruction of the signals by 3D obstacles. Simulation results show that the 3D obstacles can affect the other parameters of MANET.

Keywords: *3D Mobility Model, Ad hoc Networks, Realistic Mobility Model, Intelligent Mobile Nodes, Intelligent Mobility.*

1. Introduction

Computer simulation is a valuable tool for evaluating protocols and other parameters of computer networks before applying them in the real world. Whereas simulations can be performed easily and cheaply, applying and implementing ad hoc networks in the real world is very difficult and costly. Furthermore, simulation provides other benefits such as repeatable scenarios, parameter isolation, and the ability to measure a number of different metrics. The most popular simulators are NS2, GLOMOSIM [1], OPNET and QUALNET. The most important components of a wireless network simulator include the mobility model, the signal propagation model, and the routing protocol.

The mobility model dictates to mobile nodes their initial positions and movement patterns. Many mobility models have been proposed, but most were based on random models, which consider the simulation terrain to be open and without any obstacles or pathways. Ad hoc network performance cannot truly be evaluated by using a random model because in realistic situations, nodes usually move in predefined pathways among obstacles, and their movement patterns are not random. Additionally, node signals are blocked or weakened by obstacles.

It should be stated that several realistic mobility models have been proposed, including the Obstacle Mobility Model and the Pathway Mobility Model [2, 3]. These models consider environmental obstacles and pathways and dictate that nodes move along these predefined pathways. However, each of these models presents some advantages and disadvantages. Most of the mobility models that include obstacles and pathways in 2D still do not consider realistic node movement patterns.

Nodes in the real world do have predefined pathways and 3D obstacles, which limit their movements and block their signals. Considering obstacles in 3D improves the accuracy of mobility models, and their results thus become more acceptable.

This paper proposes a novel signal obstruction model that includes realistic environment with 3D obstacles and pathways. First, the realistic mobility model as a new category of mobility model is introduced. Next, the related work on realistic mobility models is reviewed. Finally, 3D signal obstruction model is proposed, evaluated and compared to other models.

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2. Related works

Realistic mobility models simulate realistic node movement patterns within a real environment. Thus, a realistic mobility model must be able to provide a realistic environment, including obstacles and pathways, and simulate the behavior of real nodes in this environment. Realistic mobility models generally include three sub-models, which are as follows [4]:
Environment sub-model
Signal obstruction sub-model
Movement pattern sub-model
In the Environment sub-model, obstacles such as buildings, mountains, and the pathways around these obstacles are simulated; nodes are forced to move only along these pathways so as not to hit the obstacles.
The Signal Obstruction sub-model simulates blocking and weakening of the node signals due to the obstacles.
The Movement pattern sub-model determines the movement pattern of the nodes. This pattern simulates the selection of destinations, paths, the time spent at destinations, and the speed of the nodes along the paths.
Several studies of realistic mobility have been carried out, each of which has tried to improve the realism of one of the sub-models mentioned above. However, most of the previous realistic models have not been able to consider all the aspects of the real world. Some models have just focused on environmental objects, such as obstacles and node pathways, and other models have focused only on movement patterns.
The most important of realistic mobility model is Obstacle Mobility Model [2] that has strong environment and signal obstruction sub-models that simulate environmental obstacles and pathways. Its environment sub-model includes 2D polynomial obstacles, and the pathways among the obstacles are produced by Voronoi graph[5]. Its signal obstruction sub-model considers an inhibition cone produced by an obstacle, which exists for each node and is illustrated in Figure 1. If a node is located in another's inhibition cone, the two cannot connect.

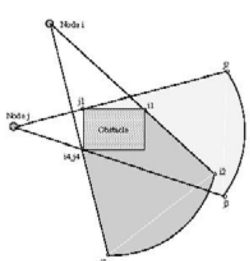


Fig. 1 inhibition cones for two nodes i and j

The Movement pattern sub-model of the Obstacle Mobility Model contains destination selection and path selection processes. Destination selection is completely random, and path selection is based on the shortest path (least hop count) using the Dijkestra algorithm.
Several models have been developed based on the Obstacle Mobility Model. In [6], for instance, a group mobility model has been proposed that uses all sub-models of the Obstacle Mobility Model. The Obstacle Model Based on Activity Area [7] uses the environment and signal obstruction sub-models of the Obstacle Mobility Model but adds a new movement pattern sub-model based on the concept of the node activity area. This model proposes that each group of nodes has an activity area, and the nodes of this group are more likely to be found within the activity area than outside of it. This addition affects the node destination selection process.
The graph-based mobility model [8] has a g raph-based pathway in the environment sub-model and no signal obstruction sub-model. The area graph-based model [9] was proposed based on the graph-based model and improved the movement pattern sub-model of the graph-based model. There exist other realistic models, such as the Environment Aware [10], Manhattan [11], Freeway [12], Voronoi-based [13], Urban Mobility Models [11] and Cluster based mobility model for intelligent nodes [4] that will be described in detail.

3. Proposed Method

In the realistic mobility models mentioned above, most of the proposed signal obstruction sub-models considered 2D obstacles, whereas in reality, the node heights play an important role in determining node signal obstruction. For example, two nodes with an obstacle between them that cannot connect to each other in 2D could still connect to each other in 3D; this situation could occur if the obstacle is so wide that the two nodes cannot connect to each other in 2D but is not high enough to block all signals in 3D.
Most communication devices use omni-directional antennas, which can send and receive signals. The radius of the sphere (r) is the transmission range of the nodes or devices. Two nodes can connect to each other directly if they are present in each other's spheres, i.e., if the maximum distance between them is r.
To introduce the 3D signal obstruction mechanism, it i s assumed that all nodes use omni-directional antennas and have the same transmission range. If the distance between two nodes is less than r and an obstacle crosses their line of sight, they can still connect to each other if the obstacle or another object in the environment can reflect their signals to each other. However, calculating how a signal is reflected and directed to another node is complex and requires detailed descriptions of the environment and obstacles. Hence, the model in this paper allows two nodes to connect if the distance between them is less than r, their

spheres overlap, and no obstacle completely blocks the region of intersection of the two spheres.

This numerical mechanism has three inputs and an output. The inputs are the coordinates of the two nodes that want to connect and those of the obstacle between them. Each coordinate is represented as (x, y, z) in 3D. The output is a binary yes or no, i.e., the nodes can connect to each other or they cannot, respectively.

The algorithm proceeds as follows:

Step 1: first, we ensure each node is present in the sphere of the corresponding node by examining the following condition:

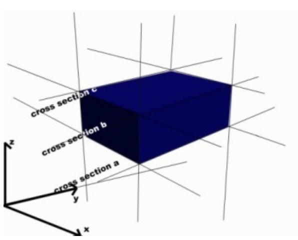
$$\sqrt{(x_1-x_2)^2+(y_1-y_2)^2+(z_1-z_2)^2} < r \qquad (1)$$

Where r is the transmission range or sphere radius, (x_1,y_1,z_1) are the coordinates of node 1 and (x_2,y_2,z_2) are the coordinates of node 2. If this condition is satisfied, i.e., the spheres have overlap and there is the possibility of connecting, then step 2 will follow. Otherwise, the algorithm ends here with a No output.

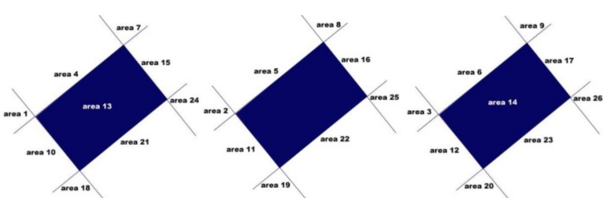
Step 2: the positions of the nodes relevant to the obstacle are determined. To this end, sub-areas around the obstacle, which is assumed to be a cube, are divided into 26 separated sub-areas. If the equation for the cubic obstacle (cube) are as follows:

$$a<X<b \quad c<Y<d \quad e<Z<f \qquad (2)$$

then the sub-area of a node with coordinates (x, y, z) are determined according to Table 1. These sub-areas are illustrated in Figure 2.



(A)



(B)

Fig 2 : (A) a cubic obstacle and (B) 26 sub-areas around it

Table 1: list of sub-areas around an obstacle

Node Position	Sub-area	Node Position	Sub-area	Node Position	Sub-area
x>b, y<c, e≤z<f	19	a<x<b, y<c z<e	10	x<a, y<c, z<e	1
x>b, y<c, z≥f	20	a<x<b, y<c, e≤z<f	11	x<a, y<c ,e≤z<f	2
x>b, c≤y<d, z<e	21	a<x<b, y<c, z≥f	12	x<a, y<c, z≥f	3
x>b, c≤y<d, e≤z<f	22	a<x<b, c≤y<d, z≤e	13	x<a, c≤y<d ,z<e	4
x>b, c≤y<d, z≥f	23	a<x<b, c≤y<d, z≥f	14	X<a, c≤y<d, e≤z<f	5
x>b, y≥d, z<e	24	a<x<b, y≥d, z<e	15	x<a, c≤y<d, z≥f	6
x>b, y≥d, e≤z<f	25	a<x<b, y≥d, e≤z<f	16	x<a, y≥d ,z<e	7
x>b, y≥d,, z≥f	26	a<x<b, y≥d, z≥f	17	x<a, y≥d, e≤z<f	8
		x>b, y<c, z<e	18	x<a, y≥d, z≥f	9

Step 3: given a node's sub-area, it sees some obstacle vertices in front of itself. In this step, the equations for the lines between the node and these vertices are calculated. Figure 3 illustrates two lines between a node and vertices of an obstacle. For instance, if the point (a, c, f) is one of the mentioned vertices and (x1, y1, z1) is the position of node 1, the line between the two points is described by the following equations:

$$x = (a - x_1)t + x_1$$
$$y = (c - y_1)t + y_1$$
$$z = (f - z_1)t + z_1 \qquad (3)$$

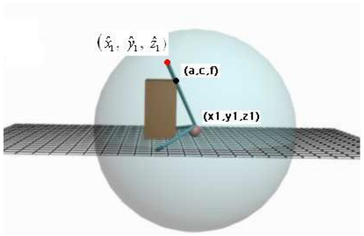


Fig. 3 signal sphere of a node with coordinates (x1,y1,z1) and a cubic obstacle.

Step 4: in this step, the calculated lines are extended, and the crossing points between them and the surface of the node's sphere are calculated. These points are called the sphere crossing points. By inserting equation 3 in 4 which represent sphere equation, sphere crossing points will be calculated (equation 5).

$$(x-x_1)^2 + (y-y_1)^2 + (z-z_1)^2 = r^2 \qquad (4)$$

$$\hat{x}_1 = (a - x_1)\hat{t}_1 + x_1$$
$$\hat{y}_1 = (c - y_1)\hat{t}_1 + y_1 \qquad \hat{t}_1 = \frac{r}{\sqrt{(a-x_1)^2 + (c-y_1)^2 + (f-z_1)^2}}$$
$$\hat{z}_1 = (f - z_1)\hat{t}_1 + z_1 \qquad (5)$$

Step 5: the information obtained in the previous steps is used to verify whether it is possible to connect the two nodes through the left, right, top and bottom sides of the obstacle. To this end, the points generated in the previous step are used. For a connection to be possible, the sphere crossing points of node 1 must be within the sphere of node 2 and vice versa. The following equation verifies whether the sphere crossing point $(\hat{x}_1, \hat{y}_1, \hat{z}_1)$ is located within the sphere of node 2 centred at (x_2,y_2,z_2):

$$(\hat{x}_1 - x_2)^2 + (\hat{y}_1 - y_2)^2 + (\hat{z}_1 - z_2)^2 < r^2 \qquad (6)$$

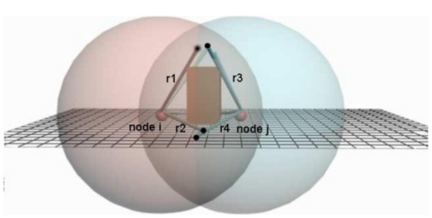


Fig 4. Connecting two nodes in the presence of an obstacle

3.1 Case Studies

First example: Figure 4 illustrates two nodes, their signal propagation spheres and an obstacle between them. We want to verify whether they can connect according to the proposed algorithm. The sphere crossing points are calculated on the left, right, top and bottom sides of the obstacle, and each crossing point is tested.
According to the illustrated figure, the spheres of the two nodes overlap. Hence, Step 1 is satisfied.
In Step 2, the sub-areas for each node are determined. Node i is located in sub-area 5 and Node j in sub-area 25.
In the next step, the vertices located in front of each node are determined. Numbering the obstacle vertices as in Figure 5, Node i sees vertices 0, 1, 6 and 7, and Node j sees vertices 2, 3, 4 and 5.

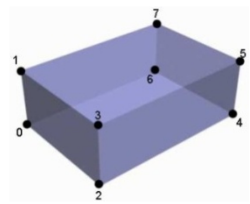


Fig. 5 numbering of obstacle vertices

In step 4, the equations of the lines between each node and the corresponding vertices are calculated.
Finally, the sphere crossing points of each node's lines and spheres are calculated. The possibility of connecting the two nodes must be verified from the left, right, top and bottom sides.

1. If Nodes i and j want to connect along the top side, the following conditions, illustrated in Figure 6, must be met.

- The sphere crossing points of Node i along Lines u1 and u2 must be inside of the sphere of Node j.
- The sphere crossing points of Node j along Lines u3 and u4 must be inside of the sphere of Node i.

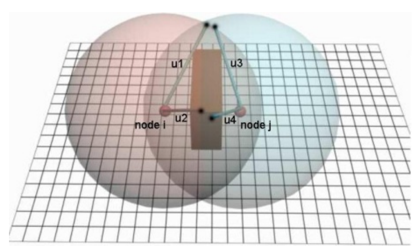


Fig. 6 connecting two nodes along the top side

If both conditions are satisfied, then the nodes can connect to each other along the top side, and there is no need to check the other sides. However, if one of these conditions is not met, then the two nodes cannot connect to each other along the top side, and the other sides must be checked, so the same process is repeated for the other sides.

2. If Nodes i and j want to connect along the left side, the following conditions, illustrated in Figure 7, must be met.
- The sphere crossing points of Node i along Lines l1 and l2 must be inside of the sphere of Node j.
- The sphere crossing points of Node j along Lines l3 and l4 must be inside of the sphere of Node i.

If both conditions are met, then the nodes can connect to each other along the left side.

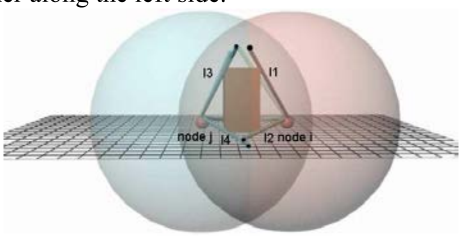


Fig. 7 connecting two nodes from the left side

3. If Nodes i and j want to connect along the right side, the following conditions, illustrated in Figure 8, must be met.
- The sphere crossing points of node i along Lines r1 and r2 must be inside of the sphere of Node j.
- The sphere crossing points of node j along Lines r3 and r4 must be inside of the sphere of Node i.

If both conditions are met, then the nodes can connect to each other along the right side.

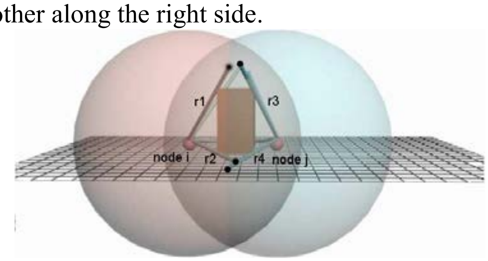


Fig. 8 connecting two nodes around the right side

4. If Nodes i and j want to connect along the bottom side, the following conditions, illustrated in Figure 9, must be met.
- The sphere crossing points of Node i along Lines d1 and d2 must be inside of the sphere of Node j.
- The sphere crossing points of Node j along Lines d3 and d4 must be inside of the sphere of Node i.

If both conditions are met, then the nodes can connect to each other along the bottom side.

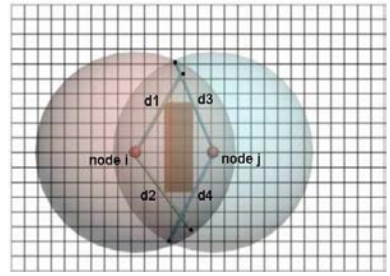


Fig. 9 connecting two nodes along the bottom side

4. Evaluation of 3D signal obstruction sub model

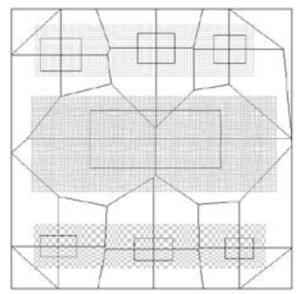


Fig. 10 Simulation terrain with three activity areas

The primary purpose of the simulations of this new method is to investigate the impact of the model on the implementation of the network. To achieve this end, two aspects of the proposed method are evaluated: the characteristics of the network topology created by this model and the impact of the model on the performance of an ad-hoc routing protocol. To understand the characteristics of the network topology created by the new mobility model, the following metrics are estimated:

- Node Density: The average number of neighbours per node.
- Average Broken Links: The average number of broken links among the nodes throughout the simulation.

To determine the impact of obstacles and pathways on the performance of routing protocols, the AODV protocol [13] is utilized for route discovery and path setup. To this end, the following metrics are evaluated:

- Data Packet Reception: The number of data packets received at their intended destinations.
- End-to-End Delay: The end-to-end transmission time for data packets. This value includes delays due to route discovery.

But as it is mentioned signal obstruction is a sub-model of a mobility model. So a mobility model should be chosen and replaced its signal obstruction sub-model with proposed signal obstruction method. Hence Obstacle

Mobility Model is chosen and enhanced with proposed signal obstruction method.
For comparison, the above metrics are obtained for the following models:

- Obstacle Mobility Model, one of the most important realistic models (OM).
- Obstacle Mobility Model Based On Activity Area(OMBA).
- Obstacle mobility model enhanced with 3D signal obstruction sub-model(3D sub model).
- Random Waypoint model(RW).[15]

4.1 Simulation Parameters

All of the simulations were run using the GLOMOSIM network simulator with 50 nodes. The simulation terrain is 1000 m x 1000 m that it is illustrated in figure 10. This terrain contains realistic obstacles and pathways and obstacles can constrain the movements of the mobile nodes and block their signals.
Maximum node transmission range is 250 m. However, in the presence of obstructions, the actual transmission range of each individual node is likely to be limited. At the MAC layer, the IEEE 802.11 DCF protocol is used, and the bandwidth is 2 M bps. As not all of the people carrying notebooks and portable wireless tools are pedestrians, the node movement speed is considered to range from 0 m/s to 10 m/s. The pause time in the simulations is randomly selected from the range 10 to 300 seconds. After the initial distribution of the nodes, each node moves for 60 seconds so that they are distributed throughout the simulation area. Then, 20 data sessions start. The data packet size is 512 bytes, and the sending rate is 4 packets/second. The maximum number of packets that can be sent per data session is set to 6000. Therefore, a heap of 6000 packets can be received by 20 destinations. Twenty destinations and 20 sources are selected randomly. Movement continues throughout the simulations for a period of 3600 seconds. Each data point is an average of 30 simulation runs with the nodes distributed in different initial positions. All data sessions use the CBR traffic model. The numbers of clients and server nodes were also selected randomly.

4.2 Simulation results

a. Node density
The average number of neighbours per node is shown in Figure 11. The average number of neighbours per node in the RW model is significantly higher than other models, because the RW model does not consider the effect of the obstacles on the node signals.
The result from 3DM is also higher than other models because the other models use 2D obstruction sub-models. Hence, some obstacles block connections between two neighbour nodes in 2D, but these obstacles may not be tall enough to block a co nnection in 3D. Therefore, the number of neighbours for each node increases.
Simulating activity area of the nodes leads to better result than OM. Because the nodes in the same activity area increase the node density.

c. Average Broken Links
Figure 12 shows the Average Broken Links for the different models. The number of broken links increases when using the RW model. Because in other models, the nodes are dictated to move along predefined pathways, they are more likely to stay within transmission range of each other than the nodes in the RW model. On the other hand, fewer links originate in other models than in the RW model; therefore, fewer broken links occur. In the 3DM, more links are generated because 3D obstacles are considered, but more links are also broken due to the mobility of the nodes.

b. Data packet reception ratio
Figure 13 shows the Data Packet Reception. The RW model produces the best result, but it does not consider obstacles, pathways or node signal blockage. 3DM produces the best results among the obstacle-based models because this model considers the obstacles and environment in 3D, and some obstacles that can block signals in 2D cannot block all node signals in 3D. The data packet reception ratio of the OMBA is better than that of the OM, because in the OMBA, the nodes in the same activity area can establish better data sessions than others.
At zero or low speed, the results of this model and the Obstacle Model are almost the same due to the lack of node movement, but when the nodes respect data delivery as a criterion and are active within their activity area more than in other regions, the data reception ratio increases.

c. Average End to End delay
Figure 14 shows the end-to-end data packet delivery delay. This measurement includes the latency for selecting routes. The end-to-end delay of 3DM is less than that of other models. Because the node density increases in the 3D situation, more and shorter paths can be found, and the end-to-end delay thus decreases. The RW has the maximum end-to-end delay because more data sessions can be completed successfully and more paths can be created. Some of the created paths can be long and increase this delay.

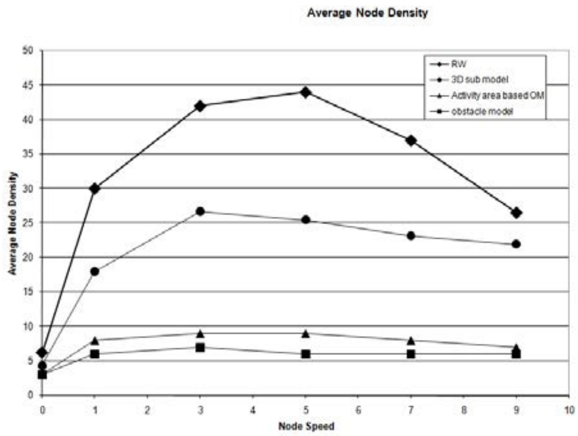


Fig. 11 Average node density

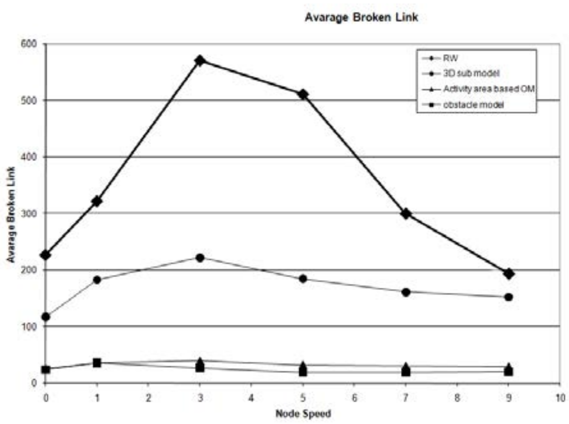


Fig. 12 Average broken link

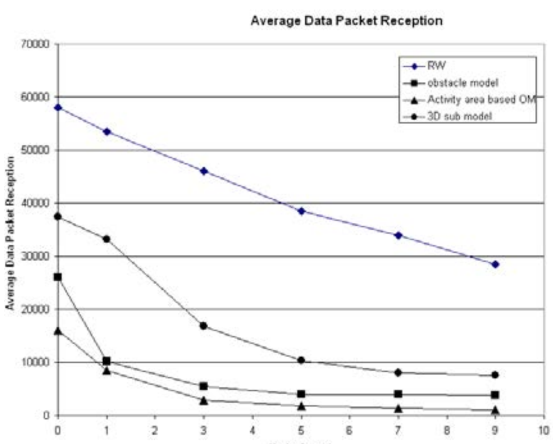


Fig. 13 Data packet reception ratio

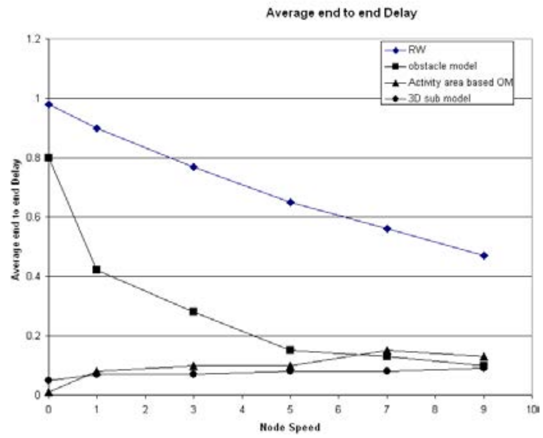


Fig.14 Average End to End delay

5. Conclusion

Authors in previous researches [4] have shown that each mobility model consist of three sub-models. T his paper focused on signal obstruction sub-model and tried to simulate effect of 3D obstacles on signals of the nodes.

The signal obstruction model can be used in all realistic mobility models without changing the environment or movement pattern sub-models and can support all kind of obstacles, even obstacles that float in the air. Furthermore, it can support nodes with different transmission ranges and different heights as well as different wireless networks, including ad hoc networks and sensor networks.

Simulation results showed that considering obstacles and pathways in 3D can effect on evaluation metrics of ad-hoc networks such as data packet reception and node density. In fact considering 3D obstacles and effect of all dimensions can effect on both topology evaluation metrics and routing performance metrics .

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