

RESEARCH ARTICLE

Engineering

Analysis of link time in Mobile Ad-Hoc Networks (MANET)

Análisis del tiempo de enlace en las redes móviles Ad-Hoc (MANET)

Amber Israr ¹ | Zain Anwar Ali ¹ | Rana Javed Masood ²
 | Muhammad Salman Pathan ³

¹Electronic Engineering Department, Sir Syed University of Engineering and Technology, Karachi, Pakistan.

²Electronic Engineering Department, Usman Institute of University, Karachi, Pakistan.

³Department of Computer Science, Maynooth University, Ireland.

Correspondence

Muhammad Salman Pathan
 Email: Muhammad.pathan@mu.ie

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Resumen

En la última década se ha observado un aumento constante del número de usuarios de móviles y del uso de la comunicación móvil. En la comunicación inalámbrica los enlaces son estables. La duración del enlace es el diseño más importante para determinar el rendimiento de la red móvil Ad Hoc (MANET). En este artículo de investigación, se ha examinado una métrica derivada de la teoría de gráficos obtenida a partir de la técnica del modelo de movilidad en la red Ad Hoc de objeto en movimiento casual, la duración del enlace de la función de densidad de probabilidad (PDF) mediante el uso de tres modelos de movilidad, específicamente, Modelo de Waypoint aleatorio, dirección aleatoria y autopista. El rendimiento se basa en la velocidad del nodo, el rango de transmisión, la densidad del nodo, el área de simulación y la complejidad computacional con el tiempo.

Abstract. In the past decade, a steady increase has been noticed in the number of mobile users and the use of mobile communication. In wireless communication links are stable. Duration of the link is the most important design by which the performance of the mobile Ad Hoc network (MANET) can be determined. In this research article, a derivative metric of graph theory attained from mobility model technique in Ad Hoc network of casually moving object, link duration of probability density function (PDF) been examined by using three mobility models namely random waypoint, random direction, and freeway model. The performance is based on the node speed, transmission range, the density of node, area of simulation, and computational complexity with time. By using Monte Carlo simulations, the reliability and robustness of models have been analyzed. The main advantage of the proposed scheme is implemented is an easy hardware platform because of the concept in mobility models and the easiness of code.

Keywords: : Mobile Ad-Hoc network, Mobility models, Link time, Monte Carlo simulation.

Mediante el uso de simulaciones de Monte Carlo, se ha analizado la fiabilidad y robustez de los modelos. La principal ventaja del esquema propuesto se implementa es una plataforma de hardware fácil debido al concepto en los modelos de movilidad y la facilidad de código.

Palabras clave: Red móvil Ad Hoc, modelos de movilidad, tiempo de enlace, simulación de Monte Carlo.

1 | INTRODUCTION

1.1 | Motivation

In the last few decades, link duration among the nodes becomes a hot topic today [1]. Mobile Ad Hoc networks (MANET) have many applications in the real world including defense, search and rescue operations, surveillance, etc. Due to the wide range of applications of Ad Hoc networking, the issue of links among mobile nodes has to attain more importance day by day [2, 3, 4]. Static and fixed networks have attained momentum in municipalities business but different challenges need to be addressed. In this era, the challenge is to design and develop techniques of routing. The Ad Hoc network is created by using technologies via phone. This field is more attractive for the research community because these networks are created by the movements of ants having a communication system. The Ad Hoc networks consist of autonomous wireless objects with different patterns and speeds which can communicate with dissimilar nodes using different radio interfaces. Each node can absorb, transfer and generate data and acts as an entity. A mobile node finds a new route to the targeted destination whenever a route becomes invalid and this affects the communication and increases overhead developed by the routing protocol [5]. If the path duration accurate prediction is done accurately, it will increase the performance of the protocol. Path duration is defined as the link's minimum residual life alongside the path to the targeted destination containing a single link. It is not easy to predict path duration for the selected path because it depends upon different parameters such as position, velocity, direction, etc. This prediction is easily done by a global positioning system (GPS) but a few mobile networks have GPS. For Ad Hoc networks, geographic routing is becoming more suitable as well as using sensor networks when easily getting used to GPS [6]. Different protocols of GR in the Ad Hoc network are proved and given progress. For so many applications, the position known is very essential. In these routing protocols, the packet forward decision is made to select the next neighbor that is dependent upon the information about the position of all its neighbors as well as about its destination. These protocols work proficiently when actual position information is known. The position errors can affect GR which can make things worse with node mobility due to the fact that every single node has changed its position error and position according to mobility level.

1.2 | Related Work

Despite predicting the communication link duration, there have been experiential studies reporting results best of knowledge. The prediction techniques for MANET are separated into three types which are 1) Movement history-based prediction method in which the future location of mobile user is predicted depending upon its movement history i.e. past user patterns of movement. 2) Physical topology-based mobility prediction method in which the prediction depends upon the use of the characteristics of physical topology. Therefore GPS is needed to attain mobility information and accurate position. 3) Logical topology-based mobility prediction method in which the prediction process depends upon the selection of logical topology e.g. clustering structure [7]. The above-mentioned prediction methods are very famous and are classified according to application and specific prediction methods. The mobility prediction research efforts that are utilized in predicting the connectivity of neighboring nodes depend upon their location information. These methods used for the better accuracy of the neighbors are proposed in [8]. The next neighbor information is easily attained by interchanging the packet messages among the two-hop range. The two hops hello packet messages will increase collision chances with data packets, thus the packet will be resent as a result of energy and end-to-end delay. **Sezaki and Creixell** presented a geographical routing protocol in which routing decisions are taken depending

upon the present and future location of the node [9]. These researchers use the prediction method to know about the future position of the node by using real trajectory data. In [10] presented a velocity-aided routing (VAR) protocol in which the nodes decide their information packet routing considering relative velocity among the destination and expected node. **Xu et al.** presented a mobility prediction mechanism in which nodes' neighborhood information is attained at a future actual transmission time [11]. Two mobility approaches are presented by **Son et al.** [11] are 1) Neighbor position prediction 2) destination position prediction to solve the lost link and loop problems in position-based routing protocols. In [12] a position delay prediction approach is proposed that provides quality of service routing protocols to expect the future position depending upon the previous position. **Ruber** [13] supposed the duration of the link to be independent of exponentially scattered random variables. With this assumption, they derived the probability distribution of path duration. **Pascoe-Chalke et al.** [14] Derivate the time duration of the node path, but this model only attains velocity without considering acceleration. In [15] a model is projected that determines the link probability in-vehicle Ad Hoc network (VANET) under these assumptions that headway distance is constant, VANET mobility patterns are ignored and lastly radio propagation model only accounts for slow fading. **Ko** and **Nekovee** supposed that the velocities of the car are distributed. The throughput is modeled by many formulas using these assumptions [16]. In [17] routing path and link based on the strength of a signal are examined.

1.3 | Contributions

The contributions of this research article are as follows:

1. A comprehensive analysis of the probability density function (PDF) is done.
2. It presents a network model comprised of link residual life, relative velocity, link time, and path duration.
3. Three mobility models have been discussed and analyzed.
4. The duration of the link between these networks was found.

1.4 | Organization

The manuscript is organized as follows. Section 1 defines the introduction comprised of motivation, related work, contribution, and organization of this research article. The problem statement is defined in section 2. In section 3, the state of the art is defined. Section 4 defines the mobility model. In section 5, the network model is done. Simulation is done in section 6. The conclusion of this research article is described in section 7.

2 | PROBLEM STATEMENT

On the issue of link duration, the inquiry has been made by seeing active distance and relative speed among the nodes by assuming that node movement tracks the random waypoint model. But, the random waypoint model did not provide the steady-state when the continuous speed of the node decreases over time. Thus, not be used in simulations directly. By examining the statistics of multi-hop path duration, PDF, the number of hops, communication range, and speed, the impression of mobility models on the stability of the link is explored. The disadvantage is that the computational cost of the networks ascends with the increase in speed and number of nodes. The exponential distribution method was found that be better for approximation of path duration distribution for nodes stirring at low velocities and high velocities in the dissimilarity of other theories signifying contact time among the nodes in Ad Hoc network is light tracked by simulations established on random waypoint model. Many scientists have done their research in this area, but one that examined the duration of link based on mobility models is in randomly moving objects.

3 | STATE OF ART

The applicability of these mobility models has its weakness and assets depending on network size, the structure of nodes, the duration of link and convergence of nodes, and some other parameters. The dynamical comportment of nodes, topology, and connectivity characteristics affects the dynamics of the link [18]. Furthermore, the mobility of the node is one of the factors which heavily influence the dynamics of the link and accurate illustration of the user mobility in the analysis of radio networks, which is a crucial element for both modeling and simulation [19]. The investigation of impact of mobility on the recital of routing protocols has been investigated. The pattern of traffic, node density, and initial placement pattern of nodes always disturb the performance of routing, and the duration of a link lacking. Similarly, work has been done by summarizing the pattern movement by organizing the derived and direct mobility while the routing protocol has been not taken seriously, which is a serious cause and concern in the duration of the link [20]. Furthermore, a study proposed an analytical model for estimating the duration of the path in MANET. Due to the highly unpredictable nature of nodes, it is a challenge to model path duration. The study demonstrates the feasibility under some assumptions. In another research article, the main contribution is an analysis of link duration in-vehicle Ad Hoc networks based on the realistic distribution of headway distance. Similarly, a study focused on different trust computing methods and trust dynamics relating to MANET [21, 22, 23, 24].

4 | MOBILITY MODELS

The three mobility models are as follows:

1. Random Waypoint (RWP)
2. Random Direction (RD)
3. Highway Scenario (HS)

4.1 | Random waypoint

This type of mobility model is one of the most frequently used models of mobility to illustrate node's mobility patterns in several networks, for example Ad Hoc network [25]. The main characteristic of the random waypoint mobility model is that it defines independent node movement. In this type of model, pause time is included among changes in speed and destination. The silence/pause time is defined as mobile node pledges residing in one location for a specific period. The mobile node chooses a target randomly in the simulation area once the pause time lapses and a speed is dispersed among minimum and maximum speeds. Then the mobility node moves toward the anew selected target at a preferred speed. When reached the selected target, the mobility node pauses for a defined period before starting the process again. Laterally with the assets, the clustering is the main weakness of the simulation area of nodes at the dominant part that may lead toward the mounding in the local area. The space of this mobility model of a mobile node is in 1 dimension or 2 dimension space [26].

1. A two-dimension space can be a bearing a radius k or rectangle area of size $a \times b$.
2. The discrete unit of time for the node is denoted by k and l respectively.
3. The vector P_k^l indicates that node l with this mobility pattern selects its movement period, denoted by k .
4. The movement trace of this random waypoint node l can be properly defined as a discrete-time stochastic process given by choosing a random waypoint P_k for each movement period k .

$$P_k^l = P_0^l, P_1^l, P_2^l, P_3^l \quad (1)$$

Considering that the waypoints are identical and independently distributed over the system space with

uniform random distribution. Neglect l because every node moves autonomously as of other nodes. Suppose that for a movement from P_{k-1} to P_k , a node having a new speed v_i has a pause time t_p , at waypoint P_k . In this particular case, the equation below defines the movement process of the node.

$$(P_k, v_k, t_{p,k}) = (P_1^l, v_1, t_{p,1}), (P_2^l, v_2, t_{p,2}) \quad (2)$$

In Eq. (2), for initialization, an additional waypoint P_o is needed and a sample of this process is expressed as $(P_k, v_k, t_{P,k}) \in \mathbb{N}$. The vector $(P_{k-1}, P_k, v_k, t_{P,k}) \in \mathbb{N}$ describes the movement period k finally. A single random variable is denoted by P , v , or t_p neglecting index k . The pause time probability density function is defined as $ft(t_p)$ in the time interval of $0 < t_{P,max}$ to $t_{P,max} \infty$. The predictable value of pause time is defined as (t_p) and the values of the time are chosen from these functions. Also, $ft(t_p)$ is the density function of the speed restricted by the interval $[v_{min}, v_{max}]$ with $v_{min} > 0$ and $v_{max} < \infty$. The values of speed are chosen from probably density function.

4.2 | Random direction

This model is produced to overawe the density waves in the average number of neighbors, which is created by the random waypoint mobility model. In this type of mobility model, the mobile node chooses an arbitrary direction similar to the arbitrary walk mobility model in which direction to travel. Formerly, mobile nodes travel to the border of the simulation area. The mobile node pauses for a definite time period when the simulation boundary is reached and selects the angle somewhere between 0 and 180° [27].

4.3 | Highway Scenario

In this manuscript, this type of mobility model is used for the dissimilarity of highway mobility without any temporal and spatial dependencies. The main characteristic of this model is to perceive the link duration probability in the Ad Hoc network of objects which is bidirectional and moving straight without any direction or angle change. This proposed model simulation area is divided into two halves with respect to Y-axis. All nodes will select their initial position according to Y-axis. It will start to change its direction right or left till the simulation end. As the boundary is reached, it will consent to the simulation area. At the same time, the node will be generated from the next extreme of the boundary to keep the density of the network constant.

5 | NETWORK MODEL

A mobile network is a static network in which topology changes at a specific time. The change in topology can be predicted by the assumed mobility model. The path between source and destination attains many paths, but analyzing the link duration of all is not possible. This section defines the network model.

5.1 | Link Residual Life

It is defined as the time in which the link befits the part of the path and becomes active. The link between two nodes remains active till they are in transmission ranges. It is signified by t and can be given as

$$t = \frac{D}{V_R} \quad (3)$$

Whereas, D signifies the distance that neighbor nodes travel to get out of transmission range and V_R denotes the two neighbor's relative velocities.

5.2 | Relative Velocity

Consider the source node to be fixed and relay node movement is considered while finding the PDF matching to relative velocity. The relative velocity between the nodes is given as

$$V_R = \sqrt{V_1^2 + V_2^2 - 2V_1V_2 \cos \theta} \quad (4)$$

All nodes will move at constant velocity, thus $V_1 = V_2 = V$ Now, the V_R can be rewritten as

$$V_R = V\sqrt{2 - 2 \cos \theta} \quad (5)$$

θ defines the ranges of the random variables from 0 to 2π The PDF of $\theta/2$ is given as

$$f\left(\frac{\theta}{2}\right) = \frac{1}{\pi} \quad (6)$$

The PDF of V_R is represented as

$$f(V_R) = \frac{1}{\sqrt{4V^2 - V_R^2}} \times \frac{1}{\pi} \quad (7)$$

5.3 | Link Time

Fig. 1 shows the link activated among nodes and . The transmission range (TR) of the node is represented by the circle. Assume and denote the velocity of the node of nodes and respectively. Similarly, denotes the position of the node. The link duration is derived when the movement behavior is observed by From the viewpoint of moves at velocity $V = V_1 - V_2$.

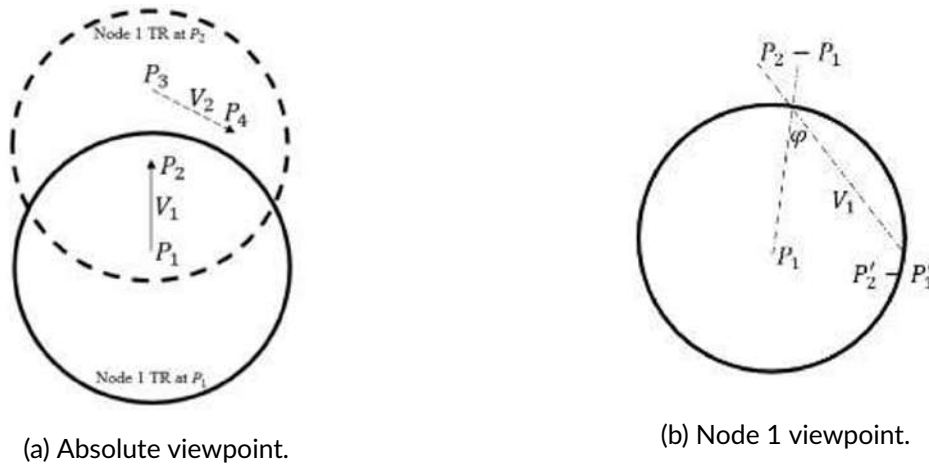


FIG. 1 Two nodes relationship.

Assume that both nodes are moving at the same speed. The angle between V_1 and V_2 is given by θ The magnitude of V can be determined by

$$|V| = 2V \sin\left(\frac{\theta}{2}\right) \quad (8)$$

Similarly, active distance is represented by d and can be given as

$$d = 2TR \cos(\phi) \quad (9)$$

Since the distance d and V are independent, the link time $E(L)$ is given as

$$E(L) = E\left(\frac{d}{V}\right) \quad (10)$$

TABLE 1 Computational complexity in terms of time

		Model 1: Random Waypoint			
		MEAN	MAX	MIN	STD
Case 1	Scenario 1	10.46	24.31	1.83	10.21
	Scenario 2	11.44	26.76	1.94	11.26
	Scenario 3	11.2	26.1	1.5	11.1
Case 2	Scenario 1	10.46	24.3	1.86	10.18
	Scenario 2	10.72	24.9	1.94	10.42
	Scenario 3	10.83	25.4	1.84	10.5
		Model 2: Random Direction			
		MEAN	MAX	MIN	STD
Case 1	Scenario 1	9.28	22.38	1.24	9.62
	Scenario 2	10.42	25.3	1.38	10.88
	Scenario 3	10.8	24.8	1.5	10.2
Case 2	Scenario 1	9.15	22.13	1.23	9.5
	Scenario 2	9.39	22.5	1.35	9.61
	Scenario 3	9.45	23.3	1.42	9.8
		Model 3: Highway Scenario			
		MEAN	MAX	MIN	STD
Case 1	Scenario 1	10.6	25.8	1.3	11.13
	Scenario 2	10.22	24.37	1.64	10.45
	Scenario 3	11.27	27.3	1.58	11.78
Case 2	Scenario 1	13.86	33.57	1.63	14.46
	Scenario 2	9.14	21.93	1.31	9.37
	Scenario 3	9.05	21.7	1.3	9.28

5.4 | Path duration

The PDF of link residual life helps in deriving the path duration t_p . Consider H the number of hops needed to reach the destination t_p is given as

$$t_p = \min(t_1, \dots, t_H) \quad (11)$$

Thus,

$$f(t_p) = H f(t_p) (A_{t_p})^{H-1} \quad (12)$$

Whereas, A_{t_p} is the cumulative distribution function. Thus, the average path duration can be written as The average number of hops needed to reach the destination is given as

$$E(t_p) = \int_0^{\theta} t_p f(t_p) dt_p \quad (13)$$

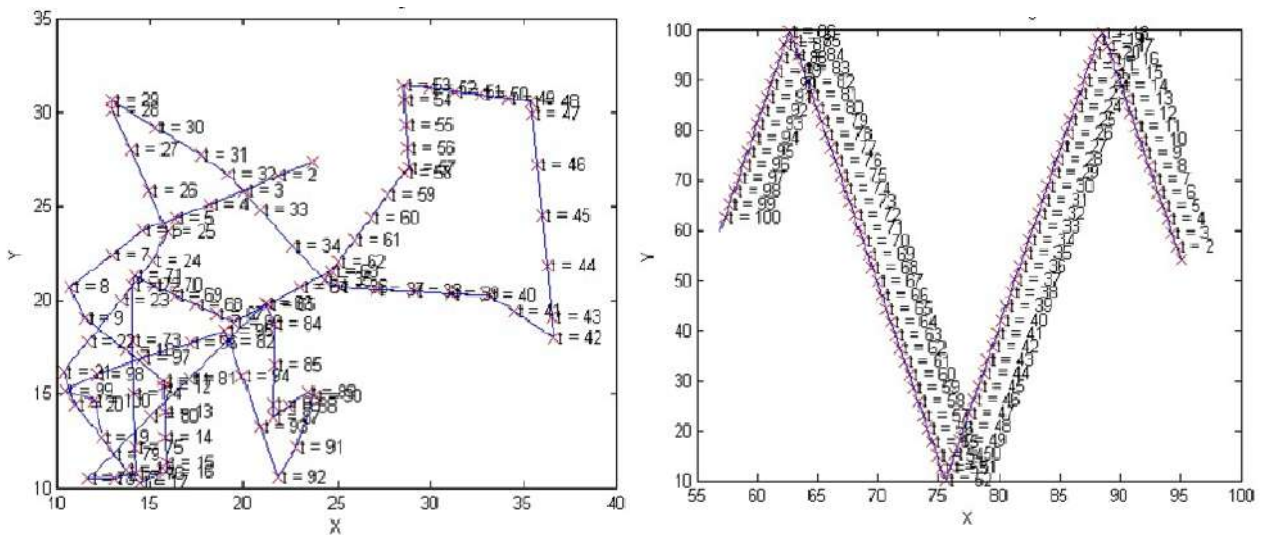
The average number of hops needed to reach the destination is given as

$$E(h) = \frac{L}{E(Y)} \tag{14}$$

Whereas, L defines the source and destination distance and $E(Y)$ is the per hop average distance progress.

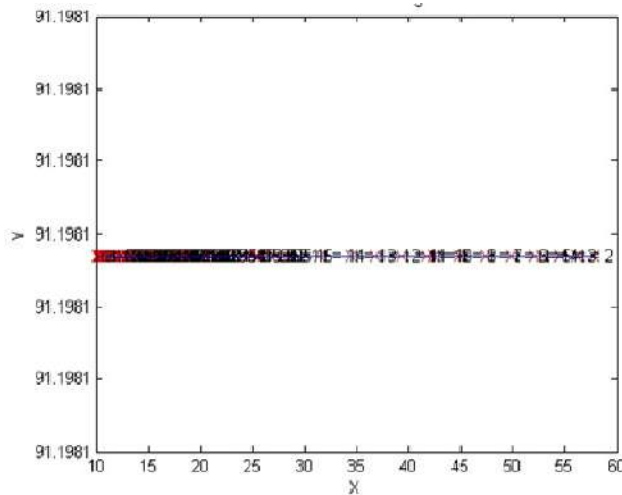
6 | SIMULATIONS AND DISCUSSION

The scenario-based simulations are done in MATLAB. Different mobility patterns are created by using a mobility generator.



(a) Random waypoint model.

(b) Random direction model.



(b) Highway scenario.

FIG. 2 Random models and highway scenario.

The Fig. 2 shows the moving patterns executed by the simulator, namely MATLAB for all three models. There are common parameter values, computational time complexity, and fitness value, although the precise

parameters include network size, velocity, and density. A comparative study of three models is being evaluated in Table 1 based on the computational complexity in terms of time. Entity models are identified by four statistical parameters based on the maximum node (**MAX**) occurring at the highest node, the lowest (**MIN**) at the lower node, the standard deviation (**STD**), and the average time taken to run the model on each independent.

Considering two different types of cases namely constant node speed and variable node speed, which are as follows

| Case 1: Constant Node Speed

The evaluation between the three mobility models has been carried out with constant node speed. The scenarios that have been evaluated are as follows:

| Scenario 1: Low Mobility and Low Transmission Range

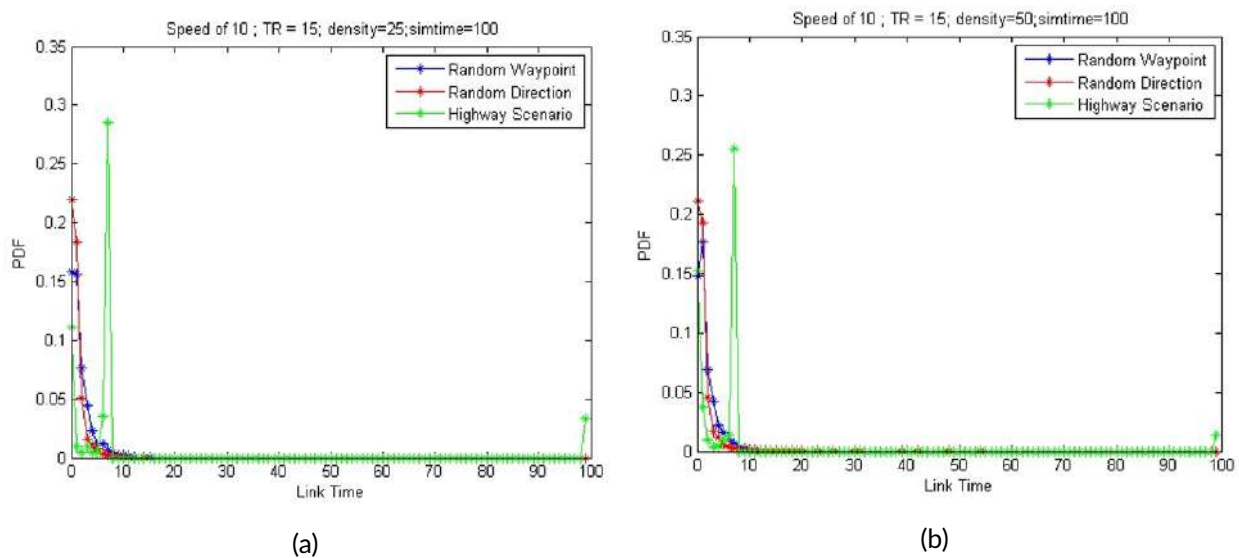


FIG. 3 Behavior of changing node density with low transmission range and mobility.

The graphs presented in Fig. 3 (a) and (b) present a clear difference as shown. In the abovementioned scenario, the speed is 10 m/s with a transmission range of 15 with different density values of 25 and 50. RWP shows a 10% to 15% of chance of establishing the connection for the period of 1 to 5 seconds. RD also has chances of around 16% of establishing a connection for 4 seconds. The highway scenario shows fair chances of 21% to 35% of establishing the connection for the time of 1 to 2 seconds with all density values, but also has a low probability of 7% for time period of 6 to 8 sec.

| Scenario 2: Modest Transmission Range and Mobility

Fig. 4 (a) and (b) presents a clear difference as shown. In the abovementioned scenario, the speed is 20 m/s with a transmission range of 25 with different density values of 25 and 50. RWP shows a 15% to 20% of chance of establishing the connection for the time period of 1 to 2 seconds. RD has chances around 14% to 19% of establishing a connection for 2 seconds. The highway scenario shows less probability of 15% to 19% of establishing the connection for time period of 1 second but also has low chances of 7% for time period of 7 seconds with density values of 25 and 50. The last scene shows the dispersed connection for 3% to 4.5% for a different time period.

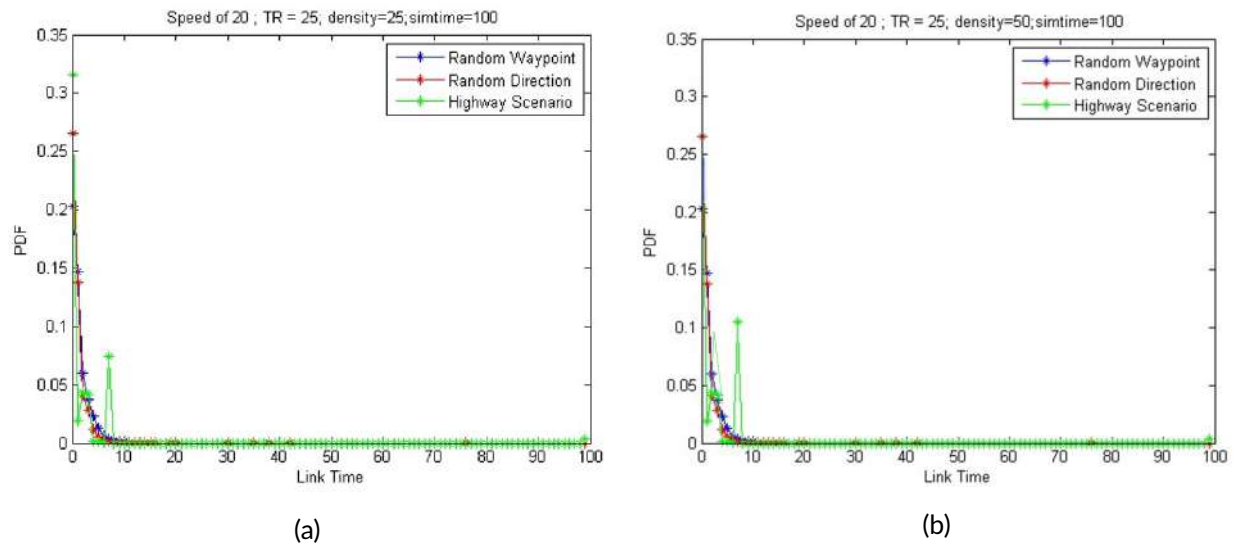


FIG. 4 Behavior of changing node density with modest transmission range and mobility.

Scenario 3: Moderate Transmission Range and High Mobility

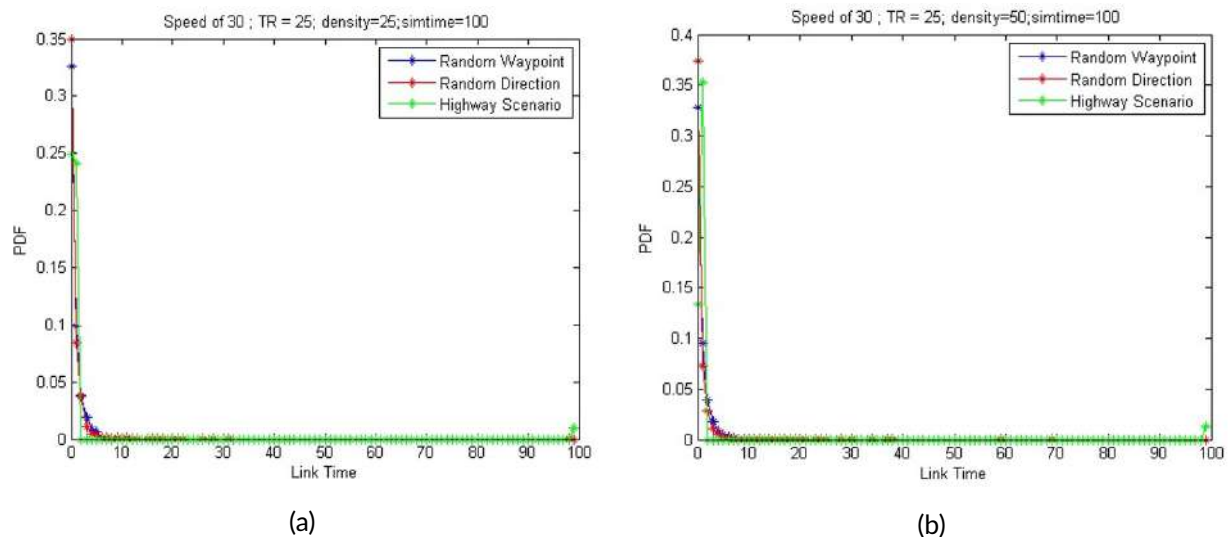


FIG. 5 Performance by changing node density with moderate transmission range and high mobility.

Fig. 5 presents a clear difference as shown. In the abovementioned scenario, the speed is $30m/s$ with transmission range 25 with different density values 25 and 50. RWP shows a 32% of chance of establishing the connection for the time period of 1 to 2 seconds. RD shows a high probability of 32% to 30% of establishing the connection for time period of 1 second with density values of 25 and 50, but also has a 7% of low chances for 6 to 7 seconds. Lastly, the highway scenario has low chances of 7% for establishing a connection for 7 seconds and greater chances of 32% for establishing a connection for 1 second.

Case 2: Variable Node Speed

The evaluation between the three mobility models has been carried out with variable node speed. The scenarios that have been evaluated are as follows:

Scenario 1: Low Transmission Range and Mobility

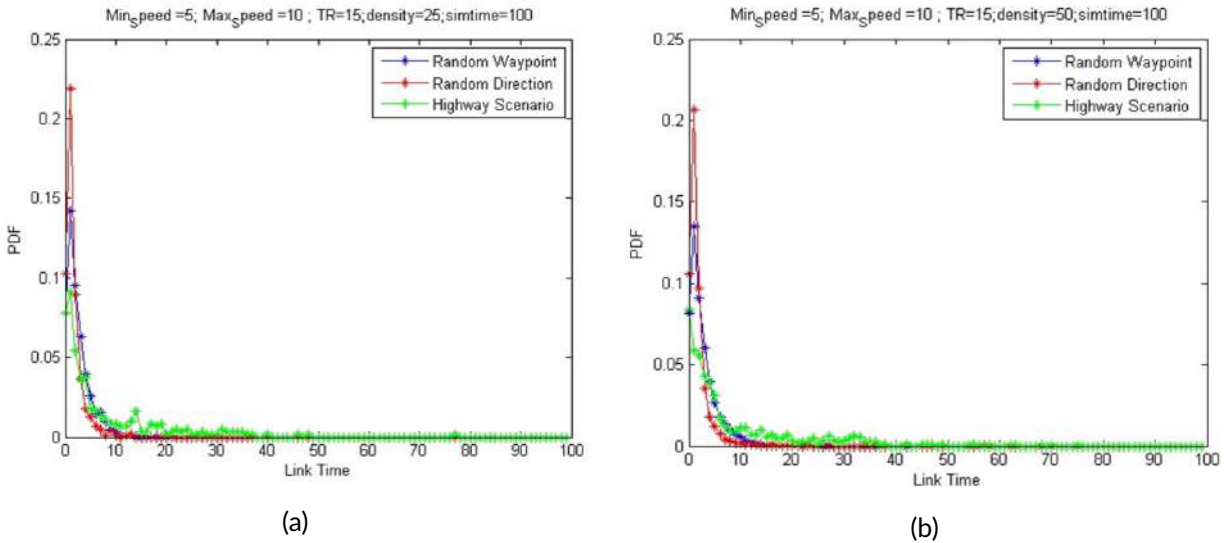


FIG. 6 Behavior of changing node density with low transmission range and mobility.

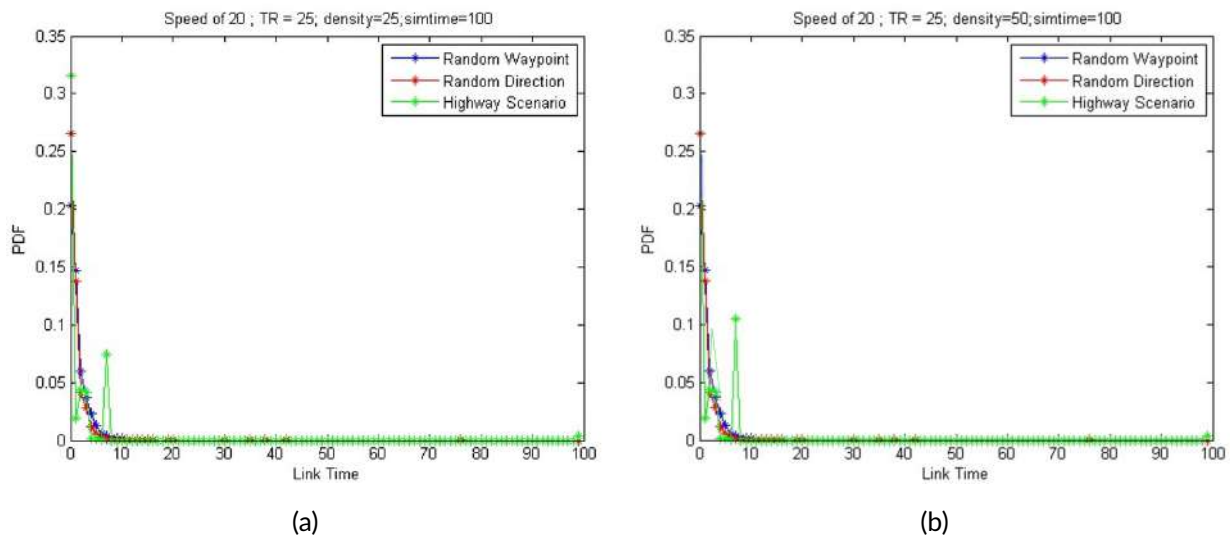


FIG. 7 Behavior of changing node density with moderate transmission range and mobility.

In the above-mentioned scenario, the low mobility ranges from 5 m/s to 10 m/s with a transmission range of 15 having a node density of 25 and 50. Fig. 6 (a) and (b) shows the clear difference as shown in the figure. RWP has a low probability of 4% to 6% of maintaining a connection for a time period of 2 seconds. RD has a low probability of 7% to 15% of establishing a connection for 2 seconds. Highway scenarios have a low probability of 7% for 1 second. In conclusion, the chances of establishing a connection for a longer period of

time are very low.

| Scenario 2: Moderate Transmission Range and Mobility

In the above-mentioned scenario, the low mobility ranges from 11m/s to 20 m/s with a transmission range of 15 having a node density varying from low to high 25 and 50. Fig. 7 (a) and (b) show the clear difference as shown in the figure.

| Scenario 3: Moderate Transmission Range and High Mobility

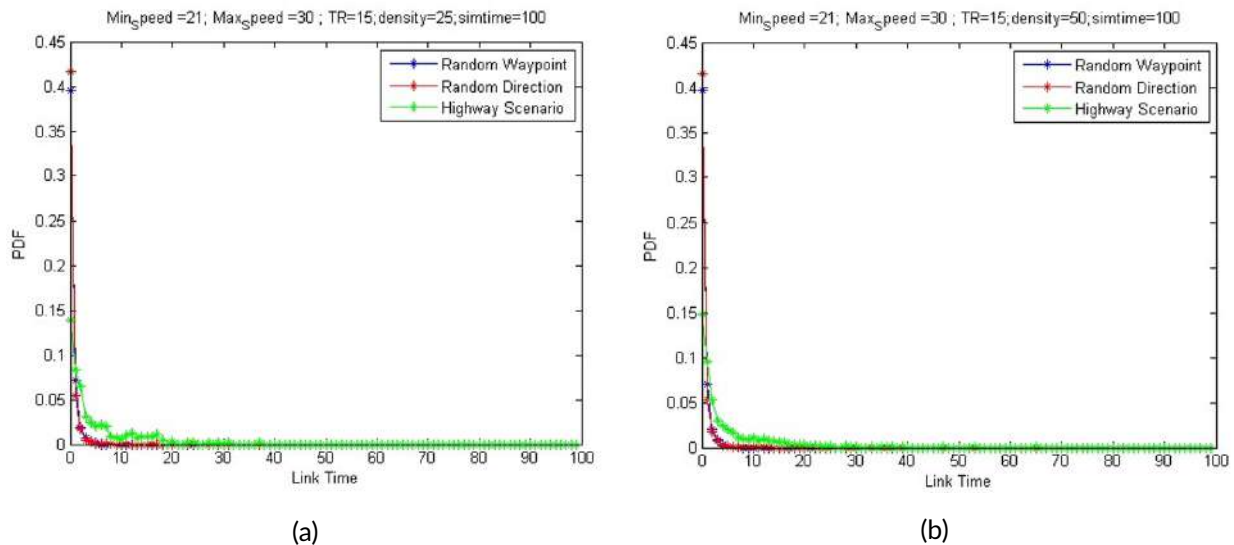


FIG. 8 Behavior of changing node density with moderate transmission range and high mobility.

In the above-mentioned scenario, the high mobility ranges from 20m/s to 30m/s with a low transmission range of 15 having a node density of 25 and 50. Figures 8 (a) and (b) show the clear difference as shown in the figure.

7 | CONCLUSION

For many researchers, the application area of the Mobile Ad Hoc network made this area very interesting. Monte Carlo simulation-based study has been executed to examine the network connectivity by creating many scenarios in this manuscript. Using three different mobility models time probability has been examined and determined. These models play a dynamic role in link simulation among the nodes. This manuscript concludes that the mobility models are capable to find the duration of the link with a value of PDF and in link duration, the important factors are speed, range, pattern, and transmission of mobility. Furthermore, the density of the nodes upsets the link quantity. Speed of mobility disturbs link duration probability. A multiplicity of happening over a long time period increases with an increase in transmission range in all mobility models. Considerably, the mobility pattern affects the duration of link probability. Similarly, RWP shows less probability as compared to the other two models and shows computer complexity. RD shows range in PDF in very low mobility cases. The best results are achieved in the freeway model. In all scenarios and cases, this model shows the probability of the occurrence of any event of the duration of the link. RD and the freeway model have moderate complexity. RWP and RD both are skewed while the last model show dominancy in creating the scattering and Gaussian behavior.

Declaration of Interest

The authors declare that there is no conflict of interest.

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