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A Hybrid Link Reliability Model for Estimating Path Reliability of Mobile Ad Hoc Network

B. Venkata Sai Kumar[a], N. Padmavathy[a,*]

[a]*Vishnu Institute of Technology, Bhimavaram (AP), 534202, INDIA*

Abstract

Mobile ad hoc networks includes self-sustaining mobile nodes that are self-making with no predefined foundation and buildup associations amongst themselves to develop exceptionally powerful topologies due to the nodes mobility in the network. Therefore, due to mobility of the nodes the wireless links may establish (disestablish) implying that the probability of successful communication increases (decreases). Most of the researchers have observed the network performance using binary model of communication links based on Euclidean distance between nodes and the radio range of the mobile nodes i.e., a free space model or line of sight model. In general, signal can reach the destination through different paths and in such cases the signal strength decreases between nodes due to various atmospheric effects such as noise, fading or interference as the distance increases. In this paper, the proposed methodology uses the free space two ray ground propagation model to determine the connectivity of the network during mission time, which helps in determining the network performance (average hop count and path reliability) of the network through simulations in MATLAB. The obtained results shows that the reliability of a homogeneous mobile ad hoc network reduces because of propagation of the signals. Though the reliability values are less, the network is still reliable and it gives an idea for the user to deploy the mobile ad hoc network in a suitable terrains.

* Corresponding author. Tel.: +91 9441703866
E-mail address: padmavathy.n@vishnu.edu.in

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1. Introduction

With the extensive quick growth of the wireless communication, the mobile computing has already turned into the field of computer communications in a high profile link like ad hoc networks. These can sustain different applications like disaster relief (e.g., floods, earthquakes); search and rescue operations; law enforcement; military tactical operations; distributed mobile computing (e.g., sensors, conferences); warfront activities; and communication between automobiles on highways [1]. Mobile Ad Hoc Network (MANET) is a completely wireless in nature; the wireless connectivity formed by the nodes itself usually has a random nature with a limited bandwidth. MANET is an autonomous system in which mobile nodes place themselves consistently for time to time over a dynamically changing environment without a centralized controller (administration). They are connected by wireless links that are free to be move randomly and form dynamic topology in a given coverage area [2]. The wireless links between nodes are assumed to have failed when either the distance between the nodes are beyond the specific transmission range of each node, or it may be due to some other reasons like mobility, interference and highly dynamic topology. Nodes can easily depart or arrive newly in the coverage area because of their random nature and these can act as router/host to communicates or forward packets.

The propagation of signal/communication between users can be done by two ways. First, there is a chance of direct connection between source and destination known as Free Space Propagation (FS). FS can be used in short distances for communicating with other over radio channel. Another, there is a chance of signal reaching the destination via different routes by hitting the obstacles if any, and is known as Two Ray Ground Propagation (TRG). This propagation analysis has been discussed in [2-8] and is used for long distance communication. In general, most of the researchers have developed algorithms to analysis the network performance (hop count, path reliability) considering free space propagation only. But in reality, signal randomness generally occur over the channel due to various conditions is considered in free space propagation. This has adverse effect on connectivity due to the radio propagation in atmosphere. Thus, there is a necessity to consider the signal randomness. In this paper, the combination of free space and two ray ground propagation models known as a hybrid model, a FSTRG propagation model [8] is taken into account for evaluation of the path reliability. This is the most convenient method or model for any signal analysis in the wireless communication to study the link connectivity. Link reliability model is a most popular model to give the exact or realistic analysis of the signal for observing the network performance in mobile ad hoc networks. Basically in wireless communications radio propagation varies significantly depending on the frequency of operation and the terrain [8].

Normally, the communication between two users are connected directly (single hop) or indirectly (multiple path) to form connectivity. Network connectivity describes the connection between any two nodes in the network. Connectivity depends on radio range (or) transmission range (r_j) of the nodes and distance (d_{ij}) between them and the propagation parameters (δ, γ) [8]. Link existence can be determined by using link reliability model based on FS-TRG model [8]. Nodes that are within the transmission range of one another are called neighbors. In general, each node have specified transmission range (r_j), and for effective communication between any two nodes the condition is that the distance (d_{ij}) between nodes need to be lesser than the nodes' transmission range. Whenever, the distance increases then there would be occurrence of partial connection between source and destination. Further, increasing the distance more and more between source and destination (n_i, n_j), the connection amongst the nodes are lost, which means the disconnection happen between nodes. That is the network may be connected (disconnected) because of the nodes mobility.

Because of the unpredictable node movements and dynamic property of MANET, maintaining the stability in the network connectivity [10] has always been an scary challenge. The unstructured nature of the network topology is due to the frequent occurrence (non-occurrence) of links; nodes failures which exists due to interference; mobility; radio channel effects; and battery limitations thus making connectivity one of the major problems of ad hoc networks. A (s-t) pair direct connectivity is a single hop connection, and if connected through nodes other than direct (s-t) pair is a multi-hop connection.

Hop count is the measure of the number of hops in between specified source and destination nodes or the number of hops (links) associated with the path between the source node and the destination node. It is indirectly consistent with connectivity because the hop count depends on node's transmission range. As the hop count increases, the link existence among all nodes increases then there will be a chance for data loss increase. As a result the network performance degrades. The hop count dynamically changes instant to instant with high mobility [11]. The single hop connection or multi hop connection in between source to destination is the representation of a path. In addition to connectivity and hop count, it is necessary to consider the path reliability for understanding the performance of network. Hence another aspect for determining the performance analysis of ad hoc network is path reliability and is defined as the grouping of the probability of successful communication and number of hops between the defined node pairs.

In this paper, the proposed algorithm explains the use of FSTRG link (hybrid model) reliability method other than the binary model of communication. Random way point mobility model is used for uniform random distribution of the mobile nodes in the given coverage region. Finally, the average hop count and path reliability under different scenario metrics has been evaluated. The obtained results show some improvement in the path reliability and hop count by reducing the redundant paths in between the source and destination.

The remaining part of this paper is organized as follows; a brief literature has been emphasized in Section II. Section III, gives the link reliability model, generation of the connectivity matrix and evaluation of the hop count and path reliability. The algorithm based flow chart to compute the network reliability of MANET is discussed in Section IV. A clear discussion on consideration of simulation parameters and the results has been emphasized in Section V and Section VI. Section VII concluded this work.

Nomenclature

δ	free-space propagation parameter
γ	two-ray ground propagation parameter
ϕ	direction
A_{ij}	adjacency matrix
$Avghc$	average hop count
C_{ij}	connectivity matrix
d_{ij}	Euclidean distance between any two nodes
L_{ij}	Status of a link
N	Network size
r_i	node reliability
r_e	path reliability
r_j	nodes' transmission range
$R_l\left(d_{ij}(\tau)\right)$	link reliability at time instant τ
L	number of links
(x, y)	node locations
Q	number of simulation runs

2. Literature Survey

Several researchers have proposed several algorithms or approaches to analyze the network performance of MANET. Methods related with connectivity and hop count evaluation of the network has been reported in the several literatures. Connectivity between nodes is the main consideration in mobile ad hoc networks for measuring the network performance. To learn about the connectivity in mobile ad hoc networks, each network should be well known along with parameters like transmission range (r_j), propagation medium (environment), and mobility. The network connectivity is affected mainly due to the propagation channel in the given coverage area. Then, there is a possibility of the links to fail while the mobile node moves. Hence, the probability of successful communication decreases.

Plentiful of researches [2-8] have developed some algorithms based on the link maintenance for establishing connectivity in the analysis of network performance. Authors in [2] studied the performance of ad hoc networks based on link reliability measurement. Two other models in the determination of link reliability [3], has been proposed. One model assumed that, the information reaches the destination with minimum transmitted power level in between source and destination; another model is the link reliability is a function of radio range of mobile nodes, channel fade state and distance between nodes. Using these models the reliability analysis for path between source and destination has been performed in [4]. In addition, [4] is applied on multi hop wireless broadcast networks to find the optimized link reliability [5] between a successive node pairs by considering transmitter power, distance and signal to noise ratio. A conditional probability link reliability model [6] used for developing a path reliable routing protocol based on statistical analysis of its lifetime has been proposed.

Propagation based models have been evaluated for static and dynamic networks in [7]. Authors in [8] evaluated the network reliability using propagation based link reliability model. A majority of the authors have proposed different connection unwavering quality models that have been applied on MANET for improving connectivity, maintaining a strategic distance from the availability issues and deciding a reliable path. Similarly for link reliability algorithms, most of the researchers [9-14] have concentrated and developed algorithms on network connectivity. The connectivity can be affected by various environment conditions like fading, noise and interference. The authors proposed an algorithm for better connectivity of different networks in the shadow fading environment [9]. An algorithm for determining the connectivity in static networks after generating the adjacency matrix and also computing the reversible path between source and destination node pair using matrix based backward route discovery process has been done [10]. But the algorithm also finds the hop count even for no connection of static networks. Adjacency matrix formed based on the distance and transmission range of nodes gives the links between nodes, by using which the connectivity matrix can easily be determined.

The authors of the proposed work modified the algorithm [10] for evaluating the connectivity between node pair and develop a systematic approach for analyzing hop count and path reliability to observe the network performance considering mobile networks [11]. All the nodes are uniformly distributed and are independent in a closed region. The generic formula for the probability of connectivity for one dimensional and two dimensional ad hoc networks derivation can be found in [12]. Author [13], studied about the connectivity in networks and give some comments and complementing their results regarding the connectivity evaluation. The statistical variations of the radio signals caused by the obstructions and irregularities [14] in the surroundings have been observed. A model that explains hop count statistics [15] under the shadowing condition and small-scale fading is addressed. The close form of hop count distribution in multi hop wireless network [16] with arbitrary node distribution and routing scheme is deduced.

Two efficient models [17] have been used to derive and estimate the operational path in between (s-t) at a particular time instant. Over the past few years, tremendous research has been in existence that helps in understanding the MANET behavior in terms of the hop count analysis; throughput; delay, connectivity and the protocol based route discovery process [18]. A cluster based multi dynamic source routing method [19] to evaluate path reliability in MANET has been developed.

Now-a-days, researchers are mainly focusing on the reliability of the MANET and referred estimation of reliability from [20-22]. The research paper [20] highlighted and elaborated on the imperative challenges, modeling of MANET (Evolving graph model, Geometric random graph model) etc. The authors [20] developed a reliability approach [21] considering the node movements and dynamic, frequent changes in the network connectivity to evaluate the network reliability of MANET. The extension of [21] is [22], where the authors evaluated the MANET reliability using propagation based link reliability model, since the binary model do not consider the signal randomness. And finally the authors Camp et al., (2002) [23] provided various types of mobility models for the distribution of nodes in ad hoc networks. Here the discussed literature gives that, the connectivity between nodes is one of the most important network feature and has significant impact on network connectivity. Hence a realistic approach for measuring hop count and the path reliability in terms of the connectivity using hybrid model has been proposed.

The main contributions of this paper as follows,

- A frame work of analyzing basic features like connectivity, hop count and path reliability using link reliability analysis has been developed.
- The changes occurring in the hop count and path reliability with changing scenario metrics and changing the propagation parameters δ and γ has been figured out.

3. Proposed Methodology

The network considered in this work contains mobile devices which are randomly distributed in a coverage region. The mobile nodes have no idea of their locations (*x*, *y*). All these devices can be moved to other locations based on applied mobility model. In this work, random way point mobility model has been considered. The mobile nodes can only communicate with the nodes in its neighborhood. The link existence (either directly or indirectly) between nodes is derived by using link reliability model. The description of the link reliability model has been discussed in detail in Ref [8].

Link reliability model

The link reliability model mainly depends on propagation of signal. The signal propagation contains either free space (line-of-sight) or two ray ground propagation (non-line-of-sight). Hence, the proposed model is a hybrid model. Link reliability model is defined as a function of distance and the reliability of links (1) can be modeled as follows,

$$R_l\left(d_{ij}(\tau)\right) = \begin{cases} 1 & for\ d_{ij}(\tau) \le \delta r_j \\ \left(\delta^2/_{1-\delta^2}\right)\left(\frac{r_j^2}{d_{ij}^2(\tau)} - 1\right) & for\ \delta r_j \le d_{ij}(\tau) \le \gamma r_j \\ \left(\delta^2\gamma^2/_{(1-\delta^2)(1+\gamma^2)}\right)\left(\frac{r_j^4}{d_{ij}^4(\tau)} - 1\right) & for\ \gamma r_j \le d_{ij}(\tau) \le r_j \\ 0 & for\ d_{ij}(\tau) \ge r_j \end{cases} \quad (1)$$

Hence, the link existence (non-existence) satisfies (not satisfies) any one of the conditions as given in (1). The link status $L_{ij}(\tau)$, can be determined.

$$L_{ij} = \begin{cases} 1\ \ if\ R_l\left(d_{ij}(\tau)\right) \ge 0.5 \\ 0\ \ if\ R_l\left(d_{ij}(\tau)\right) < 0.5 \end{cases} \quad (2)$$

The link status (2) denotes, that a link is formed when the link reliability parameter is always less than a threshold (equal to or more than 0.5), else no link is formed. The process considers the signal randomness in the transmitted signal.

1.1. Generating Adjacency Matrix and Connectivity Matrix:

The general representation of the adjacency matrix can be written as

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1M} \\ a_{21} & a_{22} & \cdots & a_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ a_{N1} & a_{N2} & \cdots & a_{NM} \end{bmatrix} i = 1,2,3, \dots N; j = 1,2,3, \dots M. \quad (3)$$

The topology or the nodes links in ad hoc network can be modeled as an adjacency matrix. In [10] an algorithm has been proposed for determining the connectivity matrix (4) in ad hoc networks based on the adjacency matrix (3). The connectivity matrix (4) is written as

$$C_{ij} = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1M} \\ c_{21} & c_{22} & \cdots & c_{2M} \\ \vdots & \vdots & \ddots & \vdots \\ c_{N1} & c_{N2} & \cdots & c_{NM} \end{bmatrix} i = 1,2,3, \dots N; j = 1,2,3, \dots M. \quad (4)$$

Determination of Average Hop Count and Path reliability:

Hop count and path reliability are determined from the connectivity matrix. The connection from source and destination has been provided from the connectivity matrix (C_{ij}). Then, the estimation of hop count is based on how many nodes are associated in between the source and destination connection. The mobile ad hoc networks are operated for certain period of time. In this period of time they generate different network topologies. Each of the topology has different hop counts. The average hop count during mission time Q (total number of simulation runs) is estimated as the network performance measure. The average hop count is determined by using (5)

$$Avghc = \frac{\sum(Hop\ counts\ for\ available\ paths\ during\ mission\ time)}{Q} \tag{5}$$

The path reliability is found by using C_{ij} for analysis of the network performance. All the mobile nodes in the network are considered as homogeneity in nature. Hence the reliability of the nodes to be fixed at a particular time instant and can be shown as given in (6),

$$p(n_i) = r_i\ \forall\ i = 1\ to\ N \tag{6}$$

At each instant, all the paths for an instantaneous topology are determined and amongst all paths, the shortest path is chosen by eliminating all the redundant paths. The product of the node reliabilities known as path reliability of nodes involved in the path from source to destination is mathematically represented by (7)

$$r_e = \frac{\sum Shortest\ path\ reliability}{Q} \tag{7}$$

Moreover, at some instances for certain topologies connectivity may not exist and hence the hop count and path reliability is zero for such topologies [11].

4. Algorithm

The detailed discussion of the algorithm is pictorially represented in the flow chart (Fig. 1) as shown below. The above steps of the algorithm have been implemented using Matlab®R2012a on Windows®8.1 pro running @ 2.00 GHz.

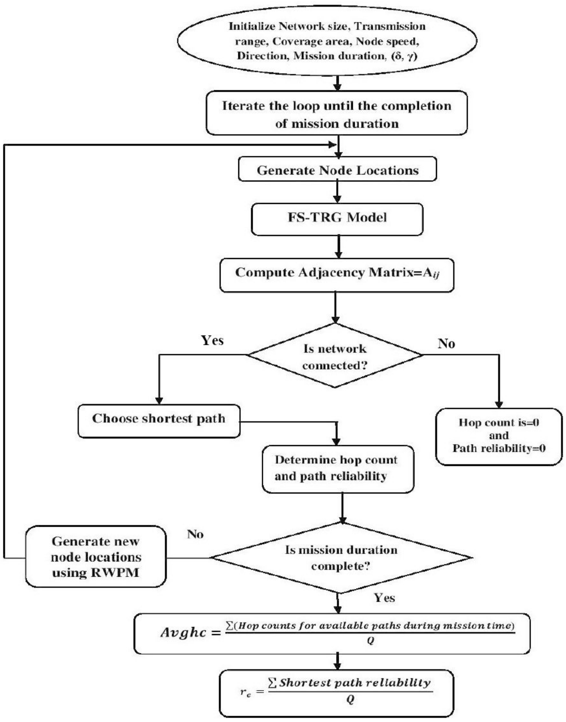

Fig 1: Flow Chart for Estimating the Hop Count and Path Reliability using FSTRG model

The topology of the ad hoc network is modeled by geometrical random graph G (N, L). The algorithm follows by calculating link reliability based on distance and transmission range rj and propagation parameters (δ, γ) using (1). The link status is determined using (2). All possible paths are determined with the knowledge of the link status; followed by finding of hop count to derive the shortest path. The computations end with the evaluation of the path reliability and the process repeats for every time instant as long as it does not exceed the mission duration.

5. Simulation Parameters

The node distributions, mobility of the nodes and procedure for analyzing the path reliability and hop count have been implemented in MATLAB. Network size N, and propagation parameters (δ, γ) have been considered. In addition to above, some important parameters and assumptions as shown in table 1 has also been considered for this study.

Table 1: Simulation parameters considered for the study

Parameters	Specifications
Network Type	Homogeneous
Radio range (r_j)	1 to 8 Miles
Geographical area (D)	25-400 Sq. Miles
Node reliability (r_e)	0.9
δ	$0 < \delta \leq 1$
γ	$\delta < \gamma \leq 1$
Mobility Model	RWPM
Maximum Speed (V_{max})	6 mph
Minimum speed (V_{min})	3 mph
Direction (ϕ)	0-360°
Pause time	1hr
Mission duration (*tMission*)	72 hrs

6. Simulation Results

In this paper, a simulation has been performed to study the effect of hop count on path reliability considering the propagation effects. The proposed algorithm determines the shortest path hop count between the (s-t) nodes after determining all possible path sets in MANET. In addition redundant paths are also eliminated. The algorithm generates the random location of the MNs. The algorithm operates under different scenario conditions and propagation parameters (δ, γ). From the results, it is significant that when (δ, γ) = 1, the path reliability is same as the reliability of binary model or free space model. Further the maximum achievable reliability has been attained when (δ, γ) = 1. The path reliability for 10 node network when (δ, γ) =1, is 0.7446 and the reliability is reduces to 0.5548 when δ = 0.6, γ = 0.8. The average hop count increases by 63% and path reliability increases by 48% of its initial value when δ = 0.2, γ = 0.8 as seen in Fig. 2 and Fig. 3. The AHC decreases in the case of a network with larger size because very often majority of network topologies are single-hop (direct) network i.e., the chances of direct connectivity between the source and destination is high.

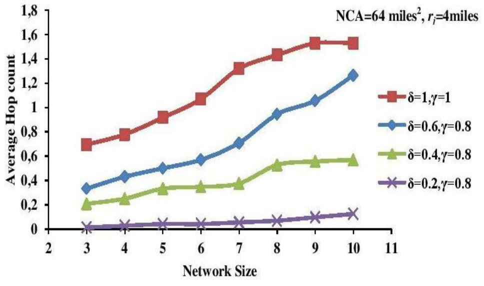

Fig 2: Network size Vs Average Hop count

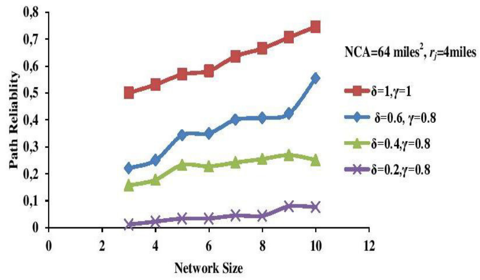

Fig 3: Network size Vs Path reliability

Moreover the nodes are densely populated in the defined simulation boundary of 64 sq. miles. From Fig. 2 and Fig. 3, it is visible for a network size (say N = 3 to 5) the number of connected topologies are less or sometimes connectivity fails and hence the path reliability is < 0.6. Further, as the network size increase, quite opposite to the above, the probability of connectivity is high giving path reliability > 0.6. However, the path reliability for a node reliability of 0.9 will never be greater than that of 0.81.

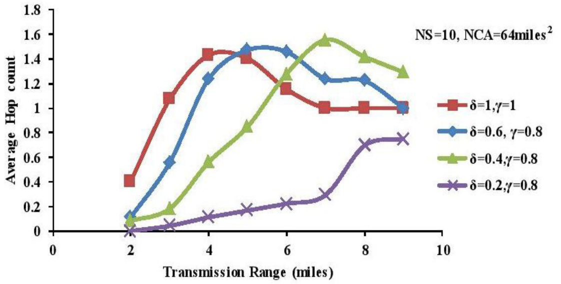

Fig 4: Transmission Range Vs Average Hop Count

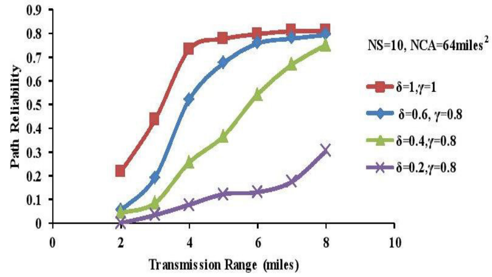

Fig 5: Transmission Range Vs Path Reliability

With changing transmission range, the performance metrics are like, when propagation parameters are δ = 0.6, γ = 0.8 the path reliability and average hop count are less compared with (δ, γ) = 1 (see Fig. 4 and Fig. 5). The majority of the network topologies are developed when the propagation parameters are equal to 1. There after still reducing the propagation parameters to ((δ, γ) = (0.4, 0.8) and (δ, γ) = (0.2, 0.8)), the connection will drops to 0. Hence, the obtained average hop count and path reliability are very small. This indicates that an optimum choice of the propagation parameter is essential to have better performance. The proposed FSTRG algorithm provides a best performance when (δ, γ) > 0.6.

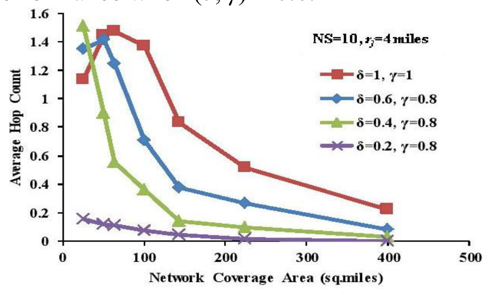

Fig 6: Network coverage area vs Average Hop Count

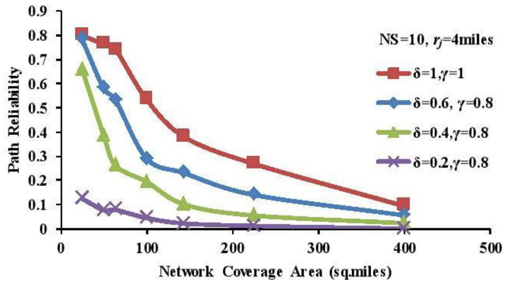

Fig 7: Network coverage area vs Path Reliability

For the case when (δ, γ) = 1, the obtained path reliability and average hop count falls drastically by almost 98% (see Fig. 6 and Fig. 7). Though the hop count falls, it does not mean that communication fails. Since available path is still reliable to help for communication to take place. Similarly, the average hop count reduces by 81% when δ = 0.6, γ = 0.8 because of lesser connectivity. For any case, the effect on the hop count and path reliability by varying scenario metrics and propagation parameters are observed and analyzed.

7. Conclusion

In this paper, a propagation based link reliability model (FS-TRG) is established instead of free space or binary model of communication for observing the signal randomness and for the evaluation of the performance measures such as connectivity, average hop count and path reliability has been proposed. Link reliability model for ad hoc networks have been used for real measurable parameters that are concerned with performance of mobile ad hoc networks. Therefore, the develop algorithm considering propagation parameters (δ, γ) through obtained results help the reader to understand the network performance in terms of path reliability. However the FS-TRG is most realistic approach and has provided the better performance of mobile ad hoc network. In present work, uniform random distribution of node locations in the coverage area, the network is homogeneous of nature, no repair has been considered. Hence, the proposed work can be extended by considering heterogeneity of the network, repairs and non-uniform distribution for studying the effect of hop count on path reliability of mobile ad hoc networks.

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