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A Systematic Approach for Evaluating the Reliability Metrics of MANET in Shadow Fading Environment using Monte Carlo Simulation

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Abstract: Several researches on reliability studies of ad hoc network, assumed that the communication links between any two mobile nodes exist if the Euclidean distance between them is not greater than the transmission range of the nodes. These methods are purely distance-dependent models and the randomness in the signal strength in radio communication is not taken care-off. This way of modeling the channel for reliability studies may be intuitively a valid theoretical study. However, the wireless channel can be modeled in a more realistic manner by considering the randomness caused due to shadowing effects. In this paper, we characterize the connectivity of the MANET in a log–normal shadow fading environment. The simulated results are of practical significance for the design of MANET and offers insights into how the channel randomness has been considered for the MANET reliability evaluation through Monte Carlo Simulation approach to depict the impact of shadowing deviation

Keywords: *Mobile Ad Hoc network, Monte Carlo Simulation, Fading, Log-Normal Shadowing, Network Reliability*

Notation

θ	Scale parameter of Weibull failure distribution of the node
β	Shape parameter of Weibull failure distribution of the node
ϕ	Direction of node movements in radians
ξ	Shadowing Parameter
η	Threshold receiver power
σ	Standard Deviation
γ	Path Loss Exponent
$\Delta\tau$	Incremental change in time
D	Network Coverage Area in square distance units
$2TR_m$	MANET 2-terminal reliability
$A(\tau)$	Connection matrix at time τ
$AoTR_m$	MANET *All-operational* terminal reliability
ATR_m	MANET *All*-terminal reliability
B	Uniform random number between (0, 1)
d_0	Reference Distance
P_0	Received Power at a reference distance d_0.

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P_r	Actual received power in FS
$P_{r,sh}$	Received power due to shadowing
Q	Total number of simulation runs
Q	One complete iteration of Q number of simulation runs.
$C_q(\tau)$	Network status at time τ at the q^{th} iterations of simulation cycle
L	$\{l_1, l_2 \dots l_p\}$: set of p links
U	$\{u_1, u_2 \dots u_n\}$: set of n mobile nodes
$G(U, L, \tau)$	A network graph
K	Set of $k \subseteq U$ nodes in $G(U, L, \tau)$
$(G\|k)$	Network derived from $G(U, L, \tau)$ by setting the success probability of the k nodes of equal to 1.
$d_{ij}(\tau)$	Euclidean distance between node u_i and node u_j at time τ
$\hat{d}_{ij}(\tau)$	Normalized Euclidean distance at time τ
$L_{ij}(\tau)$	Link Status between node u_i and node u_j at time τ
$R_G(\tau)$	Reliability of MANET at a particular instant of mission time.
$R_l(d_{ij}(\tau))$	Link Reliability at distance $d_{ij}(\tau)$
$R_{u_i}(\tau)$	Reliability of node u_i at time τ
r_j	Transmission range of a node u_j in distance units
$\hat{r}_j$	Normalized Transmission Range
(s, t)	Source-Terminal Pair
tMission	Mission time in time units
$u_i(\tau)$	Status of the i^{th} node at time τ
$Var(R_G(\tau))$	Variance of $R_G(\tau)$
V_{max}	Average maximum node speed
V_{min}	Average minimum node speed
$(x_i(\tau), y_i(\tau))$	Position of node u_i in XY-plane at time τ

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1. Introduction

Mobile Ad hoc NETworks (MANET) is a group of mobile nodes (MN) which can communicate with each other over a wireless channel. In these networks, the mobile nodes are randomly distributed and are free to move and organize themselves as an arbitrary/ dynamic topology and establishing connectivity either as a single-hop/multi-hop in a decentralized fashion in some deployed environment. Each node in the network can function as router to communicate with the destination node whenever a single-hop communication is not possible. These networks become essential when no infrastructure is available or viable (i.e., unplanned networks, network in remote areas, or after disaster). In general, the ad hoc networks face several challenges, such as dynamic topology, resource constraint, bandwidth management etc., thus making its design quite complicated [1]. Due to the dynamic characteristics of these networks, the links of the network are unstable because of the randomness in the wireless channel (e.g., fading, shadowing or noise) which affects the network performance significantly [2].

The MN moves around the deployed environment at a randomly chosen velocities and travel in various directions. As these MN move around the deployed area the radio wave propagating between the transmitting node and the receiving node passes through many types of obstacles (say, trees, buildings, moving vehicles, human beings etc.) and hence the communication between the MN gets scattered, reflected and dissipated leading to path loss. This unique phenomenon is called fading. Fading is one type of signal degradation which is characterized as a non-additive signal disturbance in the wireless channel. Fading is one factor that has significant effect on the connectivity of the network and therefore connectivity is the prerequisite to measure the network reliability [3].

The reliability of a network is defined as the probability of the network to operate over a specified period of time. [4] Addressed that reliability of a network depends on the reliability of its nodes and links as well as the network topology. Network reliability has been concerned with the interconnectivity between the entities in the network or graph. Network reliability has become an important criterion for any system viz., telecommunication system (wired/wireless), distribution system, computer networks etc., because of the growing demand for a reliable communication. According to [3], reliability can be quantitatively defined as the probability that there exists at least one feasible path between a specified set of k-nodes under predefined conditions. Among the several measures, All-terminal, 2-terminal and k-terminal reliability have been the three important measures used in assessing the performance of the infrastructure based network. The 2-terminal (terminal-pair/s-t) reliability is the probability that a specified pair of nodes (the source s and the sink t), with known success/failure probabilities of its elements, remain connected by a path of operating nodes and links. Terminal reliabilities measures have been used quite long for reliability studies that have become important and extended in new areas of reliability research such as mobile ad-hoc wireless networks, grid computing systems, and telecommunications [5] and large scale system like Benes network [6].

A sum-of-disjoint product (SDP) technique over paths was proposed [7] to evaluate the reliability of wireless communication networks and their results depict that the SDP technique solves the reliability measure in polynomial time. Using binary decision diagram and integration of progressive reduction scheme with divide-and-conquer approach, the authors [8] evaluated the reliability of infrastructure wireless sensor networks. Infrastructure communication Reliability metrics for wireless sensor networks was developed and performed analysis on WSN with tree topology [9] under different delivery modes (unicast, anycast, multicast, manycast and broadcast). In [10], authors have provided the attributes of a MAWN whose configurations are known a priori and explained how the classical analysis of network analysis can be extended to analyse dynamic networks. An analytical formula and derivation for the 2-terminal reliability evaluation of MANET was provided and done by considering the probabilistic link existence and further finally validated their analytical approach using MC-based methods. In [11], two-terminal reliability is evaluated as the sum of i- hop connectivity through (n-1) and also mathematical expressions are provided for determining the 1-hop and 2-hop connectivity of the network. The authors [12] addressed that the system reliability analysis depends on estimation of failure parameters at component level considering the working scenarios of sensor nodes like sleep, active (transmit, receive and idle) behaviour.

All-terminal (or global) reliability requires that every node be able to communicate with every other node in the network. k-terminal reliability requires that a specified set of k target nodes be able to communicate with one another. k-terminal reliability reduces to 2-terminal reliability when k=2 and to all-terminal when k = n. The probability that all the operational nodes can communicate is termed as all-operational terminal reliability [13]. Reliability is one of the factors that contributes to successful functioning of a network design and depicts the overall performance of the network. Similar, notions have been extended to MANET as well.

Connectivity studies have been extensively carried out using Geometric Random Graphs, which is also appropriate for modelling MANET [14, 15]. In most of the research work it is assumed that the communication links between any two mobile nodes exists if the Euclidean distance between them is not greater than the transmission range of the nodes i.e., FS model/binary link model [16, 17]. Authors of [13] addresses that the probability of successful communication between the nodes decreases with distance, considering the fact that the signal strength deteriorates with distance even up to the transmission range of the MN due to noise or interference. The authors used FS-TRG propagation model to model the link existence. The above mentioned models [13, 16, 17]; are the simplest model of channel propagation and also are purely distance-dependent models which do not consider the randomness present in the radio communication. This way of modelling the channel for reliability studies may be intuitively a valid simulation study. However, the wireless channel can be modelled in a realistic manner by considering the randomness in the signal strength caused due to shadow effects.

Channels modelled based on shadow fading are used in several studies, say, in connectivity analysis, protocol studies etc. [18-21]. This paper addresses the effects of shadow fading on reliability. By considering fading, we can say that the distance between the nodes is not the only parameter to determine the existence of the link. Ref. [22] defined that the probability of link existence is as a function of transmission range, power attenuation factor and distance between nodes. That is, the link existence is modelled as a function of the distance between the mobile nodes and the ratio between the standard deviation of shadowing and the path loss exponent, ξ. Due to the random strength, possibly two events can occur i.e., a link between two nodes can exist when the distance between them dij is more than rj and no link exist between nodes when nodes are located within rj [18].

In this paper, a Monte Carlo simulation (MCS) approach is proposed for the evaluation of network reliability of MANET where nodes move according to random waypoint mobility model (RWPM) and their failure is governed by a known statistical distribution; the link reliability is modelled based on log-normal shadowing model. Geometric random graph in combination with log-normal shadowing model is tailored to model the mobile ad hoc network. Under the assumption that at any instant of time, the network topology will be momentarily fixed, and the basis of our proposed approach is that the reliability of the network at that particular instant can be computed as the product of reliabilities of $k \subseteq U$ imperfect nodes and reliability of the network with $k \subseteq U$ perfect nodes.

The organization of this paper is as follows: Section 2 explains the theoretical concepts of the proposed channel model and Section 3 briefs the description on the methodology adopted. Section 4 states the assumptions made for network modelling; Section 5 describes the algorithm that is used for the evaluation of the network reliability. In support to section 5, a numerical example is illustrated in section 6 followed by extensive simulation results. Finally, the conclusions of this work are summarized in section 7.

2. Theoretical Concepts

In wireless communication, one can use free space (FS) propagation model when the MN are within the vicinity of each other (or in open area with small distances i.e., in Line-of-Sight). However, in realistic mobile radio channels the FS propagation is not the appropriate medium [23]. In such cases the MN can communicate with the other MN through indirect paths or in multi-hop fashion. To have communication for longer distances, the two-ray ground (TRG) propagation model is used. The TRG propagation has one direct path and one reflected path/multipath. As the radio waves propagates from the transmitter to the receiver in space, various signal corruptions occur due to multiple factors like obstacles (like buildings, trees), environment scenarios (like temperature, humidity), fluctuations in signal amplitude, phase and angle of arrival. This implies that the signal attenuation/fading has a significant impact on the topology due to location change of the MN leading to a considerable effect on the link states [20]. In other words, by considering fading, we can say that the distance between any two nodes is not only sufficient to determine the link status and hence the connectivity properties changes, making the connectivity analyses more complex [18].

Depending on the environment, the surroundings, and the location of the MN, the received signal strength of the MN will vary even when it lies at a same distance from the source node. This variation in signal strength is called shadow fading. The variations in radio signal power at different locations with the same distance (dij) to the receiver are assumed to be random and independent [19].

2.1 Radio Model

The radio link model is generally assumed such that each node can communicate directly via wireless link within a certain transmission range. This model corresponds to a path loss propagation model wherein the received signal power is a decreasing function of Euclidean distance, dij, between the transmitter-receiver pair. Further, the path loss (signal attenuation) can be represented by a power law [24] as given in equation (1).

$$P_r = P_0 \left(d_0 / d_{ij} \right)^{\eta} \tag{1}$$

where, P_r is the actual received power, P_0 is the received power at a reference distance d_0 (the reference distance d_0 is typically chosen to be 1 m in indoor environment and 100 m or 1 km in outdoor environment [25]), and η is the path loss exponent that varies between 2 (FS) to 6 (heavily built urban environment) and higher values of η indicate faster decay of radio signals i.e., severe randomness in received power of the radio signal [26].

The most commonly used radio propagation models viz., FS model or the TRG model is based on the path loss phenomenon in which the received power variation is equal to the area mean power. In other words, these models predict the mean received power as a deterministic function of distance [27, 28]. Modelling this way would be unrealistic since significant received power varies generally around the area mean power value. This variation has significant impact on network topology which is affected by the impairments over the radio links [26]. Hence in reality, the received power at certain distance is always a random variable due to fading effects and is termed as shadow model. The log-normal shadowing radio propagation model, a more sophisticated channel model [29] is represented as

$$P_{r,sh} = P_0 \left(d_0 / d_{ij} \right)^{\eta} 10^{x/10} \tag{2}$$

Substituting (1), we get

$$P_r = P_{r,sh} 10^{x/10} \tag{3}$$

Equation (3) is represented in decibels as

$$10 \log_{10} \left(P_{r,sh} \right) = 10 \log_{10} \left(P_r \right) + x \tag{4}$$

where, x is a zero-mean Gaussian [27] distributed random variable (in dB) with a standard deviation σ (in dB). The standard deviation is larger than zero and is a maximum of 12 for severe signal fluctuations that occur due to obstacles in the surrounding environment between the receiving and the transmitting antennas [19]. The standard deviation, zero implies the absence of randomness in the received signal and hence $P_{r,sh} = P_r$ i.e., the shadow model behaves as path-loss model.

Reliable communication between the designated nodes is assumed to be possible when received power, $P_{r,sh}$ is greater than desired received signal threshold,γ i.e., $P_{r,sh} > \gamma$. In other words the condition for correct reception is $P_{r,sh} / \gamma > 1$ or $\log (P_{r,sh} / \gamma) > 0$.

Hence, the probability of having a link between the designated nodes at normalized distance from each other, that is, the link probability [26] is

$$p\left(\hat{d}_{ij}\right) = \Pr\left[10\log_{10}\left(\hat{P}\left(\hat{d}_{ij}\right)\right) > 0\right] = \frac{1}{\sqrt{2\pi}\sigma}\int_{0}^{\infty}\exp\left[-\frac{\left(t - 10\log_{10}\left(\hat{d}_{ij}^{-\eta}\right)\right)^2}{2\sigma^2}\right]dt$$

$$= \frac{1}{2}\left[1 - erf\left(v\frac{\log\hat{d}_{ij}}{\xi}\right)\right], \xi \triangleq \sigma/\eta$$

(5)

where, $v = 10/\left(\sqrt{2}\log 10\right) = 3.07$, $\hat{d}_{ij}$ is the normalized distance and $\hat{d}_{ij} = \frac{d_{ij}}{r_j}$

and ξ is the ratio between the standard deviation of power fluctuations of radio signal (σ) and the path loss exponent (η). This implies that ξ is directly proportional to the signal power variations. Theoretically, ξ varies between 0 and 6 [26]. Fig. 1 shows the variation of the probability of the existence of a link with respect to the normalized distance for different values of shadowing deviation.

From Fig. 1, it can be seen that as ξ increases, shadowing is severe, i.e., the probability of link existence increases at larger distances with severity. In other words, higher the value of ξ indicates high probability of link existence at farther distances, increasing the probability of connectivity. Furthermore, at low value of ξ, the signal powers around the area mean are small and hence the link probability reduces. For example say, when ξ = 2, it can be noticed that the link reliability is almost zero beyond a normalized distance of 2.5 and when ξ = 6, the link reliability increases by nearly 25-30% beyond the same normalized distance of 2.5.

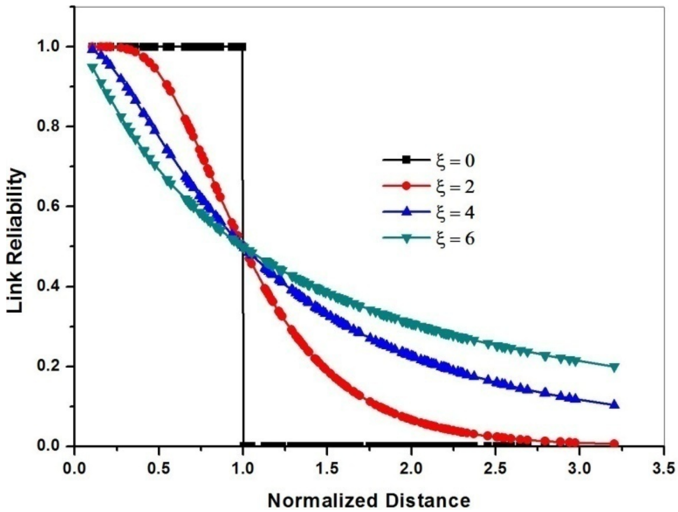

Fig. 1: Link Reliability as a Function of Normalized Distance for Different ξ Values.

3. Methodology

3.1 Network Model

Consider a MANET with a set of n nodes moving in the defined simulation boundary following a mobility model, say, RWPM. In general, the network can be represented as a fixed geometric random graph G (U, L,τ) at any instant of the mission time. The existence (non-existence) of the links L will depends on the Euclidean distance, transmission range of the nodes and the fading parameters. The time-to-failure of each MN is assumed to follow Weibull distribution because of its flexibility and versatility to model the failure patterns of various systems and component.

The successful communication between a set of nodes is a random event with a probability $R_G(\tau)$ given that the all nodes in $k \subseteq U$ must be operational. For instance, for communication to exist between the designated node-pair k = (s, t), it is necessary that the (s, t) pair must be operational. Therefore, the reliability of the network will be equal to the product of the reliability of (s, t) pair and the reliability of the network with perfect (s, t) pair of nodes. It can also be expressed mathematically as, let G (U, L,τ) be a representative network with a set of, $k = \{u_1, u_2 \ldots u_{|k|}\}$ designated nodes. Then, reliability of the network by employing factoring theorem can be expressed as (6) by noting that the failure of designated node(s) will certainly lead to network failure.

$$R_G(\tau) = \left(\prod_{u_i \in k} R_{u_i}(\tau) \right) R_{(G|k)}(\tau) \tag{6}$$

Therefore, (6) is utilized to compute the reliability of MANET at a particular instant of mission duration in our MCS.

3.2 Node Status and Link Status

As stated earlier the failure times of the MN follow Weibull distribution with a certain scale parameter (θ) and shape (β) parameter. Hence, the reliability of the MN is defined as

$$R_{u_i}(\tau) = \Pr\left(u_i(\tau) = 1\right) = e^{\left(-\tau/\theta\right)^{\beta}} \tag{7}$$

Where:

$$u_i(\tau) = \begin{cases} 1, & \text{if } i^{th} \text{ node is operational at time } \tau \\ 0, & \text{if } i^{th} \text{ node fails at time } \tau \end{cases} \tag{8}$$

And,

$$\hat{d}_{ij}(\tau) = \frac{d_{ij}(\tau)}{r_j}$$

The necessary condition for a MN in the network to successfully communicate with each other could be that the Euclidean distance $d_{ij}(\tau)$ between a pair of nodes (u_i, u_j) to be less than or equal to the transmission range r_j of the MNs, i.e., $d_{ij}(\tau) \le r_j$. But this basic criterion does not take care of the signal strength deterioration due to fading effects. This work models the probability of link existence in terms of Euclidean distance, transmission range and ξ using (5) i.e.,

$$R_L\left(\hat{d}_{ij}(\tau)\right)=\frac{1}{2}\left[1-erf\left(v\frac{\log \hat{d}_{ij}}{\xi}\right)\right] \tag{9}$$

The Euclidean distance between the node pairs at time ‘τ’ can be computed using (10)

$$d_{ij}(\tau)=\left(\left(x_j(\tau)-x_i(\tau)\right)^2+\left(y_j(\tau)-y_i(\tau)\right)^2\right)^{1/2} \tag{10}$$

Further at any instant ‘τ’, the link status $L_{ij}(\tau)$ is determined using (11), where, ‘B’ is a uniform random number between (0, 1).

$$L_{ij}(\tau)=\begin{cases}1, & if\ B\le R_L\left(\hat{d}_{ij}(\tau)\right)\\ 0, & if\ B> R_L\left(\hat{d}_{ij}(\tau)\right)\end{cases} \tag{11}$$

3.3 Mobility Model

The mobile nodes move within the deployed area according to RWPM model by assuming a velocity between (V_{min}, V_{max}), and direction, (0, 2ϕ). The RWPM model is a model which can mimic the movement behaviour of the MN and is widely chosen because of its suitability in simulations studies [29]. The MN chooses a destination in random at the selected random speed. The new positions of the MN at every incremental time interval is calculated using (12):

$$\begin{aligned}x_i(\tau+\Delta\tau)&=x_i(\tau)+\Delta\tau v_j(\tau)\cos\phi_i(\tau)\\ y_i(\tau+\Delta\tau)&=y_i(\tau)+\Delta\tau v_j(\tau)\sin\phi_i(\tau)\end{aligned} \tag{12}$$

In case, a MN violates the boundary due to its movements then the MN is forced to move within the boundary based on its location. This can be achieved by modifying the direction of the MN with which it moves. Fig. 2 depicts direction change at different locations of simulation boundary of the MN. For example, when a MN lies in the region ($x_i(\tau) < X_{min}$, $y_i(\tau) > Y_{max}$) , i.e., outside the top left corner of the second quadrant, then the direction is changed to about 315° forcing the MN to move inside the second quadrant, and the MN continues along this new path. In a similar fashion, validity checks in implementation of RWPM for nodes to move within the simulation area for all eight different positions can be simulated [30].

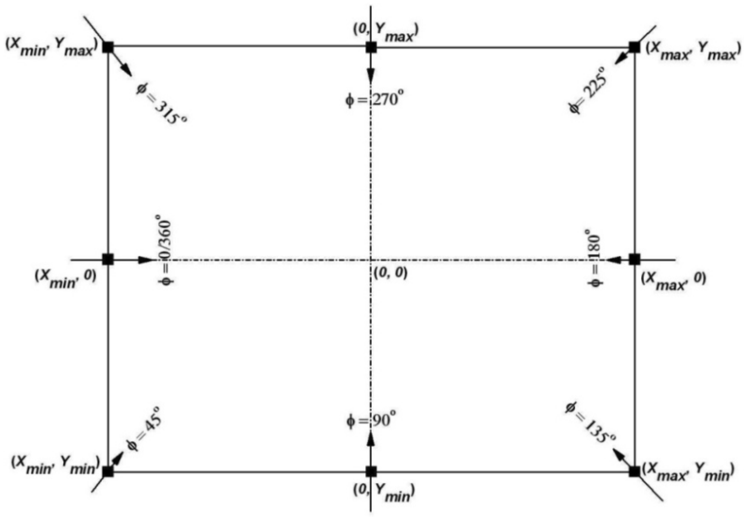

Fig. 2: Direction Change for Different Locations of the MN

The link status of the network is represented by a connection matrix to study the connectivity between the designated node pairs, and the connectivity $C_q(\tau)$ is defined as in (13)

$$C_q(\tau) = \begin{cases} 1, & \text{if } k \text{ nodes are connected at time } \tau \\ 0, & \text{otherwise} \end{cases} \tag{13}$$

Finally the reliability $R_G(\tau)$ and the variance associated with the reliability can be computed using (14) and (15) respectively.

$$R_G(\tau) = \frac{\left(\prod_{u_i \in k} R_{u_i}(\tau)\right) \sum_{q=1}^{Q} C_q(\tau)}{Q} \tag{14}$$

$$Var\left(R_G(\tau)\right) = \frac{R_G(\tau)\left(1 - R_G(\tau)\right)}{Q} \tag{15}$$

4. Assumptions

- Network is homogeneous and operational at the start of the mission time.
- The node movement follows RWPM model with zero pause time, with uniformly distributed node velocity (V_{min}, V_{max}) and node direction ($0, 2\phi$).
- Times to failure of nodes are assumed to follow Weibull distribution with scale parameter (θ) and shape parameter (β).
- Failures of node are statistically independent and once a node fails, it remains fail for the remaining period of the mission time.

- All links are bidirectional without any constraint on their load carrying capacity.
- The presence (absence) of the link is modelled as a function distance (d_{ij}), transmission range (r_j) and shadow parameter (ξ).

5. Algorithm

The algorithm considers n nodes that are randomly located around the simulation area (D) in presence of shadow fading (ξ), with same transmitting/receiving range (r_j). The algorithm proceeds with the simulation of node status by assuming the node failure follows Weibull distribution. The network is modelled using (6) and the link formation based on log-normal shadow propagation model is represented in a connection matrix. Finally, the connectivity of the network is checked from instant to instant and reliability of the network is computed. This process is repeated at each time increment $\Delta\tau$ till the specified mission time, thus, becoming the first complete iteration of 'Q' numbers of runs in our simulation study.
The step-by-step procedure of the MC simulation is as follows:

Step 1: Initialize the network parameters: $U, D, tMission, \theta, \beta, V_{min}, V_{max}, 0{,}2\phi, r_j, (x_i, y_i), q=1, \xi, C_q(\tau) = 0$.

Step 2: Initialize, $R_G(\tau) = \prod_{u_i \in k} R_{u_i}(\tau)$

Step 3: Simulate the node status vector of size n-$|k|$. The probability of success of a node is time-dependent and is determined using

$$R_{u_i}(\tau) = \Pr(u_i(\tau) = 1) = e^{\left(-\tau/\theta\right)^{\beta}} .$$

Step 4: Simulate the link status by computing the Euclidean distances and reliabilities by using equations

$$R_L\left(\hat{d}_{ij}(\tau)\right) = \frac{1}{2}\left[1 - erf\left(v\frac{\log \hat{d}_{ij}}{\xi}\right)\right] ,$$

$$d_{ij}(\tau) = \left(\left(x_j(\tau) - x_i(\tau)\right)^2 + \left(y_j(\tau) - y_i(\tau)\right)^2\right)^{1/2} \quad \text{and}$$

$$L_{ij}(\tau) = \begin{cases} 1, & if\ B \le R_L\left(\hat{d}_{ij}(\tau)\right) \\ 0, & if\ B > R_L\left(\hat{d}_{ij}(\tau)\right) \end{cases}$$

Step 5: Check for connectivity of designated nodes of the network at time τ. If network is connected then increment the $C_q(\tau)$ using

$$C_q(\tau) = \begin{cases} 1, & if\ k\ nodes\ are\ connected\ at\ time\ \tau \\ 0, & otherwise \end{cases}$$

and set $\tau = \tau + \Delta\tau$.

Step 6: Simulate the mobility of the nodes according to RWPM by uniformly and randomly choosing the velocity of nodes between (V_{min}, V_{max}) and the direction between (0, 2ϕ).

Step 7: Compute the new node positions at every time increments using

$$x_i(\tau+\Delta\tau) = x_i(\tau) + \Delta\tau v_j(\tau)\cos\phi_i(\tau)$$
$$y_i(\tau+\Delta\tau) = y_i(\tau) + \Delta\tau v_j(\tau)\sin\phi_i(\tau)\,.$$

Repeat *Step 3* through Step 6 until τ <= tMission.

Step 8: Repeat *Steps 2 to Step 7* for Q number of simulation runs.

Step 9: Compute reliability and variance as per

$$R_G(\tau) = \frac{\left(\prod_{u_i \in k} R_{u_i}(\tau)\right)\sum_{q=1}^{Q} C_q(\tau)}{Q} \text{ and } Var\left(R_G(\tau)\right) = \frac{R_G(\tau)\left(1-R_G(\tau)\right)}{Q}$$

The above steps of the algorithm are implemented using Matlab® 2009a on a Windows® XP platform running on Pentium dual processor @1.60GHz speed.

6. Example

The proposed algorithm is applied for evaluation of reliability of MANET example provided in [10, 13, 16, 17]. Here, we reproduce the same for the sake of brevity.

A network composed of 18 (n = 18) dismounted infantry (soldiers on foot) equipped with identical non-portable radios. Each radio is capable of ad hoc networking and is required to operate for duration of 72 hours. Each radio has a transmission range of 3 miles; with a reliability that is described by Weibull distribution with parameters of θ = 1000 and β = 1.5. The soldiers move randomly about a square coverage area of 64 square miles with a maximum and minimum velocity of 6 and 3 miles per hour, respectively. In addition to the above input parameters, it is assumed that the radio is deployed in a shadowing environment with shadowing parameter (ξ) ranging between 0 and 6.

7. Simulation Results

The results are obtained for 10 000 simulation runs as it is observed that simulation beyond 10 000 runs has no significant impact on the evaluated MANET reliability. The results of the 2-terminal MANET reliability of binary model [13], FS-TRG model [12] when (δ,γ) = 1, and Shadow model when ξ = 0, 2 and 6 are depicted in Fig. 3(a) – 3(c), respectively. From the results it is understandable that the achieved $2TR_m$ for all the cases, seen as single line - (binary model (black line), FS-TRG model (red line) and Shadow model (ξ = 0) (dark blue line)) turns out to be same with a negligible variation due to random generation function used in our MCS approach as seen in Fig. 3(a) – 3(c).

It can also be clearly noticed that as the severity of the environment increases (say, ξ=6), the network reliability increase by almost 25% (small coverage area) and 70% (large coverage area) of the case of with no severity (say, ξ=0). Similarly, it may be observed that 25% of increase is achieved for a small network size with each nodes' transmission range of 3 miles and a negligible increase for a large network size with larger transmission range. Furthermore, the results also show that when shadowing is severe, the $2TR_m$ reliability is almost maximum, which do not exceed R_l^2 irrespective of change in coverage area, transmission range and network size.

Our results also include the estimation of 2-terminal, all terminal and all operational terminal reliabilities with respect to network coverage area, transmission range and network size for different shadow parameters as shown in Fig. 4, Fig. 5 and Fig. 6, respectively. As seen earlier in Fig. 1, as the shadowing ξ increases, the link probability is low at short distances and as the distance increases the link reliability is high. This implies that the connectivity probability is high for higher values of ξ at farther distances. As ξ increases, the MANET reliability also increases because the probability of link existence between the nodes is higher though the power fluctuations are severe.

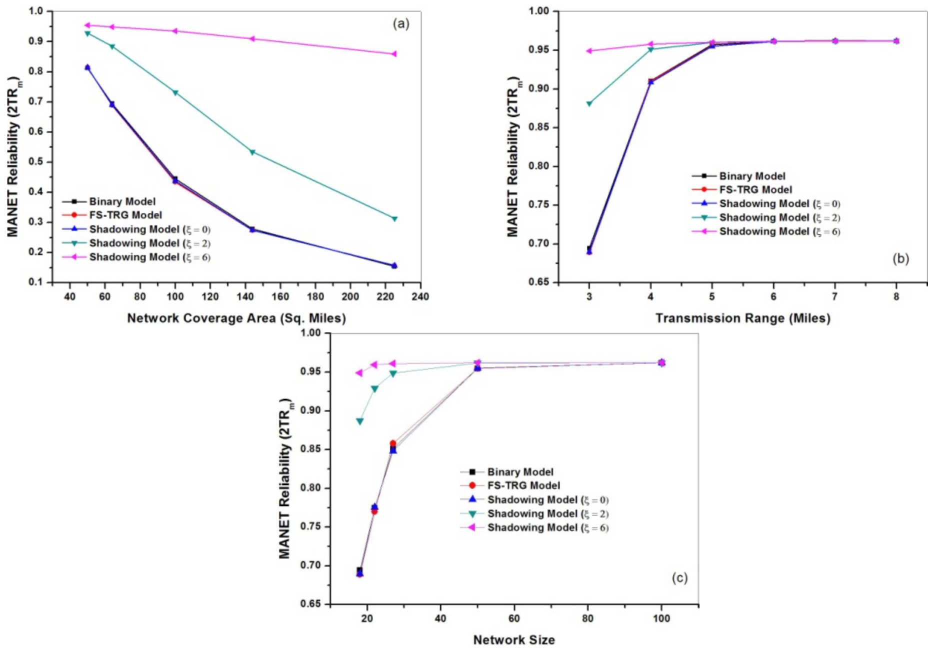

Fig. 3: Effect of (a) Network Coverage Area (b) Transmission Range (c) Network Size on *$2TR_m$* for different Link Probability Models (Binary model, FS-TRG model, Shadowing Model).

The results shown in Fig. 4(a) Fig. 5(a) and Fig. 6(a) are intuitively showing that the MANET reliability (2TR, ATR and AoTR) decreases with increasing coverage area for a fixed network size and defined nodes' transmission range. The probability of link existence is low when small number of MN is deployed in large coverage areas. Hence, the MANET reliability decreases drastically due to loss of network connectivity. However, combining the changes in node density and the coverage area has produced significant results. An increase in the node density combined with the fixed coverage showed high network connectivity existence i.e., the presence because of large number of direct connections which means the absence of small world property (a network in which any node in the network can be connected to any other node through a chain of intermediate nodes). Similarly, if the node density increases within a fixed coverage area, connectivity is through intermediate nodes because some short links could disappear while some longer links can emerge [26]. Henceforth, it may be concluded that deploying large number of nodes in defined coverage area improves network reliability.

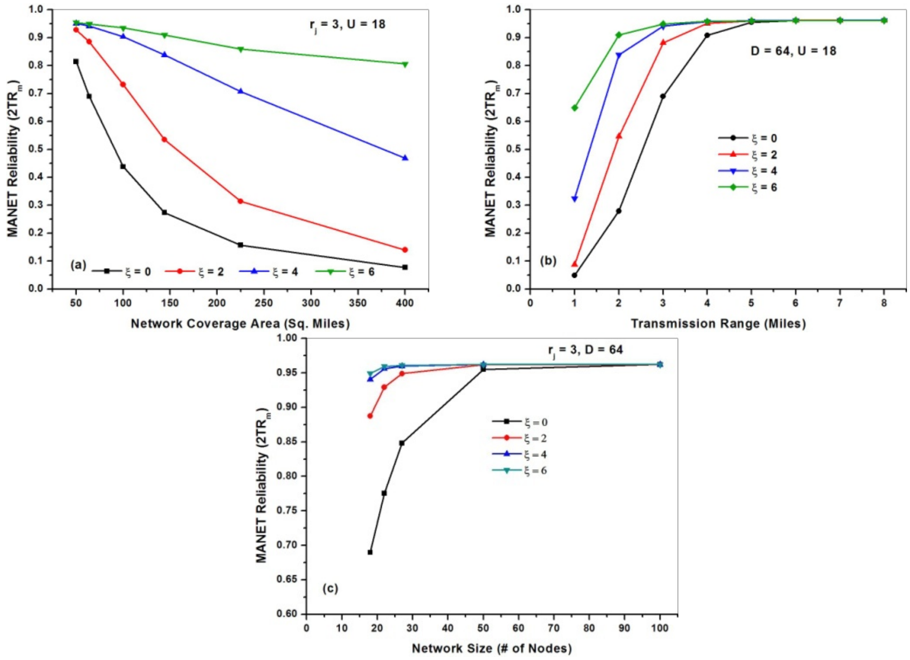

Fig. 4: Effect of (a) Network Coverage Area (b) Transmission Range (c) Network Size on $2TR_m$ for Different Values of ξ.

The results obtained from Fig. 4(b), Fig. 5(b) and Fig. 6(b) can be interpreted that MANET reliability monotonically increases with increasing transmission range. Intuitively, increase in the transmission range has a positive effect on reliability improvement. However, there is always a threshold in these increments beyond which no benefit in reliability is observed, i.e., would almost remain constant and therefore would be a waste of resources beyond the threshold. Our results show that beyond a threshold transmission range of 5 miles the achieved MANET reliability is almost stable of about 0.9551 for the case of $2TR_m$, 0.7061 for $AoTR_m$ and 0.4985 for ATR_m in a severe environment.

Fig. 5(c) and 6(c) depicts relatively interesting results on $AoTR_m$ and ATR_m with respect to network size i.e., the number of nodes deployed in the simulation area. A bell-shaped curve is obtained and is observed that there is sharp decline in the reliability estimate as the network size increases beyond the optimum value. It is noticeable that the achieved trend follows the law of diminishing returns where the network size increases with other input parameters being fixed thereby relatively decreasing the MANET reliability beyond the threshold network size.

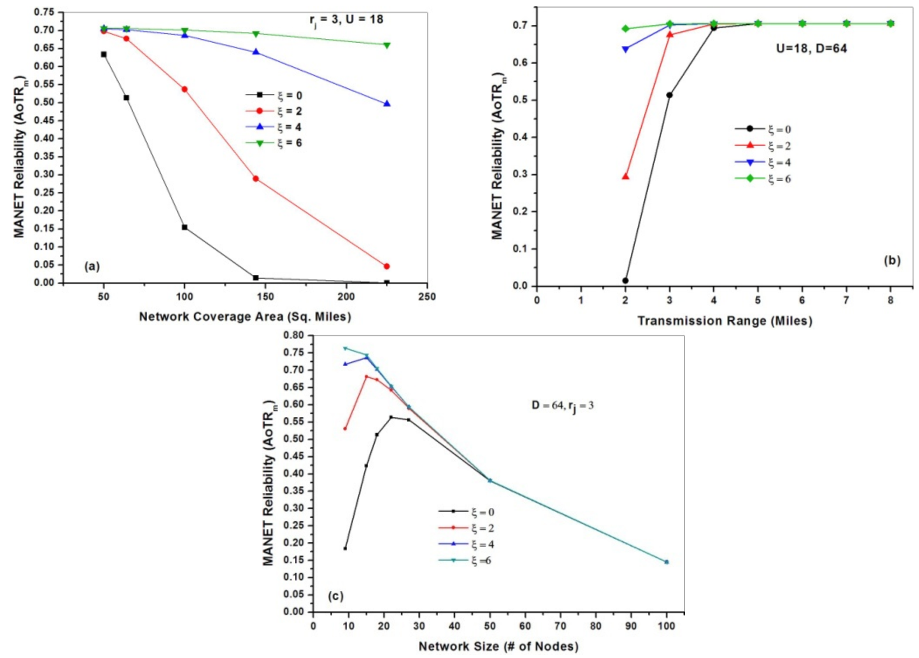

Fig. 5: Effect of (a) Network Coverage Area (b) Transmission Range (c) Network Size on $AoTR_m$ for Different Values of ξ.

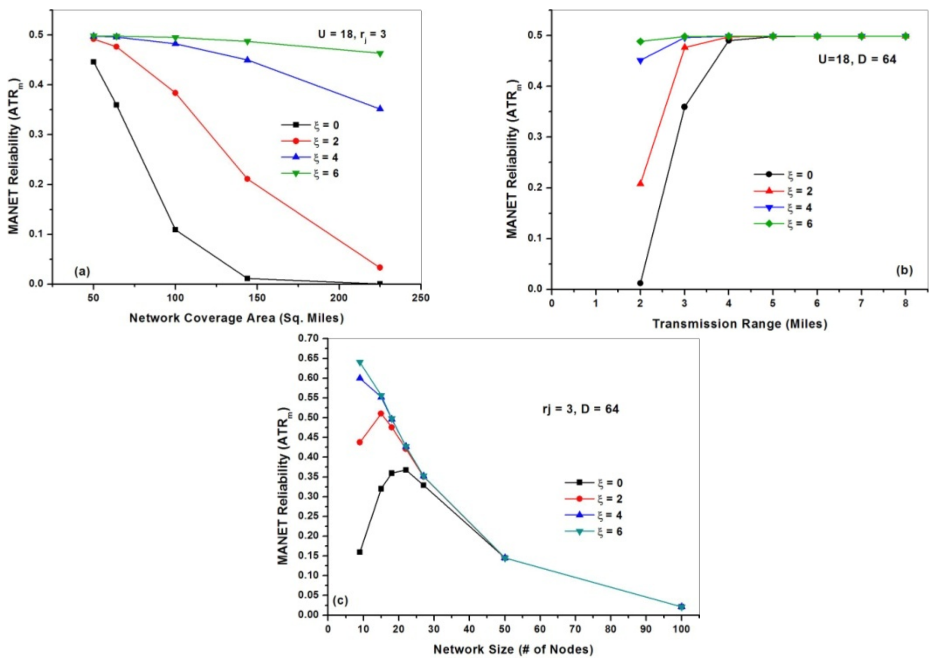

Fig. 6: Effect of (a) Network Coverage Area (b) Transmission Range (c) Network Size on ATR_m for Different Values of ξ.

Our result shows that the threshold network size is 22 nodes and at this threshold value the achieved MANET reliability in a severity environment is 0.5637 for $AoTR_m$ and 0.3696 for ATR_m, while 0.6536 for $AoTR_m$ and 0.4272 for ATR_m is the MANET reliability when deployed under a severe shadowing environment ($\xi = 6$). The peak point in the curve indicates the optimum number of nodes needed for the design of a reliable network to obtain the maximum reliability. It can be observed that the shape of the curve changes with the value of ξ, i.e., with severity the best reliability could be achieved when the network is deployed with small size networks. Hence to achieve good reliability metric, the designer can modify their design by considering their network with nodes having high transmission range deployed in suitable geographical area.

8. Conclusions

In this paper, an algorithm to evaluate the MANET reliability in presence of channel randomness with a special emphasis on the log-normal shadowing model is proposed. This model takes care of the randomness in the signal strength. The proposed algorithm represents the network topology using GRG and further combines node reliability model, movement of nodes according to RWPM, link reliability model using log-normal shadowing model. Using the MCS approach we give an insight about the impact of shadowing ξ and scenario metrics viz., network coverage area, transmission range and network size on the MANET reliability. When $\xi = 0$, the proposed model behaves as path-loss model and thereafter as ξ increases the MANET reliability also increases because of higher connectivity between the MN though the power fluctuations are severe. The simulated results is of practical significance for the design of MANET and further can be applied for planning of such networks by considering suitable number of nodes with desired transmission range that are needed to achieve a reliable communication within the defined simulation boundary operable in a severe environment.

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