STOCHASTIC PERFORMANCE MODELING OF MANETS IMPLEMENTING AODV UNDER HIDDEN-EXPOSED TERMINAL PROBLEM

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Abstract— A Mobile Ad-hoc NETwork (MANET) is a collection of wireless mobile nodes forming a self-configuring network without using any existing infrastructure. MANETs catch the great attention of researchers because of its unique characteristics like independent of infrastructure, dynamic topology behavior, limited energy source, multihop routing, mobility of nodes etc. All these characteristics chase lots of challenges about security, reliability and performance issues. These are becoming very attractive and useful in many kinds of communication and networking applications. Understanding the factors that affect the path connection availability in multi-hop ad hoc networks can help to understand the path stability under various degrees of system dynamics. In addition, the connection availability of paths can be used as a global measure for the performance of ad hoc networks. There is very little analytical study that provides a closed form solution for analytical analysis of connection availability of paths in multihop ad hoc networks with Poison arrival time. Also, the hidden node problem is not yet addressed in the analytical study. This work proposes a closed form solution for this problem using a new stochastic reward net model. The influences of different factors, such as the number of nodes in the network, transmission range, tradeoff of power dissipation of individual nodes with network connectivity and battery life, network area size, data transmission rate, and routing protocol on the path connection availability are investigated. The system dynamics and various transitions are modeled using SRN modeling to derive analytical measurements of system reliability and availability. The proposed SRN model is simulated using PIPE (Platform Independent Petri Net Simulator). The system model and the model parameters are validated by extensive simulations using OMNeT ++.

Keywords- ad hoc networks, stochastic models, SRN models, hidden exposed terminals, AODV.

I. INTRODUCTION

In MANETs, the route or path is the sequence of mobile nodes which data packets pass through in order to reach the intended destination node from a given source node [1]. Due to the mobility of nodes, mobile ad hoc networks have inherently dynamic topologies. Therefore the routes are prone to frequent breaks (called mobility failure) which reduce the throughput of the network compared to wired or cellular networks. Consequently, the route followed by packets to reach the destination varies frequently. This is a crucial factor that affects the performance of the network. In this work, a closed form solution using Stochastic Reward Net (SRN) [2] model is proposed to analyze the path connection availability in multi-hop ad hoc networks where nodes are distributed as per Poisson Probability Distribution. The effects of link failure due to the mobility of nodes on the path connection availability in MANETs are analytically investigated using the proposed model. In addition, influences of different factors, such as the number of nodes in the network, transmission range, network area size, data transmission rate, and routing protocol on the path connection availability are investigated. The proposed model incorporates the characteristics of Ad hoc On-demand Distance Vector (AODV) [3].

II. PROBLEM STATEMENT

An ad hoc mobile network is a collection of nodes, each of which communicates over wireless channels and is capable of movement. Wireless nodes have the unique capability of transmission at different power levels. As the transmission power is varied, a tradeoff exists between the number of hops from source to destination and the overall bandwidth available to individual nodes [4]. Because both battery life and channel bandwidth are limited resources in mobile networks, it is important to ascertain the effects different transmission powers have on the overall performance of the network. In this work, the nature of this transmission power tradeoff in mobile networks with available routers is investigated. Also, understanding the factors that affect the path connection avail-ability in multi-hop ad hoc networks can help to understand the path stability and maintainability under various degrees of system dynamics. In addition, the connection availability of paths can be used as a global measure for the performance of ad hoc networks. This work proposes a closed form solution for this problem using a new stochastic reward net model. The influences of different factors, such as the number of nodes in the network, transmission range, network area size, data transmission rate, and routing protocol on the path connection availability are investigated. The proposed model is validated by extensive simulations using OMNeT++ [5] and PIPE [6] (Portable Independent Petri Net Simulator).

III. EXISTING WORK

A. AODV

AODV [3] stands for Ad Hoc On Demand Distance Vector Routing protocol. It belongs to the category of reactive protocol which seek to set up routes on-demand. The AODV algorithm enables dynamic, self-starting, multi-hop routing between participating mobile nodes wishing to establish and maintain an ad hoc network. If a node wants to initiate communication with a node to which it has no route, the routing protocol will try to establish such a route. The Ad-Hoc On-Demand Distance Vector routing protocol is described in RFC 3561 [7]. The working of AODV, like all reactive protocols, is that topology information is only transmitted by nodes on-demand. When a node wishes to transmit traffic to a host to which it has no route, it will generate a route request (RREQ) message that will be flooded in a limited way to other nodes. This causes control traffic overhead to be dynamic and it will result in an initial delay when initiating such communication. A route is considered found when the RREQ message reaches either the destination itself, or an intermediate node with a valid route entry for the destination. For as long as a route exists between two endpoints, AODV remains passive. When the route becomes invalid or lost, AODV will again issue a request. The AODV routing protocol is designed for mobile ad hoc networks with populations of tens to thousands of mobile nodes. AODV can handle low, moderate, and relatively high mobility rates, as well as a variety of data traffic levels. AODV is designed for use in networks where the nodes can all trust each other, either by use of preconfigured keys, or because it is known that there are no malicious intruder nodes.

AODV avoids the "counting to infinity" [8] problem from the classical distance vector algorithm by using sequence numbers for every route.

B. Stochastic Petri Nets

Petri nets provide a graphical notation for the formal description of the dynamic behavior of systems. They are particularly well suited to systems which exhibit concurrency, synchronization, mutual exclusion and conflict. The primitives of the notation are the following [9]:

PLACES: Places are used to represent conditions or local system states, e.g. a place may relate to one phase in the behavior of a particular component.

TRANSITIONS: Transitions are used to describe events that occur in the system; these will usually result in a modification to the system state. The occurrence of the event in the system is represented by the firing of the corresponding transition in the Petri net.

TOKENS: Tokens are identity-less markers that reside in places. The presence of a token in a place indicates that the corresponding condition or local state holds.

ARCS: Arcs specify the relationships between local states or conditions (places) and events (transitions). An arc from a place to a transition is termed an input arc. This indicates the local state in which the event can occur. An arc to a place from a transition is termed an output arc. This indicates the local transformations which will be induced by the event.

Tokens move between places according to the ring rules imposed by the transitions. A transition can fire when each of the places connected to it has at least one token; when it fires, the transition removes a token from each of these places and deposits a token in each of the places it is connected to. This is called the firing rule. Sometimes a transition will require an input place to contain two or more tokens before it can fire. In this case, rather than draw more than one arc between the place and the transition, one can denote the multiplicity of the arc by a small number written next to the arc. Similarly for output arcs. The state of the system combines information about all the local states. Since each local state is represented by the number of tokens present in a particular place, the state of the system is represented by a tuple, with one entry for each place, and the value of the entries denoting the number of tokens in that place. This is termed the marking of the net. A Petri net consisting of places and transitions linked by arcs is incomplete if it does not also have tokens in some places. This initial placing of tokens is called the initial marking which represents the starting state of the system.

C. Stochastic Reward Nets

Stochastic Reward Nets (SRN) had gain much importance in recent years as a useful modeling formalism and can be used for analysis of several applications [2]. Several automated tools that support the evolution of SPN or their variants are available. These include GSPN [10], METASAN [11] and SPNP [12]. Traditionally, performance analysis assumes a fault free system. Reliability and availability analysis is carried out separately to study the behavior in presence of component faults, disregarding the different performance levels in different configurations. Several different types of interactions and corresponding tradeoffs have prompted the researchers to consider the combined evolution of performance and reliability/availability.

Most of the work on combined evolution is based on extension of Markov chains [11] to Markov Reward Models where a reward rate is attached to each state of Markov chain. Reward Models have the ability to represent concurrency, fault tolerance and performance. Hand generation of large Markov reward models is a tedious and error prone process.

Stochastic Petri nets (SPNs) provide an excellent higher level interface for a concise specification and automatic generation of the Markov model. By augmenting SPNs with a method of specifying reward rates at the net level, one can obtain the ability to specify and automatically generate large Markov reward models. These SPNs augmented with reward rates are known as stochastic reward nets (SRNs). In case of a pure reliability/availability model, reward rates of 1 for up states and 0 for down states can be assigned. By reversing the reward assignment, one can obtain unreliability/unavailability measures. Steady-state analysis of the Markov chain yields steady-state availability while transient analysis is useful in computing reliability, instantaneous or interval availability.

IV. PROPOSED WORK

A. Hidden Terminal / Exposed Terminal

Due to the lack of a centralized control entity in ad hoc networks, sharing of wireless bandwidth among ad hoc nodes (medium access control) must be organized in a decentralized manner. Therefore distributed Medium Access Control (MAC) mechanisms such as Carrier Sense Multiple Access with Collision Avoidance and its' variants such as MACA [1], MACA for Wireless (MACAW) [2] and 802.11 Distributed Coordination Function (DCF) [3] have gained widespread popularity in ad hoc networks. However, all these CSMA/CA based MAC protocols suffer from the well known "hidden terminal" problem. In wireless networks, it is a commonly accepted practice to use a pre-data control information exchange (virtual medium sensing) to avoid the hidden terminal problem. One such virtual sensing mechanism is the 802.11 Request To Send/Clear To Send (RTS/CTS) exchange resulting in nodes getting exclusive access to the channel for a well-defined time period. However, the use of RTS/CTS-like schemes introduces the "exposed terminal problem", where some nodes that heard the RTS/CTS exchange refrain from transmission even though they would not have interfered with any ongoing transmission. The hidden terminal problem was well studied for access points (infrastructure) based networks [5] and it was shown that the introduction of virtual sensing (like RTS/CTS) improves their performance [1, 2, 4]. Ad hoc networks have gained popularity among researchers within the last decade, especially in military and emergency service provision contexts. Due to technical and commercial reasons, essentially the same distributed MAC layer protocols used in infrastructure based wireless networks have been considered for ad hoc networks. However, ad hoc networks have significantly different topologies compared with the infrastructure based networks, leading to the question whether RTS/CTS like schemes have the same effect in both types of networks. Simulation studies shows that the network throughput degrades with RTS/CTS mechanisms in large 802.11 based wireless ad hoc networks.

Figure 1 illustrates the hidden terminal problem. Suppose that node A wants to transmit to node B located at a distance x from A. By only sensing the medium, node A will not be able to hear transmissions by any node (C) in the dashed area denoted by A(x), and will start transmitting, leading to collisions at node B. This is the well known hidden terminal problem, where the hidden nodes are located in the area A(x).

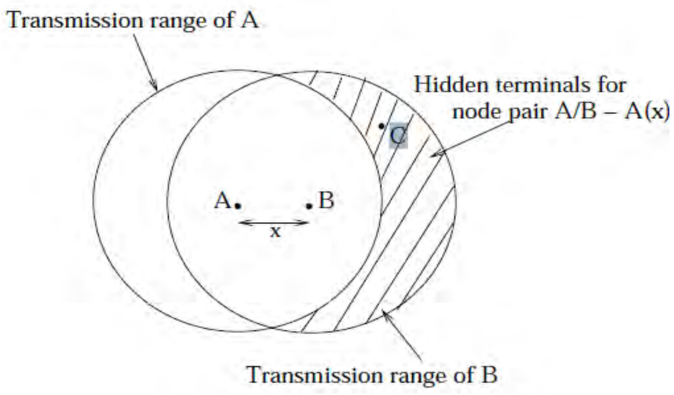

Figure 1. Hidden Node Problem

RTS/CTS handshake mechanism was introduced to wireless MAC layers to eliminate the hidden terminal problem. However, this mechanism introduces a new problem termed the exposed terminal problem. It is assumed here that an RTS/CTS exchange so that the issue of hidden terminal is addressed. Consider Figure 2 and assume that node A wants to transmit to node B.

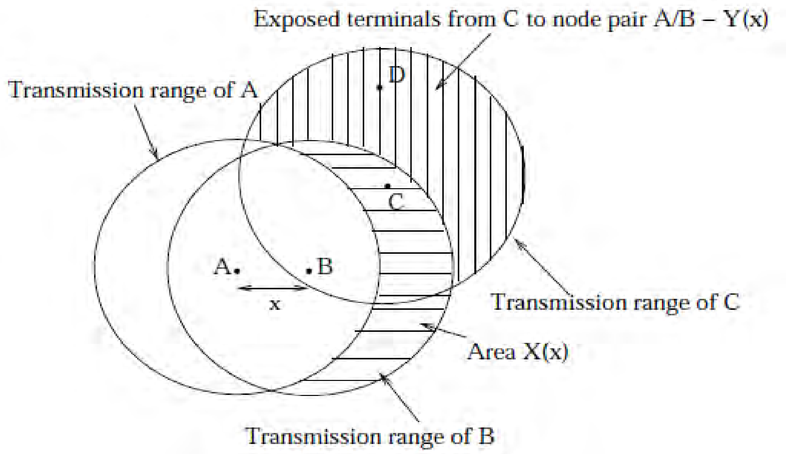

Figure 2. Exposed Terminal Problem

Node A sends an RTS and waits for B to send a CTS. Suppose a node D located in area Y (x) wants to transmit data to node C located in area X(x), and D transmits a RTS to C just before A sends the RTS to B. After receiving the RTS from D, C transmits a CTS. This CTS is heard by B upon which B will enter a back off period preventing B from sending the CTS to A. Therefore, any transmission from a node within the area Y to a node within X(x) will prevent A from transmitting data to B, although simultaneous transmissions from area Y (x) to X(x) would not have interfered with transmission from A to B. The terminals in the region Y (x) are defined as the exposed terminals for the node pair A/B. In this case, the number of transmissions that could occur between nodes from area X(x) and nodes from area Y (x) can be expressed as XY .

B. Quantitative Analysis of Hidden and Exposed Terminal Problem

In the case of hidden terminal problem, unsuccessful transmissions result from collisions between a transmission originated by a node such as A which cannot hear the ongoing transmissions to its corresponding node B. The probability of such a collision is proportional to the total number of terminals hidden from A.

In the case of exposed terminal, unsuccessful transmissions result from nodes such as A being prevented from transmitting, because their corresponding node is unable to send a CTS. Again such unsuccessful transmissions are proportional to the number of exposed terminals. Both these events lead to degradation of a node's throughput.

The shaded region in figure 1 encompass the area

$$A(x) = \pi R^2 - 2R^2 \cos^{-1}(x/2R) + x/2[4R^2 - x^2]^{1/2}$$

Note that A(x) only corresponds to the area containing nodes hidden from A when A wants to transmit to B. In order to find the total number of nodes potentially hidden from A, one needs to consider all possible nodes within the transmission range of node A. Also, the region Y in figure 2 encompass the area

$$Y(x,y,\alpha) = \pi R^2 - 2R^2 \cos^{-1}(y/2R) + y/2[4R^2 - y^2]^{1/2}$$

The expression for area Y could take different forms depending on the position of node C within the area X(x) as shown in the figure.

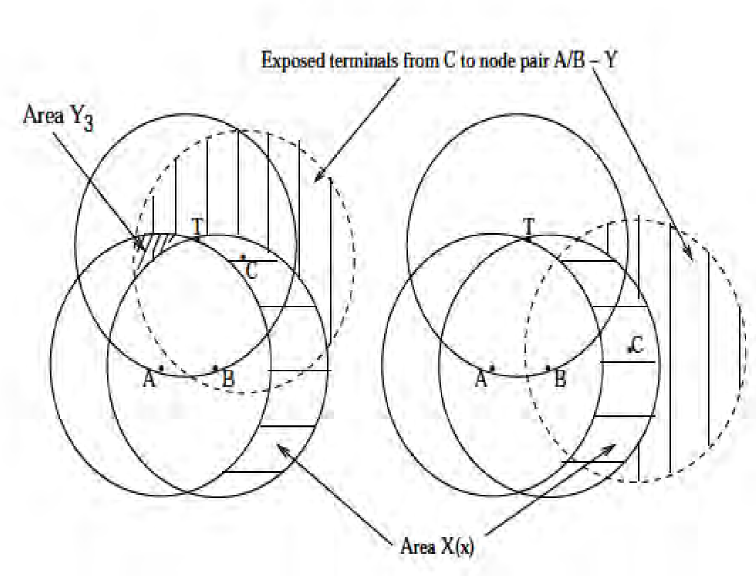

Figure 3. Various Scenarios of Exposed Terminal Calculations

C. Stochastic Model for MANETS

1)Pure Birth Process: Probability of N nodes in the intersection area

This modeling is essential and critical for evaluation of the model as the rate of occurrence of various states can be described by the described model. The most common stochastic models assume that the arrival rate and service rate follow a Poisson distribution.

Let the model be described using the following parameters

λ; Arrival Rate

μ; Service Rate

Here, the service rate describes the departure rate from the intersection area. It is assumed that the service rate (rate at which nodes leave the intersection time) are independent and identically exponentially distributed. The mean rate of the nodes leaving the intersection area is therefore $1/\mu$. It is required that $\lambda/\mu<1$, otherwise the length of queue will explode. The expression for probability of N nodes in the intersection area can be obtained from the following difference equations describing the state of the system.

Let Δt be a small time interval in which only a single arrival and/or departure is possible but not more than one. Then one can write the following state equations for the probabilities.

Consider the Probability of N nodes in the intersection area of two nodes at time $t+\Delta t$,

$$P_N(t+\Delta t) = P_{N-1} * \lambda\Delta t*(1- \mu\Delta t) + P_{N+1}*(1-\lambda\Delta t) * \mu\Delta t + P_N* (\lambda \Delta t)*(\mu\Delta t) + P_N* (1-\lambda \Delta t)*(1- \mu\Delta t)$$

(In the equation above and the once which follows, in LHS, $P_N(t)$ is written as P_N for the sake of simplicity assuming the same meaning.)

$$P_N' = \lambda P_{N-1} + \mu P_{N+1} - (\lambda+ \mu) P_N \qquad \text{(i)}$$

Using the definition of Derivation from First Principles.

Also, the Probability of 0 nodes in the intersection area of two nodes at time $t+\Delta t$,

$$P_0' = \lambda P_0 - \mu P_1 \qquad \text{(ii)}$$

Equations (i) and (ii) are differential equations describing the state of the system.

In steady state conditions, the RHS of both (i) and (ii) is zero giving

$$\lambda P_0 - \mu P_1 = 0$$

$$P_1 = (\lambda/ \mu)*P_0$$

For N=1 in the equation (i), the following results can be derived.

$$\lambda P_0 + \mu P_2 - (\lambda+ \mu) P_1 = 0$$

$$\lambda P_0 + \mu P_2 - (\lambda+ \mu) (\lambda/ \mu)*P_0 = 0$$

Giving

$$P_2 = (\lambda/\mu)^2 * P_0$$

This recurrence relation yields

$$P_n = (\lambda/\mu)^n * P_0$$

Also,

Sum of P_n for all n from 0 to N is 1. Thus

$$P_0 + (\lambda/\mu) * P_0 + (\lambda/\mu)^2 * P_0 + (\lambda/\mu)^3 * P_0 + (\lambda/\mu)^4 * P_0 + \ldots\ldots + (\lambda/\mu)^N * P_0 = 1$$

Let $\lambda/\mu = \rho$, thus

$$P_0 = (1-\rho)/(1-\rho^{N+1})$$

Giving

$$P_n = \rho^n * (1-\rho)/(1-\rho^{N+1}) \qquad \text{(iii)}$$

The above equations of the number of nodes in the intersection area are valid till the nodes do not move or move at a manner so that the area enclosed in intersection region of the two remains the same. If the nodes move towards each other, then the number of routing nodes is likely to increase and vice versa.

The expected number of nodes in the intersection area is the expected queue length which can be computed as:

$$E(I) = \sum_{n=1}^{N} n * P_n$$

D. Estimation of the number of Active Routers /Hidden Terminals for any node pair

Let the mean value of nodes per unit area of the MANET under consideration is G. It is assumed that the node movement follow Poisson Probability Distribution. Thus, the probability of k nodes in any unit area is:

$$P(k) = G^k * e^{-k}/k!$$

The size of intersection area is

$$I(x) = 2R^2 \cos^{-1}(x/2R) - (x/2)[(4R^2-x^2)]^{1/2}$$

The size of the hidden area is

$$H(x) = \pi R^2 - 2R^2 \mathrm{Cos}^{-1}(x/2R) + x/2[4R^2-x^2]^{1/2}$$

The mean value of nodes in the Intersection and Hidden area is therefore G*I and G*H respectively. The mean value of nodes in any area of size A is $G_A = A*G$. Thus, the probability of k nodes in any area of size A is

$$P(A)_k = G_A{}^k * e^{GA}/k!$$

Let E(A) be the expected number of nodes in any area A, then

$E(A) = \Sigma^N{}_{n=1}\ n*P_A(n)$, where N is the total number of nodes, assuming a finite population of nodes.

Thus, probability of n nodes in the intersection area I is

$$P(I)_n = (G*I)^n * e^{-GI} / n!$$

The expected number of nodes in the intersection area I is

$$E(I) = \Sigma^N{}_{n=1}\ n*P(I)_n$$

Likewise, the expected number of nodes in the hidden area is

$$E(H) = \Sigma^N{}_{n=1}\ n*P(H)_n$$

E. Impact of Hidden nodes in Single Hop communication scenario

Consider a finite population of N mobile nodes in a region of area L*L. Each node has transmitting range R, which describes the radius of the circle encompassing the node. Also consider two point nodes at a distance x from each other where $R < x < 2R$, R being the transmission range of the node.

It is immediately apparent that

$$I(x) + H(x) = \pi R^2$$

Assuming the uniform distribution of the nodes in the square region of size L*L, let n_I be the number of nodes in the intersection area and n_H be the number of nodes in the hidden area. The mean number of nodes per unit area is N/(L*L).

Let the distribution of node pairs communicating with each other is independently and identically distributed under Poisson Distribution with mean λ. Thus, for any pair of nodes, in which a node from hidden area is in active communication to a node in intersection area, the probability distribution of such pairs nodes in hidden area is given by is given by:

$$P_X(X=n) = \lambda^n e^{-\lambda}/!n$$

Thus, one can figure out the Expected number of nodes in the hidden area which can cause potential packet drop problem for nodes in the intersection area. The given equation approximately describes the expected number of such hidden-active node pairs.

E(Hidden Communicating Pairs | Hidden Area ↔ Intersection Area) =

Σi=1 expected number of nodes in hidden area [n*Pi]

Here, λ, N and L are model parameters to be chosen suitably to model the MANET in different physical situations. As previously mentioned, the probability of n nodes in the intersection area of the two nodes separated by a distance x (<R), is given by

$$P(I)_n = (G^*I)^n * e^{-GI} / n!$$

F. Stochastic Reward Net Modeling for the AODV Implementation

The SRN corresponding to the k^{th} intersection area, considering the hidden node transmission can be drawn as shown:

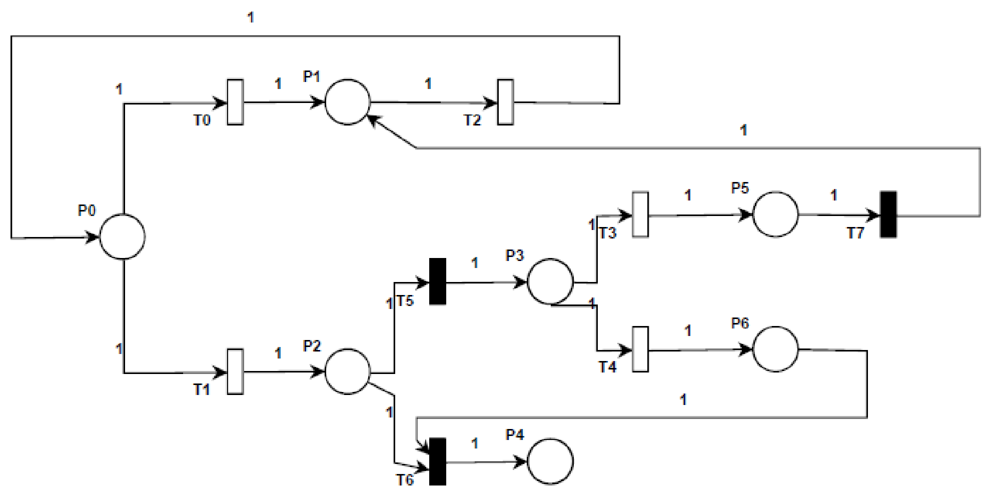

Figure 4. SRN model Describing the behavior of MANET implementing AODV

The places and the transitions can be described as shown:

TABLE 1 SPECIFICATIONS OF SRN MODEL PARAMETERS

Places / Transitions	Descriptions
P0	Initial Number of Nodes in the hidden area
P1	One backup node left the intersection area
P2	Active node left the intersection area
P3	Local Repair Process Initiated
P5	Local Repair Process is successful
P6	Local Repair Process Fail due to hidden terminal Communication
P4	Source Repair Process Initiated
T0	Backup node (router) left intersection area, Rate = #P0/μ
T1	Active router left intersection area Rate = 1/ μ
T2	One node enters at intersection area Rate = 1/λ
T3	Local Repair Process Successful Rate = α(#IA)
T4	Local Repair Process Failed (Due to hidden Terminals) Rate = β(#HT)
T5, T6 and T7	Immediate Transitions

The behavior of the network as modeled by the SPN is described as shown:

The number of tokens in the place P0 represents the number of nodes in the intersection area which represents the number of available routers to the next hop. One of the nodes in the intersection area is used as a router (active router) in the current route between the source and destination, and the other nodes work as backup routers. For Poisson arrival and departure from the intersection area, the average number of nodes in the intersection area can be computed. At any time, there is a probability that any of the backup routers can leave the intersection area. This is modeled by the arc between the place P0 and transition T0 which moves one token from the place P0 to P1 after firing of transition T0. On the other hand there is a possibility that the active router may leave the intersection area which makes the route to the destination not available. The arc between the place P0 and transition T1 represents this action. The firing of transition T1 moves one token from the place P0 to the place P2 which represents the failure of the path. Leaving time α is equivalent to $1/\mu$ for the model presented as it is the average service rate.

The average firing rate of transition T1 depends on the leaving time α (the average time that a node spends in the intersection area, whereas the average firing rate of transition T0 not only depends on α but also on the number of nodes in the intersection area. The average firing rate of T1 and T0 are $1/\alpha$ and $(\#P_{ik}/\alpha)$, respectively, where $\#P_x$ is the number of tokens in the place Px. The leaving time α depends on the size of the intersection area and the relative speed between any router in the intersection area and the source or destination node. Increasing the maximum limit of the node speed decreases the leaving time α, whereas increasing the size of the intersection area increases it. The number of tokens in the place P1 represents the number of backup routers that are left in the intersection area. The nodes that left the intersection area or any other node in the network may enter the intersection area. This is presented by firing of transition T2 which moves a token from P1 to P0. The average firing time of transition T2 is the frequency with which the nodes in the network enter into an intersection area, called entering rate λ (the arrival rate in the model parameter). Entering rate depends on network parameters such as the node density, speed of nodes, pause time, and transmission range. The larger the node density, speed of nodes, or transmission range, the greater the entering rate.

The place P2 represents the failure of active router in the intersection area and consequently the whole route. After failure of the active router, the node that detected the failure, will try to recover the route. The firing of transition T5 puts a token in the place P3, whose marking represents the initialization of a local repair process. T4 represents a transition to the place P6, which represents that packet sent to an alternative node in the intersection area is not followed by acknowledgements, indicating packet loss. Subsequent packet loss indicates packet collision at router which indicates a transmission due to hidden terminal. Thus, marking at place P6 represents failure of local repair process by the intermediate node. The transition T3 sets a mark at P5 which represents success of the local repair process, whereas the firing of transition T6 deposits a token in the place P4 representing the failure of local repair and starting of the source repair process.

The reliability and sustainability of the link can be computed by assigning appropriate reward rates to the states of the SPN. The reward rates are assigned based on the output measures of interest, in this case, the local repair process based on the number of backup routers, All the routers present in the intersection area cannot act as backup routers as there are some routers in the intersection area which are in active communication with the hidden terminals. The possibility of choosing any such router is eliminated by RTS/CTS signaling. In this work, the number of such terminals is estimated and considered for reward rates of corresponding states to give more accurate measurements of reliability and sustainability.

The following formalism is adopted for assigning the reward rates:

$$r_i = \begin{cases} 1 & \text{if } \#P_{ik} > 1 \\ 1 & \text{if } \#P_{LRSk} \geq 1 \\ 0 & \text{if } \#P_{SRk} \geq 1 \end{cases}$$

V. PERFORMANCE ANALYSIS

The analysis of the proposed SRN model for MANET is investigated in this chapter. Results obtained are then analyzed with those that are obtained without hidden-exposed terminal consideration.

A. Parameter Specification for generic MANET scenario

Consider the following parameter specification modeling a generic MANET. The specifications presented below are applicable for a wide range of physical situations including military operations, nuclear power plants or geographical surveillance.

TABLE 2 SPECIFICATION OF PARAMETERS FOR DEDUCING RESULTS

Parameter Specification	**Values**
Dimensions of the Square Area	100*100 sq. mtrs.
Total Number of nodes	500
Mean number of nodes per unit Area	0.05 nodes/mt. sq.
transmission range	8 mt.
distance of any hop (x)	3 mt.
Intersection area	153.3446819 sq. mt.
hidden area	47.7172479 sq. mt.
Mean Number of nodes in Intersection Area	7.667234097
Mean Number of nodes in Hidden Area	2.385862395

B. Derivation of Expected number of nodes in the Intersection and Hidden area

The number of nodes in the hidden and intersection area can be computed using Poisson Probability Distribution using the expression stated in the previous chapter. In the following table, the probability of any number of nodes in intersection/hidden area is derived and the sum of multiplication of number of nodes with corresponding probabilities gives the estimated number of nodes in the hidden and intersection area.

Estimated number of nodes in Intersection Area = $\sum_{n=0}^{500} P_I * \mathrm{n}$

Estimated number of nodes in Hidden Area = $\sum_{n=0}^{500} P_H * \mathrm{n}$

Here, the summation till n=100 is computed as the corresponding probability of number of nodes in intersection/hidden area to be more than 100 is negligible.

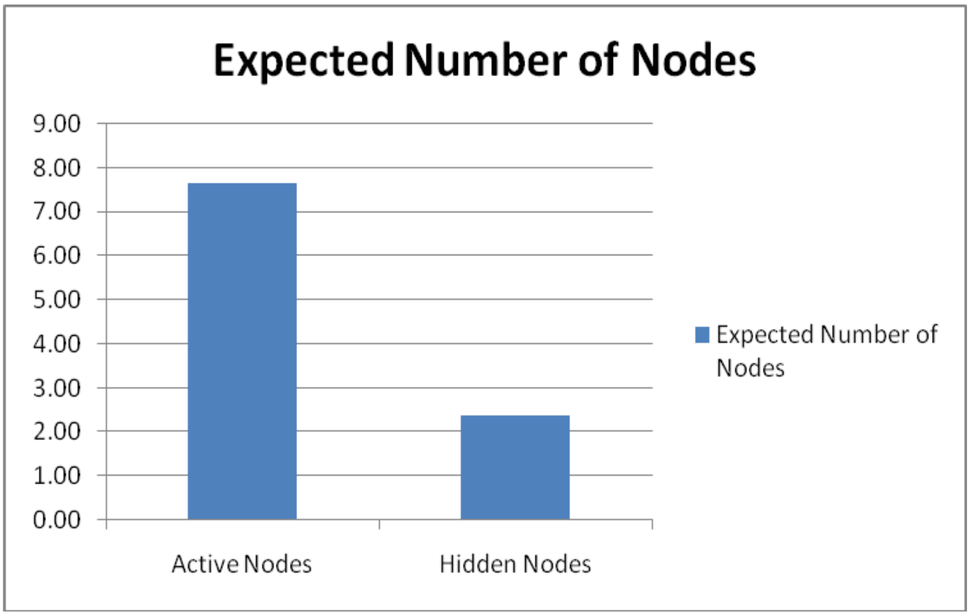

Figure 5. Expected Number of nodes in any hop in hidden and Intersection Area (Transmission Radius : 8m, Distance between hops 3m and total number of nodes is 500, assuming Poisson Probability Distribution)

C. Impact of Transmission Range on the number of nodes

As a function of the transmission range of nodes, the expected number of nodes in Hidden/Intersection area can be tabulated as shown:

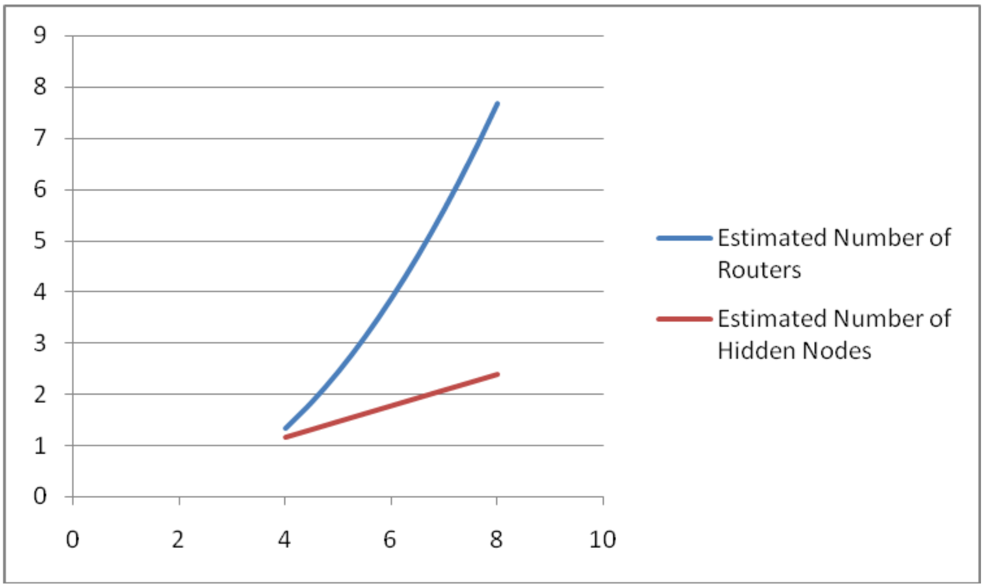

Figure 6. Number of nodes in hidden and intersection area as a function of transmission range. (Provided the distances between nodes is 3m)

D. Number of nodes in Hidden and Intersection area as a function of distance between the nodes (Provided transmission range =8m)

The following table depicts the number of nodes in hidden and intersection area, provided the transmission range for a node is 8m. Other parameters are considered as specified in the table 4.1 above.

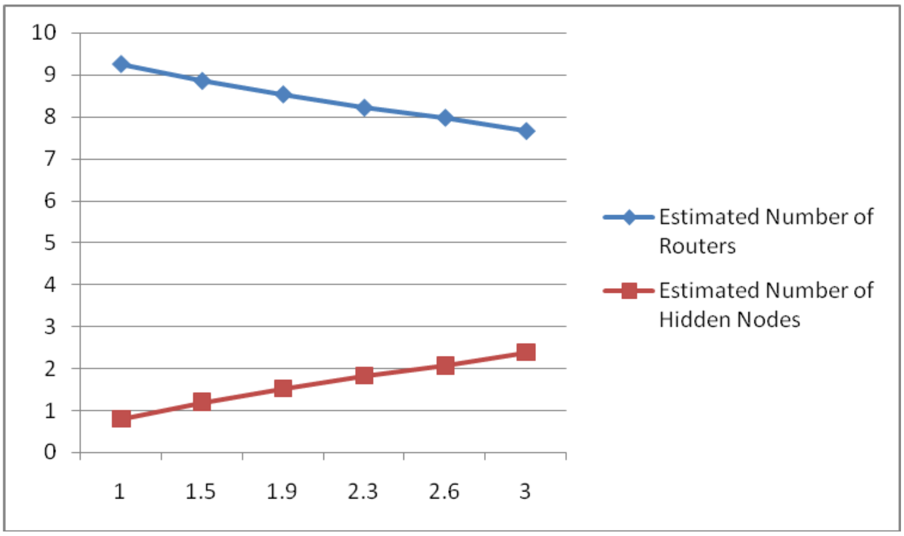

Figure 7. Number of nodes in Hidden/Intersection area, as a function of distance between the nodes.

E. Estimated number of number of nodes in the hidden area, in active communication with nodes in the intersection area

This derivation is the critical part of the analysis of the MANET performance analysis. Not all the nodes available in the intersection area can work as backup routers for any transmission path. Only those nodes which are not involved in active communication can work as backup routers. IEEE 802.1a solves this problem using RTS/CTS handshake. Here, one can compute the estimated number of nodes in intersection region, in active communication with the number of nodes in the hidden region using some mean value and again assuming Poisson Probability Distribution. The mean value to be taken depends on the particular case study of a MANET under consideration. The following table depicts the estimated number of such nodes assuming mean value 2. This assumption states that on an average, two nodes in some intersection area are in active communication with the nodes in the hidden area.

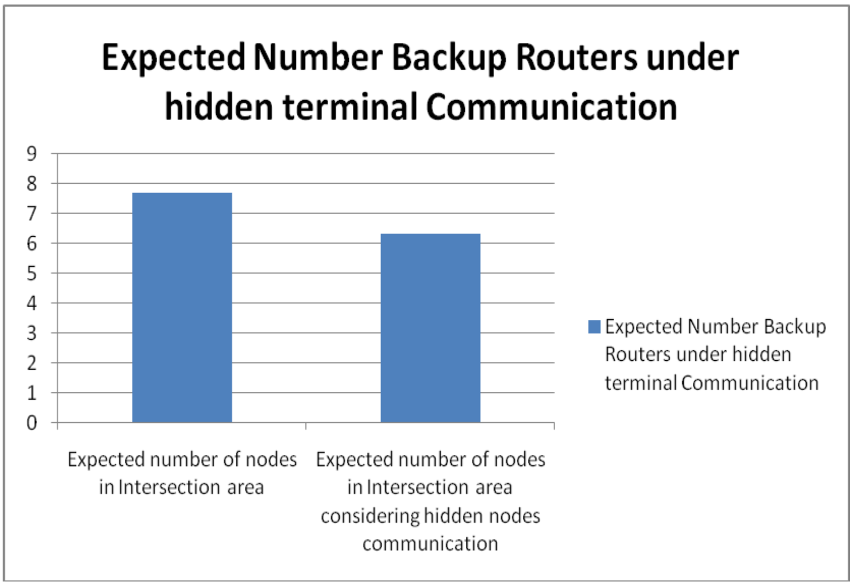

Figure 8. Expected number of backup routers under Hidden Terminal communication Problem

F. Expected number of nodes in the Intersection area as a function of Power Consumption

The most straightforward assumption relating the energy consumption with antenna range is to assume that the energy consumption is directly proportional to the signal strength. For deriving a relationship between number of nodes in the intersection area and the transmission range, the following points relating to the power can be considered.

Let the antenna strength for an omni directional antenna at the tip of the antenna be 100w. The antenna strength at a point at distance 8m from the antenna is 0.12434 w assuming that the antenna strength is uniformly distributed over complete surface area of a sphere centered at the node. let this minimum signal strength is required by the receiving antenna for communication, thereby forming the definition of the transmission range. thus, one can state that Power consumption increases with respect to the transmission range as the square of transmission range. If this is the minimal power at any specified point to sense a node, then on can derive a relationship between the power consumption and the transmission range. Assuming all the parameters as described in table 4.1, the following results can be deduced.

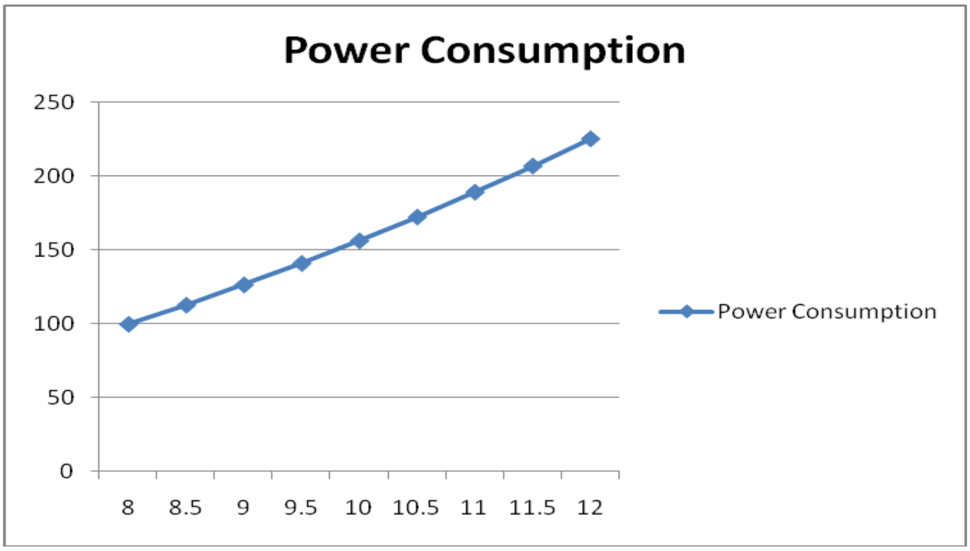

Figure 9. Power Consumption as a function of transmission range

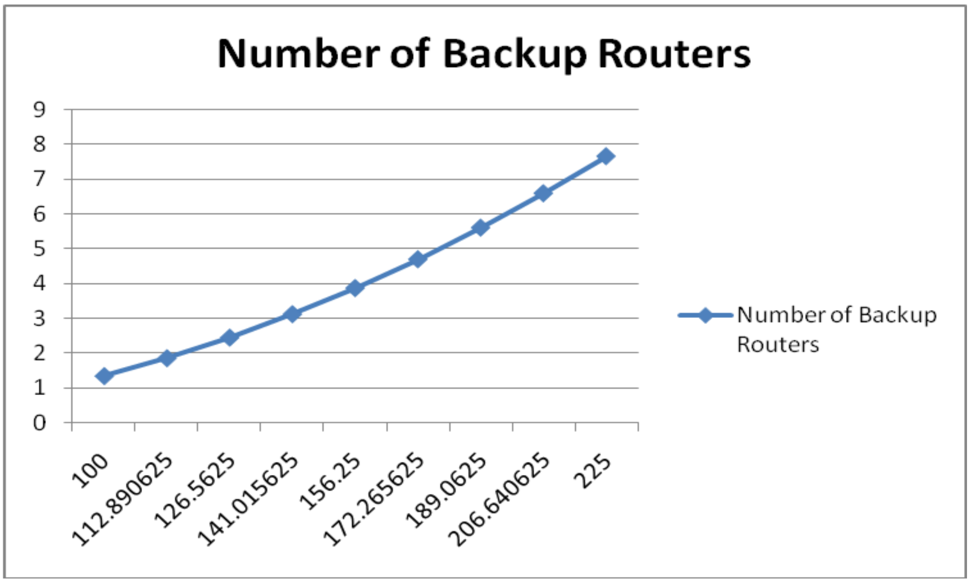

Figure 10. Number of backup routers (nodes in Intersection area) as a function of transmission range

G. Average Number of Tokens Reward Rates for proposed SRN

This clearly indicates that the reward rate is maximum for place P2 which is a direct consequence of the fact that nodes enter and leave the intersection area frequently. This also proves the validity of the proposed model in correspondence to the simulation results.

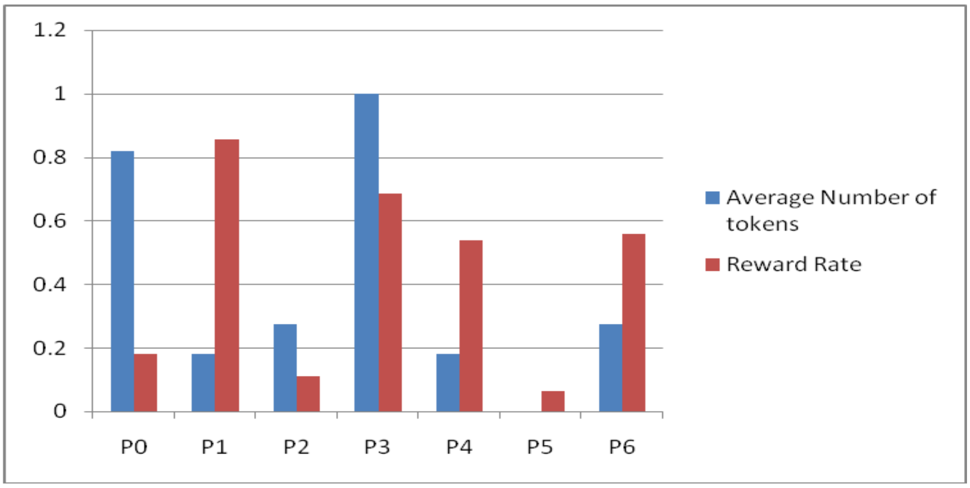

Figure 11. Average Number of Tokens Reward Rates for proposed SRN

VI. Simulation Results

OMNeT++ is an object-oriented modular discrete event network simulation framework. It has a generic architecture, so it can be (and has been) used in various problem domains: modeling of wired and wireless communication networks protocol modeling of queuing networks modeling of multiprocessors and other distributed hardware systems validating of hardware architectures evaluating performance aspects of complex software systems in general, modeling and simulation of any system where the discrete event approach is suitable, and can be conveniently mapped into entities communicating by exchanging messages.

A. Simulation Scenario Design

The project results in the following simulation model:

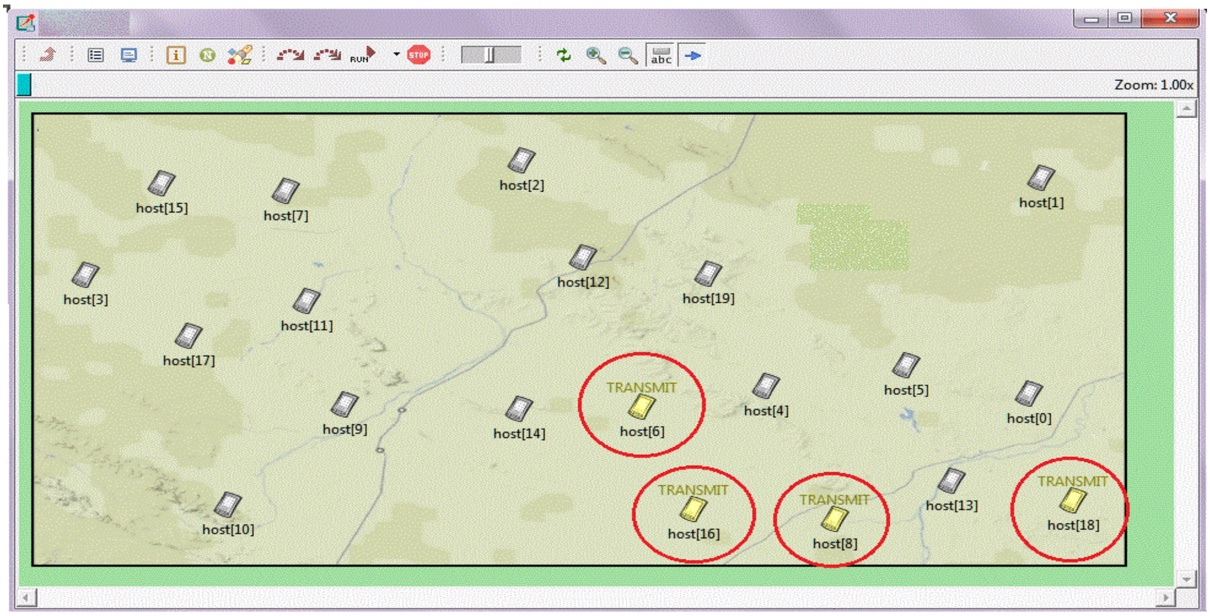

Figure 12. Simulation Screenshot

In this simulation model, the nodes have random mobility and it is supposed that host 10 (source) is supposed to sent the data to host 1 (Destination). The active nodes are shown in red circles which are transmitting and can work as hidden terminals for the simulation model. For a large data sample of nodes, the end to end packet delay, considering hidden terminals as shown in simulation results is as given below:

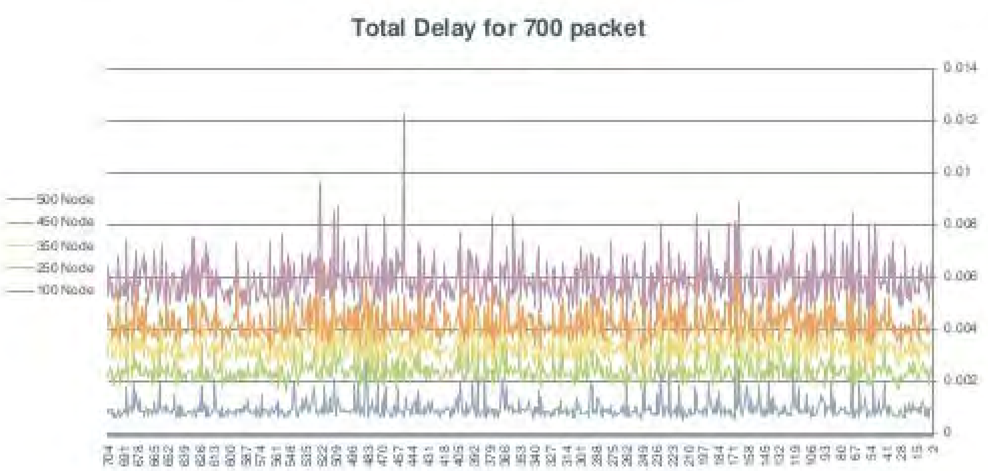

Figure 13. Delay measure in simulation results (without RTS/CTS)

The comparative analysis of the analytical results (PIPE) with those obtained by simulation model (OMNeT++) are:

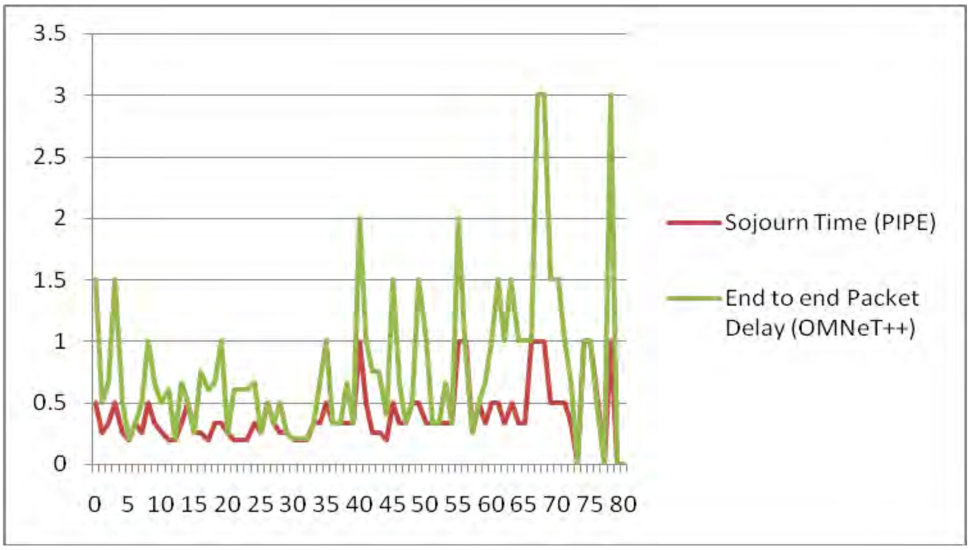

Figure 14. Comparison of Analytical and Simulation Results

The above graph shows a close match between the simulation results and the analytical results obtained through SRN model. The markings in the PIPE simulation results corresponds to the state of the mobile network at any particular time instant when the number of available routers in any hop of a path is given by tokens on the place P_0. However, the random mobility model is chosen in the OMNeT++ simulation and time averages are considered.

VII. Conclusion

In this work a closed form solution for analytical analysis of path connection avail-ability in multi-hop ad hoc networks with random waypoint mobility is presented. An SRN model is proposed to study the path connection availability and failure frequency of multi-hop paths. Analytical expressions for the leaving time and the entering rate for the intersection area, which are model parameters, are derived. The pro-posed model is validated by extensive simulations. Compared to simulation results obtained using OMNET and PIPE, analytical results are accurate. The impacts of different network parameters, such as number of nodes, data trans-mission rate, network size, transmission range and routing protocol, on the path connection availability are investigated.

The most critical part of the analysis is considering the hidden node problem, using Hidden/ Exposed Terminal problem. The larger the number of nodes or data transmission rate the smaller the path connection availability because of increasing the interference between neighbor nodes and consequently increases the end-to-end delay and route recovery delay. Due to increasing the number of intersection areas and number of hops in the path, increasing the network size or decreasing the transmission range increases the end-to-end delay and path break probability which decreases the path connection availability. In addition, the routing protocol has a significant effect on the path connection availability. For example, with high mobility patterns, DSR protocol decreases the path connection availability compared to AODV. The simulation results shows that performance of the system considering the hidden nodes. It is also analyzed that the local repairing of the AODV may result in sojourn time overhead and occasionally results in large overheads as compared to source routing of DSR. Source routing is however, not desirable due to large byte overhead in large networks. A combination of AODV and DSR could therefore be a solution with better performance than AODV and DSR.

The comparison of analytical and simulation results shows a closed match which validates the authenticity of the proposed SRN model. However, for the proposed SRN model, the variation in end to end delay, for small (<10) and large (>1000) deviates from the simulation results as the effect of hidden and exposed terminals increases exponentially with the existing assumptions that the node behavior is independent of each other and each node sends packet independent of each other and follows Poisson Probability Distribution. Packet dropping rate of AODV routing protocol was observed to be high for RWP motility. The AODV routing protocol perform well in RWP mobility model under high mobility and when the number of nodes are elevated. Elevated motilities may lead to high probability of link failures. Also, the throughput of all the mobility models decreases as the mobility increases and it remains is comparatively high for AODV as compared to DSR when the number of nodes in the network grows.

REFERENCES

[1] Ciardo, G., Muppala, J.K., Trivedi, K.S.: Analyzing concurrent and fault-tolerant software using stochastic reward nets. Journal of Parallel and Distributed Computing 15 (2012) 255-269

[2] Xianren, W., Sadjadpour, H.R., Garcia-Luna-Aceves, J.J.: Link Lifetime as a Function of Node Mobility in MANETs with Restricted Mobility: Modeling and Applications. 5th In-ternational Symposium on Modeling and Optimization in Mobile (2009) 1-10

[3] Dan, Y., Hui, L., Gruber, I.: Path availability in ad hoc network. 10th International Confer-ence on Telecommunications Vol. 1 (2003) 383-387 vol.381

[4] Yu-Chee, T., Yueh-Feng, L., Yu-Chia, C.: On route lifetime in multihop mobile ad hoc networks. Mobile Computing, IEEE Transactions on 2 (2009) 366-376

[5] Pascoe-Chalke, M., Gomez, J., Rangel, V., Lopez-Guerrero, M.: Route duration modeling for mobile ad-hoc networks. Wireless Networks 16 743-757

[6] Dongyan, C., Sunil, G., Kishor, S.T.: Network survivability performance evaluation: a quantitative approach with applications in wireless ad-hoc networks. ACM international workshop on Modeling analysis and simulation of wireless and mobile systems. ACM, At-lanta, Georgia, USA (2010).

[7] Perkins, C., Royer, E., Das, S.: RFC 3561 Ad hoc On-Demand Distance Vector (AODV) Routing. (2005)

[8] H.C. Yang and M.S. Alouini, (2010), "Markov chains and performance comparison of switched diversity systems", IEEE Transactions onCommunications, Volume: 52 , Issue: 7, Page(s): 1113– 1125.

[9] Younes, O., Thomas, N.: Analysis of the Expected Number of Hops in Mobile Ad Hoc Networks with Random Waypoint Mobility. Electronic Notes in Theoretical Computer Science 275 (2011) 143-158

[10] Kleinrock, L.: Queuing Systems, Vol. I: Theory. John Wiley and Sons (1975)

[11] L. Bajaj, M. Takai, R. Ahuja, K. Tang, R. Bagrodia, and M. Gerla. GlomoSim: A Scalable Network Simulation Environment. Technical Report CSD Technical Report, #990027, UCLA, 1997.

[12] J. Broch, D. A. Maltz, D. Johnson, Y.-C. Hu, and J. Jetcheva. A Performance Comparison of Multi-Hop Wireless Ad Hoc Network Routing Protocols. Proceedings of the . th Annual ACM/IEEE International Conference on Mobile Computing and Networking (MobiCom), pages 85–97,Dallas, Texas, October 2008.