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An Analytical Model for Evaluating Routing Performance of AODV Protocol for MANETs with Finite Buffer Capacity

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Abstract
Computer networks of any kind are vulnerable to potential queuing problems that we see in our day-to-day life, MANETs are no exception especially in the context of routing. The key challenge with the MANETs is that they are infrastructure-less, highly mobile and nodes are connected dynamically in an arbitrary manner. AODV happens to be the important reactive routing protocol. Several researchers have worked on AODV in particular queuing problems pertaining to routing in AODV. Many of the researches focused on delay time as the key metric for performance evaluation, however it is also important to consider the performance metrics like dropping probability, throughput, expected queuing delay, average response time along with delay time. In this paper an analytical study is carried out for evaluating performance of AODV based on finite queuing model M/M/1/K with "K" finite buffer capacity at a node. The afore mentioned metrics are evaluated by varying arrival rate, service rate, number of nodes, buffer capacity and probability of packets processing locally. Influence of buffer capacity, arrival rate, service rate, number of nodes and probability of packets processing locally on various performance metrics is demonstrated through well defined formulae as well as graphs.

Keywords: AODV, Finite Buffer, MANETs, Queuing Model.

Introduction
One of the emerging technology in wireless communication is Mobile Ad hoc Networks. MANET is the basic network for developing other ad hoc networks such as Mesh, Sensor, Vehicular, ANET and Opportunistic networks. In MANETs, the nodes are mobile due to this the topology of the network changes arbitrarily [1], the link between two nodes is wireless, sometimes it causes link breakage [11], hence the routing performance is a major challenge in mobile ad hoc networks. Mobile Ad hoc Networks are categorized into Homogeneous and Heterogeneous networks[15]. Homogeneous Mobile Ad hoc networks carry the same type of mobile nodes whereas heterogeneous mobile ad hoc networks comprises different types of mobile nodes.

One of the reactive routing protocol is Ad Hoc On Demand Distance Vector (AODV) [4], [7], [10], [11] which follows hop-by-hop routing methodology [11]. It establishes the route on on-demand basis [10]. When a source node wants to communicate with destination node, it broadcasts control packet Route Request RREQ to its neighbours. If the intermediate node has a route to the destination it sends Route Reply RREP to the source otherwise the RREQ is broadcast to the destination. When RREQ reaches the destination, it sends RREP to the source using unicast process [10], [11]. AODV maintains the sequence number for each node in routing table entry which shows freshness of routing information [24]. In this, AODV routing protocol is chosen to analyze the performance of the network.

In MANETs, based on node mobility, four mobility models are available vis-a-vis Random Way Point (RWP), Random Point Group Mobility (RPGM), Free Way Mobility (FWM), and Manhattan Mobility Model (MMM) [6]. In this paper Random Way Point model is considered to calculate the expected length between source and destination pair in two dimensional area because of its simple and easily implementation [6]-[8]. RWP uses two important parameters such as velocity and pause time. At the beginning every node is placed randomly and then moved towards the destination with constant velocity. The velocity of node chosen from uniform distribution $[0,V_{max}]$. After reaching some intermediate destination, the node waits for a pause time and then move towards randomly chosen destination. This process repeats until the simulation period elapses[5]-[7]. A novel graph-based mobility model was proposed in [9].

In the performance evaluation of MANETs different queuing models play vital role [2], [16], [23]. Hui Xu et al. [16] discussed about M/G/1 model, in this each node is represented as a queue with two types of customers(unicast and broadcast packets). The transmission delay or one hop delay of broadcast packets can be obtained by combining the waiting time in queue and service time for broadcast packets. The end-to-end delay is derived by summing up transmission delay from source to destination. A Unified framework was developed to evaluate both proactive and reactive routing protocols using infinite buffer queuing model. Aznida Hayati Zakaria et al. [1] discussed M/G/1 queuing model for analysing expected queuing delay and average response time. This model was implemented in Dynamic Source Routing protocol (DSR). Baskar.S and S.Palaniammal [17] proposed an Enhanced Probabilistic Ad Hoc On Demand Distance Vector (EPAODV) routing protocol to increase the throughput and packet delivery ratio and decrease the end to end delay. The EPAODV routing protocol applied M/M/C:∞/FIFO queuing model for each node in the network. This routing protocol was compared with PAODV routing protocol.

Each of the above discussed models, analyzed with the assumption of infinite buffer capacity at the node, hence the studies are not complete without considering the buffer at each node as finite. The objective of this paper is to study the influence of the finite buffer capacity at each node while conducting performance evaluation studies. When the buffer is full there would obviously be packet loss, this would increase the routing overhead as a consequence the efficiency of routing protocol will get affected [16], [20]. A theoretical framework based on G/G/1/K queuing model [20] analyzed the packet loss overhead, control overhead, total overhead, throughput and end-to-end delay by varying packet generation when buffer capacity K=5 and 10. M/M/1/B queuing network model [2] for adaptive-gossip routing algorithm analyzed queuing delay based on number of nodes, transmission range, the behaviour of routing for multimedia data and also estimated low end-to-end delay and maximum achievable throughput to reduce routing overhead in AODV routing protocol. These papers have not considered about some of the important parameters like service rate and probability of packets processing locally. In this paper a queuing model is proposed with finite buffer capacity to analyze the performance of the AODV routing protocol. In this model each node is represented as queuing node and each one deploy in two dimensional area. The analytical expressions for the performance metrics such as Expected Queuing Delay, Average Response Time, Throughput and Packet dropping probability are derived using queuing model. Analytical results are presented based on arrival rate, service rate, number of nodes, buffer capacity and probability of packets processing locally.

The rest of this paper is outlined as follows. Section II narrates the Literature review about the various queuing models implemented in different routing protocols. Section III presents the important terminology used in the proposed model. Section IV discusses the performance metrics to analyse the performance of the routing protocol. Section V discusses numerical illustrations and finally results and conclusions are presented in section VI and section VII respectively.

Literature Review

Several studies have focused on queuing models for evaluating performance of routing protocols in Mobile Ad Hoc networks.

Nabhendra Bisnik et al. [23] proposed an analytical model for the random access multi hop wireless networks established on G/G/1 queuing networks. First asses the mean and second moment of service time over a single hop by considering the back off and collision avoidance of IEEE 802.11 MAC and then use the diffusion approximation method in order to deduce closed form networks to arrive at the mathematical expressions for the average end-to-end delay. The maximum achievable throughput is prevailed by using the mean service time of nodes. The average end-to-end delay and maximum achievable throughput performance parameters are measured on the basis of the number nodes, transmission range and traffic pattern. The analytical results are compared with DSDV routing protocol.

Gaurav Khandelwal et al. [24] proposed an enhanced probabilistic routing protocol named PAODV, which uses the birth and death process in queuing model. This queuing model has infinite buffer capacity. Hence packet arrivals are infinite at a node and route finding algorithm as the service rendered to these packets. The stability of a node is evaluated by number of packets arrived at a node and the number of packets being serviced by the node per unit time. The strength of the route is less than the threshold value, then the relay node would select another node/route to forward the packets.

Saad Talib Hasson and Enass Fadil [21] described each node as queuing system to serve the arriving packets. This model was implemented to evaluate the performance metrics for each simulation area like 800m*800m, 1000m*1000m etc.. depending on the values of the mean inter arrival time, mean service time, maximum throughput, mean service utilization, minimum idle time and lost packets the optimum number of nodes is computed. This model was implemented in DSDV (Destination Sequenced Distance Vector) Routing protocol.

Ahyoung Lee and Ilkyeun Ra [2] proposed M/M/1/B queuing network model based on adaptive-gossip algorithm with probability p_n for multimedia communication. The important principle of this model is absorption probability. This model reduces routing overhead, end-to-end delay and increases throughput when compared with simple flooding mechanism in routing protocols.

Giddaluru Madhavi and M.K.Kaushik [22] formulated M/M/1 queuing model to measure the performance of the system using steady state average delay, steady state average waiting time in the system, average number of customers in the queue and average number of customers in the system. In this paper that the proposed queuing methodology is implemented in DSR, NFPQR, and clustered NFPQR routing protocols. The clustered NFPQR protocol affords good throughput, efficient power consumption and increased network life time and also decreased overhead per node.

R.B.Lenin and S.Ramaswamy [19] modelled WSN as open queuing network and arrived at analytical formula for performance metrics such as throughput, average end-to-end delay, packet loss probability and average number of hops. The basis of this model is intermittency between the communication links because of mobility. Each node of the WSN is considered as a GI/G/1/N queuing node and the links between sensor nodes are considered as intermittent links between the queuing nodes.

Yang Xu et al. [20] provided a theoretical framework based on G/G/1/K queuing model. They proposed a distributed routing algorithm called novel load-balancing cognitive routing (NLBCR) protocol. They further used OPNET network simulator to compare the performance among NLBCR, AODV and CRP. They concluded that NLBCR

reduces routing overhead, improves the network throughput and reduces the end-to-end delay.
Different authors worked with different queuing models on various routing protocols. These studies are categorized with reference of queuing model, protocol, parameters and performance metrics as presented in Table I.

Table. I. Details Of The Different Queuing Models, Protocol, Parameters, Performance Metrics

Authors	**Queuing Model**	**Protocol**	**Parameters**	**Performance metrics**	**Analytical/ Simulation**
Nabhendra Bisnik A.A.Abouzeid	G/G/1	DSDV	No. of Nodes, Arrival rate, absorption probability	end-to-end delay, maximum achievable throughput	Both
Hui Xu, Xianrenwu, H.R.Sadjadpour, J.J. Gracia-Luna-Aceves	M/G/1	AODV OLSR	Transmission Range, Speed, Traffic Flows	Protocol efficiency, packet delivery ratio, packet delivery delay	Both
Saad Talib Hasson, Enass Fadil	Queuing Model	DSDV	Number of Nodes, Simulation area	Optimal Number of Nodes	Simulation
Gaurav Khandelwel, Giridhar Prasanna, Chittaranjan Hota.	Birth and Death Process	PAODV	Number of Nodes	Packet drop, Throughput, Probability factor	Simulation
A.Lee, I.Ra	M/M/1/B	AODV	Number of nodes, transmission range, traffic	End-to-end delay, throughput, overhead, packet drop fraction	Both
Giddaluru Madhavi, M.K.Kavshik	M/M/1	NFPQR	Number of nodes, Communication period	Overhead, Network life time, Delay	Simulation
R.B.Lenin S.Ramaswamy	GI/G/1/N	--	Number of nodes, Buffer size, Sampling time, hop count	End-to-end delay, packet loss probability, Throughput, Average number of Hops	Analytical
A.Hayati Zakaria, Md.Y.M.Saman, A.S.M.Noor, R.O.M. Saleh	M/G/1	DSR	Hop count, arrival rate	Average waiting time, average response time	Analytical
Yang.Xu, Min Sheng, Jia Liu, Yan Shi	G/G/1/K	NLBCR	Packet generation, buffer capacity	Packet loss overhead, control overhead, throughput, end-to-end delay	Both
Baskar.S. S.Palaniammal	M/M/c:∞/ FIFO	EPAODV	Number of nodes	End-to-end delay, throughput, data delivery ratio	Simulation

Basic Terminology
This section is dedicated to represent the MANET as a finite queuing model and the relevant terminology which is used in this model is presented.

A. Representation of Mobile Ad hoc Networks
A Graph consists of nodes placed in d-dimensional space $R^{d,}$ with edges added to connect pairs of points which are close to each other. Let ||.|| be some norm on R^d, for example of the Euclidean norm and let r be some positive parameter. Given a finite set X R^d, denoted by G(X; r) the undirected graph with vertex set X and with undirected edges connecting all those pairs {X,Y} with $|Y-X| \leq r$. Which is called a Geometric Graph [18].
In proposed system the network topology represented as a graph G(N, r(N)) [1], [2], where N is set of Nodes and r(N) is transmission range. In Graph G set of N nodes placed randomly on two dimensional Area A. All nodes are having same transmission range r(N). The link between two nodes i and j is called distance denoted by d_{ij}. The distance between two nodes is less than or equal to transmission range i.e. $d_{ij} \leq r(N)$, then these two nodes are neighbours. Each node

has transmission range which is represented as circle so the communication area is denoted by $\pi r^2(N)$.

B. Finite Queue Model

In this paper a Finite Queuing Model M/M/1/K is used to represent the node of a MANET. In this model each node is assumed to have the finite buffer to collect arriving packets and the server to process packets one at a time. If the server is busy in processing a packet, an arriving packet joins the buffer [19]. When packets exceeds the buffer capacity, that packet is dropped, that is the arrived packet does not enter into the system [20]. The packets are processed by the server on First-Come First-Serve basis [2]. In this model each node is referred as queuing node wherein packets are customers, packets to be forwarded are arrival of customers, the packet processing place is the server and the routing delay is the service time [19]. The arrival and service rates are denoted by λ and μ respectively.

C. Arrival Rate

The Homogeneous Mobile Ad Hoc Network has set of N mobile nodes. Each node could be a source, destination and intermediate node. On average each node generates packets with rate λ packets/sec. At each node the packet generation process is i.i.d. (independent and identically distributed) Poisson process [2], [20]. The packet arrivals to the nodes is represented by λ, further it is assumed that the packet arrivals at each node is Poisson process and their sum is also Poisson process. Hence the Arrival Rate of packets at single node which is denoted by λ_s [1] is defined as

$$\lambda_s = \frac{\ell.\lambda + (\mathrm{N}-1)(1-\ell)\lambda}{(\mathrm{N}-1)} \quad (1)$$

where ℓ is the probability of packet processing locally. In the above expression the first term describes the probability of ℓ of the incoming λ packets can be processed locally and the remaining $(1-\ell)\lambda$ packets are forwarded to the nodes which happens to be the neighbours as per the routing algorithm. The other N-1 nodes also forward $(1-\ell)$ of their λ packets, which are received by each of the remaining nodes with equal probability $1/(N-1)$ [1].

D. Transmission Range

In Homogeneous mobile ad hoc network all nodes have the same capabilities and resources such as radio range, battery life, data transmission rate, etc [4]. Owing to this all nodes shares the common radio range. This network topology can be represented as random geometric graph. In this assume that all nodes are having same radio transmission range. If the two nodes are within their transmission range then these nodes can be communicate directly. In homogeneous mobile ad hoc network, the nodes are connected with wireless links. These links are bidirectional [3]. All nodes in the network move freely based on mobility models.

In MANETs, all existing routing protocols (both proactive and reactive) use broadcast mechanism to forward routing packets in both route discovery and route maintenance phases. This broadcast mechanism follows the simple flooding concept.
In this system node density is denoted by N_D which is defined as the ratio between Number of nodes N and Area A. This is given by

$$N_D = \frac{N}{A} \quad (2)$$

The communication area of each node is $\pi r^2(N)$. Then the Expected number of neighbours E(n) is

$$N_D.\pi r^2(N) \quad (3)$$

According to Penrose's formula of a high connectivity [18]

$$N_D.\pi r^2(N) = \ln(N) \quad (4)$$

Expected number of neighbours of a node within its transmission range in flooding based system is

$$E(n) = \frac{\pi r^2(N)}{A} N \quad (5)$$

From equation (5) we obtain critical transmission range which is denoted by $r_c(N)$.

$$r_c(N) = \sqrt{\frac{A.\ln(\mathrm{N})}{\pi.N}} \quad (6)$$

E. Expected Length

The Expected Transition Length L between random source and destination is denoted by E[L]. In our system E[L]=0.402*a [8]. The nodes that are being considered are represented by random way point mobility model and all nodes are placed on Rectangular Area A in this system as discussed in section 1. The size of rectangular area A=a*b for a ≥ b.
Bettstetter et al. [8] the probability density function of transition length is

$$f_L(l) = \frac{4l}{a^2 b^2} f_0(l) \quad (7)$$

Hence, the expected length L is:

$$E[\mathrm{L}] = \frac{1}{15}\left[\frac{a^3}{b^2} + \frac{b^3}{a^2} + \sqrt{a^2+b^2}\left(3 - \frac{b^2}{a^2} - \frac{b^2}{a^2}\right)\right] + \frac{1}{6}\left[\frac{b^2}{a}\cos^{-1}\frac{\sqrt{a^2+b^2}}{b} + \frac{a^2}{b}\cos^{-1}\frac{\sqrt{a^2+b^2}}{a}\right] \quad (8)$$

Bettstetter et al. [8] the E[L] for Square $a*a$ is $0.5214*a$ and the E[L] for Rectangle size of $a*a/2$ is $0.402*a$. Brahim Gaboune et al. [13] discussed other models for the expected distance between two uniformly distributed points in rectangle.

F. Expected Hop Count

In this system all nodes have equal capabilities so the delay and response time at single node are calculated and hence to obtain the average queuing delay and average response time, the values at single node is multiplied with expected hop count. The Expected Hop Count E(H) is defined as the ratio of Expected Length between random source and destination pair E[L] to critical transmission range $r_c(N)$.

$$E(H)=\frac{E[\mathrm{L}]}{r_c(N)} \tag{9}$$

Performance Analysis

In this section various expressions are used for the performance metrics vis-a-vis Expected Queuing Delay, Throughput, Average Response Time and Packet Dropping Probability for finite queuing model M/M/1/K [12], [25].

A. Expected Queuing Delay

The delay is defined as the time taken by a packet to reach its destination node after it is generated [23]. In this network model K be the buffer capacity of an M/M/1/K system, that is maximum number of packets in the system including the one under service. For steady state distribution, the probability when the queue is empty, that is denoted by P_0

$$P_0=\frac{1}{\sum_{i=0}^{K}\left(\frac{\lambda_s}{\mu}\right)^i} \tag{10}$$

where $\frac{\lambda_s}{\mu}=\rho$ that is server utilization. This is also called as utilization ratio [23]. ρ is substitute in the above formula then the P_0 is

$$P_0=\frac{1-\left[\frac{\lambda_s}{\mu}\right]}{1-\left[\frac{\lambda_s}{\mu}\right]^{K+1}} \tag{11}$$

Let P_n for 0≤n≤K, denote the probability that there are n packets in the queue by the formula definition of a single server exponential queuing system having finite buffer capacity is

$$P_n=\frac{1-\left[\frac{\lambda_s}{\mu}\right]}{1-\left[\frac{\lambda_s}{\mu}\right]^{K+1}}\left[\frac{\lambda_s}{\mu}\right]^n \tag{12}$$

The Average number of packets in the System with finite buffer capacity K is given by L_s

$$L_s=\sum_{n=0}^{K} nP_n$$

(or)

$$L_s=\frac{\rho\left[1-(1+K)\rho^K+K\rho^{K+1}\right]}{(1-\rho)\left(1-\rho^{K+1}\right)} \tag{13}$$

Average Waiting Time spent in queue is denoted by W_q at node in MANET is given by

$$W_q=\frac{L_q}{\lambda_e} \tag{14}$$

where L_q is the average packets in queue, λ_e is effective arrival rate. The average packets in Queue L_q with finite buffer capacity K at node is given by

$$L_q=L_s-L_B \tag{15}$$

where L_s is the average number of packets in the system, L_B is the average Busy Servers, i.e. number of packets in service is calculated by $L_B=1-P_0$.

It is assumed that the delay is proportional to the expected hop count between source and destination [23]. The queuing delay is defined as the sum of waiting time at source node and intermediate nodes due to route establishment and network congestion [2].The average queuing delay at all nodes are the same [1]. The Expected Queuing Delay that a packet waiting for transmission in the entire network from source to destination is given by

$$E(D_q)=W_q.E(H) \tag{16}$$

where W_q is Average waiting time at local node and E(H) is the expected hop count between a source and destination pair.

B. Throughput

The Effective Arrival Rate λ_e is defined as the mean number of arrivals per time unit who enter and remain in the system. This is also called as Throughput. For all systems $\lambda_e \leq \lambda_s$; for systems such as the present one which turn packets away when full. The effective arrival rate is computed by

$$\lambda_e = \lambda_s(1 - p_K) \tag{17}$$

C. Average Response Time

The Response Time is defined as the total time that a packet spends in the queuing system [1]. Thus the Average Waiting Time in System (Response time) is denoted by W_s at a node in MANET is given by

$$W_s = \frac{L_s}{\lambda_e} \tag{18}$$

where L_s is the average number of packets in the system, λ_e is effective arrival rate.

The Average Response Time over the entire network from source to destination is

$$\overline{W} = W_s.E(H) \tag{19}$$

where W_s is Average Waiting Time in System at node and E(H) is the expected hop count between a source and destination pair.

D. Packet Dropping Probability

The probability of packet drop is denoted by P_K when the queue is full. This is also called Blocking Probability. Each node has a single queue of finite buffer size K, the queuing system has a capacity to hold K packets that are served in an FCFS fashion. Thus, an arriving packet that sees the queue full with probability P_K is dropped, that is represented as

$$P_K = \frac{1 - \left[\frac{\lambda_s}{\mu}\right]}{1 - \left[\frac{\lambda_s}{\mu}\right]^{K+1}} \left[\frac{\lambda_s}{\mu}\right]^K \tag{20}$$

Numerical Illustration

To analyse the performance metrics such as Expected Queuing Delay, Average Response Time, Packet Dropping probability and Throughput in the network we consider various input parameters such as Number of Nodes N, service rate μ, arrival rate λ, probability ℓ, finite buffer capacity K. Here it is assumed that N is varied from 100 to 1000 with interval of 100. For these values, calculate critical transmission range $r_c(N)$ and hop count E(H). For example N is 100 then critical transmission range is 85.6m and expected hop count is 4. In the network the packets are arrived in the Poisson process at nodes. So the arrival rate of packets λ_s is obtained from equation (1) where ℓ is varying from 0.1 to 0.9. The inter arrival rate between two consecutive arrival is 15 packets per second and the probability of these packets are processed locally is 15xℓ. The probability of $(1-\ell)$x15 packets are forwarded to N-1 nodes with equal probability. Hence the total arrival rate is sum of locally processed packets and forwarded packets i.e. λ_s=13.51 when ℓ =0.1. Each packet is served by the server is called service rate μ is assumed to 20. The server utilization is $\rho = \frac{\lambda_s}{\mu}$. It is us assumed that finite buffer capacity K is 50 and by varying N and ℓ the Average number of packets in the system L_s, Average number of packets in Queue L_q, Average waiting time in the system W_s, and Average waiting time in Queue W_q are obtained. For the above values L_s=2.084, L_q=1.408, W_s=0.154 and W_q=0.104. Finally Expected Queuing Delay is computed as 0.416 and Average Response Time = 0.616.

Results

The results of various performance metrics namely Packet Dropping probability, Throughput, Expected Queuing Delay, and Average Response Time are plotted with different input parameters like arrival rate, service rate, number of nodes, buffer capacity and probability of packets processing locally.

A. Case 1

In this case it is assumed that the arrival rate at each node follows the Poisson process. Each node arrival rate at beginning is 4 packets per second and then it is increased up to 8 packets per second. Each node buffer capacity is assumed to be constant at 10 and service rate is 9 packets per second. The results are plotted in the figures 1 to 4.

i) It is being observed that while the arrival rate λ_s is increased, packet dropping probability also increases from 0.01% to 5% exponentially, the service rate μ is maintained same all the time for different values of N ranging from 100 to 500, the same is shown in Fig.1.

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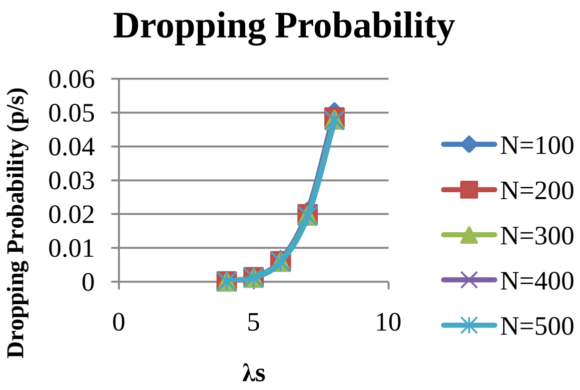

Fig.1. Arrival rate Vs Dropping probability.

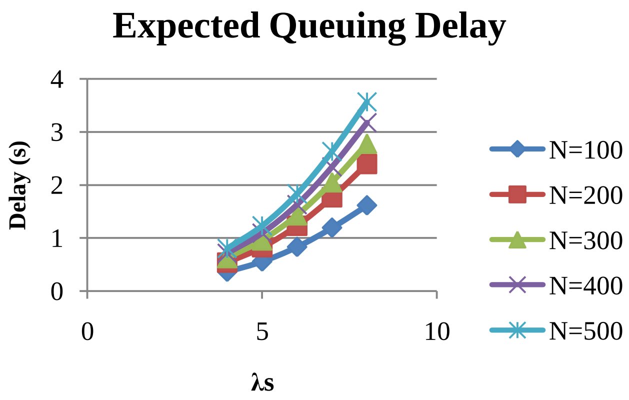

Fig.3. Arrival rate Vs Delay.

ii) It is being observed that while the arrival rate is increased, throughput also increases from 4.03 packets per second to 7.67 packets per second linearly, the service rate is maintained same all the time for different values of N ranging from 100 to 500, the same is shown in Fig.2.

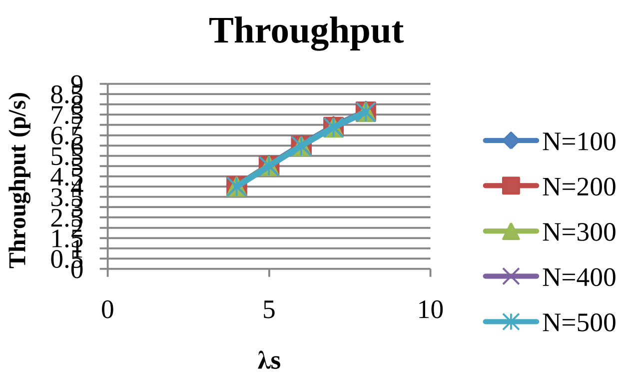

Fig.2. Arrival rate Vs Throughput.

iii) Expected Queuing Delay exponentially increases while the value of N is fixed and if N is increased the starting value of delay also starts at a higher level and then increases exponentially. For different values of N the expected queuing delay is computed and is plotted against arrival rate. It is being observed that the relationship between expected queuing delay and arrival rate is similar for different values of N. The same plotted in Fig.3.

iv) The behaviour of the Average Response Time plotted against arrival rate is more or less similar to that of expected queuing delay discussed above, because of the reason that if a packets spends more amount of time in the queue then obviously average response time would also increase. The same is plotted in the Fig.4.

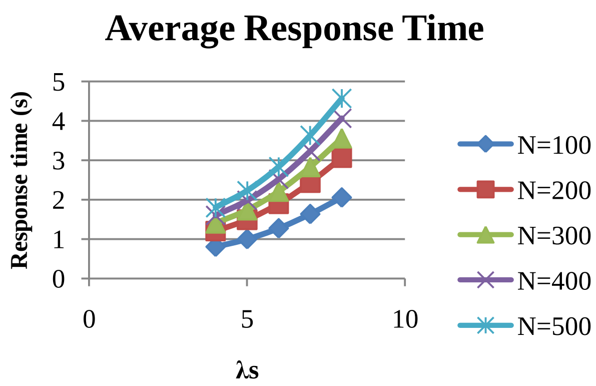

Fig.4. Arrival rate Vs Response time.

B. Case 2

In this case it is assumed that the arrival rate at each node follows the Poisson process. Each node service rate at beginning is 6 packets per second and then it is increased up to 11 packets per second. Each node buffer capacity is assumed to be constant at 10 and arrival rate of 5 packets per second. The results are plotted in the figures 5 to 8.

i) It is being observed that while the service rate is increased, packet dropping probability decreases exponentially, the arrival rate is maintained same all the time for different values of N ranging from 100 to 500, the same is shown in Fig.5.

ii) It is being observed that while the service rate is increased, throughput also increases exponentially, the arrival rate is maintained same all the time for different values of N ranging from 100 to 500. It is being observed that the relationship between throughput and service rate is similar for different values of N. The same is shown in Fig.6.

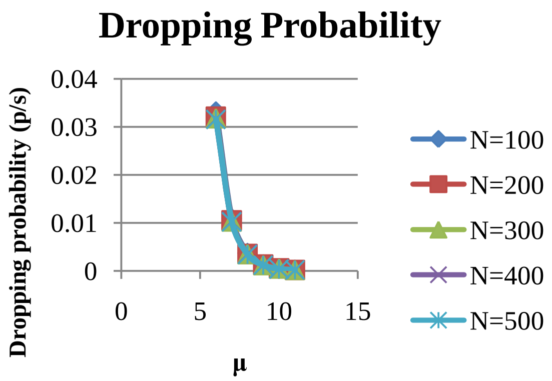

Fig.5. Service rate Vs Dropping probability.

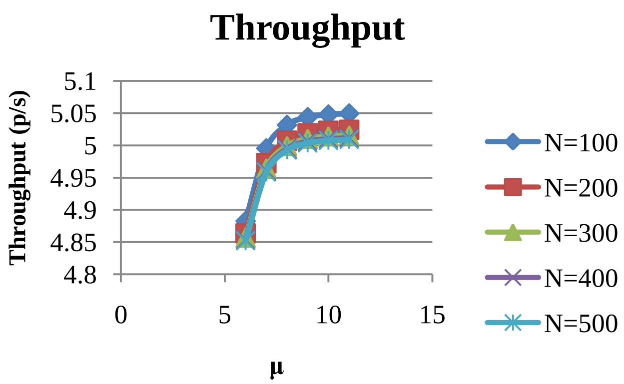

Fig.6. Service rate Vs Throughput.

iii) Expected Queuing Delay exponentially decreases while the value of N is fixed and if N is increased the starting value of delay also starts at a higher level and then decreases exponentially. For different values of N the expected queuing delay is computed and is plotted against service rate. It is being observed that the relationship between expected queuing delay and service rate is similar for different values of N. The same is plotted in Fig.7.

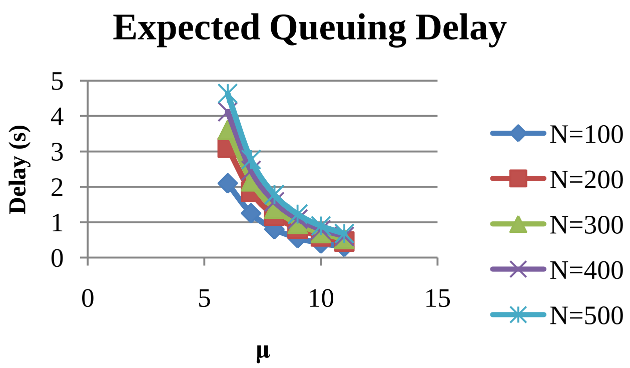

Fig.7. Service rate Vs Delay.

iv) The behaviour of the Average Response Time plotted against service rate is more or less similar to that of expected queuing delay discussed above, because of the reason that if a packets spends less amount of time in the queue then obviously average response time would also decrease. The same is plotted in the Fig.8.

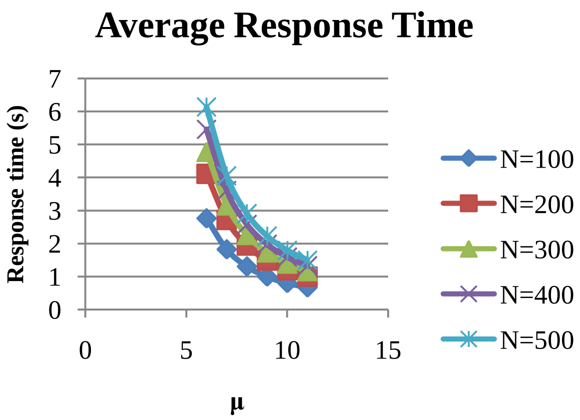

Fig.8. Service rate Vs Response time.

C. Case 3

In this case each node buffer capacity is assumed to be constant at 10 and service rate is 9 packets per second. As the probability ℓ of packets processing locally at node is increased then obviously the arrival rate λs decreases wherein λ is assumed to be constant. The results are plotted in the figures 9 to 12.

i) It is being observed that while the probability of packets processing locally is increased, packet dropping probability decreases exponentially and is same for all values of N. The service rate is maintained same all the time for different values of N ranging from 100 to 500, the same is shown in Fig.9.

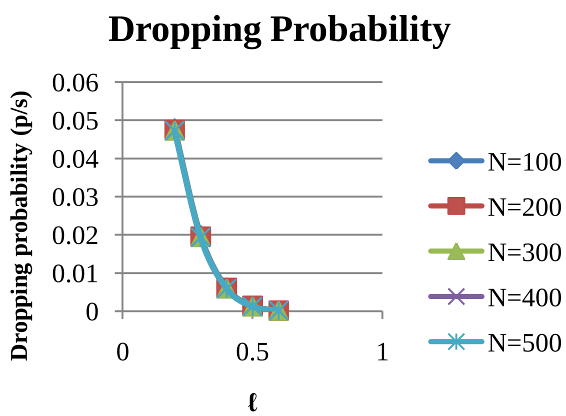

Fig.9. Probability Vs Dropping probability.

ii) It is being observed that while the probability of packets processing locally is increased, throughput decreases from linearly, the service rate is maintained same all the time for different values of N ranging from 100 to 500, the same is shown in Fig.10.

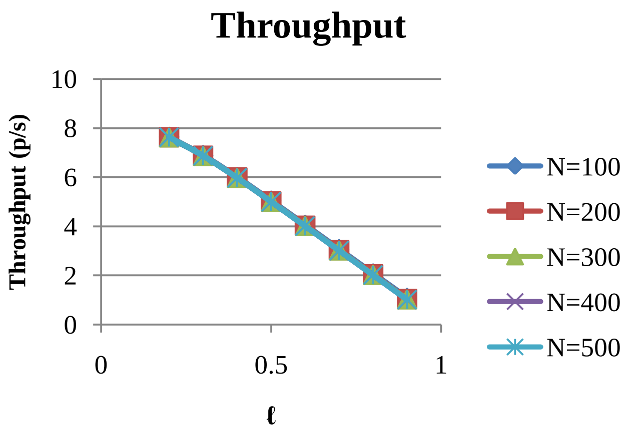

Fig.10. Probability Vs Throughput.

iii) Expected Queuing Delay exponentially decreases while the value of N is fixed and if N is increased the starting value of delay also starts at a higher level and then decreases exponentially. For different values of N the expected queuing delay is computed and is plotted against probability of packets processing locally. It is being observed that the relationship between expected queuing delay and probability of packets processing locally is similar for different values of N. It is further observed that as the value of ℓ approaches 1 the expected queuing delay becomes zero. The same is plotted in Fig.11.

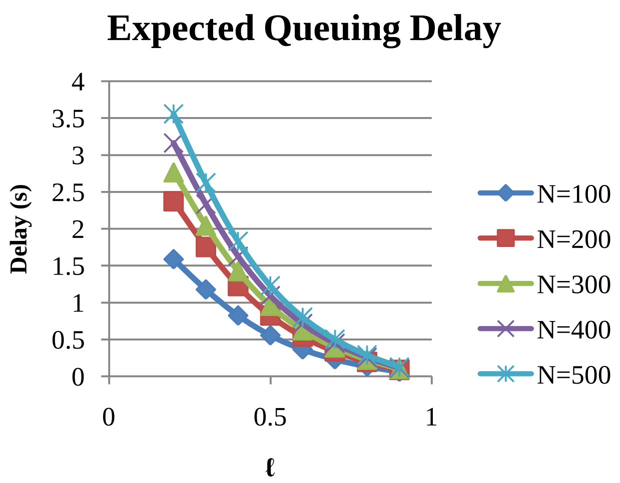

Fig.11. Probability Vs Delay.

iv) The behaviour of the Average Response Time plotted against probability of packets processing locally is more or less similar to that of expected queuing delay discussed above, because of the reason that if a packets spends less amount of time in the queue then obviously average response time would also decrease but it never approaches zero like expected queuing delay. The same is plotted in the Fig.12.

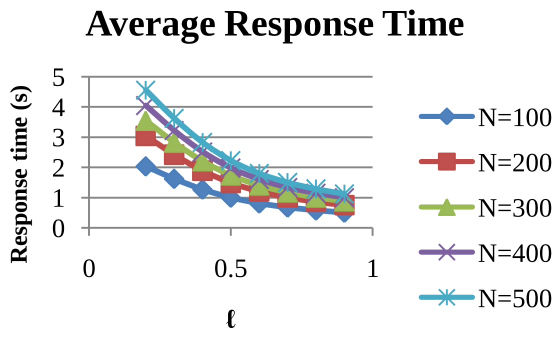

Fig.12. Probability Vs Response time.

D. Case 4

In this case it is assumed that the number of nodes to be constant at 100 in the MANET and the service rate is 9 packets per second to process the arriving packets. Arrival rate λs at each node at the beginning is 6 packets per second and then it is increased up to 8 packets per second. The results are plotted in the figures 13 to 16.

i) It is being observed that while the arrival rate λs is increased, packet dropping probability also increases linearly while the value of K is 5 and if K is increased the starting value of dropping probability starts at a very low level and increases exponentially, the service rate μ is maintained same all the time for different values of K ranging from 5 to 20, the same is shown in Fig.13.

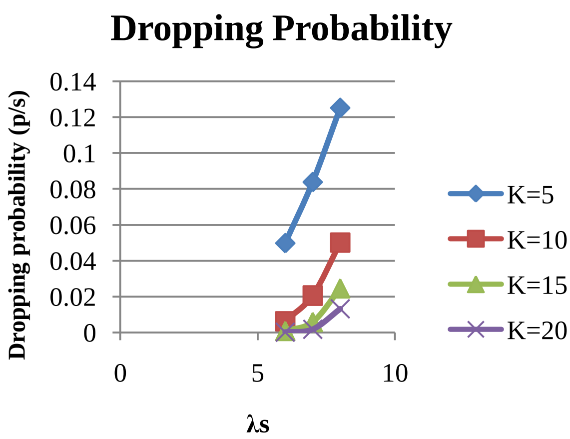

Fig.13. Arrival rate Vs Dropping probability.

ii) It is being observed that while the arrival rate is increased, throughput also increases linearly, the service rate is maintained same all the time for different values of K ranging from 5 to 20, the same is shown in Fig.14.

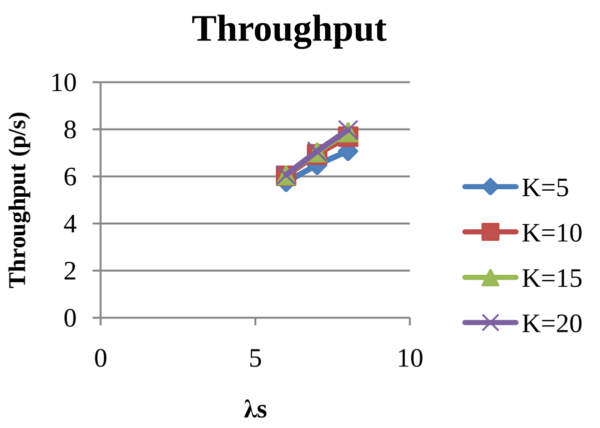

Fig.14. Arrival rate Vs Throughput.

iii) Expected Queuing Delay exponentially increases while the value of K is fixed and if K is increased the starting value of delay also starts at a higher level and then increases exponentially. For different values of K the expected queuing delay is computed and is plotted against arrival rate. It is being observed that the relationship between expected queuing delay and arrival rate is similar for different values of K. The same plotted in Fig.15.

iv) The behaviour of the Average Response Time plotted against arrival rate is more or less similar to that of expected queuing delay discussed above, because of the reason that if a packet spends more amount of time in the queue then obviously average response time would also increase. The same is plotted in the Fig.16.

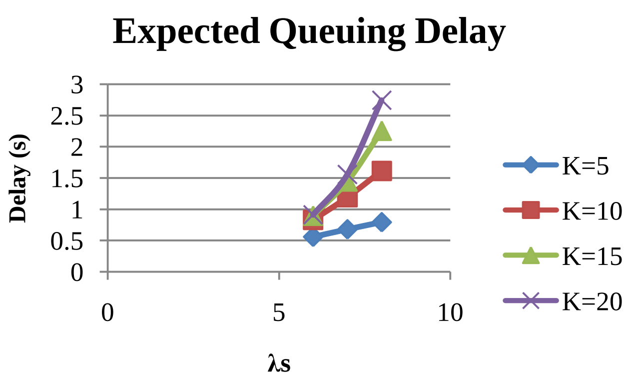

Fig.15. Arrival rate Vs Delay.

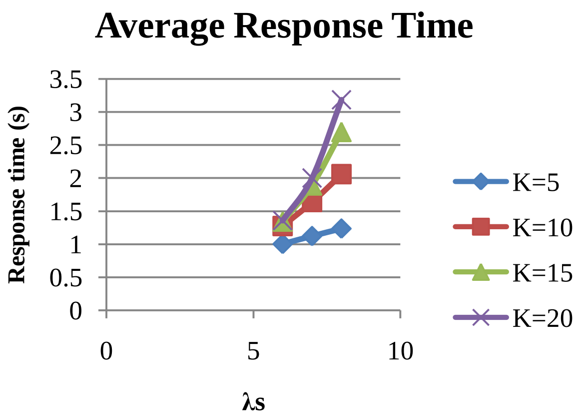

Fig.16. Arrival rate Vs Response time.

E. Case 5

In this case it is assumed that the MANET contains 100 nodes and each node arrival rate is 5 packets per second. Each node service rate at beginning is 6 packets per second and then it is increased up to 10 packets per second. The service rate follows exponential distribution. The results are plotted in the figures 17 to 20.

i) It is being observed that while the service rate is increased, packet dropping probability decreases exponentially when the value of K is 5 and if K is increased the starting value of dropping probability is starts at low level and then continues to decrease exponentially, the arrival rate is maintained same all the time for different values of K ranging from 5 to 15, the same is shown in Fig.17.

ii) It is being observed that while the arrival rate is increased, throughput also increases exponentially, the service rate is maintained same all the time for different values of K ranging from 5 to 20. Throughput is more or less same for different values of K while the service rate is 9 packets per second and then it is constant, the same is shown in Fig.18.

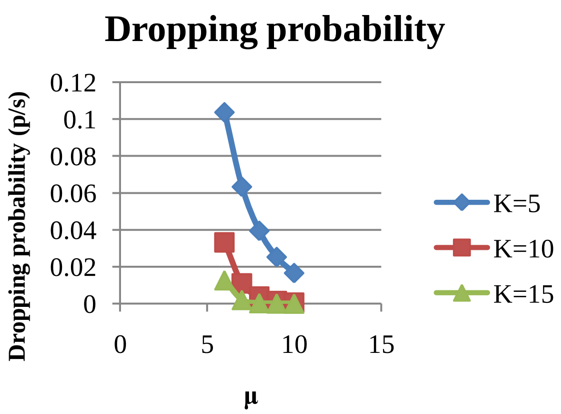

Fig.17. Service rate Vs Dropping probability.

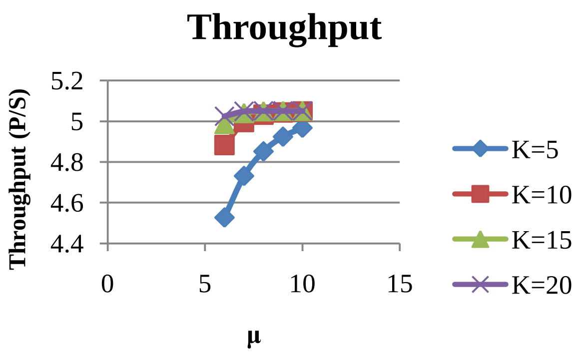

Fig.18. Service rate Vs Throughput.

iii) Expected Queuing Delay exponentially decreases while the value of K is fixed and if K is increased the starting value of delay also starts at a higher level and then decreases exponentially. For different values of K the expected queuing delay is computed and is plotted against service rate. It is being observed that the relationship between expected queuing delay and service rate is similar for different values of K. The same is plotted in Fig.19.

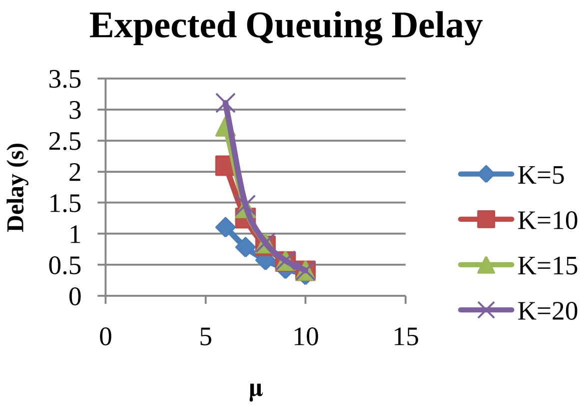

Fig.19. Service rate Vs Delay.

iv) The behaviour of the Average Response Time plotted against service rate is more or less similar to that of expected queuing delay discussed above, because of the reason that if a packet spends less amount of time in the queue then obviously average response time would also decrease. The same is plotted in the Fig.20.

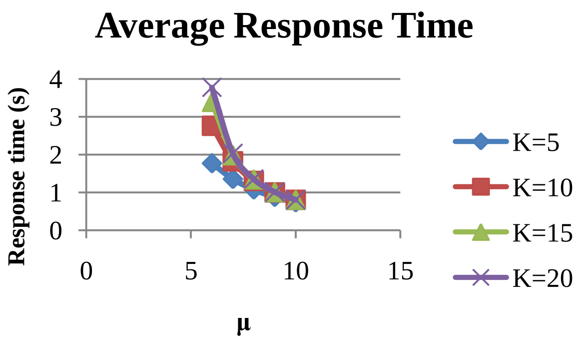

Fig.20. Service rate Vs Response time.

F. Case 6

In this case it is assumed that the number of nodes to be constant at 100 in the MANET and the service rate is 9 packets per second to process the arriving packets. The probability ℓ of packets processing locally at the beginning is 0.2 and then it is increased up to 0.9. As the probability ℓ of packets processing locally at node is increased then obviously the arrival rate λs decreases wherein λ is assumed to be constant. The results are plotted in the figures 21 to 24.

i) It is being observed that while the probability of packets processing locally is increased, packet dropping probability decreases linearly while the value of K is 5 and if K is increased the starting value of dropping probability starts at low level and then it reaches to 0. It is observed that if 50% of packets arriving at the local node are processed locally then the dropping probability reduces to zero. The service rate is maintained same all the time for different values of K ranging from 5 to 15, the same is shown in Fig.21.

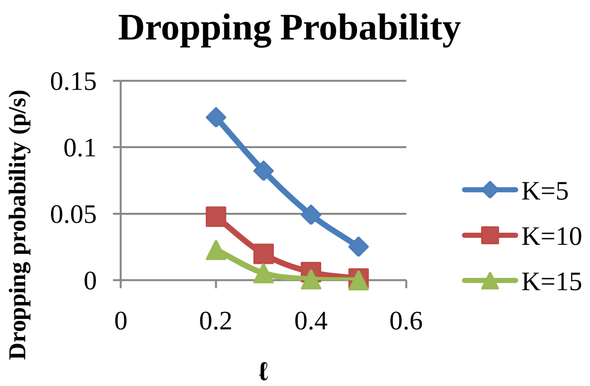

Fig.21. Probability Vs Dropping probability.

ii) It is being observed that while the probability of packets processing locally is increased, throughput decreases from 7.0 to 1.0 linearly, the service rate is maintained same all the time for different values of K ranging from 5 to 20, the same is shown in Fig. 22.

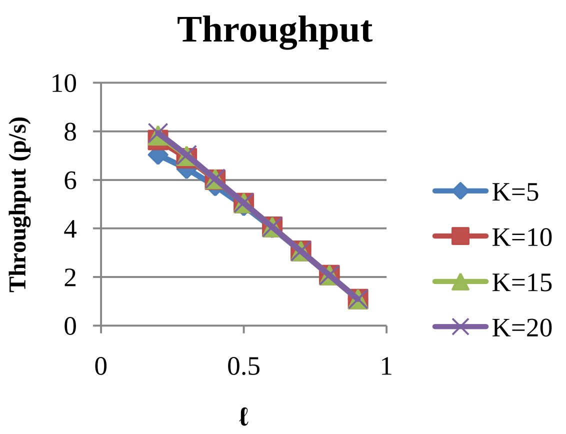

Fig.22. Probability Vs Throughput.

iii) Expected Queuing Delay linearly decreases while the value of K is fixed and if K is increased the starting value of delay also starts at a higher level and then decreases exponentially. For different values of K the expected queuing delay is computed and is plotted against probability of packets processing locally. It is being observed that the relationship between expected queuing delay and probability of packets processing locally is similar for different values of K. The same is plotted in Fig.23.

iv) The behaviour of the Average Response Time plotted against probability of packets processing locally is more or less similar to that of expected queuing delay discussed above, because of the reason that if a packet spends less amount of time in the queue then obviously average response time would also decrease. The same is plotted in the Fig.24.

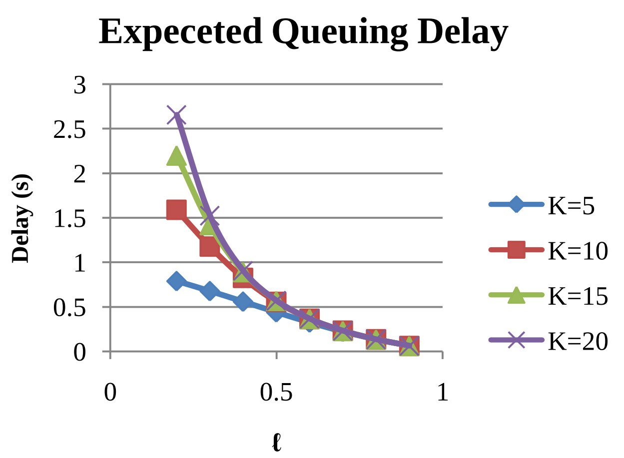

Fig.23. Probability Vs Delay.

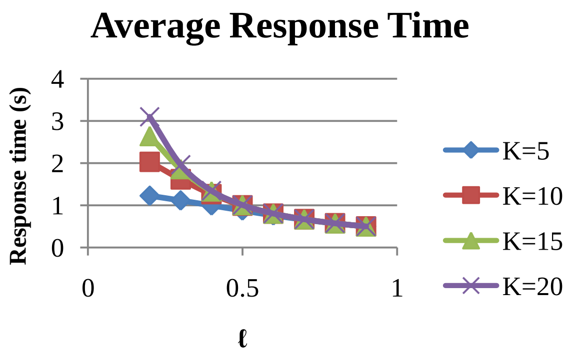

Fig.24. Probability Vs Response time.

Conclusion

In this paper a stochastic analytical queuing model is proposed to evaluate different performance measures like packet dropping probability, throughput, expected queuing delay and average response time for AODV routing protocol. These performance metrics are evaluated by varying arrival rate, service rate, number of nodes, buffer capacity and probability of packets processing locally. The evaluation is supported by numerical illustrations. It has been observed that there is direct relationship between packet dropping probability and arrival rate whereas it has inverse relationship with service rate, probability of packets processing locally. It is further observed that Throughput has direct relationship with arrival rate and service rate, where as it has inverse relationship with probability of packets processing locally. In case of expected queuing delay it is found that the queuing delay decreases while increasing service rate and probability of packets processing locally and it increases while increasing arrival rate. It has been identified that the Average response time decreases while increasing service rate and probability of packets processing locally and it increases while increasing arrival rate. These results are helpful for MANET designers to visualize and fore-see the significant impact of several important parameters on the performance metrics because of the very dynamic nature of MANETs. There is a scope for future research to do similar kind of analysis for other protocols in MANETs and also to conduct extensive simulation, the same can be compared with the analytical results.

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