M/M/1/*n*+*Flush*/n Model to Enhance the QoS for Cluster Heads in MANETs

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***Abstract*—Clustering in MANET is important to achieve scalability in presence of large networks and high mobility in order to maintain the Quality of Services (QoS) of the network. Improving the QoS is the most important and crucial issue in the area of MANET. Keeping this in mind, the research paper presents an M/M/1/*n*+*Flush*/n queueing model to perform better parametric results for cluster heads in MANETs. In an effort to make the M/M/1/*n*+*Flush*/n queueing model, the paper establishes the expressions for utilization (U_t) of the Cluster Head (*CH*), mean queue length (Lq), mean busy period (E_Q), mean waiting time ($\overline{Q}$) and average response time ($\overline{R}$) of the *CH*. The analytical results are further verified using MATLAB simulations which reveal better outcomes.**

Keywords*—Mobile Ad hoc Network (MANET); Cluster Head (CH); queueing approach; Quality of Services (QoS), flushing technique

I. Introduction

Due to rapid adaptation in Communication technology, regular desktop computing is changing itself at a very fast pace. This has lead to a situation where a huge number of diverse communication technologies transmits and exchange information over various network platforms [1]. In such an environment, the devices keep on adapting and reconfiguring themselves individually and jointly (forming cluster) to support the requirements of mobile users [2], [3]. Within the next generation of wireless network, there'll be a necessity for the quick deployment of mobile nodes on a spontaneous basis. MANETs accomplishes such extemporaneous communication among all nodes within the network without the occurrence of federal administration; however, all nodes can be treated as routers. This results in MANET's two of the most crucial qualities; adaptable and quick to deploy [4], [5]. Typically, a MANET is come to existence by spreading mobile nodes (MNs) in desolate areas or in adversity dominated areas where already existing networks have been exterminate or generally, are not possible. Therefore, one of the most reliable analytical approaches to predict and evaluate the system performance is to develop a stochastic model. These models also make available essential guidelines for the designing, implementation, and optimization of MANETs technologies [6].

Moreover, unlike simulation techniques, queueing models necessitate comparatively lesser information about the network. Additionally, in view of the fact that they are very fast to run, they offer an easy means to carry out "what-if" analyses. This helps in identifying tradeoffs among the various performance measures in the network and find attractive solutions rather than just predicting performance for a given scenario.

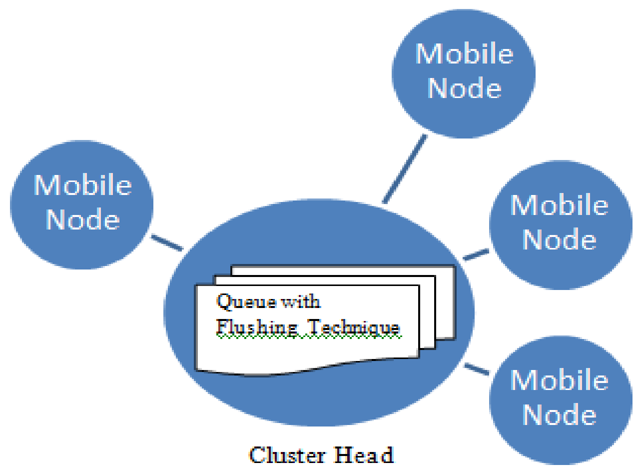

Fig. 1. Cluster head in MANET.

Queueing approach determines the performance measures in a stochastic scenario that requires some background in probability theory [7-10]. Our main objective in this paper is to determine the utilization (U_t), mean waiting time ($\overline{Q}$), mean queue length (L_q), distribution of the number of packets in the queue and average response time of the cluster heads when applying flushing technique in MANET (Fig. 1).

The research paper is prepared as follows: Related work and background is introduced briefly in Section II. Section III presents the proposed model's description in detail. Evaluation of the proposed mathematical model to calculate the performance measures such as utilization of the *CH*, mean waiting time, mean number of packets in the queue, throughput and average response time is discussed in Section IV. Section V presents the results of the proposed model. Finally, Section VI provides the conclusion of this contribution.

II. Related Work and Background

In this section, we give a short overview of few of the recent advances in the area of queueing theory. We list the research papers that are concerned with basic queueing models including finite queue capacity with a single server as well as multiple servers.

Typical outcomes of the queuing models have widely been studied and further extended in the area of the ad hoc network. Single server queuing models [11] and multiple server queuing models [12] consisting different service disciplines have been incorporated in recent years. These models adopted various disciplines like First-In-First-Out (FIFO) [13], Last-In-First-Out (LIFO) [14], random service [15], priority service and service in batches [16]. Likewise, various arrival processes have been taken into consideration, for instance Poisson input [17], superposition of various input processes [18]. Many generalizations for queuing model have already been projected like, queues in which many customers arrive simultaneously and getting serviced in batches, priority queues and finite queues, in which the queue size is considered limited [19], [20].

In the queuing model, usually minimizing the time that packets have to wait in the queue and maximizing the utilization of the nodes are sometimes contradictory goals. It is noticed from the review of the literature that it is very difficult to perfectly find out the performance of the queuing model with the help of the classical mathematical techniques [21]-[24]. Simulation modelling has widely been a part of queue modelling and various researches in the literature preferred the use of simulation models [25]-[30]. This is the reason which has motivated us to develop a queuing model using MATLAB simulation.

In MANET, various mathematical techniques have been used for studying various performance measures. In [32], the authors addressed the end-to-end delay analysis in a single-hop wireless network. The author in [31] extended the research work mentioned in [32], to address the end-to-end delay analysis in multi-hop wireless network [47]-[50] under unsaturated traffic condition in view of the hidden and exposed terminal problem. Every node in the wireless network was modelled according to M/G/1 queue and further helped to determine the service time distribution function. With the help of the service time distribution function for a single hop, the probability distribution function (PDF) of a single hop delay and its first and second moment of service were determined.

In [33], explicit delay distribution of M/M/m/k, M/M/m/K/n queueing model with FCFS service discipline along with the mixed loss-delay system is analyzed. The model includes the balking and finite population size models as the special case. Performance evaluation of queueing system was shown in [34] and mixing time and loss priorities in a single server queue was further presented in [35].

III. Proposed Queueing Model M/M/1/*N+Flush*/N

In this research paper, a single node i.e., cluster head with finite queue capacity *'n'* and a finite population of size *'n'* is formulated. Packets arrive according to a Poisson distribution with mean rate λ and the service duration follows an exponential distribution having service rate μ. All the packets wait in the queue of the *CH* till they are serviced completely so as to depart from that particular *CH* within MANET. A cluster within MANET can be depicted as a queueing model (M/M/1/*n+Flush*/n) having fixed transmission range [36]-[38]. Packets in MANET can be delivered to the *CH* through many intermediary nodes known as cluster members.

The M/M/1/*n+Flush*/n queueing model for *CH* comprises of two main sections, namely, queue with flushing technique and queue without flushing technique. This helps in providing a clear depiction of the network behavior under the impact of flushing technique.

Mathematical Model:

Effective arrival rate (λ_{eff}) is given by,

$$\lambda_{eff} = \begin{cases} (n-K)\lambda & 0 \le K \le n \\ 0 & K > n \end{cases} \qquad (1)$$

with the service rate;

$$\mu_n = \mu \text{ for } K > 1 \qquad (2)$$

where λ_{eff} Effective arrival rate at a *CH*

μ_n Actual service rate at a *CH*

n Total packets in the queue of the *CH*

λ Average arrival rate of packets at the *CH*

Assuming Poisson distribution, if P (t) is considered in the network during the time interval of length *t* then, Poisson distribution is represented by the following equation [15]:

$$P(S = s|\lambda) = \frac{e^{-\lambda}.\lambda^n}{n!} \qquad s = 0,1,2,...,\infty \qquad (3)$$

Where, P is the probability that n packets exactly reach at a *CH* within the very short time interval 'Δt (Δt->0)'.

In this model, flushing is applied to the queue of *CH* which is of finite length. Whenever the queue is full and can no longer hold the packet in it, the flushing of packet occurs. At the same time, if the *CH* within the MANET experiences failure, all the packets are flushed out and are queued in the flushing queue. This results in no packet loss at *CH*'s end, thus improving the QoS of MANET. The flushing occurrences depend on the number of packets in the queue relative to the threshold value.

A. Queue with Flushing Technique

The *CH*'s queue with flushing threshold subsystem has a signal input port labelled thresh that represents the threshold for flushing the queue. Inside the subsystem, an FCFS Queue block stores packets, while the control space usage subsystem compares the queue length to the threshold. If the queue length exceeds the threshold, the Enabled gate block (EGB) permits enough packets to depart from the queue until the queue length no longer exceeds the threshold. In this model, flushing succeeds as long as the EGB's OUT port is not blocked.

B. Queue without Flushing Technique

The *CH*'s queue without flushing threshold subsystem requires only a signal input port and it is not labelled to any thresh used for representing the flushing of the packets in the queue. Therefore, the queue can hold the packets equal to the maximum population size (n), which may result in packet drop.

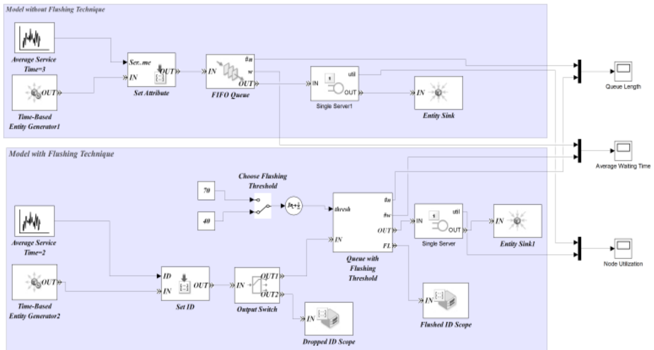

Fig. 2. M/M/1/*n*+*Flush*/n queueing model: Simulink.

IV. Performance Measures for M/M/1/*N*+*Flush*/N

In this section, various performance measures [39], [40] are evaluated based on M/M/1/*n*+*Flush*/n queueing network model.

A. *Model Input: Arrival rate, Average Service Time*

We formulate a queuing network model for MANET with their underlying multi-hop packet forwarding. The network consists of a cluster head, with finite buffer size. In this model, packets arrive at the *CH* in the network follow the Poisson distribution with rate λ packets/second on an average, where packet generation at the node is independent (not depend on the behavior of earlier packets). The packet is forwarded with service rate μ packet/sec by the *CH* follows markovian distribution [41]-[44]. The steady-state probabilities are obtained iteratively.

For the proposed model,

Traffic intensity is given by

$$\rho = \lambda/\mu \tag{4}$$

Where, ρ represents the typical proportion of time for which the *CH* is occupied. Also, it is required that $\rho < 1$ for the stable queue.

Therefore, for the distribution we have the following steady-state probabilities [45]-[46];

$$n\lambda P_0 = \mu P_1 \tag{5}$$

$$(n - k\lambda + \mu)P_K = (n - K + 1)\lambda P_K - 1 + \mu P_K + 1$$

$$1 \leq K \geq n - 1 \tag{6}$$

$$\mu P_K = \lambda P_{K-1} \tag{7}$$

$$P_K = P_0 \frac{\lambda 0\ \lambda 1 {-}{-}{-}{-}{-}{-}{-}{-} \lambda K-1}{\mu_1\ \mu_2 {-}{-}{-}{-}{-}{-}{-}{-}{-}{-}\ \mu_K} \tag{8}$$

Let us denote Poisson distribution by P(K, λ) and its cumulative distribution function by Q(K, λ).

Therefore,

$$P(K,\lambda) = [\frac{e^{-\lambda}}{!(K)}]\ \lambda^K \qquad 0 \leq K \leq \infty \tag{9}$$

$$Q(K,\lambda) = \sum_{i=0}^{K} P(i, \lambda) \qquad 0 \leq K \leq \infty \tag{10}$$

By doing elementary calculations, we can obtain that

$$\frac{P(n-K,R}{Q(n,R)} = \frac{\frac{!n}{!(n-K)}(\lambda/\mu)^K}{\sum_{i=0}^{n}[\frac{!n}{!i}(\lambda/\mu)^{n-i}} \tag{11}$$

Where,

$$R = \frac{\mu}{\lambda} = (\rho)^{-1} \tag{12}$$

Now, we can determine that

$$\frac{P(n-K,R}{Q(n,R)} = P_K \tag{13}$$

Thus for the distribution, we have

$$P_K = P_0\ \frac{!n}{!(n-K)}\rho^K \tag{14}$$

which can be written as:

$$P_K = (n-K+1)\ \rho P_K \tag{15}$$

If

$$\sum_{n=0}^{k} p_n = 1 \tag{16}$$

The probability that the *CH* is empty (i.e., there is no packet in the queue) is given by,

$$P_0 = \frac{1}{\sum_{n=0}^{k}[\frac{!n}{!(n-K)}K]} \tag{17}$$

B. *Model Output: Performance Criteria*

In this paper, we take the utilization (U_t) of the *CH*, throughput (λ_t), mean queue length (L_q), mean waiting time ($\overline{Q}$) and average response time $\overline{R}$ as the output measures for evaluating the performance of the proposed model.

1) *Utilization (U_t) of the CH*

Node utilization is the amount of packets which can a node hold within a specific time duration. It is one of the main measures to determine the performance of the node. The utilization of the *CH* can be obtained as:

$$U_t = 1 - P_0 = 1 - B\ (n, R) = 1 - \frac{1}{\sum_{n=0}^{k}[\frac{!n}{!(n-K)}K]} \tag{18}$$

With the help of cumulative distribution function, we can write this expression as:

$$U_t = \frac{Q(n-1,R)}{Q(n,R)} \tag{19}$$

Hence, throughput for the *CH* in the MANET can be given by,

$$\lambda_t = \mu.\ U_t \tag{20}$$

$$\lambda_t = \mu\ (1 - \frac{1}{\sum_{n=0}^{k}[\frac{!n}{!(n-K)}K]}) \tag{21}$$

2) *Mean queue Length (L_q)*

It is the total number of packets waiting in the queue and can be determined as follows:

$$L_q = \sum_{i=0}^{K}(K-1)P_K = n - (1 + R).\ U_t \tag{22}$$

Here, mean busy period (E_Q) of the *CH* can be derived as

$$(E_Q) = \frac{1-P_0}{n\lambda.P_0)} \quad (23)$$

Where, P_0 is the probability of empty queue, n is the maximum buffer size and λ is the mean arrival rate of the packets at the queue of the *CH* in the MANET.

3) Mean Waiting Time ($\overline{Q}$)

It is the time that a packet has to wait in the queue to get its chance for getting service. It can be determined as the follows:

$$U_t = \frac{\frac{1}{\lambda}}{\frac{1}{\lambda}+\overline{Q}+\frac{1}{\mu}]} \quad (24)$$

Hence, by Little's law, we have

$\overline{Q}$ = Mean queue length (L_q) /Actual arrival rate

$\overline{Q}$ = Mean queue length (L_q) /$\lambda. U_t. R$

and it can be derived by simple calculations as

$$\overline{Q} = \frac{1}{\mu}\left(\frac{n}{U_t} - R\right) \quad (25)$$

4) Average Response Time

It is the total amount of time a packet has to wait to get serviced (including waiting time and service time). The average response time for all the packets in the network results in

$$\overline{R} = \lambda\left(\overline{Q} + \frac{1}{\mu}\right) \quad (26)$$

$$\overline{R} = (\text{ n- } U_t. R \left(1 + \frac{1}{R}\right) + U_t \quad (27)$$

$$\overline{R} = (\text{ n- } U_t. R) \quad (28)$$

It is worth noting that utilization of the *CH* plays a very crucial role in determining the rest of performance measures of the network.

V. Results and Discussion

The simulation is performed using MATLAB to analyse the performance of the proposed model. Simulation parameters values are shown in Table I. Analytical results are validated by simulations which show better outcomes.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Simulation Time	300 sec
Arrival Rate Distribution	Poisson
Service Rate Distribution	Exponential
Queue Capacity	100 packets
Traffic Generator	CBR
Threshold Upper	70
Threshold Lower	40
Packet Size	512 byte
Number of Nodes	1 (Cluster Head)

The performance analysis is based on three performance metrics regarding QoS requirements, i.e., the node utilization, mean number of packets in the queue (buffer capacity) and mean waiting time of the packet at the node. The buffer capacity of FIFO queue in the *CH* is considered of limited length. Lower and upper flushing threshold values are set to 40 and 70, respectively.

Mean number of packets in the *CH* is compared between traditional and proposed M/M/1/*n+Flush*/n queueing model in Fig. 2. Simulation result shows the average number of packets in the queue remains same for the very short period of time, but after that, for the traditional technique, it increases linearly. For our proposed model it keeps on fluctuating near about a fixed buffer capacity, leaving no scope for queue overload. It is observed that queue length of the models does not exceed the average length of the queue at any time instant.

Simulation result in Fig. 3 shows the comparison between the average waiting time for the proposed M/M/1/*n+Flush*/n model and conventional M/M/1/n/n. Initially, till 100 sec, the value of the average waiting time remains same for both the techniques. But in the conventional model, after 100 sec it increases exponentially and keeps on fluctuating depending on the size of the queue. It can be clearly seen that the waiting time for each packet in the queue for the proposed M/M/1/*n+Flush*/n model is comparatively lesser than the conventional model. The peak value of average waiting time for the conventional model is more than 17 msec. On the contrary, for the proposed M/M/1/*n+Flush*/n model, it does not exceed 4 msec. It means that a packet for our proposed model has to wait for almost one fourth lesser time experienced by conventional model. This shows that the proposed model outperforms the conventional model.

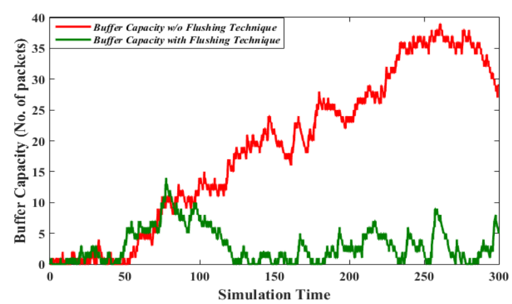

Fig. 3. Number of packets for proposed M/M/1/*n+Flush*/n.

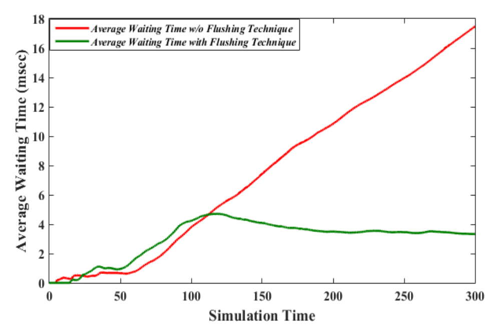

Fig. 4. Mean waiting time: Proposed M/M/1/*n+Flush*/n vs conventional M/M/1/n/n.

In Fig. 4, simulation result presents the comparison between *CH* utilization for M/M/1/*n+Flush*/n model and the conventional M/M/1/n/n. Utilization mainly depends upon the queue content, arrival and service pattern of the packets, and thus, the more is queue content, the larger is the value of utilization and vice-versa. It can be analyzed from Fig. 4 that the proposed model outperforms the conventional model in terms of *CH* utilization.

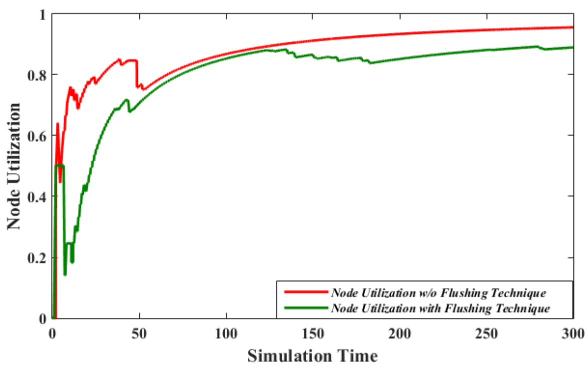

Fig. 5. Node utilization: Proposed M/M/1/*n+Flush*/n vs conventional M/M/1/n/n.

Table II presents the relationship between average waiting time and utilization with respect to the arrival rate of packets. It can be clearly seen that with increasing values of arrival rate, the average waiting time and utilization is also bound to increase. This shows a positive relationship between the performance parameters. Likewise, enhancement in average response time is caused due to the increment of waiting time. This is further validated in Fig. 3 which is reflecting outperformance of M/M/1/*n+Flush*/n model over conventional one.

TABLE II. AVERAGE WAITING TIME AND UTILIZATION

Arrival Rate (Packet/sec)	**AWT in msec**	**Utilization of Node**
1	1.080	24.9600
2	14.9980	99.9900
3	54.9993	299.9967
4	114.9997	599.9983
5	114.9997	599.9983

VI. CONCLUSION

This research paper projected an M/M/1/*n+Flush*/n queuing model for improving the performance measures of cluster heads in MANET, in order to enhance its QoS. The authors have developed the equations of the steady state probabilities based on which some crucial performance measures like *CH* utilization, queue length, average waiting time, node and average response time are obtained. Analytical results are verified with the help of simulations using MATLAB Simulink. Simulation result shows that our proposed model M/M/1/n+Flush/n outperforms the conventional model (M/M/1/n/n). In Fig. 3, 4 and 5, we have found that results of queue capacity, average waiting time and node utilization are far better than the conventional model.

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