Application of QNA to analyze the 'Queueing Network Mobility Model'of MANET

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***Abstract*—Queueing Theory finds its applications in various versatile domains in modern world. We investigate yet another application of Queueing Theory - In modeling of MANET. More specifically, we study the 'Queueing Network Mobility Model'of Mobile Ad-Hoc Networks (MANET), its applications and limitations. Motivated by its simplicity and successful performance, we use Queueing Network Analyzer (QNA) to re-analyze the model without the limiting assumptions. The QNA is a powerful tool to analyze large open networks of $GI|G|m$ nodes with infinite buffer stations, and FCFS service discipline. We use QNA to extend the existing 'Queueing Network Mobility Model'to make it more generic. We also carry out simulations to compare the analytical values of the performance measures. In this report, we present our study of the QNA, and the 'Queueing Network Mobility Model'of MANET. Then we present the results derived in order to remove the limiting assumptions, and modifying the standard QNA to capture mobility of MANET. Then, we present the numerical results verified by simulations.**

***Index Terms*—MANET, Queueing Networks, Queuing Network Analyzer, Switched General Process, Unreliable Servers.**

I. Introduction

Queueing Networks have been widely used as efficient tools to analyze the 'performance measures' in computer and communication systems. For many classes of queueing networks, elegant and efficient solution methods exist. Well known closed product-form solutions are available for simplified networks under a number of restrictions; most important of these being (i) packet service times are exponentially distributed, and (ii) arrival processes are Poisson. These restrictions, however, do not always apply in practice.

An approximate approach for the solution of large queueing networks with general inter-arrival and general service processes was proposed by Kuhn [1] and later extended by Whitt [2]. This is called the Queueing Network Analyzer (QNA). In this approach, the arrival and service processes are formulated as renewal processes, represented by first two moments. Thus the individual nodes are analyzed as $GI|G|m$ nodes. An important advantage of the QNA approach is its limited computational complexity.

Ad-hoc networks are one of the most research oriented areas of modern times. Various modeling techniques have been employed to develop mathematical models for randomly moving nodes in a MANET. The most important of these are Random walk mobility model, Random direction mobility model and Random waypoint mobility model. One such attempt, making use of Queueing Theory is 'Queueing Network Mobility Model'of MANET [3].

We present our study on the 'Queueing Network Mobility Model'to understand its limitations, and the standard QNA. Then, we explain how the standard QNA can be tweaked to capture the mobility of MANET, thus overcoming the limitations of the existing model.

II. The 'Queueing Network Mobility Model'of MANET

A. Static Model

A Jackson Network is an intuitive model for a static network of nodes, where each node of the network can be analyzed separately. The Jackson Network is a network of m interconnected nodes, where communication among the nodes is defined by the matrix of transition probabilities Q = (q_{ij}) where q_{ij} is the probability of transitions from node i to node j. The arrival and the service processes are assumed to be Poisson in nature, which makes the nodes to be defined as $M|M|1$ nodes, where first M denotes memoryless arrival, second M denotes memoryless service, and 1 denotes number of servers. A stochastic process is said to be Poisson in nature if the inter-event time interval is distributed exponentially. The network is defined by the following parameters:

q_{ij} is the probability of a customer leaving node i going to node j.

Hence, the customer leaving the node j leaves the network with probability $1 - \sum_{k=0}^{m} q_{jk}$.

λ_{0j} is the external arrival rate to node j.

λ_j is the total arrival rate to node j.

μ_j is the service rate at node j.

$\rho_j = \lambda_j / \mu_j$ is the utilization of node j.

For the j^{th} M/M/1 node, if we make the 'busy server assumption' i.e. $\rho_j \approx 1$, [4] says that the departure process is also Poisson with the rate λ_j (same as the arrival process). This is a very important result, and makes the solution of a Jackson Network easy. Using [4], we know that the departure processes are also Poisson. Since the sum of Poisson processes is again a Poisson process, the total arrival rate at any arbitrary node is the sum of the rates of flow of customers from all the other nodes, and the external arrival rate.

$$\lambda_j = \lambda_{0j} + \sum_{i=0}^{m} \lambda_i q_{ij} \tag{1}$$

B. Mobility Modeling

Mobility has to be introduced in such a static model to make it close to real-world applications. Mobility has been introduced in the 'Queueing Network Mobility Model'for MANET in two ways:

- **Case 1 - Gated Nodes**
  To model this case, an input link is introduced at the entry of each node. The input link goes ON and OFF exponentially. The link is said to be up when the link is ON, and down otherwise.
  λ_{ON} and λ_{OFF} are the rates of the input links going ON and OFF respectively. If the link is closed, the incoming Poisson stream of packets is dropped. If λ'_j denote the effective arrival rate at node j, then

$$\lambda'_j = \frac{\lambda_{OFF}}{\lambda_{ON} + \lambda_{OFF}} \cdot \lambda_j \qquad (2)$$

  This splitting of the incoming Poisson stream is also known as Interrupted Poisson Process (IPP), and gives a new probability distribution of the arrival rates, which is hyperexponential [5]. Thus, the nodes of such a model become $H_2|M|1$ nodes. The performance measures can be calculated as

$$W_s = \frac{1}{\mu(1-\sigma)} \qquad (3)$$

$$L_s = \frac{\lambda'}{\mu(1-\sigma)} \qquad (4)$$

  where, σ is effective server utilization ($\sigma \leq \rho$). Note that in this case 'busy server assumption 'is $\sigma \approx 1$.

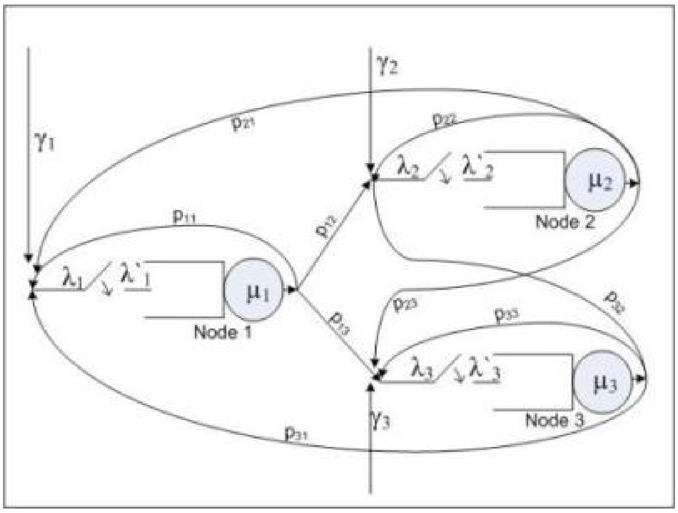

Fig. 1. 'Queueing Network Mobility Model'of a 3 node MANET. (Case 1)

- **Case 2 - Server Vacations**
  In case 1, packets are lost if the incoming link is down. Instead, if these packets are to be queued, the mobility is transferred from the link to the server. The server goes on vacation for exponential time and on duty for exponential amount of time. If the server is on a vacation, the incoming packets are queued. Thus, the effective service rate of the server is reduced, and the end-to-end delay is increased but packets are saved. μ_{ON} and μ_{OFF} are the rates of the server on duty and on vacation respectively. If μ'_j denotes the effective service rate at node j, then

$$\mu'_j = \frac{\mu_{OFF}}{\mu_{ON} + \mu_{OFF}} \cdot \mu_j \qquad (5)$$

  The performance measures can be calculated as

$$W_s = \frac{1}{\mu'(1-\rho)} \qquad (6)$$

$$L_s = \frac{\lambda}{\mu'(1-\rho)} \qquad (7)$$

  Note that in this case 'busy server assumption' is $\rho \approx 1$.

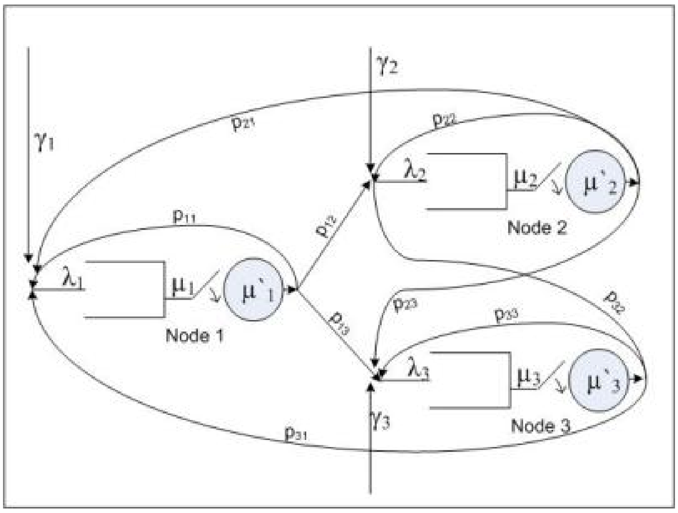

Fig. 2. 'Queueing Network Mobility Model'of a 3 node MANET. (Case 2)

C. Limitations

In the modeling and analysis of MANET using Queueing Networks, a strong implicit assumption is made that the server utilization is high i.e. $\rho_j = 1$. Without this assumption, the arrival processes to individual nodes are not Poisson and the analysis is not possible using this model.

In real world applications, the server utilization is rarely this high, and the arrival processes are rarely Poisson. The nodes in such a network are mostly $GI|G|1$ nodes, where GI denotes general independent arrival process, and G denotes general service process. As the name suggests, general processes do not follow any known probability distribution, but are general in nature.

These assumptions and constraints make the application of this model limited. The model, although a powerful one, can not serve general purpose applications.

III. Problem Definition

To overcome the limitations of the existing mobility model, a new model has to be developed and analyzed without using the 'busy server assumption', and 'Poisson arrival assumption'. Without these assumptions, the individual nodes become $GI|G|1$ nodes.

Formally, the problem can be defined as *analyzing an open network of $GI|G|1$ nodes, with input links or server going ON and OFF exponentially.*

IV. The Queueing Network Analyzer

The Queueing Network Analyzer (QNA), is an approximation technique and a software package developed at Bell Laboratories to calculate approximate congestion measures of a network of queues. The QNA is a powerful tool to analyze general queueing networks. The most important feature of the QNA is that the external arrival processes need not be Poisson, and the service-time distributions need not be exponential. The QNA can provide a fast approximate solution for large networks.

The current version of QNA uses two parameter approach. Both the arrival and service processes are formulated as renewal processes defined by the first two moments with independent and identically distributed renewal times, one to describe the rate, and other the variability of the renewal process. The entire network is broken into individual nodes, and these nodes are analyzed as standard $GI|G|m$ nodes. Congestion measures for the network as a whole are obtained by assuming that the nodes are stochastically independent.

The general approach in QNA is as follows:

- Find the parameters characterizing the flow.
- Make approximations based on the partial information provided by the parameters.
- Apply the calculus for transforming the parameters to perform operations.
- Devise a synthesis algorithm to solve the system of equations resulting from the basic calculus.

A. Applications of QNA

The QNA has been used extensively in many theoretical and practical applications and the results have been compared with simulation results and/or the results of other techniques. The low relative error percentage makes QNA one of the most important tools in analyzing the general networks.

Results for complex network like a queue with a superposition arrival process, eight queues in series, a tightly coupled network of two nodes, Kuehn's nine node network, a computer system model etc are studied by Whitt in [6]. Other important applications include analysis of $PH|PH|1|K$ queues by Haverkort [7], Virtual Circuit Connection in a high speed ATM WAN [8], and communication networks with multicast data streams [9].

B. Input to Standard QNA

The input to QNA comprises of:
Number of nodes: m
Rate and SCV for external arrival: $\lambda_{0i}, c^2_{a_i}$, $i = 1, 2...m$
Mean and SCV for service time: $\tau_i, c^2_{s_i}$, $i = 1, 2...m$
The Routing Matrix: $Q = (q_{ij})$, $i = 1, 2...m, j = 1, 2...m$

C. Traffic rate equations in Standard QNA

If λ_{0j} is the external arrival rate to node j, q_{ij} is the probability that a customer leaving node i goes to node j, then the internal rates flowing to various nodes in the network can be calculated using the following equation:

$$\lambda_j = \lambda_{0j} + \sum_{i=1}^{m} \lambda_i q_{ij} \tag{8}$$

Traffic intensities or utilizations at each node are given by $\rho_i = \lambda_i \tau_i$. Arrival rate from node i to node j is given by $\lambda_{ij} = \lambda_i q_{ij}$. The proportion of arrivals to j that came from i, $i \geq 0$ is defined as $p_{ij} = \lambda_{ij}/\lambda_j$.

D. Traffic variability equations in Standard QNA

The variabilities of internal traffic flows are calculated using the following linear equations:

$$c^2_{a_j} = a_j + \sum_{i=1}^{m} c^2_{a_i} b_{ij} \tag{9}$$

where expressions for a_j and b_{ij} are derived after considering merging and spilitting of traffic streams as:

$$a_j = 1 + w_j \left\{ (p_{0j} c^2_{0j} - 1) + \sum_{i=1}^{m} p_{ij} \left[(1 - q_{ij}) + (q_{ij} \rho_i^2 x_i) \right] \right\} \tag{10}$$

and

$$b_{ij} = w_j p_{ij} q_{ij} (1 - \rho_i^2) \tag{11}$$

where, x_i and w_j are constants depending upon the input data, and the data determined previously.

E. Performance Measures of $GI|G|1$ queue in Standard QNA

The approximation formula for the mean waiting time of a customer in queue is given by:

$$W_q = \frac{\tau \rho (c^2_a + c^2_s) g}{2(1 - \rho)} \tag{12}$$

where $g \equiv g(\rho, c^2_a, c^2_s)$, such that $g = 1$, for $c^2_a \geq 1$

Other performance measures like mean waiting time in system, mean number of customers in the system, mean delay etc can also be calculated easily.

V. QNA with MOBILITY - Gated Nodes

While analyzing the 'gated nodes'model, we model the arrival and service processes as general renewal processes with parameters λ_i, $c^2_{a_i}$, τ_i, $c^2_{s_i}$. There are no existing techniques to model the splitting of a general arrival process. Hence, the PDF of the effective arrival process can not be found. But, the power of QNA makes it possible to analyze the model without actually finding out the PDF of the effective arrival. We need the parameters for effective arrival as functions of the parameters of the actual arrival. i.e λ'_i as a function of λ_i, and $c'^2_{a_j}$ as a function of $c^2_{a_j}$.

We consider a Switched General Process (SGP) as proposed in [10]. In a SGP, the switching between two general renewal processes with rates λ_1 and λ_2 is governed by general renewal switching periods. For our case, since the packets are dropped when the link is down, $\lambda_2 = 0$. The effective arrival rate, and the squared coefficient of variation are given by

$$\lambda'_j = p_{ON} \cdot \lambda_j \tag{13}$$

and

$$c'^2_{a_j} = c^2_{a_j} + k \cdot \lambda_j \tag{14}$$

Here, probability that an incoming packet will find the link ON is given by

$$p_{ON} = \frac{\lambda_{OFF}}{\lambda_{ON} + \lambda_{OFF}} \tag{15}$$

and constant k defines the proportional change in the $c^2_{a_j}$ due to the intermittent link.

$$k = \frac{\lambda_{ON} \cdot \left[V_{ON}\lambda^2_{ON} + V_{OFF}\lambda^2_{OFF}\right]}{(\lambda_{ON} + \lambda_{OFF})^2} \tag{16}$$

where, V_{ON} and V_{OFF} are variance of ON and OFF periods respectively. Now, we are able to modify the equations of standard QNA.

The traffic rate equation **??** becomes

$$\lambda_j = \lambda_{0j} + \sum_{i=1}^{m} \lambda'_i q_{ij} \tag{17}$$

Traffic intensities or utilizations at each node are given by $\rho_i = \lambda'_i \tau_i$. Arrival rate from node i to node j is given by $\lambda'_{ij} = \lambda'_i q_{ij}$. The proportion of arrivals to j that came from i, $i \geq 0$ is defined as $p_{ij} = \lambda'_{ij}/\lambda_j$.

The variabilities of internal traffic flows are calculated using the following linear equations:

$$c^2_{a_j} = a_j + \sum_{i=1}^{m} c'^2_{a_i} b_{ij} \tag{18}$$

$$c^2_{a_j} = \left(a_j + \sum_{i=1}^{m} c^2_{a_i} b_{ij}\right) + k_j \sum_{i=1}^{m} \lambda_i b_{ij} \tag{19}$$

where expressions for a_j and b_{ij} have their usual forms, and $k_j = k$ for j^{th} node).

After calculating the moments of effective arrival, we can use the standard QNA equations to find the perofmance measures.

VI. QNA with MOBILITY - Server Vacations

Again, we model the arrival and service processes as general renewal processes with parameters λ_i, $c^2_{a_i}$, τ_i, $c^2_{s_i}$. We need the parameters for effective service as functions of the parameters of the actual service. i.e μ'_i as a function of μ_i, and $c'^2_{s_j}$ as a function of $c^2_{s_i}$. This model falls under the category of the unreliable server models, as explained in [11]. For an unreliable server with general service and general up and down times, the first two moments can be found easily. Using the first two moments, we get

$$\mu'_j = p_{ON} \cdot \mu_j \tag{20}$$

and

$$c'^2_{s_j} = (c^2_{s_j} + 1)\frac{1}{p_{ON}} + l \tag{21}$$

where,

$$p_{ON} = \frac{\mu_{OFF}}{\mu_{ON} + \mu_{OFF}} \tag{22}$$

and constant l defines the proportional change in the $c^2_{s_j}$ due to the server vacations.

$$l = \mu_{ON} \cdot p_{ON} \frac{(1 + c^2_{OFF})}{\mu^2_{OFF}} - 1 \tag{23}$$

Since there are no changes in the arrival process, and its moments, we can get the various performance measures by simply replacing μ by μ', and $c^2_{s_j}$ by $c'^2_{s_j}$ in the standard QNA.

VII. QNA with MOBILITY - Intermittent Links

The 'gated nodes'model gives mobility to nodes by considering a link per node, which implies that if the link is ON, the node is connected to the network, but if it is OFF, the node is completely isolated, since no other node can send packets to this node. This is, however, an unrealistic assumption to make. Most of the times in real-world networks, a link between two nodes may be down, but they may still be connected via a third node. Since using QNA, we do not need to find the PDF of the various traffic flows, it becomes possible to analyze this more realistic scenario.

According to standard QNA, the squared coefficient of variation of the traffic flow from node i to node j is given by

$$\begin{aligned} c^2_{ij} \;\; = \;\; & q_{ij}[1 + (1 - \rho^2_i)(c^2_{a_i} - 1) \\ & + \rho^2_i[\max(c^2_{s_i}, 0.2) - 1)] + 1 - q_{ij} \end{aligned} \tag{24}$$

If mobility is considered in the individual links, then

$$\lambda'_{ij} = p_{ON} \cdot \lambda_{ij} \tag{25}$$

and

$$c'^2_{ij} = c^2_{ij} + k \cdot \lambda_{ij} \tag{26}$$

The above subsititution is reflected in the standard QNA variability equation as

$$c^2_{a_j} = \left(a_j + \sum_{i=1}^{m} c^2_{a_i} b_{ij}\right) + w_j \sum_{i=1}^{m} p_{ij} k_{ij} \lambda_{ij} \tag{27}$$

However, the rate equation remains the same.

A. Comparison

A direct comparison between (19), and (27) shows the difference in the two models. Using (11), (19) can be rewritten as

$$c_{a_j}^2 = \left(a_j + \sum_{i=1}^{m} c_{a_i}^2 b_{ij} \right) + \sum_{i=1}^{m} w_j p_{ij} q_{ij} k_j \lambda_i (1 - \rho_i^2) \quad (28)$$

If $k_{ij} = k_j$ i.e. the rates of links going ON and OFF are same, then using $\lambda_{ij} = \lambda_i q_{ij}$ (27) reduces to

$$c_{a_j}^2 = \left(a_j + \sum_{i=1}^{m} c_{a_i}^2 b_{ij} \right) + \sum_{i=1}^{m} w_j p_{ij} q_{ij} k_j \lambda_i \quad (29)$$

For $(1 - \rho_i^2) \approx 1$, (28) and (29) are equal. Thus, if the servers are kept idle, the two models yield same performance measures.

VIII. Simulation Model

To verify the analytical results, simulation model was set up. We used OMNeT++ (a discrete-event simulator) to perform all the simulations. The main idea behind the simulation is to avoid any of the theoretical assumptions that we might have made in analysis, because it is these assumptions that we want to verify.

In the simulation, the network is defined as a group of nodes linked in a prescribed manner. The simulation simply proceeds event-wise for each module (or node), and is not bothered with the rest of the network. Hence, we get the performance measures for individual nodes.

IX. Numerical Results

All the derived results have been verified with simulation. We have used the arrival process as a Poisson process, service as exponentially distributed, and UP and DOWN periods also exponentially distributed.

In analysis, effective arrival, and effective service has been used to calculate the effective waiting time in the system. Since we aimed to remove the 'busy server'assumption, the input values have been chosen so as to keep the servers not-busy.

The relatice error in the analytical values given by QNA and simulation values is expressed as percentage of analytical value, and is given by

$$Error\% = 100 \cdot \frac{QNA\ Value - Simulation\ Value}{QNA\ Value}$$

A. QNA with MOBILITY - Gated Nodes

Tables I and II give results for a 10 nodes network in tandem, and scattered respectively.

Node	τ	λ_0	W_s - QNA	W_s - Sim	Error %
1	0.0500	2.0	0.1077	0.1086	0.8635
2	0.0500	2.0	0.1864	0.1887	1.2473
3	0.0500	2.0	0.1664	0.1693	1.7338
4	0.0500	2.0	0.2567	0.2621	2.1161
5	0.0500	2.0	0.1497	0.1498	0.0969
6	0.0500	2.0	0.2368	0.2407	1.6364
7	0.0500	2.0	0.1133	0.1150	1.5260
8	0.0500	2.0	0.1480	0.1506	1.7193
9	0.0500	2.0	0.1201	0.1196	0.4030
10	0.0500	2.0	0.0985	0.0992	0.7086
				Average Error % =	1.2081

TABLE II
QNA with MOBILITY - Gated Nodes: 10 scattered nodes $\lambda_{ON} = 10/9, \lambda_{OFF} = 25$

Node	τ	W_s - QNA	W_s - Sim	Error %
1	0.1000	0.2350	0.2373	0.9655
2	0.1010	0.2281	0.2295	0.6195
3	0.1100	0.2631	0.2647	0.5952
4	0.1200	0.3063	0.3090	0.8975
5	0.1189	0.2813	0.2842	1.0331
6	0.1090	0.2213	0.2231	0.7958
7	0.1321	0.3211	0.3234	0.7175
8	0.1200	0.2461	0.2490	1.1682
9	0.1140	0.2138	0.2152	0.6773
10	0.1000	0.1647	0.1658	0.6515
			Average Error % =	0.8121

TABLE I
QNA with MOBILITY - Gated Nodes: 10 nodes in tandem$\lambda = 6, \lambda_{ON} = 10/9, \lambda_{OFF} = 25$

B. QNA with MOBILITY - Server Vacations

Tables III and IV give results for a 10 nodes network in tandem, and scattered respectively.

Node	τ	W_s - QNA	W_s - Sim	Error %
1	0.1000	0.2879	0.2800	2.7123
2	0.0110	0.0124	0.0137	10.1403
3	0.0200	0.0241	0.0251	4.2349
4	0.0200	0.0241	0.0251	4.2046
5	0.0289	0.0373	0.0381	2.1536
6	0.0090	0.0100	0.0114	14.2940
7	0.0121	0.0137	0.0152	10.5993
8	0.0100	0.0112	0.0126	12.9259
9	0.0140	0.0161	0.0176	9.0658
10	0.0100	0.0112	0.0127	13.2804
			Average Error % =	8.3641

TABLE III
QNA with MOBILITY - Server Vacations: 10 nodes in tandem $\lambda = 6, \lambda_{ON} = 10/9, \lambda_{OFF} = 25$

Node	τ	λ_0	W_s - QNA	W_s - Sim	Error %
1	0.0250	2.0	0.0733	0.0746	1.8102
2	0.0250	2.0	0.2647	0.2729	3.0914
3	0.0250	2.0	0.1817	0.1805	0.6604
4	0.0250	2.0	0.9924	1.0010	0.8666
5	0.0250	2.0	0.1391	0.1388	0.1934
6	0.0250	2.0	0.8976	0.8862	1.2734
7	0.0250	2.0	0.0812	0.8862	1.5899
8	0.0250	2.0	0.1372	0.0825	0.2471
9	0.0250	2.0	0.0753	0.1369	1.5341
10	0.0250	2.0	0.0624	0.0635	1.7897
				Average Error % =	1.3056

TABLE IV
QNA WITH MOBILITY - SERVER VACATIONS: 10 SCATTERED NODES
$\lambda_{ON} = 10/9, \lambda_{OFF} = 25$

C. QNA with MOBILITY - Intermittent Links

Tables V gives results for a 10 nodes scattered network.

Node	τ	λ_0	W_s - QNA	W_s - Sim	Error %
1	0.0400	2.0	0.0724	0.0719	0.7026
2	0.0400	2.0	0.1029	0.1026	0.3236
3	0.0400	2.0	0.0962	0.0950	1.2475
4	0.0400	2.0	0.1222	1.1207	1.2520
5	0.0400	2.0	0.0902	0.0885	1.8765
6	0.0400	2.0	0.1173	0.1159	1.2080
7	0.0400	2.0	0.0750	0.0746	0.4724
8	0.0400	2.0	0.0896	0.0881	1.6272
9	0.0400	2.0	0.0781	0.0762	2.3851
10	0.0400	2.0	0.0679	0.0675	0.5775
				Average Error % =	1.1673

TABLE V
QNA WITH MOBILITY - INTERMITTENT LINKS: 10 SCATTERED NODES
$\lambda_{ON} = 10/9, \lambda_{OFF} = 25$

The simulation values match with the analytical values given by QNA with very less error. In most of the cases, the relative error is approx 1 %. However, in one of the case, due to randomness of the system, the error goes upto 8 %. But, in general the error is very reasonable.

However, the numerical results show that the QNA is a very powerful tool to analyze general networks, and verify our derived equations.

X. CONCLUSION

This work gives an insight to the power of the Queueing Network Analyzer, which, although an approximation technique, gives results with very less error. The ease with which QNA can be applied to any real-world network is apprehended. The 'Queueing Network Mobility Model'of MANET is also a very effective application of Queueing Theory in real-world scenario. It is very promising, but being a novel model, it makes many limiting assumptions.

This study was intended to overcome the limiting assumptions of this model. We started with aiming to remove the 'Poisson Arrival', 'exponential service', and 'busy server' assumptions. But as we started analyzing the model using QNA, we found that we could as well remove the 'exponential UP time', and 'exponential DOWN time' assumptions very easily.

The 'Queueing Network Mobility Model'of MANET also assumes that either a node is in the network, or it is completely isolated. In other words, the mobility is in node. QNA makes it very easy to re-analyze the network by giving mobility to each link, and thus making the analysis more close to the real-world scenario.

As future work to this study, it is important to find the various paramaters that may cause the links (and/or server) go up and down. So far, we have incorporated all such possible parameters into one 'down period'. However, the different parameters contribute to the links (and/or server) in different manners. Modeling of the individual parameters' behaviours can be an immediate next step from here.

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