Performance Analysis of WSN based Earthquake Monitoring System using Queues in Tandem Concept

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Abstract –In this paper performance analysis of WSN based earthquake monitoring system is carried out using queuing theory. Queuing Theory has been used as an analyzing tool for any communication system. The WSN nodes transmit their data packets (obtained from the ground motion as input) to the centralized node/server which subsequently forwards the incoming data packets to the main station using backhaul link. While evaluating the performance, in this study we have considered two scenarios. In first scenario, the modeling of wireless channel (present between nodes and centralized node) is not taken into account, whereas in second scenario the wireless channel is modeled as M/M/c queue. Here both M/M/1 and M/M/c queues are used to model the system. The performance analysis is carried out in terms of two Quality of Service (QoS) parameters namely mean system delay and utilization. The analytical results show that delay increases with the increase in the number of nodes in the system (i.e. the increase in the traffic intensity). Utilization of the system however is the linear function of the traffic intensity. While employing real time scenario, it is necessary that number of WSN nodes must be according to need so that mean system delay can be minimized and warning for the earthquake can be generated on time. Furthermore, data packets should not be increased at input, otherwise congestion (blockage) would occur. The results obtained via this research helps to improve the performance of WSN based earthquake monitoring system.

Keywords – delay, earthquake, queuing, utilization, WSN

I. INTRODUCTION

The earthquake is among one of the dangerous natural calamities. *The* disaster is caused time to time by the accumulated energy deposited in the earth's crust and when that accumulated energy approaches the significant amount, seismic waves are created [7]. In the past, this issue was not paid a serious attention but when on 26 Dec 2004 a massive earthquake of magnitude 9.0 struck the coastal areas of Indonesia and neighboring countries, it resulted in the great loss. After that, the scientists and researchers started paying a huge attention in developing new approaches and mechanisms that can help in providing warning ahead of time so that the effects of the huge loss could be minimized [4].

Nowadays, there are numerous mechanisms developed for the earthquake detection and monitoring but in our research work, a wireless sensing network (WSN) based earthquake monitoring system is considered. WSN is basically the combination of several nodes that work together to perform some important task. WSN nodes are capable to perform the specified tasks by sensing, processing, and communicating with each other. That processed information is finally sent to the main station [6]. WSN are application specific, hence for each application, design and implementation considerations are different.

Conventionally, seismic networks were designed and installed to detect and monitor the earthquake. But that approach was costly and time consuming. That's why a new mechanism was developed that was quick, and inexpensive while providing the same effectiveness and efficiency like a complete seismic station known as the Quake Catcher Network (QCN) [14]. Quake Catcher Network is a structure developed by combining different sensors of low cost in order to communicate with volunteer computers in a particular region where the seismic activity need to be monitored [14].

Queuing theory is being considered as an effective tool for the performance analysis of WSN based system in terms of Quality of service (QoS) parameters [13]. Each node in WSN based system earthquake monitoring system represents a complete QCN and the combination of nodes represents a network of nodes known as wireless sensor network. The performance evaluation is mostly carried out in terms of QoS parameter such as mean system delay, packet dropping probability and utilization which directly impacts on the efficiency of the system. The word "tandem" refers to the placement of the objects one after the other in the same direction (in series) where the output of one queue becomes the input to the next queue. Queues in tandem concept is used when data packets pass through multiple queues before reaching the final destination [13].

In this work, we have considered a WSN system for earthquake monitoring because it provides many advantages such as accuracy, reliability, self-organization, and ease of deployment. We focus on performance evaluation of WSN based system using queues in tandem concept in terms of average system delay and system utilization.

After the introduction, the paper consists of following sections: Section II discusses the related work. Section III presents studied scenarios. Section IV provides the mathematical model for the proposed system. In Section V we have analyzed the results. Finally, in Section VI the paper concludes.

II. RELATED WORK

In [1] authors have minimized queuing delay to make efficient WSN. To achieve this, radios of nodes in WSN are being activated using the wake up mechanism. In [2] the scalability of WSN network is analyzed with large number nodes that work together to fulfill the requirements. In [3] authors have developed a queuing model for an energy efficient femtocell network. In [5] the idea of wireless vibration detection for the seismic exploration is introduced where 3D signals were picked effectively. Researchers in [6] believe that animals act abnormally before and after earthquake and their behavior is helpful in the determining an earthquake. On this basis, they have proposed an overall network architecture in which middleware software infrastructure, WSN, end user system, different detectors, mobile base stations and animals play major role. Earthquake is simulated and analyzed in [7]. It is carried out using MATLAB software, which helps in discovering very important findings about the great disaster known as earthquake. Status update can also be performed through queues [8]. In [9], authors highlighted the importance of location and density of low cost sensors used in QCN to detect and monitor the seismic activities efficiently and accurately. In [10] WSN is modeled using the open queuing network theory for path planning. The issue of path planning is solved by calculating the path delay to find out the optimal path for efficient data transmission in WSN. Performance evaluation of multiuser wireless sensor network is carried out in [11] by means of queuing theory. Here end to end link level queuing performance is evaluated with automatic repeat request (ARQ) based error control mechanism in a multiuser single cell WSN. Authors have designed an alarm in [12] to determine the magnitude of the longitudinal wave with the help of the accelerometer and compared it with the predetermined threshold. If that magnitude is found to exceed the threshold, then the notification for earthquake in the form of alarm is sent to the concerned alarm devices of the network. Researchers in [14] have replaced traditional seismic networks with a new, more efficient and inexpensive alternate named as QCN using MEMs accelerometer. It has been suggested in [15] that by using variable data rate with automatic rate selection not only network latency but also average power consumption can be reduced. Moreover it is essential for improving scalability and minimizing network overhead. This technique, when compared with other techniques, provided energy saving of 40%. In [16], a novel early warning system for earthquake based on WSN is proposed. This WSN consists of several thousands of nodes, each node consists of a single antenna and these nodes cooperate with each other to form a multiple antenna WSN known as Virtual MIMO WSN.

III. STUDIED SCENARIO

As discussed already, each WSN node is considered to incorporate a complete QCN and a USB sensor/accelerometer to detect the earthquake. Input is assumed to be taken as a ground motion. Each node performs the task of collecting the seismic data, processes it, and transmits the data packets to the centralized node/server which further forwards the incoming data packets to the main station using the backhaul link. Two scenarios are considered in this work.

The scenario-I, shown in Figure 1, represents two stages of queues in tandem where the data packets arrive with a mean rate λ_n at each source node and then arrive at the input of centralized node. At centralized node the combined arrival rate becomes $M\lambda_n$. The function of the centralized node is to process the data packets (provide service) and then forward data packets to the main station using certain backhaul link. The data transmission from the M sensor nodes and reception at the centralized node/server in the form of data packets is modeled as M/M/1 queue. In this work, M WSN nodes are considered to possess the same data packet arrival rate λ_n. Packet arrival rate of each node follows a Poisson distribution. The data packets from each node are forwarded to the centralized node having mean service time $\frac{1}{\mu}$ which is exponentially distributed.

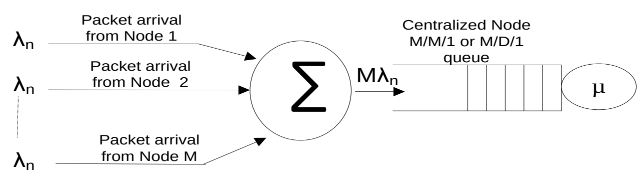

Figure 1: Queuing Model for the proposed Scenario-I

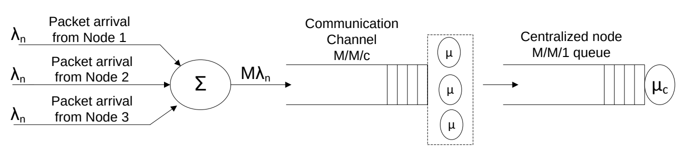

Figure 2: Queuing Model for the proposed Scenario-II

The second scenario, shown in Figure 2, is same as the above scenario, the only difference is that here three queues in tandem are considered instead of a two queues. The source nodes are modeled with M/M/1 queuing system. The data packets arriving at the source node follow Poisson process with a mean arrival rate of λ_n. This data is then forwarded centralized node using a wireless communication channel. A slotted MAC protocol such as TDMA is assumed for fair use of available bandwidth. The wireless channel with centralized MAC protocol is modeled as M/M/c queue (c represents the number of servers). Three time slots are considered in this work for the sake of simplicity. The centralized entity/server is again modeled as M/M/1 queue.

In this paper for both scenarios the performance of WSN based earthquake system is evaluated using queues in tandem concept in terms of two QoS parameters; mean system delay and utilization. In the first scenario, two stages of queues in tandem with 2, 3 and 4 source nodes are considered in order to analyze the impact of increase in the number of source nodes on the mean system delay and utilization whereas in the second scenario three stages of queues in tandem case with two source nodes.

IV. ANALYTICAL MODELING

In both of the scenarios considered, the aim of each WSN node is to transmit the data to the centralized server. The combined mean arrival rate from M nodes at centralized node is $M\lambda_n$. In the first scenario, the data is served at the centralized node on the first come first serve (FIFO) priority. The centralized node serves (forwards to main station) the incoming data packets with the mean service rate μ. The whole scenario is modeled as M/M/1 [13].
In the second scenario, communication channel is considered between all M nodes and centralized node. The wireless channel is divided into three time slots to serve incoming packets. The communication channel is modeled as M/M/c (where c=3) whereas the source nodes and the centralized entity are modeled as M/M/1 queue.

a) M/M/1 Queue:

It consists of single server with FCFS (first come first serve) scheduling discipline. The arrival process is Poisson and the service time is exponentially distributed [13]. The state transition diagram for the M/M/1 queuing model is shown in Figure 3.

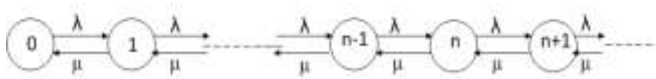

Figure 3: State transition diagram of M/M/1 queue

The equilibrium probability for this queue is

$$p_n = \rho^n(1-\rho) \qquad (1)$$

where $\rho = \lambda/\mu$ represents the traffic intensity and n represents the number of data packets in the system. The value of traffic intensity at each node should be less than 1 to ensure the stability of the system. The system will be stable when service rate is greater than arrival rate otherwise blocking of data packets will occur due to congestion in the system [13].

The mean number of packets present in the system is

$$L = \sum_{n=0}^{\infty} np_n \qquad (2)$$

The average waiting time for a data packet in the system is

$$W = \frac{L}{\lambda} \qquad (3)$$

Utilization of the system is represented mathematically as

$$U = \frac{\lambda}{\mu} \qquad (4)$$

b) M/M/c Queue:

In M/M/c there are c independent and identical servers instead of a single server [13]. The state transition diagram for the M/M/c is shown in following figure.

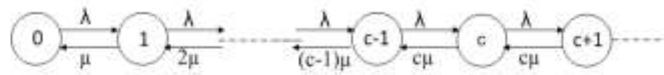

Figure 3: State transition diagram of M/M/c queue

The equilibrium probability for the M/M/c is

$$p_n = \begin{cases} \dfrac{p_o(c\rho)^n}{n!}, & n < c \\ \dfrac{p_o c^c \rho^n}{c!}, & n \geq c \end{cases} \qquad (4)$$

where

$$p_o = \left[\sum_{n=0}^{c-1} \frac{c\rho^n}{n} + \frac{(c\rho)^c}{c}(1/1-\rho)\right]^{-1}$$

The number of packets waiting in the queue is represented by

$$L_q = \sum_{n=c}^{\infty} (n-c)p \qquad (5)$$

So the average waiting time in the queue is

$$W_q = \frac{L_q}{\lambda} \qquad (6)$$

The mean system delay is

$$W = W_q + \frac{1}{\mu} \qquad (7)$$

V. RESULTS AND DISCUSSION

Matlab software is used in this research for simulation purpose. As shown in the first scenario, all M WSN source nodes transmit their data cumulatively to the centralized node/server where data is further processed and then is transmitted to the final destination. The centralized node/server and the data transmitting source nodes are modeled as M/M/1. This whole scenario corresponds to the queues in tandem.
In the mentioned scenario, 2, 3 and 4 source nodes are considered (2 stage of queues in tandem) in order to analyze the behavior of the system when the number of WSN based source nodes is increased. The packets from each node arrive at input of centralized node which processes data with the

mean service rate μ. Real packet size from [2] is taken in this work while the service rate considered is 1Mbps [15]. Hence the average service rate is 1250 packets/sec.

We have evaluated the performance of the system in terms of two QoS parameters; mean system delay and utilization. Mean system delay is of great importance here because it plays the role while evaluating the performance of the WSN based earthquake monitoring system as it should be as minimum as possible so that the warning for the earthquake may be generated in time to avoid loss of human lives or infrastructure. Utilization is also a very essential parameter which indicates that how well available resources are utilized when there is congestion in the system.

First, we have considered the first scenario with two, three and four source nodes, and one centralized node. The real packet size (i.e. 100 Bytes) is considered here [2]. The Figure 3 shows variation of delay in scenario-I for all three cases with varying traffic intensity value. It is clear from the results that as the number of nodes increases, the mean system delay increases. It is because the increase in the number of nodes in the network represents increase in the packet arrival rate. Traffic intensity increases with increase in arrival rate.

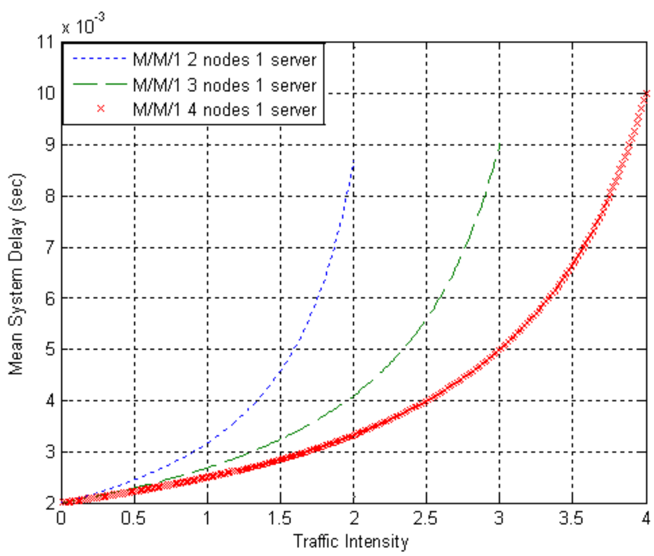

Figure 3: Mean System Delay for Scenario-I

Individually if the behavior of average delay for each case is observed, then the value of average delay is very low in the beginning for $\rho = 0.5$. After that, it increases sharply when the value of ρ exceeds 1 (for more than one node). The average delay caused by the system collectively is different for all cases and is shown in the figure. It implies that the increase in the number of nodes also plays an important role in the increase of the mean system delay.

Now for the same scenario, we analyze the effect of traffic intensity on the utilization of the system. Utilization of the system corresponds to the amount of the time that the server is busy [13]. Generally, it is directly proportional to the traffic intensity ρ. Since the traffic intensity depicts the arrival rate of the data packets at the source nodes that's why increase in the number of data packets (traffic intensity) demands greater time duration from the server to remain busy and this causes a proportional increase in the utilization as shown in the Figure 4. However, it is also observed from the figure that the utilization values are greater for the cases in which there is greater number of nodes as compared to the cases where number of nodes is less.

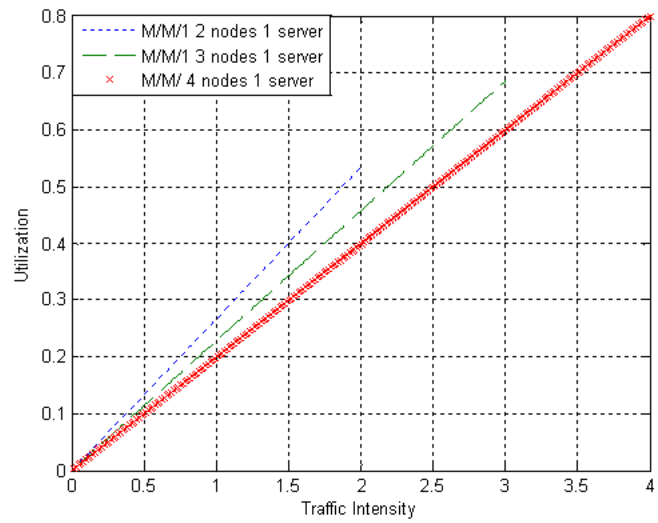

Figure 4: System utilization

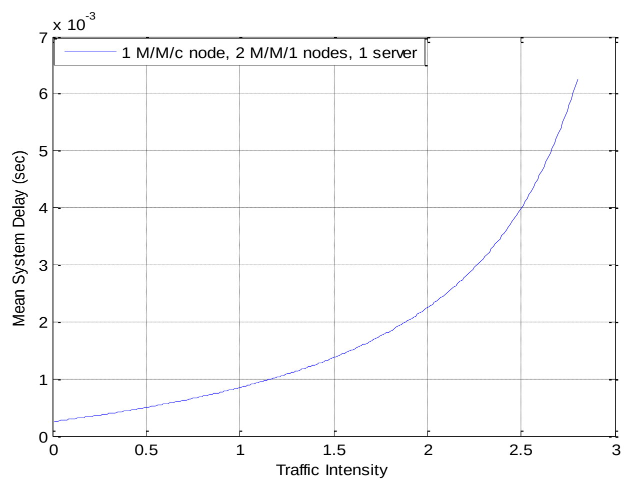

Fig 5: Mean System Delay for Scenario II

In the second scenario, three queues in tandem are considered. Output of Node 1 and Node 2 become input to the wireless channel which in turn is responsible for supplying input to the centralized server/node. Data packet size and the service rate considered are same as considered in the first scenario. Figure 5 shows variation in the mean system delay with the change in values of traffic intensity ρ when the queues are arranged in tandem for scenario II. The results show that the mean system delay increases with the increase in traffic intensity. Initially, if we observe the mean system delay, it increases slowly however, it starts increasing rapidly after ρ crosses the value of 0.5. This rapid increase in system delay is observed because of the increase in the arrival rate of data packets with the passage of time. The mean system delay increases in the exponential manner until it reaches its maximum possible value i.e. 7ms. The utilization is also linear function of traffic intensity in this case.

VI. CONCLUSION

In this paper, we have analyzed the performance of the WSN based earthquake monitoring system using queuing theory. Here, we have considered *M* WSN nodes and these nodes were arranged as queues in tandem. The ground motion (that is assumed here as an input) is detected by the source nodes and represented in form of data packets. All nodes were modeled using M/M/1 queues and wireless channel with centralized MAC protocol was modeled as M/M/c queue. The performance of the WSN based earthquake monitoring system was analyzed in terms of QoS parameters such as mean system delay and utilization using real packet size and the data rates of the communication link. It is concluded by analyzing the results that average delay caused by the system increases with increase in traffic intensityρ. Furthermore, utilization is also found to be directly proportional to the traffic intensity. These results are useful for analyzing the WSN based earthquake monitoring system with number of nodes and available service capacity.

ACKNOWLEDGEMENT

The Authors are grateful to Mehran University of Engineering & Technology Jamshoro for providing the necessary facilities for conducting the research.

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