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Abstract:

Earthquake monitoring and detection has been in great focus for many years. A possible solution of this problem is the deployment of an efficient system that can generate the warning for the earthquake as early as possible. This kind of deployment not only helps to save human lives but also provides support in exploring many hidden facts about great disaster. In this paper, performance analysis of Wireless Sensor Network (WSN) based earthquake monitoring system is carried out using queuing theory. The WSN nodes transmit their data to a centralized node which further sends this data to main station using a wireless/wired backhaul link. This scenario is modeled using two queues; M/M/1 queue and M/D/1 queue. The performance of the system is evaluated and compared in terms of mean system delay and utilization for both queuing models. The results reveal that the system delay decreases with increase in the data rate of the communication link (server).

Keywords: delay, earthquake, queuing, WSN.

I. Introduction

Earthquake is a type of natural disaster. This disaster occurs due to the sudden release of stored energy in the Earth's crust that creates seismic waves [1]. On 26 December 2004, an earthquake of magnitude 9.0 caused huge loss of human lives in Indonesia and its neighboring countries. That great loss motivated scientists and researchers to discover new mechanisms for detecting and monitoring the earthquake so that people can get warning in time, and thus any serious loss can be avoided. The WSN based monitoring system is one of these paradigms considered.

A node in wireless sensor network is capable of sensing, processing, and communicating with other nodes in the range or a centralized entity (node). This helps to observe and react according to the condition in a particular environment. WSNs are application specific; hence design considerations are different for each application [2]. A node in WSN consists of a transmitter, receiver or a transceiver for detecting, measuring and transferring the data to the central node/server. Such a network called Quake-Catcher Network (QCN) is built upon the Berkeley Open Infrastructure for Network Computing (BOINC) software for volunteer computing [3]. The QCN is a large network of low-cost sensors connected to volunteer computers, in a specific region to monitor seismic events.

Recently, an increased interest has been observed to analyze the network performance using analytical or simulation tools before the actual deployment. In this regard the Queuing theory offers a promising analytical solution to evaluate the performance of such networks in terms of quality of service (QoS) parameters. Therefore, in this work, a detailed analysis based on queuing theory for modeling WSN is carried out for analyzing the mean system delay and utilization. Single node of WSN acts as a complete QCN node and combination of number of nodes represents a network of nodes (i.e. WSN). Theses nodes transmit their packets to a centralized node which further communicate these packets to main office using wireless/wired backhaul link.

Following the introduction, the paper is organized as follows: Section II describes Related Work. Section III presents Studied Scenario. In section IV, mathematical model for the proposed design is discussed. The performance analysis is carried out in section V. Paper concludes in section VI.

II. Related Work

In [1], 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. Researchers in [2] believe that animals act abnormally before and after earthquake and their behavior is helpful in the prediction of an earthquake. On that 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. In [3], authors highlight the importance of location and density of low cost sensors used in QCN in order to detect and monitor the seismic activities efficiently and accurately. Researchers in [4] have replaced traditional seismic networks with a new, more efficient and inexpensive alternate named as QCN using MEMs accelerometer. In [5] authors have developed an accelerometer which provides high sensitivity and a wide measureable range, while in a traditional accelerometer, there is a tradeoff between the measureable range and sensitivity.

Authors have designed an alarm system in [6] 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. Authors in [7] have taken initiative towards design of a new wireless sensor node that is not having only minimum physical size and less power consumption but also able to perform simple processing on the acquired data in order to reduce the amount of data that is to be stored at the node. It is based on an ultra-low power System on Chip (SOC) microcontroller with a temperature sensor and a 3-axis accelerometer.

Traditionally queuing theory has been used to analyze the performance of communication networks. However, to the best of our knowledge, little work has been carried out in regards to WSN for earthquake monitoring using this theory. In [8] 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. Authors in [9] have derived the expression for the distribution and first two moments for both steady state and transient conditions for different random variables and then investigated the output process of M/D/1 queuing system.

The issue of WSN scaling is highlighted in [10]. Authors found that network dynamics mainly depends on network operations rather than environmental changes but environment is able to put an unpredictable effect on sensor network. They also found that network indicators can't identify the problem if small portion of nodes bottlenecks the whole network.

It has been suggested in [11] that by using variable data rate with automatic rate selection not only network latency but also average power consumption can be reduced and is essential for improving scalability and minimizing network overhead. This technique when compared with other techniques provided energy consumption with 40% saving.

III. Studied Scenario

The USB sensor/accelerometer and computing capability constitute a single WSN node. The ground motion is detected with the help of MEMS accelerometer present in WSN node. The information (seismic data) is collected by every node individually and transmitted to the centralized node in terms of data packets as shown in Figure 1. The data transmission (in form of packets) from M sensor nodes and reception at centralized node is modeled as M/M/1 and M/D/1 queues [12]. Here single server is considered which is wireless/wired backhaul link to the main station. Without loss of generality, in this work, M WSN nodes are assumed to have the same mean packet arrival rate λ_n which further collectively sums to the $M\lambda_n$. Packet arrival rate of each node follows a Poisson distribution with mean λ_n. The arrived packets are further communicated to the main station by central node using a service rate. Our aim in this paper is to analyze the performance of WSN based earthquake monitoring using queuing theory in terms of average system delay and utilization.

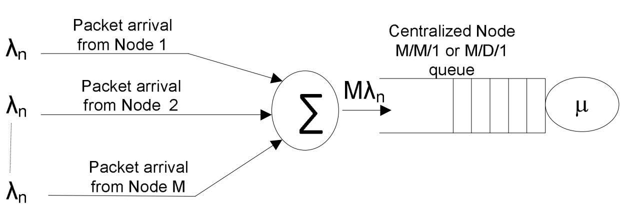

Figure 1: Queuing Model for the Proposed System

IV. Analytical Modeling

In this section we present the analytical modeling of M/M/1 queue and M/D/1 queue.

a) M/M/1 Queuing Model:

In scenario considered, each node transmits the data packet with mean arrival rate λ_n, hence the combined arrival process becomes Poisson process with mean arrival rate $\lambda = M\lambda_n$. These data packets are sent to a centralized node for further communication to the main station using backhaul connection. This scenario is modeled as M/M/1 queue [12]. Central node further forwards the data packets with service rate μ using the First-In First-Out (FIFO) priority. The complete representation of this WSN based system for earthquake monitoring using M/M/1 is shown in figure 1. Figure 2 shows the state transition diagram of M/M/1 queue represented as a birth-death model.

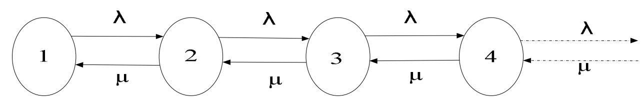

Figure 2: The state transition diagram for M/M/1 queue

The equilibrium probability for M/M/1 queue is

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

where $\rho = \lambda/\mu$ is the traffic intensity, n is number of packets [12]. To ensure the stability of the system, ρ should be less than 1. It means that arrival rate is smaller than service rate; otherwise the number of packets will keep increasing with passage of time.

The mean number of packets in the system is

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

The average delay experienced by each data packet is the combination of waiting time in the queue and service time and can be calculated using Little's theorem [12] as

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

The utilization of the system is given by

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

a) M/D/1 Queuing Model:

In M/D/1 queuing model, the arrival process is Poisson distributed and service time of each packet is constant [9]. Service time is fixed because both the packet length and the data rate of link are deterministic.

The mean number of packets in the system

$$L = \rho + \frac{\rho^2}{2(1-\rho)} \qquad (5)$$

The mean system delay in this model is

$$W = \frac{2-\rho}{2\mu(1-\rho)} \qquad (6)$$

V. Performance Evaluation

All M WSN nodes send their data to a centralized node as shown in figure 1. The communication through this central node is modeled as both M/M/1 and M/D/1 queue. The real packet length (i.e. 100 **Bytes**) used in [11] is considered here. The communication link used for transferring data from M WSN nodes to the main station through centralized node has data rate of 1Mbps [10]. Hence, the mean service rate turns out to be $1250\frac{\textbf{packets}}{\textbf{sec}}$. In this work, we evaluate the performance of the WSN for earthquake monitoring using average packet delay and utilization as QoS metrics for both M/M/1 and M/D/1 queuing models.

Figure 3 shows the impact of traffic intensity on the system delay. This analysis of mean system delay is necessary in order to select the values of ρ (traffic intensity), in such a way that the delay can be as minimum as possible and the warning for earthquake may be generated and processed in time. The results reveal that the average delay of the data packets increases with the increase in ρ values. In case of M/M/1 queue, the system delay is very low for $\rho = 0.1$. The delay starts to increase rapidly when ρ exceeds 0.2. This is because the arrival of data packets from M WSN nodes increases and a single server has fixed service capability. The maximum mean delay caused by the system to the data packets generated by source nodes is 4 **ms**. In case of M/D/1 queue, the service time (provided by single server) is fixed for each WSN packet and the mean system delay is reduced compared to the M/M/1 queuing model. This is due to the uniformity of the service rate.

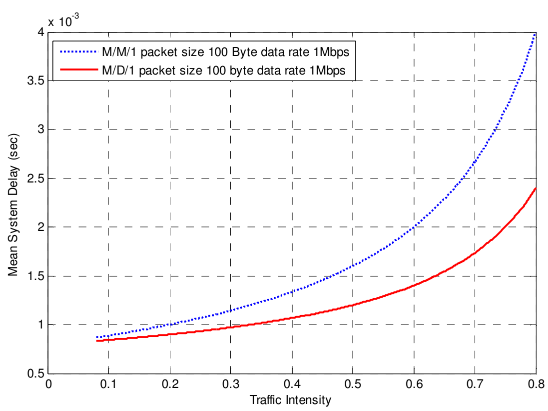

Figure 3: System Delay as a function of Traffic Intensity with 1 Mbps link

Now, we consider data rate of communication link to be 2 **Mbps** with same packet size and data generation rate. Hence, the service rate of the system doubles and value of the traffic intensity becomes half compared to the parameters considered for results shown in Figure 3. With this communication link, each packet is served faster. In this system setup, as shown in Figure 4, the mean delay for M/M/1 queue at $\rho = 0.04$ is less than 0.7 **ms** compared to previous setup (with link rate of 1 Mbps) where it was about 1.3**ms**. Moreover, for M/D/1 queue, the mean delay is lower compared to M/M/1 queue.

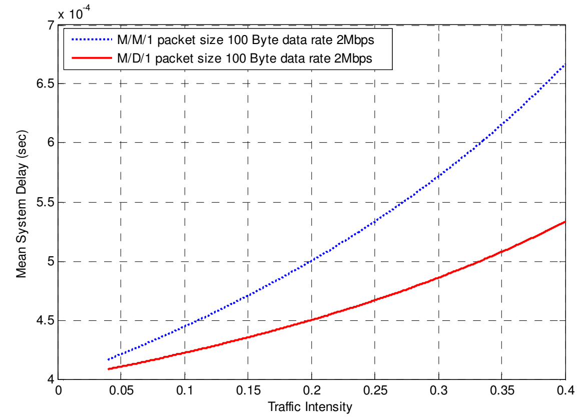

Figure 4: System Delay as a function of Traffic Intensity with 2 Mbps link

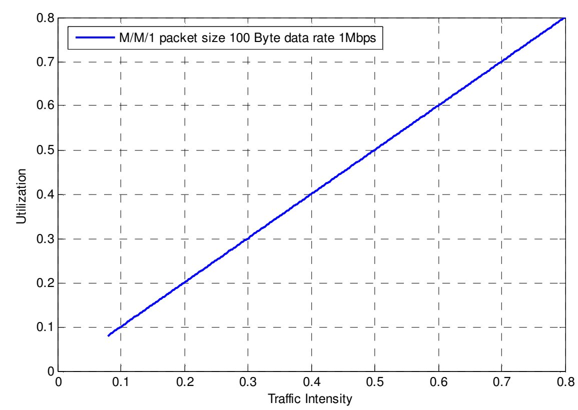

Figure 5: Utilization as a function of Traffic Intensity

System utilization is directly proportional to the traffic intensity values for both queuing models. The utilization is the measure of how much server is busy and is equal to ρ. It is due to the fact that ρ depends on the arrival of packets (with the mean service rate of the system is kept constant). As arrival rate of data packets increases, ρ increases and this in turn causes utilization to increase. This effect always gives a linear curve when utilization is plotted against traffic intensity. It is shown for M/M/1 queue in Figure 5. M/D/1 queue has a linear trend as well.

IV. Conclusion

In this paper, performance analysis of WSN based earthquake monitoring system has been carried out. For this purpose, we have considered M WSN nodes, assuming that ground motion recorded by these nodes is presented in terms of data packets, and these data packets are transmitted to a central node. The combined arrival rate from these M nodes at centralized node becomes a multiple Poisson process with mean arrival rate $M\lambda_n$. The network has been modeled as M/M/1 queue and M/D/1 queue. By considering typical data rates for WSN and real packet length from literature, the performance of the system has been evaluated in terms of QoS parameters such as mean system delay and utilization. The results show that average delay of the system decreases with increase in data rate of link (server). Moreover delay is less in case of M/D/1 queue compared to M/M/1 queue. The results also show that utilization is a linear function of traffic intensity.

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