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Path Delay Analysis of Multiserver Wireless Sensor Networks

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Abstract— in this work, we study and analyze a wireless queuing model that can contribute to a path delay analysis of multi-server wireless networks in order to resolve the problem of delay of the nodes with in the wireless network transmission queue. As the recent researchers had come up with an M/M/1 model of analysis, this model have provided inadequate end –to –end avoidance since it has been designed in a form that it only a single serve of receiving all incoming data from different network sensors. Therefore, it is under this network queuing mode where we have proposed to design another network queuing model which we be having multi-servers, and technically we called this model an M/M/m queuing model where the last m standards for multi-servers and this model the outgoing data will be having different options of paths to reach the destination of data without any delay. By using MATLAB for simulation, we analyzed different parameters for end –to –end delay as well as data arrival rates of different loads in the queue and the implementation of the queuing model M/M/m for path delay analysis of multi-server wireless sensor networks. It is found that the path delay of data in wireless network can be minimized at a very high level but not to be avoided completely due to other inevitable incidences data occurs during data transmission in wireless sensor networks

Keywords— M/M/1 model, M/M/n model, wireless sensors, path delay analysis, Queuing model

I. INTRODUCTION

A wireless sensor network by definition is an adhoc multi-hop network which consists of large number of tiny homogeneous sensor nodes that are resource-constrained, mostly immobile and randomly deployed in the area of interest [4]. A typical sensor network consists of a large number of sensor nodes deployed either inside the phenomenon of interest or close to it. The primary purpose of sensor networks is to provide users access to the information gathered by the spatially distributed sensors, rather than enabling end-to-end communication between pairs of nodes as in other large-scale networks such as the Internet or wireless mesh networks. These sensor nodes can collaborate on real-time monitoring, sensing, collecting network distribution of the various environments within the region or monitoring object information [5]. This information is then processed to obtain useful data, which is then sent to the user [6]. Wireless sensor networks typically feature dynamic topology, limited energy, nodes with limited resources and non-reliability of data transmission. Therefore, they need real-time, economy, energy conservation and coordination in above four aspects to improve the network performance of WSNs and satisfy the performance requirements of the task scheduling system [7].

Recently, the design of sensor networks has become very important, due to several civil and military applications. Emerging sensor applications include habitat monitoring, pollution detection, weather forecasting, and monitoring disasters such as earthquakes, fires, and floods.

Sensor networks have different constraints than traditional wired networks. First, the avail-able energy of the sensor nodes is the most critical resource in the sensor network. The limitation of the energy source is the battery which is the only source of power for the nodes. The sensors cannot operate with exhausted batteries. According to the analysis of sensor nodes, the main sources of energy consumption are sensing, wireless transmission and data processing. However, the energy consumption caused by wireless transmission is much more than sensing and data processing.

Furthermore, since sensor nodes behave as relay nodes for data propagation of other sensors to sink nodes, network connectivity decreases gradually and may result in disconnected sub-networks of sensors. Therefore, the level of power consumption must be considered at each stage of wireless sensor network design [8]. Second, since sensors have limited computing power, they may not be able to run sophisticated network protocols. Third, since the bandwidth of the wireless links connecting sensor nodes is often limited, inter-sensor communication is further constrained.

Fourth, sensors have limited memory size [9]: Too much memory space would increase the cost and size of sensors, while too little memory space cannot meet the requirements of applications. Hence, it is important to estimate the required memory space before the deployment of sensor networks.

Lastly, a sensor network is subject to a number of uncertainties from several factors [10, 11]. First, the sensor network may be deployed in a hostile environment dealing with uncontrollable factors. Second, the wireless communication is unreliable due to interference, attenuation and fading effects. Third, some nodes may die over time and some new nodes may join later. As a consequence, the network topology and routing structures change dynamically.

Therefore sensor nodes must consider the following design issues [12]:

- Consume extremely low power,
- Operate in high volumetric densities,
- Have low production cost and be dispensable,
- Be autonomous and operate unattended,
- Be adaptive to the environment.

In a sensor network, data is transmitted from the source node to target node. If data takes a long time searching for the target node, that node will always be in the data transmission state. During this time, because the utilization of nodes are not in equilibrium [13], the energy of individual nodes will run out as a result of node failure [14, 15]. This causes delay in transmission. Therefore, the problem of path planning, i.e., how to improve the speed of source node searching target node, is one of the challenging issues in the field of WSN.

Statement of the problem

Improving the speed of source node searching a target node is one of the problems in Wireless Sensor Networks. Tie *et al.* [16] analyzed the path delay based on *M/M/*1 queuing network for large-scale WSNs, where the first *M* stands for Markovian and indicates that the arrival process is Poisson (with exponential inter arrival times), the second *M* is the data size which is assumed to be exponentially distributed and a single server. However, their results did not consider a multi-server situation where a node has multiple parallel processors. Therefore, we propose to extend this model to an *M/M/m* system where nodes have multiple parallel processors.

General objectives

The main objective of this study to propose and design a path delay model for a multi-server wireless sensor network.

Specific objectives

Specific objectives of the research will include the following:

1. Review and analyze the existing models
2. To develop a model for path delay for multi-server WSNs using M/M/m queuing technique.
3. To evaluate the performance of the proposed model.

Scope

The scope of the research shall include a multi-server WSNs used for monitoring temperature. We shall consider an open queuing network for modeling the path delay analysis. In particular, we consider an M/M/m queue system which based modes multi-server system.

Research questions

1. What models are being used in path delay analysis for WSNs?
2. What model can be designed to improve the performance of real time data transmission in WSNs?
3. Significance of the research

Path planning is one of the important factors that affect data transmission and processing in wireless sensor networks (WSNs). The delay performance of wireless networks has always been a problem primarily because of the complex interactions in the network (e.g preposition, routing, departure etc.) that make its analysis difficult. The problem is farther exacerbated by the mutual interference inherent in wireless networks which complicates both the scheduling mechanisms and there analysis.

When the time of an individual node communication is not normal or if there is energy depletion, the packets to be processed are queued in the blocking node. If the blocking cannot be solved in time, blocking occurs in all the nodes of the link path, resulting in the congestion of the entire network. This requires keeping a high efficiency of path selection in the system for communication, and the searching paths occupying the smallest delay. Therefore, this model is explored to reduce the transmission delays of the network at a minimal level when the system is blocked.

Research methodology

To realize this study, we review possible path delay analysis in wireless sensor networks to recommend the appropriate path delay avoidance of wireless network data transmission. We explore the possibilities of applying the queuing theories to improve upon path selections. Using MATLAB and analysis we analyze the arrival rates of nodes and the ratio of end-to –end delay and compare the results with the queuing techniques.

II. OVERVIEW OF PATHDELAY ANALYSIS FOR WIRELESS SENSOR NETWORK

The rapid development of low power wireless communication, micro sensor, and micro-processor hardware: small-scale energy supplies in conjunction with the significant progress in distributed signal processing. Ad-hoc network protocols and pervasive computing have made wireless sensor networks (WSNs) a new technological vision. [13, 14, 15].

A sensor node consists of five basic units: processing, memory, sensing, power and communication units. A processing unit is responsible for executing the set of routines that form a sensor's task.

A memory unit consists of three parts:

- The program flash memory that is used by the processing unit as a temporary storage area to execute routines
- measurement flash memory which is used to store sensory measurement obtained by the sensing unit
- Configuration EEPROM where all configuration data for sensor is kept [16]. The general architecture of a sensor node is shown in the figure 2.1

A sensing unit includes different kinds of sensors. Like temperature, light, and humidity, depending on the application. The most important component is power unit which supplies all other units with the required power to operate.
In addition to regular batteries, a power unit might be sustained by solar cells. A communication unit connects a sensor node with its neighbors via radio communication.

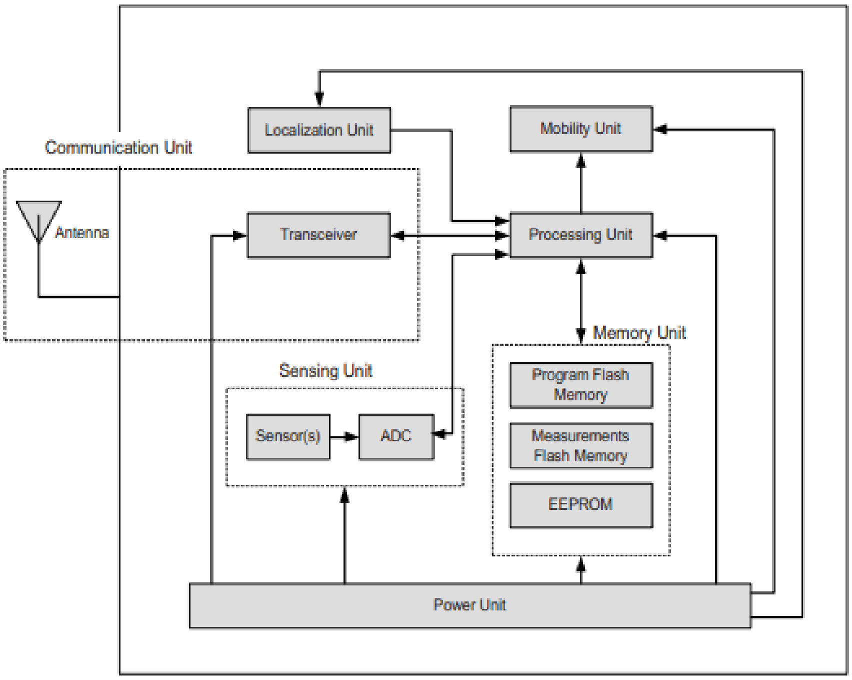

Figure: II. 1. General architecture of a sensor node. Adopted [1]

A sensor network consists of a large number of tiny sensors deployed randomly in an area of interest. Nodes in a sensor network communicate in multi-hop fashion to deliver the collected data to a central processing unit called the base station or the sink node. Networking of sensor nodes is quite challenging due to its special characteristics. For example the limited sensor's powers require all protocols designed for sensor networks to be energy efficient in order to prolog the network life time.
Likewise, the random deployment poses other constraints on sensor networks to be self-organized. The small memory size and limited power restricts the computational capabilities of the sensor nodes as well as the storage capabilities. On the other hand, sensor networks have some unique characteristics that make it so attractive to use in many applications. Some of these characteristics include availability of data sources as well as the dense random deployment of sensor nodes.
Potential application of WSNs includes environmental monitoring, industrial control, battlefield surveillance and reconnaissance. Home automation and security, health monitoring, and asset tracking. The characteristics of a sensor network may vary greatly according to the specific application scenario. However, most sensor networks share some basic features which are:

- The life time of the network depends on the limited energy available at individual sensor nodes.
- Cheap sensor nodes are usually deployed in large amounts.
- The sensor devices may fail frequently due to their low-cost nature.

From the designer's perspective these features give rise to the issues of energy saving, scalability, and fault-tolerances respectively.

Sources of energy wastage in wireless sensor networks

The major sources of energy wastage in wireless sensor networks are basically of four types: [20,21]

- Collision: when a transmitted packet is corrupted due to interference, it has to be discarded and then retransmitted. Retransmission increase energy consumption which in turn increase latency.
- Packet over head: sending and receiving control packets consume energy too and sometimes less useful data packets are transmitted.
- Overhearing: this means that nodes picks up packets that are destined to other nodes

- Idle listening: the last major source of inefficiency is idle listening, i.e. listening to receive possible traffic that is not sent. This is especially true in many sensor network applications. If nothing is sensed, the sensor node will be in idle state for most of the time.

The main goal of MAC protocol for sensor network is to minimize the energy wastage due to idle listening, overhearing and collision.

Energy minimization technique in wireless sensor networks

Since WSNs are expected to operate for months if not years on small inexpensive batteries with limited lifetimes, energy efficiency becomes the primary goal in these networks. One of the methods proposed for saving energy in sensor networks is the sleep and active states [22]. During sleep periods, the radios are completely turned off, and during active periods, they are turned back on to transmit and receive messages. This is based on MAC layer protocols, on which each sensor node is characterized by two operational states, active an sleep states. When a sensor node has packets to send, it turns o and switches to active state and sends packet. When a sensor node does not have any packet to send, it switches to a sleep state and turns off. If the number of transitions between the active and sleep state is high, energy consumption is high. The sleep state I characterized by a low energy consumption because most parts of the circuits in the sensor node are shutdown.

Two main types of mechanisms to control the transition amongst states are considered:

Random sleep and coordinate sleep. In the random sleep type [23] the scheduling of active and sleep times of a generic sensor node is independent of one another. In the coordinated sleep type [24] the sensor nodes coordinate with each other in order to reach an active-sleep schedule. When a sensor node is in sleep state, it cannot take part in the network activity implying that the network topology changes as nodes enter or exit the sleep state, and this degrades the operation and performance of the network. On the other hand, keeping the network in the active state can unnecessarily reduce the sensor and network lifetimes.

Medium access control (MAC) protocols.

Medium access control (MAC) protocols determines how nodes in a sensor network access the shares wireless medium, and they play a crucial role on overall energy utilization in the network. MAC protocols fall into two broad classes; contention-based and contention free

Contention-based MAC protocols

Contention-based MAC protocols also known as random access protocols, requiring no coordination among the nodes accessing the channel [17]. Colliding nodes back-off for a random duration and try to access the channel lager again. Collision of radio packets in the wireless medium has usually a destructive effect on the packets and may require retransmission at the sender's side. Severe energy wastage may be caused by frequent collisions in in a sensor network.

A contention-free MAC protocols should be able to bring the network from an arbitrary state to a collision-free state. Contention occurs when two nearby sensor nodes both attempt to access the communication channel. Contention causes message collision, which is very likely to occur when traffic is frequent and correlated, and they decrease the lifetime of a sensor network [17]. Severe energy wastage may be caused by frequency collisions in a sensor network.

Contention-free MAC protocols

In these protocols**,** the nodes follow some particular schedule which guarantees collision-free transmission times. A MAC protocol is contention-free if it does not allow any collisions. All existing contention-free MAC protocols assume that the sensor nodes re time-synchronized in some way.

This is usually not possible an account of large scale of sensor networks. When the nodes reach the stable state, they use a contention-free MAC protocol to transmit messages without collisions.

More recent works have focused on developing distributed algorithms that schedules the channel access among nodes in a sensor network so that collisions are prevented before they occur [18, 19]. These are known as contention-free (CF) MAC protocols, mostly based on a distributed implementation of the TDMA (Time Division Multiple Access) protocol.

Many recent work urge that contention- free MAC protocols are more suitable for energy – limited sensor networks [20] and they provide channel access scheduling algorithms, mostly by using a time multiplexer (TDMA based) technique. In TDMA, time is divided into frames and frames are further divided into time slots. Each node is allocated a time slot in its frame it can use for transmission.

The collision – free transmission by the use of TDMA-based MAC protocols comes with the price of increased latency. This is because a packet suffers a delay at each intermediate node due to the fact that a node has to wait for its time slot before it can relay the packet to the next hop. However, if the routing path is carefully chosen for a source-destination pair, the delay can be minimized.

To avoid more delay in the data delivery that happens through multi-hoping communication, sensor nodes form clusters and a cluster head is selected for each cluster. In this case, all nodes in a cluster can communicate with the cluster head directly but the energy consumed and the time involved while selecting the cluster head is more [21].

One of the most important networking performance quantities is delay as it strongly influences the configuration and performance of network protocols such as routing and flow control and network services such as voice and video over the internet protocol (IP). The delay performance of any scheduling policy is primarily limited by the interference which causes many bottlenecks to be formed in the network.

Other research papers [22, 23, and 24] have made some progress about analysis and improving the network performance in the application of finite capacity queuing networks. Performance issues in WSNs play a vital role in many applications, for example in the time sensitive WSN application, the maximum allowable messages transfer delay must be bounded. Hence, algorithms that minimize the maximum worst-case delays in WSNs are crucial.

Grorgiadis *et al*. [23] derive stochastic upper bounds on the average delay of the network using the technique of lyapunov drifts. Papaiannaki *et al*. [23] measured the shortest delay of queuing system based on maximum entropy methods.

Bisnik *et al.* [33] modeled random access multi-hop wireless networks as open G/G/1 queuing network and used the diffusion approximation in order to evaluate closed form expression for the average end –to –end delay, but it did not involve path planning.

The M/M/1 queue

In this system, customers arrive according to a Poisson process with rate, λ. The time it take to serve a customer is exponentially distributed with service rate, μ. The service times are independent of inner-arrival times when a customer enters an empty system its service sars a once; if the system is non empty the incoming customer joins the queue. When the service completion occurs, a customer from the queue, if any, enters the service facility at once to get served. Let *X(t)* be the number of customers in the system at any time *t.* the process $(X(t), t \geq 0)$ is a birth and death process with birth rate $\lambda_i = \lambda$ for all $i \geq 0$ and with death rate $\mu_i = \mu$ for all $i \geq 1$

Figure II.2 shows the transition diagram for the M/M/1 model with birth rate λ and death rate μ

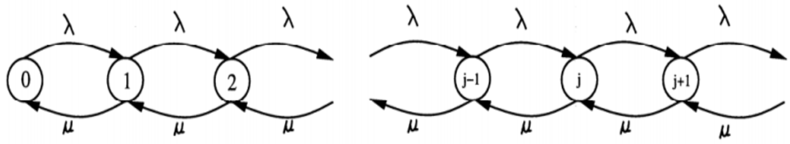

Figure II.2: state transition diagram for an *M/M/1* queue model. Adopted from [2]

Therefore, for an M/M/1 queue the probability tha there are *I* customers in the system is given by

$$\pi(i) = (1-\rho)\,\rho_I \qquad (2.1)$$

For all $i \geq 0$. Hence, the mean waiting time (that Is queuing and aervice) for M/M/1 wue is given by:

$$\frac{\rho}{(1-\rho)\,\lambda} = \frac{1}{\mu-\lambda} \qquad (2.2)$$

end –to –end path delay calculation

Each queue delay is frmed by queuing delay (wait elay) and transimision delay in the queuing network for WSNs. Transimision delay is linked with the arrival rate of packets and the service rate nodes. if the utilization (or traffic intensity) of node *i* is given by :

$$\rho_I = \frac{\lambda i}{\mu i} \qquad (2.3)$$

Then the end –to –end delay caused by an M/M/1 queing model of N-level nodes is given by [16] :

$$E(T) = \sum_{i=1}^{N} \frac{1}{\mu i - \lambda i} = \sum_{i=1}^{N} \frac{1/\mu i}{(1-\rho)} = \sum_{I=1}^{N} \frac{\rho}{i(1-\rho)\,\lambda i} \qquad (2.4)$$

Average delay calculation for entire queuing networks

In the queuin network for wireless sensor networks , each node is considered as an M/M/1 queue, and each path is considered as a queuing model [35,36] with N-level serial nodes, with service rate μ and pure packet rate ϒ of entering the queuing network. The average network delay with M paths is then given in [16] as:

$$Em\ (T) = \frac{1}{\Upsilon}\sum_{n=1}^{M} \frac{\lambda n}{\mu n - \lambda n} \qquad (2.5)$$

Research gap

In [24], a time – slot allocation algorithm was proposed for TDMA- based WSNs to minimize end – end delay. An optimized problem was formulated to minimize the maximum delay, however, it is limited in that it assumes a single – channel system.

Another recent study [25] extends the algorithms proposed in [24] to the multiple channel environment. More specifically, they consider a multichannel TDMA - based mesh network and propose channel and time –slot allocation algorithms with an objective of reducing delay. Their work is different from previous studies in that the algorithms are based on the length of flow to perform channel assignment and time –slot allocation.

In [26], delay optimal schemes for wireless networks have been proposed, which typically minimize an expected delay metric assuming that the system behaves as M/M/1 queue. Given the complexity involved in scheduling link transmission in a multi-hop wireless system. The M/M/1 approximation is too coarse. Therefore, we propose to extend this model to a multi-server scenario where anode has multiple parallel servers so as to reduce both delay and blocking using an M/M/m queue system.

III. M/M/M QUEUING MODEL FOR PATH DELAY ANALYSIS OF MULTI-SERVER WIRELESS SENSOR NETWORKS

Over view

In this chapter, we describe the, we describe the model proposed for analysing the path delay. We then present analytical models upon which the implementation of multi servers are based. The model is based on the *M/M/m* queue system. We further derive the expression for the average end –to –end delay for M/M/m queue system. To assess the performance of the proposed model *M/M/m* queue system against the *M/M/1* queue system, we use the MATLAB tool.

Since path delays have the most computational overhead and slow down the speed of operation of WSNs, a modelling method on large –scale network nodes is needed for optional paths in WSNs.

Queuing network is an effective system –level modelling method which is widely used in the modelling and performance analysis of the computer systems and communication systems

[27, 28]. Using queuing network delay evaluation, problems of analysing modelling and path delay planning in various fields are successfully resolved.

We particularly used analytic models. An analytical model is a set of formulae or computational algorithms used to abstract the essential characteristics of computer systems and to analyse or predict system behaviour [41]. Analytical models provide faster and more computationally efficient methods of obtaining performance measures. In particular, queuing theory [42] is used to model arrival and service rate of jobs in the system. Queuing models are suitable in a variety of environments ranging from common daily life scenarios to complex services a business processes, operations research problems, or computer and communication systems. Queuing theory has been extensively applied to evaluate and improve system behaviours [43, 44, 45, and 46].

An advantage of the queuing model is that one can use various results available in queuing theory to get appropriate approximations.

Queuing theory

Queues are common in computer and networked systems. There are always queues of inquires waiting to be processed by an interactive computer system, queue of database requests, queue of I/O requests, etc. typically a queue (or queuing system) has one service facility, although there may be more than one server in the service facility, and waiting room (or buffer) of infinite or finite capacity.

Customers from a source enter a queuing system to receive some service. The word customers is used in its generic form and may be packet in communication network, a program in a computer system, a request or an inquiry in a database system, etc. upon arrival a customer joins the waiting room if all servers in these service centre are busy. When a customer is serve, it leaves the queuing system. A special notation, called Kendall's notation, is used to describe a queuing system. The notation has the form [47]: *A/B/c/K.* where;

- A denotes the inter-arrival time distribution,
- B denotes the service time distribution,
- C denotes the number of servers,
- K denotes the size of the system capacity (including the servers).

The symbols used for A and B are:

- M for exponential distribution (M represent Markov),
- D for deterministic distribution,
- G or GI for general distribution.

When the system capacity is infinity ($k = \infty$) one simply uses the symbol A/B/c. for example M/M/1, M/M/m, M/G/1 are common queuing systems.

Performance Metric

We draw performance metrics from queuing theory; queuing theory is suitable in a range of communication environments. Queuing theory has been extensively applied to evaluate and improve system behaviour. In this particular case, we consider average end –to –end delay as the performance metric.

Average end –to –end delay is defined as the sum of the transmission delay and queuing delay. Where transmission delay is the amount of time required to transmit all of the packet's bits into the link. On the other hand, queuing delay is the delay between the point of entry of a packet in the transmit queue to the actual point of transmission of the packet. Average end –to –end delay has been use as a primary performance metric in analysing path delay in [16].

The analysis involved investigating the variation of average end –to –end delay for single and multiple servers under different arrival rate of traffic and load values. The performance parameters included arrival rate of traffic, service rare of traffic, the load in the system, and traffic size.

Derivation of average end –to –end delay for M/M/m queue system

In M/M/m queue model, the first M represents poison arrival with exponentially distributed inter arrival times. Poisson distribution best models random arrivals [3]. The second *M* represents exponential service time and the last m represents the number of servers. In this case we shall assume that the servers are identical. The decision by each packet to be served by any server is assumed to be independent of each other.

Figure III.1 shows the *M/M/m* queuing system with equal service rate, the corresponding state diagram is shown in Figure III.2

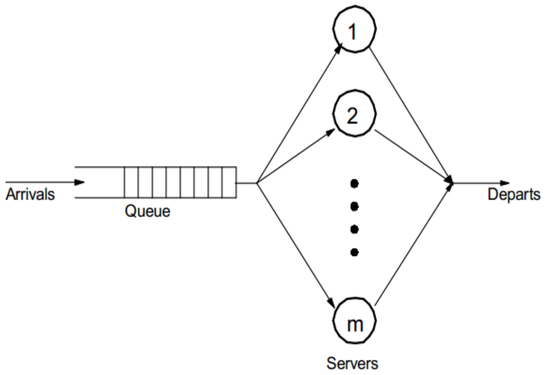

Figure III.1. M/M/m queueing system with equal service rate. Aopted from [3]

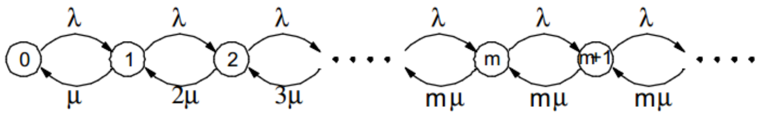

Figure III. 2. state transition diagram. Adopte from [3]

For an M/M/m queue system, there are $m \geq 2$ servers and the waiting room is infinite. When a new customer arrives, then the incoming customer may enter any of the free servers. Let λ and μ be the rate of arrivals and service times, respectively. The number of customers in the system can be modelled as a birth death process. The birth rate is $\lambda_i = \lambda$ where $i \geq 0$. The death rate is given by:

$$\mu_i = \begin{cases} i\mu & i = 0, 1, \ldots\ldots, m-1 \\ m\mu & i \geq m \end{cases} \quad (3.1)$$

Using the balance equation of birth and death process, where the capacity:

$$m = 1 + \frac{\lambda 0}{\mu 0} + \frac{\lambda 0\ \lambda 1}{\mu 0\ \mu 1} + \ldots\ldots\ldots\ldots + \frac{\lambda 0\ \lambda 1 \ldots\ldots\ldots \lambda n-1}{\mu 0\ \mu 1 \ldots\ldots\ldots \mu n} + \cdots \quad (3.2)$$

if $m < \infty$ then for $n = 1,2,3,\ldots\ldots\ldots$ $P_n = \frac{\lambda 0\ \lambda 1 \ldots\ldots\ldots \lambda n-1}{\mu 0\ \mu 1 \ldots\ldots\ldots \mu n} P_0$ (3.3)

Where $P_0 = \frac{1}{m}$ and $\sum_{n=0}^{\infty} Pn = 1$

The stationary queue length in an M/M/ queue is given by:

$$\pi(i) = \begin{cases} \pi(0)\frac{\rho^i}{i!} & i = 0,1, \ldots, m \\ \pi(0)\frac{\pi^i m^{m-1}}{m!} & i \geq m \end{cases} \quad (3.4)$$

Where,

$$\pi(0) = \left[\sum_{i=0}^{m-1} \frac{\rho^i}{i!} + \left(\frac{\rho^m}{m!}\right)\left(\frac{1}{1-\frac{\rho}{m}}\right)\right]$$

The probability than an arriving request has to wait in the queue is given by:

$$P_Q = \sum_{i=m}^{\infty} p_i$$
$$= \sum_{i=m}^{\infty} p_0 \frac{m_m p_i}{m!}$$
$$= \frac{P_0.(m\rho)^m}{m!(1-\rho)} \sum_{i=m}^{\infty} \rho^{i-m}$$
$$= \frac{P_0.(m\rho)^m}{m!(1-\rho)} \quad (3.5)$$

Similarly, the number of waiting requests in the queue is given by:

$$N_Q = \sum_{i=m}^{\infty} (i-m)p_i$$
$$= \sum_{i=m}^{\infty} i.p_{i+m}$$
$$= \sum_{i=0}^{\infty} i.p_0 \frac{m^m \rho^{i+m}}{m!}$$
$$= P_0.(m\rho)^m \sum_{i=0}^{\infty} i.p_i$$

$$=P_0 . (m\rho)^m \sum_i^{\infty} \frac{\rho}{(1-\rho)^2}$$

$$N_Q = P_Q . \left(\frac{\rho}{1-\rho}\right) \quad (3.6)$$

The average waiting time in the queue, W is given by:

$$W = \frac{N_Q}{\lambda} = \frac{\rho . P_Q}{\lambda(1-\rho)} \quad (3.7)$$

Using little's law, the average time a request spends in the system is given by:

$$T = \frac{1}{\mu} + W$$

$$T = \frac{1}{\mu} + \frac{P_Q}{\lambda(m\mu-\lambda)} \quad (3.8)$$

Therefore, the end –to –end delay caused by an M/M/m queuing model for N nodes can be deduced from equation 3.8 as:

$$E(T) = \sum_{I=1}^{N} \left(\frac{1}{\mu_i} + \frac{P_Q}{m\mu_i - \lambda_i}\right) \quad (3.9)$$

Where $P_Q = \frac{P_0 . (m\rho)^m}{m!(1-\rho)}$

And $P_0 = \left[\sum_{k=0}^{m-1} \frac{(m\rho)^k}{k!} + \frac{(m\rho)^k}{m!} . \frac{1}{(1-\rho)}\right]^{-1}$

The load, ρ is given as λ/μ, where λ is the average arrival rate of traffic into the system, while μ is the average service rate of traffic into the system. The quantity ρ is also referred to as the traffic intensity since it gives the mean quality of work brought to the system per unit time.

IV. SIMULATION AND ANALYSIS OF RESULTS

Overview

In this chapter we test the performance of the derived models for multiple servers. In particular, we analyze the variation of end-to-end delay with load for the *M/M/m* and *M/M/1* queue models to assess the effect of increasing the load on the end-to-end delay. We also analyze the variation of end-to-end delay with average arrival rate of requests in the system to assess the effect of increasing arrival rates on the end-to-end delay. We further analyze the variation of end-to-end delay with number of servers to investigate the effect of increasing the number of servers on the average end-to-end delay. In addition, we also investigate the effect of increasing number of nodes on the average end-to-end delay.

Model parameters

In order to analyze the proposed system, we use the following notations to denote the parameters of interest.

Table: IV.1 Shows the parameters used in this study

Parameter	Description
M	Number of paths
N	Total number of nodes in the queuing network.
N	Total number of nodes in the paths.
M	Total number of paths in the queueing network.
λ_i	Average task arrival rate of node i.
μ_i	Service rate of node i.
ρ_i	Utilization of Node i.
Γ	Pure packet arrival rate, which enter the queueing network.
K	Node state.
E(*T*)	End-to-end delay with N-level nodes.
E_M (*T*)	Average network delay with M paths.

Model parameters

Next, we show results for end-to-end delay for the single and multiple server scenarios. In particular, we investigate the effect of increasing load and arrival rate of requests into the system.

Table IV.2 shows the parameter values used to generate the graphs.

Parameter	Value
Arrival rate, λ_i	15 packets/second
Service rate, μ_i	20 packets/second
Total number of nodes	20
Utilization ρ_i	0-1

Variation of end-to-end delay with load

In assessing the variation of end-to-end delay with load, we used equations 2.4 and 3.9 to plot a graph of end-to-end delay against load as illustrated in figure 4.1.

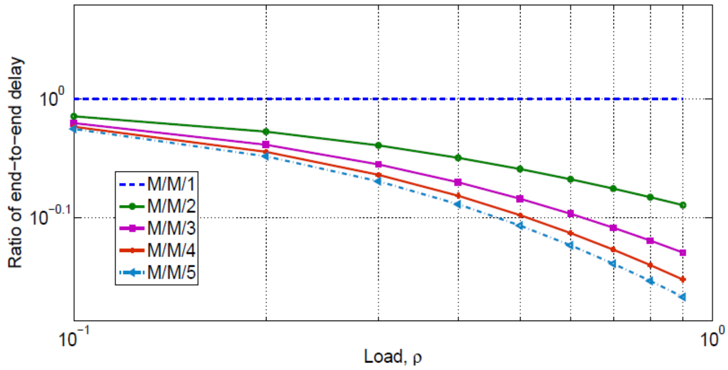

Figure: IV.1. Ratio of end-to-end delay against load

Variation of end-to-end delay with arrival rate

In this section, we investigate the effect of increasing arrival rate at low load ρ = 0.5 and high load ρ = 0.9.

End-to-end delay with arrival rate at low load

In assessing the variation of end-to-end delay with arrival rate, we used equations 2.4 and 3.9 to plot a graph of ratio of end-to-end delay against arrival rate as illustrated in figure 4.2. In particular, we investigate the variation of end-to-end delay with arrival rate at low load, ρ = 0.5.

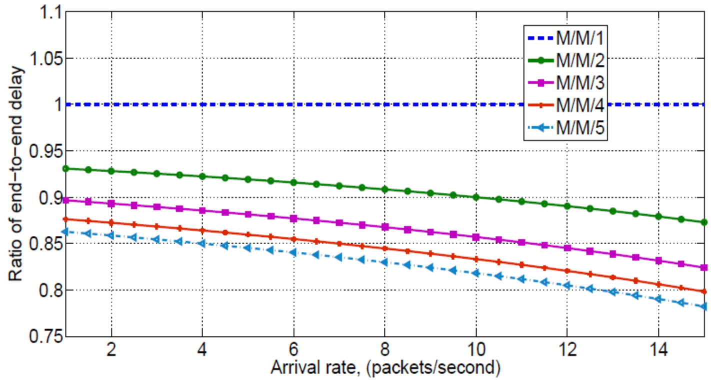

Figure:IV.2. Ratio of end-to-end delay against arrival rate.

End-to-end delay with arrival rate at high load

In assessing the variation of end-to-end delay with arrival rate, we used equations 2.4 and 3.9 to plot a graph of ratio of end-to-end delay against arrival rate as illustrated in figure 4.8. In particular, we investigate the variation of end-to-end delay with arrival rate at high load, ρ = 0.9.

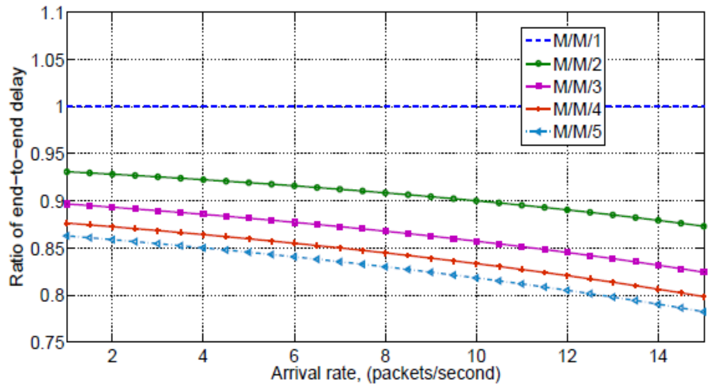

Figure: IV.3.Ratio of end-to-end delay against arrival rate

Variation of end-to-end delay with number of servers

We investigate the effect of increasing the number of servers on the end-to-end delay at low load, ρ = 0.5 and high load, ρ = 0.9.

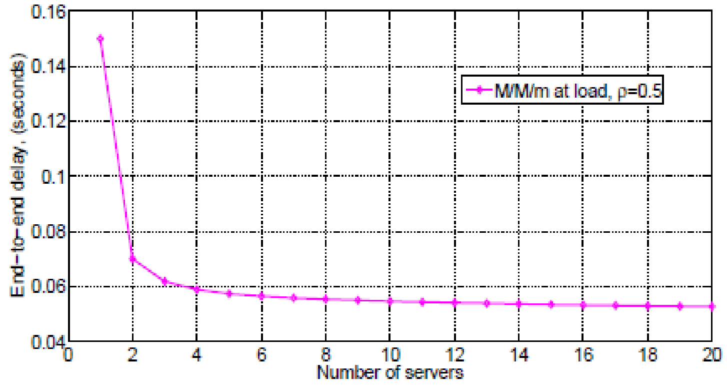

Figure: IV.4. End –to –end delay against number of servers

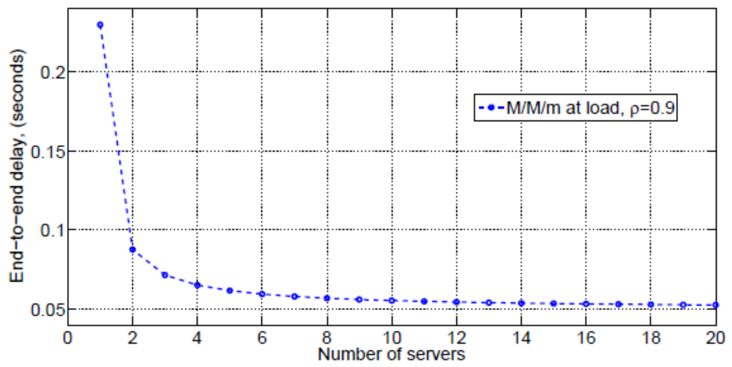

Figure: IV.5. End-to-end delay against number of servers

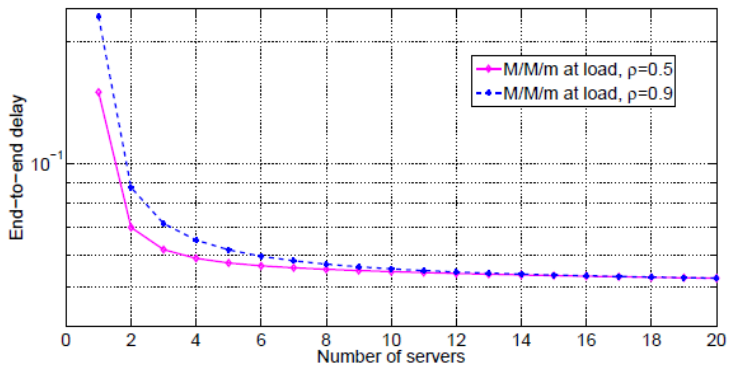

Figure: IV.6. End-to-end delay against number of servers

Variation of end-to-end delay with rate of service

We investigate the effect of increasing the rate of service on the end-to-end delay at low load, $\rho = 0.5$ and high load, $\rho = 0.9$.

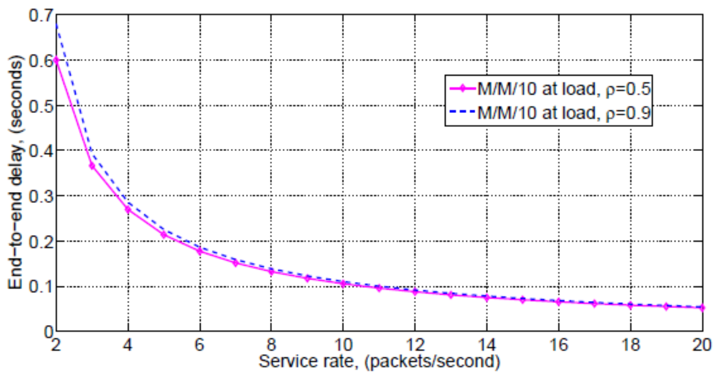

Figure: IV.7. End-to-end delay against rate of service

Variation of end-to-end delay with number of paths

We investigate the effect of increasing the number of paths on the end-to-end delay.

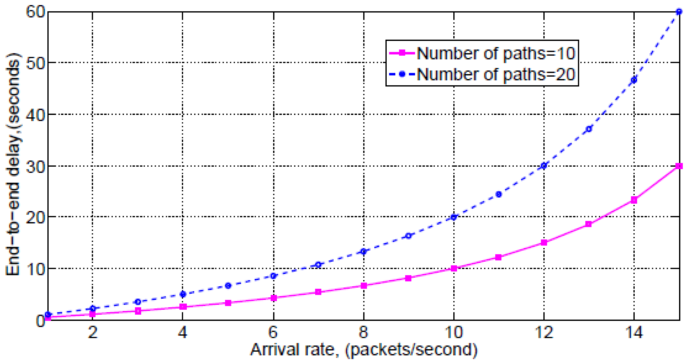

Figure: IV.8. End-to-end delay against number of paths

V. DISCUSSION OF RESULTS

We have gone under several tests and simulations and we came up with several results as shown in different figure s i.e from figure IV.1 to figure IV.8

According to results of figure IV.1, we simulated the variation of end –to –end with respect to load ρ and we have considered several sever, after considering M/M/1 to M/M/5, it is seen that however much the load increases, there is always a decrease in an end –to –end delay as the number of servers in queue are increased.

Therefore, irrespective of an increase of the load an increase of the number of servers in the queuing model leads to a decrease in delay of the nodes.

In figure IV.2 and figure IV.3 we have considered a variation of end-to-end delay arrival rate with respect to both the low load ρ = 0.5 (figure IV.2) and high load ρ = 0.9 (figure IV.3) the results shows that, as the number of servers increase I the end-to-end queuing model, the ratio of end –to –end delay decrease hence leading to an increase in the service rate.

We have also simulated an end –to –end delay model which have proposed as the preferable model of M/M/m, and under this simulation we have considered both the low load of ρ = 0.5 as indicated in the figure IV.4 and the high load of ρ = 0.9 as indicated in figure IV.5 both results are compared at the same graph named figure IV.6 which shows that the end -to -end delay is on its lowest level when we use a multi-server queuing model.

We have also considered a variation of end –to –end delay with respect to the number of paths and according to figure IV.8, the results indicates that as the number paths increases the arrival of packets also increases.

VI. CONCLUSION AND RECOMMENDATIONS

Conclusion

In this research we have considered a WSN queuing model of path delay analysis where the recent research was done was M/M/1 which was based on a single and we have based on the recent this research and we extended this model to a multi-server model as M/M/m of which we named as path delay analysis of multi-server wireless networks and our study shows that the proposed M/M/m model as shown in different simulation results in chapter 4, has perfectly minimized the rate of delay in WSNs while increasing the arrival rate of the nodes at the respected (targeted nodes) destinations in the real time hence increasing the performance rate of wireless sensor networks (WSNs).

Recommendations

As we have seen that multi-server queuing model is a suitable model for path delay problem, we would like to recommend the feature researchers to consider a virtual server mechanism in the implementation of M/M/m so as to reduce the level of power consumption of multi-servers in this M/M/m queuing model.

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