Performance Analysis of Patient Monitoring Wireless Body Area Networks using Queueing Models

Kusum Grewal Dangi*
Research Scholar, The NorthCap University,
(Formerly ITM University)
Gurgaon, Haryana, India.

Supriya P Panda
Associate Professor The NorthCap University
(Formerly ITM University)
Gurgaon, Haryana, India.

Abstract
The objective of this paper is to analyse the server utilization and delay tolerance of a patient monitoring wireless body area network (WBAN) in hospital premises. The WBAN considered in this paper uses three tier heterogeneous networking method for communication and the vital data packets are prioritized as normal and emergency packets. In network, first tier consists of ZigBee nodes, second tier has Wi-Fi router acting as server for the packets queues generated by ZigBee radio module. In tier three hospital information system is connected using Ethernet. M/G/1 and M/G/N priority queueing models are implemented at tier two. The performance parameters considered for analysis are priority queueing, delay and server utilization time. By implementing the M/G/1 and M/G/N priority queueing models, it is found that when the number of emergency patients is more, using more number of Wi-Fi routers improves the delay parameters but reduces the server utilization. This factor is further optimized to improve the server utilization. A delay tolerant WBAN is proposed which uses priority queueing with bulk data arrival conditions.

Keywords: Wireless body area network (WBAN); hospital-centered WBAN; queueing model; delay; M/G/1; M/G/N; heterogeneous communication methods; delay tolerant; ZigBee; Wi-Fi.

Introduction
World Health Organization (WHO) report (2015) reveals an increase in deaths due to chronic disease by 18% 1. The same report reveals that 35% deaths have been caused by high blood pressure and high blood glucose level. Most of the mishaps occur when the patient doesn’t get timely assistance. Most of patient monitoring systems in hospitals consists of physiological monitoring devices (PMD) that are attached to the patient’s body and needs human intervention to interpret the data and raise the alarm if emergency condition arrises. When an emergency arrives (like sudden fluctuation in vital parameters e.g. heart rate, body temperature), the patient himself or the accompanying guardian is responsible for raising the alarm. Such situations can become fatal, if not handled timely. So, to entertain all the patients well in time in staff scarcity, the emergency vital data of the patient must reach the help desk well in time for timely assistance.

Thanks to the advancements in electronics and communication engineering which developed the microelectromechanical sensors and their interface with data networks. This has enabled us to sense surroundings and send the sensed data to the required destination with quite less cost and power consumption. This multifaceted technology is known as wireless sensor network (WSN). WSN has various applications in environmental monitoring, health monitoring, entertainment etc. WSN’s application for health monitoring is known as wireless body area network (WBAN) 2. Use of WBANs can make the PMDs wireless and hence less cumbersome. WBAN has enabled our medical system to reach different paradigm of health monitoring and in detection of life threatening events at quite an early stage 3.

This paper presents the application of queueing theory on emergency care of patients in hospital-centered wireless body area network (WBAN). There is a small literature available on the WSNs using queueing theory. A deployment optimization model for non-beacon mode for IEEE 802.15.4 sensor networks is proposed using M/M/1 queueing model in 4. In authors showed by both analysis and simulation that the input process for the WSN sinks can be modeled as Poisson’s process. They compared M/G/1 and M/G/c model for WSN on multimedia application that does not implement priority. In this work, the effect of M/G/1 and M/G/N queueing models is analyzed and compared for vital data delivery management system to resolve the issue of delay in care taking of patients with normal and emergency vital conditions. M/G/1 and M/G/N models proved to be efficient in incorporating the arrival and service time distribution of the considered hospital system.

Architecture of WBAN
WBAN consists of wireless sensors which are attached to the human body and are responsible for sensing, processing and communicating the physiological signal to the medical server for further analysis. Sensors communicate to the medical server with the help of various networking strategies depending on their distance from Hospital Information System (HIS). Wireless sensors used for monitoring of physiological changes in human body can be invasive (few examples are endoscopy
capsules, heart arrhythmia monitor and brain fluid monitoring sensors) or non invasive (few examples are monitoring of heart rate, SpO2, temperature and electroencephalograph). Various networking strategies used are personal area network (PAN), local area network (LAN) and Wide Area Network (WAN) techniques. A comprehensive survey of WBAN on physical MAC and network layers is presented in 6. The standard architecture of WBAN follows three-tier network for communication. The first tier consists of sensors attached to body either invasively or non-invasively. There can be one or more sensors on/in the body. Two or more sensors attached to one patient make a cluster and the data from cluster is assimilated at a cluster head. Data from cluster head is sent to the PAN coordinator. Bluetooth, ZigBee, MICS etc. are used at first tier communication network. Second tier consists of LAN. The PAN coordinator sends the information packets to the LAN router, for example, Wi-Fi access point. The third tier uses WAN and LAN technologies, for instance, Ethernet or Personal digital assistant (PDA) with internet facility 7,8,9. This architecture is shown in Figure 1.

The WBANs are classified as Patient centered WBAN (Figure 2) and Hospital centered WBAN (Figure 3) according to their use. Patient-centered WBAN systems are generally used for remote health monitoring. They are characterized by a three-tier architecture composed of sensors on the body or implanted in the body of the patient for monitoring of vital parameters, a Hospital Information System (HIS) for storage and management of health data, generally located in the medical facility, and a mobile device that generally acts as a personal gateway between the previous two entities. IBM introduced this model in 10. Hospital-centered WBAN systems are designed to support medical professionals in their activities. The system contributes to improve efficiency and productivity of care professionals through increasing data access, and to provide additional instruments that can help reduce the number of medical errors 11. A few WBAN design techniques for medical applications are presented in 12, where the authors examined the WBAN design issues with particular emphasis on the queueing models using MATLAB and OPNET simulations.

**Proposed Scenario**

The proposed scenario is a patient-centered WBAN used inside the hospital premises is shown in Figure 4. Patients are given a ZigBee module in full functional device (FFD) mode. PAN coordinator is placed in the vicinity; it is a dedicated ZigBee node which will always be present in the room and also in corridor to facilitate seamless communication even when the patient is moving in the hospital. This PAN coordinator will transfer the data to the Wi-Fi router with the help of a bridging device. Wi-Fi router (access point) further sends the data to the hospital information system with the help of Ethernet.
Figure 4: Proposed Scenario

Modeling of WBAN using queuing theory:
In the considered scenario, the patient’s vital parameters packets are sent to the HIS using heterogeneous network. For the calculations to be simple the PAN coordinator is assumed to be the data generator for the system and the Wi-Fi router is treated as server. It is also assumed that after getting service from the access point, all packets reach the HIS successfully immediately. The arrival rate of the vital parameter packets is assumed to follow the Poisson distribution and the service rate follows General distribution. The vital packets enter in the queue at the Wi-Fi router and sent to HIS after giving service. The scenario is assumed to be single-hop transmission and the buffer capacity is assumed to be too large than required for the packet arrival rate and packet size. Once the packet is received at the HIS, it is saved for further processing. The vital parameter monitoring is done continuously for the patients.

The hospital system is considered to have intensive care unit (ICU) and general ward facility. Every admitted patient is assumed to have a WBAN system for monitoring the vital parameters using ZigBee and Wi-Fi. The monitoring device and Wi-Fi routers are active throughout for 24-hours. Priority queuing is used at the Wi-Fi router for normal and emergency vital data packets. Priority is given to the emergency vital data packets and service discipline is considered as First in First Out (FIFO). The vital data may arrive in bulk.

The objective of this study is to determine the following measures:
1. The average number of vital data packets waiting in the queue at Wi-Fi router.
   \[ E[N_Q] = \sum_{n=1} \left( n-1 \right) \cdot P(N=n) = \rho^2 / (1-\rho) \]
2. The average waiting time of the vital data packets in the queue.
   \[ E[W_Q] = E[T] \cdot 1 / \mu \]
   where \[ E[T] = E[N] / \lambda \] and \[ E[N] = \rho / (1-\rho) \] (Little’s Law)
3. The percentage utilization of the server (Wi-Fi router) in the system.
   \[ P(N=n) = \rho^n (1-\rho) \]

   a. (indicates fraction of time spent with no packet in queue)
   b. Utilization factor = \[ 1 - P(N=0) = \rho \]

4. Number of servers needed to facilitate efficient quality of service.

Abbreviations used in formulas:
- \( \lambda \): Arrival rate of vital data packets
- \( \mu \): Service rate of vital data packets
- \( P \): \( \lambda / \mu; \lambda < \mu \)
- \( N \): Number of vital data packets in system
- \( T \): Packet time in system
- \( N_Q \): Number of vital data packets in queue
- \( W_Q \): Waiting time in queue

System Requirements
In order to analyze the effect of M/G/1 and M/G/N queuing models on the proposed scenario, the simulations are conducted using MATLAB 7.2 on personal computer with 2.2 GHz Core i7 and 8GB of RAM.

Results
The simulated and mathematical analysis results for M/G/1 and M/G/N queuing models are presented in this section. Figure 5 shows the results of simulation study in form of a graph between average number of packets in the system with probability of occurrence at any given time in the system in the M/G/1 queuing model, whereas Figure 6 shows the comparison graph for M/G/N queuing model when the number of servers was increased, N taking values as 2, 3 and 4. With the help of this study we analyzed that for higher bandwidth (BW) Wi-Fi router, probability of having lesser average number of packets in the system increases if we are using more than one number of routers but the system utilization goes very poor. On contrary if lesser BW Wi-Fi routers are used there is significant improvement is system utilization. Figure 7 shows the server utilization graph for the mentioned discussion.

By analyzing the table 1 showing comparative study of M/G/1 and M/G/N models, we infer that when the number of servers are more in M/G/N model, it gives better results for all the quality of service parameters viz a viz expected number of packets in queue (Nq), expected number of packets in system (N), average waiting time in queue (Wq) \( 14,15,16,17 \). But as the number of servers is increasing from 1 to 4, the server utilization at any given point of time is going down; therefore we conclude that when the number of emergency patients is more and we need to make the number of servers more, we can use the servers with lesser bandwidth and lesser radiating power. It will not only reduce the delay but also improves the server utilization and causes less harmful effects on patients due to radio frequency radiations. It will further conserve the power requirements of the system, which is a separate area of research.
Table 1: Result for M/G/1 and M/G/N queueing models for the proposed scenario

<table>
<thead>
<tr>
<th>S. No.</th>
<th>No. of servers</th>
<th>System utilization (%)</th>
<th>Expected No. of packets in queue (N₀)</th>
<th>Expected No. of packets in system (N)</th>
<th>Average Waiting Time in Queue (W₀)</th>
<th>Average Waiting Time in System (W)(includes service)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>100</td>
<td>8.0</td>
<td>10.01</td>
<td>5.236</td>
<td>4.212</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>90</td>
<td>7.673</td>
<td>9.473</td>
<td>3.197</td>
<td>3.947</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>60</td>
<td>0.532</td>
<td>2.332</td>
<td>0.221</td>
<td>0.971</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>45</td>
<td>0.105</td>
<td>1.905</td>
<td>0.043</td>
<td>0.793</td>
</tr>
</tbody>
</table>

Conclusions and Future Scope

WBAN are being deployed all over the world for patient monitoring. Their use can bring various advantages to the health care system. The use of queuing theory used in healthcare system is not new; however no study is present to the best of my knowledge that has considered bulk vital data packet arrival and human resource scarcity in WBANs. In this paper we proposed the solution to the emergency handling in scarcity of human resources in the hospital management system. By deploying queuing with WBAN we can save many lives by timely assistance and at the same time give a sigh of relief to the monitoring staff in panic situations. The proposed delay tolerant WBAN with queuing method can prioritize the emergency vital data information to take timely measures to improve the quality of service and reduce human resource intervention. This analysis can also help in rating disaster management efficiency of a hospital. The future scope of this work is to optimize the server utilization and average waiting time in queue parameter to decrease the overall cost of the system and enhance the quality of service of the system. And also apply this analysis in cardiology and neurology hospitals where a patient usually comes with severe emergency and prone to sudden critical conditions which need timely response.

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References


