International Journal of Digital Information and Wireless Communications (IJDIWC) 4(1): 114-123
The Society of Digital Information and Wireless Communications, 2014 (ISSN: 2225-658X)

Lightweight Priority Scheduling Scheme for Smart Home and Ambient Assisted Living System

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ABSTRACT

Smart Home and Ambient Assisted Living (SHAAL) systems utilize advanced and ubiquitous technologies including sensors and other devices that are integrated in the residential infrastructure or wearable, to capture data describing activities of daily living and health related events. However, with the introduction of these technology-orientated services come a number of challenges, which to date are still largely unsolved. The management and processing of the large quantities of data generated from multiple sensors is recognized as one of the most significant challenges. Therefore, a simple yet efficient data scheduling scheme is proposed in this paper to manage incoming data packet from the system based on their application types and priorities. The performances of this lightweight context-aware scheme are investigated in a real SHAAL setting under two scenarios; centralized and distributed set-ups. The experimental results show the proposed scheme offers a promising solution for guaranteeing higher throughput to the high priority data while giving sufficient access to low priority data without introducing much delay impact.

KEYWORDS

Smart Home; Ambient Assisted Living; Wireless Sensor Network; Priority Scheduling

1 INTRODUCTION

The emerging demographic change towards an ageing population introduces dramatic need to improve the health and quality of life of the elderly and provide assisted living, aided by technology while maintaining a high degree of autonomy and dignity. Pilot studies have shown that facilitating elderly people with their essential demands for independent life and sovereignty, added together with self-care and self-management technologies can enhance their health outcomes. Information and Communication Technologies (ICTs) can play a major role in order to help achieve the above goals.

A smart home is not only a modern home of the future, but rather an integration of various devices at home to a network that controls all of the functions at once. The Malaysian agency known as IDC Energy Insights and Real Estate and Housing Developers Association Malaysia (REHDA) has reported that by 2015, the worldwide market share for smart home would reach a staggering 10.2 billion USD while in Malaysia, a steady 2.22% growth rate in real estate sector is a promising figure for SHAAL to take off [13]. From their survey, in average, over 40% candidates have a positive acceptance to the Smart Home idea.

A Smart Home and Ambient Assisted Living (SHAAL) system is a residential setting equipped with a set of advanced electronics, sensors and automated devices specifically designed for care delivery, remote monitoring, early detection of problems or emergency cases and promotion of residential safety and automated living [1], [2], [3], [4], [5], [6]. It typically makes use of Wireless Sensor Network (WSN) technology in order to monitor physical or environmental conditions [2]. The parameters include temperature, humidity, sound, vibration, pressure, motion, pollutants, images and even biometrics parameters such as ECG, blood pressure, SpO2 and etc. These sensed data would be locally processed before being transmitted to a remote location for further analysis and interpreted before any decision making takes place. In general, SHAAL system can provide care for out-patient, elderly, disabled people or individuals needing assistance with activities of daily living and wishing for independent living as well as secure, comfortable and convenient living environment [3], [4].

Surveys on home automated health-care system projects and frameworks [7], [8], [9] illustrate that the sensor commutations for identifying the environmental data has attained a considerable maturity, but still there exists a gap related to data resources management. Moreover, the priority for each data differs, i.e., the health and security data are considered more significant than others. Thus, the data management is crucial when different packets of data reach the base node at the same time [10]. A robust and reliable framework is needed for effective data scheduling based on the set priority of different applications. Authors in [12] have demonstrated the scheduling of sensor data to provide an insight into the use of sensor based system and improving the level of automated support within a system context. However, the management of data is based on module synchronization. In this paper, we propose a lightweight priority scheduling scheme to manage the sensor data based on application types and their respective priorities. The performances of this proposed context-aware scheme are analyzed in a real SHAAL setting. The findings show the delay-throughput tradeoff using this scheme is within acceptable limit in addition to its feasibility for practical deployment.

The rest of the paper is organized as follows. Section 2 describes the general system model for SHAAL. The concept of priority scheduling is introduced in Section 3 while Section 4 presents the performances of the proposed lightweight data scheduling scheme in SHAAL system in terms of throughput, delay and system architecture. The conclusion of this paper is outlined in Section 5.

2 SMART HOME AND AMBIENT ASSISTED LIVING (SHAAL) SYSTEM

The proposed SHAAL system is based on Machine-to-Machine (M2M) communication and also cloud computing in a cloud network. M2M communication is proposed to enable electronic devices (smart sensors) to communicate and share the data via wireless networks. Within the deployed WSN as shown in Figure 1 and home area network (HAN), M2M communication for heterogeneous devices normally adopts IEEE 802.15.4 and IEEE 802.11 radio technologies while Wide Area Network (WAN) implements cellular based (GSM, 3G) or internet based cloud communication technology [5]. Base controller/station serves as data center where the sensed or collected data can be visualized and analyzed. The base station also acts as a gateway to allow remote access to the system. This would allow web-enabled devices to access the system through Internet while GSM network allows access using cellphone. The information can be relayed to home owners and authorized personnel through current gadgets such smart phone, laptop, tablet and others.

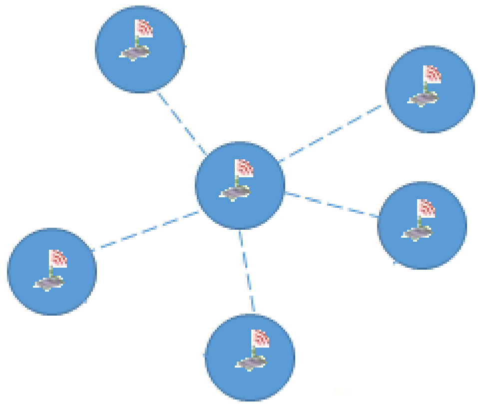


Figure 1 WSN deployment using star topology

While the Smart Home system described in [6] deals with energy management system, the SHAAL platform at the UTM-MIMOS Center of Excellence in Telecommunication Technology, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, concentrates on smart home applications such as automated control of electronic appliances and security solution which include door access system and web-based log-in record. Figure 2 shows a few of the devices used in our smart home module.

Component	Specification
Light	Bulk Lamp
Appliances	Socket 3 Pin
RFID Door	RFID reader, magnetic lock
Alarm	Buzzer
Camera	C328R CMOS Camera
WSN Mote	TelG(Atmega644PV, WiseOS)

Figure 2 Smart Home devices and respective specifications

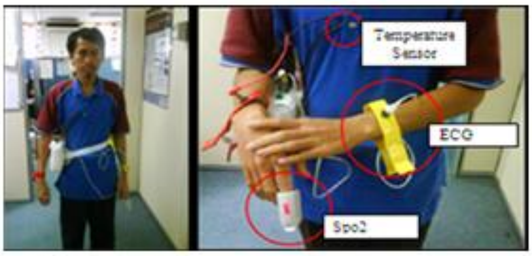


Figure 3 Ambient Assisted Living contraptions

In addition, the AAL framework is integrated into the existing platform by utilizing wearable body sensors as illustrated in Figure 3. The communication within this wireless sensor based SHAAL system is facilitated by self-designed WSN motes called TelG motes; each embedded with self-developed WiseOS as the operating system. The 5.5 cm x 3.5 cm mote, as presented in Figure 4, uses IEEE802.15.4 technology and operates in the ISM band of 2.4 GHz. It is composed of low power components in term of processing, communication and sensing. It is also designed to have small footprint for easy deployment, cheap maintenance and ubiquitous functionality.

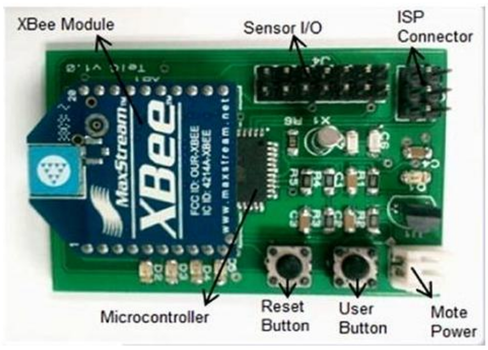
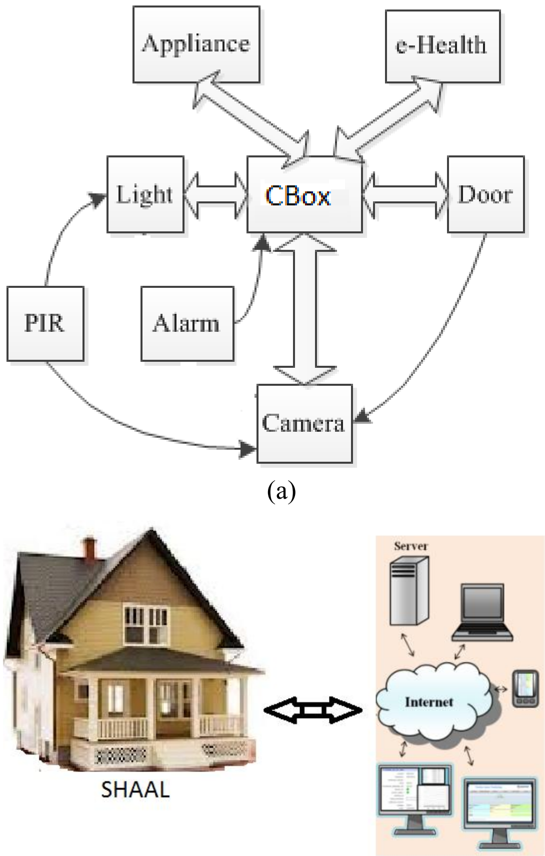


Figure 4 WSN based TelG mote

The sensor motes automate the process of collecting data which will be transmitted to the home main controller (i.e., the CBox) and consequently processed and stored in a server. Vital physiological data such as blood pressure, electrocardiogram (ECG) and temperature, collected from respective sensors worn by the person with related health problems, will be delivered to the remote authorized medical personnel or center via internet gateway for monitoring of health status and storage, respectively. TelG mote and WiseOS operating system is designed to be "ready out-of-box" for rapid application development. This MCU + RFIC design enables wide arrays of sensors to be fitted and a whole range of applications can be deployed. Although this generic design of packet oriented communication between radio and processor has several shortcomings such as limited low-level access of the radio parameters as pointed in [17], for SHAAL system, this generic mote provides adequate functionalities to support the application requirements. Figures 5(a) and 5(b) summarize the overall system functionalities.



(a)

(b)

Figure 5 (a) SHAAL functional state diagram (b) SHAAL System

This paper focuses on the complexities of managing different sources of sensor-based information with the overall goal of improving the levels of automated support. The scheduling for resource allocation will be based on the required Quality of Service (QoS) for each application. In this work, high priority will be assigned to AAL application, followed by Smart Home services such as security, control and monitoring of electrical/electronic devices.

3 PRIORITY SCHEDULING SCHEME

Priority scheduling is an abstract data type, normally in the form of queue or stack data structure, in which each element has an additional "priority" associated with it. Priority scheduling is used to determine which processes need to be implemented first. Processing is conducted in accordance with the priority given; high priority is served before lower priority element. If two elements have the same priority, they are served according to their order in the queue. It is widely used in CPU processor and the running of devices in our SHAAL system employs similar mechanism, where priority scheduling is required to optimize the performances. Data processing nodes that act as sinks can implement scheduling algorithm to guarantee applications' QoS requirements. For example, the scheduling algorithm can be implemented in middle tier network in K-HAS as proposed in [15]. The implementation of the scheduling algorithm can also be extended into routing protocol mechanism. In the case of flat network architecture, an efficient scheduling algorithm in routing protocol is required when the data collected has different priority. In the literature, most of the routing protocol only concern with energy efficiency and scalability such as chain forming technique using Ant Colony Optimization (ACO) in [16] for data gathering. With recent developments in Cognitive Wireless Sensor Network (CWSN), context aware routing protocol has become a standard requirement and priority scheduling can be used to achieve this objective.

There are two types of priority packet scheduling, non-preemptive and preemptive [11], [12].

A non-preemptive packet scheduling scheme is based on the deadline of arrival of data packets to the base station (BS). The packet is classified as First Come First Serve (FCFS), of which the scheduler processes data in the order of their arrival times at the queue, i.e. a round-robin. In contrast, preemptive scheduling may interrupt a running task for some time and the task will be resumed once the priority task completes its execution. The preemptive may apply FCFS if two or more packets arrive with same priority. It means that in priority based scheduling, if there are two packets with the same priority in the queue, the first packet in queue will be processed followed by the next packet in queue.

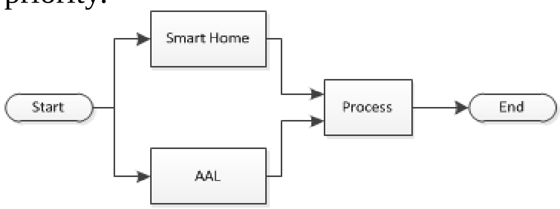
4 PROPOSED LIGHTWEIGHT SCHEDULING SCHEME FOR SHAAL

In this section, the proposed priority packet scheduling scheme to manage data packets in our SHAAL system will be further explained. A case study is presented for the proof of concept of the proposed scheme.

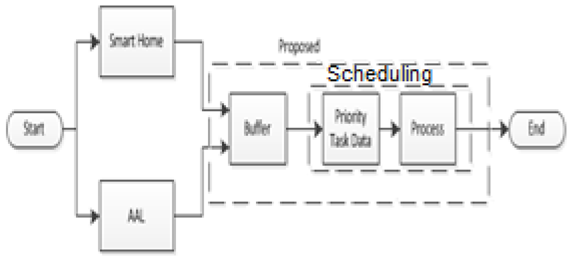
4.1 General Working Principle of SHAAL

By default, the data packet will be processed by first-come first-serve (FCFS) in the CBox using the conventional method as in Figure 6(a). This will affect the delay of high priority packet if the total amount of data packets in queue is too many. Within a SHAAL system, the data packet of AAL is given high priority, because it contains the health information. Hence, it is important to ensure its processing takes place with minimum delay. If the system grows too large where more new functionalities are introduced, its performance might be overwhelmed with the enormous amount of data to be processed.

The model of the proposed solution is shown in Figure 6(b). In the design, a buffer handles the incoming packet and outgoing packet before the packet is forwarded. The next task is more important as it will schedule the data packet by its priority.



(a)



(b)

Figure 6 Data Scheduler Model (a) conventional model and (b) proposed model

Figure 7 illustrates the proposed priority based scheduling mechanism. In this scheduling scheme, specific applications such as e-health and security are given higher priority than other applications such as lighting and temperature controls. The former is denoted in term of 'E' and the latter by 'T'. The execution for high priority applications is enabled by hardware or software interrupt. For instance, low priority application/task T1 in Figure 5 is being executed by the scheduler but preempted at t1 by high priority application E1. E1 would run till completion before resuming task T1 at t2. As illustrated, T1, T2 and T3 are being executed in an order by sequence and can only be preempted by an event of high priority application.

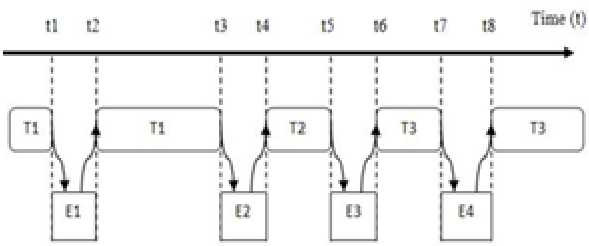


Figure 7 Priority Application/Task Data Flow

For example, an alert or alarm data which is considered high in priority and therefore will be processed immediately and subsequently relayed to the authorized personnel. This guarantees the reliability of high priority data.

From the proposed algorithm, it is clear that the scheduling algorithm can also be used in other applications with data that have different priorities. For instance, WSN has two well-known protocols that are being used in sports application which are ANT/ANT+ protocol and Bluetooth Low Energy (BLE) protocol. In [18], the authors concluded that ANT/ANT+ can only be used for application with low traffic characteristics with no QoS enforcement despite having no interference from the neighboring nodes. This is due to the nature of ANT protocol Time Division Multiple Access (TDMA) scheme which allows only one node to transmit at one time. By implementing priority scheduling to the system, it is possible to alleviate this problem where nodes with low priority have less timeslots allocated and nodes with higher priority have more timeslots allocated for them.

4.2 Architecture Model

SHAAL system implements WSN for data transmission. Data control in WSN depends on two types of architecture; centralized and distributed. The centralized architecture only allows communication between sensor modules via the base station (BS) as illustrated in Figure 1. This type of architecture is common in wireless networks such as WiFi and ad-hoc network. The advantages of this architecture include easy maintenance and debugging as well as monitoring since the entire event inside the system is logged to the main controller.

In the distributed architecture, the communications between nodes are not restricted to be carried out through the BS. It is possible for each node to communicate directly and independently to another node in its cluster as shown in Figure 8. Among its benefits are scalability and ease of expansion. The expanded system can be realized not just by adding more sensor modules, but also by introducing new BS node in a new network which communicates with another BS node. This concept describes hierarchical network architecture [14] and is presented in Figure 9.

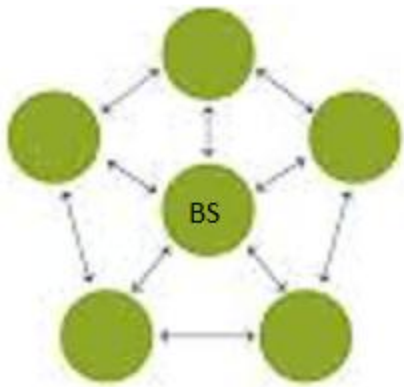


Figure 8 Distributed WSN Architecture

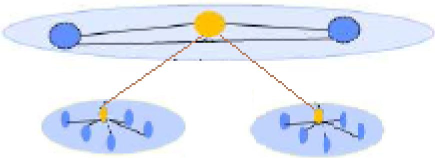


Figure 9 Hierarchical Network Architecture

Both architectures are utilized in our SHAAL system for performance analysis.

4.3 Case Study

The proposed data scheduling scheme is applied in a case study with a set-up as shown in Figure 10. Sensor modules like camera, light, alarm and AAL-related sensors such as temperature, ECG and SPO2 sensors, are placed in specific location and the performances of data transmission are studied in two scenarios; centralized and distributed experimental set-ups.

In both scenarios, CBox is responsible as an events logger as well as a gateway to the outside world i.e. remote terminals. These functionalities provides the mechanism required for SHAAL system to facilitates notification of any event occurred to authorized personnel via remote terminal as well as receiving commands to be executed by SHAAL system.

a) Distributed Approach

In this particular set-up, each sensor node exposes their services directly to each other without the CBox coordination. For smart home (SH) or home automation application, sensor nodes in turn negotiate with each other to form an application that has been programmed and only communicate with CBox for event notifications or receiving a command in a multi-hop manner if required. For AAL on the other hand, the CBox would act as a data processing node where the vital signals would be processed before being transmitted to the remote authorized medical personnel or center via internet gateway. In this scheme, SH nodes also act as a relay node for data transmission i.e., Light status and captured ECG data from a wearable device on a moving person.

b) Centralized Approach

CBox in the centralized scheme would act as data processing node for both SH and AAL. In this scheme, all nodes are coordinated by CBox. In home automation application, each node would register their services to the CBox and request services provided by other nodes through CBox to perform the programmed tasks. CBox in other words are responsible for resource allocation in the SH system. AAL related sensor nodes in this scenario are required to transmit its data directly to the CBox for processing. Note that in centralized scheme, multi-hop communication is not allowed.

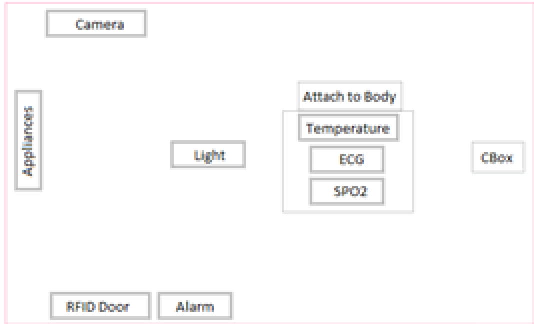


Figure 10 Topology of scenario for SHAAL system

The assigned priority of applications within our SHAAL system for both set-ups is shown in Table 1.

Table 1. SHAAL Priority

Application	Module	Priority
Smart Home	Light	2
	Appliances	2
	Door	2
	Alarm	1
	Camera	2
AAL	ECG	1
	Pulse	1
	SPO2	1
	Temperature	1

Based on the algorithm presented in Figure 11, the task's priority will be given by reading data packet priority and the task will be classified by *p1* or *p2*. This packet will queue in buffer *buff* and the base station/main controller module will read all tasks in the buffer. The task with the priority *p1* will be processed first and follows by the task with priority *p2* if the preemptive scheduler is enabled.

Algorithm: **Priority data scheduling scheme**

while $task_k$ received by $module_i$ **do**
  if $task_k$ priority = $p1$ **then**
    process $task_k$
  else
    if hastask = true **then**
      queue until $task_k$ finish
    else
      process $task_k$
    end if
  end if
end if

Figure 11 Priority Data Scheduling Scheme

The packet throughput (P_t) measures the capability of system to carry the data and defined as the following:

P_t = Total Packet Receive per second (P_r) / Total Packet Send per second (P_s) (1)

The higher the packet throughput, the better the system is. Our SHAAL system consists of two different types of data, of which are generated from Smart Home and AAL systems, respectively. The AAL data is given higher priority than smart home data. In other words, the proposed scheduling aims to produce a higher packet throughput for AAL system.

Figure 12 shows the average packet throughput in the system with no priority scheduling scheme. The measurement is based on the conventional model of Figure 6(a) and taken over one minute time duration. When the *data*1 packet starts execution, the processing task carries on even if a higher priority *data*2 packet than the currently running packet arrives at the ready queue. Thus *data*2 has to wait in the ready queue until the execution of *data*1 is complete after 10 seconds. The processing of *data*2 will start right after.

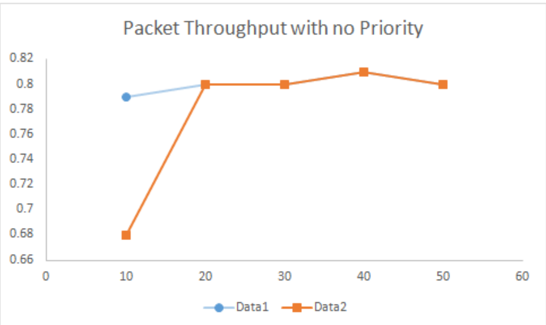


Figure 12 Average Packet Throughputs with no Priority

For SHAAL system with priority scheduling scheme, the ECG data has the chance to be processed first and can pre-empt the light data by saving the context of the light data if they are already running. Figure 13 shows the recorded average packet throughput for the system with priority scheduling under centralized architecture scenario. It can be observed that high average throughput is achieved for the ECG data from the recorded measurement over one minute period. Although the recorded throughput for light data is low, it should be reminded that the measurement taken is the average throughput over one minute time duration of when it is pre-empted by ECG data and only resumes its transmission after ECG data completes its execution. Moreover, the light data usually corresponds to ON/OFF switches.

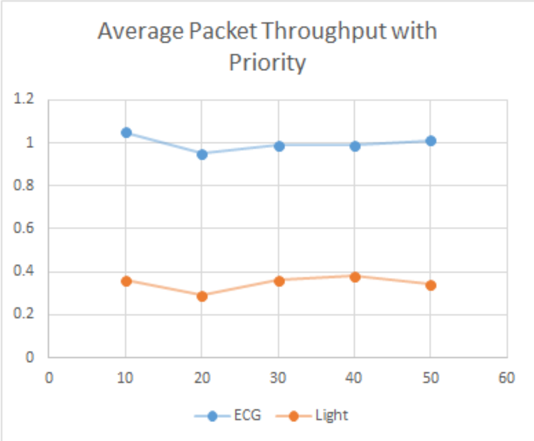


Figure 13 Packet Throughputs with Priority

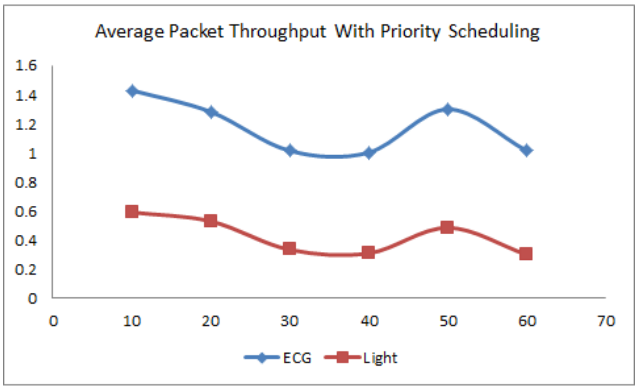


Figure 14 Average Packet Throughputs with Priority in Distributed Mode

Figure 14 shows the average packet throughput using priority based on distributed architecture approach. It can be observed that the achieved throughput is higher compared to the one achieved under centralized approach. The reason is due to a higher amount of packet in the network as the sensor module is set with the capability to operate with 2-hop communication. As a result, the packet with higher priority gets more chances to be processed in the system.

The delay is the waiting time for a task to be executed. The delay will affect the performance and reliability of a system. In a real system, delay is inevitable, but the length of the delay must be in an acceptable range for system application. In our SHAAL system, delay is measured in term of packet delay (P_d). The calculation of the packet delay is shown in (2).

P_d = Packet Time Schedule (P_{ts}) – Packet Time Receive (P_{tr}) (2)

The lower the packet delay is, the better the system performance. The experiments from this point onwards are based on centralized approach.

Figure 15 shows the packet delay performance for SHAAL system with priority scheduling. The ECG data has lower delay than Light data. This is because the ECG data is processed immediately as it has higher priority, where the Light data is being queued until the processor finishes his current task. In our experimental set-up, the recorded maximum delay for ECG and Light data is 4 ms and 6.5 ms, respectively.

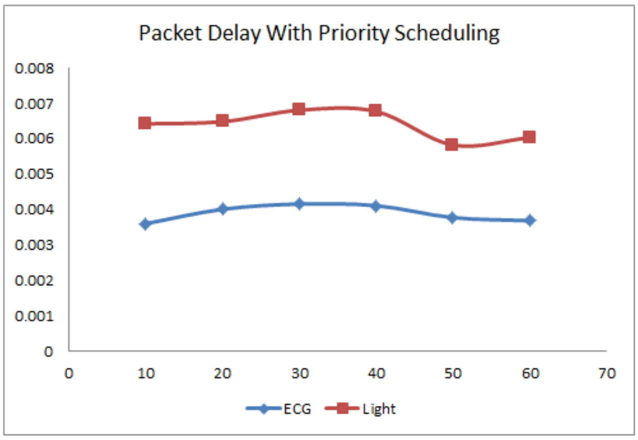


Figure 15 Packet Delay with Priority

Figure 16 shows the packet delay for system with no priority scheduling over a period of 60 seconds. The delays are quite similar for both ECG and Light data. This is due to the equal probability for both ECG and Light data packets to be processed which depends on FCFS method. The trend line for the packet throughput is the same as in Figure 12. The average P_d for both ECG and Light data is 1.7 ms in the experimental set-up.

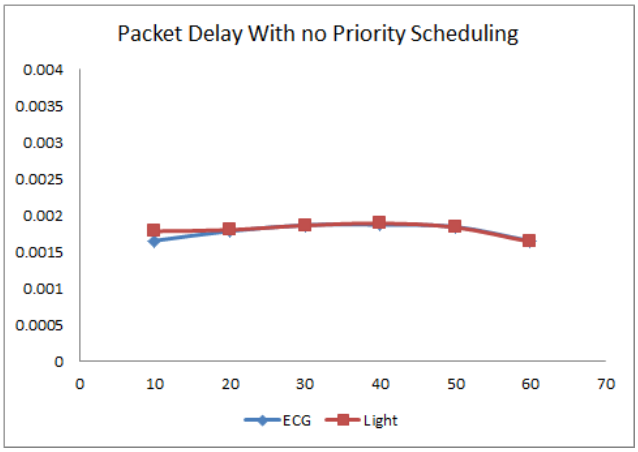


Figure 16 Packet Delay with no Priority

A comparison of P_d performance for high priority ECG data in systems with priority and without priority scheduling is illustrated in Figure 17. Although P_d is 2.2 times higher for system with priority scheduling as compared to the one with FCFS, we consider this value to be practically acceptable for our SHAAL system. With priority scheduling, the reason for the increase in delay time is because the system needs to check and confirm the priority level of the incoming packet. Hence, the time consumed to process the packet is affected. However, this is compensated by an increase in throughput for high priority data. In contrast, under FCFS method, data only needs to be processed without undergoing any priority check as well as no throughput gain.

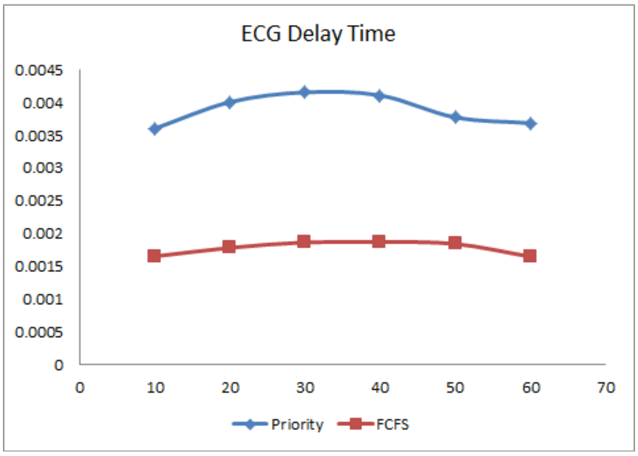


Figure 17 ECG delay with Priority and without Priority

From the performance analysis, we discover that the impact of delay on the throughput achieved for system with priority scheduling needs to be considered. It can be seen that the proposed priority scheduling scheme is feasible for practical implementation as its lightweight nature delivers a higher throughput for high priority data at the expense of incurring a slight increase in system delay. Although the throughput gain is higher in a distributed architecture, we expect the system delay also to be further compromised.

5 CONCLUSION

The creation of a smart environment within the home not only offers an opportunity to embed sensors in order to acquire information about a person within their own home, it also allows us to process the information collected and subsequently interact with the person while aiming to enhance their underlying quality of life. To date, research conducted within the AAL domain has provided a deeper insight into factors associated with the design and development of technology to support independent living. Nevertheless, a number of challenges still remain in all of the three main components within the smart home: sensors, data processing and environmental control. In this paper, the tradeoff between delay and throughput is addressed in a case study utilizing the lightweight priority scheduling scheme. The findings show that the proposed scheme demonstrates promising solution to support decision making to facilitate SHAAL system in a real setting deployment.

6 ACKNOWLEDGEMENT

The authors would like to thank all those who contributed toward making this research successful. The authors wish to express their gratitude to Ministry of Higher Education (MOHE), Malaysia Research Management Centre (RMC) for the sponsorship,and Telematic Research Group (TRG), Universiti Teknologi Malaysia for the financial support and advice of this project.(Vot number Q.J130000.2623.08J96)

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