SENSOR MEDIUM ACCESS CONTROL PROTOCOL-BASED EPILEPSY PATIENTS MONITORING SYSTEM

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ABSTRACT

This thesis focuses on using Wireless Sensor Networks (WSNs) for monitoring applications on epilepsy patients (EPs). With the increase of these types of patients and the necessity of continuous daily monitoring and the need for an immediate response to their seizures, the main objective of this thesis is to decrease the response time in order to save them from severe consequences, as well as to make them comfortable with the monitoring procedure.

Our proposed Epilepsy Patients Monitoring System (EPMS) consists of five ordinary nodes distributed over the patient's body, as well as a coordinator node and a receive node. These nodes detect the seizures and forward the data to the coordinator, which, in turn, collects the data and transmits it to the receiver, triggering an alarm concerning the seizure occurrence.

We focus on the Medium Access Control (MAC) protocol, using the Sensor Medium Access Control (SMAC) protocol to decrease the generated delay, and the Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA) scheme to prevent collisions that can prolong the response time.

ACKNOWLEDGEMENT

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LIST OF ABBREVIATIONS

ANN	Artificial Neural Network
AP	Access Point
BAN	Body Area Network
BO	Beacon Order
CA	Collision Avoidance
CaOA	Collision and Overhearing Avoidance
CS	Carrier Sense
CSMA	Carrier Sense Multiple Access
CTS	Clear To Send
DMAC	energy efficient and low latency MAC protocol
e-2-e	end-to-end
ECG	ElectroCardioGram
EEG	ElectroEncephaloGam
EMG	ElectroMyoGraphy
EPMS	Epilepsy Patients Monitoring System
EPs	Epilepsy Patients
ESs	Epileptic Seizures
FFD	Full-Function Device
KF	Kalman Filter
KNN	K Nearest Neighbour
HWSN	Healthcare Wireless Sensor Network
MAC	Medium Access Control
MD-SMAC	Mobility-aware, Delay-sensitive MAC protocol
MicaZ	Crossbow sensor node
MP	Message Passing
NAV	Network Allocation Vector
NC	Network Coding
NS-2	Network Simulator version 2
OA	Overhearing Avoidance

PLaS	Periodic Listen and Sleep
RFD	Reduced-Function Devices
RMSV	Root Mean Square Value
RTS	Request To Send
SMAC	Sensor Medium Access Control
SN	Sensor Network
SO	Superframe Order
SYNC	Synchronization
TDMA	Time Division Multiple Access
TMAC	Timeout MAC
WHMS	Wearable Health Monitoring Systems
WPAN	Wearable Personal Area Network
WSN	Wireless Sensor Network

CHAPTER 1 INTRODUCTION

The main goal of this thesis is to provide Epilepsy Patients (EPs) with a Wireless Sensor Networks (WSNs)-Based system in order to decrease the epilepsy seizures reaction time. The system is based on the WSNs and the Wireless Personal Area Networks (WPANs). In this chapter, the first section presents the motivation for the research as well as the problem statement. The second section, we discuss the thesis objectives. The thesis contributions are stated in the third section. The last section of this chapter presents the organization of the thesis.

1.1 MOTIVATION

Epilepsy is a group of neurological disorders characterized by Epileptic Seizures (ESs) with a percentage of 1-2% of the world population [TZA12]. 70% of the cases can be controlled by medications or surgery, however 30% do not respond to medications. Therefore, EPs require continuous monitoring using seizure detection methods [AAN13]. Nowadays the epilepsy monitoring is done by using the traditional method which uses the Electroencephalogram (EEG) sensors and consists of many phases. One of its most complicated being the intracranial monitoring: thin wires placed deep in the patient brain to detect seizures, undetectable by electrodes on the surface of the head. This EEG-based method is uncomfortable for the EPs for the following reasons: first, the wires, second, the electrodes in and out of the patient's brain. The use of the WSN-based method facilitates patients' interaction while creating a sense of ease in their lives [AAN13].

It is our belief that by replacing the EEG sensors-based monitoring system with the sensor nodes connected wirelessly as a WSN-based system, which is more patient friendly, efficient and seizure sensitive, a major issue for the patients can be resolved. The system provides continuous monitoring during daily activities and the sensors are user-friendly, flexible and comfortable due to the size and weight of the sensors which are relatively small. In addition, the power consumption is minimal and the system is controlled and more dependable [BOR13].

A WSN consists of a large number of sensor nodes connected wirelessly and spread randomly inside or near the target site. The nodes in the network are small in size and sense environment circumstances, process, communicated data, and their cost-effectiveness and power-saving capabilities render them exceptionally beneficial. Sensor Networks (SNs) employ diverse types of sensors, i.e.: thermal, visual, radar, infrared or magnetic, increasing its ability to monitor a variety of conditions such as humidity, pressure, temperature, and noise levels [AKY02].

MICAz is a type of sensors, sense several conditions: temperature, pressure, acceleration and magnetic. It is useful in different applications: security applications, environmental monitoring applications, WSNs, and large scale wireless networks [WIK13].

Applications in WSNs may be categorized into: a) military applications, b) environmental applications, c) health applications, d) home monitoring, e) space exploration and f) chemical processing [AKY02].

An example of a healthcare monitoring system for a WSN is described in Wearable Health Monitoring Systems (WHMS) [OTT13] Figure 1.1. It consists of sensor nodes distributed over the patient's body, a personal server as a network coordinator which receives data from the sensors and is connected to an external network such as the Internet. The external network transmits the patient information to the desired receiver.

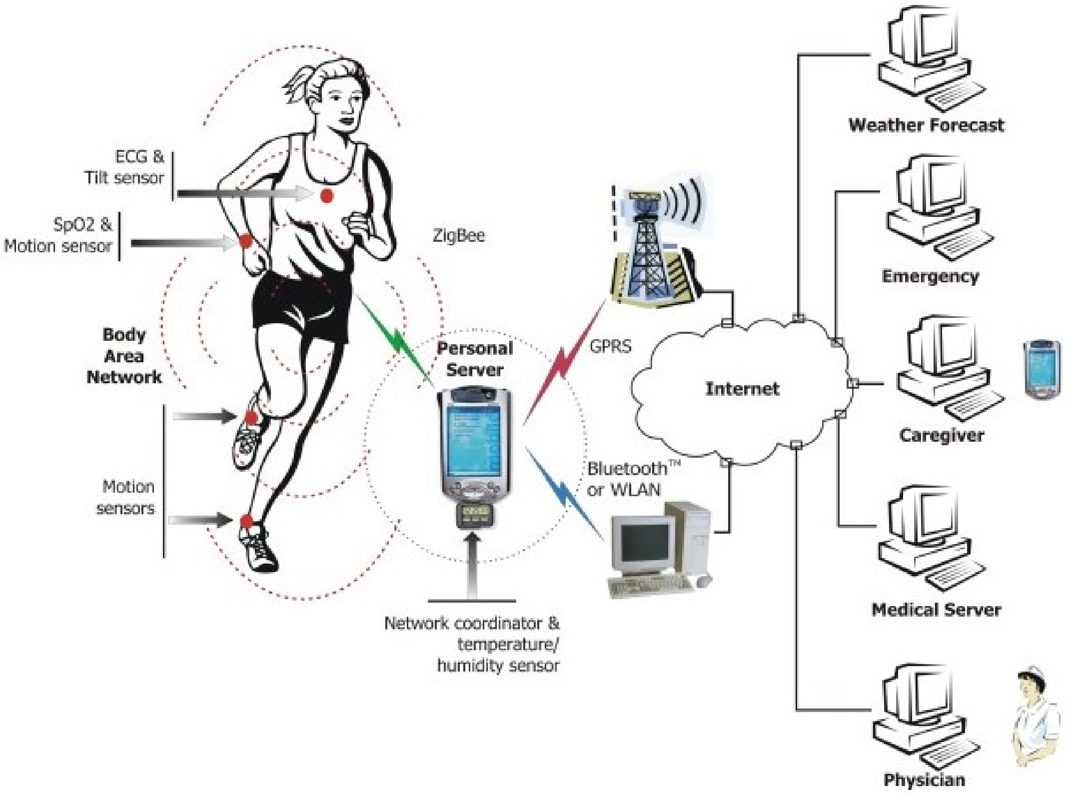

Figure 1.1: Architecture of a wireless sensor network [OTT13].

In this thesis, we tackle the critical issues discussed previously. We provide EPs with a new WSN system based on the SMAC (A new MAC protocol specifically designed for WSNs), replacing the EEG sensors-based monitoring system with the SMAC-based WSN monitoring system. The mobile sensors used in our system are the MICAz; which sense, collect and process health attributes. The SMAC-based WSN system should overcome the EEG system limitations by:

- Decreasing the delay between seizure action and detection.
- Decreasing the delays in response to seizures.
- Using the SMAC protocol, an energy- efficient MAC protocol, which is a beneficial alternative for EPs.
- Using the SMAC protocol with the multipath routing protocol avoids the collision, decreases the delay, and increases the flexibility of the WSNs.
- Using the Carrier Sense Multiple Access/ Collision Avoidance (CSMA/CA) based WPAN decreases the generated delays.

1.2 OBJECTIVES

The Main objective of this thesis is to provide the EPs with a seizure monitoring application which helps them in living their lives easily, comfortably, and securely.

The objectives are to review the related works, derive the Epilepsy Patients Monitoring System(EPMS) requirements, propose an architecture to the EPMS by using the SMAC protocol-based WSN, investigate the possible solution for it, investigate the performance of the proposed system using the Network Simulator version 2 (NS-2), and validate the proposed system.

There are two implementations for the proposed EPMS by using the NS-2 simulator for two different protocols. The first implementation is by using the SMAC protocol with the adaptive listening criteria. The second implementation is by using the WPAN/ZigBee protocol. It is part of our objectives to compare the derived results for the two protocols in order to prove the functionality of the SMAC protocol in the critical applications.

1.3 THESIS CONTRIBUTION

This thesis focuses on introducing an efficient monitoring system for the EPs based in WSNs. The use of WSNs overcomes the traditional system limitations, and provides continuous monitoring. WSNs-based applications are more comfortable, flexible and easy to use which creates a less stressful lifestyle for the EPs. The major contributions of the thesis are as follows:

- Derived the requirements of the monitoring system.

  We have derived the requirements related to the EPs monitoring system (EPMS) and the requirements related to the SMAC protocol, in order to include important features in the system.
- Proposed a model for EPMS.

  A new model of the EPMS based on the SMAC protocol is proposed, to meet all of the desired requirements.
- Evaluated the performance of the proposed model.

  The model is tested using the NS-2 simulator to evaluate the efficiency of using the SMAC protocol on it (evaluated the end-to-end delay and the throughput of the proposed system).
- Proved the importance of using the SMAC protocol along with the ZigBee protocol for the critical monitoring applications.

  The SMAC protocol gave smaller e-to-e delays and better throughput values.

1.4 THESIS ORGANIZATION

This thesis is composed of five chapters, and the remaining four chapters are organized as follows: Chapter 2 provides a comprehensive study of monitoring applications, based on the use of a WSN. It presents different solutions to resolve the healthcare monitoring issues, particularly for EPs systems. Chapter 3 explains the proposed system architecture, and provides the details of the architecture, including the overall model of our solution. Chapter 4 focuses on the performance evaluation by describing the development of the system model that has been implemented using the NS-2 simulator. It also presents the results, and compares the proposed and alternate systems. Finally, Chapter 5 presents conclusions and discusses future research.

CHAPTER 2 RELATED WORK FOR THE HEALTHCARE MONITORING APPLICATIONS

2.1 INTRODUCTION

The healthcare monitoring system has distinct limitations. One of the most serious for Epilepsy Patients (EPs) is the delay between seizure detection and response from the receiver. This drawback causes the EPs discomfort and insecure.

In this chapter, we review the existing monitoring system to determine the significant constrains. The work is divided into three categories: (1) the use of Wireless Sensor Networks (WSNs) for healthcare monitoring applications, (2) Sensor Medium Access Control (SMAC) protocol for healthcare monitoring and, (3) Wearable Personal Area Network (WPAN) for healthcare monitoring.

2.2 RELATED WORK

Work related to our research is divided into three sub-sections. The first focuses on using WSNs for healthcare monitoring. The second sub-section examines the use of the SMAC protocol in healthcare monitoring. And the third introduces the use of WPANs to healthcare monitoring.

2.2.1 WSNS IN HEALTHCARE MONITORING APPLICATIONS

There are various types of sensors, including magnetic, thermal, visual, optical and chemical. Sensors monitor and detect specific conditions, such as temperature, humidity, pressure and movement [AKY02]. Some WSN applications are classified as described below.

WSNs can be used in different healthcare applications: 1) to monitor patients using nodes that can track and detect patient behavior, by assigning the sensors specific tasks (e.g. heart rate, temperature, blood pressure) and promptly notify doctors of the symptoms to respond quickly to the detection events. 2) to monitor drug administration by using the sensor nodes to minimize the chance of patients receiving incorrect medications. 3) to track doctors with sensors on their bodies/clothing, allowing other doctors and authorized persons to track and locate them in case of emergencies [AKY02].

Sensor nodes are user-friendly for the patients, efficient and sensitive in observed conditions, provide continuous monitoring during daily activities, and allow patients increased flexibility in their lives. They are comfortable due to their small size and minimal weight, reliable and energy efficient, and changing the battery is a simple procedure.

In addition to the protocols, WSNs can also be used for emergency medical services in disaster situations. As the number of disaster victims increases, emergency service may become less efficient. Wireless sensors could facilitate reporting victim triage levels and tracking their status [KO10].

Some researches related to the use of the WSNs for the healthcare monitoring application includes: 1) The continuous monitoring, 2) the elderly people monitoring, and 3) the EPs monitoring.

2.2.1.1. WSNs for patients continuous monitoring

CustoMed as provided in [JAF05], is a platform for healthcare monitoring using WSNs, aims to decrease the times of the customization and the reconfiguration for the medical systems which work based on the reconfigurable embedded systems. It is a network-enabled system supports numerous wearable sensor nodes and contains the computing capabilities for performing the detection, the alerts, and the communications with the different medical services.

The researchers in [JAF05] introduce the concept of the custom-built in unit time by bringing the use of wireless sensor nodes, stand-alone components with processing units and batteries that support various types of sensors that can read human physiological attributes [JAF05]. It also provides flexibility for the CustoMed medical system.

The CustoMed platform can be used with our proposed system since it offers continuous monitoring criteria, which is crucial for our research, but it focus on the customization idea which is not related to our work.

A solution for the reliable continuous monitoring for the hospitalized patients is proposed in [HAL14], where the healthcare wireless sensor network (HWSN) with mobility support has been used.

The implemented system in [HAL14] consists of four components: sensor nodes, Access point (AP), Mobility support and Gateway. The sensor nodes can move from one access point to another, and register at the new access point by transmitting data to it. The mobility support module (MSM) works with the AP. It stores all nodes which have a registration with the AP, and sends a unicast notification to every AP registered node. If a node is no longer connected with the AP it sends a break message and an acknowledgement message to the new AP, notifying it of the new registration. The Gateway registers an AP to the network, allowing it to collect the neighboring details and forward them to the gateway.

The authors in [HAL14] support the sensor nodes with the mobility in a controlled scenario. They presented an approach for the intra-handover mechanism, which minimizes the message exchange between the sensor nodes and their APs, and creates a continuous communication for the sensor nodes, even if they change their APs.

This system does not benefit our proposed system, since it concentrates on the mobility mechanisms. It focuses generally on the random motions of the sensor nodes (not a criteria by defining fixed locations for the sensor nodes on the patient’s body).

In [KIM09], the authors propose a tree-based routing protocol to study and solve the problem of the mobility managements in WSNs. the system limitations were summarized in: providing a bi-directional connectivity to the mobile nodes, the use of the procedures for the association/re-association speeds up. Theses used procedures could not help the continuous monitoring requirement which make it not helpful in our work.

The system in [ZIN10] focuses widely on using the mobility in the monitoring applications since it studies the insertion of the sensor node in the mobility-related message exchange, which makes it completely different from our research.

In [KUM12] the researchers propose some ideas of using the wearable body area network (WBAN) for patient’s continuous monitoring purpose and to help the patients to live independently. They use specific types of sensors to sense and collect physiological data from the patients and send it to an intelligent device they called it Intelligent Personal Digit Assistant (IPDA).

Some researchers provide a summary of the limitations and challenges they met when designing the WSN for healthcare applications: accuracy, reliability, security, privacy, energy consumption, delay and Quality of Service (QoS), as mentioned in [CHA14].

The reliability criterion provides a high level of accuracy, as the sensor nodes must deliver accurate data regarding the patient's case. Incorrect data can lead to improper treatment.

Unlike wired data, wireless data has a high risk of attack, which makes security criteria a critical area for research, particularly in healthcare applications. Assailants can acquire monitored data using diverse techniques, such as the General Packet Radio Service (GPRS). Data encryption is currently the best means of protecting wireless data.

One of the main concerns with continuous monitoring applications is energy consumption, with the highest expenditure is due to the communication process. The use of duty cycling procedures can minimize consumption.

The most important challenge in WSN healthcare applications is minimizing time delay in the transmission process, particularly for hospitals located in critical areas. The use of synchronization criteria [CHA14] can improve the QoS and minimize delay.

The work in [CHA14] can be of benefit to our proposed system despite it focused on duty cycling procedures, which are used in the SMAC protocol. It also addresses the security mechanism, which is one of the most important challenges to our work.

2.2.1.2. WSNs for elderly people monitoring

Some researchers have used WSNs to design a healthcare system for the elderly people as in [HUO09], integrating WSN techniques with public communication technologies. The major functions of this system are indoor/outdoor monitoring, activity/health state decisions, emergency decisions and alarms.

Huo, Xu, and Yan in [HUO09] established a WSN prototype which supports the real time events, health case reports to the desired person, and a large range of data interconnections. The researchers used the database concept by dividing their proposed system to four sections.

[HUO09] proposed system related to our system in being focus on the healthcare monitoring on the other hand it does not benefit our work, since the researchers used a database concept, which does not apply to our system.

Another study in this area is the Wireless Sensor Network 4 Quality of Life (WSN4QoL), which is a three year project focusing on the elderly people too [TEN14]. Its goal is to employ new advanced WSN technologies to meet the healthcare application requirements of elderly persons.

The scenario shown in Figure 2.1 is one of the implementations of WSN4QoL. It consists of four nodes: two are sources carried by patients, another is a relay node with a fixed location that is responsible for network schedule broadcasting of a synchronization packet, and the last is a destination node, which does not transmit feedback based on the network coding technique.

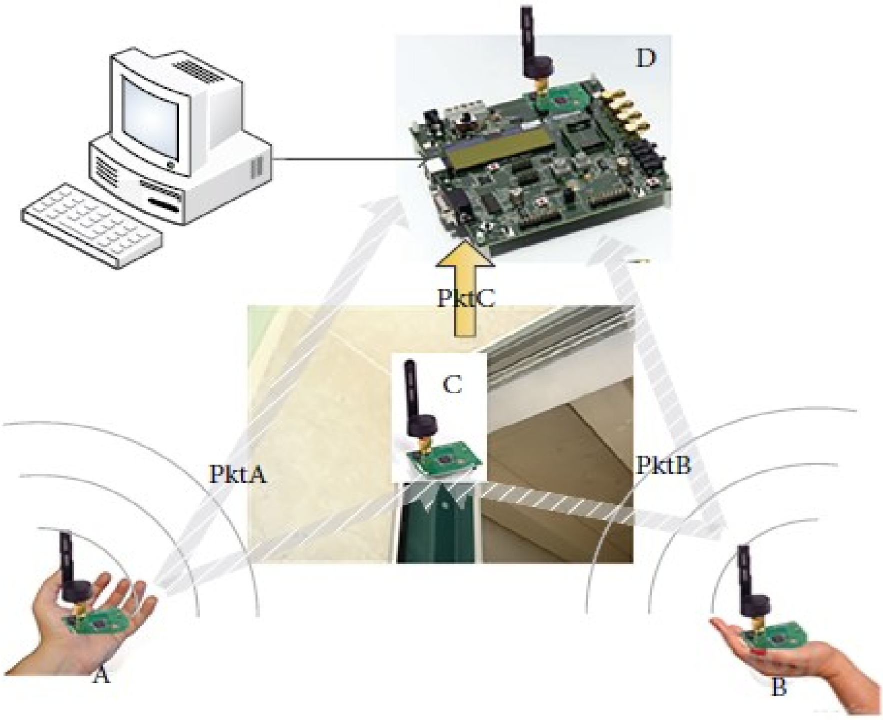

Figure 2.1: A scenario for the WSN4QoL system [TEN14].

The authors in [TEN14] introduce the use of the network coding (NC) application as shown in Figure 2.2. The relay node takes messages from both A and B, combines them to one message using the XOR operation, and delivers the combined message to the destination node. This process helps in decreasing the network power consumption.

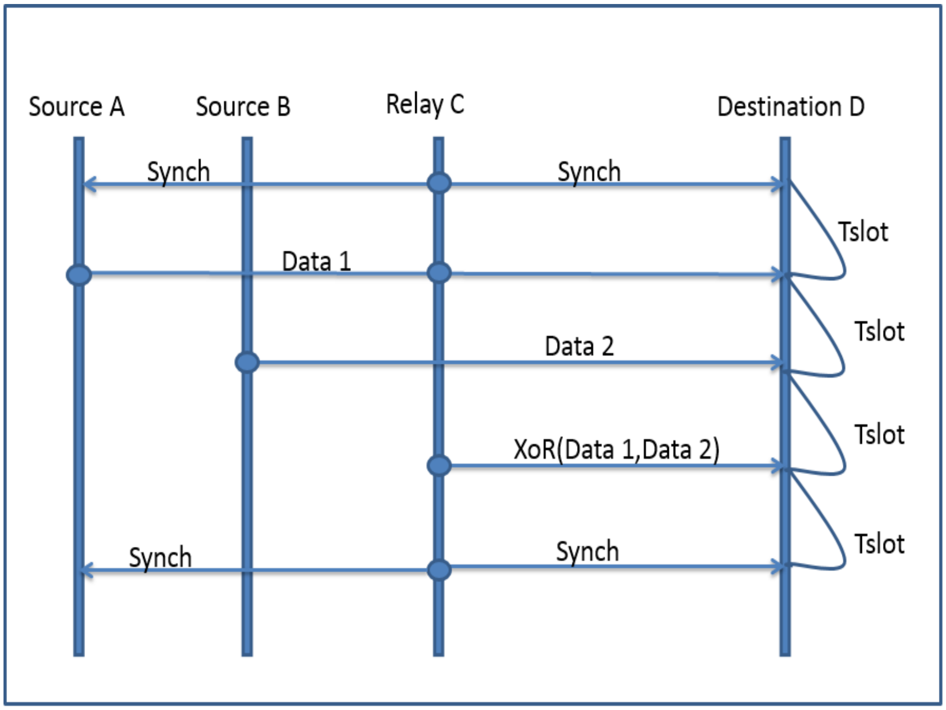

Figure 2.2: WSN4QoL network coding approach [TEN14].

The proposed solution in [TEN14] focus widely in using the NC approach, monitoring the elderly people and not focusing on time-delay limitation, which make it not relate directly to our research.

2.2.1.3. WSNs for EPs monitoring

One of the most important applications for healthcare monitoring using WSNs is the one for the Epilepsy Patients (EPs), its importance is due to the increasing number of EPs, their essential need for constant monitoring throughout their daily life in and outside their homes, and the necessity for a delay-free response to seizures.

EPs monitoring is performed using the traditional Electroencephalogram (EEG) method. This is uncomfortable for the patients, as it requires wires and electrodes to be attached directly to the patient's brain. Thus, the WSN methods are the best choice for monitoring EPs in a comfortable and trouble-free manner.

Much research has been devoted to epilepsy monitoring applications based on WSNs. In [BOR13], researchers introduced a WSN-based system that detects the seizures of the Epilepsy Patients (EPs) based on the using of the accelerometer sensors for the seizures detection purposes [BOR13]. The system employs two types of nodes: mobile sensor and static. Static nodes transmit the collected data from the sensor nodes to the Base Station (BS), which in turn transmits it by cables to the server, it is also has the EP's location determination facility which makes the EPs feel secure all the times.

[BOR13] is largely focused on filtering the data collected from the sensor nodes, to detect whether or not it indicates an epileptic seizure (ES). In some situations, the collected signals may be not strong enough to categorize the event as a seizure.

In order to recognize the ESs from the normal ones, the Artificial Neural Network (ANN) and K Nearest Neighbor (KNN) are used to perform the data analysis. The detection of an ES is done in several steps: 1) data collection using three patients with accelerometer sensors located on their right arm, left arm and left thigh, 2) preprocessing using a noise filtering procedure (the accelerometer produces some noise) and 3) using classifiers to differentiate an ES from normal movement. The results of the system in [BOR13] indicate a sensitivity of 85%. The filtering and the data analysis procedures mentioned in [BOR13] does not serve our proposed system, as it is a software based system and not in direct contact with the patient.

Another ES detection procedure using the electroencephalogram (EEG) approach is done in [TZA06]. The authors propose an approach for the ES detection based on the Time-Varying Autoregressive Model (TVAM) which uses the non-stationaries of the EEG [TZA06]. The researchers used the Kalman Filter (KF) to detect epileptic spike movement by applying two steps: 1) pre-emphasis of ESs by using the KF approach equation results to enhance the detection process, and 2) using thresholding procedures to detect ESs by acquiring the results from the KF approach and comparing them with predefined thresholds using specific equations.

Another system for ES monitoring has been introduced in [ALT11]. It concentrated on selecting sensor node specifications that achieve the desired purpose. The system consists of many Human++ wireless sensors attached to the patient's body. Human++ nodes are based on generic nodes, and allow the sensors to change according to the required application. Other hardware components in this system include ultra-low power ExG readout, an ADXL330 accelerometer from Analog, and a microSD-card which provides low-power storage capability [ALT11].

The authors have implemented this system using a low-power Time Division Multiple Access (TDMA) MAC protocol, which makes the sensor nodes work in a star-topology. Each sensor node can sample and store the data before transmitting it, and receive a beacon from the BS every 200 ms.

In [ALT11], the researchers collected data from five health situations, in order to compare the use of Human++ nodes with a reference system of different type of nodes. They calculated the root mean square value (RMSV) of the surface Electromyography (EMG) (Figure 2.3), and found that using the Human++ helps achieve good quality data.

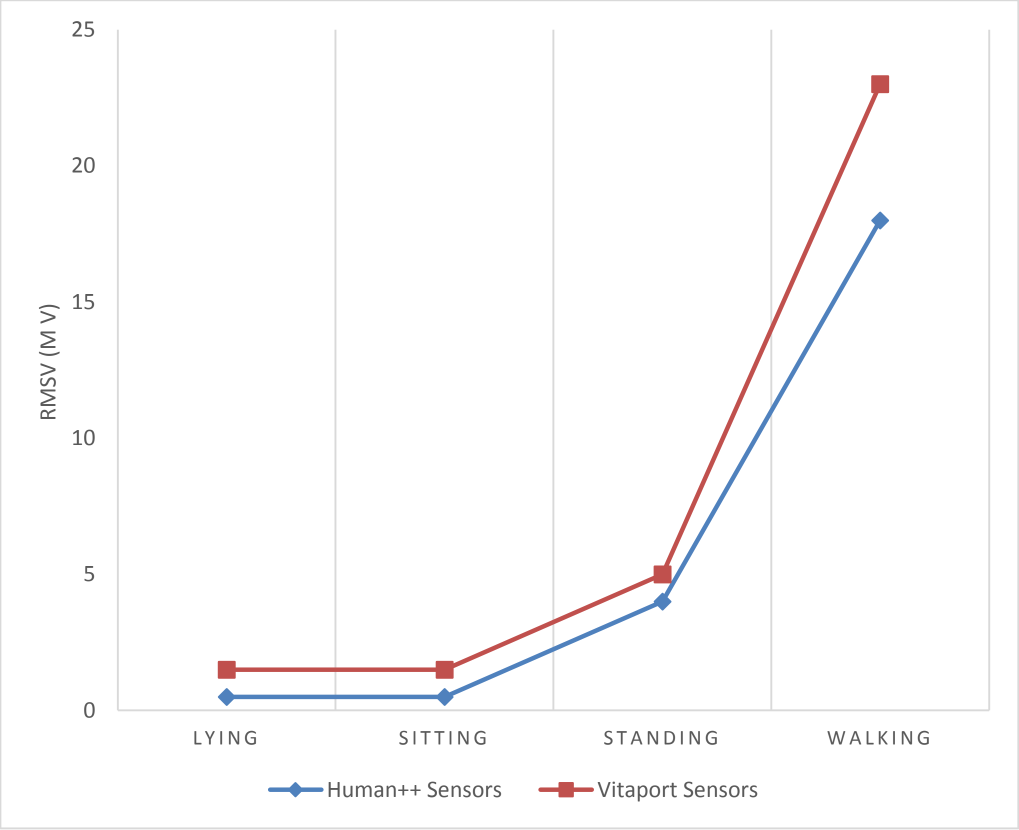

Figure 2.3: RMSV of EMG for Human++ and another node [ALT11].

The system in [ALT11] differs from our proposed system in three ways: it uses star topology, it focuses on using the TDMA, and it also focuses on the type of nodes.

Another system for epilepsy patients is mentioned in [MAR14]. It discusses a WSN for the Body Area Network (BAN), for continuous monitoring and event monitoring.

The continuous monitoring is conducted with the EEG and the electrocardiogram (ECG), while events monitoring is performed by the electrocardiogram (ECG).

The proposed system scenario in [MAR14] defines sensor nodes spread randomly over a location. The WSN is applied at the BAN in a small area near the sensor nodes, with a transmission distance of 2 to 3 meters. The TDMA is proposed because it is a collision-free protocol.

Figure 2.4 demonstrates the key procedure of the proposed system in [MAR14]. It is obvious that in a system of n nodes, the TDMA consists of n time slots. The continuous monitoring operation nodes are assigned to time slots in the first part of the TDMA frame, and the event monitoring nodes are assigned to the second part of the frame.

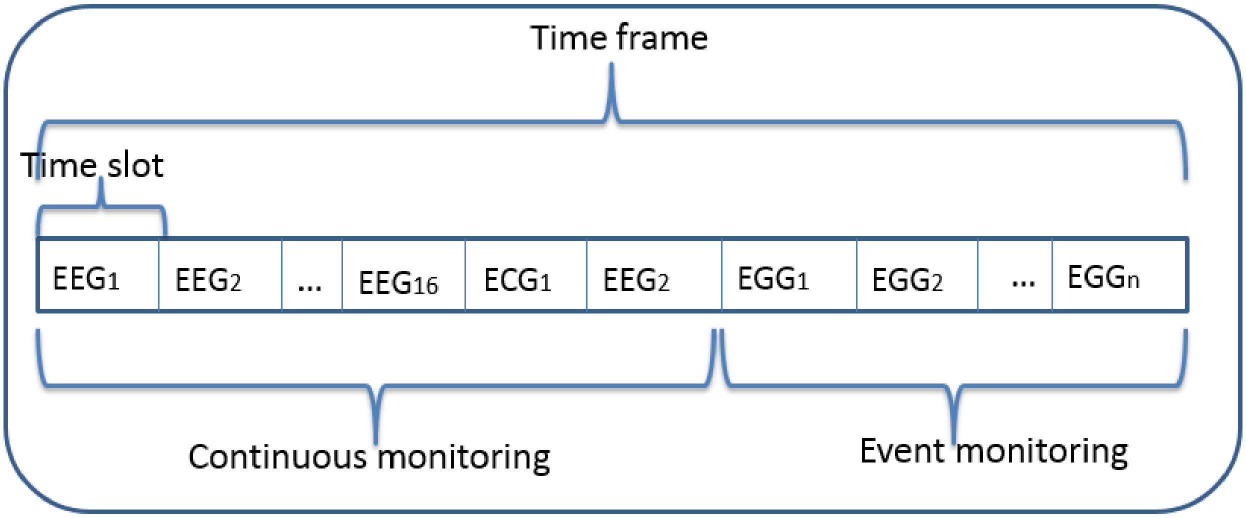

Figure 2.4: TDMA system [MAR14].

The authors in [MAR14] have focused broadly on the EPs monitoring which is directly related to our work, in the other hand the use of the hybrid WSN based TDMA protocol, the focus on the ECG, EEG and EGG is out of the scope of our study, and the emphasis on defining the system using mathematical models make the system not related to our research.

2.2.2 SMAC PROTOCOL IN THE HEALTHCARE MONITORING APPLICATIONS

SMAC is a new MAC protocol designed for WSNs. It has many advantages, including power-saving sensor batteries, a more flexible network and the capability to avoid expected collisions.

SMAC can be employed in several applications, such as environmental and healthcare monitoring. In this research, we use it for healthcare monitoring.

Research in this field is discussed in [SAK12], where they analyzed the suitability of the SMAC protocol in mission critical WSN applications, including industrial monitoring, military operations, and medical monitoring applications. They study some important parameters for the critical applications such as the throughput, packet delivery ratio, and the left over energy.

The proposed system in [SAK12] employed in a multi-hop scenario which consists of a source node, a sink node and nine other nodes, and each node begins with 1000 joules of energy. The source node continuously transfers 80 packets of data to the sink with the DSR used as the routing protocol. They have focused on analyzing the impact of altering the traffic load, by changing the transmission inter-arrival time at the source node for different duty cycles [SAK12]. The used multi-hop topology is shown in Figure 2.5.

Due to their work, better throughput was achieved when the duty cycle was 40% and the message inter-arrival time was increased. While the throughput is negligible when the inter-arrival time is very low, increasing the duty cycle to 40% doubles the listening time and reduces the residual energy. These results show that they improved the efficiency of the SMAC protocol for mission critical applications.

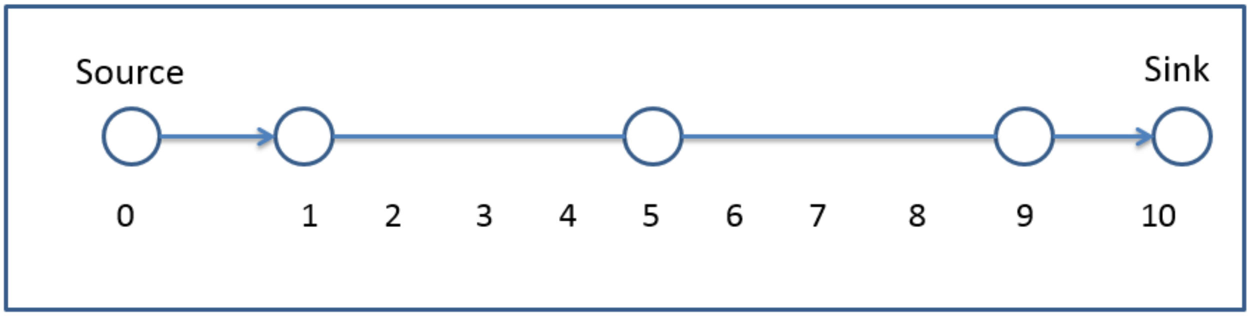

Figure 2.5: [SAK12] System topology.

Some of the [SAK12] results are shown in Figure 2.6, and the impact of message inter-arrival time and duty cycles on network throughput is clear.

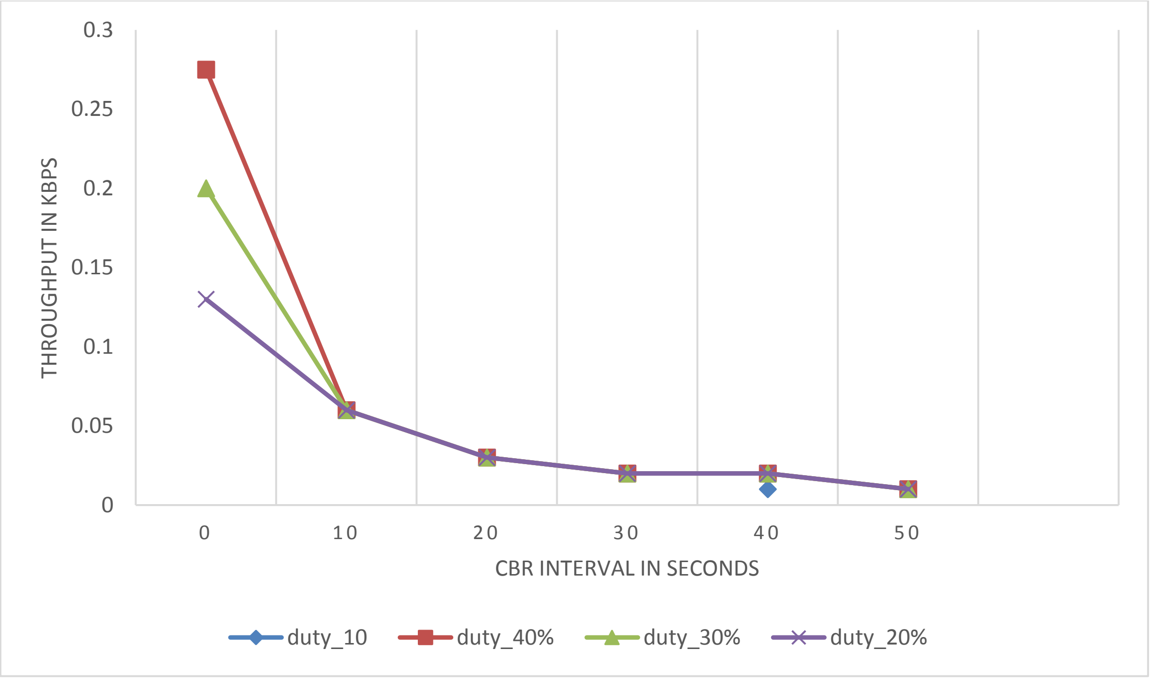

Figure 2.6: The impact of inter-arrival time and duty cycles on throughput [SAK12].

This system benefits our research in a number of ways. Its broad focus on data throughput, the effect and impact of the duty cycles, and its concentration on using the SMAC protocol correlate directly to our research.

Suriyachai, Roedig and Scott in [SUR12] make a survey to study the different MAC protocols and its suitability for the critical applications such as the contention-based and the schedule-based MAC protocols. They organize the studied protocols based on the suitability and performance for the applications which need an on time and a reliable data transmission.

The message transfer delay and reliability have been studied as their objectives, some MAC protocols achieve the reliability but they are unsuccessful in achieving the expected message transfer delay. Other MAC protocols achieve the two objectives but some of them can serve the critical applications [SUR12].

A MAC protocol with an energy efficient and low latency which designed for the data gathering trees in WSNs named as DMAC is addressed in [LU04]. The authors have solved the data forwarding interruption problems occur in the networks based on using the active and sleep duty cycles, as well as the limitations revealed in the data delivery notification process in the multi-hop networks by introducing the DMAC protocol. They conclude by the suitability of the DMAC for the transfer data reliability with the energy saving and delays reduction [LU04].

The work in [SUR12] and [LU04] does not directly help our research on being focus on other MAC protocols; on the other hand they put a big focus on studying the end-to-end delays which is the most important objective of our proposed system.

Some researchers have focused on comparing the SMAC protocol with different protocols, such as in [KHA13], [HAM09], [PRE12] and [HUM05]. In [KHA13] the authors presented the SMAC and the Timeout (TMAC) protocols with their advantages and disadvantages and discussed the energy waste issue in WSNs. In [HAM09], they proposed a mobility-aware, delay-sensitive MAC protocol (MD-SMAC), tested it with the NS-2 simulator, and compared it to other different MAC protocols include the SMAC protocols, their focus was on testing the performance in the real hardware. The authors in [PRE12] proposed an approach for a new Energy Aware MAC (EA-MAC) algorithm, and compared it with the S-MAC protocol based on energy consumption, throughput and the average e-2-e delay. Humos and Alhalabi in [HUM05] introduced an enhanced protocol called A Low Latency and Energy Efficient MAC Protocol (FASMAC), which combines the passive property of adaptive listening with the use of FRTS packets in a TMAC protocol, to reduce the latency of the SMAC protocol.

The works done in [KHA13], [HAM09], [PRE12], and [HUM05] help us in our research in understanding the metrics performance analysis of the SMAC protocol compared to the other protocols and in deciding the importance of using the SMAC protocol for the critical applications.

Some researchers have focused in achieving the optimal values of the network throughputs and delays using the SMAC protocol, such as the work done in [KAU11]. They have explored the maximum throughput under network architecture, and focused on determining the best design for the network to achieve the optimal throughput and delay values, while conserving energy by improving the S-MAC protocol. This research helps our work in the performance evaluation analysis.

[HAF14] also presents a comparison between different MAC protocols. The researchers tested the SMAC protocol using TinyOS software and Mica2 Motes hardware. Latency is an important aspect of testing, and it differs if the SMAC has adaptive listening or not. They included a figure of [YE04] to show the impact of adaptive listening on average latency, as shown in Figure 2.7.

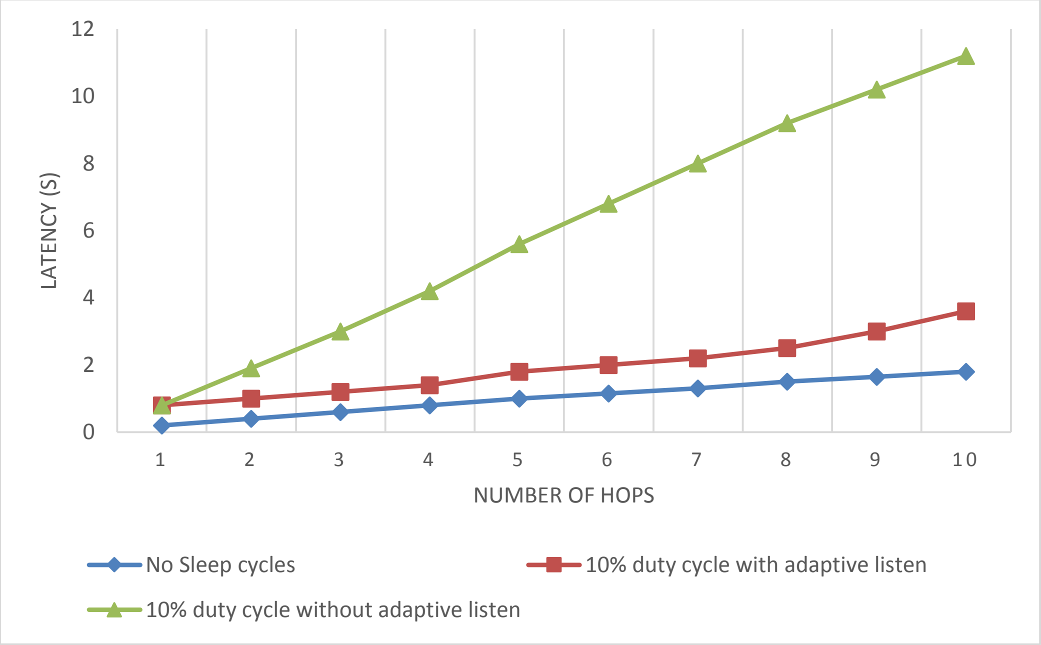

Figure 2.7: Latency with the Number of hops for SMAC protocol [YE04] [HAF14].

The throughput in SMAC increases continuously with the addition of sensor nodes, as discovered in [HAF14]. The researchers included the Figure 2.8 from [POL04], which indicates the correlation between throughput and the number of nodes. [HAF14] is helpful to our research, since our focus is on acquiring the SMAC broadcast criteria from [POL04], and the 10% duty cycle with adaptive listening from [YE04]. These results are compared with ours to perform the performance evaluation.

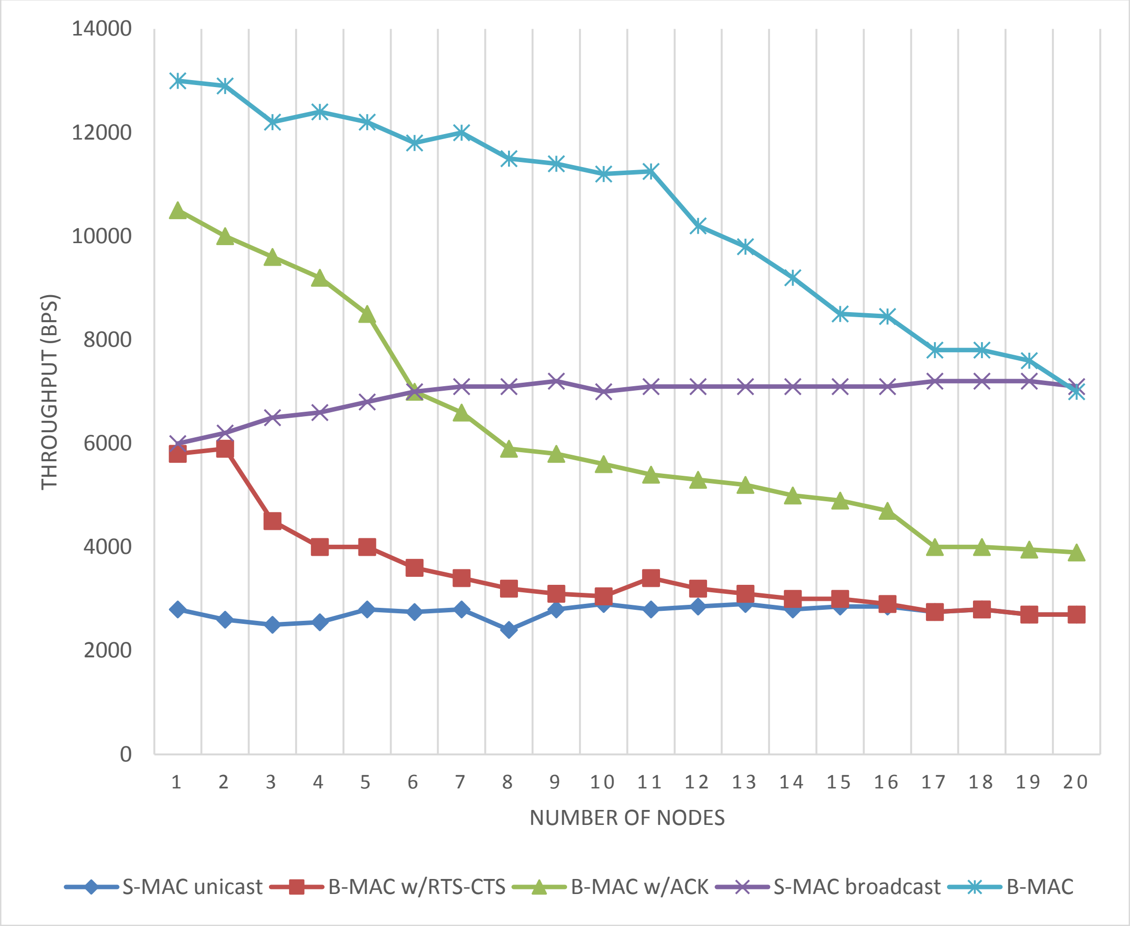

Figure 2.8: Throughput with number of nodes [POL04] [HAF14].

2.2.3 WPANS IN HEALTHCARE MONITORING APPLICATIONS

WPAN is a group of wearable medical sensor nodes attached to a patient's clothing, which communicate using the personal area network (or the body area network), and connect to a specific receiver in the event of an emergency (e.g. medical services).

Traditionally, some healthcare monitoring was accomplished using the Holter monitoring procedure. The Holter monitor is a portable device that continuously monitors the electrical activity of the cardiovascular system It is applied for at least 24 hours, and often as long as two weeks [ART13]. The monitor is well-known for its efficient tracking of heart activity, and it is also effective for monitoring brain and pressure functions. It monitors electrical signals from the target observation area using a number of electrodes attached to the patient's body, and records the signals on cassette tape or a flash memory drive for subsequent analysis by certain systems [JOV01].

WPANs for health monitoring are useful for 1) intelligent health monitoring of ischemia and epilepsy to reduce patient visits to medical centers, 2) controlling medication delivery and dosing systems, 3) breathing monitoring, and 4) assisting the disabled [JOV01].

In [KIM07], the authors have introduced the idea of using WSNs in a Wearable Healthcare Gadget (WHG), through ZigBee communication for Life-Log purposes.

The WHG system introduces the using of the Global Positioning System (GPS) module [KIM07]. To ensure that the ECG signals amplified by certain filters remove the noise and receive reliable physiological data regarding user movement levels, ZigBee is modified to be a wireless network element of the WHG, due to its low power wireless data transmission as shown in Figure 2.9.

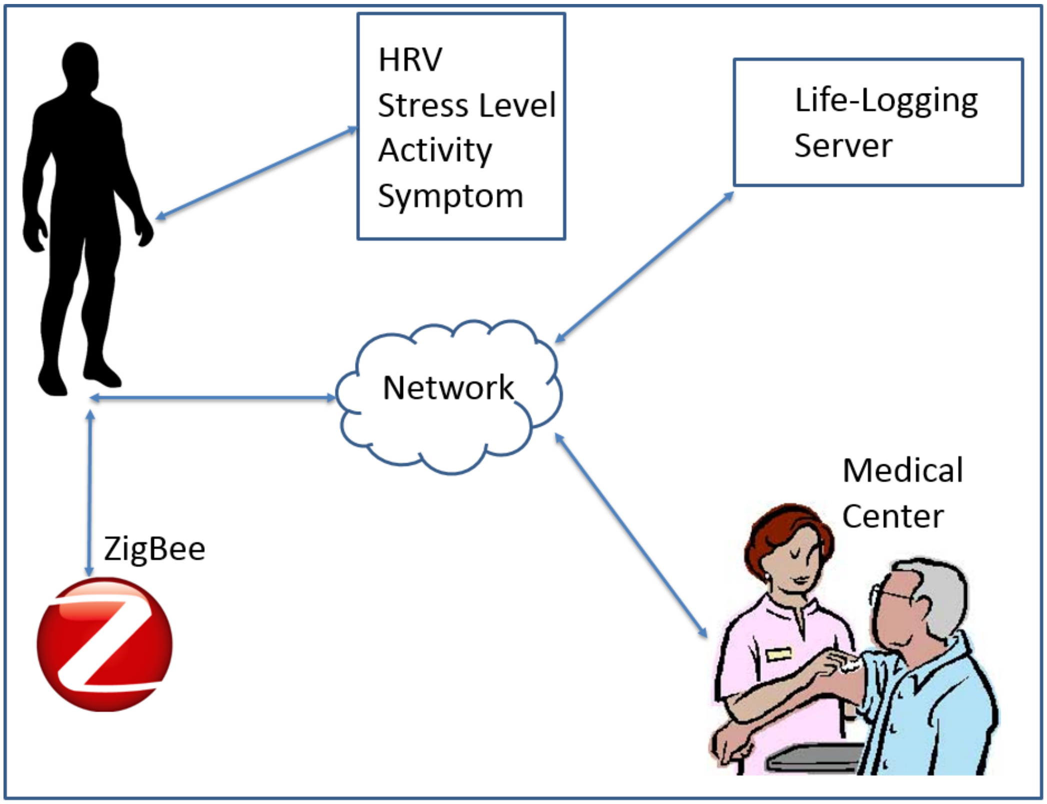

Figure 2.9: Life-Log service system [KIM07].

The system in [KIM07] is an effective tool for heart attack and disease prevention. It can also measure stress-levels to help prevent certain stress-related diseases. The monitored data is synchronized by time and location, which helps doctors and medical centers retrieve information according to when and where. This system give us an idea of using the GPS module as our future research.

Some researchers were aware of the suitability of wireless network technologies, particularly WPANs for medical applications (referenced in [CHE05]). The research focused on evaluating the adaptability of WPAN and IEEE 802.15.4 for healthcare applications.

In [CHE05], the researchers focused on various parameters and scenarios to compare IEEE 802.15.4/WPAN and Bluetooth technologies. They concentrated on end-to-end delay, packet loss and network efficiency. As illustrated in Figure 2.10- Figure 2.12, this provided an indication of the suitability of wireless technologies for healthcare applications.

In Figure 2.10, the authors calculate the average delays for different scenarios of using the IEEE 802.15.4 with and without the acknowledgement, and with the Bluetooth service.

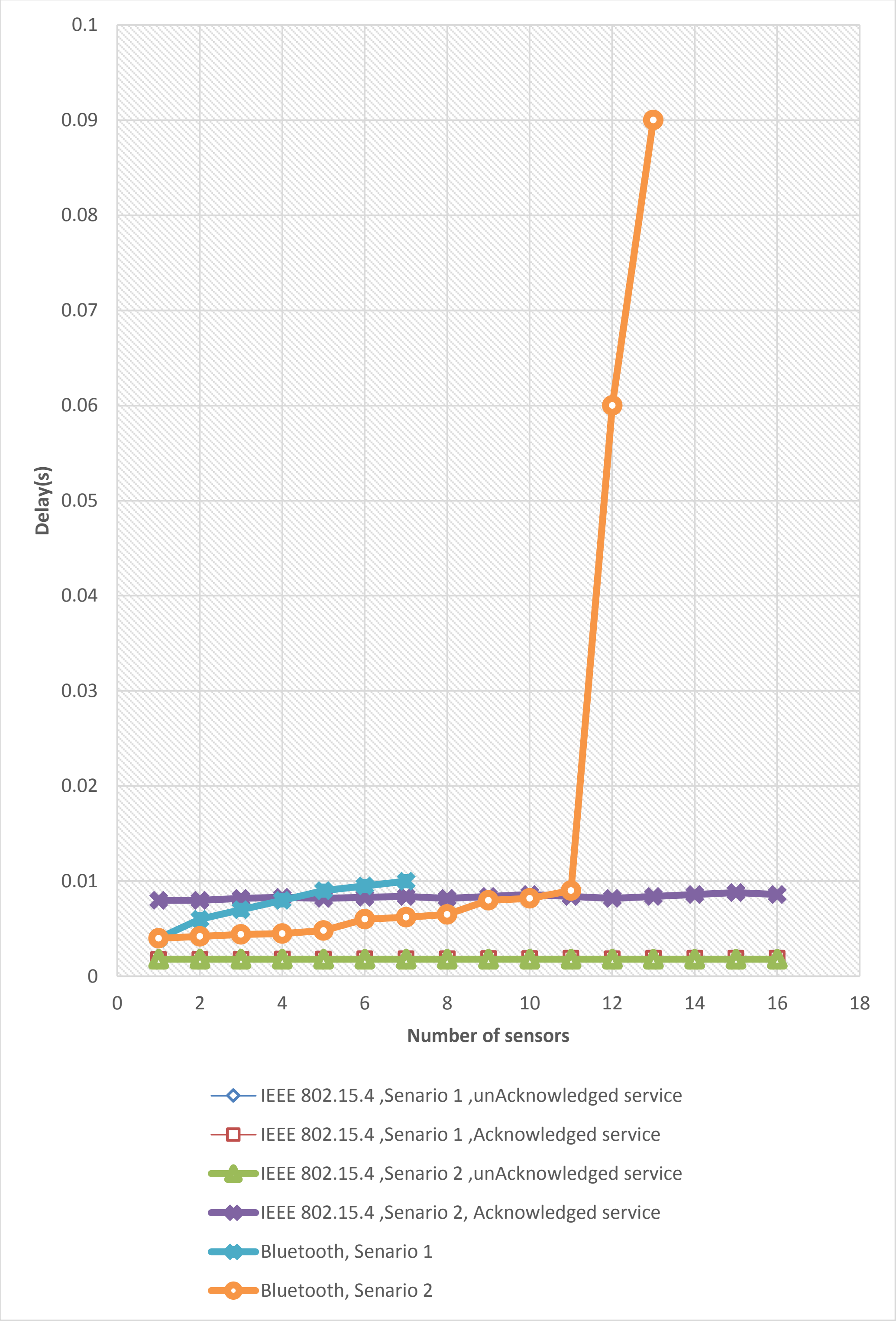

Figure 2.10: Delay comparison between the WPANs and 802.15.4 [CHE05].

From Figure 2.10, it is obvious that the Bluetooth delays increase with the increasing in the number of sensor nodes, as well as the delays values is higher than the one generated by using the IEEE 802.15.4.

Another comparison between the studied scenarios has been done according to the packet loss as shown in Figure 2.11.

From Figure 2.11, it is clear that the minimum packet loss has been achieved by using the IEEE 802.15.4 protocol, which gives an indication of the suitability of it for the medical applications.

The network efficiency is also calculated for the studied scenarios in [CHE05], the IEEE 802.15.4 has achieved the highest efficiency as shown in Figure 2.12 below.

Some researchers have evaluated the performance of WPANs in medical applications (e.g. the focus on low rate WPANs in [GOL04]). The authors chose certain parameters for their simulated environment, based on detailed MAC, PHY and channel models for IEEE 802.15.4. The generated results are highly dependent on network configuration, the usage scenario and the application required [GOL04].

The MAC Sublayer access delays were the performance metrics used in [GOL04]. They included the percentage of packets dropped at the transmitter's application layer and in the MAC layer of the receiver node, as well as the goodput (the number of successful packets received divided by the available capacity).

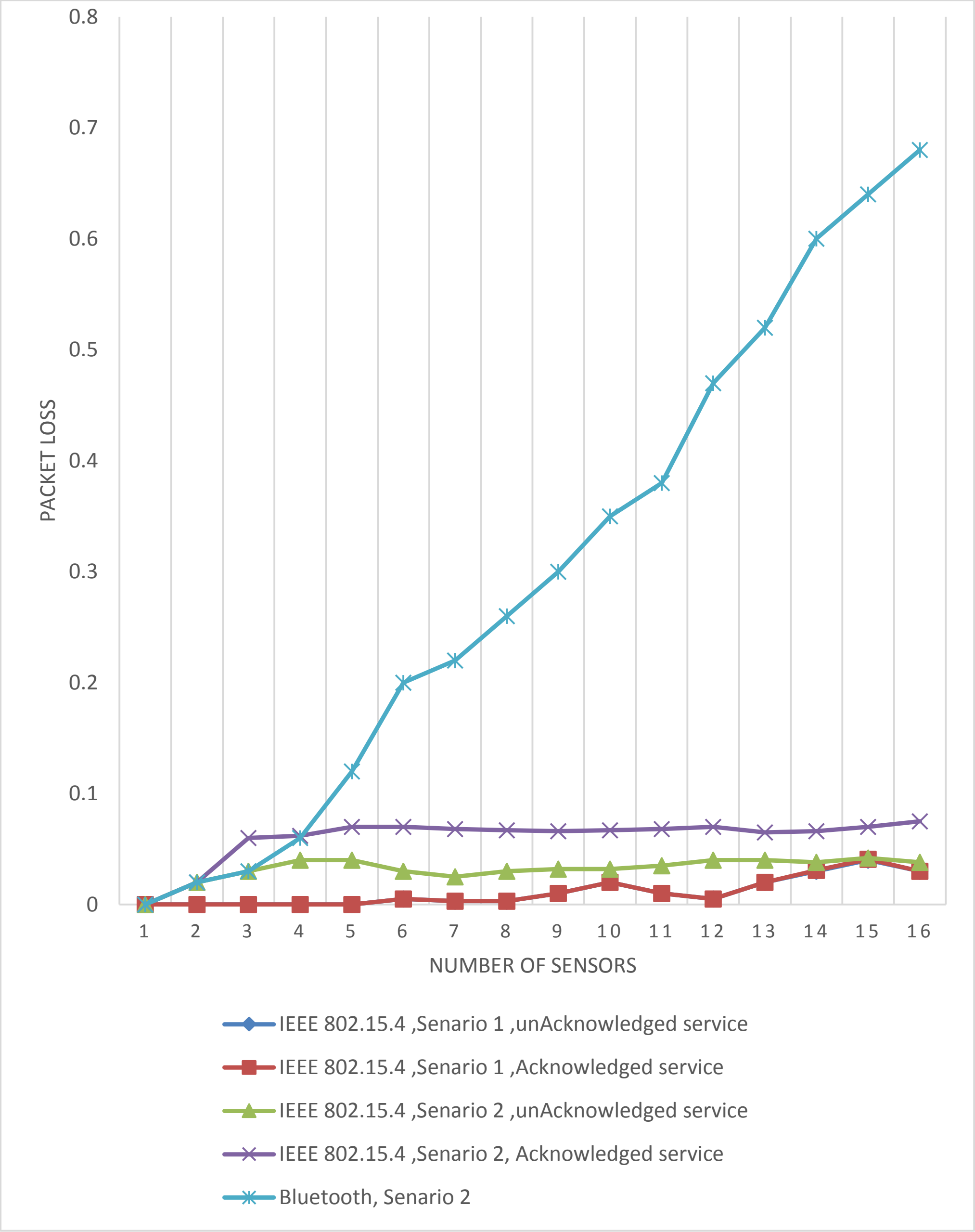

Figure 2.11: Packet loss comparison between the WPANs and 802.15.4 [CHE05].

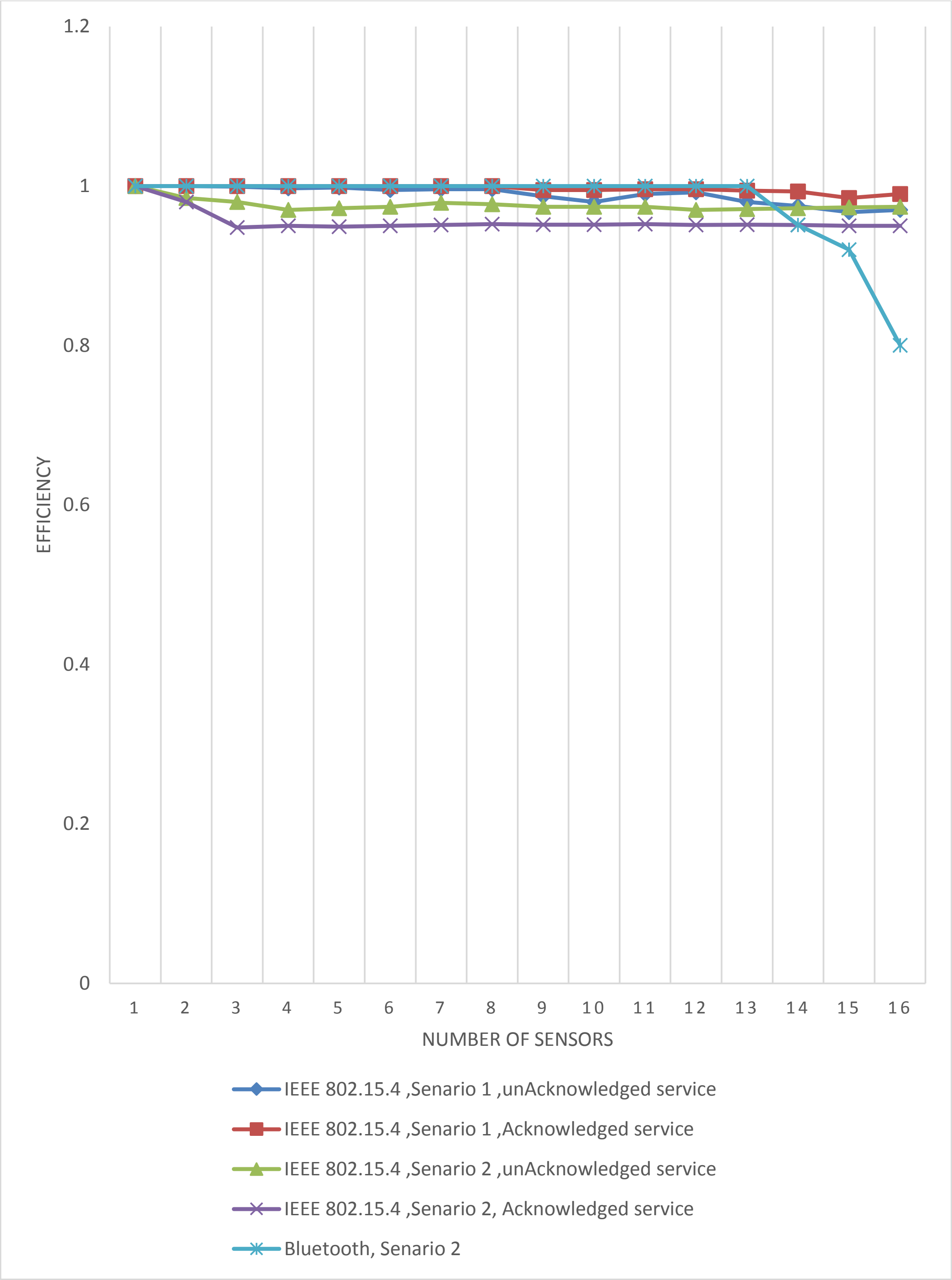

Figure 2.12: Efficiency comparison between the WPANs and 802.15.4 [CHE05].

The authors presented performance results for three different scenarios, including 1) using the default 802.15.4 MAC parameters in only one WPAN, 2) the impact of the interference of another WPAN, and 3) the impact of WLAN interference.

For the first scenario, though the packet delays were useful for medical requirements, the goodput decreased rapidly as shown in Figure 2.14. This was due to the network topology of 16 transmitters in a ring topology with a central receiver, which allowed the WPAN maximum load to reach only two devices. Adding another transmitter caused an overload of WPAN capacity, decreasing the goodput level. The MAC access delay function results with a number of transmitters using the OPNET simulator are shown in Figure 2.13.

Another set of results shows the impact of the number of transmitters on the goodput level, is displayed in Figure 2.14.

In the second scenario, the interference is negated due to the use of 16 channels for 16 transmitters. The added WPAN can be connected to any channel by a manual configuration procedure, or by implementing optional dynamic procedures [GOL04].

To test this scenario, the researchers assumed two WPANs using the same transmission channel. They observed a significant negative impact from the interference, which resulted in elevated packet loss and delays on the two WPANs monitors.

In the third scenario, the WPAN using 802.15.4 was disabled from the interference of WLAN on the same channel. It is re-enabled if the WLAN is idle the majority of the time or on a different channel [GOL04].

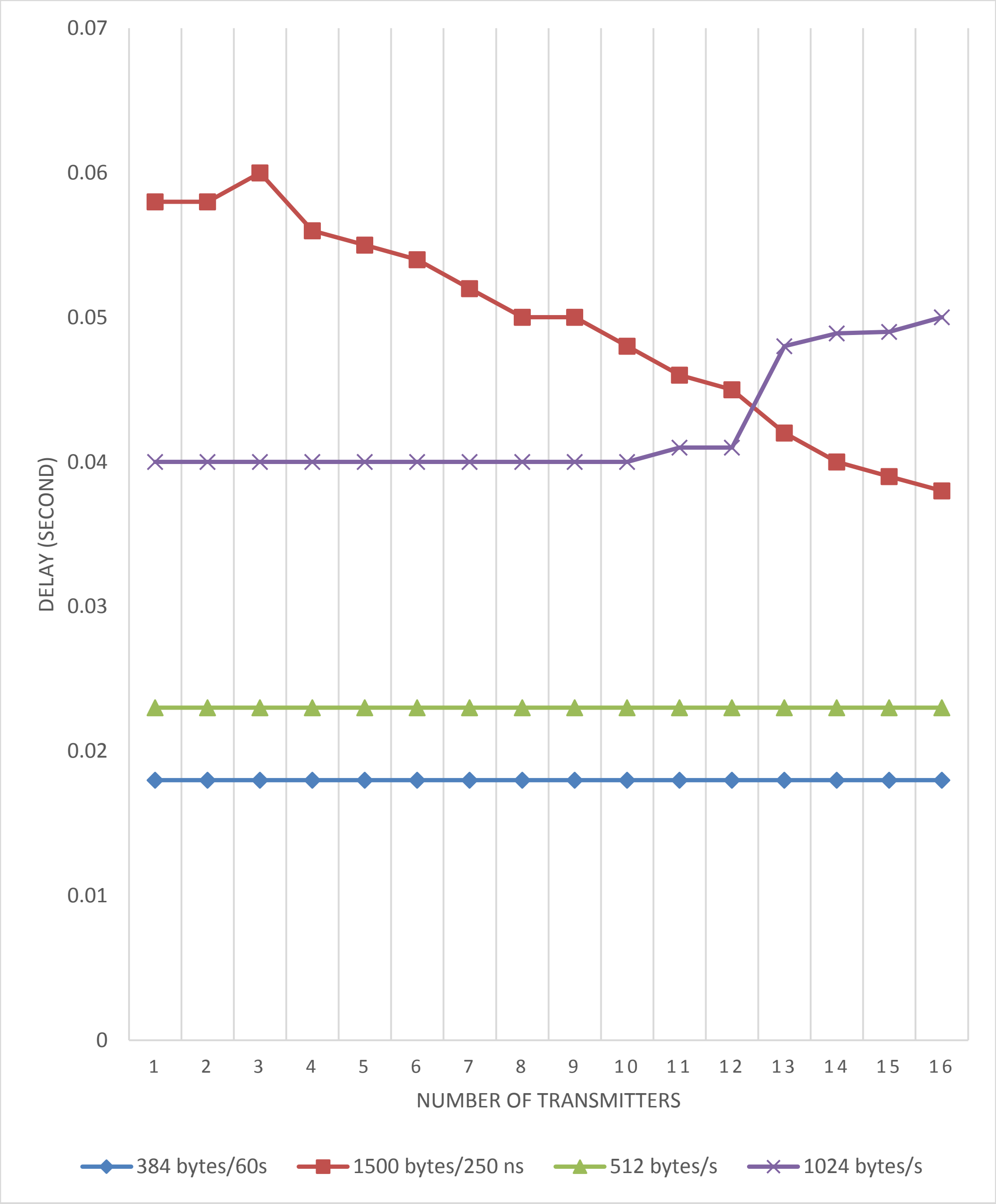

Figure 2.13: MAC access delay [GOL04].

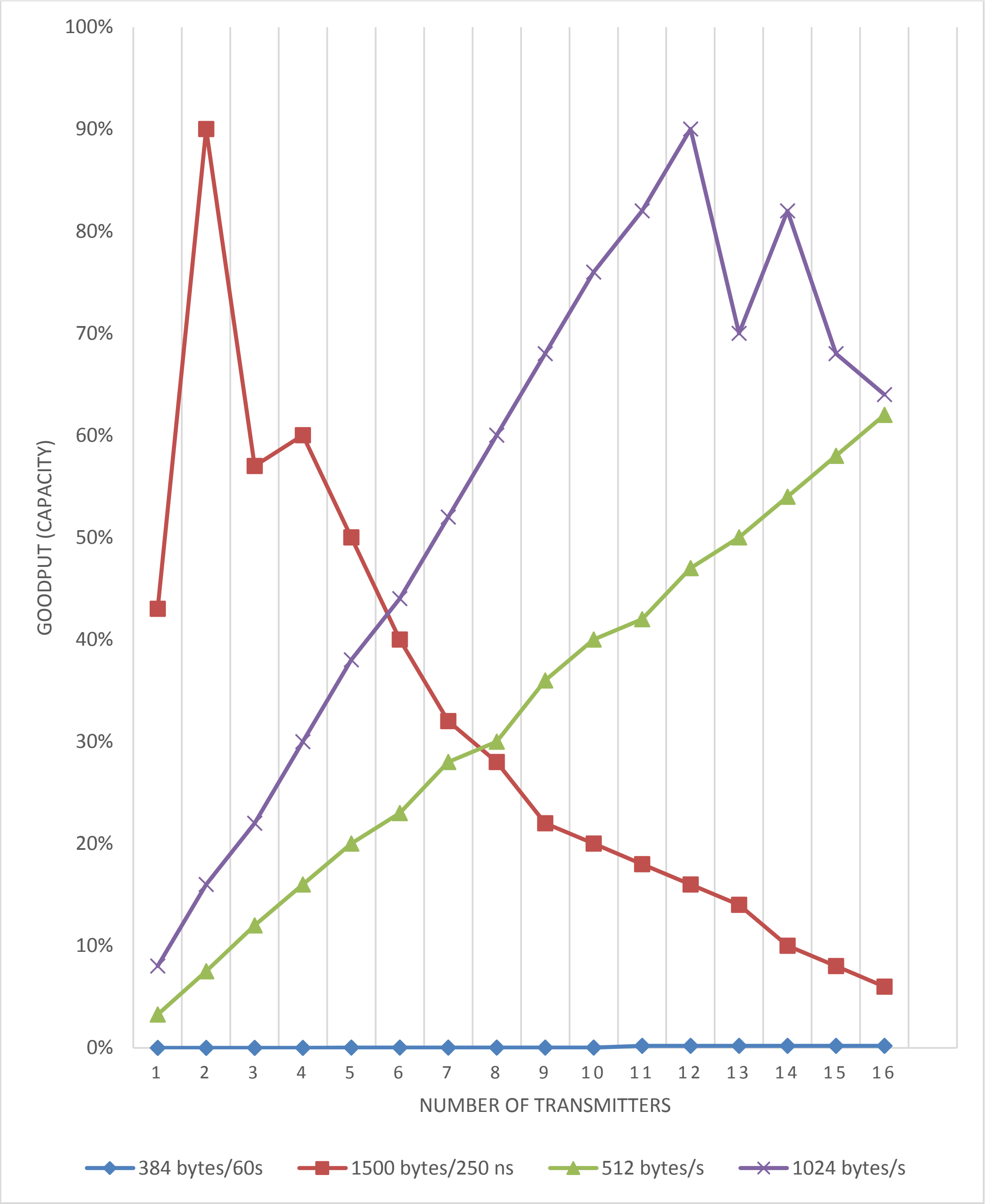

Figure 2.14: Goodput with number of transmitters [GOL04].

2.3 SUMMARY

In this chapter we have provided an overview of the work related to the use of WSNs in different monitoring applications especially in healthcare, particularly for the EPs monitoring application. The use of the SMAC protocol for healthcare monitoring is also reviewed. Finally, we examined the use of the WPAN protocol in healthcare monitoring applications.

From the reviewed studies, we have found that the use of the SMAC protocol for the EP's applications focused on the seizures detection from the hardware perspectives such as the EEG signals filtering.

Different protocols of the same category have been used for the monitoring applications such as the DMAC, MD-SMAC, and the SMAC, our focus is on making comparisons between two different protocols from two different categories.

Different related results have been included to facilitate the observing of the impact of different parameters on some performance measurements such as the average delays, goodput and the network efficiency.

CHAPTER 3 EPILEPSY PATIENTS MONITORING SYSTEM ARCHITECTURE

3.1 INTRODUCTION

In order to test the efficiency and to predict the success of any proposed system, it has to meet the expected requirements of it. Proposed Epilepsy Patient Monitoring System (EPMS) requirements can be considered in two categories:

1) Communication Requirements.

The use of Wireless Sensor Networks (WSNs) in monitoring applications simplifies patients' lives. The first requirement is sensor monitoring nodes organized in a tree topology with the coordinator. Though Wearable Personal Area Network (WPAN) can use peer-to-peer topology or tree topology, tree topology works best with EPMS. The monitoring nodes connect to the coordinator node and transmit the data, eliminating the need to send or receive data to/from each other.

The second communication requirement is that the system must use specific types of medical nodes, and include the characteristics of the nodes in the simulation environment. Our research focuses on the Medium Access Control (MAC) layer and software analysis, with embedding the sensor node characteristics without the use of hardware.

The third requirement is receiver nodes that collect the data sent by the coordinator and forward an alarm, via any type of communication network, to the appropriate receiver, such as a medical center or hospital.

2) Patient requirements.

The first user requirement of the EPMS is that it must have an extensive coverage area in and around the home. This is particularly important if children are involved, as it gives them the freedom to play outside while remaining safe.

The second patient requirement is that the system must be comfortable. Using sensor nodes that are lightweight, small, cost -effective and energy efficient allows EPs to feel secure, and conduct their daily activities with only the simple sensor nodes affixed to their clothing or body.

The third requirement is that the system be user friendly. The sensor nodes must be simple to install/ uninstall, so patients can easily remove them when they wish (e.g. eating, sleeping, playtime), and replace them afterwards.

This chapter examines the proposed EPMS which is a WSN-based monitoring system focuses on the continuous monitoring of the Epilepsy Patients (EPs), discusses the overall system model, highlights the components and their manner of implementation and analyzes the functionality. It presents the communication architectures in WSNs, including the use of the Sensor Medium Access Control (S-MAC) protocol in our proposed system, and demonstrates the communication architecture in WPANs for the EPs monitoring. It concludes with a summary of the system description.

3.2 OVERALL MODEL ARCHITECTURE

In this section, we define two architectures: the EPs system architecture and the overall monitor architecture.

3.2.1 EPS SYSTEM ARCHITECTURE

Here, we demonstrate the monitoring system, including the sensor nodes attached to a patient's body. Figure 3.1 shows the EPMS, which consists of five MICAz sensors positioned on the patient's left arm, right arm, left thigh, right thigh and over the heart. The nodes connect wirelessly with a coordinator node positioned on the patient's mid-torso, and the coordinator node connects with a receiving node located away from the patient's body. Four sensors are spread over the motion body parts to sense the EP sudden motions; the fifth sensor is on the patient heart to sense the rapid beat.

The EPMS uses MICAz sensor motes developed by Crossbow Technology, which enable low-power networking.

For networking, the MICAz nodes communicate using the IEEE 802.15.4 standard, and include MAC layer specifications. They are powered by an AA batteries that are changed at least once a year [WIK13] [CRO13].

The MICAz mote has various specifications that control its performance, which means it must be used according to its specified datasheet. A MICAz mote is shown in Figure 3.2.

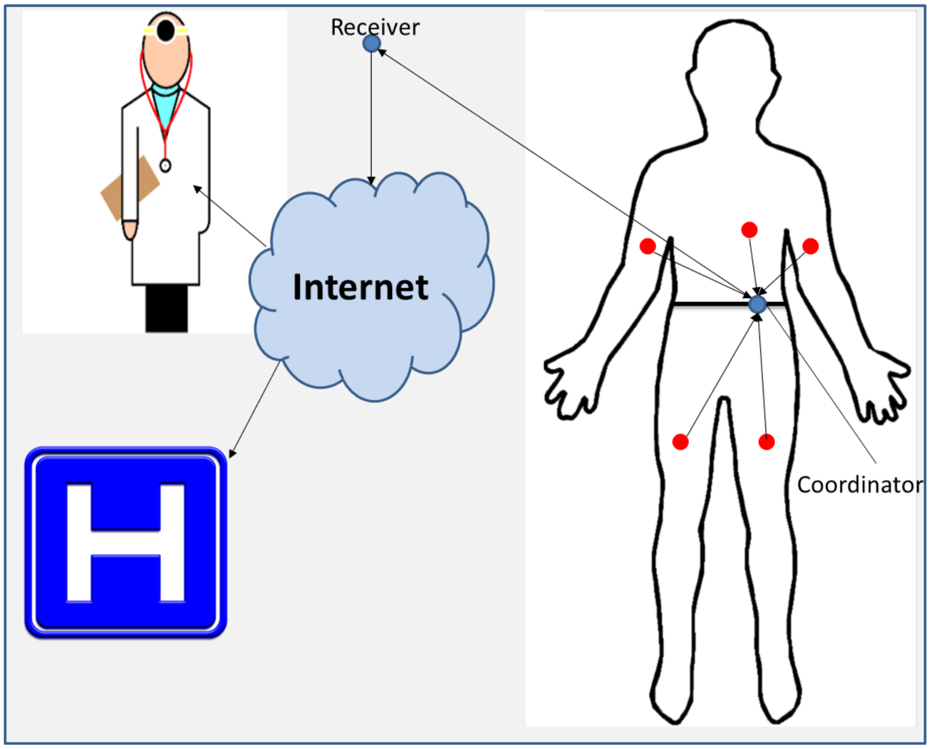

Figure 3.1: Epilepsy Patients Monitoring System.

Figure 3.2: MICAz mote [CRO13].

EPMS employs the tree topology. The five nodes on the patient's body are connected to the coordinator and can transmit data to it; they are not connected to each other and do not exchange data. The coordinator collects the information from the five nodes and transmits it to the receiver node, which is located away from the patient's body. The receiver collects the data and sends it to the desired end user (e.g. hospital, doctor) through a network connection.

3.2.2 OVERALL MONITORING ARCHITECTURE MODEL

The overall architecture model for the EPMS based on the existence of nodes is shown in Figure 3.3.

The overall architecture model consists of two sections, the first section contains the sensor nodes which are spread on the EP's body (the coordinator with the nodes (N1-N5)), and on the other hand the second section contains the nodes which are outside the EP's body (Receiver node).

In order to simplify the EPMS overall model, we implement it by using layers as shown in Figure 3.4.

From Figure 3.4, it is clear that the system consists of three layers, connected in a 5:1:1 layout. The first layer consists of five nodes connected wirelessly with the second layer which send data and are connected to the coordinator. The relation between the first and the second layers is represented as a 5:1 connection. The third layer contains the receiver where the relation between the second and the third layers is represented as a 1:1

connection, in which the coordinator connects wirelessly and sends data to the receiver node only.

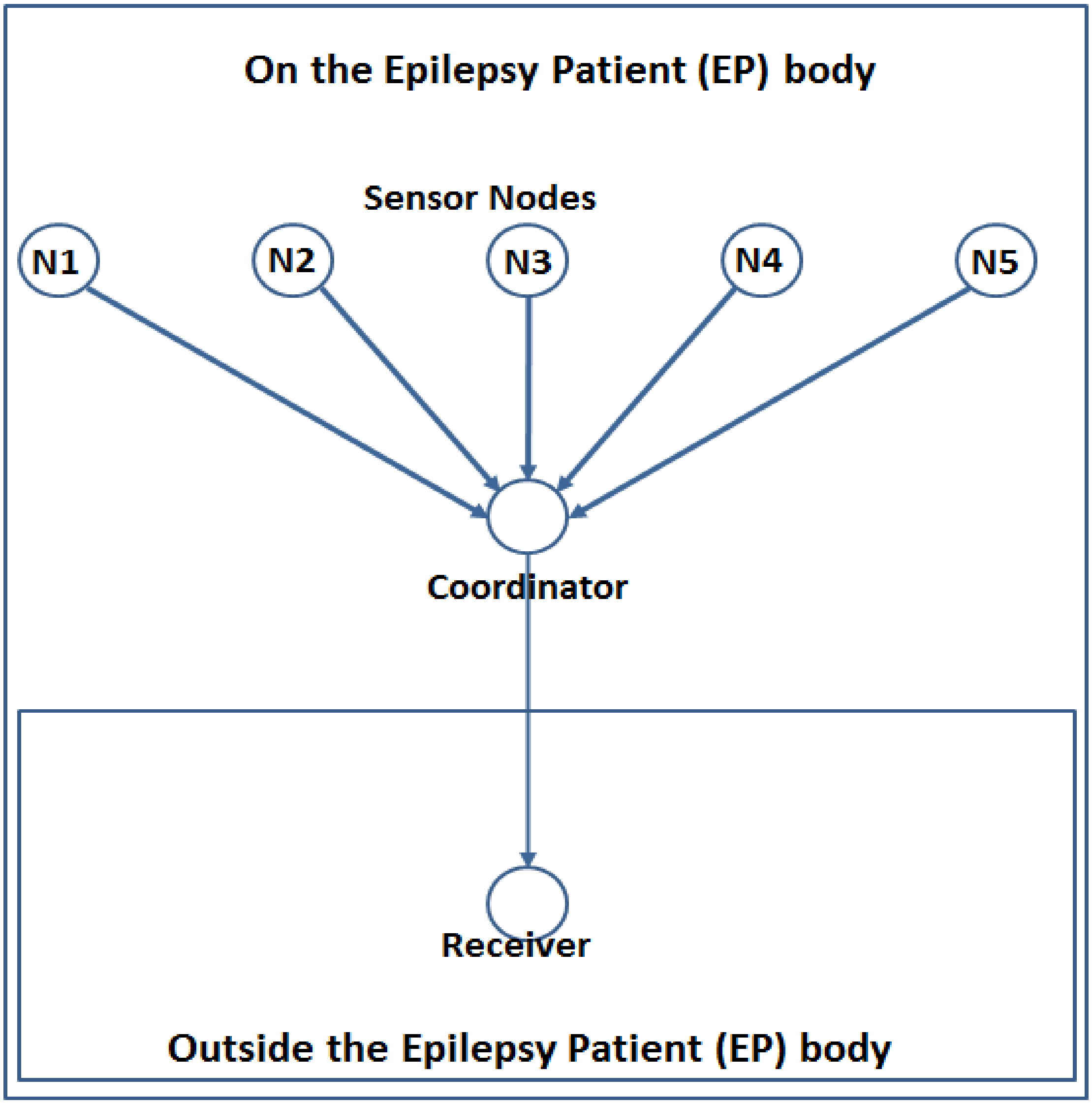

Figure 3.3: EPs overall architecture.

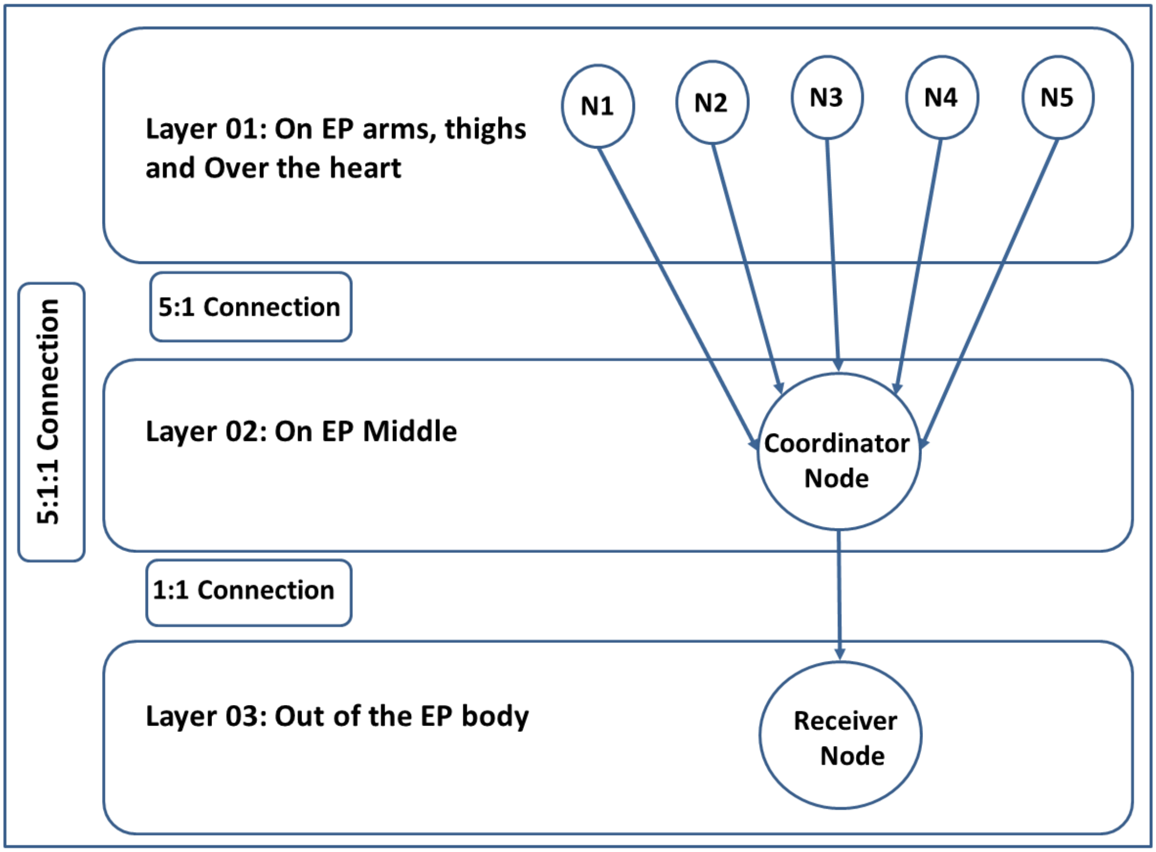

Figure 3.4: Layers presentation of EPMS.

3.3 COMMUNICATION ARCHITECTURE IN WSNS

This section discusses the communication architecture for different protocols. The first sub-section focuses on the MAC protocol, and the second on the SMAC protocol. The third sub-section presents the WPAN/ZigBee protocol.

3.3.1 MAC PROTOCOL

MAC is the data communication protocol that enables terminals and network sensor nodes to communicate with a multi-access network. This protocol has diverse functions, including 1) framing by defining the data frame format and doing the data encapsulation and the de-capsulation, 2) flow control by preventing any frame losses through overloaded buffers, 3) controlling medium access (the main function in MAC) by monitoring the connected devices in communication at any time, 4) error control by applying the error detection and correction algorithms to monitor the number of errors generated, and 5) ensuring the success of data transmission between the connected nodes (i.e. reliability) [KRE06].

3.3.2 SENSOR-MAC (S-MAC) PROTOCOL

S-MAC is a new MAC protocol, designed to enable WSNs to perform functions such as decreasing power consumption, increasing flexibility for the WSNs and avoiding collisions between the sensor nodes. S-MAC consists of three elementary and another secondary component, as described below [YE02]:

1) Periodic Listen and Sleep (PLaS)

In many WSN applications some nodes are idle for long periods, not sending or receiving data and thereby conserving approximately 50% of the overall energy [YE02]. PLaS means a node is in sleep-mode for a while (ex. set the duty cycle to 10%; sleep for 2s), then awakens and listens for any node trying to contact it. In the sleep state, the node powers off its radio and set a timer for when to wake. The sleeping and waking times are calculated according to different scenarios, application dependent, and are identical for all nodes.

Synchronization is an essential issue in the S-MAC listening time, as it establishes the synchronization between neighboring sensor nodes. The SYNC message is exchanged within the synchronization time. A scenario of the messaging mechanism in SMAC is shown in the Figure (3.5).

In the listening period, the messaging process is subdivided into two parts. The first part includes the SYNC message exchanges, and the second one includes the CTS, RTS and the data packets exchange [ABI12].

It is obvious that the data packets follow the RTS/CTS/ DATA /ACK sequence which indicate the using of unicast data transmissions while the broadcast sent without using the RTS/CTS control packets.

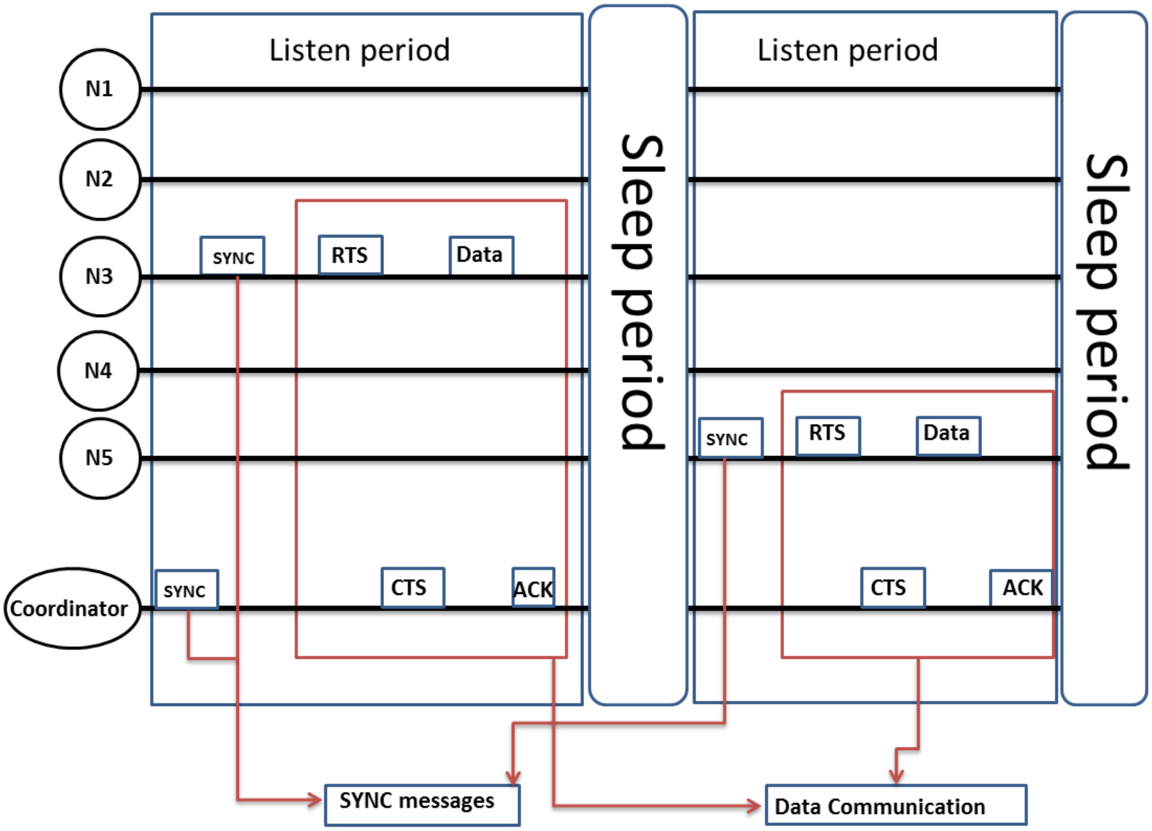

Figure 3.5: Unicast PLaS messaging.

All nodes choose their sleep/listen schedules, exchange the schedules by broadcasting to all neighboring nodes, and keep the schedule tables of their neighbors' schedules. When a node wishes to communicate with the coordinator, it waits until the coordinator node is in listening status, performs carrier sense before initiating a transmission then begins the sending process with a Request To Send packet (RTS). The coordinator node replies with a Clear To Send packet (CTS). The timing between the sender nodes and the coordinator is shown in Figures 3.5 and 3.6.

If a node misses the transition medium, it goes to sleep and wakes up when the coordinator is free and in the listen period.

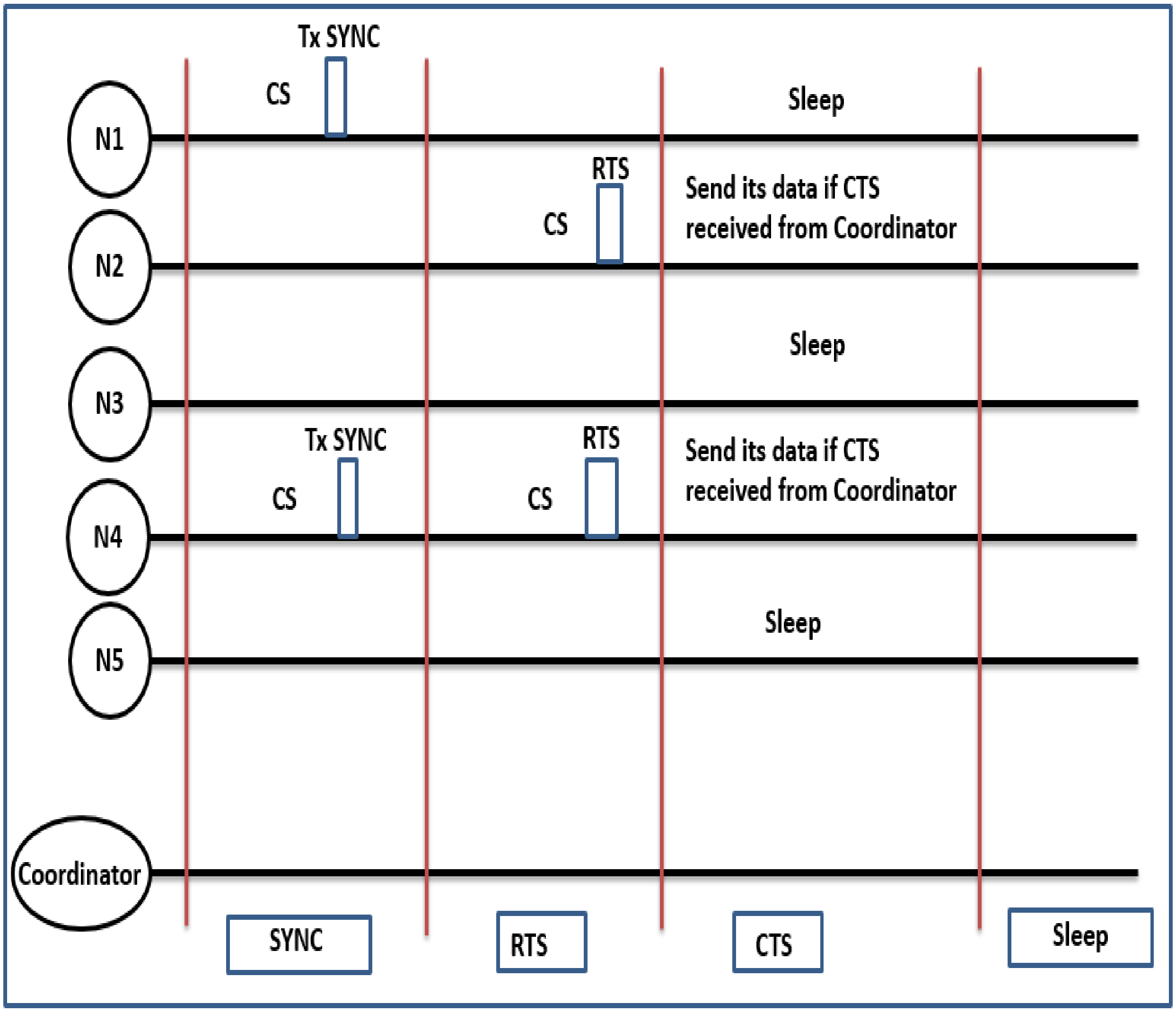

Figure 3.6: timing between sender nodes and the coordinator in SMAC protocol.

When a node is choosing its schedule and building its schedule table, it first listens for a while depends on the chosen duty cycle (ex. 10% duty cycle means a frame length for 1.15 sec).Then, based on the synchronization procedure, it has many options, as follows [YE02]:

A. If it does not hear a schedule, it chooses when to sleep and broadcasts its schedule in a SYNC message indicating the time of sleep. This node is the synchronizer, because it initiates the synchronization process and all nodes synchronize with it.

B. If it hears a schedule, it sets its schedule the same as the received one. Then it becomes a follower node, and waits a while (based on the chosen duty cycle) before rebroadcasting its schedule to avoid expected collisions.

C. If it selects and broadcasts its schedule then hears a different one, it adopts the two schedules and broadcasts the new one before sleeping.

D. In the large networks, all nodes could not follow the same schedule. The node on the border has to follow two schedules, so when it's time to broadcast a packet, it has to broadcast it twice; first for the schedule 1 and second for the schedule 2.

2) Collision and Overhearing Avoidance (CaOA)

A. Collision Avoidance (CA)

The basic mission of the MAC protocol is to avoid collisions that occur when multiple senders attempt to simultaneously broadcast to the same receiver. In each transmitted packet there is a field indicating the length of transmission process. This helps introduce a variable called the Network Allocation Vector (NAV) [YE02] which functions as a timer for the node. Thus, if a node wants to transmit data it first checks the NAV, where a value (known as the virtual carrier sense [JOV01]) above zero indicates that the medium is still busy. Another sense (the physical carrier sense) functions in the physical layer, and indicates the availability of the transmission channel. When the virtual and the physical carriers are free, the entire medium can be transmitted.

The Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) mechanism is used to begin transmission of the data when the DATA time arrives, and it also helps manage the collision problem [INF14].

Figure 3.7 presents an example of the data transmission in our proposed EPMS system. The five ordinary nodes (sender) are represented as (N1-N5). The CSMA/CA mechanism is used to avoid any collisions.

In this example N1 is start the data transmission by sending the RTS packet , the coordinator reply by the CTS control packet then N1 start its Data transmission and the coordinator reply by the ACK packet to confirm the arrival of data. During the data transmission between the N1 and the coordinator it is clear that the other nodes are in the sleep period. N2 is ready to send data but it waits until the coordinator is clear to receive data. Another data transmission example is shown between the coordinator and the receiver.

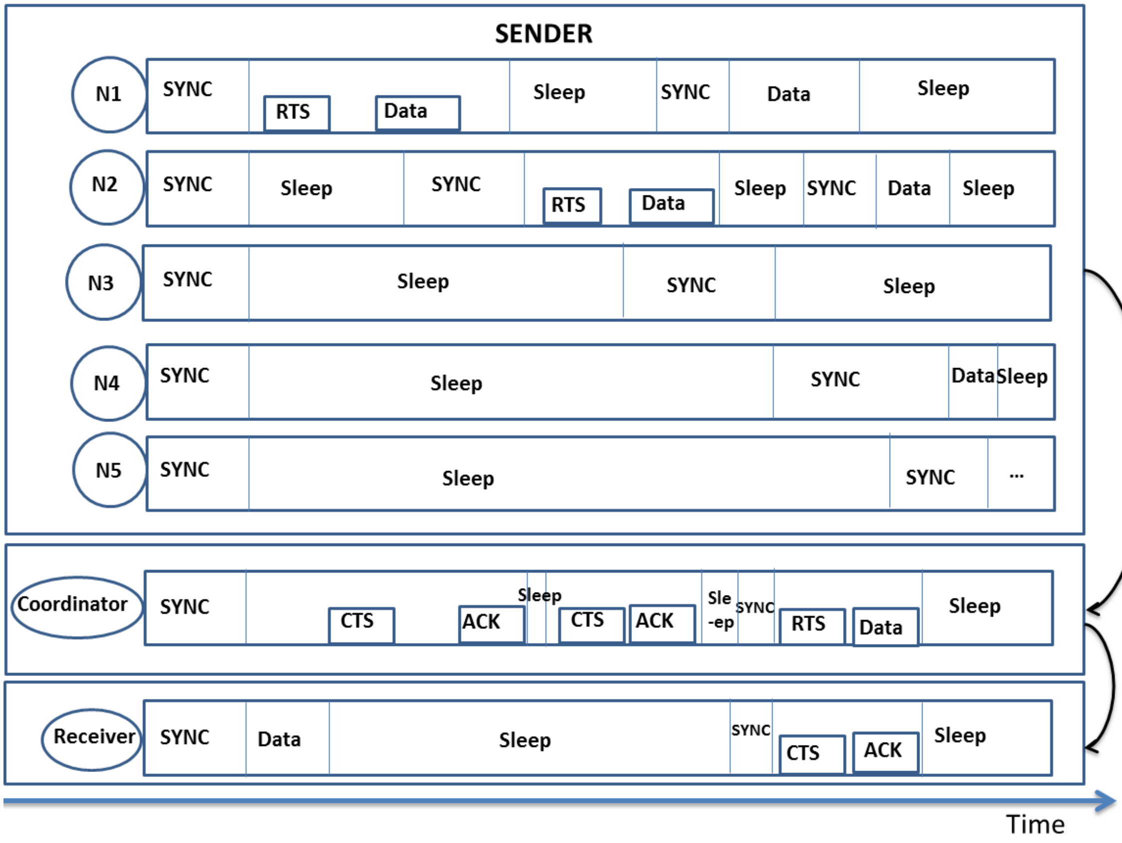

Figure 3.7: Data transmission example in the proposed Epilepsy Patients Monitoring System.

A flowchart representation of the data transmission in EPMS is shown in Figure 3.8.

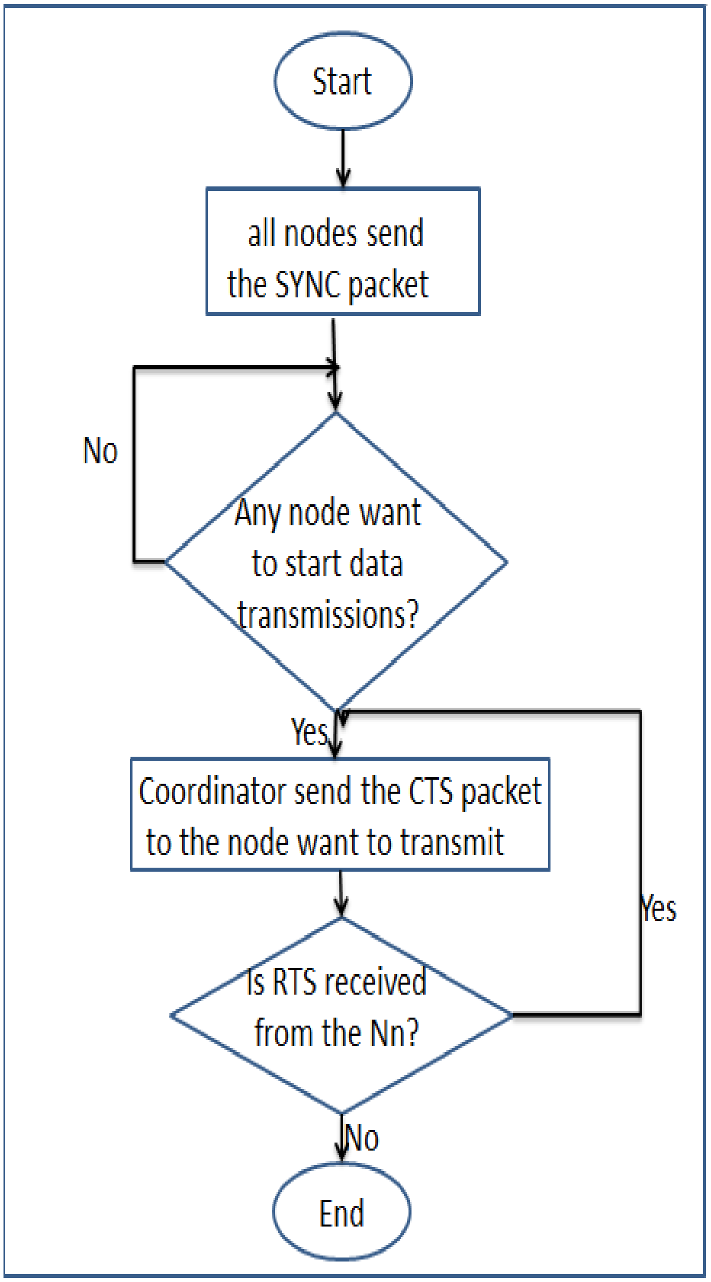

Figure 3.8: Data transmission in Epilepsy Patients Monitoring System flowchart.

B. Overhearing Avoidance (OA)

This is done by placing the interfering nodes in sleep mode after they hear control packets such as the RTS or CTS.

This approach prevents neighboring nodes from overhearing the DATA packets and the ACKs that follow them [YE02].

3) Message passing (MP)

If a long message is divided into several smaller ones, and begins to transmit them, every time a data fragment is transmitted the receiver sends back an ACK indicator. If the sender does not receive the ACK it increases the reserved time for another fragment, and re-transmits the failed one.

The MP procedure has certain disadvantages, including 1) the high cost of retransmission of a long message if parts are corrupt, and 2) a decreased number of control packets, since it uses only one CTS and RTS for all the parts of a long message [YE02]. An example of the MP procedure is shown in Figure 3.9.

4) Adaptive listening

By letting the nodes who overhear its neighbor transmission stay awake. It helps in reduce the periodic sleep by at least a half of its value. The neighbors determine the long of the transmission process from the CTS and RTS packets duration field. And they adaptively wake up when the data transmission finish.

An example about the adaptive listening is shown in Figure 3.10.

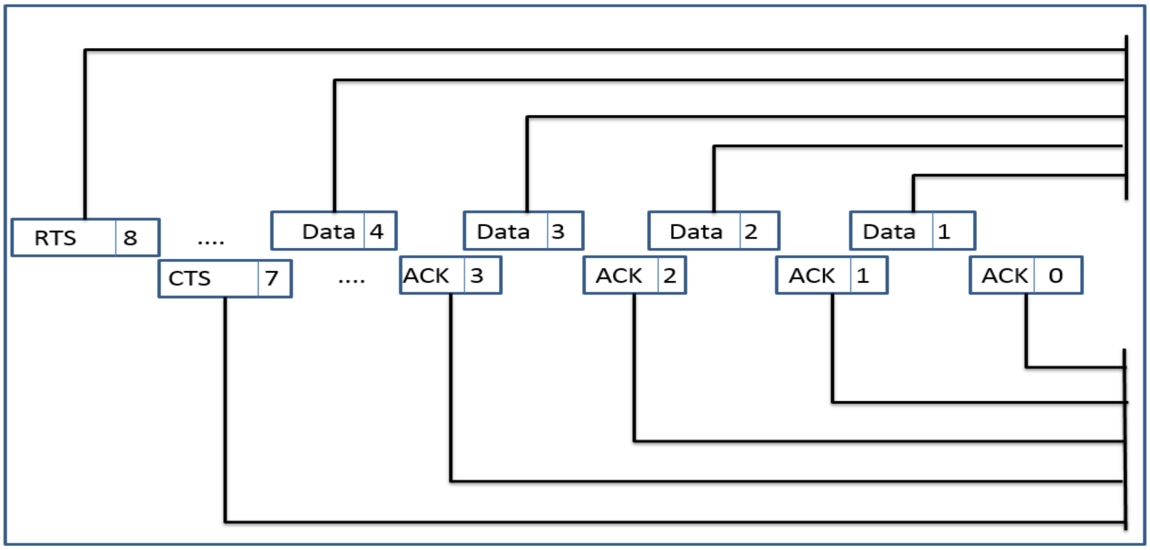

Figure 3.9: Message passing procedure.

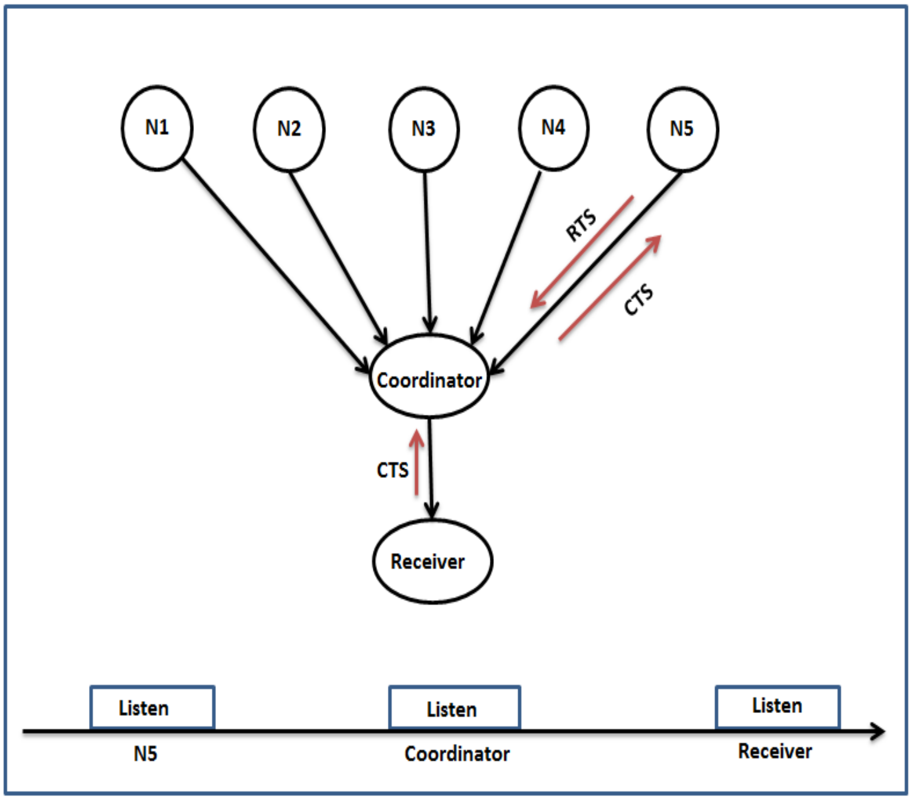

Figure 3.10: Adaptive listening in Epilepsy Patients Monitoring System example.

From Figure 3.10, it is clear that the N5 try to send its data to the coordinator by send the RTS packet, the coordinator reply by the CTS packet which is heard from the receiver. The receiver leftovers awake as a result for the coordinator CTS hearing.

As a result of the previous studied characteristics, SMAC meets the major communication and patient requirements needed for the proposed EPMS system, as detailed in Tables 3.1 and 3.2.

Table 3-1: SMAC Communication requirements analysis.

EPMS Communication Requirements	SMAC Characteristics	Requirements met or not
Energy saving	Power savings with CSMA/CA MAC	Encountered
Need to be in tree topology	Work for tree	Encountered
Need specific type of medical nodes for monitoring purpose	Work with mission critical applications with specific medical nodes.	Encountered
Need to cover a large area for the outdoor monitoring purposes	Coverage is high	Encountered
Reliability	Use the CA packet before each transition. Use the CSMA/CA	Encountered

Table 3-2: SMAC Patients requirements analysis.

EPMS Patients Requirements	SMAC with the MICAz Characteristics	Requirements met or not
The life time of the system which has to be long enough	Use the MICAz w motes which use an AA batteries for a more than year	Encountered
The system has to be easy to install and uninstall by the patients	MICAz sensors very easy to attach/de attach	Encountered

3.3.3 COMMUNICATION ARCHITECTURE IN WPANS/IEEE 802.15.4

WPAN is a group of wearable medical sensor nodes attached to the user's clothing. They communicate using the personal area network or the body area network, and connect to a specific receiver (e.g. medical services for emergencies).

Using WPANs in wireless monitoring systems requires a strong focus on security and reliability. Security is achieved by data encryption and by balancing the strength of the encryption with the power [JOV01].

ZigBee is a standard developed by the ZigBee alliance for PAN networks that assists EPs with monitoring procedures. Due to its networking characteristics, ZigBee meets the relevant communication and patient requirements, as detailed in Tables 3.3 and 3.4.

Table 3-3: ZigBee Communication requirements analysis.

EPMS Communication Requirements	ZigBee (IEEE 802.15.4) Characteristics	Requirements met or not
Need to be in tree topology	Work for Star, tree, mesh	Encountered
Need specific type of medical nodes for monitoring purpose	Work with control and monitor applications	Encountered
Need to cover a large area for the outdoor monitoring purposes	Coverage range from 1m to 75 m and more	Encountered
Reliability	Use the CSMA/CA	Encountered

Table 3-4: ZigBee Patients requirements analysis.

EPMS Patients Requirements	ZigBee (IEEE 802.15.4) Characteristics	Requirements met or not
Need to cover a large area for the outdoor monitoring purposes	Coverage range from 1m to 75 m and more	Encountered
The life time of the system which has to be long enough	100 – 7000 days	Encountered
The system has to be easy to install and uninstall by the patients	ZigBee automatically establish its network	Encountered

The EPMS system consists of seven nodes that are processed using the ZigBee-based network. The five ordinary nodes are represented as five ZigBee-based nodes, and each node consists of three units: a microcontroller, a transceiver and an antenna. Reduced-Function Devices (RFD) transmits the information to the coordinator and do not receive data. The coordinator is a Full-Function Device (FFD) because it receives data from the ordinary nodes and sends data to the receiving node, represented in ZigBee-based network as the Router which is also an FFD.

In the EPMS system, the focus is on only the physical and MAC layers of the ZigBee Architecture. The physical layer performs transmission and reception of information. The MAC layer accesses the network using Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) to transmit the beacon frames.

When ZigBee-based network is in the beacon enabled transmission mode, the sensor node does not transmit data to the coordinator until it receives a beacon frame that indicates transmission procedure startup. To reply to the beacon frame, the sensor node begins transmitting the data to the coordinator, who confirms receipt by sending an acknowledgement packet. The transmission of data in the EP system is based on the beacon enabled mode, as represented in Figure 3.11.

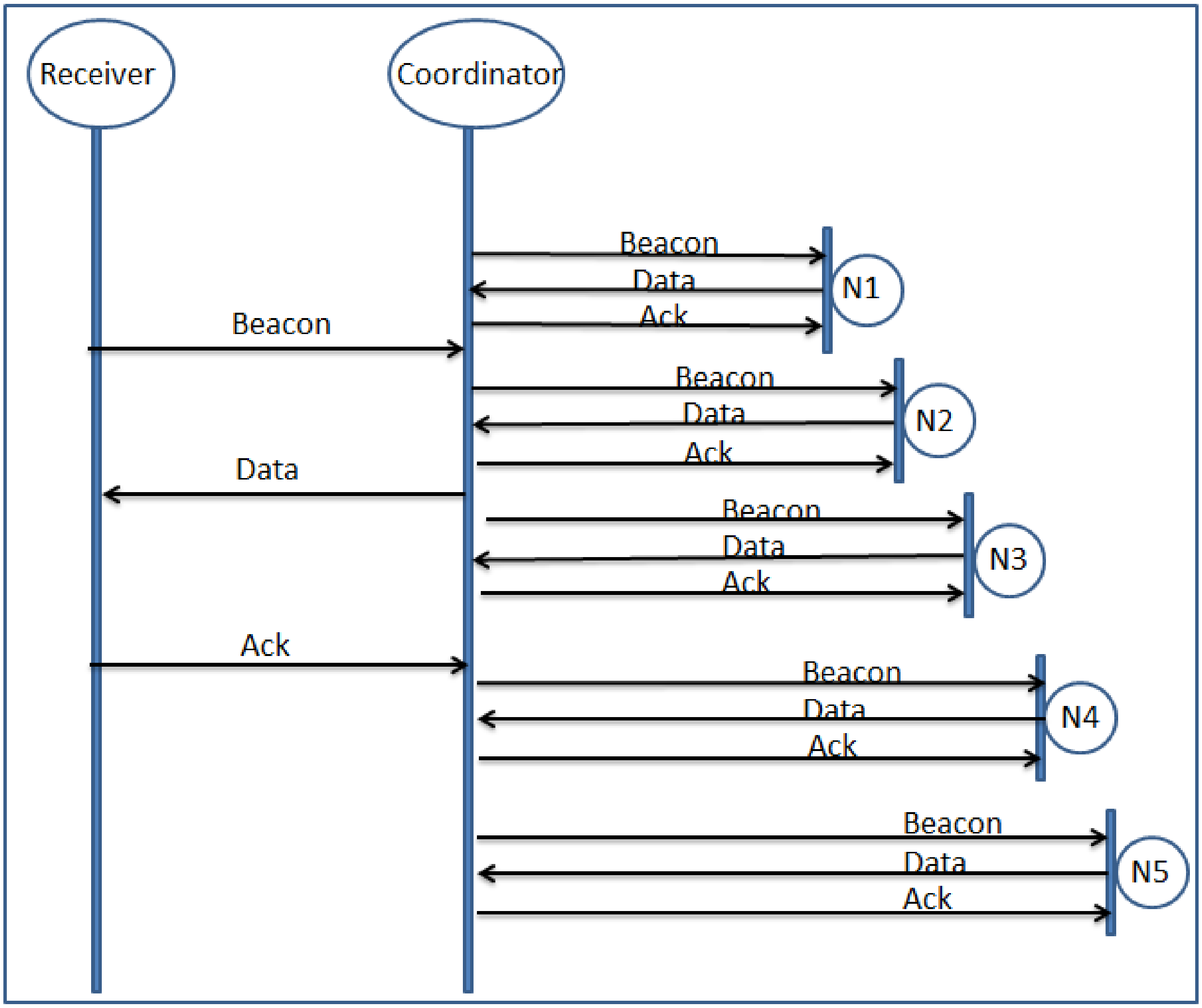

Figure 3.11: Beacon enabled transmission for EPMS system.

3.4 SUMMARY

We have summarized the potential communications and users requirements. We have also proposed an architecture for the EPMS, using the SMAC-based WSNs and the WPANs networking procedures. The WSN system model has been described using the MAC wireless protocols, specifically the SMAC, and the WPANs have been described using the IEEE 802.15.4 standard.

The description and communication procedures of each entity are presented and all relevant requirements, including those of patients and communications, are met in our model.

CHAPTER 4 SIMULATION AND PERFORMANCE EVALUATION

4.1 INTRODUCTION

In the previous chapter, we have proposed an architecture model that addresses the monitoring issues of Epilepsy Patients (EPs) using Wireless Sensor Networks (WSNs) and Wearable Personal Area Networks (WPANs). This chapter describes the implementation of the architecture using the Network Simulator version-2 (NS-2) simulator, based on the Sensor Medium Access Control (SMAC) and ZigBee protocols. We also discuss the use of different settings for each communication protocol.

We validated the system architecture for different scenarios, and calculated specific performance measures. Our focus was on the end-to-end delay and the data throughput for the different tested protocols, and the comparisons made between them.

4.2 SIMULATION MODEL

Our research developed a monitoring system in WSNs and WPANs that can be used by EPs. We implemented all the sensor nodes (Ordinary, Coordinator and Receiver), as well as the different communication protocols used.

NS-2 and the C++ programming language in the Linux environment are used in the EPMS to simulate the proposed system. The NS-2 definition and tools in Appendix A.

The researchers focused on the simulation of SMAC protocol and ZigBee protocol in NS-2, and compared the two protocols to determine if the SMAC protocol is more efficient for healthcare monitoring applications (particularly for epilepsy).

The simulation model section is in two parts. The first part defines the important features of the SMAC and ZigBee protocols in the NS-2 simulator, and the second presents the detailed system topology in a schematic graph.

4.2.1 SMAC AND WPAN/ZIGBEE/IEEE 802.15.4 IN NS-2

Similar to other protocols, the SMAC protocol can be simulated in NS-2. However, it has many elementary features not found in other protocols, including Periodic Listen and Sleep (PLaS), Collision and Overhearing Avoidance (CaOA), Massage Passing (MP), synchronization algorithms and Adaptive Listening. The SMAC parameters can be written and altered in a C++ file, while other parameters are written in a tcl file to enable users to change the values. Some of these parameters are listed in Table 4.1. We can set up the values in the Tcl file before the running of the simulation.

Table 4-1: SMAC-NS2 parameters.

SMAC parameters	Definition
dutyCycle_	It controls the length of sleep. The default value is 10%. Active only when syncFlag_ is 1.
syncFlag_	If =1, SMAC runs with periodic sleep. If =0, SMAC runs without periodic sleep.
selfConfigFlag_	If=1, SMAC nodes follow the schedule initialization algorithm. If=0, the schedule start time for each node is user-configurable.

The researchers excluded some commands of the SMAC simulation in the NS-2 environment. It is clear that the system topology ranges over 500m x 500m, the Mac protocol used is the SMAC, the simulation time is 20000 seconds, the syncFlag property is activated, there are seven nodes, and the dutyCycle is the default value, as shown in Figure 4.1.

```
set opt(x)          500   ;
set opt(y)          500   ;
set opt(nn)              7;
set opt(mac)    Mac/SMAC
set opt(stop)        20000.0
Mac/SMAC set syncFlag_ 1
Mac/SMAC set dutyCycle_ 10
```

Figure 4.1: SMAC NS-2 parameters.

The ZigBee modules in the NS-2 version require definition of the Medium Access Control (MAC) and the physical (PHY) layers only. Therefore, any interface needed for the higher layers must be achieved using intermediate sub-layers above the MAC layer: the Service Specific Convergence Sub-layers (SSCS).

The WPAN simulation procedure begins by scheduling the events already predefined by the user in the scenario file. The written TCL file is scheduled first, including the events (i.e. creating a new simulator, starting the nodes and starting the traffic).

The Personal Area Network (PAN) coordinator is switched on, and defines the transmission start time for the remote nodes: the Beacon Order (BO), the Superframe Order (SO) and the Beacon Transmissions (txBeacon) values, as in the following example.

```
$ns_ at 0.0 "$node_ (5) NodeLabel PAN Coor"
$ns_ at 0.0 "$node_ (5) sscs startPANCoord 1 4 4"
```

The researchers exclude some of the ZigBee simulation commands in the NS-2 environment, use the Mac/802_15_4 protocols and the DSR routing protocol, and includes some of the ZigBee NS-2 settings, as shown in Figure 4.2.

```
set val(mac)          Mac/802_15_4            ;# MAC type
set val(rp)          DSR      ;# routing protocol script
set val(x)               500     ;# X dimension of the topography
set val(y)               500             ;# Y dimension of the topography
set val(nn)              7               ;# number of nodes
Mac/802_15_4 wpanCmd verbose on
Mac/802_15_4 wpanNam namStatus on
```

Figure 4.2: ZigBee NS-2 parameters

4.2.2 EPS SYSTEM TOPOLOGY

The researchers created a WSN topology using seven sensor nodes. Five of the nodes are ordinary nodes affixed on the patient’s body, another is the coordinator node located on the EP’s mid-torso, and the seventh node is the receiver, located somewhere away from the patient’s body. All the nodes are of the MICAz type.

The network topology is 500m x 500m, and the sensor nodes are dispersed within it. To facilitate recognition by the users, the nodes are different colors; the coordinator is blue, the receiver is yellow and the other five are red. The simulation time is set to 20000 seconds, and the packet transmission begins at 8000 seconds and terminates at 20000 seconds. The routing protocol used for the program is the TCP agent, with the FTP for the application layer.

Figure 4.3 presents a diagram of the sensor nodes in the Epilepsy Patient Monitoring System (EPMS). The NS-2 Visual Trace Analyzer program was used to draw the sensor nodes [ROC14].

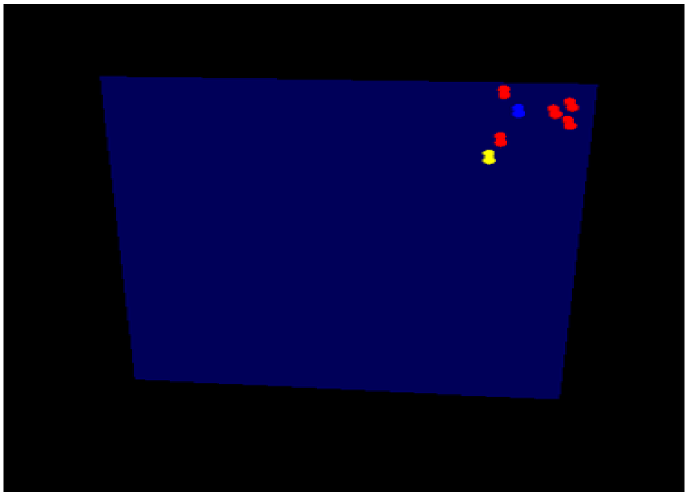

Figure 4.3: Sensor nodes of the Epilepsy Patients Monitoring System [ROC14].

The EPMS topology in a schematic graph, as shown in Figure 4.4. The NSG beta [WU14] program is used to create the graph.

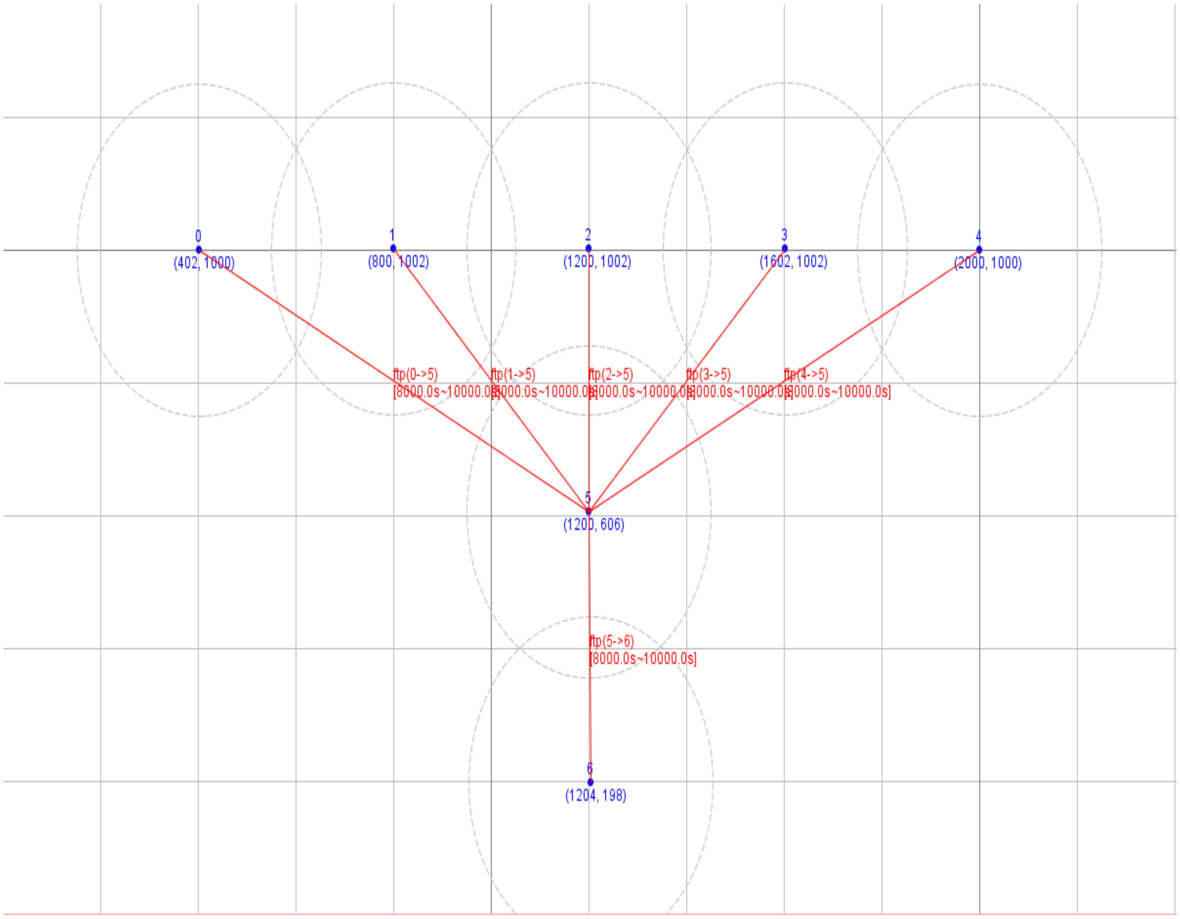

Figure 4.4: Schematic graph for the EPMS topology [WU14].

The system parameters assigned in the simulation are shown in Table 4.2.

Table 4-2: EPMS simulation parameters.

Simulation Parameter	Value
Channel	Channel/WirelessChannel
Propagation	Propagation/TwoRayGround
Mac Protocol	Mac/SMAC Mac/802_15_4
Queue	Queue/DropTail/PriQueue
Link layer	LL
Antenna	Antenna/OmniAntenna

Topology X and Y	500x500
Physical layer	Phy/WirelessPhy
number of nodes	7
Simulation time	20000 second
Agent	Agent/TCP
Energy model	EnergyModel
Radio model	RadioModel
Initial energy	1000
Packet Size	512

4.3 PERFORMANCE MEASUREMENTS

In this section, we discuss the performance results of the system topology simulation using the SMAC and the IEEE 802.15.4/ZigBee protocols, in two parts. The first part presents the performance metrics of the end-to-end delay and the throughput for each protocol, and the comparison results for the protocols. The second part shows the verification and the validation of the results to decide which protocol best serves the EPMS, and defines why we chose the SMAC protocol for our system.

4.3.1 METRICS

This section presents the simulation results of the tested EPMS. The basic goal of this research is to minimize delay between a seizure occurrence and the response. The first section focuses on finding the end-to-end delays and the throughput for the system using the SMAC/ZigBee protocols. The second section compares the protocols, and indicates the research goal satisfaction.

4.3.1.1. The end-to-end (e-2-e) delays and throughputs

4.3.1.1.1. SMAC delays

This section presents the e-2-e delays for the EPMS, using the SMAC protocol over the receiver node. The e-2-e delays have been calculated with the number of transmitted packets and the number of nodes.

A. SMAC delays with transmitted packets

This section presents the e-2-e delays per transmitted packets for the EPMS, using the SMAC protocol over the receiver node. Figure 4.5 shows the average e-2-e delay per transmitted packet for the SMAC protocol.

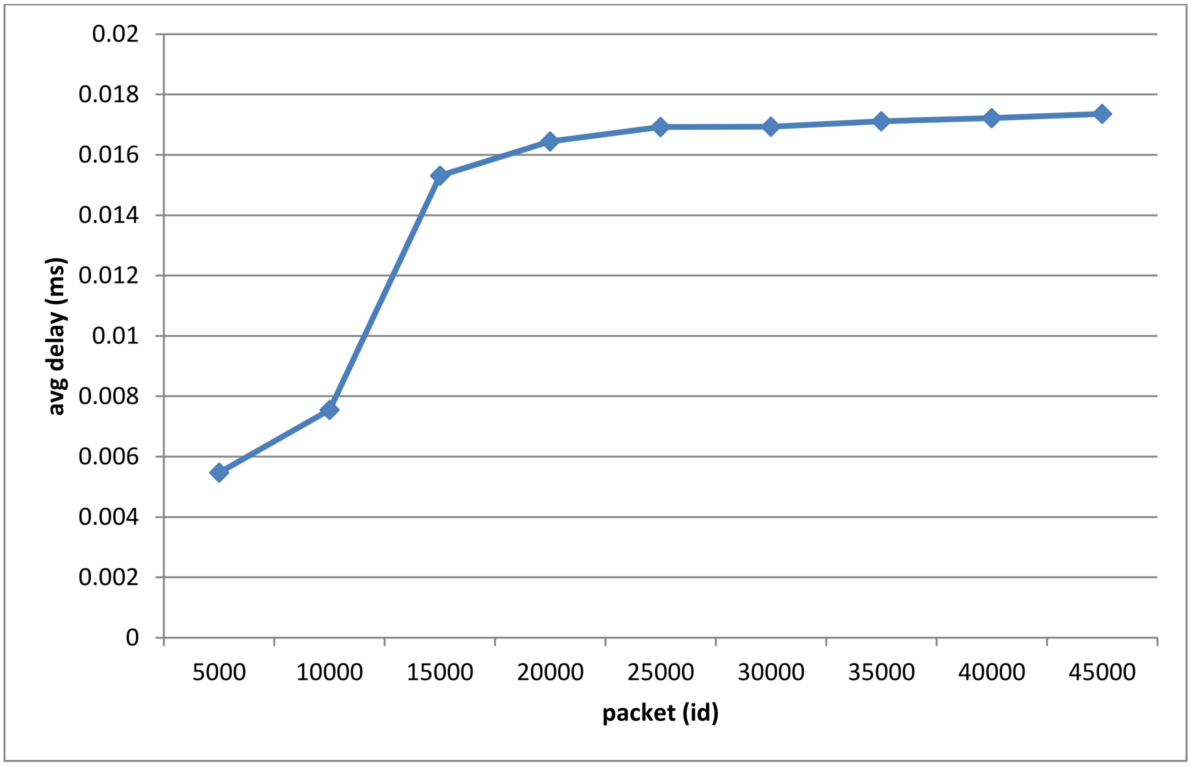

Figure 4.5: Average e-2-e delay with the number of transmitted packets in SMAC.

The e-2-e delay is start being in the steady-state with the first ~15000 transmitted packets; it reaches to ~ 0.015-0.02 ms.

B. SMAC delays with number of nodes

To make the results obvious, we found the average delay with the different numbers of hops as shown in the Figure (4.6). The average delay is increasing with the number of nodes.

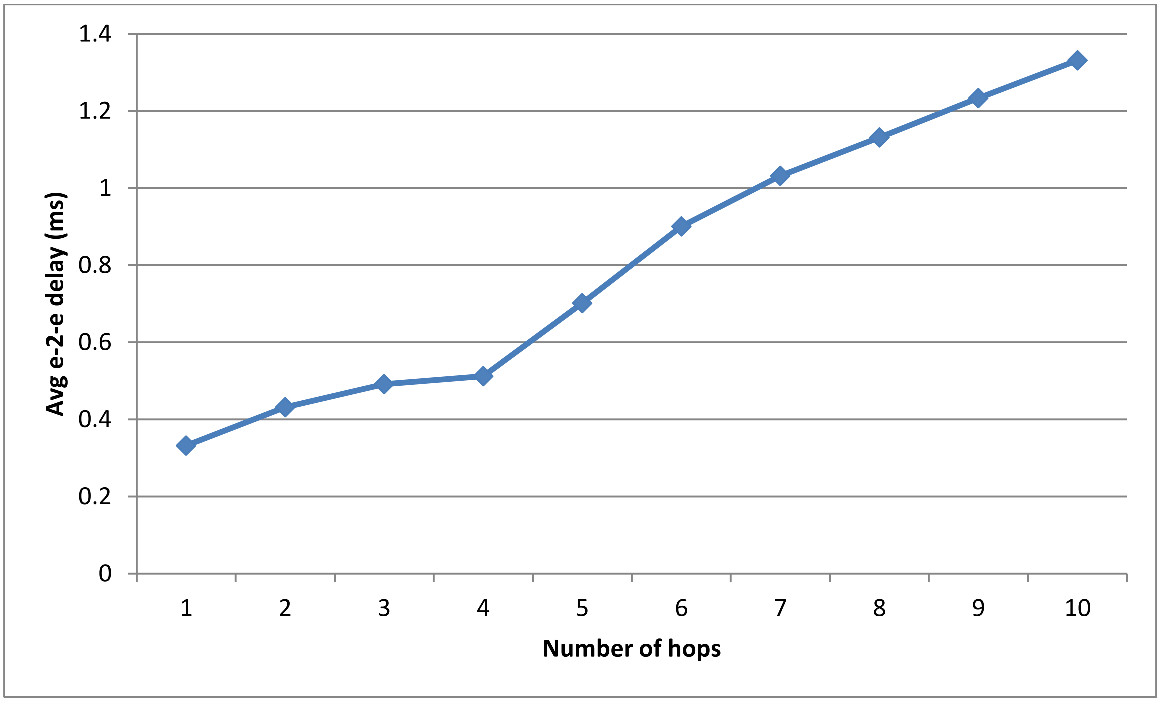

Figure 4.6: The e-2-e delay in SMAC protocol with the Number of hops.

4.3.1.1.2. ZigBee delays

This section presents the e-2-e delays for the EPMS, using the ZigBee protocol over the receiver node. The e-2-e delays have been calculated with the number of transmitted packets and the number of nodes.

A. ZigBee delays with transmitted packets

This section presents the e-2-e delays per transmitted packets for the EPMS, using the ZigBee protocol over the receiver node.

Figure 4.7 shows the average e-2-e delay per transmitted packet for the ZigBee protocol.

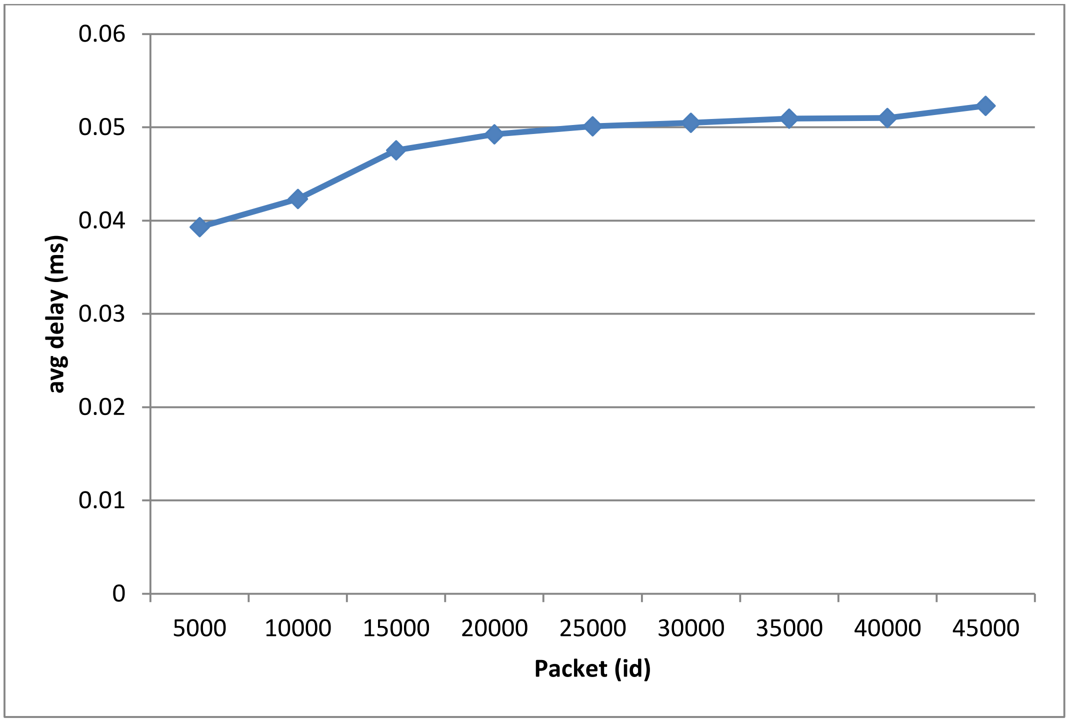

Figure 4.7: Average e-2-e delay with the number of transmitted packets in ZigBee.

The e-2-e delay is start being in the steady-state with the first ~15000 transmitted packets; it reaches to ~ 0.05 ms.

B. ZigBee delay with number of nodes

In Figure 4.8, the researchers find the e-2-e delay with the number of nodes using the ZigBee protocol.

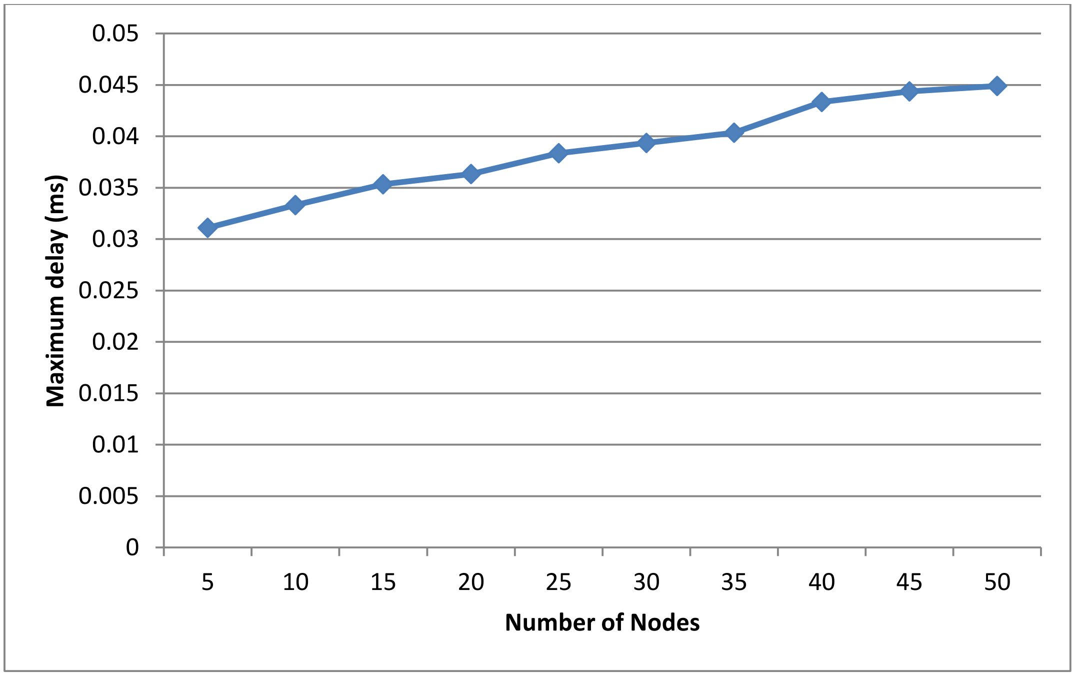

Figure 4.8: Average delay with the number of nodes.

From Figure 4.8 it is clear that the average e-2-e delay is increasing with the number of nodes increase.

4.3.1.1.3. SMAC throughput

Here, researchers focused on studying the throughput results for the SMAC protocol.

A. SMAC throughput with number of nodes

The SMAC throughput with the number of nodes is shown in figure 4.9.

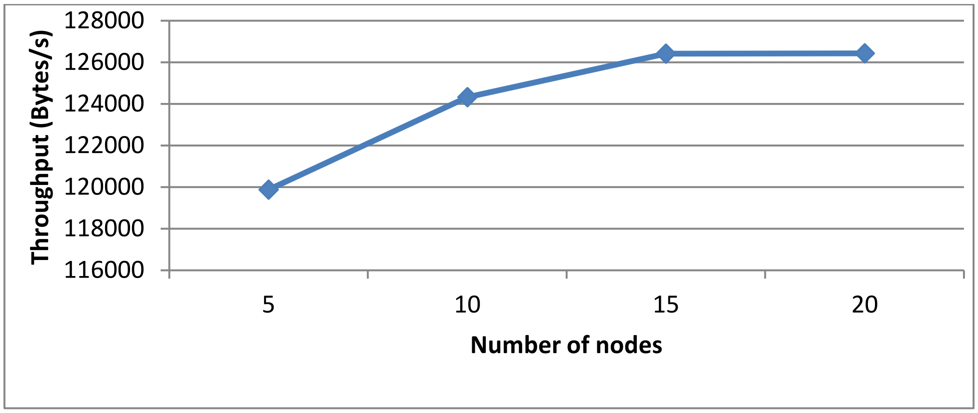

Figure 4.9: SMAC throughput with number of nodes.

4.3.1.1.4. ZigBee throughput

Here, we have focused on studying the throughput results for the ZigBee protocol.

A. ZigBee throughput per number of nodes

The ZigBee throughput with the number of nodes is shown in figure 4.10.

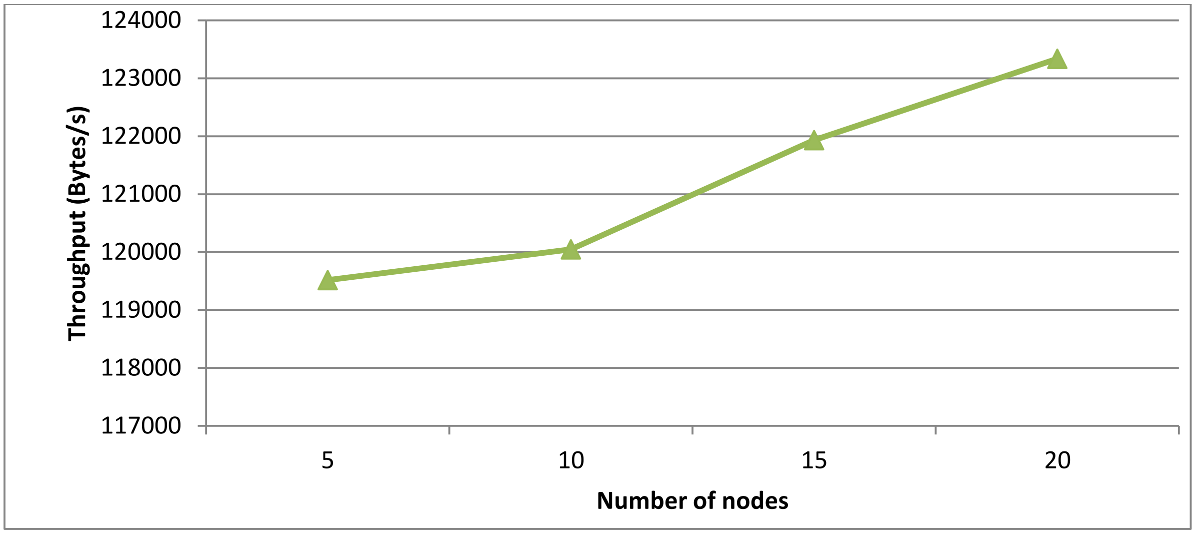

Figure 4.10: ZigBee throughput with the number of nodes.

4.3.1.2. Comparison between SMAC and ZigBee protocols

4.3.1.2.1. Delays per number of nodes

The results shown in Figure 4.11 represent the e-2-e delays with the number of nodes for the SMAC and the ZigBee protocols.

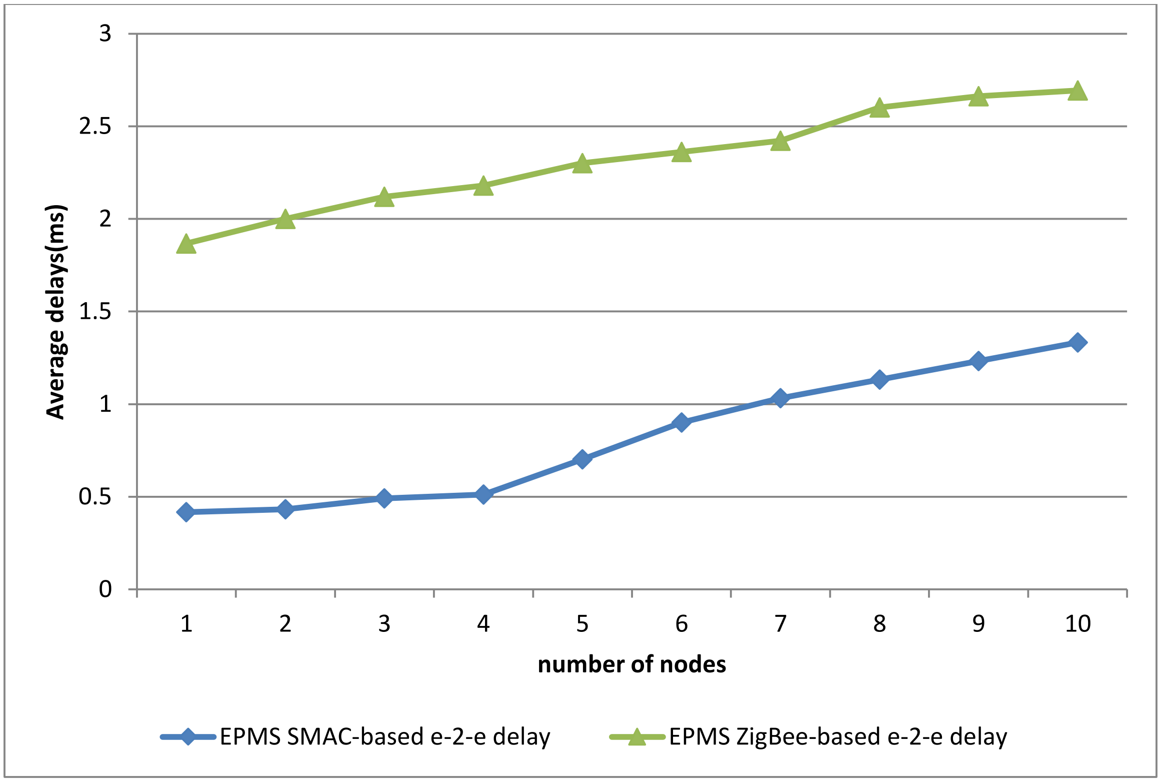

Figure 4.11: e-2-e delays with the number of nodes.

It is prove that the SMAC protocol provides smaller values of the e-2-e delays than the ZigBee protocol, which makes it more suitable for critical uses, such as medical applications.

4.3.1.2.2. Delays per transmitted packets

Other results have been founded to prove the suitability of using the SMAC protocol for the critical applications more than the ZigBee protocol, as shown in Figure 4.12. It represents the comparison in the generated delays by using the ZigBee and the SMAC protocols with the transmitted packets.

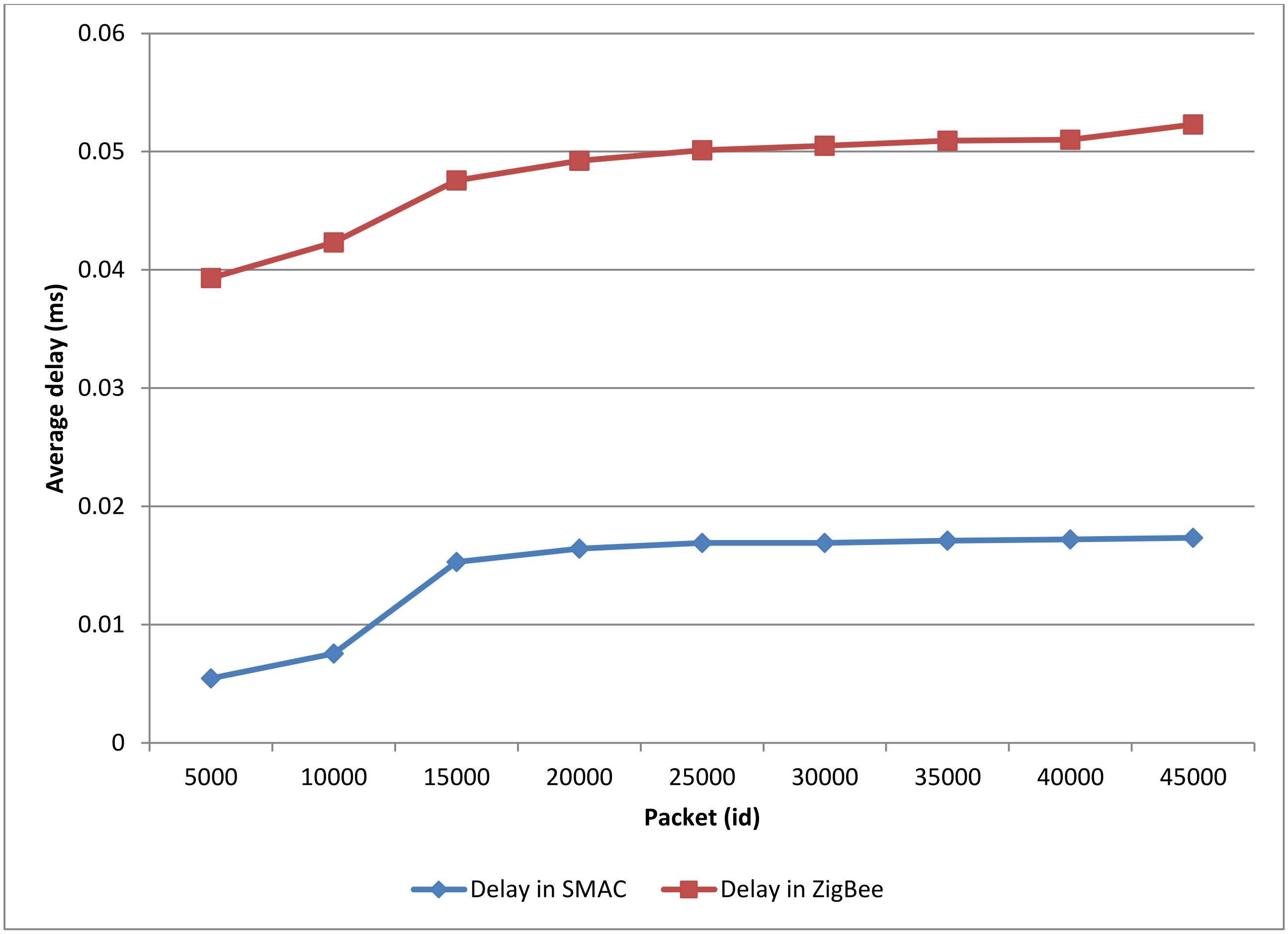

Figure 4.12: Average e-2-e delays with the transmitted packets.

It is clear that the average e-2-e delay per transmitted packet in the SMAC protocol is smaller than the average e-2-e delay using the ZigBee Protocol. This indicates the advantage of the using of the SMAC protocol rather than the ZigBee protocol for the proposed EPMS.

4.3.1.2.3. Throughput per number of nodes

A comparison between the SMAC and the ZigBee protocols based on their throughput with the number of node is shown in Figure 4.13.

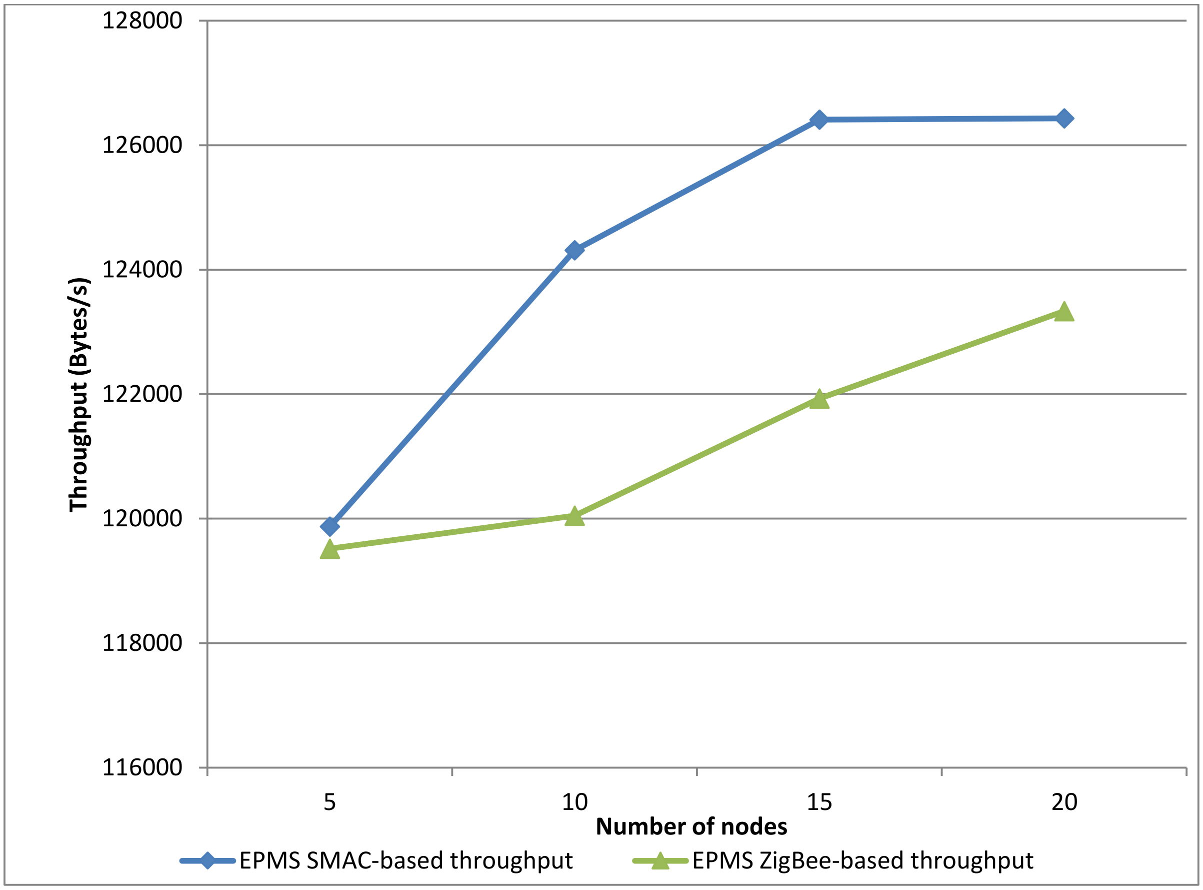

Figure 4.13: SMAC vs. ZigBee throughput with the simulation time.

4.3.2 VERIFICATION AND VALIDATION OF THE EPMS SMAC-BASED PROTOCOL

The verification and validation is a significant part of the model development process to decide if the system model and its implementation are correct, and to test the satisfactory level of accuracy [SAR12].

The relationships between the real and the simulation worlds with the verifying and validating approaches are described in Figure 4.14 as shown below [SAR12].

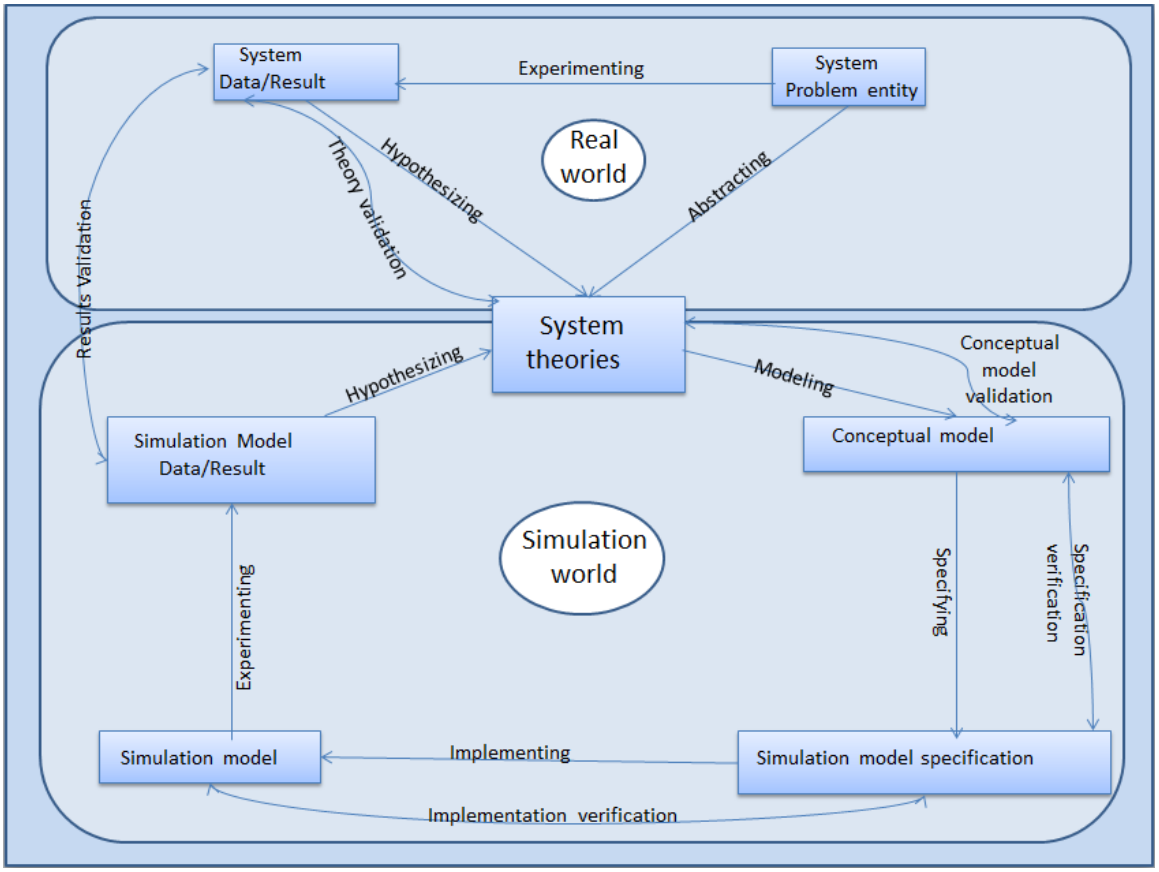

Figure 4.14: Real world and Simulation world relations with Verification and Validation [SAR12].

Figure (4.14) consists of two parts, the upper part describes the real world and the lower part defines the simulation world. In the real world, there is some system or problem entity. The system theories define the relationships, the features and the behavior of the system/problem entity. The system Data/Result is obtained by accompanying experiments on the system [SAR12].

The system theories developed by abstracting the observations of the system and by hypothesizing from the real/simulation system data and generated results, and validated by applying the theory validation process [SAR12].

The simulation world consists of the conceptual model which is the logical/ graphical/ mathematical representation of the studied system, the simulation model specification which is a detailed description of the software implementation of the conceptual model, the simulation model is the computerized conceptual model, and the simulation model data/result which are the data given and the generated results from the experiments done on the simulation model [SAR12].

The real world and the simulation world are described briefly. Now we give a description about our EPMS verification and validation used procedures.

One of the validation techniques is the comparison of the simulation model output behaviors; it is done by compare it with another model output. The graphical approach is the most common used for the validation [SAR12].

To test the validity of the SMAC protocol for the proposed EPMS, we compare the generated results of our EPMS SMAC-based with the system in [HAF14].

In [HAF14] [YE04], the researchers found the average delay and throughput with the number of nodes, which facilitates our comparison.

Figure 4.15 show the average e-2-e delays for the SMAC-based EPMS, Zigbee-Based EPMS and the [HAF14] [YE04] systems.

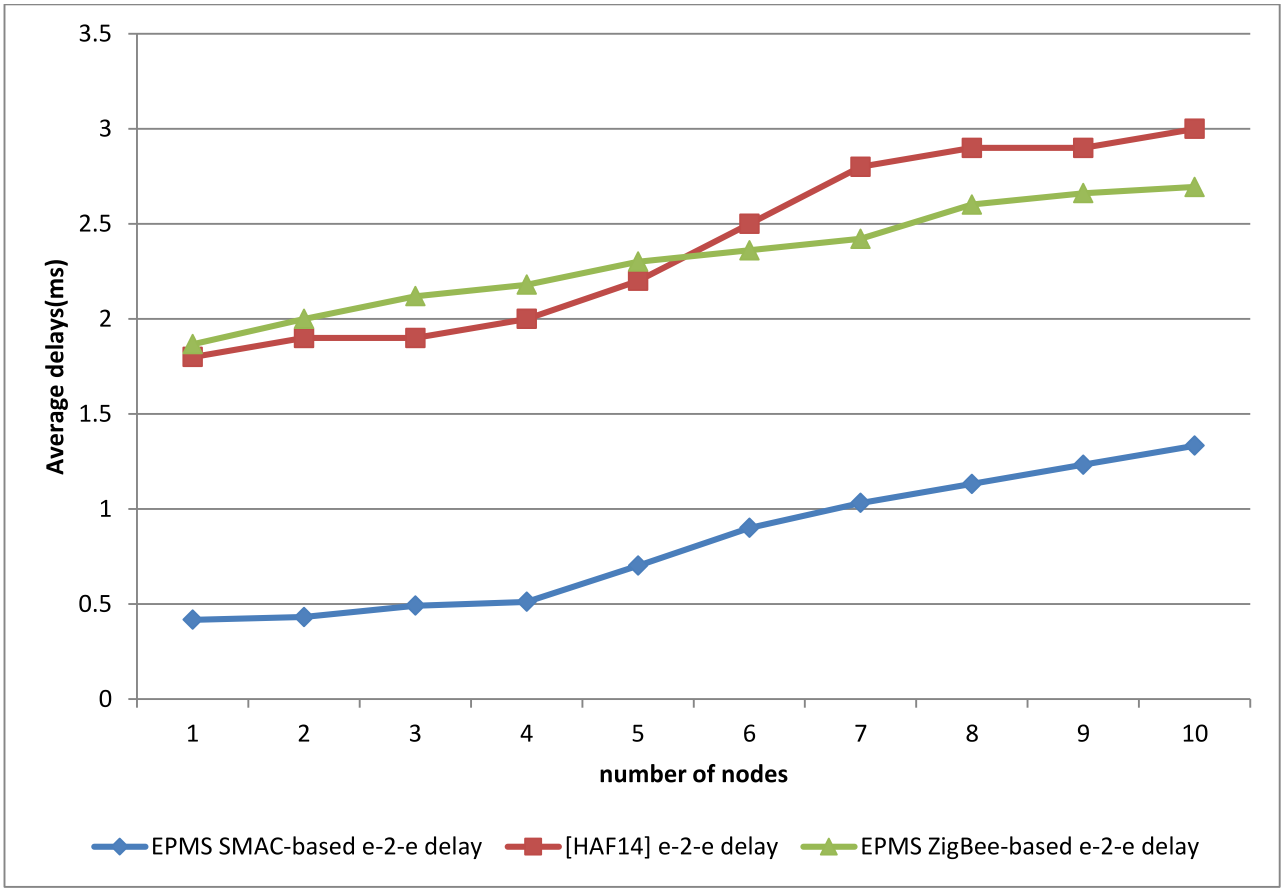

Figure 4.15: Comparison of the e-2-e delay.

The [HAF14] e-2-e delay line in Figure 4.15 refers to the Figure 4.16 below, which represents the system in [HAF14] [YE04].

In Figure 4.16, our focus is on making the 10% duty cycle with the adaptive listen values compatible with our system settings.

Our research also found the throughputs of [HAF14] and [POL04], which we compared with our throughput, as shown in Figure 4.17.

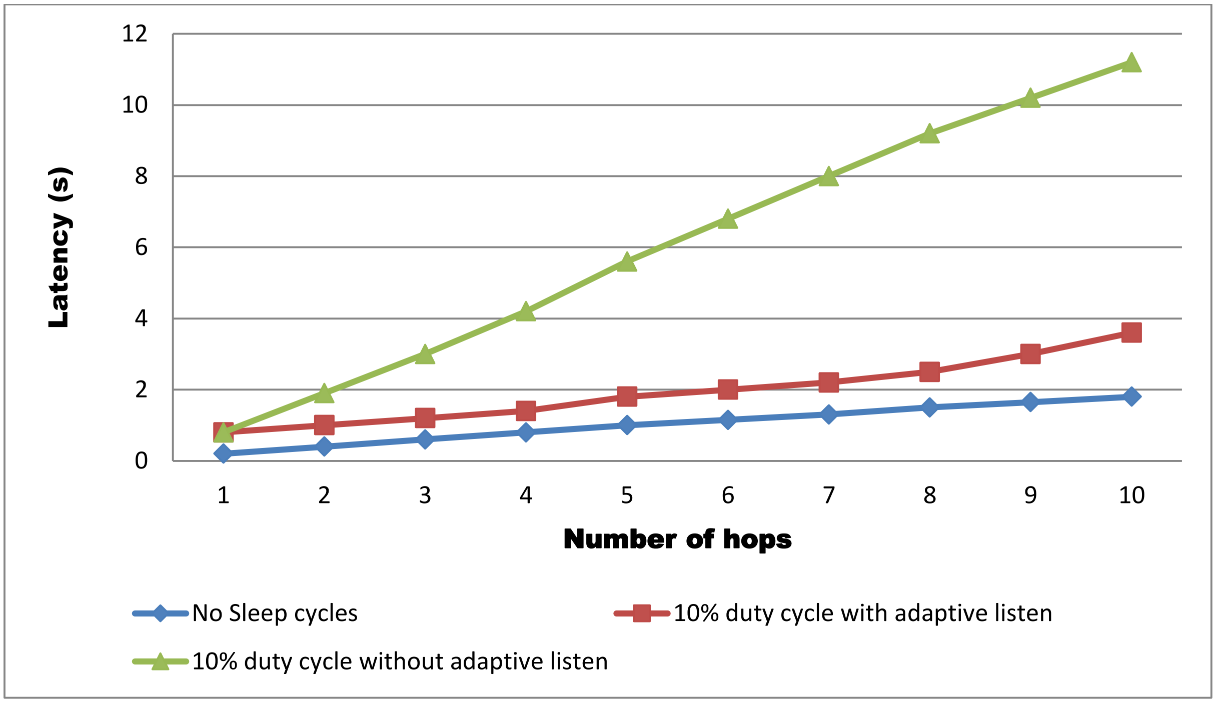

Figure 4.16: The average latency with the number of hops [HAF14] [YE04].

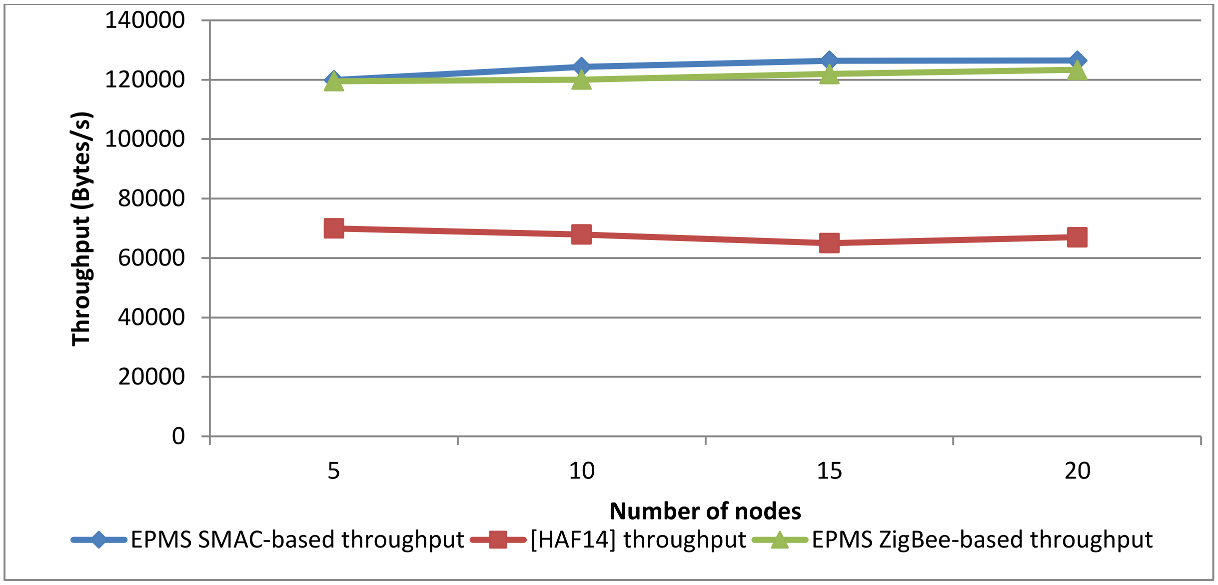

Figure 4.17: Throughput comparison between EPMS and [HAF14] [POL04] system.

The [HAF14] throughput line refers to the Figure 4.18 which represents the throughput in [HAF14] system. The focus in Figure 4.18 is on the S-MAC broadcast values.

From comparing the generated results from the simulation procedure for the EPMS with the output for the systems in [HAF14][POL04][YE04], we believe in the validity of our proposed system (EPMS) and in the importance of using the SMAC protocol for the healthcare applications, particularly for the EPs and the incoming applications.

One of the commonly used techniques to verify a model is the confidence intervals verification technique. It is used to test the performance measures for the simulation system and the real system and to decide whether the results are close.

The quantitative method has been used to determine the confidence intervals as the verification approach for our generated results.

Based on our recorded results, we took a sample of 18 simulation read and made a mathematically test by using the quantitative method as shown in Appendix B.

Figures 4.19 – 4.21 represent the plotting of some of our results with its confidence intervals.

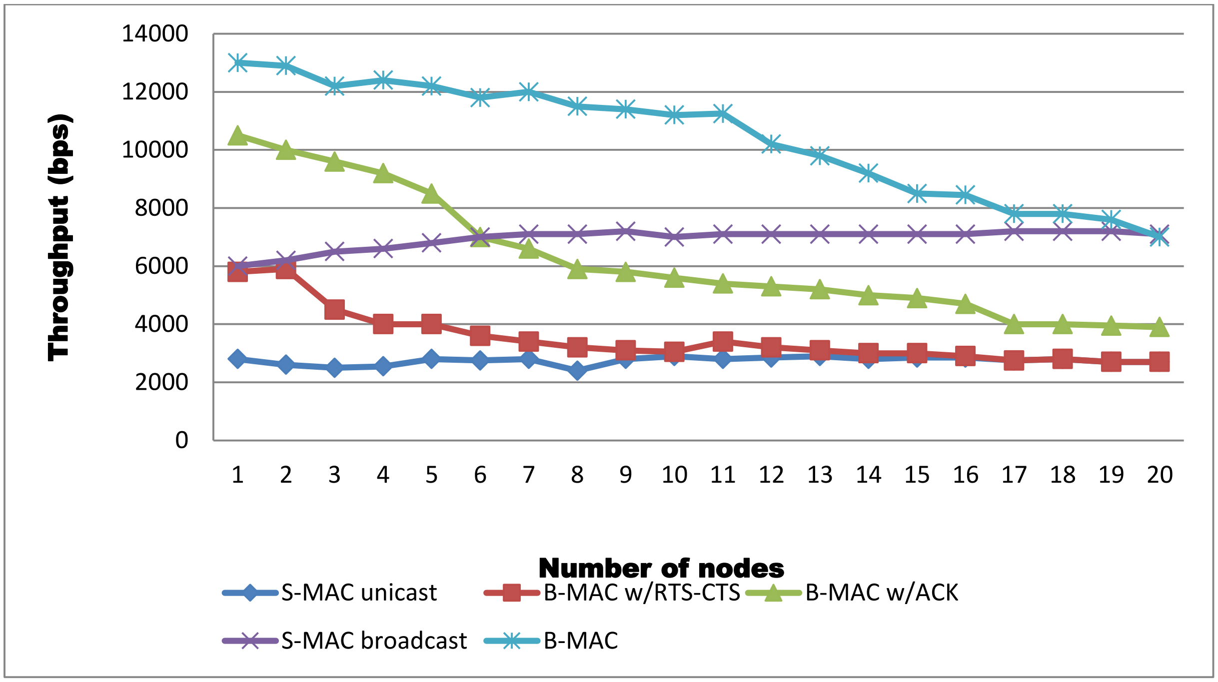

Figure 4.18: Throughput for different mac protocols [HAF14] [POL04].

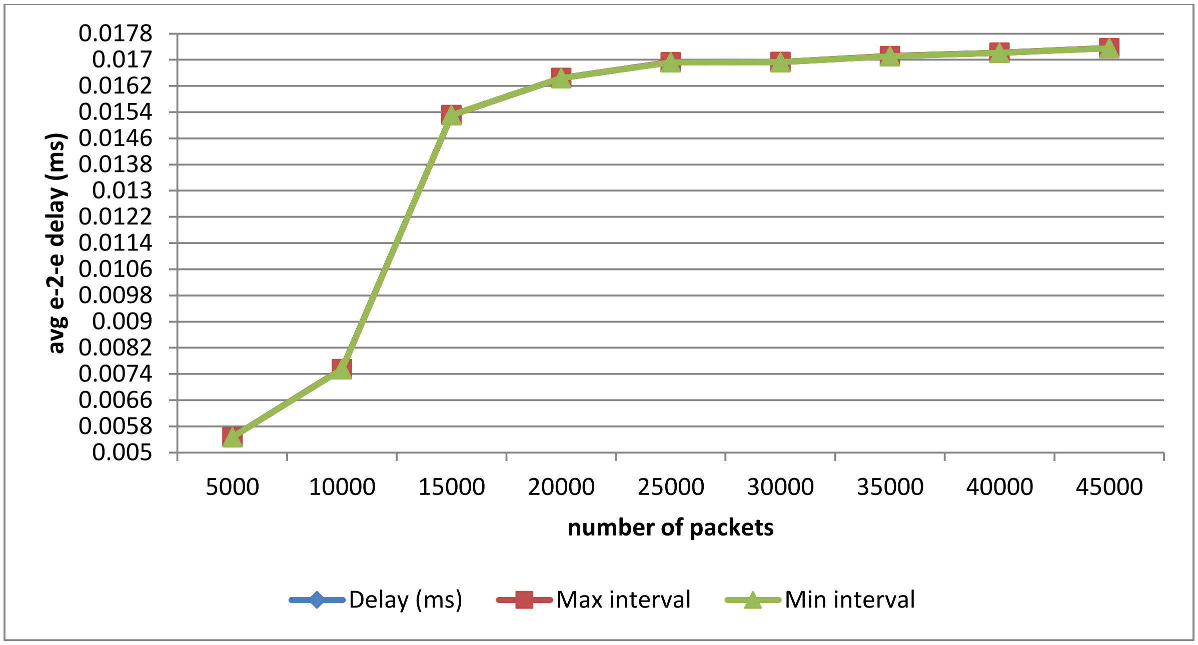

Figure 4.19: SMAC end-to-end delays with the number of transmitted packets.

The values of the confidence intervals in Figure 4.19 are very small; we have put it in Table 4-3.

Table 4-3: Confidence intervals of the average e-2-e delays with the transmitted packets.

Number of transmitted packets	Average e-2-e delay(ms)	Max interval	Min interval
5000	0.00546967	0.005472	0.005468
10000	0.0075498	0.007552	0.007548
15000	0.015309827	0.015312	0.015308
20000	0.016439733	0.016442	0.016438
25000	0.016925585	0.016928	0.016923
30000	0.016929804	0.016932	0.016928
35000	0.0171125	0.017115	0.01711
40000	0.017213889	0.017216	0.017212
45000	0.0173569	0.017359	0.017355

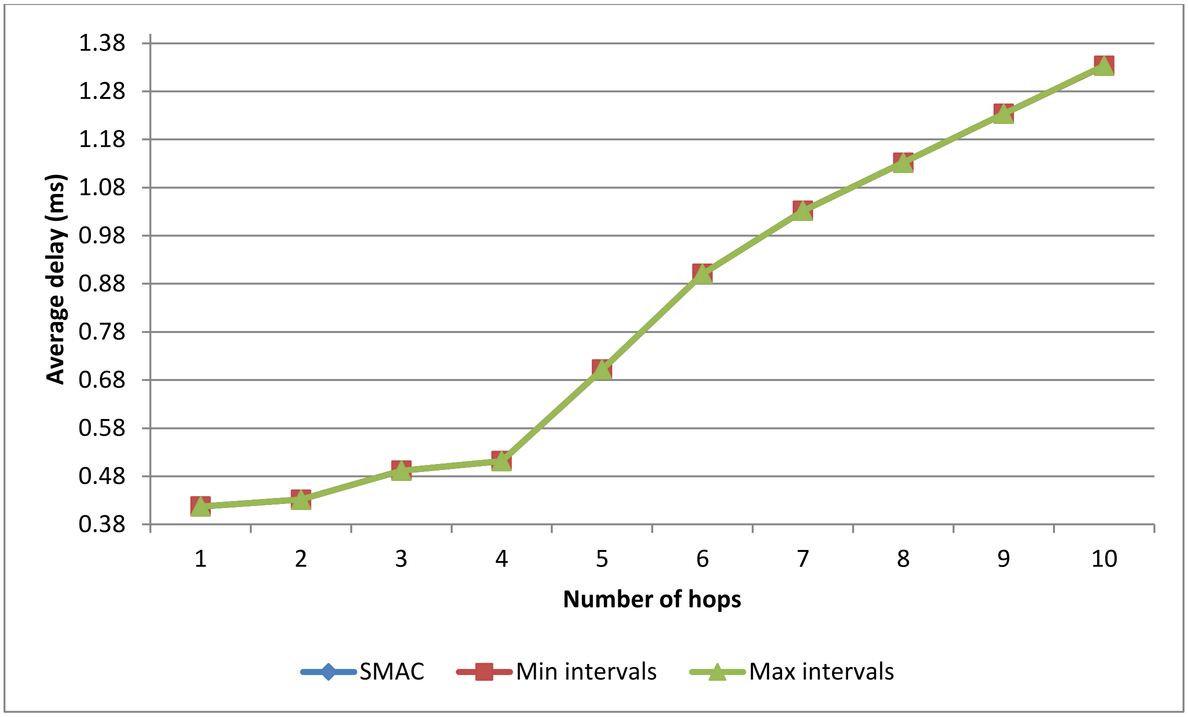

Figure 4.20: SMAC average delay with the number of hops.

The values of the confidence intervals of Figure 4.20 are represented in Table 4-4.

Table 4-4: Confidence intervals of the average e-2-e delays with the transmitted packets.

Number of hops	SMAC delay	Min intervals	Max intervals
1	0.417436	0.417434	0.417438
2	0.431745	0.431743	0.431748
3	0.49175	0.491748	0.491752
4	0.511768	0.511766	0.51177
5	0.701774	0.701772	0.701776
6	0.90078	0.900778	0.900782
7	1.031792	1.03179	1.031794
8	1.131792	1.13179	1.131794
9	1.23318	1.233178	1.233182
10	1.33318	1.333178	1.333182

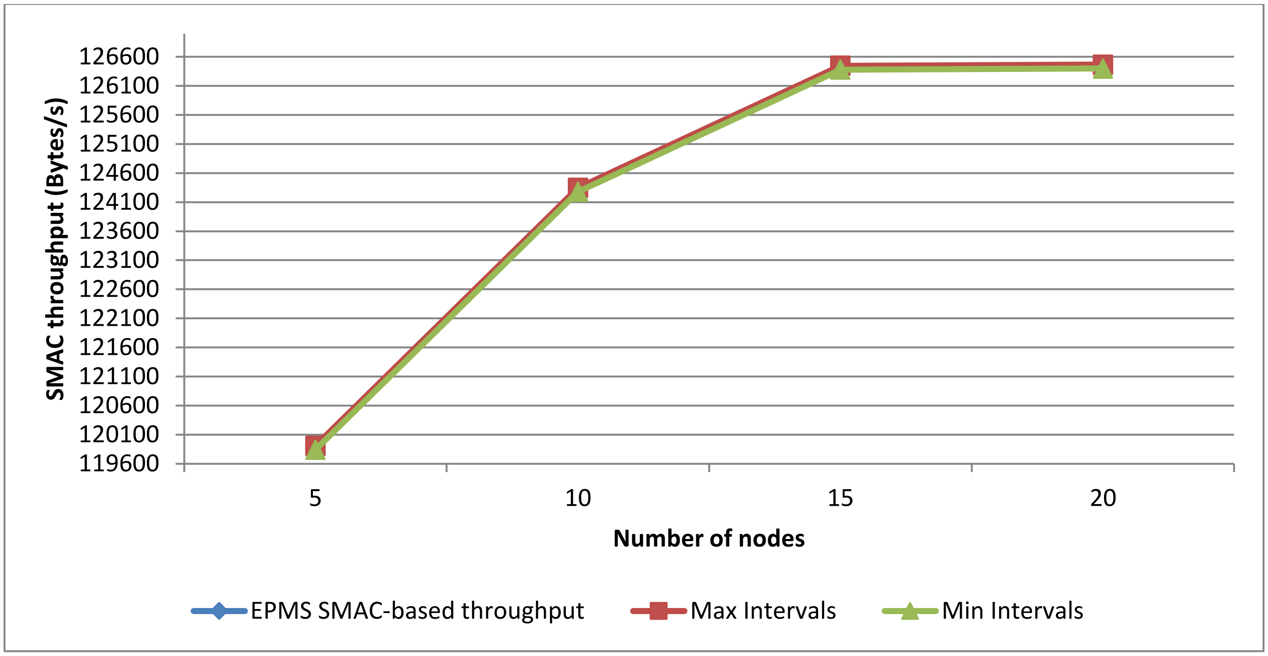

Figure 4.21: SMAC average throughput with the number of nodes.

The values of the confidence intervals of Figure 4.21 are represented in Table 4-5

Table 4-5: Confidence intervals of the throughput with the number of nodes.

Number of nodes	SMAC throughput (B/s)	Max Intervals	Min Intervals
5	119872.645	119905.6	119839.7
10	124312.4701	124345.5	124279.5
15	126412.7	126445.7	126379.7
20	126431.856	126464.8	126398.9

From these results, it is clear that our data intervals come with the confidential intervals, which indicate the excellence of the EPMS generated results.

4.4 SUMMARY

We have implemented the monitoring system for EPs in WSN using different types of protocols, including the ZigBee and MAC/SMAC protocols.

The purpose of this research is to determine the impact of using the SMAC protocol to reduce the e-2-e delay generated in the EPMS, increase the network throughput, and compare the delay with that generated using the ZigBee protocol.

Based on the previous results, we believe that using the MAC/SMAC protocol is the best choice for decreasing delays in monitoring systems, and providing optimal throughput for critical systems.

CHAPTER 5 CONCLUSIONS AND FUTURE RESEARCH

In this chapter, we summarize the concluding remarks and discuss future research related to the Epilepsy Patients Monitoring System (EPMS).

5.1 CONCLUDING REMARKS

We proposed that EPMS be used as a healthcare monitoring application for epilepsy patients (EPs). We designed an EPMS model consisting of five sensors arranged on the patient's body, as well as a coordinator sensor and a receiver sensor.

EPMS is implemented using different routing protocols, including the Medium Access Control/ Sensor Medium Access Control (MAC/SMAC) protocol and the Wearable Personal Area Network (WPAN)/ZigBee protocol. The purpose of this research is to test and determine the impact of using the SMAC protocol on the generated end-to-end delays and throughputs of EPMS.

The EPMS implementation is accomplished using an NS-2 simulator with the MICAz motes specifications.

Our aim is to increase network throughputs, decrease generated end-to-end delays by using the SMAC protocol, and compare the results with the ZigBee protocol.

The generated end-to-end delays using the SMAC protocol are divided into three categories: delay per simulation time, delay per transmitted packets and delay per number of sensor nodes.

The ZigBee generated end-to-end delays are divided into two categories: delay per transmitted packet and delay per simulation time.

The generated throughput is applied over the simulation time for both protocols.

By assessing the results, it is clear that the generated delay values with the SMAC protocol are smaller than those generated using the ZigBee Protocol.

As well, the throughput with the SMAC protocol is better than that generated using the ZigBee protocol.

We compared our results with those of [POL04] and [YE04]. The comparisons show that the results for the EPMS significantly decrease the delay and increase the throughput.

SMAC protocol has a wide range of special functions which make a major impact comparing to other protocols such as ZigBee. Some of these functions are:

- The collision and overhearing avoidance. Such functions decrease the probability of collision and increase the network throughput.
- The use of the Network Allocation Vector (NAV) frame helps in increasing the throughput and decreasing the collision probability.
- The nodes synchronization tables helps in decreasing the generated delays between the nodes.
- The periodic listen-and-sleep function helps in decreasing the collisions between the nodes and decreasing the delay.

- The use of the Carrier Sense (CS) frame before each transmission helps in increasing the throughput and decreasing the collisions.

Based on our results, we believe that the MAC/SMAC protocol is the best choice for decreasing generated delays and providing enhanced throughput for critical systems such as healthcare monitoring.

5.2 FUTURE RESEARCH

This thesis presents a new solution for decreasing the end-to-end delay generated in the EPMS using WSNs. The aim of the solution is to provide EPs with simple and easy monitoring, thereby increasing their quality of life. The work is tested using the NS2 simulator.

There are a number of issues that are not yet addressed:

We believe using a location determination facility with GPS to determine a patient's location would improve the system and further help patients.

Expanding our architecture model to include the main responders of the system (doctors, hospitals, and medical centers) in the same communication network would enhance system functionality.

For performance measurement, the researchers evaluated an architecture model with seven nodes. It would be helpful to increase the number of nodes significantly, and determine the effect on performance measurements.

Using multi-path routing protocols would further decrease the delays, and would also support our results.

The current proposed EPMS model covers an area of 500m x 500m. It would be useful to increase the area to cover a small town, thereby allowing EPs more freedom of movement.

The nodes are located on specific parts of the EP's body. It would be an improvement if patients could choose the sensor locations.

The simulation time for the proposed model was 20000 seconds. Increasing this time would also be a useful future endeavor.

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APPENDIX A NETWORK SIMULATOR VERSION 2 (NS-2)

NS2 is an object-oriented simulator used for the discrete-event network simulation, it supports a powerful simulation for the TCP, routing procedures, and the multicast protocols for the wireless and the wire networks. The NS2 simulation starts by defining the overall network topology includes the nodes, the links, the sources, the destinations, the routers and attach the routing protocols to the desired nodes.

NS2 is written in C++ and has an object-oriented different script languages tcl which is called the Otcl which is used for the scenarios and actions generation, and for the manipulation, where the tcl file is used for setup the communication network and then running this tcl file to get the results for the simulation process [WEB14].

The results can be found in a regular trace file (tr) or in Nam file which is a graphical visualizer to help the user in the simulation by visualizing the data, the tr file can be analyzed by using some scripts such as the awk scripts and the perl scripts to get the performance results such as the end-to-end delay, throughput and the network load.

NS2 is free open-source software to be used by users; accordingly the user can modify arguments, create different applications, and add new protocols.

APPENDIX B CONFIDENCE INTERVALS

The Quantitative methods have been used to calculate the result's confidence intervals of the proposed SMAC-based EPMS.

Simulated metrics such as the end-to-end delays are measured by calculating the mean of its values after n runs. All simulation runs are independent of each other and give an identical reads. The n simulation reads are represented by R1, R2, R3… Rn.

The Mean $\bar{R} = \frac{1}{n} \sum_{i=1}^{n} R_i$ (B.1)

In order to calculate the confidence intervals, it is a need to calculate the variance V_r^2 and the standard deviation σ.

The Variance $V_r^2 = \frac{1}{n-1} \sum_{i=1}^{n} (R_i - \bar{R})^2$ (B.2)

The Standard deviation $\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (R_i - \bar{R})^2}$ (B.3)

After finding the variance and the standard deviation, the z-statistic can be used to calculate the reliability factor.

For establishing confidence intervals with the variance, the interval is created with this formula B.4:

The Confidence intervals $\mathrm{CI} = \bar{R} \mp Z_{\alpha/2} * \frac{\sigma}{\sqrt{n}}$ (B.4)

For α of 5% which is equivalent to a 95% confidence interval, the reliability factor (Zα/2) is 1.96.

The upper and lower values of the 95% confidence interval can be calculated as follows.

$$\mathrm{U(R)} = \bar{R} + Z_{\alpha/2} * \frac{\sigma}{\sqrt{n}} \qquad \text{(B.5)}$$

$$\mathrm{L(R)} = \bar{R} - Z_{\alpha/2} * \frac{\sigma}{\sqrt{n}} \qquad \text{(B.6)}$$

Based on our results, we took a sample of 18 simulation runs and mathematically tested them to determine the confidence intervals.

Table B.1 shows an example of confidence interval calculations. The table shows the end-to-end performance of using the SMAC protocol with the number of nodes as presented in chapter 4 in Figure 4.7. The table shows the average end-to-end delays for 18 simulation runs, the upper values and the lower values.

Table B.1: Example of confidence intervals calculations

Number of nodes	$\bar{R}$	L(R)	U(R)
1	0.417436	0.417434	0.417438
2	0.431745	0.431743	0.431748
3	0.49175	0.491748	0.491752
4	0.511768	0.511766	0.51177
5	0.701774	0.701772	0.701776
6	0.90078	0.900778	0.900782
7	1.031792	1.03179	1.031794
8	1.131792	1.13179	1.131794
9	1.23318	1.233178	1.233182
10	1.33318	1.333178	1.333182