February 2016
Master's Degree Thesis

Study on the IEEE 802.15.4 MAC Protocols for Emergency Handling in Wireless Body Area Networks

Graduate School of Chosun University

Department of Computer Engineering

Sabita Nepal

Study on the IEEE 802.15.4 MAC Protocols for Emergency Handling in Wireless Body Area Networks

WBAN 에서 응급 상황 처리를위한 IEEE 802.15.4 MAC 프로토콜 연구

February 25, 2016

Graduate School of Chosun University

Department of Computer Engineering

Sabita Nepal

Study on the IEEE 802.15.4 MAC Protocols for Emergency Handling in Wireless Body Area Networks

Advisor: Prof. Seokjoo Shin, PhD

A thesis submitted in partial fulfillment of the requirements for a Master's degree

October 2015

Graduate School of Chosun University

Department of Computer Engineering

Sabita Nepal

네팔 사비타의 석사학위논문을 인준함

위원장 조선대학교 교수 (인)

위 원 조선대학교 교수 (인)

위 원 조선대학교 교수 (인)

2015 년 11 월

조선대학교 대학원

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Study on the IEEE 802.15.4 MAC Protocols for Emergency Handling in Wireless Body Area Networks

Sabita Nepal
Advisor: Prof. Seokjoo Shin, Ph.D.
Department of Computer Engineering
Graduate School of Chosun University

Recent developments in the field of communication deploy self-organizing miniature hardware which has features like high computational capability, low cost and energy efficient, focusing on specific applications and task. One of most promising technologies that can be used in the application of various spectrums is Wireless Sensor Networks (WSNs). Wireless Body Area Network (WBAN) is special purpose sensor application network which can be applied for an applications relating to health care. However, fundamental wireless networking issues must be addressed and resolved for designing a robust WBAN system. In addition to these fundamental issues, another most significant issue in WBAN system is emergency handling. It is necessary to process critical medical data with the highest priority. These data should be transmitted as soon as they are reported within the specified delay margin.

Existing researches have favored IEEE 802.15.4 as the most appropriate technology for WBAN application due to the characteristics such as low energy consumption, lower cost, and reliable data transmission features. However, to achieve an effective WBAN application service on the existing WSN based on

IEEE 802.15.4 is still a challenging task. In particular, time-sensitive emergency event message cannot be delivered effectively within the delay margin, because IEEE 802.15.4 doesn't differentiate the time criticality of the monitored events and hence doesn't provide any preferential access to medical devices at the time of emergency while accessing the shared wireless channel. As, a result the reporting latency of the medical events may significantly increase.

This thesis defines the requirements for the WBAN MAC and proposes a new WBAN MAC protocol, based on the integrated superframe structure of IEEE 802.15.4 to satisfy these requirements: The proposed WBAN MAC provides an Emergency Contention Period (ECP) for emergency data and DTS allocation in inactive period for medical data when emergency happens in order to reduce delay. The performance of the proposed scheme is evaluated through analytical results and computer simulation using Castalia 3.2, which is a network simulator specifically designed for the sensor and body area networks which is based on OMNeT++ platform. Both the numerical analysis and simulation result shows a lower latency and increased throughput of the proposed MAC when compared with conventional IEEE 802.15.4 MAC.

한 글 요 약

WBAN 에서 응급 상황 처리를위한 IEEE 802.15.4 MAC 프로토콜 연구

네팔 사비타
지도 교수: 신석주
컴퓨터공학과
대학원, 조선대학교

컴퓨팅 기술과 통신 기술의 빠른 발전은 저전력, 저비용, 그리고 소형 이면서 자기 구성 (self-organizing) 특성을 갖는 디바이스를 통해 특정 응용분야 및 임무에 특화된 다양한 하드웨어 형태로의 구현을 가능하게 한다. 이와 관련된 다양한 스펙트럼의 응용 분야에서 사용될 수 있는 유망한 기술 중 하나는 무선 센서 네트워크 (WSN) 이다. 무선 인체 영역 네트워크 (WBAN)는 헬스케어와 관련된 응용분야에 적용될 수 있는 특별한 목적의 센서 응용 네트워크 기술이다. 헬스케어 등의 응용에 있어서, 무선 채널 환경 등 무선망에서 다루어지는 문제들에 대한 적절한 해결 방안을 통해 강건한 WBAN 시스템을 디자인할 수 있다. 이러한 근본적 이슈들 이외에 WBAN과 관련된 중요한 이슈 중 하나는 긴급 상황에 대한 데이터 처리이다. 중요한 메디컬 데이터 (medical data)는 가장 높은 우선순위로 처리되어야 하며 이러한 데이터는 특별히 정의된 지연 한계값 이내에서 전송될 수 있도록 제어되어야 한다.

저전력 소비, 저비용, 신뢰적 데이터 전송 특성 등을 고려하여 WBAN 응용 분야에 대한 통신 표준 중 IEEE802.15.4가 가장 적절한 대안으로 많은 연구가 수행되었다. 그러나, IEEE802.15.4를 기반으로 하는 기존의 WSN 상에서 효과적인 WBAN 응용 서비스를 실현하는 것은 아직은 도전적인 과제이다. 특히 공유된 무선 채널에 접속을 시도할 때 긴급 데이터를 발생하는 메디컬 디바이스에 대한 우선화 정책이 IEEE802.15.4에 명시 되어 있지 않기 때문에 시간 지연에 민감한 긴급 이벤트 메시지가 효과적으로 전달되지 못한다는 문제점이 여러 연구에서 지적되어왔다. 이러한 우선순위 정책의 부재로 인해 긴급 이벤트 데이터의 리포팅까지 걸리는 지연이 상당히 클 수 도 있다.

본 논문에서는 WBAN MAC에 대한 요구사항을 정의하고 이러한 요구조건을 만족시키기 위해 IEEE802.15.4의 수퍼프레임 구조를 기반으로 한 새로운 WBAN MAC 프로토콜 제안 및 성능평가 연구를 수행하였다. 제안된 WBAN MAC은 긴급 데이터 전송의 지연을 감소시키기 위해 긴급 데이터가 발생한 경우 이를 전송하기 위한 ECAP 구간을 정의하고 메티컬 데이터를 위한 DTS를 할당하는 메커니즘을 제공한다. 수리적 분석의 결과는 제안된 기법과 기존의 IEEE802.15.4 MAC 과 비교하였을 때 기존의 방식에 비해 더 낮은 지연과 향상된 처리률을 보여준다.

I. INTRODUCTION

A. Research Context

The extensive use of cell phones, PDAs, laptops and intelligent electronics has emerged towards ubiquitous computing. With the increasing trends of wireless networking system and modern embedded systems, new possibilities for distributed system applications are emerging. These advancements in information and communication technology led to the implementation of wireless sensor networks (WSN) [1] which is a prominent innovation that connects the physical world with the advanced data world through spatially appropriated self-governing sensors and actuators.

Sensor networks are extensively used in applications like health inspection, habitat supervision, weather monitoring, smart home systems, and defense application. Technically, Wireless Sensor Network (WSNs) is a combination of spatially distributed, inexpensive miniaturized devices, called sensors, usually performing computation, communication and sensing. WSNs outweigh the conventional wired communication technology in terms of the system cost, flexibility, and deployment complexity. With all these attributes, wireless sensor networks are like to dominate the world of data communication.

Recently, there has been increasing interest from researchers, system designers, and application developers on a new type of network architecture generally known as body sensor networks or WBANs, made feasible by novel advances on lightweight, small-size, ultra-low-power, and intelligent monitoring wearable sensors. In WBANs, sensors continuously monitor human’s physiological activities and actions, such as health status and motion pattern [3–5]. It is one of the rapid advancements of wireless communications connecting various sensor nodes within a wireless network. Moreover, it supports various innovative and interesting applications such as ubiquitous health-care, entertainment, interactive gaming, and military applications. Although WBAN is relative to WPAN, WBAN provides closer interconnection (2-5 meters) with more strict technical requirements such as the high reliability, extreme power efficiency and security. Especially WBAN is a network which employing wireless sensor technology that forms a system to continuously monitor the patient situation. Specific sensors for each physiological data are placed near to the human body, but it limits the patient mobility. The wireless network is necessary to design for monitoring the mobile patient within specified area. This gives freedom to the patient to move without medical professional within the campus.

According to the World Health Organization statistics, in 2010, there were approximately 524 million people aged 65 or older – 8 percentage of world's population. Due to the increased life expectancy of the people in industrialized countries, this number is increasing day by day and is expected to be nearly triple to about 1.5 billion 2050 [6]. As such, the manual health monitoring process of these elderly people requires more resources in terms of time, finance and skilled human powers (doctors, nurses, caregivers etc.). Another statistic reports says that about 17.3 million people around the globe die of cardiovascular diseases each year and a number is expected to grow to more than 23.6 million by 2030 [7]. So, the interest has sloped on developing the remote, autonomous and ubiquitous health care and monitoring system which address the existing and potential health hazards.

Implementing wireless communication network system for WBAN application demands stringent network requirements. Reliably transmitting any real-time data and timely reporting of any emergency events are one of such requirements. The real time data if not transmitted at time will be useless when transmitted later. Also in human health, one event may trigger another event or series of events. So an emergency event may induce several emergencies simultaneously. E.g. a patient suffering from a fever triggers temperature, blood pressure, and respiration sensors at the same time [8]. Similarly the emergency events when not fulfilled it may cause the permanent impairment of body organs or even becomes life threatening. E.g. blurred vision/blindness, kidney failure and heart attack/ failure are the consequences of hypertension. An efficient WBAN application system must be able to report all such co-related signals and emergencies within the delay margin. But in wireless BAN application system, all the radio devices share the same channel, so it is a difficult task to make the channel readily available for such emergent condition. That is why, efficient emergency reporting and handling schemes are quite essential. Unfortunately there is not such provision in IEEE802.15.4 [2] and ZigBee [9] based WBAN application system.

B. Research Motivation

With the significant increase of people over the age of 65, chronic diseases are becoming the world’s leading cause of death and disability for the elderly. Advances in low power electronics and semiconductor technologies have been enduring these last decades and is promoting for the improvement of more and more smaller-sized medical sensors. These medical sensors are intended to be appended on ones bodies without any limitation to the movement and are capable of observing a human’s health state. Likewise, the progression in wireless technologies is empowering more efficient information trade among small portable devices at different ranges. Incorporating these two advancements, a new type of wireless network called Wireless Body Area Network (WBAN) has emerged as the system of all wireless devices that can be installed on a human body and could communicate.

In WBAN, various kinds of sensors which can sense and communicate are deployed inside or outside the human body. These sensors report different kinds of sensed events to the coordinator and coordinator in turn reports to medical personnel or centers. Depending upon different application types, these sensors can sense different physiological as well as vital signs like respiration rate, blood pressure, humidity, temperature, electrocardiogram (ECG), electromyography (EMG), sugar level etc [10]. These sensed events can be categorized as irregular emergency traffics and regular periodic traffics. Irregular emergency traffics could be a sudden fluctuation in ECG signal, reduce blood level in the brain, sudden rise or fall in blood pressure, rise in sugar level in blood while regular periodic traffics include events like blood pressure, body temperature, oxygen saturation level and sugar level. Both the events should be reported urgently within the deadlines for immediate and accurate diagnosis. Human body signals are correlated i.e. one event can trigger another event or series of events. For example, a patient suffering from a fever has a high body temperature, blood pressure and respiration rate. These changes may also affect the oxygen saturation level (SpO2) in the blood. As such, an emergency event may induce several emergencies simultaneously. An efficient wireless body area network must be able to report all such co-related signals and emergencies within the delay margin. Thus, along with Irregular emergency traffics, the corresponding regular periodic traffics also need to be transmitted so that doctors can diagnose the problems well and patient can receive proper treatment.

IEEE 802.15.4 standard defines physical (PHY) layer and MAC layer protocol specification for low rate wireless personal area network (LR-WPAN) which is widely used for health monitoring applications due to its features like energy efficiency, scalability and design flexibility. IEEE 802.15.4 implements a combination of carrier sense multiple access with collision avoidance (CSMA/CA) and time division multiple access (TDMA) mechanisms. GTS slots are assigned on a first-come-first-serve basis to devices for reliable data transmission. So it is not guaranteed that the GTS will be assigned to needy devices. IEEE 802.15.4 doesn't have priority scheme to distinguish various kinds of traffics. So it cannot handle the emergency data with priority to transmit within the delay margin. All the data are treated in the same manner. Since co-related periodic data are also important in case of emergency, IEEE 802.15.4 is unable to transmit these regular data within delay margin. Such inefficiency of IEEE 802.15.4 needs an attention to be solved.

C. Research Contribution

The main research contributions of this Thesis are:-

- Modified IEEE 802.15.4 superframe structure to handle emergency events.
- Modified IEEE 802.15.4 superframe structure to handle medical data in case of emergency.
- Achievement of reduced emergency reporting delay and successive medical reporting delay.

D. Thesis Layout

The rest of the thesis is organized as follows. Chapter II gives the introduction to the Wireless Body Area Network and IEEE 802.15.4 standard and inefficiency of IEEE 802.15.4 MAC. Proposed scheme are presented in Chapter III. In Chapter IV, numerical analysis and its results are described. Detail simulation environment and performance evaluation of the simulation are presented in chapter V. Finally, Chapter VI concludes the thesis.

II. PRELIMINARIES

A. Wireless Body Area Network (WBAN)

With the swift improvement of wireless communication and semiconductor technologies the area of sensor network has extend notably supporting a wide range of applications including medical and healthcare systems. A Wireless Body Area Network (WBAN) is a uniquely designed sensor network intended to operate independently to connect various medical sensor and appliances, located around a human body. Introduction of a WBAN for monitoring of health and other applications will provide pliability and economic option to both health care expertise and patients. A WBAN offer a two significant advantages contrasted with current electronic patients due to utilization of compact monitoring gadgets. The first one is the mobility of patients due to use of convenient monitoring gadgets. For example, WBANs provide remote health monitoring of patients for a long period of time without any restriction on his/her normal activities [11, 12]. Second is the location independent monitoring facility.

A WBAN is a collection of miniaturized, multi-functional, and energy efficient wireless sensor nodes which monitor human body functions and its surroundings. Generally WBAN consists of in-body and on-body area networks. An in-body area network allows communication between invasive/implanted devices and a base station. An on-body area network, on the other hand, allows communication between non-invasive/wearable devices and a base station. Different nodes such as Electrocardiogram (ECG), Electromyography (EMG), and Electroencephalography (EEG) are deployed on the human body to collect the physiological parameters and forward them to a remote medical server for further analysis as given in Figure 1. As shown in figure sensor nodes are monitoring different parameters relating to human body and are reporting to a central node called as a coordinator node/PDA. Coordinator node itself can be a sensor node or it can simply be an accumulating and broadcasting device. Coordinator node in turn transmits monitored data for further processing to the backbone network through wireless access point (AP).

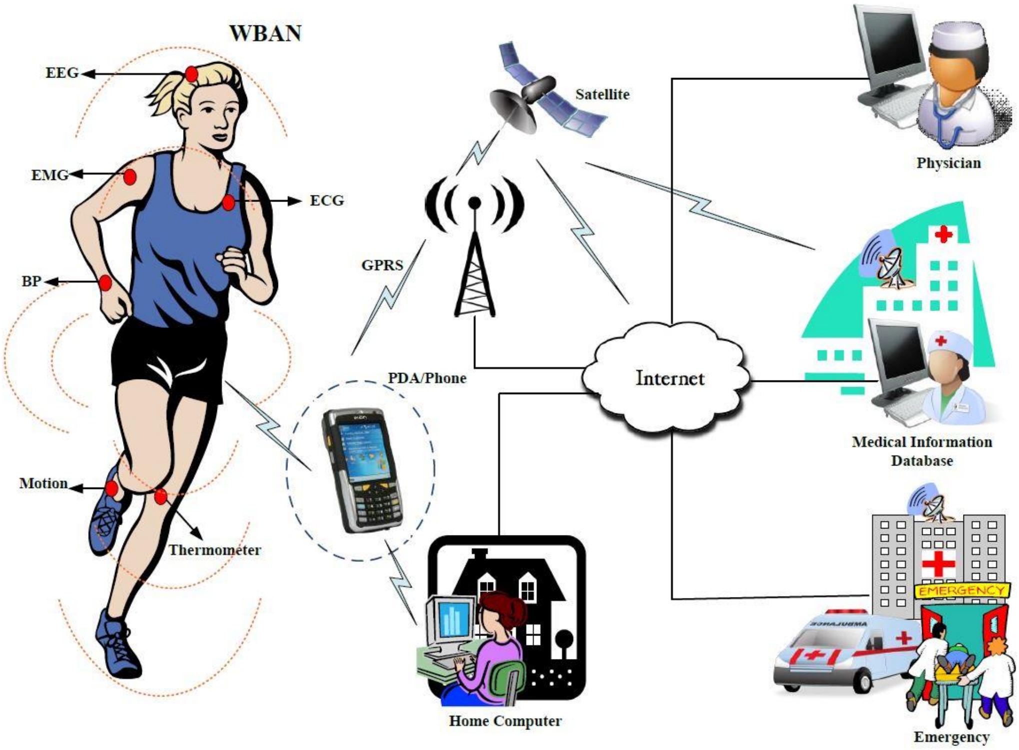


Figure 1. Architecture of a WBAN

In this thesis work, we are focused only with the communication network between in-body or on-body area network and personal server (PDA) known as coordinator node, where IEEE 802.15.4 is used as a communication protocol.

B. Challenges in WBAN

This section highlights the main design challenges of WBANs. Due to their special properties such as size, data rate, reliability, security, QoS requirements, transmission range etc., they require special design adjustment to meet their particular needs. The most essential function of WBAN is to efficiently deliver reported information from a certain application. Effective communication is described as reliable, secure, fast, fault-tolerant, scalable, interference-immune, and low power data communication.

Wireless body area networks have diverse functions and demand strict network requirements, which make it different from other WPANs applications. There are lots of issues which still need to address, and still many problems require better solution. There are many factors which need to be considered while implementing WPAN based BAN application systems [13, 14]. Some of them are listed as follows:

A. Heterogeneous Traffic

Wireless body sensor networks (WBSN) and wireless body area networks (WBAN) have been widely applied in ubiquitous healthcare systems that are capable of monitoring human body dynamic health conditions and transmit sensor data in real-time and reliable manner. In WBSN and WBAN, sensor nodes have different bandwidth requirements, therefore heterogeneous traffic is created. The entire WBAN traffic is categorized into three groups: Normal, On-demand, and Emergency traffic as shown in Figure 2 [15]. WBAN should handle all these diverse traffics. As WBAN is related to human health, efficient and quick response to emergency as well as on demand traffic is needed.

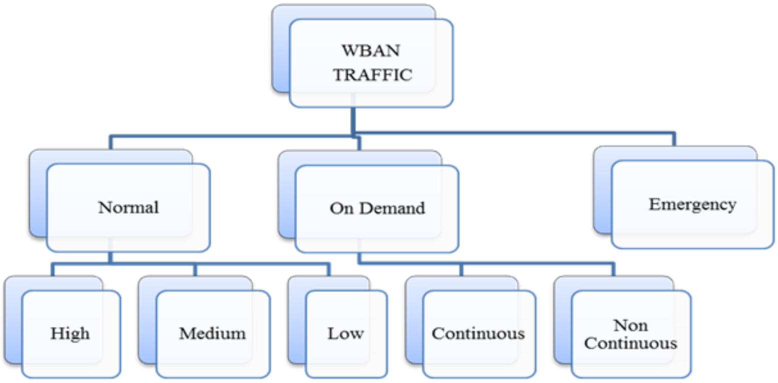


Figure 2. Classification of Traffics

B. Interoperability

Depending on the application types, the sensors in WBAN application can be wearable on the body surface and also can be implanted inside the body. These sensors hence can operate on different frequency bands and PHY layers. So, the sensors must be interoperable at multiple frequency bands and support multiple physical layers (PHYs).

C. Latency

Wireless body area network contains emergency data which can be life critical, if is not responded quickly. The delay requirement for medical data is no greater than 125ms. So, latency is a one of the important factor which needs to be considered in WBAN.

D. Scalability

Scalability of the network refers to capability of the network to add or remove at least one or more nodes without any overheads. Random access MACs like contention based CSMA/CA MACs provides good scalability than the rigid TDMA based MACs. Similarly, scalability can also be referred to handling of different heterogeneous traffics and variable data rates. The WBAN MAC must be scalable for both the periodic and non-periodic data. Most of the time physiological information from nodes is normal but often in case of emergency the data are non-periodic and bursty in nature [16].

E. Energy Efficiency

Sensor nodes in WBAN are powered by batteries. Once nodes are implanted inside the body, batteries should be durable for a longer period since they cannot be easily replaced. Hence, energy conservation is an important attribute. The main sources of energy depletion are the activities of radio such as idle collision, idle listening, over hearing, control packet overheads, frequent nodes synchronization etc.

F. Security and Privacy

WBAN has provided to help in real-time health monitoring of a patient and diagnose many life threats diseases. So, the data collected from a BAN application system or during their transmission outside of wireless BAN must be highly secured and maintain the highest degree of privacy protection. The alteration in data could lead to serious problems. The sensors devotedly employed for a person only should generate the data for that patient. The data transmission over the networks should be secured and accurate. It requires a high system level and device level security [17].

G. Quality of service (QoS)

QoS is another attribute to be considered while designing MAC. MAC level QoS includes the communication range, throughput, and reliability, delay variations etc. Since the WBAN nodes are either implanted inside the human body or worn on human body, the nodes must support the simultaneous operations.

H. Co-existence and Interference Mitigation

Multiple WBAN applications may exist in a confined area like a hospital room. In that condition, there can be a high chance of interference between the wireless networks in a user standing next to each other or even the possibility of colliding signal within user itself. In order to prevent from data collision due to interference, these networks must co-exist without any interference between them. And, the wireless link should also increase the coexistence of sensor node devices with distinct network devices available in the environment.

Besides these, there are other challenges like node size, date rates, throughput etc. In order to design an appropriate MAC protocol, all above attributes need to be considered.

C. Wireless Network Technologies for WBAN Application system

The diverse applications ranging from the medical field (e.g., vital signs monitoring, automatic drug delivery, etc.) to the entertainment, gaming, and ambient intelligence areas requires a diverse set of requirements in terms of expected performance metrics such as throughput, delay. Therefore a suitable architecture or protocol is required. The main communication standard solutions considered as reference are: IEEE 802.15.4 [2], IEEE 802.15.6 [18], and Bluetooth Low Energy [19].

IEEE 802.15.4 (published in 2006), specifies the physical (PHY), medium access control (MAC) layers for short-range wireless communications, devised to support low power, low cost, and low bit rate networks. The IEEE 802.15.6 (published in 2012), was specifically designed for wireless communications in the vicinity of, or inside, a human body. Finally, Bluetooth Low Energy (BT LE) (published in 2010) is the ultra-low power consumption configuration of Bluetooth technology, targeting several applications for small and cheap devices powered by button-cell batteries, such as wireless sensors. Due to the quite large number of available standards, it is necessary to identify the best solution, depending on the application requirements.

The focus of the thesis lies on IEEE802.15.4 protocol standard. Applications, network configuration, routing protocols and other parts are not standardized by IEEE802.15.4, which gives researchers the design flexibility. For developers IEEE802.15.4 uses the 2.45 GHz ISM band, because it is freely accessible worldwide. IEEE802.15.4 was designed to support low power usage and low cost transceivers which try to minimize the Inter Technology Interference by some small output powers. Small chips and antenna sizes and already available hardware are the other reasons. The combination of these reasons is the determining factor for the selection of IEEE802.15.4 as the wireless technology of choice for further investigation in this thesis.

D. The IEEE 802.15.4-2006

1. Overview

The IEEE 802.15.4 standard is a low-power standard designed for low data rate Wireless Personal Area Network (WPAN), low power consumption, low hardware cost features [2] and is quite flexible for a wide range of application. Ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life are the main objectives of a Low Rate-WPAN [2].The standard provides only the physical (PHY) layer and the medium access control (MAC) layer specification. In particular, it defines two PHYs representing three license-free bands that include sixteen channels at 2.4 GHz, 10 channels at 902 to

928 MHz and 1 channel at 868 to 870 MHz with maximum data rates of 250 Kbps, 40 Kbps and 20 Kbps, for each band respectively [20].

The standard specifies three different device types in IEEE 802.15.4 network, a full-function device (FFD), a reduced-function device (RFD) and a coordinator. FFD is a node that has full levels of functionality. It can work as a personal area network (PAN) coordinator and can talk to FFD or RFD. RFD is a device that has reduced level of functionality. Typically it is an end node which may be typically a sensor or switch. RFDs can only talk to FFDs as they contain no routing functionality. It is a low power device as they do not need to route other traffic and can be put into a sleep mode when they are not in use. These RFDs are often known as child devices as they need other parent devices with which to communicate. Coordinator is a node that controls the IEEE 802.15.4 network. This is a special form of FFD. It acts as a manager of the networks.

IEEE 802.15.4 LR-WPAN may operate either in star topology or peer-to-peer topology [2]. The communication is established between devices and a single central controller, called the PAN coordinator in star topology. The peer-to-peer topology also has a PAN coordinator; however, it differentiates from star topology such that any device may communicate with any other device as long as they are in range of one another.

2. IEEE 80215.4 Architecture

a. PHY Layer

It is a first layer of OSI reference model which provides an interface between the MAC layer and the physical radio channel. It handles the data transmission request from the MAC layer and passes the incoming frame to the MAC layer. In order to provide these services efficiently, it supports activation and deactivation of the radio transceiver, energy detection (ED), link quality indication (LQI), and clear channel assessment (CCA). The feature of activation/deactivation of the radio transceiver is very important for energy conservation in battery-powered devices. It allows devices to turn off their radio to avoid overhearing and idle listening. Receiver energy detection is intended for use by a network layer as part of channel selection algorithm. It is an estimate of the received signal power within the bandwidth of an 802.15.4 channel. Link quality indication measurement is a characterization of the strength and quality of a received packet. The measurement may be implemented using receiver energy detection, a signal-to-noise estimation or a combination of these methods. How to use the LQI is up to the network or application layers. Before the physical layer transmits a frame in the contention access period, it checks whether the channel is available. Thus CCA is performed by the physical layer using energy detection, carrier sense or a combination of both of them. In some sense, it is the front end of CSMA-CA in MAC layer.

The IEEE 802.15.4 standard offers two PHY option according to the frequency band. Both frequescy bands are based on direct sequence spread spectrum (DSSS). The data rates are 250kbps at 2.4 GHz, 40kbps at 915MHz and 20kbps at 868MHz respectively.

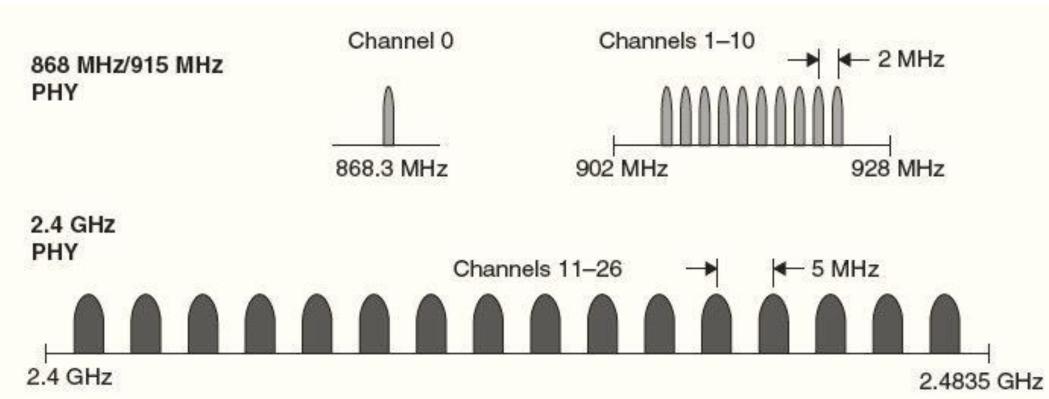


Figure 3. IEEE 802.15.4 Frequency band

A total of 27 frequency channels are are allocated in 802.15.4 as shown in Figure 3. There are 16 channels in the 2.4 GHz band, 10 channels in the 915 MHz band, and 1 channel in the 868 MHz band [21]. Channel 0 to 26 are available across the free frequency band. There are a single channel between 868.0 and 868.6 MHz, 10 channels between 902.0 and 928.0 MHz, and 16 channels between 2.4 and 2.4835 GHz.

b. IEEE 802.15.4 MAC Layer

The MAC sub-layer is the second layer specified in the standard. It allows the forwarding of MAC frames through physical channel and manages accessing of physical channel and network beaconing. MAC layer provides time synchronization and frame validation. It mainly provides two services, data and management service, both accessible through different interfaces. The MAC layer protocol supports two operational modes as shown in Figure 4 [2].

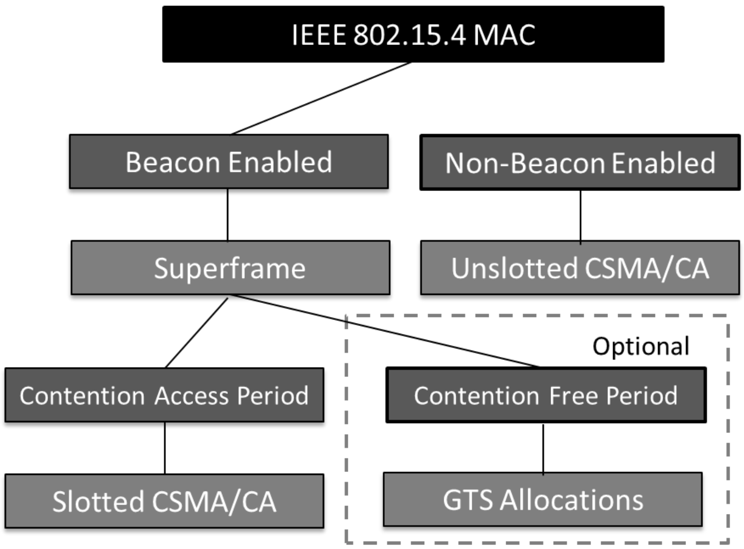


Figure 4. IEEE 802.15.4 operational modes.

The non-beacon-enabled mode: During this mode, there exist neither beacons nor superframe and medium is accessed by an unslotted CSMA/CA mechanism.

The beacon-enabled mode: In this mode, beacons are periodically sent by the PAN coordinator for synchronization and association control of the nodes associated with it, and to identify the PAN. A superframe is always initiated by the beacon frame that defines a time interval during which frames are exchanged between different nodes in the PAN. Medium access is basically ruled by the slotted CSMA/CA. However, the beacon-enabled mode also enables the allocation of contention free time slots, called Guaranteed Time Slots (GTSs) for the nodes requiring guaranteed bandwidth. IEEE 802.15.4 MAC frame format and Superframe Structure are discussed below.

- MAC frame format

The MAC frame structure is very flexible to accommodate the needs of different applications and network topologies while maintaining a simple protocol. The general format of a MAC frame is shown in Figure 5.

The MAC frame is called the MAC protocol data unit (MPDU) and is composed of the MAC header (MHR), MAC service data unit (MSDU), and MAC footer (MFR). The first field of the MAC header is the frame control field. It indicates the type of MAC frame being transmitted, specifies the format of the address field, and controls the acknowledgment. In short, the frame controls the field, specifies how the rest of the frame looks and what it contains [22].

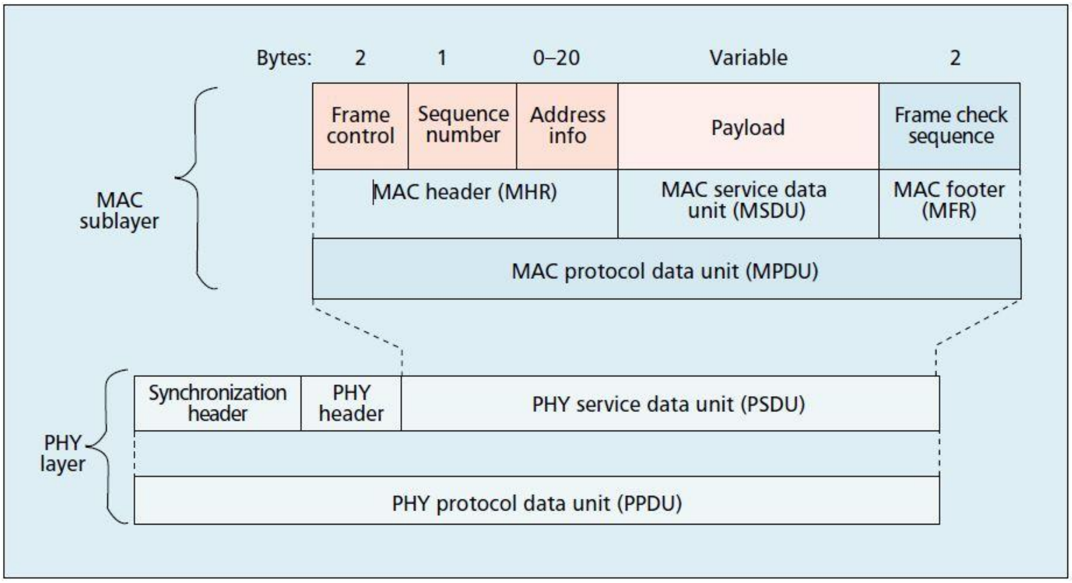


Figure 5. The general MAC frame format.

The address field is variable of length 0 to 20 bytes. Based on the frame type, the address field may contain source and destination addresses, while the return acknowledgment frame does not contain any address information at all. On the other hand, a beacon frame may only contain source address information. In addition, short 8-bit device addresses or 64-bit IEEE device addresses may be used. This flexible structure helps increase the efficiency of the protocol by keeping the packets short.

The payload field is variable in length; however, the complete MAC frame may not exceed 127 bytes in length. The data contained in the payload is dependent on the frame type. The IEEE 802.15.4 MAC has four different frame types.

- Beacon frame,
- Data frame,
- Acknowledgment frame, and
- MAC command frame.

Only the data and beacon frames actually contain information sent by higher layers; the acknowledgment and MAC command frames originate in the MAC and are used for MAC peer-to-peer communication.

Other fields in a MAC frame are the sequence number and frame check sequence (FCS). The sequence number in the MAC header matches the acknowledgment frame with the previous transmission. The transaction is considered successful only when the acknowledgment frame contains the same sequence number as the previously transmitted frame. The FCS helps verify the integrity of the MAC frame. The FCS in an IEEE 802.15.4 MAC frame is a 16-bit International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) cyclic redundancy check (CRC) [22].

- Superframe structure

IEEE 802.15.4 supports low rate wireless personal area networks working in beacon mode by the use of superframe. The coordinator of the PAN defines the format of the superframe. The superframe beacons are transmitted periodically by the coordinator and are used to identify the PAN, synchronize the attached devices and describe the structure of superframes.

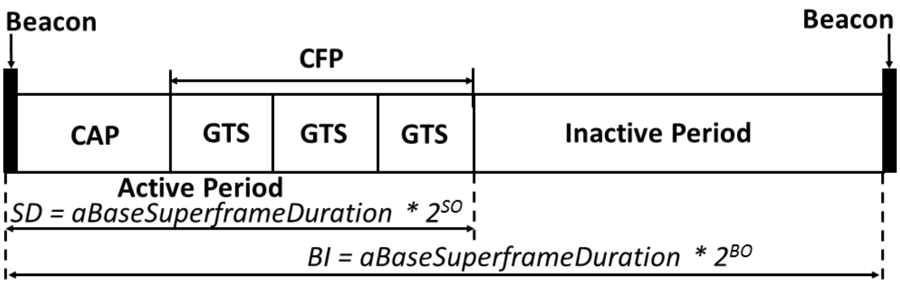


Figure 6. IEEE 802.15.4 superframe structure

In beacon-enabled mode, each coordinator defines a superframe structure as shown in Figure 6 based on: Beacon Interval (BI), which defines the time between two consecutive beacon frames; Superframe Duration (SD), which defines the active portion in the BI, during which frame transmissions are allowed.

Optionally, an inactive period is defined if BI > SD. During the inactive period (if exists), all nodes may enter into a sleep mode to save energy. BI and SD are determined by two parameters, the Beacon Order (BO) and the Superframe Order (SO), respectively, as follows:

$BI = aBaseSuperframeDuration * 2^{BO}$
$SD = aBaseSuperframeDuration * 2^{SO}$
$Inactive\ Period = BI - SD$
Where,
$0 \leq SO \leq BO \leq 14, and$
$aBaseSuperframeDuration = 960\ symbols$

The active portion of the superframe is divided into 16 equally-sized time slots. It may consist of two periods, namely contention access period (CAP) and contention free period (CFP). The CAP immediately follows the superframe beacon and competes before the CFP begins. The channel access mechanism during CAP is Slotted CSMA/CA mechanism, except for acknowledgement (ACK) frames which are transmitted without contention. A transmission in the CAP shall be complete one inter frame space (IFS) period before the end of the CAP. If this is not possible, it defers its transmission until the CAP of the following superframe. CFP starts immediately after the end of the CAP and must complete before the start of the next beacon frames or the end of the superframe. Unlike CAP, channel access in CFP is based on reservations and is free of contention. All GTSs are allocated as per request by PAN Coordinator if there are available resources. It allocates up to 7 of them which may contain one or more time slots either in transmit or receive direction. The allocation of the GTS cannot reduce the length of the CAP to less than aMinCAPLength (440 Symbols). Note that a device to which a GTS has been allocated can also transmit during the CAP.

c. CSMA/CA Mechanism

If superframe structure is used in the PAN, the slotted CSMA-CA is used. The algorithm is implemented using units of time called backoff periods, which is equal to aUnitBackoffPeriod symbols. Each time a device wishes to transmit data or command frames during the CAP, it locates the boundary of the next backoff period.

Each device maintains three variables for CSMA-CA algorithm: NB, CW, and BE. NB is the number of times the CSMA-CA algorithm was required to backoff while attempting the current transmission. It is initialized to 0 before each new transmission. CW is the contention window length, which defines the number of backoff periods that need to be clear of activity before the transmission can start. It is initialized to 2 before each transmission attempt and reset to 2 each time the channel is assessed to be busy. BE is the backoff exponent, which is related to how many backoff periods a device shall wait before attempting to assess the channel.

In the slotted CSMA-CA, NB, CW, and BE are initialized and the boundary of the next backoff period is located. The MAC layer delays for a random number of backoff periods in the range of 0 to $2^{BE} - 1$, then requests the PHY to perform a clear channel assessment (CCA).

If the channel is assessed to be busy, the MAC layer increments both NB and BE by one, ensuring that BE shall be no more than aMaxBE. If the value of NB is less than or equal to macMaxCSMABackoffs, the CSMA-CA will start another around of delay for a random number of backoff periods. Otherwise, it declares channel access failure.

If the channel is assessed to be idle, the MAC sub layer ensures the contention window is expired before starting transmission. For this, CW is decremented by one first. If CW is not equal to 0, CCA is performed on backoff boundary. Otherwise, it starts transmission on the boundary of the next backoff period. Figure 7 illustrates the steps of the CSMA-CA algorithm.

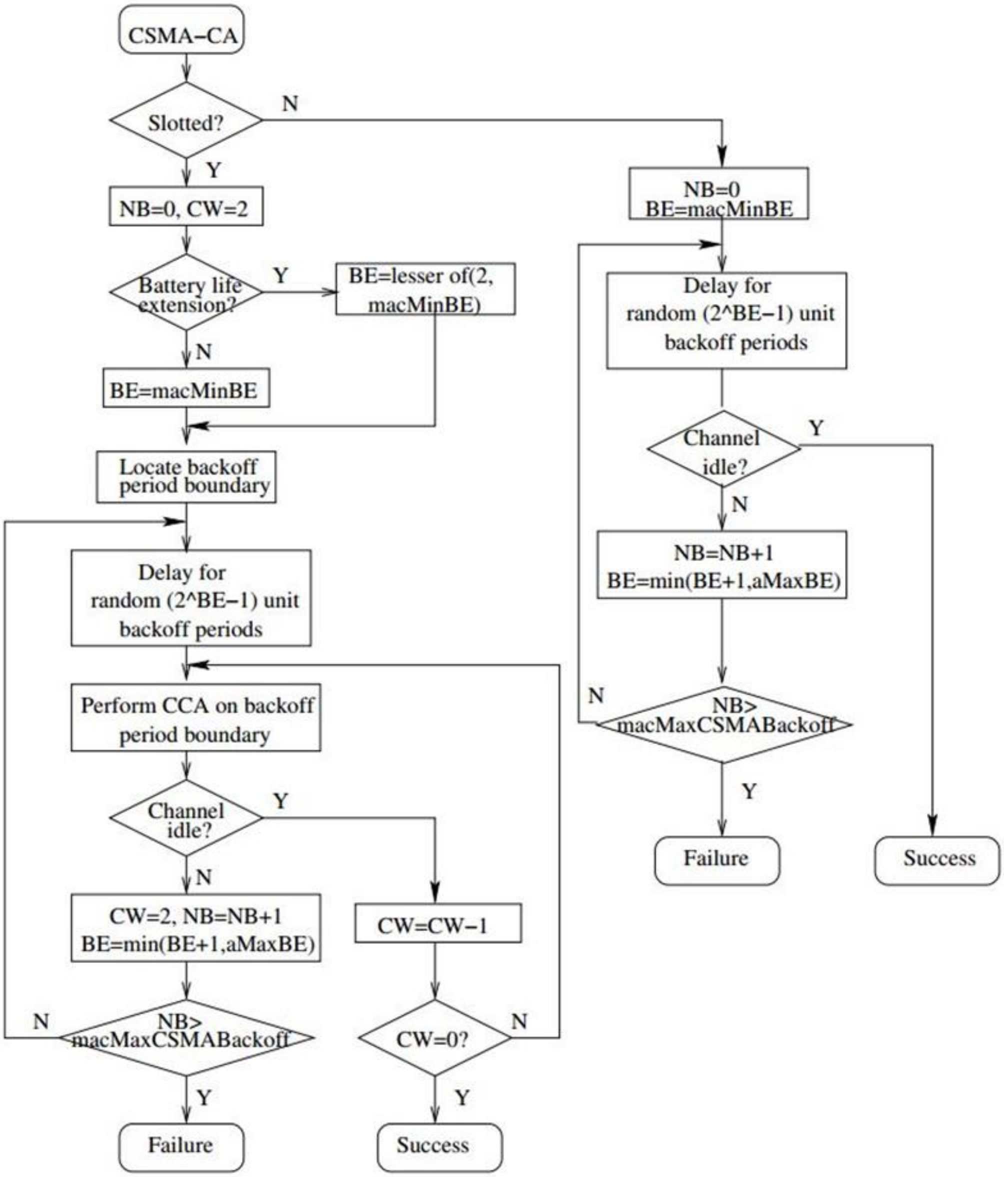


Figure 7. The CSMA/CA Algorithm

d. Data Transfer Model

Three types of data transfer models are supported in 802.15.4. The first one is the data transfer from a device to a PAN coordinator. In a beacon-enabled PAN, the device has to synchronize to the superframe structure. Then the device could transmit a data frame using slotted CSMA-CA at the appropriate time. The coordinator returns an acknowledgement when receiving the frame. The transaction is now completed. This type of transfer is called direct transfer model.

The second type is the data transfer from a coordinator to a device. In a beacon-enabled PAN, the PAN coordinator stores the data frame in a transaction list, and notifies the device through beacons. After the device decodes the beacon, it transmits a data request to the coordinator if there is a transaction pending for it. The coordinator acknowledges the reception of the request and the pending data frame is transmitted at the appropriate time using slotted CSMA-CA. The pending data frame is removed from the transaction list only after the acknowledgement for this frame is received or the data frame remains unhandled in the list over the maximal transaction persistence time. An example for this type of data transfer is the association response issued by a PAN coordinator. Because the data transfer is instigated from the destination (device) instead of the data source (coordinator), this type of transfer is called indirect transfer model.

The third type is the peer-to-peer data transfer between two devices in a peer-to-peer PAN. This type of transfer model allows devices to communicate with each other directly through unslotted CSMA-CA or some synchronization mechanisms.

3. Problem Statement

Several benefits over other wireless technologies have enabled IEEE 802.15.4 standard protocol to be used in health monitoring applications. Although it is popular in health monitoring applications, it possesses some inefficiency while considering the strict QOS requirement in terms of delay for reporting the emergency events and the successive medical events.

IEEE 802.15.4 standard doesn't differentiate the traffics. Therefore, all data are treated as same, so there is no way that critical or medical data gets higher priority during channel access. Also there is lack of priority based mechanism for GTS allocation. GTSs are served in first-come-first-serve manner. So, it is not guaranteed that emergency nodes always get GTS for guaranteed data transmission.

IEEE 802.15.4 doesn't have any provision to send the medical data without delay after an emergency event has occurred. In fact the GTS request in a frame is acknowledged only by beacon in the subsequent frame if it is available. So an undesired waiting delay is incurred prior to the actual transmission in the GTS.

The delay exceeds the minimum delay requirement for reporting emergency and medical data when such events are triggered during CFP. For example, if an emergency event occurs at the beginning of CFP, it will be reported only in the subsequent CAP (in the next frame) or else the emergency event demands GTS then it has to first contend for GTS in the subsequent CAP and will be scheduled with GTS in the next's next frame if only the GTS is available. Considering the situation, taking BO and SO as 4 and 3 respectively, the length of superframe will be 256.76 ms. If the CFP of a superframe consists of 7 GTS with each GTS expanding to a slot then as such the emergency events occurring at the beginning of CFP will be considered for access at least only after 176.76 ms in the subsequent CAP (considering the summation of CFP and inactive period only) which is higher than the target delay limit for reporting medical data, 125 ms [14]. Some emergency signals like ECG gets distorted at the receiving end if they are not transmitted within the delay margin [32]. Similarly there will be delay to report the successive medical data following the emergency events.

E. Related Works

Over the past decades, a number of MAC protocols have been researched and proposed based on IEEE 802.15.4, such that it can fulfill the requirement of WBAN. As WBAN technology gains worldwide interests, considerable research efforts are dedicated to propose new MAC protocols based on 802.15.4 in order to satisfy the stringent requirements of WBAN.

In [23], the authors presented a priority guaranteed MAC protocol, where the data and the control channels are split to support collision-free high data rate communication. Application specific control channels are adopted to provide priority guarantee to the life-critical medical applications from much busier CE traffic. Improvements on throughput and energy efficiency are achieved from this MAC protocol.

Eui-Jik et al. [24] have proposed a mechanism for IEEE 802.15.4 to provide traffic differentiation scheme based on the contention window (CW) size and Backoff Exponent (BE). In this scheme, higher-priority-class nodes have the lower CW and BE values than others. CW effect more on the saturation throughput while BE is affected more by the average delay of every device. So, tuning of the throughput could be performed by varying backoff exponent while the better throughput could be performed by adjusting contention window size.

Kwak and Ullah have proposed a traffic-adaptive MAC for handling emergency and on-demand traffic, in which a table is maintained to store the traffic patterns of the nodes [25]. It also consists of configurable contention access period (CCAP) but rest of the superframe parts resembles the conventional IEEE 802.15.4 MAC.

This superframe helps to solve the idle listening and overhearing problems by exploiting the traffic information of the nodes.

B. Kim et al. [26] focus on the emergency handling schemes for WBANs. They proposed a superframe structure with Mixed Period (MP) and Extended Period (EP). In MP, CAP slot called the contention time slot (CTS) is inserted in front of GTS for immediate transmission of emergency data, while EP consists of an extending request period (ERP), a re-allocated CFP, and an additional CAP. EP guarantees transmissions of, failed slot in MP, at reallocated CFP. MP and EP can handle emergency data with low latency.

C. Lee, H. S. Lee and S. Choi have proposed an enhanced MAC protocol of IEEE 802.15.4 for health-monitoring application with an enhanced superframe structure containing polling period (PP) and an emergency slot (ES) for emergency handling [27]. ES is a quite short period where data transmission is described by success or fail. The protocol contains a long CFP and inactive period follows the CFP.

J. S. Ranjit, S. Pudasaini and S. Shin have also proposed an emergency-handling MAC protocol for health-monitoring application using ERP period and Emergency beacon. This superframe handles the emergency traffic by minimizing the delay by sending the data in the same superframe instead of next superframe [28].

PNP-MAC [29] protocol is based on IEEE 802.15.4 superframe structure. It can flexibly handle applications with diverse requirements through fast, preemptive slot allocation, nonpreemptive transmission, and superframe adjustments. This MAC inherits the best breeds of contention-based and contention-free medium access techniques, hence supports various types of traffics: continuous streaming, periodic data, time-critical emergency alarm, as well as non-periodic data. It supports QoS in accordance with priority of traffics.

Authors proposed an OCDP-MAC [30] protocol for contention-based medical and CE applications. To support bursty CE data and emergency medical data, the proposed WBAN MAC protocol provides a temporary switching method between the Inactive period and the Opportunity period through OCDP (opportunistic contention decision period), and 4-mode opportunity period.

In [31], authors proposed Medical Medium Access Control (MedMAC) protocol for WBANs to improve channel access mechanism and reduce energy dissipation. This protocol include: contention free channel access over a variable number of TDMA channels; energy efficient and dynamically adjustable time slots; a novel adaptive and low-overhead TDMA synchronization mechanism; optimized energy efficiency by dynamically adjusting the QoS requirements using ongoing traffic analysis; and optional contention period used for low grade data, emergency operation, and network initialization procedures.

.

III. PROPOSED PROTOCOL

A. System Model and Assumptions

The proposed scheme is based on IEEE 802.15.4 standard, operating in 2.4 GHz RF band with a star network topology that consist of a central coordinating FFD called network coordinator (NC) and many other RFDs known as sensing nodes (SNs). Being a FFD device, NC can perform some enhanced functions like synchronization with other surrounding SNs, slot allocation to SNs, exchanging control packets etc. whereas SNs only sense and transmit the sensed data to NC. SNs can directly communicate with NC following single hop communication architecture.

SNs can be wearable or implanted devices and NC also be attached with the body or detached to some location but within the communication range of the SNs. The SNs are energy-constrained since they are battery powered. But, NC is assumed to have an external power supply. SNs can transmit two types of traffics: Irregular emergency traffic and regular periodic traffic. Besides these, SNs can transmit the control frames like association request, GTS request, DTS request etc.

The NC can process data received from SNs and then sends it to the monitoring station or server through other networks (i.e., cellular, WLAN or wired); this communication paradigm is beyond the scope of this thesis. Here in this thesis we only considered SNs to NC communication, and our concern is to design a MAC framework within a single WPAN with WBAN application.

B. Proposed Scheme Scenario

In conventional 802.15.4 MAC, there is a provision of GTS allocation in the contention free period that allows dedicated bandwidth to a device ensuring low latency. Any SN can transmit its data in CAP or in GTS if allocated. So any regular periodic data after emergency events can be reported in CAP or in GTS depending on the instance of occurrence.

Let us consider a scenario in which emergency event happen at the CAP portion and regular periodic data at the end of CAP portion. Since emergency data are small, they can be sent in the CAP portion. Here, we assume that a SN node doesn't require GTS slots to transmit emergency data. After emergency has occurred, regular periodic data also need to be transmitted within delay margin for effective diagnosis of patient. As regular periodic data occur at the end of CAP, for transmitting such data, SN node will first send a GTS request to NC in the CAP of next superframe and if the request is granted, it will successfully transmit data in the CFP of next next superframe.

The SN node suffers waiting time in order to transmit the regular periodic data, after emergency, to NC. It has to wait till the sum of inactive period of current superframe and the beacon period of next superframe so as to transmit GTS request. This delay margin is the inflexibility of IEEE 802.15.4 MAC to handle RPE data in case of emergency.

The proposed scheme is designed in such a way that the emergency data as well as the regular periodic data occurring after emergency are handled within the delay margin. In the proposed scheme, a special time slot ECP (Emergency Contention Period) is allocated after the beacon period for transmitting emergency data. And to report the regular periodic data occurring after emergency, PCAP and inactive period is used. A fraction of inactive period is used for transmitting such periodic data. In this way, the delay for reporting both emergency as well as regular periodic data is minimized in the proposed scheme.

C. Modified Superframe Structure

In the conventional beacon enabled IEEE 802.15.4 MAC, after CAP and CFP, SNs and NC go to sleep mode in inactive period. In our proposed scheme, the inactive period is utilized for sending medical data when emergency condition is noted. The modified frame format consist of Beacon, Emergency Contention Period (ECP), Advertisement Beacon (AB), Contention Free Period (CFP), Periodic Contention Access Period (PCAP), Notification Beacon (NB), Data Transmission Period (DTP) and Inactive Period as shown in Figure 8.

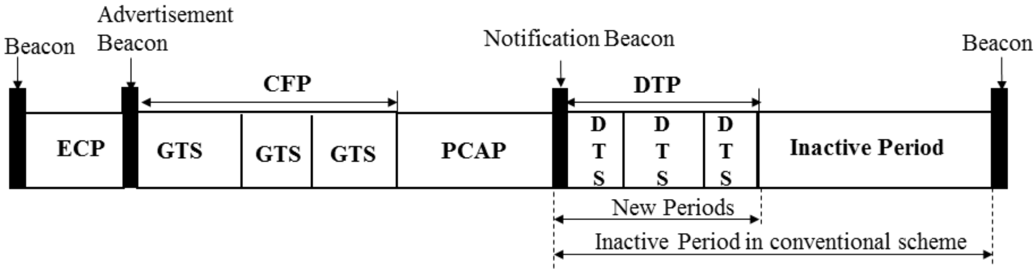


Figure 8. Superframe Structure

The superframe starts with a Beacon Period, where beacon contains the information on the addressing fields, the superframe specification, the GTS fields, the pending address fields and other PAN related.

ECP starts just after the beacon ends and ends before the beginning of advertisement beacon. In this period if any node has emergency data and needs to be reported, they are transmitted directly to the network coordinator. CSMA/CA is used to access the channel during ECP. For our proposed scheme, we assume ECP as two time slots.

Upon receiving an emergency data from sensor nodes in ECP, NC broadcast a set flag through Advertisement Beacon (AB) to indicate the presence of emergency events to the sensor nodes. And if there is no emergency a reset flag is broadcasted through AB. Figure 9 shows the advertisement beacon frame structure. AB consists of 2 bytes of Frame Control, 1 byte of Sequence Frame, 4 bytes of Addressing Fields, 1 byte of Flag Field, and 2 bytes of the Frame Check Sequence field.

Octets: 2	1	4/10	1	2
Frame Control	Sequence Frame	Addressing fields	Flag Fields	Frame Check Sequence

Figure 9. Advertisement Beacon Frame Structure

CFP functions same as that of IEEE 802.15.4 standard. PCAP starts immediately after CFP ends. Only the SNs with regular periodic data are allowed to report and transmit in these periods. If SN nodes receive set flag through AB, then they send DTS request frame to NC in order to transmit regular periodic traffics after emergency otherwise they send GTS request frame to NC in order to operate normally as IEEE 802.15.4. CSMA/CA is used in PCAP.

NB follows the PCAP. But NB is broadcasted by NC only if any DTS request frame is requested to NC from PCAP; otherwise NB period is used as inactive period. NB contains the transmission schedules (i.e. allocated Dedicated Transmission Slots (DTS)) as shown in Figure 10, in the following DTP. All the SNs who have requested DTS request frame in PCAP should listen to NB to check whether their reporting in PCAP are acknowledged by NC and are allocated with DTS schedule.

DTP is a TDMA based access period which appears after NB. DTP is divided into a number of slots called as DTS. The length of a DTS slot is so determined to accommodate regular periodic data and an ACK message. The number of such DTSs is limited to seven.

Octets: 2	1	4/10	variable	2
Frame Control	Sequence Frame	Addressing fields	DTS Fields	Frame Check Sequence

Figure 10. Notification Beacon Frame Structure

D. Flow Scheme of Proposed Superframe

Figure 11 shows the flow diagram of proposed scheme. Let us assume that a SN has emergency data at ECP period and regular periodic data at the end of ECP period (equivalent to CAP in conventional). This emergency data will be sent to the coordinator within the ECP period. Thus emergency data is handled within the required delay margin. Now, since regular periodic data also has its importance in case of emergency, it also needs to be reported to coordinator within the delay margin. When coordinator receives the emergency data, it then broadcasts a set flag through advertisement beacon to all the nodes to inform that the emergency has been occurred. Then SNs having regular periodic data wait until the start of PCAP and perform CSMA/CA. Once the channel is idle, the SN sends a DTS request frame and waits for ACK. If it receives ACK for the sent DTS request frame and DTS allocation information (regarding which DTS has been assigned to it) by coordinator through Notification Beacon (NB), it will transmit its regular periodic data in the DTS allocated to it. On the other hand, if it does not receive ACK or DTS is not allocated in the NB message, the SN wait till the next PCAP for data transmission by contention.

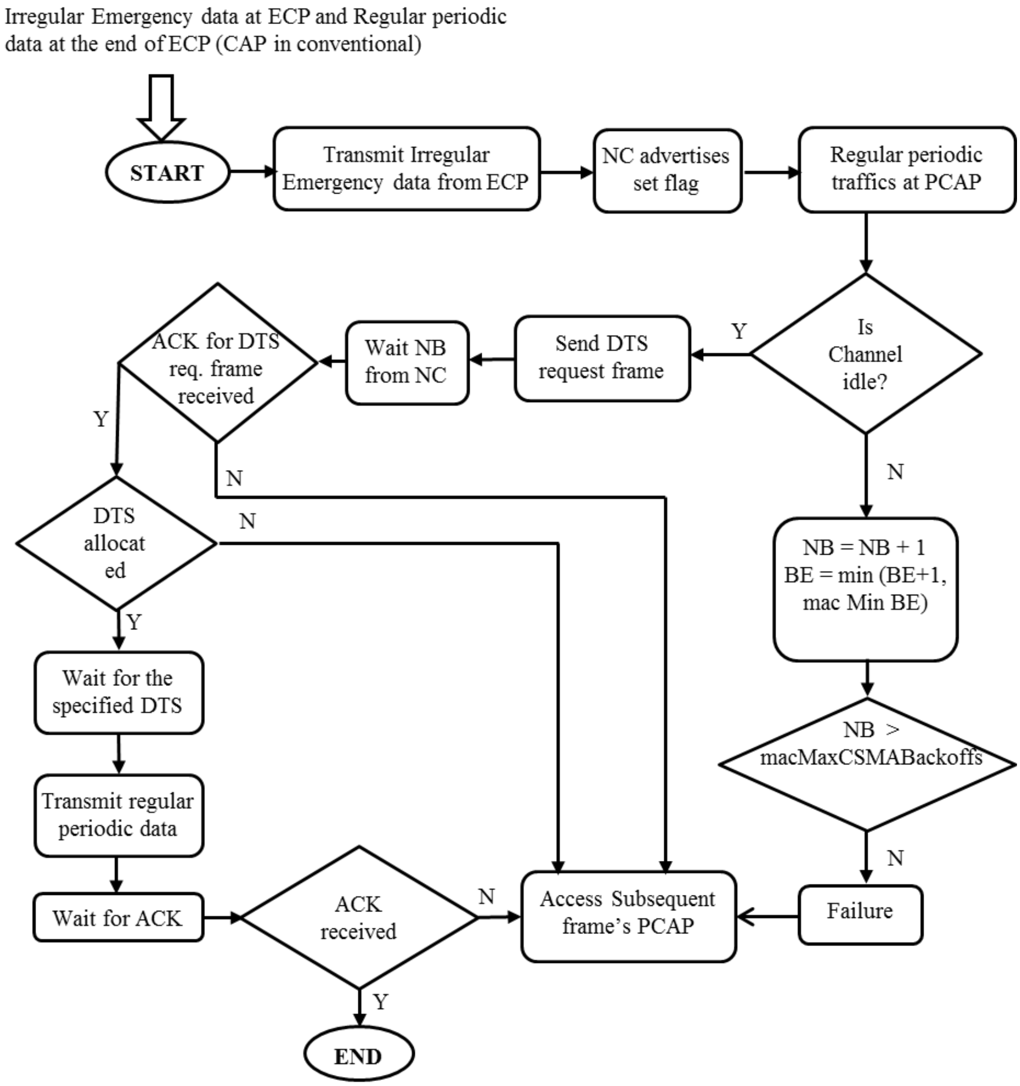


Figure 11. Flow diagram of Proposed Scheme

IV. NUMERICAL ANALYSIS

A. Performance Metrics

In this section, we formulate some expressions to calculate the two important performance metrics related to delay, throughput and energy. Here we analyze the minimum achievable delay, maximum achievable throughput and maximum energy consumption. Such performance can be achieved only in ideal conditions when there is no packet failure in the network either due to collision or channel error.

1. Delay

For sending a packet of size x, DLB for the conventional scheme can be calculated using the following expression:

$$Delay_c(x) = T_{CFP} + T_{Inactive} + T_{Beacon} + T_{SIFS} + T_{BO} + T_{(x)} + T_{TA} + T_{ACK} + T_{IFS(x)}$$

where,

T_{CFP} = Duration of CFP,

$T_{Inactive}$ = Duration of the inactive period,

T_{Beacon} = Beacon duration,

$T_{(x)}$ = Time taken to transmit packet of size x,

T_{TA} = Turnaround time,

T_{ACK} = Time taken for ACK transmission,

$T_{IFS(x)}$ = The IFS time for packet of size x,

T_{BO} = The duration of backoff period.

Note that in IEEE 802.15.4, $T_{IFS(x)}$ is 640µs for x greater than 18 Bytes, otherwise it is 192µs. During backoff procedure in beacon enabled IEEE 802.15.4, a node performs clear channel assessment (CCA) twice and hence backoff duration can be expressed as

$$T_{BO} = BO_{slots} * T_{BO_{slot}} + 2T_{CCA}$$

where,

BO_{slots} = Average number of slots that the node deferred its transmission,

T_{BO_slot} = slot duration (320μs),

T_{CCA} = Time required for CCA.

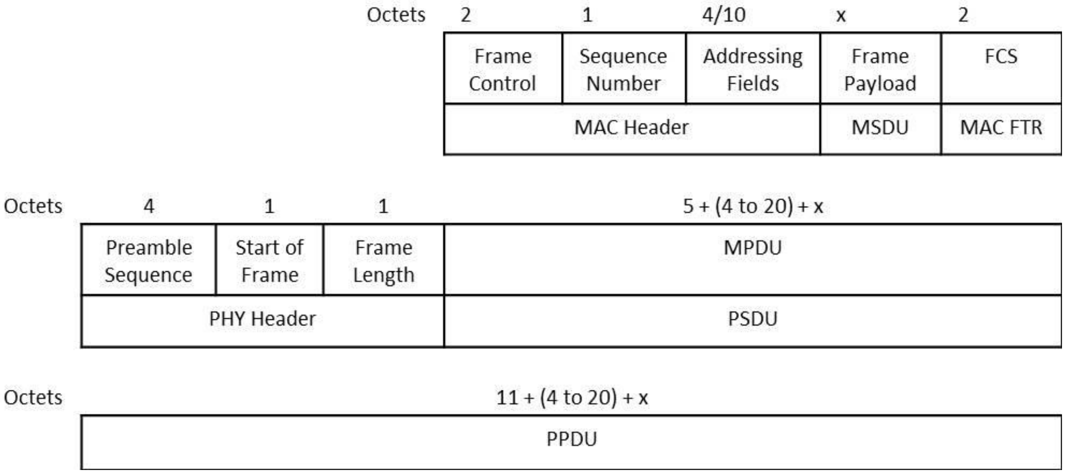


Figure 12. Frame format (IEEE 802.15.4).

Based on frame format shown in Figure 12, we calculate T(x) to be

$$T_{(x)} = 8.\frac{L_{PHY} + L_{MAC\_HDR} + L_{address} + \mathrm{x} + L_{MAC\_FTR}}{R_{data}}$$

Where,

L_{PHY} = Length of the PHY header in bytes,

L_{MAC_HDR} = Length of the MAC header in bytes,

$L_{address}$ = Length of the MAC address,

L_{MAC_FTR} = Length of the MAC footer in bytes, and

R_{data} = Raw data rate in bits per second (bps)

Finally, T_{ACK} can be calculated as,

$$T_{ACK} = 8.\frac{L_{PHY} + L_{MAC\_HDR} + L_{MAC\_FTR}}{R_{data}}$$

We calculate the minimum achievable delay for the proposed scheme by summing the durations required for packet exchange and protocol timing specifications as in the case of the conventional scheme. Delay for the proposed scheme for reporting the medical data in case of emergency event using x Byte packet is

$$Delay_P(x) = T_{CFP} + T_{AB} + T_{SIFS} + T_{PCAP} + T_{SIFS} + T_{NB} + T_{SIFS} + T_{(x)} + T_{TA} + T_{ACK} + T_{IFS(x)}$$

where,

T_{AB} is the AB duration. T_{PCAP} is PCAP duration and T_{NB} is NB duration.

It is worthwhile to mention that the length of CFP is a variable one which is dependent on the number of GTSs allocated. At maximum 7 such GTSs can be allocated in a time provided that there is a sufficient resource available. Each GTS can occupy a single or more transmission slots. So, the smallest length of CFP denoted by CFP_{min} is a single GTS extending to a single transmission slot. On the basis of these varying CFP lengths, the different cases of Delay calculation for proposed scheme hence are calculated for best case delay and worst case delay.

2. Throughput

Once the delay for the conventional scheme and the proposed scheme are calculated, throughput for both the schemes can be calculated as

$$Throughput_c(x) = 8 * \frac{x}{Delay_c(x)} \;\; and \;\; Throughput_p(x) = 8 * \frac{x}{Delay_p(x)}$$

where,

Throughput$_c$ and Throughput$_p$ are throughput for scheme and the proposed scheme, respectively.

3. Energy

Energy consumption to achieve the above throughput and delay is given as

$$E_c(x) = 2P_rT_{Beacon} + P_iT_{BO} + P_tT_{(x)} + P_rT_{ACK}$$

$$E_p(x) = 3P_rT_{Beacon} + P_iT_{BO} + P_tT_{(x)} + P_rT_{ACK}$$

where,

E_c and E_p are energy consumption for conventional and proposed scheme respectively.

P_t, P_r and P_i are Power of radio transmission, radio reception and idle listening respectively.

T_{Beacon} is the beacon duration.

T_{BO} is the duration of backoff period.

$T_{(x)}$ is the time taken to transmit packet of size x and

T_{ACK} is the time taken for ACK transmission.

B. Numerical Result

In this section, we have compared Delay, Throughput and Energy of the proposed scheme and the conventional scheme using the expression derived in the previous section and considering the parameters in Table 1. Considered parameters are taken from IEEE standard. It is noteworthy to mention that in our numerical analysis medical events are considered to occur at the beginning of CFP. Besides, two different cases for Delay and Throughput viz. best and worst are presented and discussed for both the proposed and conventional scheme.

Table 1 Considered parameters and their values

Parameters/Variables	Values
Data rate (R_{data})	250 kbps
aBaseSuperframeDuration	960 symbols (15.36ms)
macBeaconOrder (BO)	4
macSuperframeOrder (SO)	3
Beacon Interval (BI)	245.76 ms
aNumSuperframeSlots	16
UnitBackoff Period	20 symbol (0.32ms)
aMaxSIFSFrameSize	18 octets
aTurnaroundTime	12 symbols (0.196ms)
macAckWaitDuration	54 symbols (0.864ms)
Notification Beacon	40 bytes
Beacon	40 bytes (1.28ms)
macMinBE	3
macMaxBE	5
macMaxCSMABackoffs	4
macMaxFrameRetries	3
CCA	8 symbols
SIFS	12 symbols (0.192ms)
LIFS	40 symbols (0.64ms)
Advertisement Beacon	40 bytes
T_{TA} (Turnaround Time)	12 symbols (192µs)
$T_{IFS(x)}$	12 symbols (192µs) (for $x \leq 18$ Bytes), 40 symbols (640µs) (for $x > 18$ Bytes)
L_{PHY}	6 bytes
L_{MAC_HDR}	3 bytes
$L_{address}$	2 bytes
L_{MAC_FTR}	2 bytes
P_t = Power of radio transmission	36.5 mW
P_r = Power of radio reception	41.4 mW
P_i = Power of idle listening	41.4 mW

Packet size	Delay (IEEE 802.15.4)	Delay (proposed)
10	133.76	19.328
20	134.528	20.096
30	134.848	20.416
40	135.168	20.736

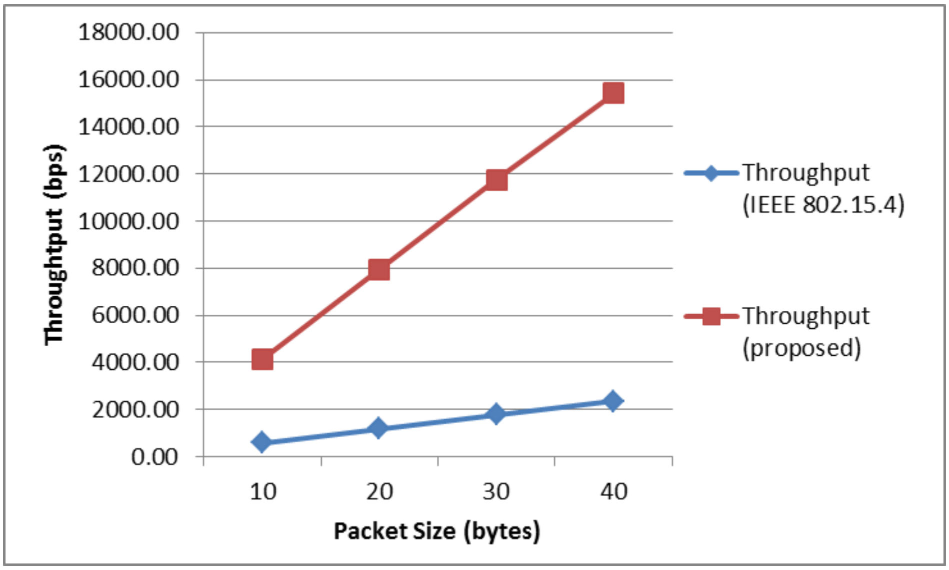
a. Delay of proposed and conventional schemes (Best Case).

Packet size	Delay (IEEE 802.15.4)	Delay (proposed)
10	179.84	117.248
20	180.608	118.016
30	180.928	118.336
40	181.248	118.656

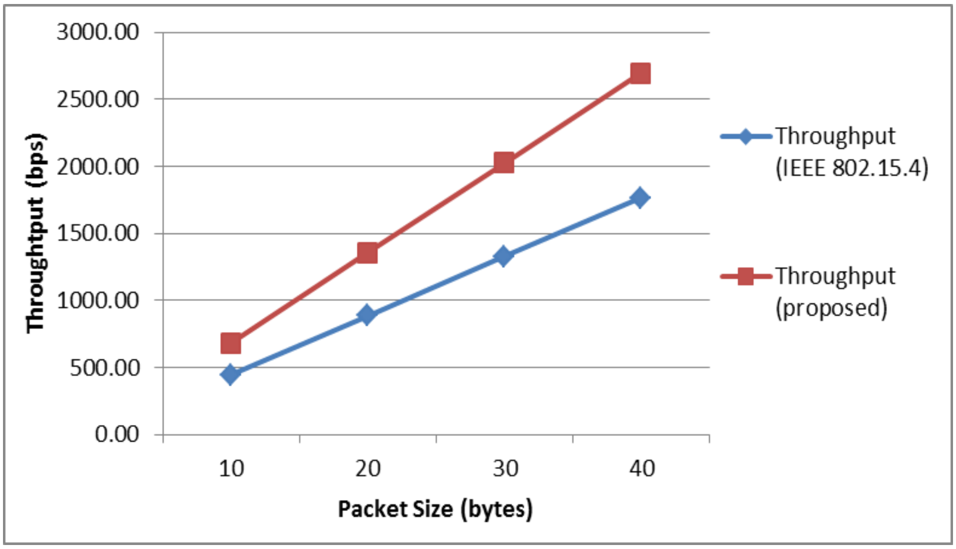
b. Delay of proposed and conventional schemes (Worst Case)

Table 2 Minimum Achievable Delay of the proposed and the conventional Schemes.

Table 2a and 2b shows the minimum achievable delay of the proposed scheme and the conventional IEEE 802.15.4 at two different cases, best and worst. It is observed from the table that, delays of the proposed scheme are less than that of the conventional scheme, regardless of the payload size. It can be also seen that delay is not much affected by the packet size. In either of the cases, the proposed scheme has the delay lower than the delay requirement of WBAN whereas the delays in conventional scheme do not meet this target. This makes proposed scheme much more favorable for WBAN applications.



a. Throughput of proposed and conventional schemes (Best Case).



b. Throughput of proposed and conventional schemes (Worst Case).

Figure 13 Maximum Achievable Throughput of the proposed and the conventional

Figure 13 shows the maximum achievable throughputs of the proposed scheme with suggested two approaches and the conventional IEEE 802.15.4 scheme increase linearly with increase in the payload size. Moreover, Throughputs of the proposed scheme are higher than that of the conventional scheme.

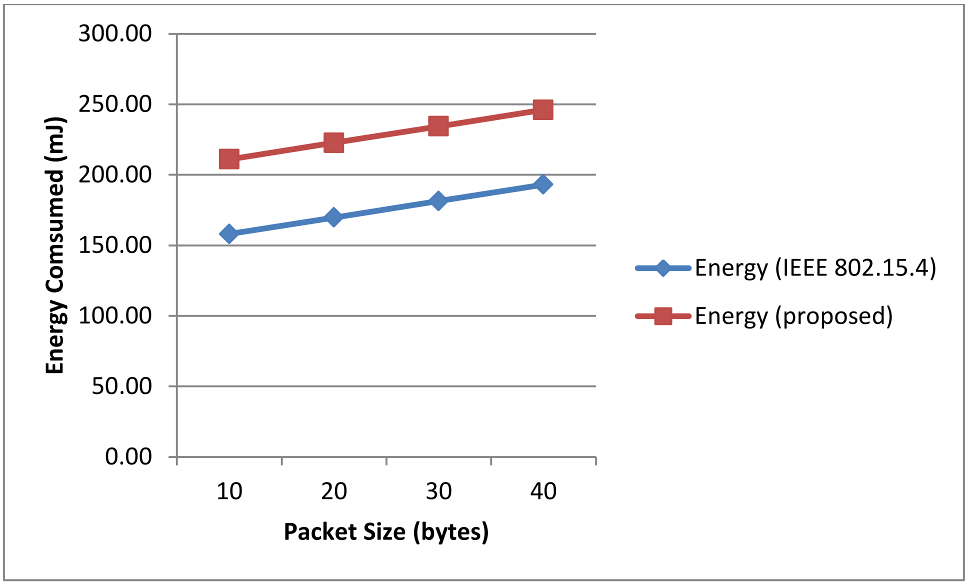


Figure 14. Maximum Energy Consumption of the proposed and the conventional Schemes.

Figure 14 shows graph for energy consumption versus packet size for proposed and conventional protocol. It can be seen that in proposed scheme energy consumed is more than in conventional protocol.

From above comparison we can say that to achieve minimum delay and maximum throughput, energy consumption is high. In our proposed scheme, when packet size is 40 bytes, delay is reduced by 85%, throughput is increased by 551.85% and 27.44% energy is consumed.

V. Evaluation

A. Simulation Environment

To evaluate the proposed scheme, Castalia-3.2 [33], a network simulator specifically designed for sensor and body area networks based on OMNeT++ platform [34], has been used. The simulation was carried out with star topology, with the single hop communication between the Network Coordinator (NC) and Sensor Nodes. The numbers of nodes are varied starting from 10 nodes and the packet length is fixed to 40 bytes. The traffic is generated using the Poisson distribution. The detailed simulation parameters and their values are summarized in table 3.

Table 3 Simulation Parameters

Parameters/Variables	Values
Data rate (R_{data})	250 kbps
Simulation time	50 sec
Frequency band	2.4 GHz
aBaseSuperframeDuration	960 symbols (15.36ms)
macBeaconOrder (BO)	4
macSuperframeOrder (SO)	3
Beacon Interval (BI)	245.76 ms
aNumSuperframeSlots	16
UnitBackoff Period	20 symbol (0.32ms)
aMaxSIFSFrameSize	18 octets
Notification Beacon	40 bytes
Beacon	40 bytes (1.28ms)
macMinBE	3
macMaxBE	5
macMaxCSMABackoffs	4
macMaxFrameRetries	3
CCA	8 symbols
Advertisement Beacon	40 bytes

B. Simulation Results

In this section the simulated results of the proposed scheme is evaluated against the conventional IEEE 802.15.4. The proposed scheme is compared using the performance matrices; end-to-end delay and throughput.

1. End-to-End Delay

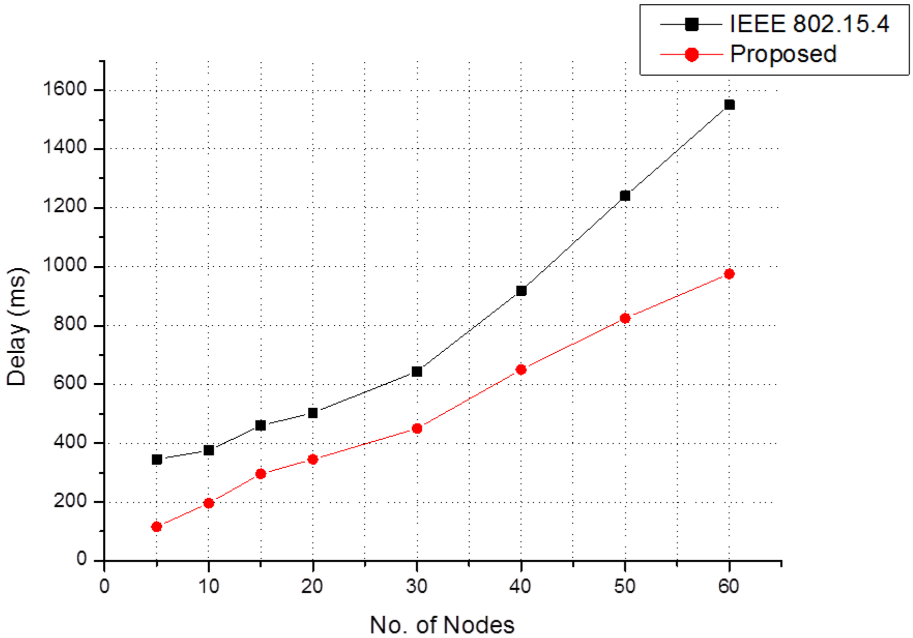


Figure 15. Regular periodic traffic end-to-end delay comparison of proposed and conventional schemes in case of emergency events.

Figure 15 shows the graph of end-to-end delay versus packet size comparing proposed and conventional IEEE 802.15.4. In general, delay increases as the No of nodes increases for both schemes. If more number of nodes are added to the network then the delay increases abruptly. But the proposed scheme has a lower delay than the conventional one.

2. End-to-End Throughput

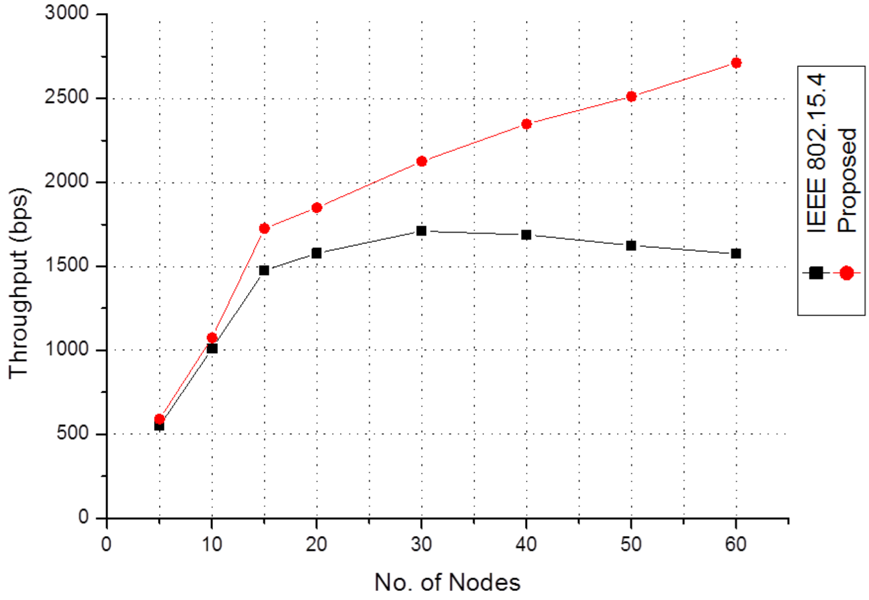


Figure 16. Regular periodic traffic end-to-end throughput comparison of proposed and conventional schemes in case of emergency events.

Figure 16 shows the graph of end-to-end throughput versus no. of nodes comparing proposed and conventional IEEE 802.15.4. Here throughput increases as the no of nodes increases up to a certain point for both schemes. But the proposed scheme has a higher throughput than the conventional one. And after a certain point throughput tends to decrease. This is due to the fact that the system could handle certain number of nodes and increasing more nodes caused the system to have more collisions.

VI. CONCLUSION

A modified IEEE 802.15.4 frame structure is proposed that opportunistically uses the inactive period for handling regular periodic data when emergency happens in WBANs. Here it is showed through numerical results that for the proposed scheme, delay are smaller whereas throughputs are larger than that of conventional scheme. The numerical analysis shows that the proposed scheme provides 80% decrease in delay and 500% increase in throughput. From numerical analysis it is also seen that, to decrease the delay and to increase throughput, nodes consume more energy. From simulation result also we can conclude that our proposed scheme has lower delay and higher throughput. If there is no emergency event, the proposed protocol shows behavior of IEEE 802.15.4 functionally and hence makes it compatible with IEEE 802.15.4.

As this work is primarily focused on minimizing the reporting delay of regular periodic data when emergency event occurs, other network issues such as security, energy efficiency are not addressed in detail. Since this proposed scheme use advertisement beacon for broadcasting whether emergency occur or not and notification beacon for broadcasting the schedules for regular periodic data, energy is consumed more for these beacon broadcasting. As reporting data related to human health is utmost importance, the tradeoff between performance of the system and its energy is acceptable. But it is due necessary that the MAC protocol must be energy efficient in BAN application as the sensor devices used in the application has limited energy. So in the future, this scheme can be evaluated and researched on the basis of these issues.

BIBLIOGRAPHY

[1] C. S. Raghavendra, K. M. Sivalingam, and T. Znati, "Eds. Wireless Sensor Networks," Kluwer Academic Pub, 2004

[2] IEEE Std. 802.15.6-2012, Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY) Specifications for Low-Rate Wireless Personal Area Networks (WPANs), 2006,

[3] M. Chen, S. Gonzalez, A. Vasilakos, H. Cao, and V. C. Leung, "Body area networks: A survey", Mobile Networks and Applications, vol. 16, no 2, pp. 171–193, 2011.

[4] S. Ullah, H. Higgins, B. Braem, B. Latre, C. Blondia, I. Moerman, S. Saleem, Z. Rahman, and K. S. Kwak., "A comprehensive survey of wireless body area networks", Journal of Medical Systems, vol. 36, no 3, pp. 1065–1094, 2012.

[5] K. S. Kwak, S. Ullah, and N. Ullah. "An overview of ieee 802.15.6 standard," 3rd International Symposium on Applied Sciences in Biomedical and Communication Technologies (ISABEL), pp. 1 –6, 2010.

[6] World Health Organization "Global Health and Aging", Available at http://www.who.int/ageing/publications/global_health.pdf, 2011.

[7] American Heart Association "Heart Disease and Stroke Statistics – At-a-Glance", Available at https://www.heart.org/idc/groups/ahamah-public/@wcm/@sop/@smd/documents/downloadable/ucm_470704.pdf

[8] D. Malan, T. Fulford-Jones, M. Welsh, and S. Moulton, "Codeblue: An ad hoc sensor network infrastructure for emergency medical care", International workshop on wearable and implantable body sensor networks, vol. 5, 2004.

[9] Y. Kim and S. R. Lee, "Coexistence of ZigBee-based WBAN and WiFi for Health Telemonitoring Systems", 2015.

[10] H. Cao, V. Leung, C. Chow, and H. Chan, "Enabling technologies for wireless body area networks: A survey and outlook", IEEE Communications Magazine, vol. 47, no.12, pp.84-93, 2009.

[11] S. Ullah, H. Higgins, B. Braem, B. Latre, C. Blondia, I. Moerman, S. Saleem, Z. Rahman, and K. S. Kwak, "A comprehensive survey of wireless body area networks", Journal of medical systems, vol. 36, no. 3, pp. 1065-1094, 2012.

[12] S. Ullah, H. Higgins, B. Shen, and K. S. Kwak, "On the implant communication and MAC protocols for WBAN", International Journal of Communication Systems, vol. 23, no. 8, pp. 982-999, 2010

[13] 15-09-0366-01-0006-inha-mac-proposal, Available: https:// mentor.ieee.org /802.15/dcn/09/15-09-0366-01-0006-inha-mac-proposal.pdf

[14] IEEE 802.15-08-0644-09-0006, TG6 Technical Requirement (TRD), Available: https://mentor.ieee.org/802.15/dcn/08/15-08-0644-09-000 6-tg6-technical-requirements-document.doc

[15] S. Ullah, P. Khan, and K. S. Kwak, "On the development of low-power MAC protocol for WBANs", Proceedings of the International Multi Conference of Engineers and Computer Scientists, vol. 1, 2009

[16] S. E. O. Young-Sun, D. Y Kim, J. CHO, “A Dynamic CFP Allocation and Opportunity Contention-Bases WBAN MAC Protocol”, IEICE transactions on communications, vol. 93, no. 4, pp. 850-853, 2010.

[17] M. Al. Ameen, J. Liu, and K. Kwak, "Security and privacy issues in wireless sensor networks for healthcare applications", Journal of medical systems, vol. 36, no. 1, pp. 93-101, 2012.

[18] “IEEE standard for local and metropolitan area networks part 15.6: Wireless body area networks,” IEEE Std 802.15.6-2012, pp. 1 –271, 2012.

[19] Specification of the Bluetooth System version 4.0. Bluetooth SIG, June 2010. Available at: http://www.bluetooth.com

[20] IEEE 802.15 WPAN Task Group 4 (TG4), Available: http://www.ieee802.org /15/pub /TG4.html.

[21] G. Lu, B. Krishnamachari, and C. S. Raghavendra, "An adaptive energy-efficient and low-latency MAC for data gathering in wireless sensor networks", Proceedings of Parallel and Distributed Processing Symposium, pp. 224, 2004.

[22] E. Callaway, P. Gorday, L. Hester, J. A. Gutierrez, M. Naeve, B. Heile, and V. Bahl, "Home networking with IEEE 802. 15. 4: a developing standard for low-rate wireless personal area networks", IEEE Communications magazine, vol. 40, no. 8, pp. 70-77, 2002.

[23] Y. Zhang and G. Dolmans, "A New Priority-Guaranteed MAC Protocol for Emerging Body Area Networks", 5th International Conference on Wireless and Mobile Communications, pp. 140-145, 2009.

[24] E. J. Kim, M. Kim, S. K. Youm, S. Choi and C. H. Kang, "Priority-based Service Differentiation Scheme for IEEE 802.15.4 Sensor Networks", International Journal of Electronics and Communications, vol. 61, no. 2, pp. 69-81, 2007.

[25] K. S. Kwak and S. Ullah, "A traffic-adaptive MAC Protocol for WBAN", Proceedings of IEEE GLOBECOM Workshops, pp. 1286-1289, 2010.

[26] B. S. Kim, J. Cho, and D. Y. Kim, "An Emergency Handling Scheme for Superframe-Structured MAC Protocols in WBANs", IEICE transactions on communications, vol. 94, no. 9, pp. 2484-2487, 2011.

[27] C. Lee, H. S. Lee and S. Choi, "An Enhanced MAC Protocol of IEEE 802.15. 4 for Wireless Body Area Networks," Proceedings of 5th International Conference on Computer Sciences and Convergence Information Technology, pp. 916-919, 2010.

[28] J.S Ranjit, S. Pudasaini and S. Shin, "A New Emergency-Handling Mechanism based on IEEE 802.15.4 for Health-Monitoring Applications", KSII Transactions on Internet and Information Systems, vol. 8, No. 6, pp. 406-423, 2014.

[29] J. S. Yoon, G. S. Ahn, S. S. Joo, and M. J. Lee, "PNP-MAC: preemptive slot allocation and non-preemptive transmission for providing QoS in body area networks", Proceedings of the 7th IEEE Consumer Communications and Networking Conference, pp. 1-5, 2010.

[30] Y. S. Seo, D. Y. Kim, J. Cho and B. Lee, "OCDP: A WBAN MAC Protocol for Contention-based Medical and CE applications", Proceedings of the 4th International Conference on Uniquitous Information Management and Communication, pp. 12, 2010.

[31] N. F. Timmons and W. G. Scanlon, "An adaptive energy efficient MAC protocol for the medical body area networks", 1st International Conference on Wireless communication, pp. 587-593, 2009.

[32] H. Lee, K. J. Park, Y. B. Ko, and C. H. Choi, "Wireless LAN with medical-grade QoS for E-healthcare", Journal of Communications and Networks, vol. 13, no. 2, pp. 149-159, 2011.

[33] Castalia: Wireless Sensor Network Simulator, Available at: https://castalia.forge.nicta.com.au/index.php/en/

[34] OMNeT++: Simulation Environment, Available at: https://omnetpp.org/

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to my advisor, Professor Seokjoo Shin for his warm encouragement, patience guidance and support throughout this research. Without his continuous support and sometimes critical comments this study would not have been at this stage.

I would like to show appreciation to the entire thesis examining committee members Prof. Sangman Moh and Prof. Moonsoo Kang, for their comments and expertise feedback to complete my thesis. Likewise, I would like to thank the Department of Computer Engineering, Chosun University, to provide me an opportunity to pursue my Master's degree.

It was a great experience for me to work in Wireless Communication and Networking Lab (WHYNET) with other members. I would like to thank all the members of WHYNET Lab for their warm friendship and kind assistance.

I am very grateful and deeply indebted to my parents and all the member of my family especially my husband Saurav, for their unconditional support and encouragement in all my endeavors. Thank you all!!!!

Sabita Nepal