Quality of Service Aware MAC Protocol for Body Sensor Networks

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Declaration

We, hereby, declare that the work presented in this project is the outcome of the investigation performed by us under the supervision of Dr. Md. Abdur Razzaque, Associate Professor, Department of Computer Science and engineering, University of Dhaka. We also declare that no part of this project has been or is being submitted elsewhere for the award of any degree or diploma.

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Abstract

Body Sensor network (BSN) is a topic of huge interest in today's progressive world of smart health monitoring system. BSN is not only applicable to the medical environment but also it has applicability in battle field, health monitoring of deep sea divers, space explorers etc. All of these applications produce time-critical and loss-intolerant data packets. Because of that, consideration of Quality of Service (QoS) in BSNs have become more important. Moreover, these applications may also have to deliver non-critical data packets and thus, body sensor network have to transmit heterogeneous data traffic. The mixture of different levels of QoS requirements imposes new challenges in designing communication MAC protocols for BSNs. Designing such a data communication framework which can fulfill these QoS requirements, has opened a challenging research window.

Our earnest attempt in this exposition is to address the QoS provisioning in the MAC layer of Body Sensor Networks. We design a priority based traffic load adaptive medium access control (MAC) protocol for BSNs, namely PLA-MAC, which addresses the aforementioned requirements and maintains efficiency in energy consumption. In PLA-MAC, we classify sensed data packets according to their QoS requirements and accordingly calculate their priorities. The transmission schedule of the packets are determined based on their priorities. Also, PLA-MAC's dynamic superframe structure that varies depending on the amount of traffic load ensures minimal energy consumption.

The effectiveness of PLA-MAC has been evaluated using ns-3 simulator. The results of the simulations demonstrate that PLA-MAC effectively improves the reliability, delay guarantee and throughput with reduced operation overhead compared to the state-of-the-art solutions.

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Chapter 1

Introduction

1.1 Introduction

Wireless Body Sensor Networks (BSNs) are getting immense research interests worldwide as it makes drastic advancement in medical applications, and, in particular, health monitoring systems. With the invention of miniature, cost effective and wearable sensor devices, it has attracted large amount of research time [1].

Body Sensor Network has significant effect in the advancement of health care applications; at the same time there are some constraints which control the applicability and reliability of it. Although there is drastic advancement in sensor technology in this century, still they are battery powered. So, energy consumption for processing and data transmission of sensor nodes should be controlled. As used in Medical application, reliable and timely delivery should also be maintained strictly in BSN. For example, data generated from a operation theater should be transmitted immediately, without any loss. Therefore QoS provisioning is an important issue in Body Sensor Network. There is existing literature that addressed some of these constraints, however very few of them addressed all the constraints.

In this dissertation, we investigate both the reliability and delay constraints in QoS provisioning while preserving the energy efficiency. We developed a MAC protocol for Body Sensor Network that classifies the data packets generated by medical application based on their QoS requirement. Then we prioritized the data packets using data class, packet size and data generation rate. We designed the transmission mechanism such that, energy efficiency is maintained, ensuring consistency in network.

1.2 Body Sensor Network

Body Sensor Networks (BSNs) are comprised of a variable number of autonomous electronic devices, with components that has the capability of remote sensing, signal processing and communication in an ad-hoc fashion. Current sensor networks can exploit technologies not available 25 years ago and perform functions that were not even dreamed of at that time. Also sensors, processors, and communication devices are all getting much smaller and cheaper. Commercial companies such as Ember, Crossbow, and Sensoria are now building and deploying small sensor nodes and systems. Continuous encouragement on the development of technologies and algorithms for short range networks ensures that more capable and versatile sensor nodes are coming.

Now-a-days huge number of commercial companies develop PDAs, Smart Watches, Smart Phones which are capable of acting as communication coordinator. This coordinator serves as primary processor, database and also the connector to the global network.

When an event occurs in a body sensor network, one or more associated sensor nodes will sense the event and transmit request to the coordinator node. Then coordinator node will allocate time slots for the sensor nodes. After sending data to the coordinator, responsibility of sensor node ends and they go to sleep. Its the responsibily of coordinator to transmit data to the outer network.

1.2.1 BSN Architecture

The Communication achitecture of a typical Wireless Body Sensor Network is illustrated in figure 3.1. Usually a BSN comprises of a number of biomedical sensor nodes which are placed on or implanted in a human body. These sensors collect various physiological data and transmit the data packets to a coordinator node. This coordinator node connects this local sensor network to the internet, that is, it tranmits data to the main server via internet. The coordinator node can be a smart phone, smart watch or a PDA. It should contain enough buffering and processing power to handle the large amount of sophisticated physiological data.

BSNs primarily use a star topology with a communication range of around 3 meters [6] and the sensors usually need to transmit data at relatively wide range of data rates from 1 Kbps to 1 Mbps [7]. The sensor nodes would have to be self-contained and battery operated and also should be able to gather data from a specific part of human body.

There are some contradictory challenges in the architectural design of BSN like reliability, timely delivery, energy efficency and prioritized transmisson. The sensor nodes are battery powered. So when the network is formed they should be full powered, and the topology and protocol design should be such that all the challeges are met.

1.2.2 BSN Applications

The availability of small, low-cost networked sensors combined with advanced signal processing and information management is bringing a revolution in physiological monitoring system. Body Sensor Networks (BSN) are enabling technologies for improved healthcare, enhanced sports and fitness training, novel life-style monitoring, individualized security and many other sectors.

For example, recent advances in electronics have enabled the development of small and intelligent bio-medical sensors which can be worn on or implanted in the human body. These include monitoring of the activity of the transplanted

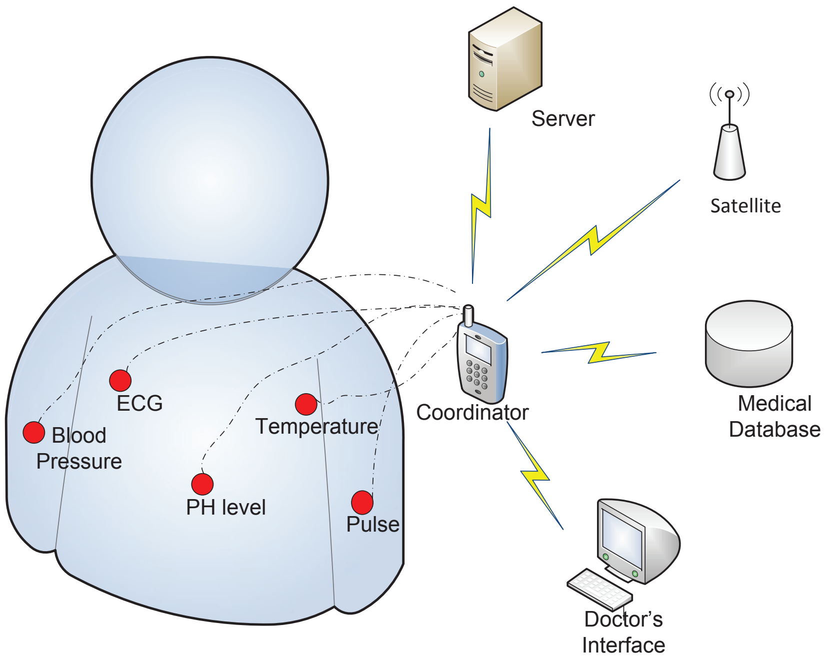

FIGURE 1.1: General BSN architecture

organs or activity of the affected organs in order to monitor and provide better services in advance. The Rogers research group, Illinois University is developing the in-body sensors and implants for cardio and neural activities and artificial eyes [18]. These sensors need to send their data to an external medical server where it can be analyzed and stored. Using a wired connection for this purpose will be too cumbersome and involves a high cost for deployment and maintenance [19].

BSN allows continuous monitoring of the physiological parameters. Whether the patient is in the hospital, at home or on the move, the patient will no longer need to stay in bed, but will be able to move around freely [2]. Furthermore, the data obtained during a large time interval in the patient's natural environment will offer clearer view to the doctors than data obtained during short stays at the hospital [20]. Also, they can be deployed inexpensively in existing structures without any advance IT infrastructure [3].

The traditional method of providing healthcare is to consult a doctor. With the help of recent advancements in medical technologies the vice versa of the traditional methods are enabled. The new healthcare model encourages the use of remote clinic care, consultants and home healthcare to assist in remote patient assessments. Systems like Distance Doc by "Mediphan" and Transportable Exam Station by "GlobalMed" are some of examples for latest trends in telemedicine [21] [22].

Body Sensor Networs are not only used in medical and health-care purpose. This technology can be used to help protect those exposed to potentially life-threatening environments, such as soldiers, first responders, and deep-sea and space explorers [4]. It is also being used successfully for entertainment applications also [5].

For example, BSN is now used in driver distraction monitoring systems to avoid car accidents. Being stuck in a traffic jam, doing other tasks simultaneously while driving like drinking, reading, talking over the mobile phone are various forms of distractions. Early detection of driver distraction can reduce the number of accidents. Motion detector sensors are used to detect leg and head movements of the driver [23].

BSN is also used in under-water diver health monitoring, as under-water diving is very risky and can become life threatening sometimes. In this monitoring system, sensor devices are installed on diver's body which can monitor the respiratory, blood pressure, body temperature, mussel movement etc [26].

A BAN is expected to be a very useful technology with potential to offer a wide range of benefits to patients, medical personnel and society through continuous monitoring and early detection of possible problems. Step by step, these evolutions will bring us closer to a fully operational BAN that acts as an pioneer for improving the Quality of Life.

1.3 MAC Protocols in BSNs

Body Sensor networks work under conflicting requirements. There should be maintenance of reliability and latency of data transmission and on the other hand maximization of the battery life of body sensors should be maintained. To meet these requirements, the entire system, physical (PHY), MAC and application layer have to be considered. But the MAC layer is the one that is responsible for coordinating channel accesses, collision avoidance, data transmission, maximization of efficiency and also the energy consumption. From these prospective we can say that, MAC layer and Mac layer protocols will define the future of BSN.

1.3.1 MAC Protocols

The Media Access Control (MAC) is the data communication Networks' protocol sub-layer, also known as the Medium Access Control. It is a sub-layer of the data link layer specified in the seven-layer OSI model. The medium access layer was made for systems that share a common communications medium. Typically these are local area networks. If all devices on the network are trying to speak at the same time, nobody will be able to hear anything (except lots of noise). There needs to be some protocol or a procedure by which devices decide whether they should transmit or not at any given time. The MAC sub-layer has two primary responsibilities: Data encapsulation, including packet assembly before transmission, and parsing error detection during and after reception. Media access control includes initiation of packet transmission and recovery from transmission failure [24].

There are two main approaches to medium access:

- *Random Access :* Each node on its own decides when to transmit.
- *Controlled Access :* There is some other scheme that determines when a node is allowed to transmitsomething.

There are many protocols that are used by Medium Access Layer,

- *Carrier Sensed Multiple Access (CSMA) :* CSMA is a network access method used on shared network topologies such as Ethernet to control access to the network channel. Devices attached to the network cable listen (carrier sense) before transmitting. If the channel is in use, devices wait before transmitting.

MA (Multiple Access) indicates that many devices can connect to and share the same network. All devices have equal access to use the network when it is clear.

- *CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance) :* In CA collision avoidance), collisions are avoided because each node signals its intention to transmit before actually doing so. Each node listens to the medium prior to transmit. If the energy is higher than a specific level the transceiver waits for a random time (including an interval) and tries again. [25].

- *IEEE 802.15.4 :* IEEE 802.15.4 is the pioneer of body sensor network MAC protocols. It uses two techniques to avoid emission of data from all the nodes at the same time: CSMA/CA and GTS. We have already discussed CSMA/CA above, IEEE 802.15.4 uses almost the same technique. The second one is Guaranteed Time Slots (GTS). This systems uses a centralized node (PAN coordinator) which allocates slots of time to each node so that all the nodes knows when they can transmit. There are 16 possible slots of time. As a first step a node must send a GTS request message to the PAN coordinator. As response the coordinator will send a beacon message containing slot allocation information.

1.3.2 QoS and Energy Efficiency in MAC Protocols

The two fundamental design challenges in BSNs are energy efficiency and quality of service (QoS) provisioning [8]. And BSNs, which are deployed permanently to monitor human physiological parameters, must satisfy far more strict Quality of Service (QoS) demands than those of other existing wireless sensor networks [9]. Provisioning QoS such as reliability and timely delivery is very crucial for BSN. Most of the time, these sensor nodes are very small in size and have low battery power, so energy efficiency should also be maintained.

1.3.2.1 QoS Provisioning

Providing guaranteed QoS to various applications, is an important objective in designing the next-generation Wireless Sensor Networks. Different applications can have very diverse QoS requirements in terms of data rates, delay bounds, and reliability. For example, applications such as power plant control or emergency medical service, demand reliable and timely delivery of information; so, it is critical to guarantee that no packet is lost or delayed during the packet transmission. This type of QoS guarantees is usually called deterministic or hard guarantees. On the other hand, most multimedia applications including video telephony, multimedia streaming, and Internet gaming, do not require such stringent QoS. This is because these applications can tolerate a certain small probability of QoS violation. This type of QoS guarantees is commonly referred to as statistical or soft guarantees [27]. For wireless networks like BSN, the capacity of a wireless channel and application requirements varies randomly with time, so deterministic QoS will serve most efficiently.

1.3.2.2 Energy Efficiency

The battery size versus battery life tradeoff plays a major role in defining any BSN. Applying design techniques to reduce energy consumption can improve both size and lifetime. If energy consumption can be reduced enough, deployment of sensor devices and their applications will reach the next level. Thus, BSN node sensing, processing, storage, and data transmission must all be done in a way that nodes can reliably deliver data but with the lowest possible energy consumption. In this way minimizing battery size and maximizing battery life will be done, both of which has impact on the performance and continuous availability of different applications.

For life-critical applications like BSN, continuous and reliable transmission of sensed data for real-time assessment and intervention is required. Reduction of wireless transmission may be necessary to meet longer battery life and other requirements. This system level design decision by priority classification and data classification will help to reduce node energy consumption and also satisfy other system requirements [28].

1.4 Problem Definition and Solution Methodology

1.4.1 Problem Definition

A number of medium access control (MAC) protocols have been proposed for provisioning QoS in BSN. IEEE 802.15.4 [14], [15], [16] is a standard defining the specifications for the MAC layer of a low rate wireless personal area network (WPAN), which also provides a way for QoS provisioning in BSN. But the superframe structure of IEE 802.15.4 is not flexible and also the latency involved is high. BodyQoS [11] implements a virtual MAC to schedule and represent channel resources, which makes it radio-agnostic. But there is no priority consideration and also high computational complexity is involved. ATLAS [12] proposes a traffic load aware MAC protocol where the structure of the superframe depends on the estimated traffic load. But it does not take priority into account. PNP-MAC [13] adopts the superframe structure of IEEE 802.15.4. It proposes a MAC protocol with preemptive slot allocation and non-preemptive transmission and also takes priority into account. But it does not take traffic load into account, also duration of the CFP period of its superframe structure is fixed.

From the above discussion on the state-of the-art MAC protocols we can now define the Body Sensor Network's actual design and implementation problems, and that will at the end furnish our path to the alternative solution. In this exposition our main goal will be to design a reliable, delay-aware and energy-efficient protocol.

Traffic classification is one of the important factors to consider. In health care systems, different types of sensor nodes produce packets that can have different types of QoS requirement. So it will not be feasible to serve all type of packets on same level.

Packet Prioritization is also important. Different sensor nodes have different data generation rate and generated packet sizes are also different. Also buffer storage of sensor nodes is limited, so priority calculation based on these parameters is crucial.

QoS scheduling is the most critical part in any type of wireless sensor network, also in BSN. Different types of QoS requirements should be maintained like reliability, timely delivery etc.

Energy consumption control should be handled carefully as sensor nodes are battery powered.

1.4.2 Solution Methodology

In order to provide more reliable, efficient and QoS aware mechanism than the state-of-the-art protocols discussed in the previous section, we have to develop a MAC layer protocol that has three basic components. The components are Traffic Classification, Packet Prioritization, and QoS Packet Scheduling as illustrated in figure 1.2. The Energy efficiency is crucial for sensor nodes, so more devotion for increasing the battery life of the sensor nodes should be given. Classification of data packets based on their QoS requirements and urgency is also critical. Reliability critical packets should be sent such a way that they don‘t have to conpete with others. On the other hand, when we are talking about delay critical packets, fast delivery is the more important to thing to consider. At the end traffic load of the environment should also be considered. we cannot address a sensor node with higher packet generation rate and another one with lower packet generation rate in the same way as packet loss is critical in healthcare environment. The superframe structure also has to be adopted with the changed protocol design and methodologies.

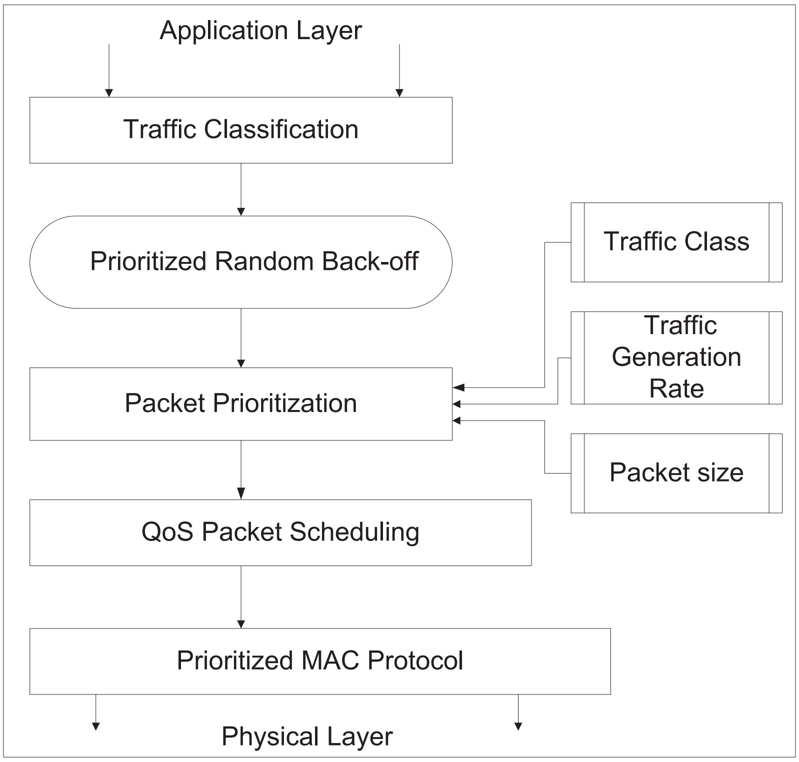

FIGURE 1.2: Overview of the developed QoS architecture.

1.5 Contributions of this work

In this project, we develop a priority based load aware MAC protocol for BSN where the data packets are served based on their priority and the superframe structure is dynamic. In the proposed MAC protocol, we categorize the data packets into four priority classes based on their data type and generation rate. The superframe structure of the protocol varies based on the traffic load as the number of slot allocation in the superframe structure depends on the traffic load. So the superframe structure contains a large inactive period when the traffic load is low and the opposite when the traffic load is high.

The first contribution of the proposed work is priority classification based on data class , generation rate of the sensor nodes, and packet size. Priority classification allows protocol to address different types of packets according to their need.

Timely delivery of delay critical packets, is another contribution of our work. Delay critical packets are sent in the contention access period, without any request for data slots. Also emegency data packets which should be sent immidiately, are sent in differnt emergency time slots, without further delay.

Another contribution is Reliability maintainance. We send reliability critical packets in guarntied time slots (GTS).

Another contribution is Energy efficiency of the sensor nodes. The sensor nodes don't have be active in the whole superframe period, they can go to sleep or LPL after sending their data packets. The number of GTS slots is dynamic and the coordinator can go to sleep state after the GTS slots.

The detail discussion on the development of QoS aware routing is carried out in Chapter 3.

1.6 Project Outline

The five chapters are labeled as Introduction, Motivation and Background, Proposed PLA-MAC Protocol, Performance Evaluation and Discussion and Conclusion. The outline of the thesis is as follows. In Chapter 2, we provide overview of necessary background for MAC layer and MAC routing protocols in body sensor networks and discuss about the motivation of this work. In Chapter 3, we describe the proposed priority based and traffic load adaptive MAC protocol for body sensor networks in detail. The performance evaluation and results are presented in Chapter 4. Finally, we conclude the thesis in Chapter 5 by summarizing the findings in the project and describing scope of possible extensions to this work.

Chapter 2

Motivation and Background

In this chapter, we go through the background of media access control protocols in Body Sensor Networks (BSNs). We also discuss the characteristics of a number of BSN MAC protocols dealing with QoS provisioning.

2.1 Introduction

With the increase in advancement of sensor technology, now sensor devices are small, inexpensive, and powerful, and also with better processing and wireless networking capability. All these advancements have motivated researchers to give more effort in collaborating health monitoring with sensor networks.

For battery-powered sensor nodes, the primary concern should be energy efficiency of the over-all network and protocol design, operation and processing. With this requirement, BSNs present several new and unique research challenges such as signal propagation in and around a human body. Also the whole system must be safe and reliable. As for maximization of the life time of Body area sensor networks, MAC layer protocol specification plays most significant role. A significant amount of research efforts have been devoted to MAC layer protocol design ensuring energy efficiency and other QoS requirements.

The existing efficient MAC protocols are broadly categorized in low power listening (LPL), Contention-based and time division multiple access (TDMA).

In LPL protocols [29], a receiver periodically wakes up from inactive (sleep) mode and checks for a preamble signal from the sender. If the signal is available then receiver stays awake to receive data packet, otherwise it goes back to sleep again. A pure LPL protocols are ineffective for BANs since the push transmission and periodic sampling are not suitable for energy constraint sensor nodes and application requirements. However, the sender-initiated concepts are more applicable, because it serves energy conservation.

In a contention-based protocol such as CSMA/CA, the main sources of energy inefficiency are idle listening, overhearing, collision and protocol deployment overhead [30]. Under a low traffic environment, load adaptive contention and sleep approach would work well and make best use of network capacity. Hence, during low traffic periods in a BAN, adoption of such an approach instead of TDMA may give a better trade-off between energy and delay.

Finally, in time-synchronized and superframe oriented TDMA protocols [10] like the IEEE 802.15.4 [14], time-slots are assigned using notification(beacon) packets. Although TDMA is the best suited MAC protocols of BSN, during low-load traffic periods the overall capacity utilization drastically drops with existing protocols.

From the concepts described above, we can say, A BSN MAC protocol should balance between those three approaches and adopt the concepts dynamically matching the environment need.

2.2 IEEE 802.15.4 protocol (WPAN)

2.2.1 Overview

Although the IEEE 802.15.4 [14], [15], [16] standard was specifically devised to support low power, low data rate networks where latency and bit rate are not so critical, and as a response to the growth in Wireless Personal Area Network, many earlier works [10] adopted IEEE 802.15.4 MAC protocol and its super-frame structure to support the QoS requirements of BSN . From figure 3.2, we can see the super-frame structure of 802.15.4 consists of a contention access period (CAP), a contention free period (CFP), and an inactive period (IP). In the contention access period, sensor nodes send request packets to the coordinator. The coordinator then allocated slots for the nodes in the contention free period which contains up to seven GTS slots. The beacon containing the slot allocation information is transmitted to the sensor nodes in the next superframe.

2.2.2 Limitations

The CFP period contains up to seven guaranteed time slots (GTS), which limits the dynamic behavior of BSN applications. Secondly, IEEE 802.15.4 don't have any mechanism for prioritizing among different applications, low priority data can block the transmission of high priority one, which can cause a severe problem in BSN. Thirdly, the requested GTS time slots are not allocated in the current super-frame; they are scheduled to the next super-frame, which increases the packet delay or latency.

2.3 State-of-the-art MAC protocols

2.3.1 LDTA-MAC

2.3.1.1 Overview

LDTA-MAC [10] protocol improves some of the shortcomings of IEEE 802.15.4. The number of guaranteed time slots (GTSs) is not fixed, and they are allocated dynamically based on traffic load. And also on successful GTS allocations, data packets are transmitted in the current superframe, instead of waiting for next superframe and thereby increasing packet delivery delay.

2.3.1.2 Limitations

Although there is some advancement from IEEE 802.15.4, there is no consideration of the priority of the applications. Without this consideration classification of data packet based on importance, traffic load and urgency is not possible and all packets are serviced with the same priority, which is not a desired characteristic in BSN. Again, the duration of the superframe and the CAP is constant in the current superframe. That means the boundary between CAP and CFP is fixed and also the IP period is fixed, which results in loss of energy in low traffic load periods, and data-loss in high traffic load periods.

2.3.2 BodyQoS

2.3.2.1 Overview

BodyQoS [11] separates QoS scheduler from the underlying MAC implementation, a virtual MAC is developed here to make it radio-agnostic, allowing BodyQoS to schedule wireless transmissions without knowing the implementation details of the underlying MAC protocols. BodyQos does not suffer from the limited number of GTSs; it has the ability to adaptively schedule transmission. The allocation control and scheduler components are implemented as a master (aggregator) and slave (sensor) module. The main part of admission (allocation) control and the QoS maintenance carried on by the aggregator.

2.3.2.2 Limitations

However, BodyQoS uses non-preemptive slot allocation schemes, so high priority data transmissions can be blocked by low priority transmissions. The aggregator (coordinator) initiated communication part is not energy efficient, as sensor nodes should be in listening mode all the time. Also separate MAC implementation can increase computational complexity of the aggregator and sensor nodes which is not acceptable as sensors nodes are battery powered.

2.3.3 ATLAS

2.3.3.1 Overview

ATLAS [12] has proposed a traffic load aware MAC protocol. It has adopted the superframe structure of IEEE 802.15.4, taking different communication environment in account, and most efficient superframe structure is chosen dynamically based on the estimated traffic load and communication environment. ATLAS has implemented a multi-hop communication pattern.

2.3.3.2 Limitations

ATLAS does not take the priority of different applications into account. There is also no indication of back-off class depending on the priority to avoid collision and to let higher priority application to request first. Also managing four type of adaptive super-frame structure depending on traffic load may become a computational load on the gateway, affecting the over-all energy and QoS requirements. As BSN is a small network deployed over a human body, there is less necessity of multi-hop communication, in fact it can become a computational overhead for sensor nodes.

2.3.4 PNP-MAC

2.3.4.1 Overview

PNP-MAC [13] protocol is based on IEEE 802.15.4 superframe structure. It can flexibly handle applications with diverse requirements through fast, preemptive slot allocation, non-preemptive transmission, and super-frame adjustments. By preemptive slot allocation, PNP-MAC addresses that the slots already allocated for low priority packet transmission can be preempted and allocated to high priority data packets. And by non-preemptive transmission, it addresses that emergency data, the most time-critical data are not transmitted in the slots that are allocated for other types of data packets. It also contains some special guranteed time slots

TABLE 2.1: Characteristics of QoS provisioning schemes.

Protocol \ Awareness	Reliability	Energy Efficiency	Delay	Traffic Class	Priority
IEEE 802.15.4 [14]	Yes	Yes	No	No	No
LDTA-MAC [10]	Yes	Yes	No	No	No
BodyQoS [11]	Yes	Yes	No	No	No
ATLAS [12]	Yes	Yes	Yes	No	Yes
PNP-MAC [13]	Yes	Yes	No	No	Yes
PLA-MAC [32]	Yes	Yes	Yes	Yes	Yes

called emergency time slots(ETS) which are mainly reserved for emergency data packets generated after the contention access period.

2.3.4.2 Limitations

As in PNP-MAC the duration of CFP is fixed, if we have lower data rate, it will cause loss of time and energy for being awake on this period. Again if the data rate is high then the fixed inactive period (IP) can cause many important and high priority data to wait for the next super-frame. Again the CAP period only takes request of GTS, not data packets. For some application this period of delay can be significant. There is no balance between the priority consideration and traffic load of sensor nodes. As low priority sensors can have a higher traffic load and they have greater back-off, they will not be able to send most of the data and drop them, which can cause a major problem in medical environment.

2.4 Summary

In this chapter, the key operation principles of a number of medium access control layer protocols for Body Sensor Networks have been discussed. Also in above discussion we have addressed our scope of work by indicating the performance requirement of medical environment, and level of service requirement fulfilled by existing works.

Chapter 3

Proposed Protocol: PLA-MAC

In the previous chapter, we have discussed about state-of-the-art MAC protocols and also defined the scope of the work. In this chapter we will introduce our proposed protocol and its mechanism in providing QoS provisioning and Energy Efficiency.

3.1 Introduction

In this project, we propose a priority based MAC protocol for body sensor networks that modifies the superframe structure of IEEE 802.15.4. It has a dynamic superframe structure depending on the variation of traffic loads. Based on the delay and reliability constraints of data packets we primarily perform a traffic classification. Using this classification and data generation rates from sensor nodes we calculate the different *priority* and *back-off* values. The priority class is used by the coordinator while allocating slots for data packets. The back-off values are used by the sensor nodes to perform prioritized random back-off before transmitting the data packets.

3.2 Network Model and Assumption

In the proposed PLA-MAC protocol, we assume that several biomedical sensor devices are attached to a human body, they all collect data and transmit the data

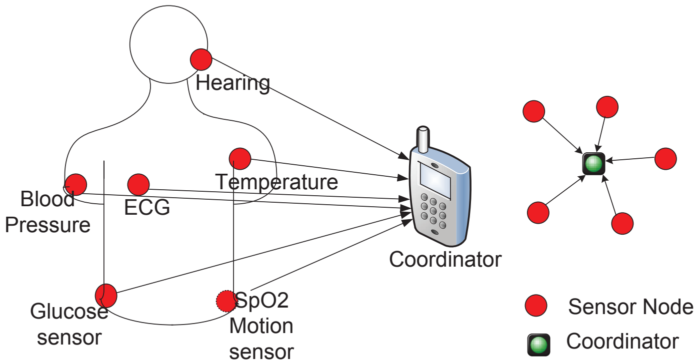

FIGURE 3.1: Body sensor network topology

to a central coordinator node using a star topology. The coordinator node can be a Smartphone or a Smart-watch or PDA, which will transmit the data to the external network. The sensor nodes are assumed to have limited energy supply and limited processing power. The coordinator is significantly more powerful than the sensor nodes. Therefore, it is desirable to push as much computation and communication overhead to the coordinator as possible.

In addition, considering the normal application scenario of a BSN such as a data collection system where data are sent from the sensor nodes to coordinator, the down link traffic like notification or beacon from the coordinator are not considered significant.

We assume that every data packet has a lifetime T_{life}, specified specific application, which indicates the time limit within what the packet should be delivered to the coordinator; otherwise, the information in the packet is useless, and it should be dropped.

In the proposed PLA-MAC protocol, the superframe structure is a modified version of the superframe of the IEEE 802.1.5.4 protocol.

A proper description of the superframe structure used in PLA-MAC can be found in section 3.4 of this chapter. Here, we have assumed the superframe to have a dynamic structure; the length of the active part of the superframe changes based on the traffic load in the network. The superframe is assumed to contain a fixed CAP of 20 slots and the length of the superframe is 128 slots. The number

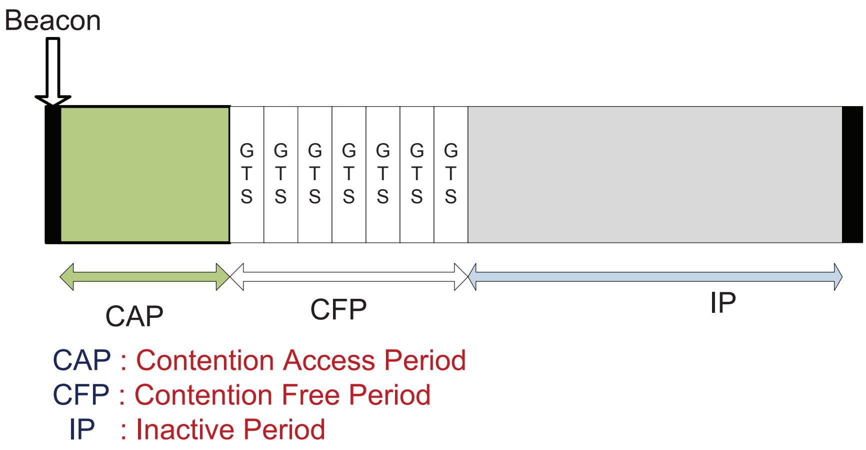

FIGURE 3.2: Superframe stucture of IEEE 802.15.4.

of CFP slots are not fixed. So, when there is minimal traffic, the length of the active part of the superframe can be just a little more than 20, and when there is a huge traffic load, the length of the active part of the superframe can be near 128. The rest of the superframe will be inactive period.

3.3 Traffic Classification

In this protocol, the generated data packets are divided in four types : ordinary data packets (OP), delay-driven data packets (DP), reliability-driven data packets (RP), and critical data packets (CP) [DMQoS](Table 1). The OP corresponds to data packet that contains regular physiological measurements like body temperature, which don't have any serious reliability or delay constraints. The DP packets correspond to packets that have to be delivered timely, don't have much reliability constraint, e. g. video streaming. RP packets must be delivered with reliability that is without any data loss, but don't have any deadline, e. g. respiration monitoring, PH monitoring. The CP packets have high reliability and delay constraints; they have to be delivered with high reliability and low delay, e. g. ECG data packets. Note also that CP packets involve higher data generation

TABLE 3.1: Traffic classification

Traffic-class value	**Traffic Class**
4	Ordinary data packets (OP)
3	Delay-driven data packets (DP)
2	Reliability-driven data packets (RP)
1	Critical data packets (CP)

rate and packet size compared to other classes; OP packets contain lower data generation rate and packet size compared to other packets.

Here the data packets are assigned a data type number T_i. Where the critical data packets are assigned the lowest and ordinary packets are assigned the highest data type number. Based on this data type number, the corresponding back-off and priority values will be calculated.

3.4 Superframe Structure

The BSN superframe structure contains five periods: Beacon, Contention access period (CAP), Notification, Contention free period (CFP) and Inactive period.

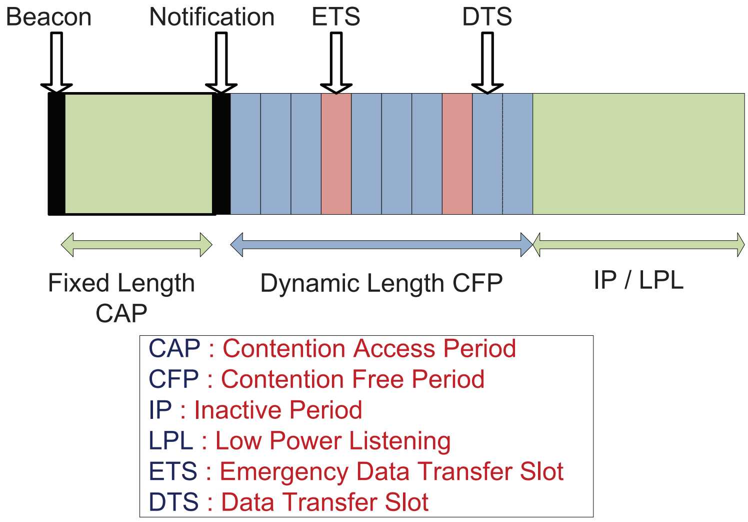

FIGURE 3.3: Proposed PLA-MAC superframe stucture

In Fig. 3.3, we can see that every superframe starts with a beacon period, the beacon informs all the member nodes about the basic information about the coordinator, other nodes and about the starting of the superframe. In the (CAP) slot, the allocation requests of the CP, RP and OP (can also for DP packets) class of packets for the (CFP) slots, and data packets of the DP classes' are received from sensor nodes. Whether a node will transmit a DP packet or a DP request in CAP period it is totally implementation dependent. After CAP, the coordinator allocates DTS slots to the packets and the allocation status is announced through a notification to all the sensor nodes. The coordinator node allocates DTS slots to the packets based on their priority. Higher priority packets are allocated first. Then there is a CFP period, during which the allocated packets are transmitted. Here we have a dynamic CFP, so the CFP can be very small when there is very low traffic load or it can occupy the rest of the superframe when there is a high traffic load.

If the CFP does not occupy the entire of the superframe, then rest of the period is inactive period. The inactive period can be optionally used as Low Power Listening (LPL).

In the CFP, there is a percentage of ETS which are kept for the emergency data packets that are generated after the CAP. The emergency packets can perform a CCA to occupy the ETS. If generated in CAP it will transmit data by contention.

If a sensor node cannot send the request for slots successfully during CAP period, the transmission of packets from those nodes will be handled as follows.

- As described earlier, the emergency packets will be sent in the ETS time slots, after doing a (CCA).
- For (RP) and (OP) packet types, they will be stored in the buffer of the corresponding node, waiting for slot allocation in the next superframe. Such packets may be dropped if the node buffer overflows or packet lifetime (T_{life}) exceeds.

3.5 Back-off Calculation

Prioritized random back-off is performed in CAP. A node, that sends either a data packet or a request packet, performs a random back-off. The back-off value is chosen from the range [0, 2^{T_i+2} -1], where, T_i is the traffic class number. So, the probability of a critical data packet to enjoy less delay is higher than other data packets.

As the back-off value is calculated based on the traffic class value, data packet that has lower traffic class value will get small back-off value and have to wait small period of time before sending a data packet or request. And data packets with higher traffic class value will get larger back-off value. For example, assume we have a critical data packet and a ordinary data packet to send. As traffic class value for CP is 1, it will get a random back-off value between the range of [0, 7]. The traffic class value for OP is 4, so its back-off will be in the range of [0, 63]. As in most of the case, OP will have higher back-off value then CP, so request of CP will be sent before OP.

3.6 Priority Calculation

The sensor nodes calculates the priority of each packet using the following equation,

$$P_i = \frac{T_i}{G_i \times S_i}, \tag{3.1}$$

where, P_i = priority, T_i = traffic class value, G_i = data generation rate and S_i = size in bytes.

We can see that the priority value of a packet depends on its traffic class value and the data generation rate of the node. Based on the priority calculated above, the packets will be categorized to be in one of the four following classes:

- Emergency
- High

- Average
- Low

The packets with the lowest traffic class value (critical packets) and highest data generation rate will have the lowest score and highest priority and they will be defined to be in emergency class. The significance of doing this is that the packets with low traffic class value contains the most important data which must be delivered timely and with reliability; and packets that are from a node with high data generation rate also must be delivered quickly as the buffer of the sensor node will overflow otherwise and data will be lost. Similarly, the packets with the highest traffic class value and lowest data generation rate will have the highest score and lowest priority and they will be defined to be in low class. The data packets with priority values in between these two classes will be defined to be in high and average class depending on their value. The range of the priority classes is application dependent.

The coordinator node will allocate slots in the CFP period for the sensor nodes based on aforementioned priority classes. Emergency packets are given the highest priority and they are allocated slots before any other packets. When slot allocation for emergency packets is finished, then slots for high priority packets are allocated. Average priority packets are allocated next and followed by low priority packets. The rest of the superframe structure is considered as inactive period.

3.7 Protocol Operation

As sensor nodes has low battery-life, computational load should be kept as small as possible. Also each sensor node has a small buffer. If it has a data packet to send, the sensor stores it in the buffer and wait in low power listening mode for next Beacon signal from coordinator. Each data packet has a maximum lifetime T_{life} within which it has to reach the coordinator; otherwise, the sensor node drops the packet.

The BSN superframe structure has been designed to be flexible depending on the traffic need. Every superframe starts with a Beacon signal. After the Beacon signal, the contention access period (CAP) starts, in which the nodes having CP, RP and OP type data packets make requests for DTS slots. CP and RP data packets are sent using reserved time slots since they are loss-sensitive. On the other hand, the loss-insensitive DP type data packets content with each other to be transmitted in the CAP slot. In CAP, the receiver node sends back an ACK (acknowledgement) message after a packet is successfully received. This strategy is much helpful for DP packets to reach the coordinator node within their lifetime.

The sensor nodes may also request for DTS slots for sending DP during the contention free period (CFP), depending on the applications need. The requests for DTS slots, that has been received in CAP, are first sorted by the coordinator node based on their priority values and then allocated accordingly. The coordinator node sends this allocation information to all nodes in the notification period and thus the sensors get to know whether their requests have been granted or not; it also informs the slot number, if a request is granted. Therefore, there is no need of sending ACK for every request; the notification does that part. A sensor node can *sleep* in the CAP period if it has nothing to send. The other nodes, after sending data or request packet, will go to *LPL* and wait for receiving any ACK (if data packet is sent) or notification (if request for DTS is sent). These *sleep* and *LPL* periods save the energy of sensor nodes.

The coordinator node allocates the DTS slots based on the priority of the requests. After completion of the transmissions in DTS slots during the contention free period (CFP), the BSN superframe proceeds with inactive period (IP) or LPL period. In IP, the coordinator node goes to sleep mode and the sensor nodes turn off their transceiver circuitries, saving energy. In LPL, the sensor nodes might transmit emergency data packets only, depending on the implementation. Whether the IP or LPL will be activated can be determined dynamically by the coordinator node based on the traffic load of the network. Also, the IP may not be present in the superframe structure at very high traffic load conditions.

We also keep provisions of transferring emergency packets during contention free period by allocating few emergency time slots (ETS). More specifically, the ETSs are for transmitting emergency data packets that are generated after the CAP period. Here the number of ETSs can be calculated using exponential weighted moving average in the following way:

$$NumETS = (1 - \alpha) \times NumETS + \alpha \times NumEMR, \tag{3.2}$$

Here, the value of NumETS is a weighted combination of the previous value of NumETS and the last value of NumEMR, which is the number of emergency data packets received in the last superframe. In this way, the number of ETSs will be dynamically adjusted during each superframe according to the number of emergency data packets received in the most recent superframe. So, the number of ETSs will increase when a large number of emergency data packets are generated and decrease when the number of emergency data packets go down.

3.8 Summary

The proposed a MAC protocol provisions QoS to the packets according to their importance. The packets with higher priority gets better service than the packets with lower priorities, which is very significant in medical applications of body area sensor network, as the higher priority packets may contain emergency data. The delay driven packets are transmitted in the CAP period, so they encounter minimum delay. The critical and reliability packets are transmitted in CFP period, so reliability is also ensured. The superframe structure adapts its active section length according to the traffic load and the calculations for priority classification at the sensor nodes are kept to a minimum level, so efficiency in power consumption is also maintained.

Chapter 4

Performance Evaluation

4.1 Introduction

In this section, we compare the performance of the proposed priority aware and traffic load adaptive MAC protocol with PNP-MAC [13] and IEEE 802.15.4 [14]. Here, we have conducted simulation using network simulator ns3. To analyze the performance of the studied protocols, we have compared them in the fields of average packet delay, throughput and energy consumption.

4.2 Simulation Environment

For the simulation of the aforementioned MAC protocols, we consider a body area sensor network consisting of a single coordinator and a number of sensor devices. The sensor devices collect data and transmits them to the coordinator using a single-hop star topology. Here we have used NS-3 (Network Simulator 3)for the simulation of the proposed MAC protocol. The superframe parameters used in this simulation are slot size = 7.68 ms, number of slots = 128 and the CAP size of proposed MAC protocol = 20. We consider the CFP size of the PNP-MAC [13] protocol as 40 slots in the simulation as there were no specific size mentioned in the paper. For the proposed MAC protocol, we consider the number of DP packets

Table 4.1: Simulation parameters

Parameter	**Value**
Channel data rate	250 kbps
Initial energy	100 joule
Number of nodes	varied to collect data(1-10)
Superframe period	1 s
Number of slots in a superframe	128
Slot duration	7.68 ms
CAP duration in IEEE802.15.4 and PNP-MAC	8 slots
CAP duration in proposed protocol	20 slots
CFP duration of PNP-MAC	40 slots
Simulation time	100s

Table 4.2: Energy consumption parameters

Operation mode	**Energy Comsumption**
Transmit	10 mA
Receive	4 mA
Sleep	20 uA
LPL	1 mA

to be 20% to 30% of the total data packets, and the CP, RP and OP packets to be the other 70% to 80%.

The network parameters used here are summerized in table 4.1.

The parameters used for evaluating energy consumption are given in table 4.2.

4.3 Performance Metrics

The following four metrics have been considered for the performance evaluation of our proposed PLA-MAC.

- *Average packet delivery delay:* In our network there are several sensor nodes and a coordinator. Each of the nodes transmits packets, which are received by the coordinator. Packet delivery delay here is the time between generation of a packet at a sensor node and its reception at the coordinator node in specific slot of the corresponding super-frame.

- *Average delivery delay for delay driven packets:* Delay driven packets correspond to packets that have to be delivered timely. If they are not delivered in time, they are useless. In our protocol, we have given special treatment to the delay-driven packets; the delay-driven packets are transferred in the CAP period; so they don't have to make request and then transmit in CFP slots.

- *Throughput:* In communication networks, throughput or network throughput is the average rate of successful packet delivery over a communication channel. This data may be delivered over a physical or logical link, or pass through a certain network node. The throughput is usually measured in bits per second (bps), and sometimes in data packets per second or data packets per time slot. In our evaluation, we have used kbps (kilo bits per second); we have calculated the amount of payload bits carried in the total number of data packets received at the coordinator node.

- *Coordinator energy consumption:* Coordinator energy consumption is the amount of energy consumed at its different states, like transmit, receive, sleep and low power listening states. As the architecture and orientation of the super-frame in PLA-MAC is different than IEEE 802.15.4 and PNP-MAC; there is a significant difference in amount of energy consumption as well.

4.4 Simulation Result

In our simulation performance evaluation, we study the impacts of the number of end devices and the amount of traffic loads from different devices.

4.4.0.3 Impacts of the number of end devices

Here we vary the number of end devices from 1 to 10. Each node generates data at the rate of 5 Pkts/s.

First, we measure the average packet delay, the time needed to transmit a data packet to the coordinator in figure 4.1. We can see that the average delay increases with the increase in the number of nodes; the reason behind that is the increased traffic and collision. In IEEE 802.15.4, as the GTS allocation information for the requests received in the current superframe is broadcasted in the beacon of the next superframe, the sensor has to wait for the next superframe to transmit data. So the delay for IEEE 802.15.4 protocol is quite long. In the PNP-MAC protocol, the sensor nodes can transmit data in the same superframe in which they make request for slots, so the delay is much less than the IEEE 802.15.4. But, as PNP-MAC contains a fixed number of GTS slots, the delay increases when the number of data packet exceeds the number of GTS slots. However, in PLA-MAC, the CFP duration is not fixed and depends on the traffic load and also the DP packets are transmitted in the CAP period, thus the waiting time of a packet is reduced and the average packet delivery delay is minimized even when there is a large amount of data traffic in the network.

In figure 4.2, we plot the average delay for the delay-driven packets. These packets have delay constraints and they need to be delivered to the coordinator node within their lifetime. The IEEE 802.15.4 does not contain any special mechanism for handling delay-driven packets, so they are transmitted in the same way the other packets do. The PNP-MAC protocol has a priority classification and the packets are transmitted based on their priority values, still the sensor nodes have to send requests first and then the packets are transmitted in the allocated GTS slots. Furthermore, in the case an allocation fails, the packet has to wait for the next superframe and thus the delay increases a lot. However, in PLA-MAC, sensor nodes don't have to send requests and wait for slot allocation for the DP packets; rather they can send the DP packets in the CAP period, minimizing the

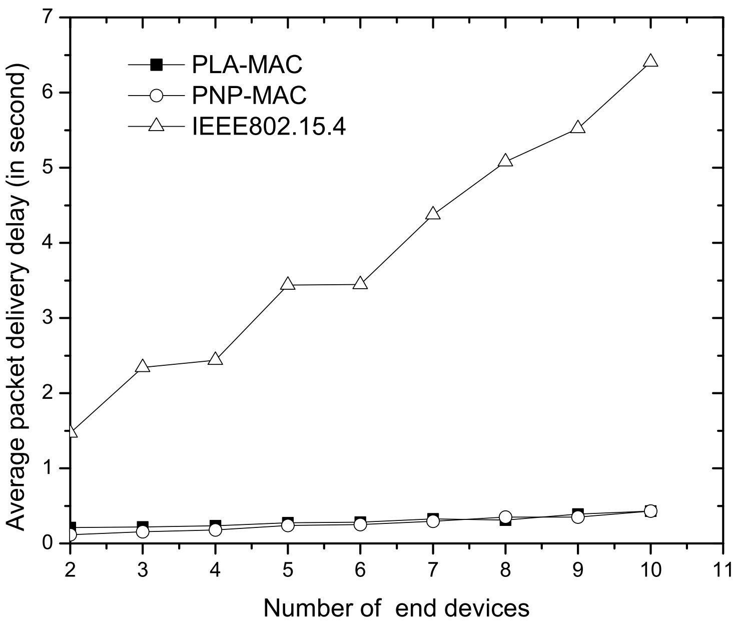

FIGURE 4.1: Average packet delivery delay versus number of end devices.

delay considerably.

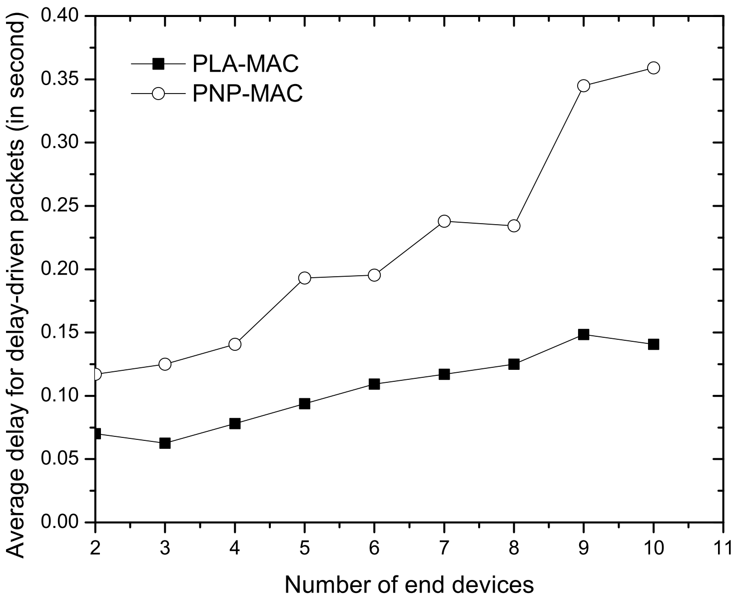

FIGURE 4.2: Average packet delivery delay for delay-driven packets versus number of end devices.

Next, we evaluate the throughput of the studied protocols in figure 4.3. Throughput is the amount of data packets received by the coordinator in a specific time unit. Here, the throughput of all protocols increases with the increase in number of nodes. We can see that, as the IEEE 802.15.4 has only 7 GTS slots, the throughput becomes constant when the limit of 7 slots is reached. PNP-MAC also has a fixed CFP period, so the throughput of PNP-MAC also becomes constant after the traffic load exceeds the number of CFP slots. As the proposed protocol contains a dynamic CFP period and also some packets are passed through the CAP period, the throughput of the proposed protocol continues to grow.

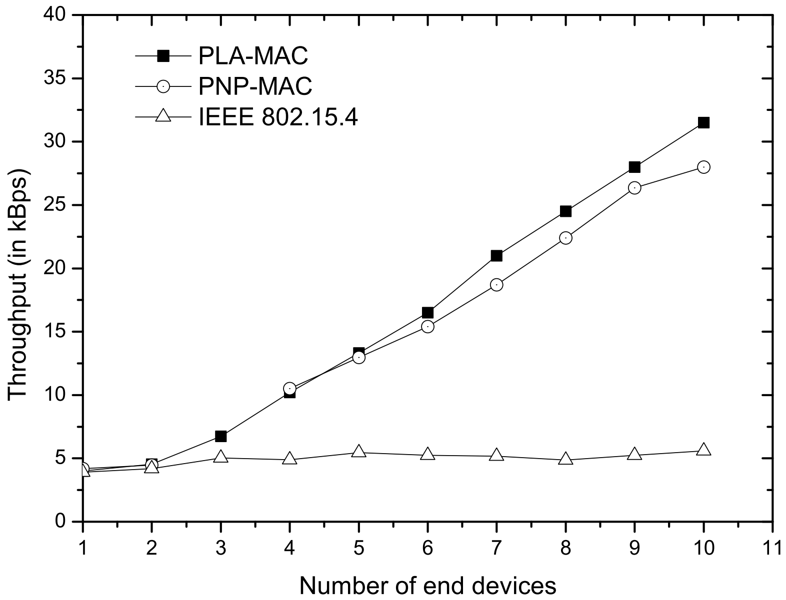

FIGURE 4.3: Throughput versus number of end devices.

In figure 4.4, we evaluate the energy consumption of the compared protocols. Here, the IEEE 802.15.4 protocol shows a low consumption due to the long inactive period. The IEEE 802.15.4 contains a fixed CAP and a fixed CFP of 7 slots, so the power consumption is also fixed, regardless of the traffic load. The PNP-MAC protocol also has a fixed number of CFP periods, which is 40 in this simulation, so the power consumption here is fixed also. But the proposed protocol consists of a dynamic superframe structure that varies depending on the traffic load. So the power consumption of the proposed protocol is low when the traffic is low, and it increases linearly with the traffic load.

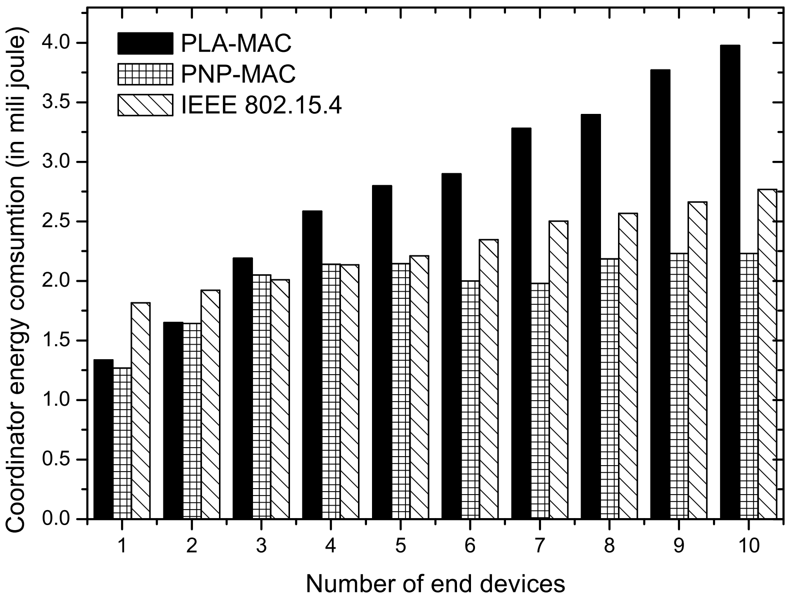

FIGURE 4.4: Coordinator energy consumption versus number of end devices.

4.4.0.4 Impacts of traffic load

Now, we measure the perfomance of PLA-MAC with respect to various traffic load. For this we assume there are a fixed number of node which is 7, and their traffic load will vary from 1 Pkts/s to 7 Pkts/s.

In figure 4.5, we perform the evaluation of average packet delivery delay with respect to diverse traffic load. We can see that PLA-MAC shows a good result compared to the other protocols specially in the higher traffic load section. The IEEE 802.15.4 experiences a large amount of delay and the delay increases with the increasing traffic loads. The PNP-MAC protocol shows lower delay than the IEEE 802.15.4, but this delay is increased when traffic load is larger than the fixed number of GTS slots of PNP-MAC. The PLA-MAC is capable to achieve consistent low packet delivery delay with the increasing traffic loads. This nice result is the artifact of traffic-load adaptive dynamic superframe structure and special treatment of DP packets defined in our proposed PLA-MAC.

In figure 4.6, we can see the average delivery delay for the delay driven packets. Here, PLA-MAC shows a overall low delay but the PNP-MAC fails to do so. The PNP-MAC is a priority based protocol, but it doesn't have any special scheme for

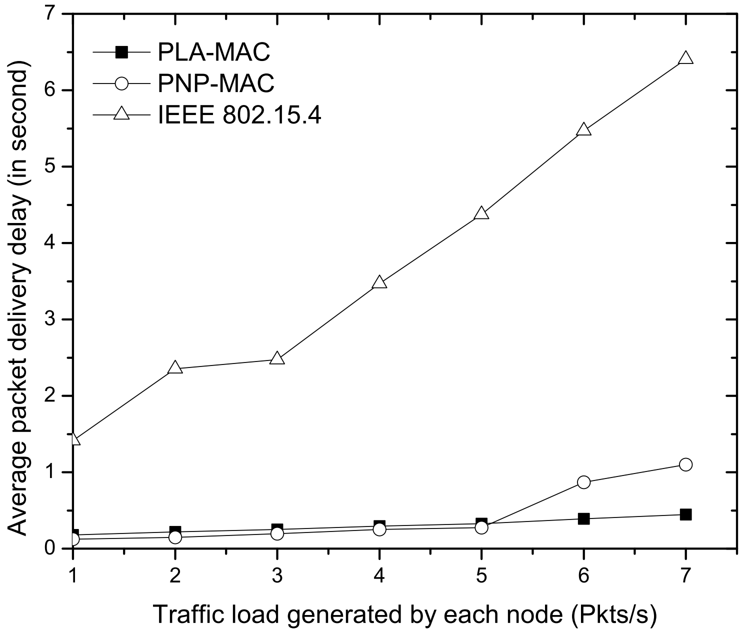

FIGURE 4.5: Average packet delivery delay versus traffic loads.

the delay-driven packets; they are transmitted in the same way the other packet follow in the CFP periods. But in PLA-MAC, delay-driven packets enjoy a special service so that they can be delivered within their time constraint. In PLA-MAC, the delay-driven packets can be transmitted directly in the CAP period. So, the delay is low even in diverse traffic loads.

Next, we evaluate the throughput of the compared protocols in figure 4.7. We can see that PLA-MAC achieves the maximum throughput of 16.3 kbps in the compared protocols. Here, as the IEEE 802.15.4 has only 7 GTS slots, so the throughput never increases from the first transmission. The growth of PNP-MAC also stops after the traffic load exceeds the fixed number of CFP slots. But because of the adaptive CFP period in PLA-MAC, the throughput of the proposed protocol continues to grow gradually.

In figure 4.8, we evaluate the energy consumption of the coordinator of the studied protocols. It presents similar results with that in figure 4.4. Here the IEEE 802.15.4 and the PNP-MAC protocol shows a fixed power consumption, the reason being the fixed number of CFP slots in both protocols. But the PLA-MAC

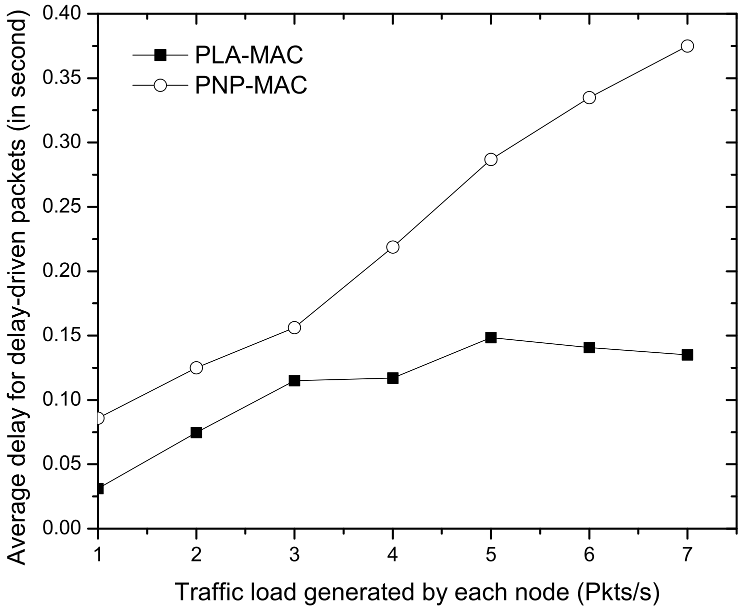

FIGURE 4.6: Average delay for delay driven packet versus traffic load.

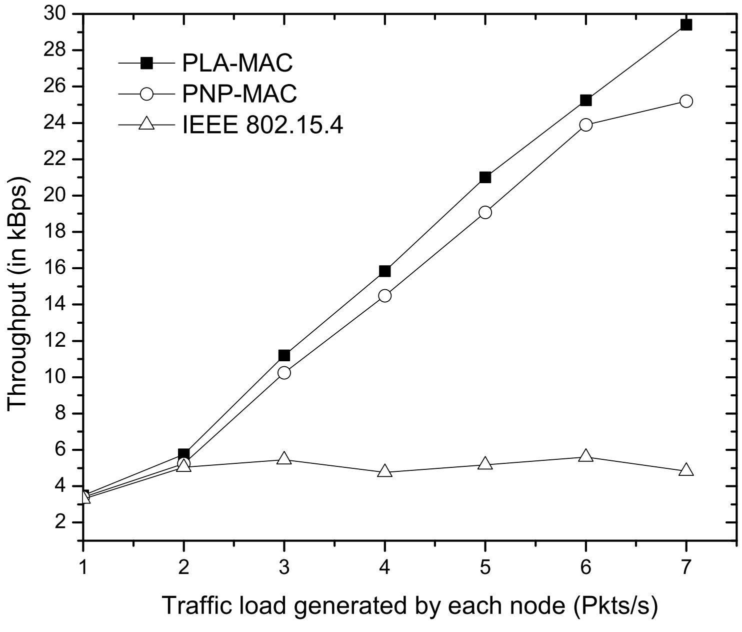

FIGURE 4.7: Throughput versus traffic load.

protocol shows a varying power consumption depending on the amount of traffic load, as it contains a dynamic superframe structure with adaptive CFP period.

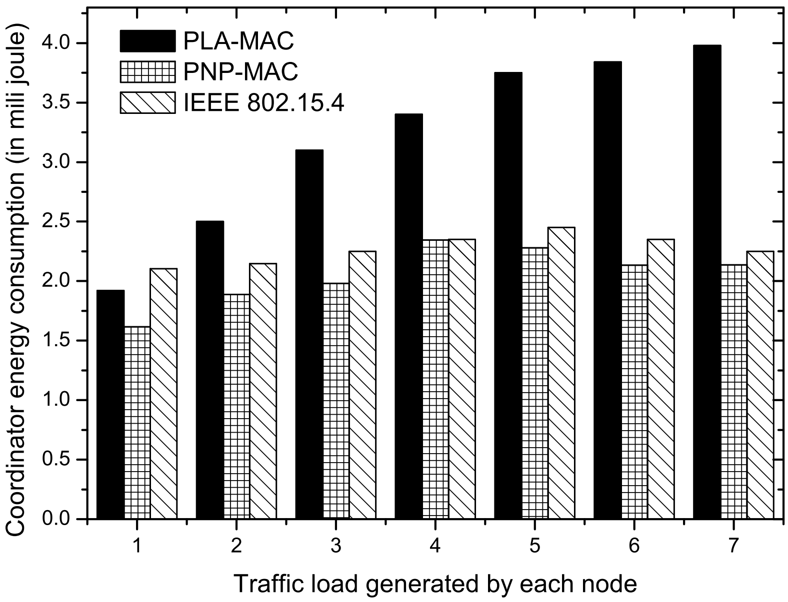

FIGURE 4.8: Coordinator energy consumption versus traffic load.

4.5 Discussion

From figure 7 and figure 11 we can see, PLA-MAC consumes more energy than IEEE 802.15.4 and PNP-MAC mostly when the number of nodes is higher. Actually, there is a trade-off here between the network throughput and energy consumption of nodes. From figures 6 and 10, we see that the achieved throughput of our proposed PLA-MAC protocol is better than the other two state-of-the-art protocols. Also, the average packet delay is much lower than the other two (figure 4, 5, 8 and 9). However, the energy consumption of the PLA-MAC is little higher than the other two when the number of end devices is more than 8. This is happening due to carrying additional data packets compared to others.

Chapter 5

Discussion and Conclusion

In this chapter, we summarize the research results presented in this thesis and state few directions for future works.

5.1 Summary of Project

In this project, we develop a MAC protocol called PLA-MAC for Body sensor networks to provide QoS provisioning in the delay and reliability domains, while preserving energy efficiency of the network. For the delay constraint, we provide multiple transmission option in the full superframe structure. The generated packet can dynamically decide where to send and how depending on their delay requirement. For the reliability domain, guaranteed time slots are used. These slots are allocated by the coordinator node to the sensor nodes where the allocation is based on the requests for transmitting data generated by the sensor nodes. And for delay driven packets which are sent in the contention period, acknowledgement packets are used for reliability. For maintaining Energy Efficiency, sensor nodes are active only in the period when they have something to send, otherwise they go to sleep or LPL. Coordinator node also follow the same mechanism for energy saving.

Traffic Classification has been done based on the QoS requirements of the generated data packets. for example, reliability critical packet and delay critical packets has been handled following different mechanism. Delay driven packets and request for guaranteed data slots are sent in contention with each other. To avoid collision and data loss we have introduced prioritized random back-off based on traffic class number.

As sensor nodes has small buffer space, PLA-MAC assigns higher priority to nodes with greater generation rate and larger packet size. Traffic class is also considered in priority calculation, which gives the balance between QoS provisioning and data generation rate. Emergency data packets which has the most critical delay and reliability requirement, has also been given special consideration. PLA-MAC reserved some special emergency transmission slots on which emergency data can be sent without slot allocation. Number of emergency transmission slots is calculated using weighted moving average, insuring dynamic adjustment.

Simulation results show that PLA-MAC can efficiently cater for the needs of various traffic types with different combinations of reliability and delay requirements. As a result, PLA-MAC can significantly improve the effective capacity of a body sensor network in terms of both energy and QoS requirements.

The developed multi-constrained QoS provisioning and energy aware scheme is expected to work providing good performance in BSN applications. However, it will not work well when data generation rate and their QoS requirements are too diverse. Its network diameter is small as it is designed for human body diameter. As a result it will not work well in large diameter.

5.2 Discussion

Analyzing the state-of-the-art protocols in Body Sensor Network and Wireless sensor Network, and finding out the drawbacks from those works was the main focus for us. A Big challenge for us was to find out the alternative solutions and also the design and exploration of the implementation details of the alterative solution.

Designing a useful superframe from existing protocols so that we can meet-up all the QoS requirements, and also impose different classification on generated data traffics of the sensor nodes, all-in-one designing a QoS aware MAC was very challenging.

We evaluated our proposed PLA-MAC in network simulator-3 and compared its performance with other popular state-of the-art protocols, like IEEE 802.15.4, PNP-MAC. Evaluating our proposed mechanism in ns-3 was also a huge challenge. In simulation, we extensively measured our performance and at the end of the evaluation part, we can say all of our hard-work and devotion paid-off when our proposed PLA-MAC showed better performance from the others.

5.3 Future Works

We are currently working on the advancement of our protocol, to adopt it with upcoming IEEE 802.15.6 standard on 2013 [31]. IEEE 802 has established a Task Group called IEEE 802.15.6 for the standardization of WBAN. The standard defines a Medium Access Control (MAC) layer supporting several Physical (PHY) layers and also introduces security consideration in data transmission, like encryption and authentication. We are working on the implementation details of supporting several physical layers. For encryption and authentication part we will use any of the well known algorithms. Some modification should also come in traffic classification, back-off calculation, and priority calculation section of our protocol. The superframe structure may also go though some modification and enhancement.

The proposed PLA-MAC protocol is described considering only a single-path and single coordinator-rooted network topology, even though a BAN might consist of multi-path, multi-coordinator, and multi-tree topology. We will adopt those mechanism in our future work.

This work can also be extended to the design of routing protocol from coordinator to end-devices. Although that will exceed the range of body sensor network, this work will give a complete specification for a medical network system or for other applications.

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List of Publications

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- Iffat Anjum, Nazia Alam, Md. Abdur Razzaque, Mohammad Mehedi Hassan, and Atif Alamri, Traffic Priority and Load Adaptive MAC Protocol for QoS Provisioning in Body Sensor Networks, *International Journal of Distributed Sensor Networks*, vol. 2013, Article ID 205192, 9 pages, 2013. doi:10.1155/2013/205192.