Reliable and Energy Efficient MAC for Medical Body Area Networks for Patient Monitoring in Hospitals

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Approval

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Abstract

In medical body area network small sized medical sensors are attached to a patient's body for continuous and real-time monitoring of biomedical vital signs. These nodes collect data from patient's body and send it to base station via intermediate node so that doctors/caregivers can access the patient's data or can be timely informed if any patient's condition goes critical. But due to the small size, these sensor nodes have low data rates, small transmission ranges, limited battery power and processing capabilities etc. On the other hand reliability is most important issue in medical body area network because of critical nature of patient's data. Any wrong or missing or delayed data can create a situation in which doctors or caregivers may take wrong decisions about patient's health which can have fatal results. Reliability of data transmission can be ensured on the cost of power consumption in network by using different methods such as retransmissions, acknowledgments and guaranteed time slot mechanism etc. We propose an efficient MAC to achieve both reliability and energy efficiency in medical body area network at acceptable trade-off levels. The Proposed MAC not only overcomes the limitations of existing ZigBee MAC such as inefficient CSMA/CA mechanism and underutilization of guaranteed time slots but also it adapts different traffic types such as emergency traffic and normal traffic. The proposed MAC is implemented in Castalia simulator and simulations results show that the application level throughput and packet delivery ratio of network increase and packet loss rate decreases at MAC level. We also optimize the energy utilization of network by reducing the number of retransmissions and also by tuning the parameters of ZigBee MAC i.e. macMaxCSMABackoffs and macMinBE.

Certificate of Originality

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any degree or diploma at National University of Sciences & Technology (NUST) School of Electrical Engineering & Computer Science (SEECS) or at any other educational institute, except where due acknowledgement has been made in the thesis. Any contribution made to the research by others, with whom I have worked at NUST SEECS or elsewhere, is explicitly acknowledged in the thesis.

I also declare that the intellectual content of this thesis is the product of my own work, except for the assistance from others in the project's design and conception or in style, presentation and linguistics which has been acknowledged.

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Acknowledgment

All praise to **ALMIGHTY ALLAH**, most Merciful and Compassionate. I am grateful from the core of my heart , to the Almighty Who bestowed me with health and strength to do this research work.

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Madiha Fatima

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List of Abbreviations

Abbreviations	Descriptions
MAC	Media Access Control
CAP	Contention Access Period
CFP	Contention Free Period
GTS	Guaranteed Time Slot

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Chapter 1

INTRODUCTION

Body area network is a subcategory of wireless sensor networks which is used for monitoring physiological conditions around human and animal body. Body area network has many human targeted applications such as sports, entertainment and health-care etc. Medical body area networks keep track of patients' vital signs in hospitals, in homes and even when patients are mobile through continuous and real-time monitoring to provide health-care services to them. For better understanding of technology, first we will introduce wireless sensor networks then body area network and its health-care applications.

Wireless sensor networks (2) are composed of thickly inhabited tiny sensors which interact with the environment by sensing or monitoring it and pass their data to a base station for further processing and controlling actions. It has a wide variety of applications (3) including but not limited to industry, agriculture, habitat, forest and environmental monitoring, home and office automation, health-care and medicine, urban sensor network and energy management etc. It can also be used in the application areas of security, defense, military and disaster monitoring. Its health-care applications (4) include home-based care, hospital or clinical monitoring, management of disaster relief and medical facility, sports health etc.

Sensor nodes in wireless sensor networks are small in size and memory, low cost, low power, and equipped with low processing and computing power. These nodes are of two types i.e. source node which monitors the environment and sink which collects the information from the source and sends to base station. These nodes can be mobile depending on the nature of the application. In temperature monitoring application nodes are usually static and some applications like flood forecasting, transportation monitoring etc contain mobile nodes. Mobility can be categorized as sensor mobility, sink mobility and event mobility. Sensor nodes can be mobile to monitor a region or sense a phenomenon. For sink mobility it might be possible that a sink

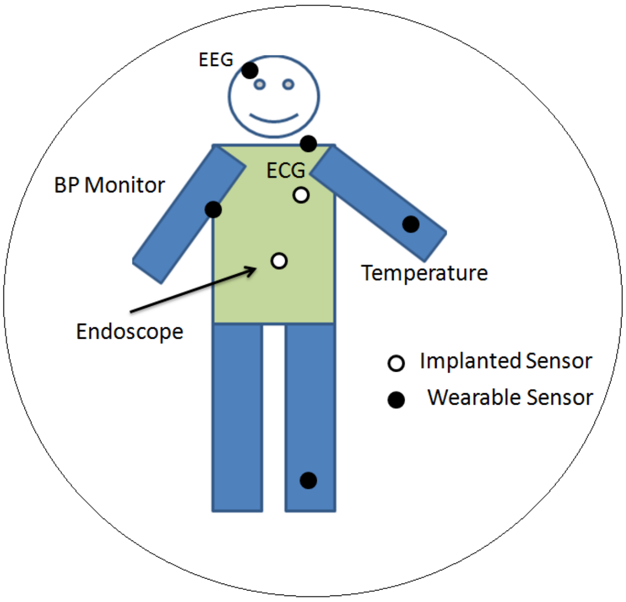

Figure 1.1: Placement of sensor nodes on human body

node is not a part of wireless sensor network e.g. PDA or laptop which remain mobile. The event can also be mobile. E.g. water in a river. There is a data centric communication in wireless sensor network which can be either in single-hop or multi-hop fashion (5). Single hop communication supported in Bluetooth based wireless sensor network uses star like topology. In multi-hop communication relay nodes are involved which cooperatively pass on data to sink node. It is supported in ZigBee based wireless sensor network. Communication models used in wireless sensor network are periodic, event driven and query driven. In periodic data communication, sensor node periodically senses and sends data to the sink node e.g. monitoring weather, temperature etc. In a query based communication sensor nodes only transmit data when they receive any request from the sink node. In an event driven communication, sensor nodes only become active when a certain event occurs e.g. rise in temperature to threshold level etc.

Medical body area networks slightly differ from other applications of wireless sensor networks. Placement of sensor nodes on human body is shown in Fig. 1.1. Both internal and external sensors (6) can be used for monitoring patient's vital signs. Internal sensors can be ingestible or implanted devices e.g. core body temperature sensor. External sensors can be wearable or detachable electrical signaling devices e.g. pulse OXIMETER, ECG, EEG sensors etc. Sensor nodes in medical body area networks possess all characteristics of wireless sensor networks and are of two types i.e. source and sink which can be static or mobile. For example in ICU rooms patients are static but in emergency rooms patients can be mobile where they are waiting for a checkup. Communication model used in medical body area networks mainly depends on the patient's condition. Sensor nodes in the network can communicate with each other either in single hop or multi-hop manner. Topology in medical body area networks is usually known. There is hybrid communication in medical body area networks because some patients need continuous monitoring and some non critical patients need only periodic or query based reporting. In medical body area networks information is both data centric and identity centric (7) because data comes from different sensors which belong to different patients.

The rest of the chapter is organized as follows. In Section 1.1, the problem statement is stated. In Section 1.2, thesis contributions are stated. In Section 1.3, we conclude the chapter with an outline for the rest of the thesis.

1.1 Problem Statement

Medical body area networks have gained much attention in research because of their important and beneficial applications for mankind. A Huge research has been done in field of body area networks including applications, architectural design and challenges of medical body area network. Research on architectural deign of medical body area network is important because architectural deign of a network has always a significant impact on its performance. Architectural design issues(8) include network topology, sensor types and maximum number of sensors in the network, different access technologies and protocols, databases design issues and access of patient's data at doctors' smart phones etc. Wrong choice of architectural design can badly affect the performance of body area network for medical applications such as reliability(9) and energy efficiency(10). Although medical body area networks is very beneficial application of wireless sensor networks but there is still a space for improvement in this field because improving reliability and energy efficiency is really a big challenge in medical body area networks. A huge research is going on in medical body area network for efficient routing, reliable communication and energy efficiency etc. Reliability is important because any corrupt data or late delivery of data can cause critical results for patient's health and we need energy efficiency in medical body area networks because of limited battery power. That is why in this paper we focus on reliability and energy efficiency in medical body area networks and propose an enhancement in ZigBee MAC protocol to achieve these performance outcomes.

A formal problem statement is given as:

"Our objective is to propose a reliable and energy efficient MAC mechanism for medical body area networks for patient monitoring in hospitals."

1.2 Thesis Contribution

We propose enhancement in ZigBee MAC to improve reliability and energy efficiency in medical body area network. In medical body area networks attached to a patient's body monitor patient's vital signs and forward their data to sink node for further processing and taking actions. Sink node sends this information to base station from where doctors or caregivers can access patients' information in order to take necessary actions. There are many benefits of medical body area networks such as continuous and real-time patient's monitoring, early detection of patient's critical health conditions, timely treatment, and solving the issues of medical staff shortage etc. Medical body area networks also enable doctors to give timely treatment if any patient has critical condition. Medical body area networks can be used in remote patient monitoring such as at homes or old people houses(11) and it can be used within hospitals(12) for continuous monitoring of critical patients in ICUs or sitting in waiting rooms of hospitals. Another application of medical body area networks is to monitor the victims' health during the time of disasters by attaching medical sensor to their body. This application of medical body area networks is very useful because during the time of disasters there are highest numbers of victims and it is not possible to look after all patients at the same time. All these applications of medical body area networks have two major benefits. First benefit of medical body area networks is continuously monitoring of critical patients. Continuous patient's monitoring is not possible if nurses attend to patients because every hospital have limited nursing staff and each nurse has to attend to multiple patients periodically. Second major benefit of medical body area network is that we can attend a large number of patients at a time by attaching medical sensors to patients' bodies to monitor and analyze their vital signs data.

Moreover developing countries like Pakistan have limited resources and are very deficient in education and health-care facilities. Pakistan is also a disaster prone country. People in such countries are also very prone to diseases due to poor living conditions and food quality. Patients' monitoring using wireless medical sensors would become a very cost-effective system Pakistan. These systems also provide ease of mobility to patients along with continuous and real time monitoring of their vital signs.

1.3 Thesis Organization

The rest of the thesis is organized as follows:

Chapter 2 presents the overview of ZigBee which covers its functionality, its advantages and drawbacks when used in medical body area networks.

Chapter 3 discusses the state of the art related to the current research, and reviews the relevant literature aimed at finding research challenges in medical body area network and existing proposed solutions

In Chapter 4, the proposed solution is discussed and we present the proposed methodology and its implementation.

In Chapter 5, the results are given along with detailed discussions.

In Chapter 6, the conclusion and future work is presented.

Chapter 2

THE ZIGBEE MAC

IEEE 802.15.4 MAC(1) also known as ZigBee is a standard for personal area networks for short range communications with low data rates i.e. 250 kbps. ZigBee is used in different applications of wireless sensor networks and medical body area networks such as home automation, agriculture, military and health-care etc. On the other hand wireless sensor nodes with limited capabilities need a light weight protocol for wireless communication in order to minimize power consumption but not on the cost of network performance such as reliability, minimal delay, shortest latency etc which are most important requirements of medical body area network because of the critical nature of patient's data. That is why ZigBee MAC is good option for medical body area networks applications. In this section we discuss about the functionality of ZigBee MAC (IEEE 802.15.4).

ZigBee MAC supports two types of devices in network are full-function devices (FFD) sand reduced-function devices (RFD). Personal area network(PAN) coordinator which acts as in-charge of whole network is a full-function device and it is capable of performing high duty job in network such as data collection and processing, storage of information, network management etc. Intermediate router in wireless sensor network is also a full-function devices. Source nodes with limited functionality in the network are reduced-function devices which sense and collect data from the network and forward it to PAN coordinator. ZigBee MAC can support star and peer to peer topologies in order to connect these devices with each other in the network. In star topology, source nodes are connected to PAN coordinator and cannot directly communicate with each other. PAN coordinator manages the network and collects data from the sensor nodes. In peer to peer topology, nodes can directly communication with each other. These nodes are capable of transmitting their own data and can cooperatively pass on the data of neighboring nodes to the sink node. ZigBee MAC provides two types of services e.g. data service

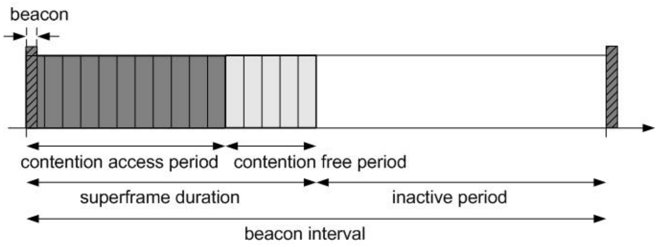

Figure 2.1: Zigbee Superframe Structure (1)

and management service. Data service includes transmission and reception of data at MAC layer and the management service includes the management of PAN and coordination among the nodes.

Beacon enabled and non-beacon enabled are two network operating modes supported in ZigBee MAC in order to enable two way data communication in the network. Beacon enabled mode is best suited for battery powered PAN coordinator and end devices because of duty cycling. PAN coordinator periodically wakes up and sends beacon packets to end devices in the network. Similarly end devices periodically wake up to check for incoming beacon packets from PAN coordinator. In non-beacon enabled modes, some devices remain active all the time such as coordinator and router while other end devices remain in sleep state such as source nodes. Active devices in the non-beacon enabled nodes in network have high power consumption so they need a main power supply. Both beacon and non-beacon enabled operating modes of ZigBee can mange different traffic types such as periodic, burst data etc. In beacon enabled network slotted CSMA/CA scheme and an optional guaranteed time slot(GTS) allocation scheme are used for channel access and unslotted CSMA/CA channel access scheme is used in non-beacon enabled network. But for the body area networks applications we focus on beacon enabled network. Superframe structure of ZigBee MAC is shown in Fig. 2.1 in which beacon interval is divided into superframe duration and an inactive period. In an inactive period all nodes go into partially sleep mode to save battery power. Superframe duration is further divided into sixteen equal sized time slots. In first slot of every super frame PAN coordinator node broadcast a beacon packet to advertise the network information in the network. All those nodes who are willing to communicate in the network capture the network information from beacon packets and synchronize themselves with the network. Next fifteen time slots are divided into contention access period and an optional contention free period. Alternate terms for contention access period and contention free period are GTS-off mode and GTS-on mode respectively. We use these alternate terms instead of conventional names such CAP and CFP in rest of our paper. We discuss about these modes in the following subsections.

2.1 GTS-off Mode

Default working mode of ZigBee is GTS-off in which CSMA/CA mechanism is used for contention avoidance in the network. In this mode every source node maintains three variables which are backoff exponent(BE), number of backoffs (NB) and contention window (CW) for each transmission attempt in the network. BE refers to a number of backoff periods a node should wait before trying to access channel. Backoff period is a basic time unit equal to 80 bits(0.32ms). NB refers to number of backoffs required by CSMA/CA algorithm while trying to attempt current transmission. If NB is exceeded by maximum number of backoffs then the algorithm reports failure and device terminates its current channel access attempt. CW is length of backoff period which need to be clear before a transmission attempt. Default value of BE is in the range from 3 to 5 i.e. macMinBE and macMaxBE refer to minimum and maximum values of BE in Zigbee MAC. Default value of NB is 4 and of contention window is 2. Each node which has data to send, competes for free channel access and if it gets channel free then it transmits its data. If channel is busy then node backoffs its transmissions for random period of time and try for channel access after some time. In CSMA/CA, after each successful clear channel assessment, value of CW decrement (CW = CW - 1) until its value reaches to 0. If CW = 0, node transmits its packet otherwise the algorithm performs another CCA. After finding the channel busy each time the states of NB and BE is updated by increment in the values of NB, BE and CW such as NB is incremented as NB = NB + 1 until the NB < macMaxCSMABackoffs, and increment in BE is as BE = min (BE+l,macMaxBE) and the size of CW resets to 2.

CSMA/CA is a good mechanism to avoid collisions in network but it is not as much efficient as needed for medical body area networks because operating state of network is always changing and network traffic especially emergency traffic is totally random and unpredictable. This type of traffic not only needs a collision avoidance mechanism but also needs a mechanism which should be able to cope with such conditions when there is high packet drop rate due to collision in network in order to ensure reliability at an acceptable level. That is why there is a need of a flexible CSMA/CA mechanism which adapts according to network conditions.

2.2 GTS-on Mode

Along with collision avoidance mechanism, ZigBee MAC provides the facility of reliable data transfer by offering GTS allocation mechanism in which nodes can send GTS requests in current superframe for advance reservation of a time slots in the next superframe. GTS is only used for two way communication between PAN coordinator and source node in network. Only PAN coordinator can allocate GTS to nodes on first come first serve basis. GTS always appear at the end of superframe structure i.e. contention free period. PAN coordinator node allocates GTS to nodes on the basis of requirement of GTS request and available capacity in superframe which can be determined by minimum contention access period length which is equal to 440 symbols when use GTS allocation mechanism in zigBee MAC. A single GTS can span more than one slot in superframe and it allows a node to transmit in network within that portion of superframe while other nodes defer their transmission in that portion and remain into sleep mode which helps to reduce energy consumption and avoid collision in network. Drawback of GTS allocation scheme is that it is not a flexible scheme. It follows the first come first serve mechanism which causes some nodes fail to get GTS because those nodes who send GTS request earlier get the slot and avail all available capacity in superframe structure. Similarly if a selfish node joins the network who always gets a guaranteed time slot while other nodes have important data to send fail to reserve a slot in next superframe. In both cases nodes shall not be able to transmit their data which results in buffer overflow. Another inflexibility of GTS allocation scheme is that each node can send a request for fixed number of slots irrespective of its bandwidth requirements. If a node has small amount of data to send but according to standard limitation it has to reserve a fixed number of slots which are larger then its requirement causes bandwidth underutilization.

In the next section we present literature review for reliability and energy efficiency in medical body area networks and background study of ZigBEE MAC for ensuring these requirements of medical body area networks.

Chapter 3

LITERATURE REVIEW

In our previous study we present a survey(8) on network architecture and research challenges in medical body area networks. In that paper we discussed about state of the art and some existing application examples of medical body area networks such as patient monitoring in hospitals and a remote areas. We also discussed about some already proposed functional architectures and highlighted some research challenges and architectural requirement of medical body area networks. This survey also covers the research challenges of medical body area networks which includes efficient routing, reliability and energy efficiency. We concluded that both reliability and energy efficiency are most important performance metrics in medical body area networks and there is a tradeoff between reliability and energy efficiency and need a special care while designing a communication protocol in medical body area networks. Now we discuss about exiting solutions and current state of the art to resolve the reliability and energy efficiency issues in medical body area networks for patient's monitoring in hospitals.

Yu-Kai et al.(13) proposed an adaptive GTS allocation scheme to achieve low latency and fairness in body area networks. In the proposed scheme nodes reserve guaranteed time slots in advance either they have data to send or not and priority of each node is set on basis of time slot usage by that node. Liang et al.(14) proposed a GTS allocation scheme in which more than one device can share a single time slot in order to solve the problem of bandwidth underutilization. Yong et al.(15) proposed a GTS allocation scheme in which they increase the number of slots by decreasing the size of time slots in contention free period according to superframe order values. Bharat et al.(16) proposed an algorithm for optimization of GTS allocation scheme in which nodes send a GTS request only if number of packets cross the buffer threshold to improve reliability and bandwidth utilization. Hyung et al.(17) proposed an utilization aware GTS allocation scheme in which coordinator node maintains states of nodes on basis of their network joining time, allocated GTS and utilization and desire for GTS allocation to improve the bandwidth utilization and reduce the latency in network. Shrestha et al.(18) presented a Markov model hybrid communication in the network in which if a node gets a guaranteed time slot then it will defer its transmission in CAP and only send in the CFP otherwise the node will transmit its data in the CAP. Sherstha et al.(19) enhanced their work presented in (18) for wireless propagation and also evaluated the performance of proposed mechanism using a wheel chair body area network scenario. Nam-Tuan et al.(20) proposed an unbalance GTS allocation scheme to allocate GTS to nodes with different slot durations in wireless personal area network in order to solve bandwidth underutilization problem. Ho et al.(21) proposed a multi-factor dynamic GTS allocation scheme which considers the size of data, delay and GTS utilization to allocate GTS to nodes to improve the performance of network by reducing delay and increasing throughput in network. Zhisheng et al.(22) proposed a QoS driven scheduling approach which uses Markov model to adjust the transmission order of nodes by using a threshold based scheme and addresses the packet delivery probability and energy efficiency. Mohammad et al.(23) proposed a GTS allocation scheme for emergency traffic using parameters such as traffic type and data rates in which traffic with highest data rate will have highest priority. Haoran et al.(24) proposed a superframe based GTS allocation scheme in which priority of each node to be allocated maximum number of slots is defined on basis of sample rate, buffer size and slot utilization to improve energy efficiency in medical body area network. jin et al.(25) proposed an adaptive slot allocation scheme in which contention access period is divided in to three phases and restricts the nodes to send their data on the basis of data type. Kong et al.(26) proposed a slot allocation scheme which uses two heuristic algorithms which are sampling rate oriented algorithm and successive approximation algorithm to determine the amount of data in buffer and to set priority of each node on basis of sample rate. This scheme also takes a benefit from fixed topology of wireless body area networks. Haoru et al.(27) proposed a distributed access scheme to solve the problem of beacon collision among different cluster heads in body area networks. Fang et al.(28) proposed an energy efficient MAC protocol to improve energy efficiency in medical body area networks by reducing the overhead of control packets, transmission time and idle listening by introducing an efficient sleep mode. Ali et al.(29) proposed a random access protocol to improve the throughput of critical health information by prioritizing the critical packets by reducing the retransmission of critical heath information. Shajahan et al.(30) presented a survey on QoS requirements of medical body area networks such as less latency and improved reliability especially for transmission of emergency traffic. On the basis of these requirements authors studied and evaluated the performance of already proposed MAC protocols and architecture of medical body area networks. Gopalan et al.(31) presented a survey on MAC layer protocols for medical body area networks in which they also discussed about the characteristics of an efficient MAC, and mentioned the possible ways of energy wastage such as idle listening, over emitting, collisions, retransmissions, control packet overhead etc. They also mentioned some open research challenges for MAC layer protocols in medical body area networks. Tuomas et al.(32) proposed a dynamic GTS allocation scheme to solve the problem of unfairness in GTS allocation scheme by including the number of packets and priority of each single packet in the GTS request packet.

In order to ensure the minimum latency in emergency data transmission, Cheolhyo et al. (33) proposed an enhancement in superframe structure of IEEE 802.15.4 by including polling period, emergency slot and beacon interval division into mini slots to set a boundary between different access periods such as contention access period, contention free period, polling period and emergency slot. Pradnya et al.(34) proposed a modification in superframe structure of IEEE 802.15.4 in which a fixed contention access period is used for the activities such as GTS management, network management etc to addresses the issues of scalability and interference etc. Hikma et al.(35) proposed a modification in superframe structure of ZigBee MAC in order to enable it for mesh sensor networks by exchanging the positions of contention access period and contention free period and introducing a new packet type after contention access period in order to advertise the information about recent packet transmissions in the last period. Maman et al. (36) proposed a wake up radio mechanism which considers two types of traffic in network i.e. normal traffic and emergency traffic and uses a separate channel to send wakeup radio in order to ensure energy efficiency in body area networks. Muhammad et al.(37) proposed a traffic aware dynamic medium access control protocol in order to improve the energy efficiency in wireless body area network by reducing energy consumption due to idle listening. Hayat et al.(38) and Kikuzuki et al.(39) proposed some modifications in superframe structure of IEEE 802.15.6 to ensure the QoS in medical body area network. But we only focus on ZigBee MAC because it is more flexible as compare to IEEE 802.15.6(40).

Okundu et al.(41) proposed an energy efficient MAC protocol which follows the listen before transmit algorithm to access transmission channel and uses single-hop communication by adapting star topology to avoid collision and ensuring energy efficiency in medical body area networks. Mario et al.(42) proposed an adaptive access parameter tuning of ZigBee MAC such as macMinBE and macMaxCSMABackoffs to achieve desirable level of reliability and energy efficiency in body area network. Simone et al.(43) presented a comparison of proposed mechanisms of parameter setting in ZigBee MAC to improve reliability and energy efficiency in body area networks. They compared the proposed approaches such as measurement based adaptation proposed by Mario et al.(44), model based adaptation proposed by Mario et al.(42) and offline computation proposed by Pangun et al.(45) and concluded that flexible and adaptive tuning of parameters is better because network operating conditions tend to change from time to time. Shuanglong et al.(46) proposed an adaptive tuning algorithm in which they jointly tune the number of retransmissions which is a MAC parameter and sampling rate which is a parameter of control system for the purpose of finding a parameter set to attain the energy efficiency and a stable control system in the network.

ZigBee MAC is suitable for other applications of wireless sensor network but it is not best suited for medical body area network requirements. Because in medical body area networks, network conditions and traffic pattern are variable and random. There is also very high demand of reliability, energy efficiency and minimum delay for communication in medical body area networks. That is why there is a need of a flexible and adaptive MAC layer mechanism to improve performance of medical body area networks. In the next section we discuss about our proposed MAC scheme to overcome the limitations of ZigBee MAC and to improve reliability and energy efficiency in medical body area networks.

Chapter 4

IMPLEMENTATION

We propose a reliable and energy efficient MAC mechanism which can adapt operation in two modes i.e. GTS-off and GTS-on. The proposed MAC adapts different traffic pattern in network such as normal traffic and emergency traffics and switches its modes according to it. In the proposed mechanism nodes transmit normal traffic in GTS-off mode and in order to ensure reliability, nodes use guaranteed time slot scheme to transmit emergency data in the network. PAN coordinator allocates guaranteed time slots to nodes on their GTS request basis. Nodes send request for GTS allocation according to amount of data present in their buffer. We propose some flexibility in GTS allocation scheme of ZigBee MAC to make it suitable for patient's monitoring in medical body area networks. We also propose tuning of some CSMA/CA parameters to improve the shortcomings of ZigBee MAC and to ensure reliability and energy efficiency in medical body area networks during the GTS-off mode. In methodology section we discuss the proposed MAC mechanism with detail.

4.1 Methodology

We subdivide the details of proposed MAC into three parts such as GTS-off mode, GTS-on mode and adaptive MAC and discuss each of them in separate sections. In GTS-off mode subsection we discuss about the proposed mechanism of parameter tuning of CSMA/CA mechanism. In GTS-on mode subsection we talk about the proposed flexible GTS allocation scheme and in adaptive MAC subsection we discuss that how the proposed adaptive MAC mechanism takes decisions and switches its modes on traffic type basis.

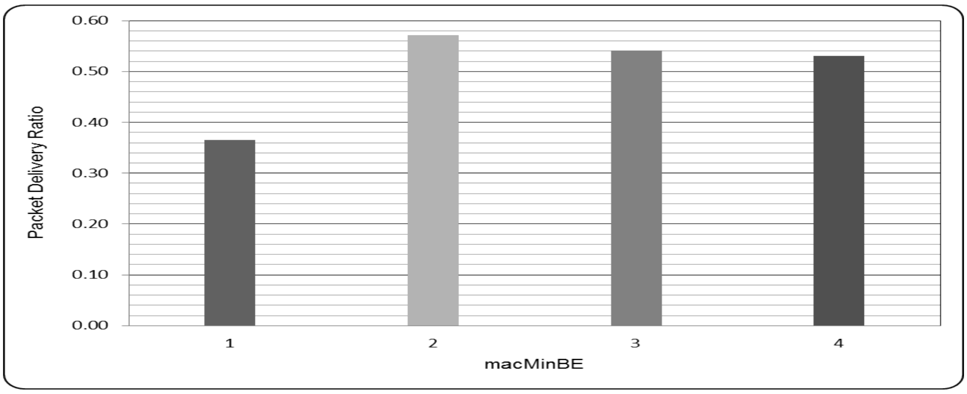

Figure 4.1: Effect of Changing Values of macMinBE on Packet Delivery Ratio

4.1.1 GTS-off mode

In the GTS-off mode of ZigBee MAC all nodes in the network who have data to send, compete for free channel access which causes collision in network and results into packet transmission failure. According to ZigBee standard, in CSMA/CA mechanism a small range of BE i.e. from 3 to 5 is used to avoid packet collisions among the nodes but due to such a small range of BE parameter packet collisions are high because of early recovery of nodes from back-off state and become part of network again. On the other hand if we increase the range of BE it helps to reduce packet collision rate but it also introduces the delay in network because in this case most of nodes remain in inactive state and do not take part in communication for most of the time. Similarly small value of macMinBE decreases the overall delay in the network but on the cost of reducing network throughput because of high collision rate and high energy consumption. The reason is that due to small value of macMinBE nodes come into active state within short time which again causes contention among the nodes. Transmission failure due to collisions increases the number of retransmissions in network which leads to high energy consumption in network. Fig. 4.1, Fig. 4.2 and Fig. 4.3 show the effect of different values of macMinBE on packet delivery ration, goodput(Kbits/Sec) and Energy consumption in term of packet retransmissions. Fig. 4.4 shows the effect of changing values of minMinBE on MAC packet breakdown.

If we keep the value of macMinBE constant and change the value of macMaxBE, increasing value of macMaxBE increases the packet delivery ratio and goodput(Kbits/Sec) but on the cost of increasing energy consumption as shown in Fig. 4.5, Fig. 4.6, Fig. 4.7 and Fig. 4.8. These figures show the effect of different values of macMaxBE on packet delivery ration, good-

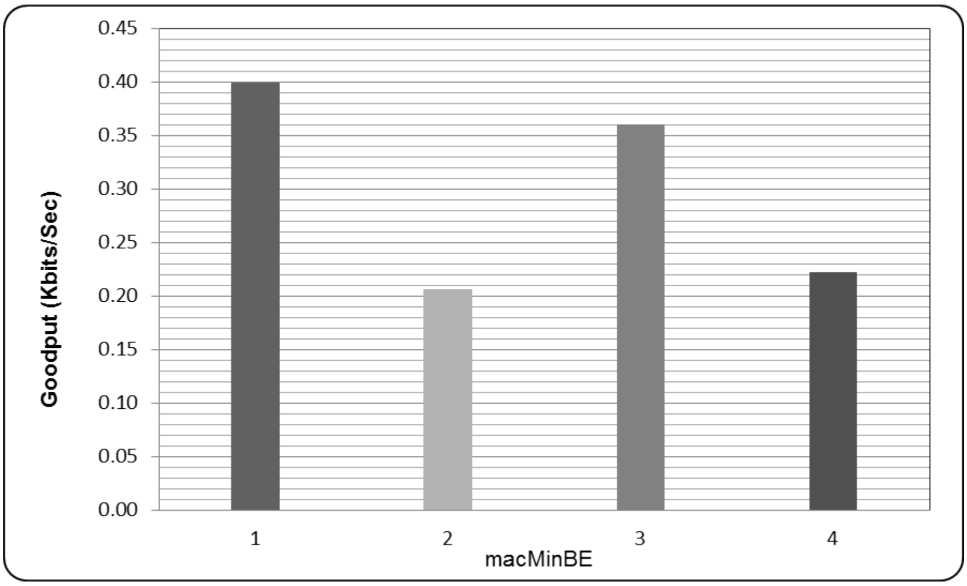

Figure 4.2: Effect of Changing Values of macMinBE on Goodput (Kbits/Sec)

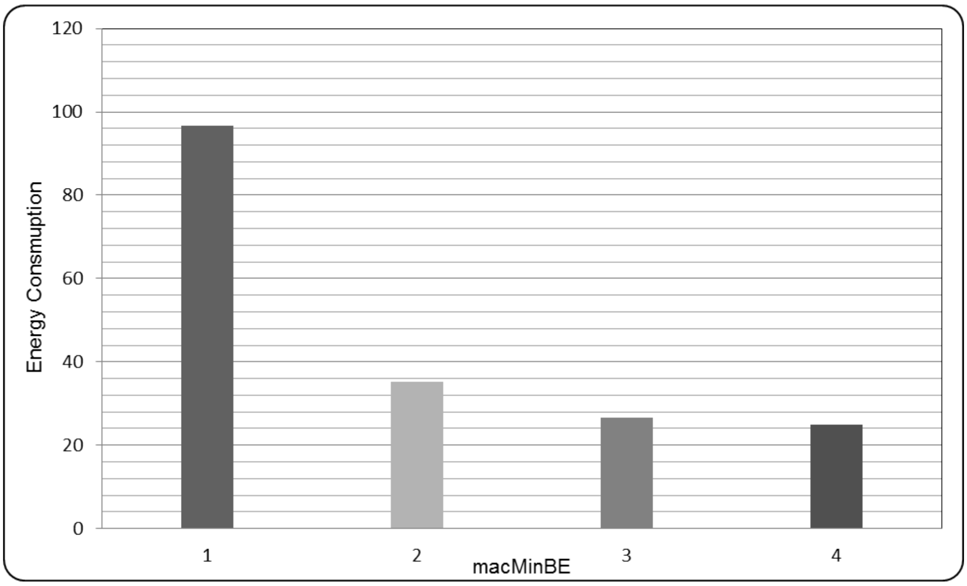

Figure 4.3: Effect of Changing Values of macMinBE on Energy Consumption

put(Kbits/Sec) and Energy consumption and MAC packet breakdown.

Another problem with ZigBee MAC is with the value of macMaxCSMABackoffs because smaller value of macMaxCSMABackoffs make a node to terminate the algorithm after failure of few attempts of clear channel assessment and nodes have to start the algorithm from very first state which

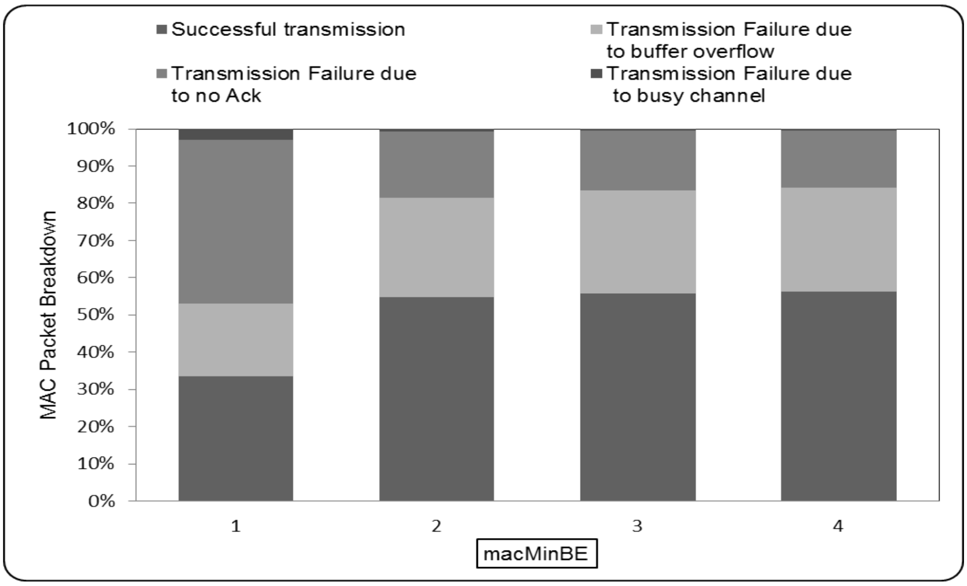

Figure 4.4: Effect of Changing Values of macMinBE on MAC Packet Breakdown

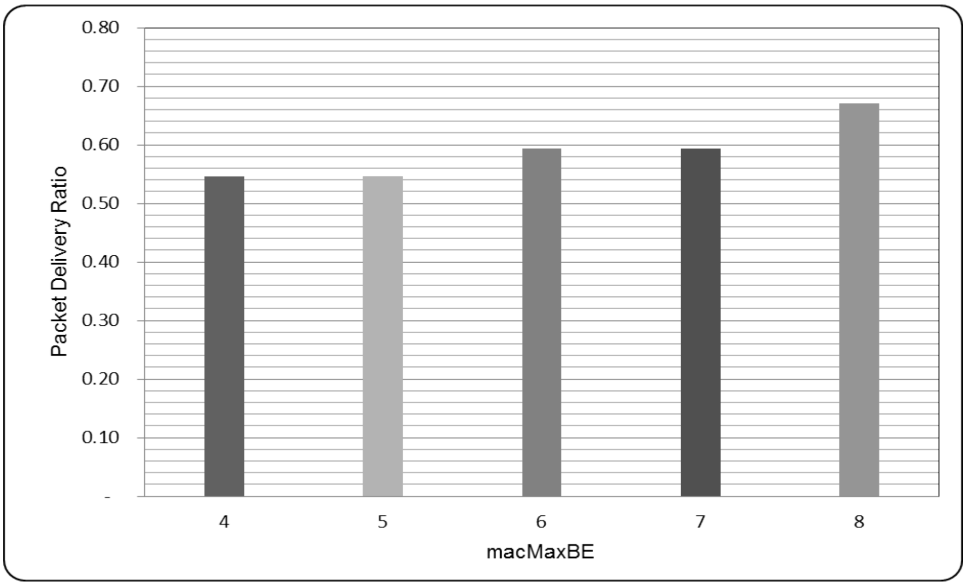

Figure 4.5: Effect of Changing Values of macMaxBE on Packet Delivery Ratio

cause delay in packet transmission. Larger value of macMaxCSMABackoffs introduces delay in network because nodes try to access channel again and again when there is no possibility of being communication channel free be-

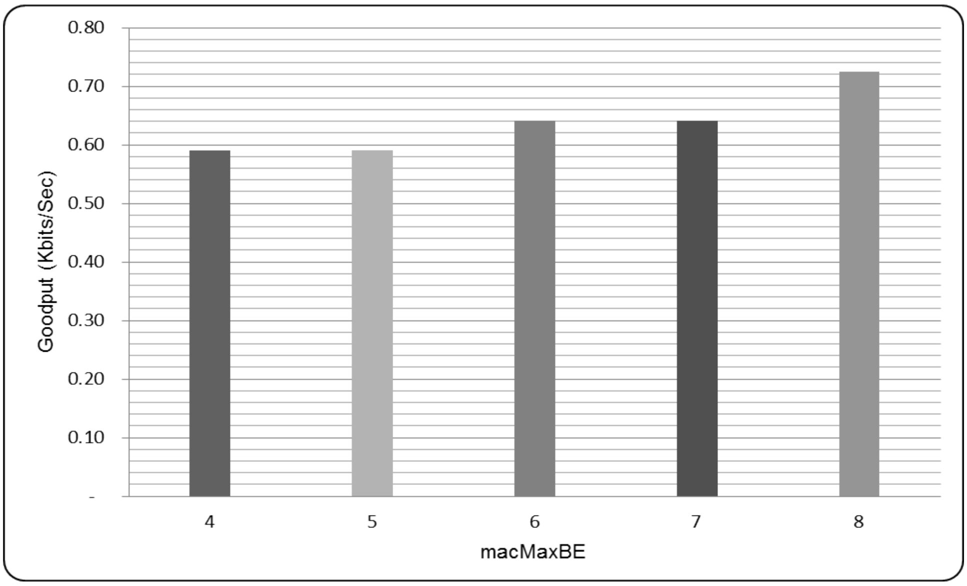

Figure 4.6: Effect of Changing Values of macMaxBE on Goodput (Kbits/Sec)

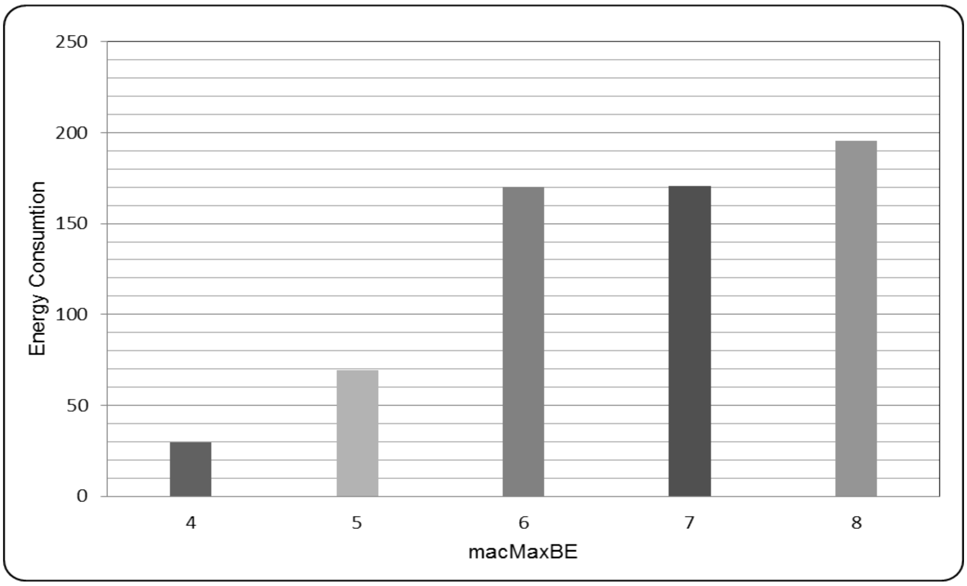

Figure 4.7: Effect of Changing Values of macMaxBE on Energy Consumption

cause of high contention in network. Another problem with ZigBee MAC is transmission failure due to acknowledgment loss. Increasing packet loss in the network also increases the retransmissions in the network which causes high energy consumption. Packet delivery ratio is also decreases due to packet transmission failure which introduces the reliability issues in medical body

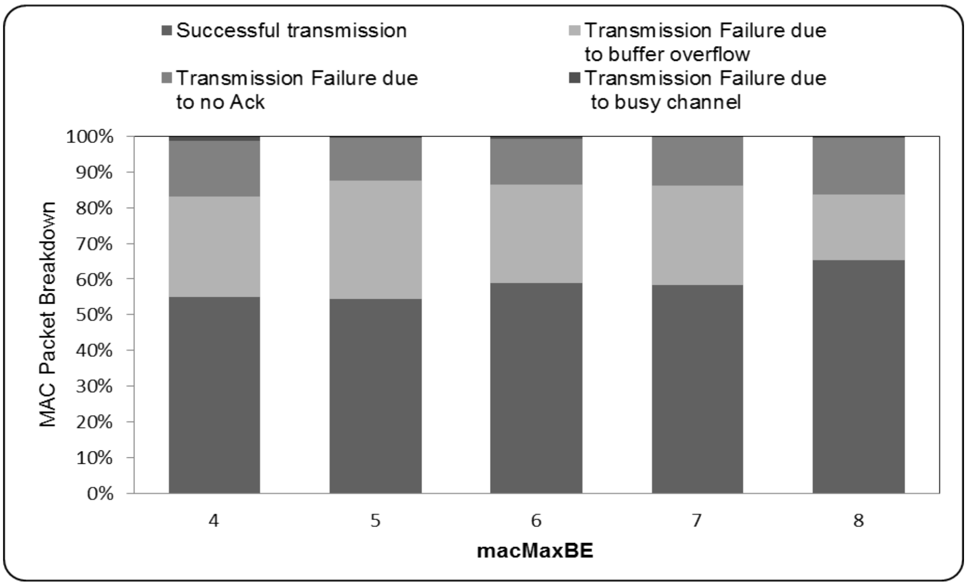

Figure 4.8: Effect of Changing Values of macMaxBE on MAC Packet Breakdown

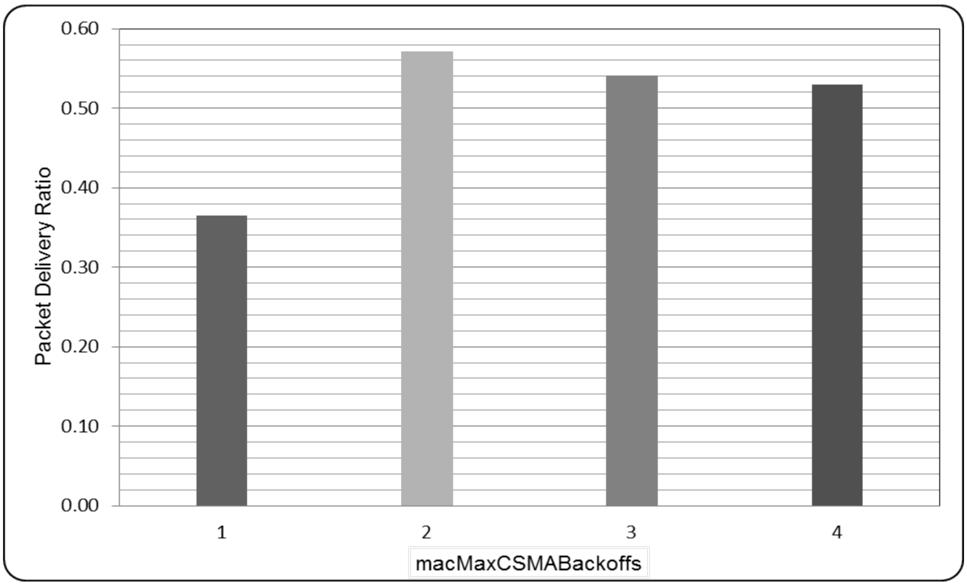

Figure 4.9: Effect of Changing Values of macMaxCSMABackoffs on Packet Delivery Ratio

area networks. Effect of changing value of macMaxCSMABackoffs is shown in Fig. 4.9, Fig. 4.10, Fig. 4.11 and Fig. 4.12.

In order to solve these problems we propose a mechanism of flexible tuning

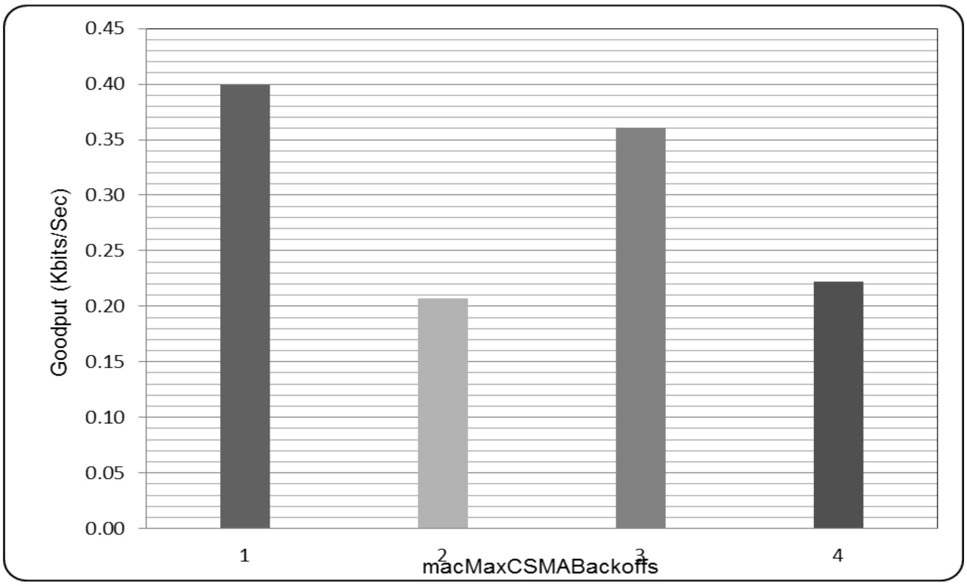

Figure 4.10: Effect of Changing Values of macMaxCSMABackoffs on Goodput (Kbits/Sec)

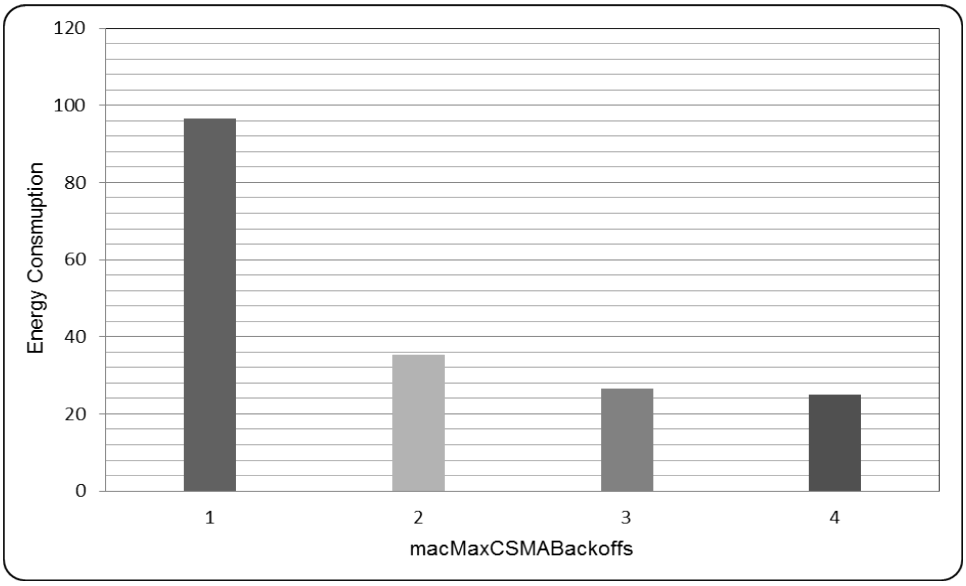

Figure 4.11: Effect of Changing Values of macMaxCSMABackoffs on Energy Consumption

of CSMA/CA parameters such as macMinBE and macMaxCSMABackoffs to avoid unnecessary retransmissions and to improve reliability and energy efficiency in the network at acceptable levels. In the proposed mechanism

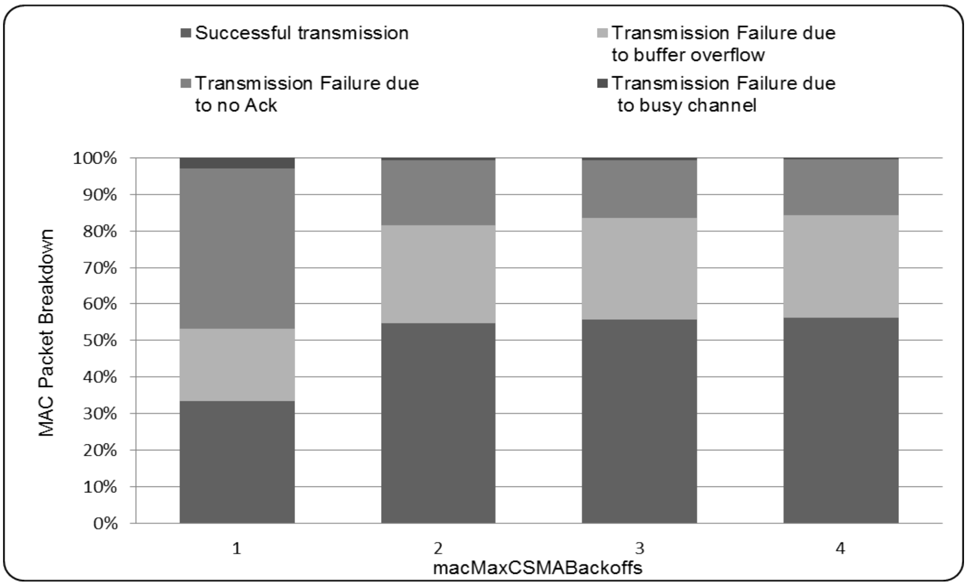

Figure 4.12: Effect of Changing Values of macMaxCSMABackoffs on MAC Packet Breakdown

Table 4.1: MAC Parameter Values

Zigbee MAC parameters	**Default Values [11]**	**New Values**
macMaxFrameRetries	3	2
macMaxCSMABackoffs	4	Range: 4 to 7
macMinBE	3	Range: 2 to 7
macMaxBE	5	7
requestGTS	Fixed no of slots	Depends on buffer size

these parameters adapts best value set according different network conditions such as contention among the nodes and packet collisions in the network etc in order to improve the network performance. In the proposed solution we also change some default values of some MAC parameters as shown in Table. 4.1.

In the proposed mechanism we reduce the value of macMaxFrameRetries because there is no need to retransmit a packet again and again when packet loss is due to contention in network. There is also a need to avoid the circumstances which cause energy wastage such as retransmissions but there is also necessary to take some actions to reduce collisions in network. We propose tuning of two Zigbee MAC parameters macMinBE and macMaxCSMABackoffs to improve performance of ZigBee MAC in terms of reliability and energy efficiency by reducing the transmission failure rate and retransmissions.

4.1.1.1 Flexible macMaxCSMABackoffs

We define a new range of macMaxCSMABackoffs and its tuning in which value of macMaxCSMABackoffs increases or decreases according to clear channel assessment result. If there is no contention or small contention in network and nodes are not competing for channel access then there is no need to set a larger value of CSMABackoffs. So we propose that when CSMA/CA is successful and node successfully transmits it packets for consecutive 3 times then decrement in macMaxCSMABackoffs as follows:-

```
If ((macMaxCSMABackoffs > defaultmacMaxCSMABackoffs) &&
(macMaxCSMABackoffs ≤ 7))
{ macMaxCSMABackoffs–; }
```

When there is channel access failure in the network it means that there is high contention among the nodes in network. When a large number of nodes have data to send and they try to access the channel at the same time they encounter channel access failure. In this case they have to terminate the algorithm after few attempts because of smaller value of macMaxCSMABackoffs. Terminating an algorithm and start it from first step introduce some delay in network. In order to solve this issue we propose an increment in value of macMaxCSMABackoffs after three consecutive times of CSMA/CA failure. Mechanism to increase the value of macMaxCSMABackoffs after consecutive three times CSMA/CA failure is as given below:-

```
If ((macMaxCSMABackoffs ≥ defaultmacMaxCSMABackoffs) &&
(macMaxCSMABackoffs < 7))
{ macMaxCSMABackoffs++; }
```

4.1.1.2 Flexible macMinBE

We define a new range of macBE from 2 to 7. We also propose flexible tuning of macMinBE according to network conditions such as packet collision rate and acknowledgment loss. When a large number of nodes try to transmit their data at the same time then there is possibility of packet collision in the network. In order to avoid collisions using CSMA/CA mechanism, we propose an increment in value of manMinBE after consecutive three packet collisions. By this way in case of high collision in network we put some nodes to be in backoff state in order to reduce the contention in network. Proposed mechanism to increment the manMinBE value is as follows:-

```
if ((macMinBE ≥ defaultmacMinBE) && (macMinBE < macMaxBE
))
{ macMinBE++ ;}
```

When there are small number of collisions due to less contention in the network then there is no need for a node to be in backoff state for longer time. It only introduces unnecessary delay in the network. To resolve this issue we propose a decrement in value of macMinBE. Mechanism to decrement in value of macMinBE is given below:-

```
if ((macMinBE > defaultmacMinBE) && (macMinBE ≤ macMaxBE
))
{ macMinBE– ;}
```

4.1.2 GTS-on Mode

In order to solve the problem of bandwidth underutilization in Zigbee MAC as shown in Fig. 4.13, Fig. 4.14, Fig. 4.15 and Fig. 4.16, we revise the mechanism

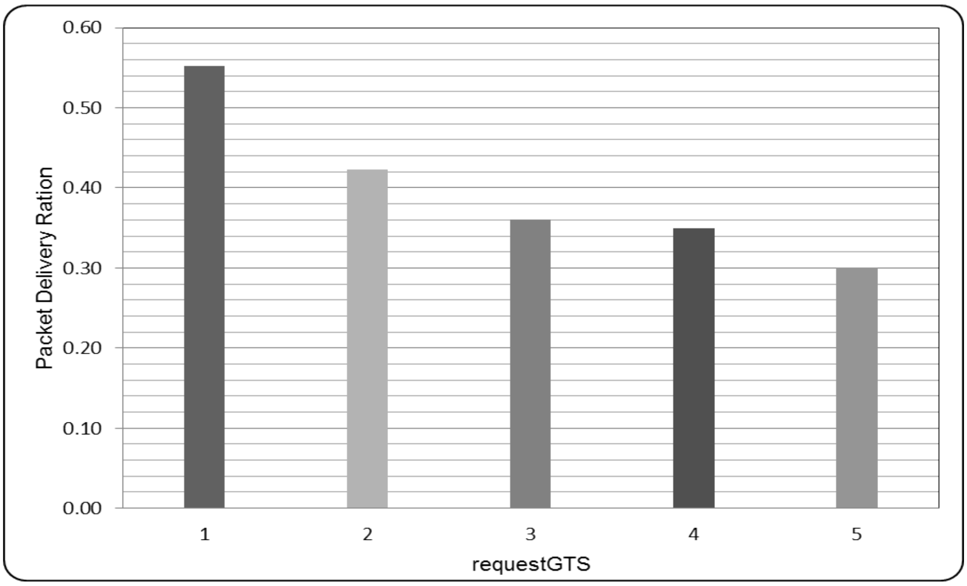

Figure 4.13: Effect of Changing Values of requestGTS on Packet Delivery Ratio

of node to send a GTS request.ly send its emergency data otherwise it send the data into emergency buffer and send a request to reserve a guaranteed time slot.

We also propose that instead of sending a request for fixed number of slots, each node check total number of packets in its buffer and send a GTS request according to buffer size. Proposed mechanism for sending GTS request is given below.

```
If ((GTSbuffersize ≥ 1) && (GTSbuffersize ≤ 7))
GTSrequest = 1;

else if ((GTSbuffersize ≥ 8) && (GTSbuffersize ≤ 14))
GTSrequest = 2;

else if ((GTSbufersize >14) && (GTSbufersize ≤ emergencyBfr))
GTSrequest = 3;
```

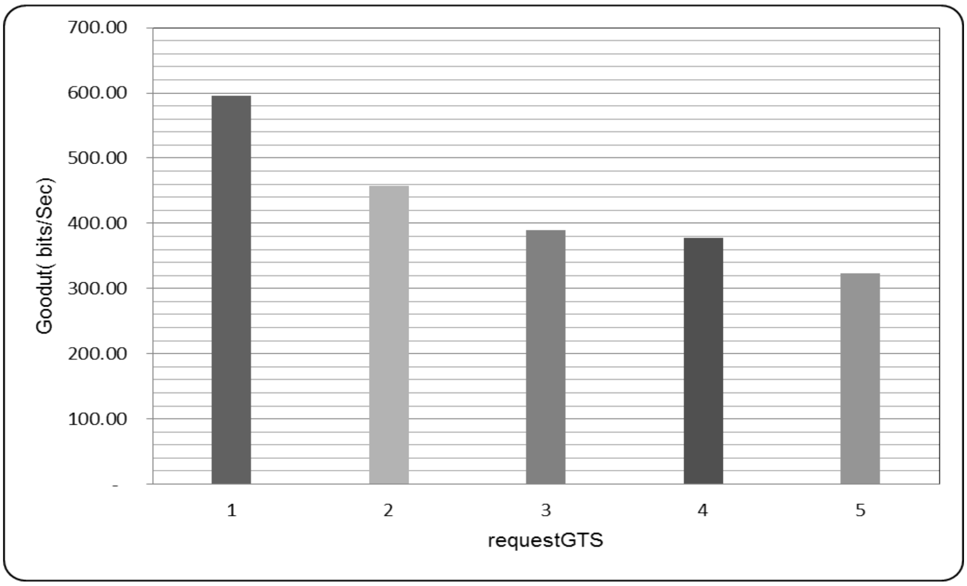

Figure 4.14: Effect of Changing Values of requestGTS on Goodput (Kbits/Sec)

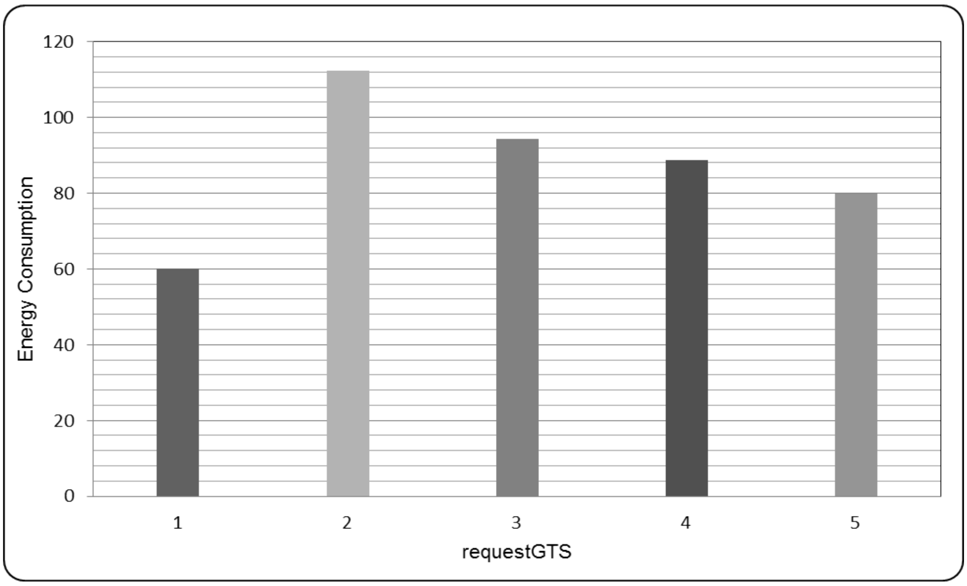

Figure 4.15: Effect of Changing Values of requestGTS on Energy Consumption

4.1.3 Adaptive MAC

Traffic in medical body area network is hybrid and it depends on the patient's health conditions. If values of patent's vital signs do not exceed a

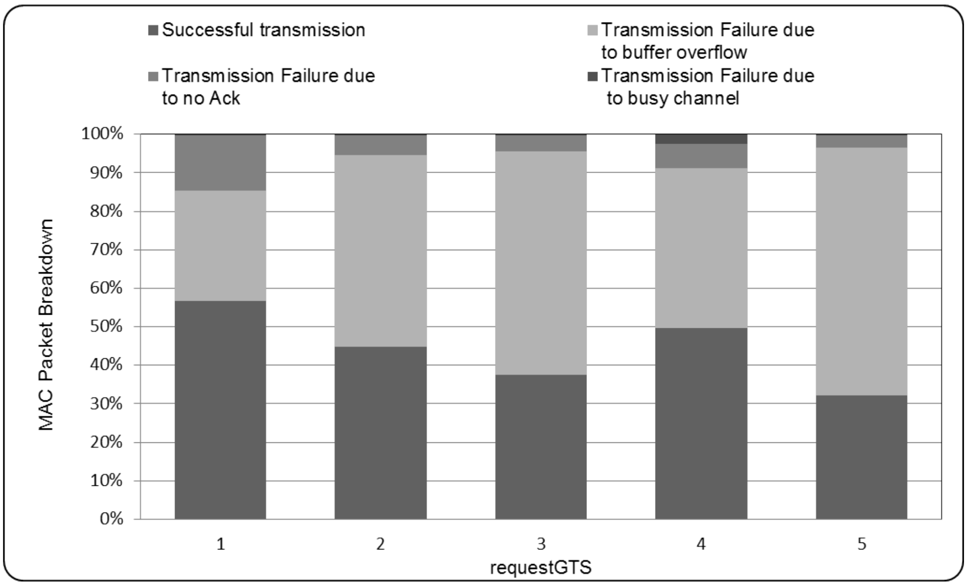

Figure 4.16: Effect of Changing Values of requestGTS on MAC Packet Breakdown

certain threshold, we consider it as normal traffic. If a condition of patient goes critical and patent's vital signs values exceed the threshold level we label it as emergency traffic. Emergency traffic needs highest reliability as compare to normal traffic because of critical condition of patient. We propose a mechanism which enables the algorithm to adapts its modes i.e. GTS-off and GTS-on according to traffic type. Proposed mechanism for adapting modes of MAC is given below.

if sensor value $\geq$ maxThreshold || sensor value $\leq$ minThreshold // emergency traffic
then packet will send in GTS-on mode (CFP)
else packet will send in GTS-off mode (CAP)

4.2 Implementation Details

We represent the medical body area network for patient's monitoring in Fig. 4.17. Details of network implementation are given in Table. 4.2. The proposed mechanism is implemented in an Omnet++ based Castalia Simula-

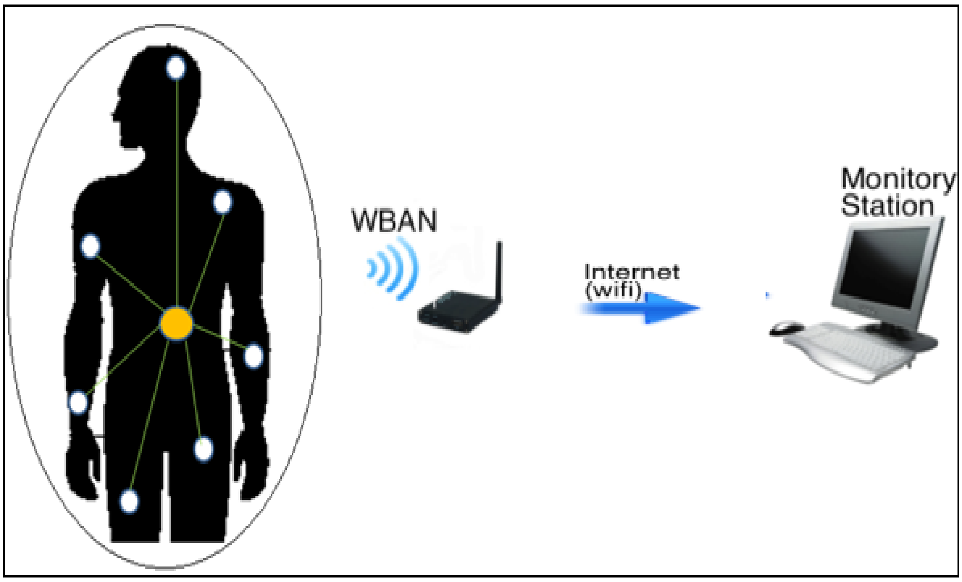

Figure 4.17: Medical Body Area Network

Table 4.2: Implementation Scenario

Simulator	Castalia
Field Size(x,y)	10 meter
Topology	Star
(PAN Coordinator, Source Nodes)	{(1,1)(1, 2)(1, 3)((1,5)(1,8)(1, 10), (1, 15)(1, 20)(1, 30)(1, 40)(1,50)}
Packet Size	48 bytes
Routing Protocol	None
No of Simulation Runs	30

tor. We set field size to 10 meters and select star topology because it is best suited for short range communications in medical body area networks. We take simulations for different network scenarios by changing number of source nodes or by changing packet rates. There is no need of routing protocol in our implementation because in star topology routing paths are predefined.

Chapter 5

RESULTS AND DISCUSSION

We select four performance metrics to compare the performance of proposed mechanism with the ZigBee MAC which are packet delivery ratio, goodput(bits/Second), MAC packet break down and energy efficiency. Packet delivery ratio represents the ratio of number of packets successfully received at destination divided by total number packets sent at application layer. Unit of goodput is bits per second and it is an application layer throughput which represents the actual data transmitted from source to destination per unit time. MAC packet breakdown has four sub performance metrics i.e. transmission failure due to buffer overflow, transmission failure due to acknowledgment loss, transmission failure due to busy channel and the rate of successful packet transmission at MAC layer. We calculate energy efficiency in term of retransmissions overhead e.g. smaller the number of retransmissions and duplicate packets smaller the energy consumption of network.

We compare simulation results of both MACs against six different scenarios based on different packet rates and number of nodes. In scenario 1 packet rate of all nodes is same but number of nodes is different. In scenario 2, packer rate is different such as 1 packet/sec 2 packets/second, 3 packets/second, 5 packets/second and 10 packets/second but number of nodes remains constant. In this scenario there are 10 source nodes and one PAN coordinator in the network. In scenario 3 20% nodes in network have packet rate of 1 packet/second and 80% nodes have 5 packets/second packet rate. In scenario 4 packet rate of 20% nodes in network have 5 packets/second and 80% nodes have 1 packet/second. In scenario 5 50% nodes in network have packet rate of 1 packet/second and 50% nodes have 5 packets/second. In the last scenario each node in network has different packet rate between the range of 1 packet/second to 8 packets/second.

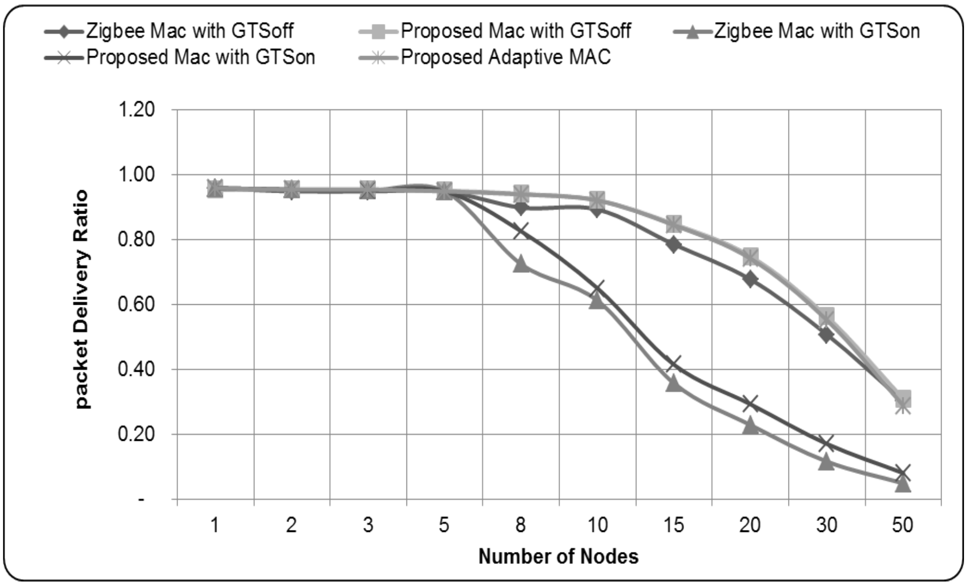

Figure 5.1: Packet Delivery Ratio of Scenario 1

5.1 Simulation Results

We subdivide this section to packet delivery ratio, goodput(Bits/Second), MAC packet break down and energy efficiency subsections.

5.1.1 Packet Delivery Ratio

Fig. 5.1 and Fig. 5.2 show the simulation results of proposed MAC and ZigBee MAC of scenario 1 and 2 respectively. Simulation results for scenarios 3, 4, 5 and 6 are shown in Fig. 5.3. From the simulation results we can see that all modes of proposed MAC perform better than ZigBee MAC when we increase the number of nodes in the network or increase the packet rates. Proposed MAC performs better in case of setting different packet rates for each node as shown in Fig. 5.3.

5.1.2 Goodput(Kbits/sec)

Fig. 5.4 and Fig. 5.5 represent the goodput of both MACs for scenario 1, 2 and Fig. 5.6 shows the results of scenario 3, 4, 5 and 6. If we compare the performance both MACs we can see that all modes of proposed MAC have better performance as compare to ZigBee MAC. When we compare the simulations results of scenario 3, 4, 5 and 6 we can see that when 80% of nodes have

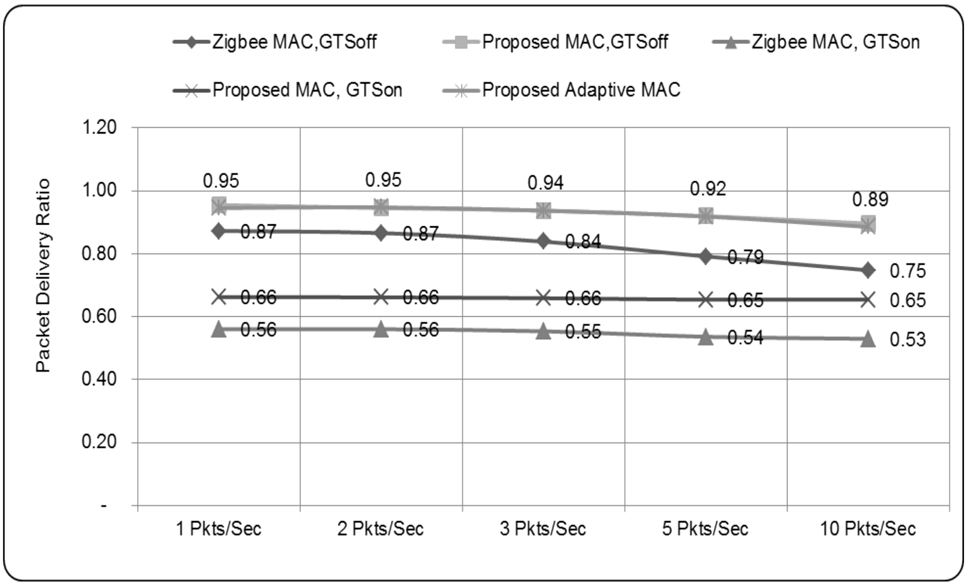

Figure 5.2: Packet Delivery Ratio of Scenario 2

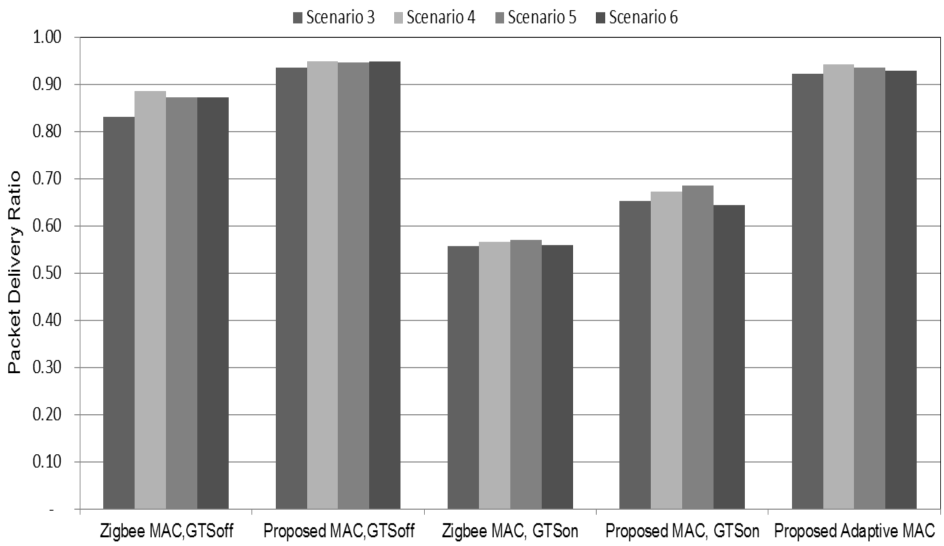

Figure 5.3: Packet Delivery Ratio of Scenario 3, 4, 5 & 6

highest data rates such as 10 packets/second and only 20% nodes are sending 1 packet/second the goodput of network is high as compare to scenario in which 80% of nodes are sending packets at packet rate of 1 packet/second and remaining 20% nodes are sending 5 packets/second. Proposed MAC has better goodput as compare to ZigBee MAC in all scenarios.

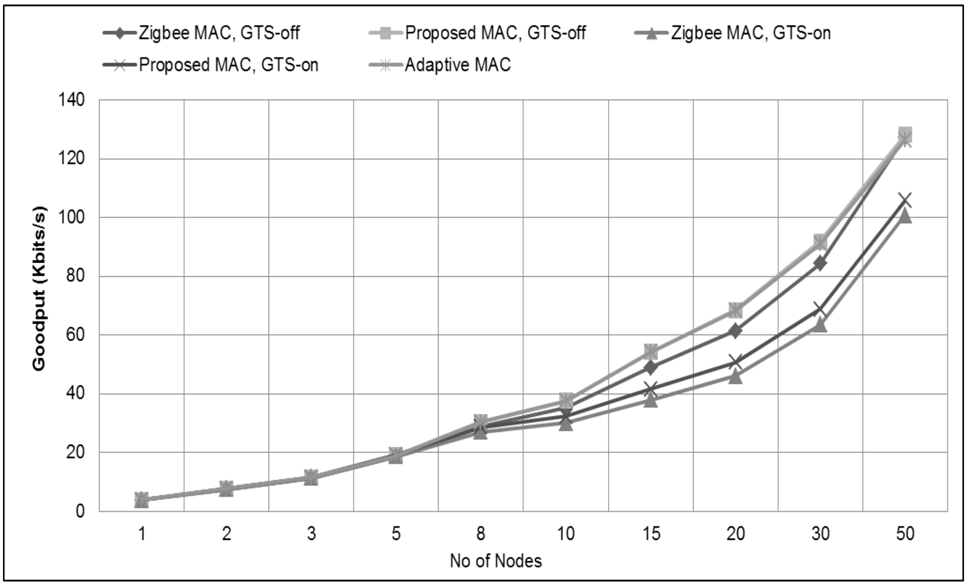

Figure 5.4: Goodput (Kbits/Sec) of Scenario 1

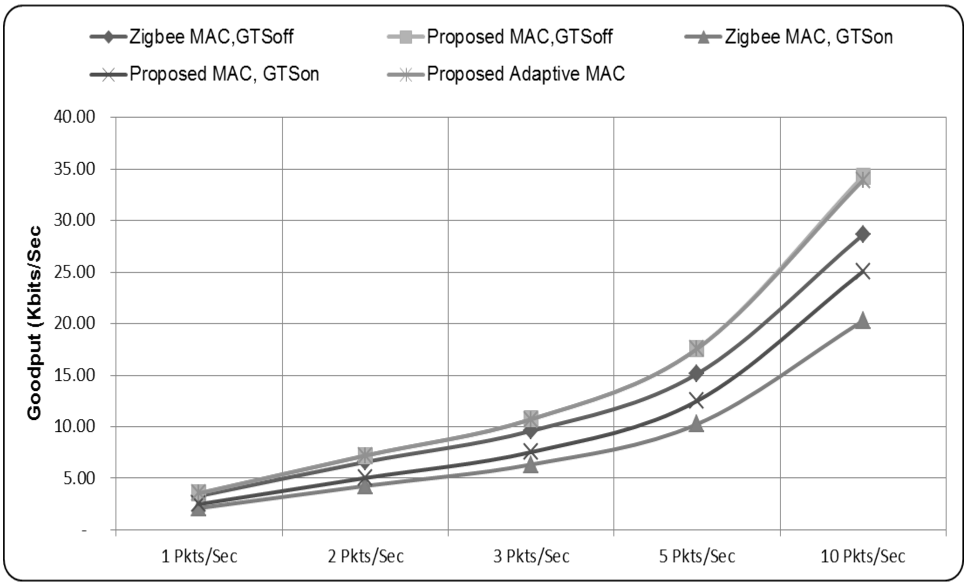

Figure 5.5: Goodput (Kbits/Sec) of Scenario 2

5.1.3 MAC Packet Breakdown

MAC packet breakdown is one of our most important performance metrics. Under this performance metric we have further four performance sub-metrics such as transmission failure due to buffer overflow, transmission failure due

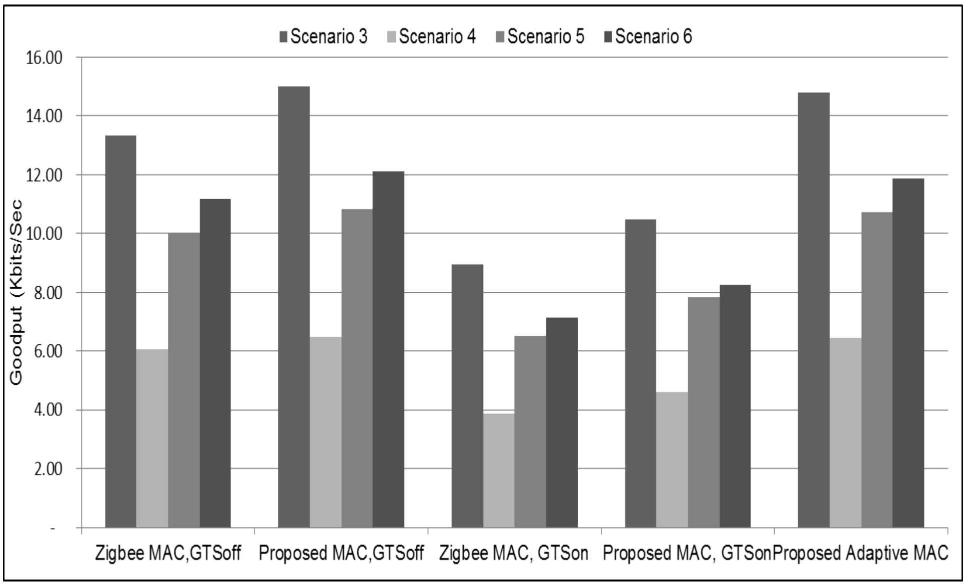

Figure 5.6: Goodput (Kbits/Sec) of Scenario 3, 4, 5 & 6

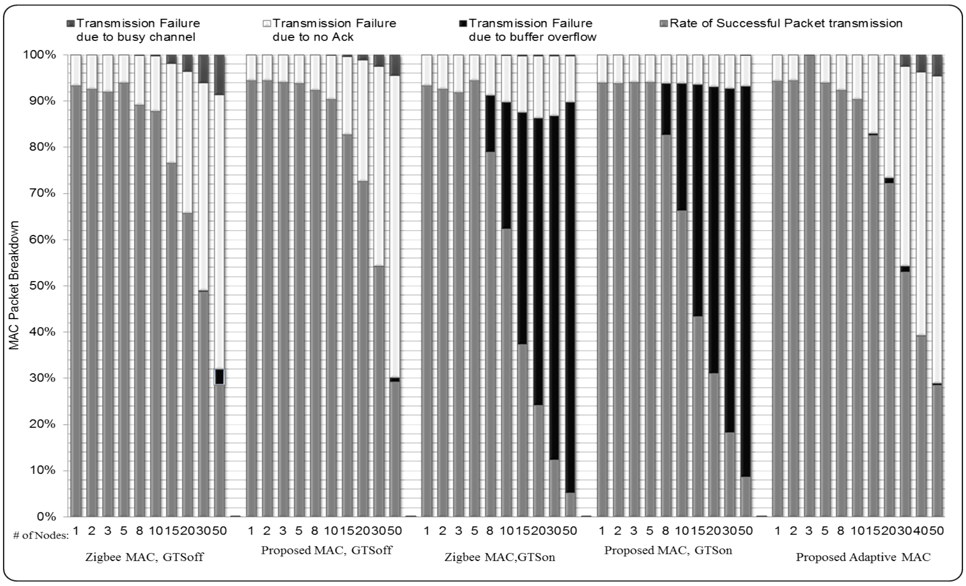

Figure 5.7: MAC Packet Breakdown of Scenario 1

to acknowledgment loss, transmission failure due to busy channel and the rate of successful packet transmission at MAC layer. Basically it tells us that what actually happened to a packet at MAC layer when a node tries to send it to sink node. If packet fails to transmit, there can be multiple possible reasons of this failure. We can also know that how many packets

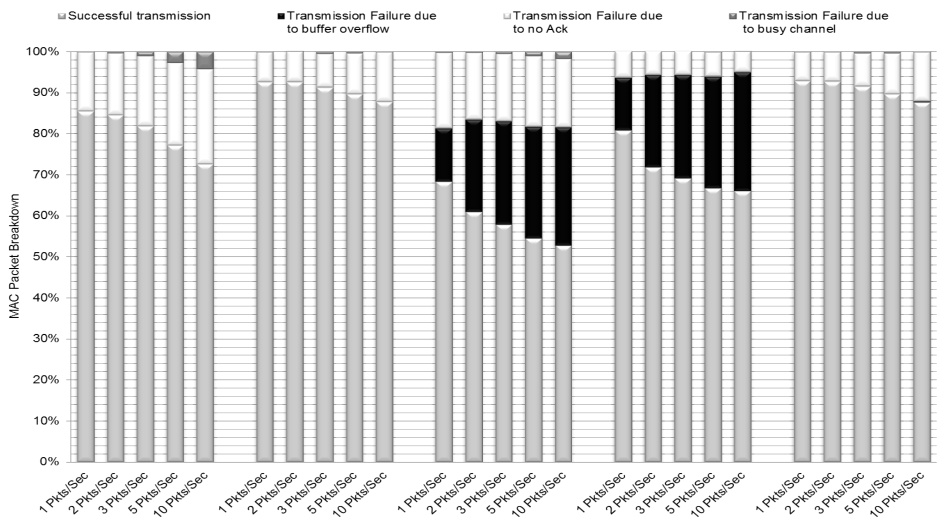

Figure 5.8: MAC Packet Breakdown of Scenario 2

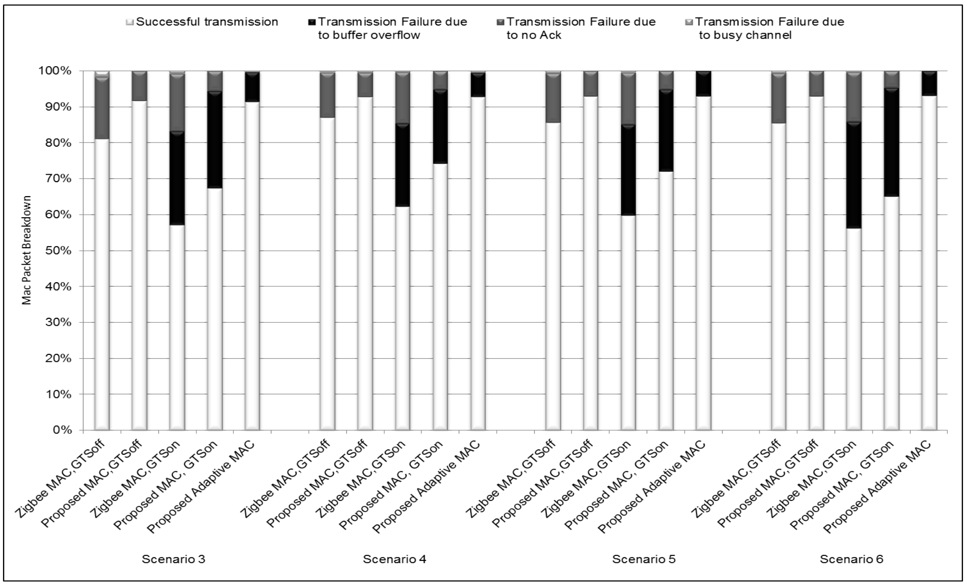

Figure 5.9: MAC Packet Breakdown of Scenario 3, 4, 5 & 6

successfully received at destination out of total packets sent at MAC layer and how many packets failed to transmit and discarded at MAC layer due to contention among the nodes. Fig. 5.7 shows the MAC packet breakdown of scenario 1 in which we compare the performance of three modes of proposed MAC with ZigBee MAC. Fig. 5.8 shows the results of zigbee MAC, GTS-off, Proposed MAC,GTS-off, Zigbee MAC, GTSon, Proposed MAC, GTS-on and Proposed Adaptive MAC from left to right.

Rate of transmission failure due to buffer overflow in GTS-on mode is highest. The reason is that only nodes which are able to get guaranteed time slots can send their packets and other nodes have to wait. Those nodes which are waiting for time slots and have buffer filled have to drop their packets. If we compare the performance of proposed and ZigBee MAC with GTS-on mode, proposed MAC shows better performance as compare to zigbee MAC.

Rate of packet failure due to buffer overflow in GTS-off modes is minimal because in these nodes each node competes for channel access whenever it has a packet to transmit. So nodes transmit their data as a soon as these nodes get free channel so in this modes there is a space for newly arriving packets most of the time. Rate of transmission failure due to acknowledgment loss is high in GTS-off mode because due to high traffic rate which causes packet collision or acknowledgment loss in the network. After sending a packet a node wait for the acknowledgment for a specific time period. If acknowledgment does not receive at the source node within that time then node declares transmission failure. In the GTS-on mode the transmission failure due to acknowledgment loss is small because in this mode each node only transmits its data in the portion of allocated guaranteed time slots of superframe. During that portion of superframe other nodes defer their transmission and go into an inactive state. So chances of packet collision or acknowledgment loss are less in network. If we compare the transmission failure due to busy channel, it is clear from the results that proposed MAC performs better in all scenarios. There is no transmission failure due to busy channel in GTS-on mode because of the same reason that each node transmits its data only in allocated time slot.

Fig. 5.8 shows the simulation results of scenario 2 and Fig. 5.9 shows the combined graph of results of scenario 3, 4, 5 and 6. From the results we can see that all modes of proposed MAC show better MAC packet breakdown performance for as compare to ZigBee MAC in all scenarios.

5.1.4 Energy Efficiency

In this section we compare energy efficiency of proposed MAC with ZigBee MAC. Simulation results are shown in Fig. 5.10, Fig. 5.11 and Fig. 5.12. In the Fig. 5.10 we show the simulations results of both MACs for scenario 1. We can see that when there are small numbers of nodes in the network then retransmission overhead is less because of small contention in the network so the less energy consumption. Energy consumption in network increases when contention increases in the network because it causes high rate of transmission

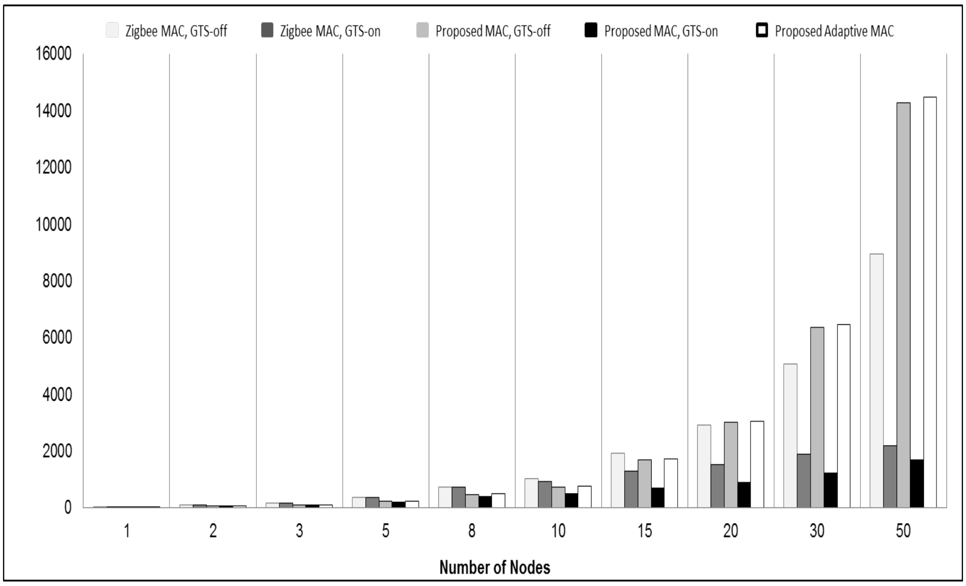

Figure 5.10: Energy Consumption of Scenario 1

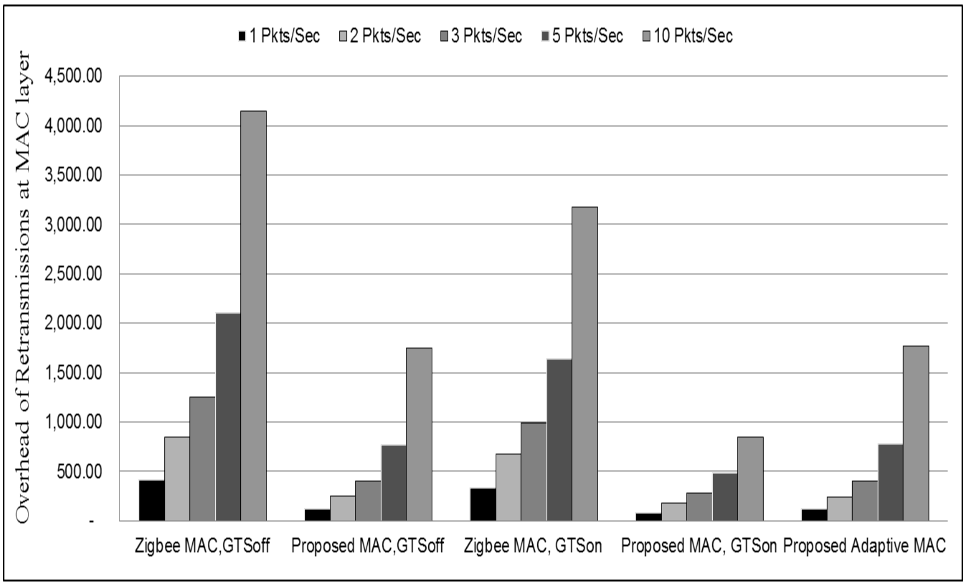

Figure 5.11: Energy Consumption of Scenario 2

failure.

From the result shown in Fig. 5.10, with increasing number of nodes energy consumption is also increasing but proposed MAC maintain energy efficiency above a certain level as compare to ZigBee MAC. When there are large numbers of nodes and there is high collision rate in the network, proposed

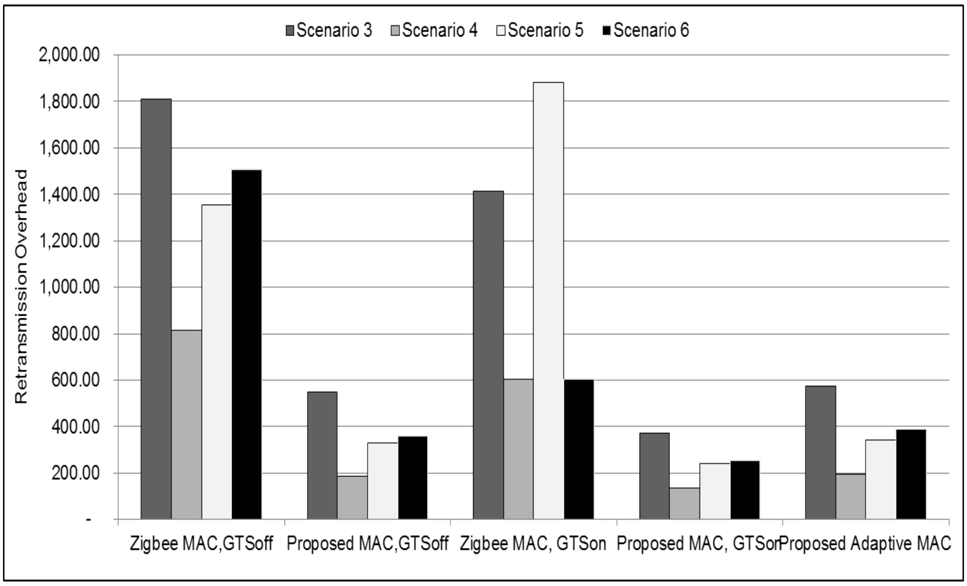

Figure 5.12: Energy Consumption 3, 4, 5 & 6

MAC maintains an acceptable balance between the energy consumption and reliability by increasing number of retransmissions to a certain level.

Fig. 5.11 shows simulation results of scenario 2. In this scenario we increase the packet rate and compare the energy efficiency of both MACs. We can see that by increasing packet rate in the network retransmission overhead is also increasing and energy efficiency is decreasing. But the proposed MAC has better energy efficiency as compare to ZigBee MAC.

From Fig. 5.11 we can also see the low retransmission overhead of proposed MAC as compare to ZigBee MAC. We can see same performance trend in Fig. 5.12 which shows results of scenarios 3, 4, 5 and 6. In all scenarios retransmission energy efficiency of proposed MAC greater than the ZigBee MAC.

There are some other results shown in figure Fig. 5.13, Fig. 5.14 and Fig. 5.15 which represent the details of packet transmission and retransmission of adaptive proposed MAC in all scenarios. These results shows the total number of packets created at an application layer, total packets transmitted at MAC layer, number of packet sent at first try and second try, total number of retransmission and comparisons of the retransmission overhead of both MACs. Fig. 5.13 shows the results of scenario 1, Fig. 5.14 shows the results of scenario 2 and Fig. 5.15 shows the simulation results of scenario 3, 4, 5 and 6. The proposed MAC compromise on energy efficiency in order to keep reliability at acceptable level if there is high contention in network by

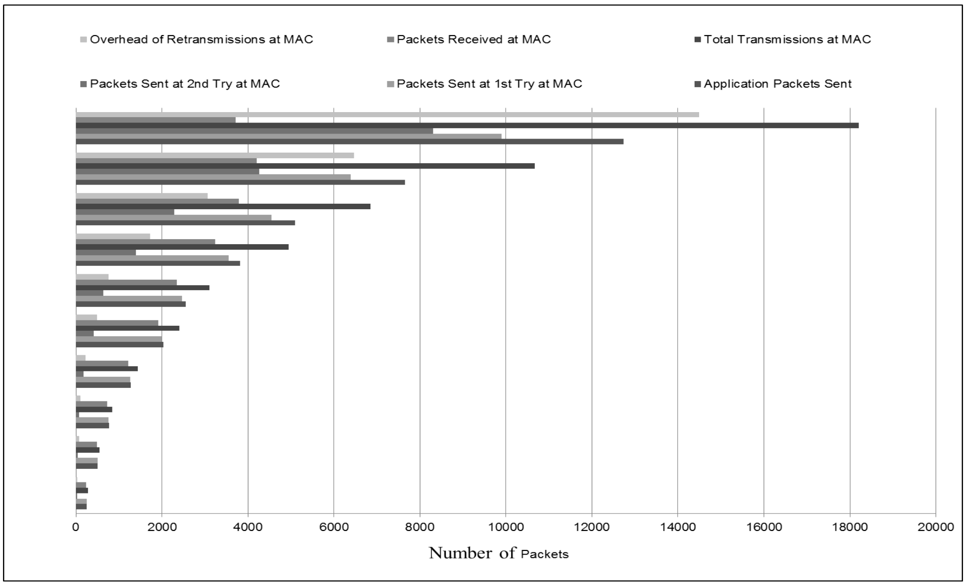

Figure 5.13: Retransmission Overhead of Scenario 1

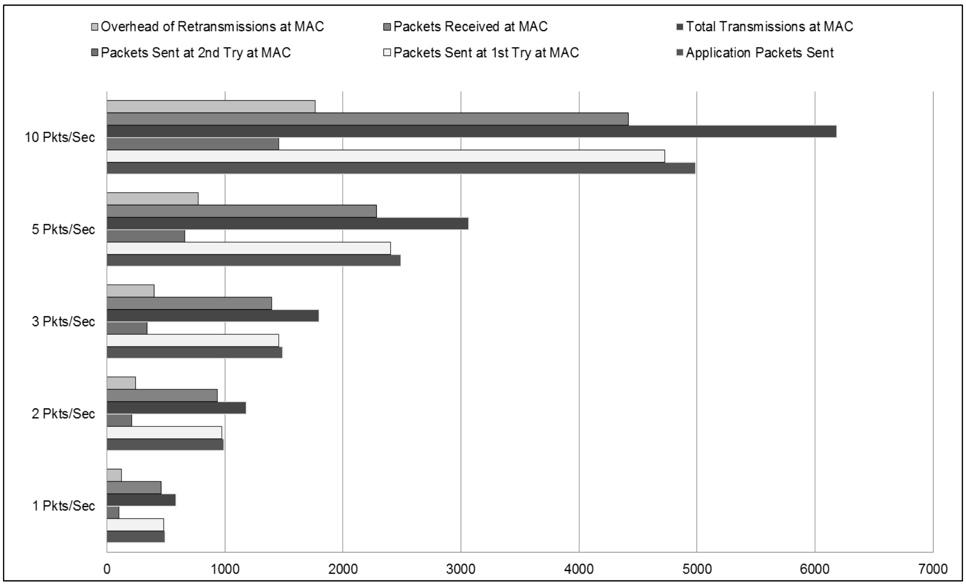

Figure 5.14: Retransmission Overhead of Scenario 2

increasing retransmissions.

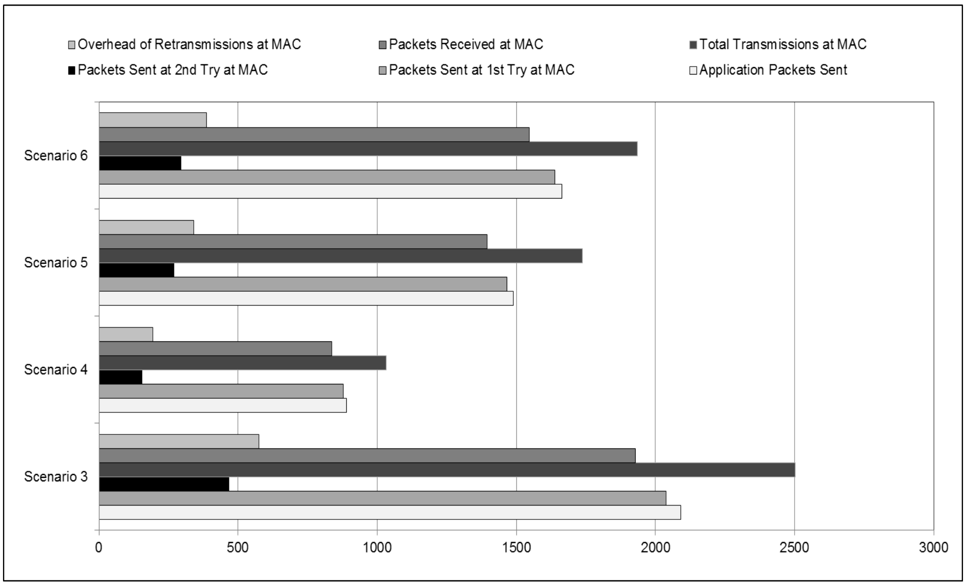

Figure 5.15: Retransmission Overhead of Scenario 3, 4, 5 & 6

Chapter 6

CONCLUSION AND FUTURE WORK

In this chapter, the conclusion with a summary of the research findings along with future directions is presented.

6.1 Conclusion

In this thesis document we discuss about different applications and requirements of medical body area networks. We also give an overview of ZigBee MAC and highlight its limitations when we use it for medical body area networks. Then we propose a reliable and energy efficient MAC mechanism for medical body area network for patient's monitoring in hospitals. We select four performance metrics which are packet delivery ratio, goodput, MAC packet breakdown and energy efficiency. We compare the simulations results of propose MAC with Zigbee MAC and prove that proposed MAC has better performance as compare to ZigBee MAC. We also highlight some issues of ZigBee MAC which are still present in proposed MAC as future directions.

6.2 Future Work

We propose some enhancements in ZigBee MAC to make it best suitable for medical body area networks. We compare the results of proposed MAC with ZigBee and see that proposed MAC performs better than ZigBee MAC in term of reliability and energy efficiency. We compare the reliability of both MACs by comparing the results of goodput, packet delivery ratio and MAC packet breakdown. In order to compare the energy efficiency of both MACs we calculate the number of retransmissions and duplicate packets of both

MACs and compare it with each other. Although proposed MAC shows better performance as compare to ZigBee MAC but there are still some issues which need to be addressed. If we see results of MAC packet breakdown in Fig. 5.13, Fig. 5.14 and Fig. 5.15 transmission failure due to acknowledgment loss is still an issue. It is necessary to resolve this issue to improve the reliability in medical body area network. It will also help to improve the energy efficiency of network by reducing the number of retransmissions. GTS allocations scheme also needs some improvements and there is need to put some more efforts to make more flexible. Performance of GTS allocation mechanism can be improved bt introducing some fairness policy among the nodes. We can also specify priorities of different nodes depending on the nature of vital signs data which they are monitoring. Another possible enhancement is that we should make sure the reliability of GTS request and reply messages. Because in case of not getting the guaranteed time slot, node have to wait until next superframe which can introduce extra delay in packet transmission and can also cause packet drop due to buffer over.

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