A New Energy Efficient Protocol for Wireless Body Area Networks

By

Qaisar Nadeem

FA10-REE-029-ISB

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Name	Registration Number
Qaisar Nadeem	FA10-REE-029-ISB

Supervisor

Supervisor Name:

Dr. Nadeem Javaid
Department of Electrical Engineering
COMSATS Institute of information Technology
Islamabad Pakistan.
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This thesis titled

A New Energy Efficient Protocol for Wireless Body Area Networks

By

Qaisar Nadeem

FA10-REE-029-ISB

Has been approved

For the COMSATS Institute of Information Technology Islamabad

External Examiner: ___________________________

Dr. Ijaz Mansoor Qureshi
Professor, Dept. of Electrical Engineering
Air University, Islamabad Pakistan

Supervisor: ___________________________________

Dr. Nadeem Javaid
Assistant Professor, Dept. of Electrical Engineering
COMSATS Institute of Technology
Islamabad Pakistan

HoD: _______________________________________

Dr. Muhammad Fasih Uddin Butt
Assistant Professor, Dept. of Electrical Engineering
COMSATS Institute of Technology
Islamabad Pakistan

Declaration

I **Qaisar Nadeem, Reg # FA10-REE-029** hereby declare that I have produced the work presented in this thesis, during the scheduled period of study. I also declare that I have not taken any material from any source except referred to wherever due that amount of plagiarism is within acceptable range. If a violation of HEC rules on research has occurred in this thesis, I shall be liable to punishable action under the plagiarism rules of the HEC.

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____
Qaisar Nadeem
FA10-REE-029-ISB

Certificate

It is certified that **<u>Qaisar Nadeem Reg# FA10-REE-029</u>** has carried out all the work Related to this thesis under my supervision at the Department of Electrical Engineering, COMSATS Institute of Information Technology, Islamabad and the work fulfills the requirement for award of MS degree.

Date: ________________

Supervisor:

____

Dr. Nadeem Javaid, Assistant Professor
Department of Electrical Engineering
COMSATS Institute of Technology
Islamabad Pakistan

Head of Department:

____

Dr. Muhammad Fasih Uddin Butt
Assistant Professor, Dept. of Electrical Engineering
COMSATS Institute of Technology
Islamabad Pakistan

Dedication

I dedicate this thesis to my family for nursing me with affections, love and their dedicated partnership for success in my life.

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Abstract

In current era of technology, applications of wireless sensor networks (WSNs) are rising in various fields. The deployment of WSNs for real life applications is greater than before. Still, the energy constraints remain one of the key issues; it prevents the complete utilization of WSN technology. Sensors typically powered with battery, which have insufficient life span. Even though renewable energy sources like solar energy or piezo-electric means are used as supplementary energy in WSNs, it is still some degree of reserve to consume energy judiciously. Proficient energy routing is thus a key requirement for a trustworthy design of a wireless sensor network. In this article, we advise a new Gateway Based Energy-Efficient Clustering Routing Protocol (M-GEAR) for WSNs. We divide the sensor nodes into four logical regions based on their distance from the gateway node and Base Station (BS). We install BS faraway from sensing area and a gateway node at the centre of the sensing area. If the distance of a sensor node from BS or gateway is less than predefined distance threshold, the node uses direct communication to transmit its sensed data. We divide the rest of nodes into two equal regions whose distance is beyond the threshold distance. We then divide these two regions into clusters and each region elects its own Cluster Heads (CHs) independent of other region. We compare performance of our protocol with LEACH (Low Energy Adaptive Clustering Hierarchy). Performance analysis and compared statistic results show that our proposed protocol perform well in terms of energy consumption and network lifetime.

We also propose a reliable, power efficient and high throughput routing protocol for wireless body area networks (WBANs). We use multi hop topology to minimize energy consumption and maximizing network lifetime. We use a cost function to select parent node or forwarder. Proposed cost function selects a parent node, which has high residual energy and less distance to sink. Residual energy parameter balances the energy consumption among the sensor nodes and distance parameter ensures successful packet delivery to sink. Simulation results shows that proposed protocol enhance the network stability period and nodes stay alive for longer period. Longer stability period contributes high packet delivery to sink which is major interest for continuous patient monitoring.

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Chapter 1

Introduction

1.1 Wireless Sensor Networks

A wireless sensor network(WSN) is a group of miniaturized sensor nodes which are deployed in a field to monitor physical conditions autonomously. WSNs measure a great number of physical conditions like sound, pressure, temperature etcetera. Sensor nodes than pass this sensed data to a base station or sink. The current advance WSNs are bidirectional that also control the activity of sensor node. The military applications give rise in development and advancement in wireless sensor networks. Today these WSNs are deployed in many industrial applications to monitor industrial process, industrial control and monitoring health of machine. The WSN is composed of 'sensor nodes' which can be few in numbers, hundreds or thousands in numbers. A sensor node in WSN is connected with other sensor node or with several sensor nodes. A sensor node consists of many components, a microprocessor or a microcontroller to control the operation of node, a radio trasciever to communicate, and to interface sensors with power source, an electronic circuitry is used. Batteries are normally used as power source in these sensors or energy is harvested from any available source. The size of the sensor node varies according to application, as sensor node can have a size of shoe box or a tiny senor like dust grain. Similarly the sensor have have variable cost. The prise of a sensor node may range from few dollars to hundreds of dollars as a node contain complex circuitry and advance features. Many topologies are used in these networks like simple star topology or advance multihop topologies [1]

1.2 wireless Body Area Networks

One of the major application of WSN technology is monitoring of human health [2]. In WBAN, only few sensors are used which are implanted in body or positioned on the body. These tiny sensors placed on patient's body measure vital signs like blood pressure, Glucose level, pulse rate etcetera. These measured values are than forwarded to the medical server or doctor to further analyse the patients condition. Wireless sensors provide continuous monitoring of patient at remote place. Advancement in wireless technology born a new generation of WSN which is suitable for networking on the human body or in the human body. For data transfer among sensor nodes a point to point topology or multihop topology is used in these networks. Use of topology depend on the application, for example to measure the postures of a athlete require a multihop topology. The sensed data is exchange among sensor nodes and than it reaches to base station or sink. Sensors can be implanted or placed on the athlete 's body.

1.3 Standards for WBAN Communication

A large number of communication standards are used for WBAN. Wearable devices which are based on micro chips also rely on these standards. Most widely used standards are Bluetooth, ZigBee,MICS, and Ultra Wide Band (UWB) IEEE 802.15.6

1.3.1 IEEE 802.15.1 (Bluetooth)

IEEE 802.15.1 is a communication standard which is used for short range communication, typically within 10m range. The data rate of Bluetooth standard is 3Mbps. The bandwidth of Bluetooth standard is high while latency rate is low. High bandwidth encourges use of bluetooth standard in UHC. However, this standard consumes high energy, so this standard is normally avoided in UHC. This standard is not well fit for network of sensitive bandwidth and latency.

1.3.2 ZigBee

It is another frequently used communication standard. ZigBee is used in communication devices which utilize less energy like sensor nodes. This standard is employed with a collision avoidance technique. ZigBee got the power to control complex operations related to communication. It utilizes very less energy in communication nearly about 60mW. The data rate of this standard is low nearly 250kbps. ZigBee has the capability of encryption to give considerable protected communication.

1.3.3 MICS

MICS standard is particularly designed for communication in medical applications. This standard is specifically used for on body or in body communication in WBAN. This standard is used at distance of short range, that is a range of human body. It collects data from different sensors placed on the body or implanted inside the body and transfer data to sink in multihop manner. MICS utilizes low power as compared Ultra Wide Band (UWB) so it radiates less energy that is good for human body tissues.

1.3.4 IEEE 802.15.6 Ultra Wide Band(UWB)

UWB is a high bandwidth communication standard and it is used in high data rate applications. UWB is best choice whenever a application requires a high bandwidth. In emergency applications, UWB is considered best choice to use for communication. UWB are implemented with Global Positioning System(GPS). This feature provide short routing path to medical coordinator. GPS facility provide routes which has less traffic and that makes communication faster and emergency data can be easily forward to medical server in critical situation. The receiver of UWB band is very complex, that makes it not good for use in wearable application.

1.4 Challenges in WBAN

WBAN technology has following Problems

1.4.1 Interoperability

To provide plug and play interaction between devices, the data must have to exchange across standards. The data of one standard has to transfer to another standard. The system would have to migrate from one network to another network and during this transfer the connectivity should not be interrupted. In addition, the system must have the capability to scale.

1.4.2 System devices

The WBAN sensors are mostly used for medical applications so the weight of these sensors must be small, so they can easily placed on the human body or implant in human body. Sensor would have to energy efficient as they have to run for several years to monitor patient. WBAN sensors must be reconfigurable and easy to use. In addition to that the patient data must be store in remote storage devices so that the medical specialist can view and analyze the data through internet.

1.4.3 System and device-level security

The patients data is very important for its health monitoring so it must be secure. The standard must support security and accurate data transfer. It is highly required that the patient's data securely transfer to WBAN system coordinator and the data of one patient should not mixed up with data of another patient. The data generated of a patient would have limited access and must be highly secure.

1.4.4 Invasion of privacy

The WBAN technology is used for human health monitoring, however some people consider that WBAN technology may cause threat to freedom if the use of WBAN technology cross the limits of secure medical use.

1.4.5 Sensor validation

The sensing node in WBAN technology must have reliable wireless communication link. These sensing devices have inherent communication limitations in form for limited energy source and interference. These inherited issues in WBAN may cause false data transmission back to user. For health care application or patient monitoring application, it is very important that the readings of the patient are valid and than securely transmitted to medical server. It can overcome false alarms.

1.4.6 Data consistency

The data of a patient sensed by wireless sensors must be gathered to analyse in smooth way. The vital data of a patient resides on multiple nodes and transmitted to other networked medical servers. This data must reach to medical specialist for further analysis, if not then the quality of patient's health care and monitoring process decays [3].

1.4.7 Interference

In WBAN technology the body sensors must have minimum interference in wireless link. The body sensors must increase peaceful existence with the other devices of network. It is required for implementation of large network [4]

1.4.8 Constant Monitoring

WBANs are used to monitor different kind of monitoring. Some time it is required to monitor a patient continuously like cardiac ischemia monitoring. Some patients are monitored in walking or moving scenarios.

1.5 Energy Minimization Techniques in MAC Protocol For WBANs

Performance of MAC protocol is enhanced through utilization of low power mechanisms. Different techniques and methods available in literature are used to provide efficient utilization of energy in WBANs, some of them we discussed here. Sensors in WBAN are energy constrains and it is required to run the network for longer period of time with battery capacity constraints. The major aspects to trim down the energy utilization in low power sensor network is to sense data, process that data and then communication with other communication device [5].
when a node communicate with other nodes, it deplete most of its energy. Energy wasted in idle listening, over transmitting, overhead of control packet, collision and fluctuations in traffic.
WBAN has three major approaches to minimize energy utilization.

1.5.1 Low Power Listening

The Low power listening (LPL) method, a node normally stays in sleep mode and it checks the channel activity after short intervals. A nodes switch from sleep mode to active mode, checks channel activity, if channel is found active, the sensor also stay alive and receive data. if the channel is idle, the nodes switch back to idle mode. It is known as channel polling. Each node continue this process independently without any concern with other nodes. The sender use a long preamble to monitor receiver's polling. The performance of LPL is degraded when the traffic rates are varying highly. however, periodic traffic rates method can be utilized to enhance the performance of LPL. Wise MAC protocol is based on the LPL. It uses non-persistent CSMA technique and sampling preamble to minimize the idle listening.

1.5.2 Scheduled Contention

This scheme is the sum of the two mechanisms, scheduling mechanism and contention based mechanisms. It is used to overcome the collision problem as well as scalability issues. The contending nodes in contention based protocols give rise to packet collision because all the contending node wants to transmit data through channel. Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) is a contention based prot. Node In CSMA/CA protocol perform Clear Channel Assessment (CCA) before the transmission. The scheduling mechanism assign a time slot or bandwidth to all sensors and all sensors transfer its data only in its own scheduled time slot. it is a contention free mechanism. CSMA/CA is contention based MAC protocol in which Clear Channel Assessment (CCA) is carried out by the nodes before transmission of data. Code division multiple access(CDMA), Frequency Division Multiple Access(FDMA), Time Division Multiple Access(TDMA), Carrier Sense Multiple Access(CSMA) are all scheduling schemes. However, CDMA and FDMA has high overhead of computations and are limited in terms of frequency range so they are not considered good for WBAN. sensor MAC(S-MAC) is schedule contention based MAC protocol in which the default mode od sensor nodes set as low duty mode. Nodes coordinate with their neighbor node in sleeping. The node remains in sleeping mode and become active when data has to transmit. It avoids packet collision, reduce overhearing and idle listening. These features leads to minimize energy consumption.

1.5.3 TDMA

It is also a scheduling mechanism in which nodes are scheduled in time slots. In TDMA, nodes are synchronized which causes more energy utilization even than it is prominent scheduling mechanism among others. As discussed earlier that schedule contention technique is the joint of two mechanisms termed as scheduling and contention techniques. All nodes use a common schedule to transmit its data. To have a adaptive, scalable and effective communication between nodes, all nodes exchange its schedule with other nodes. However, TDMA technique uses a super frame which composed of fixed time slots and each time slot is assigned to a node. It is the responsibility of central node to allocate time slots to each node. We call central node as Master Node(MN),Coordinator or Base Station(BS). coordinator assign time slots to contending nodes on the basis of traffic rates. TDMA mechanism has constraints in throughput due to drift in clock. It utilizes low energy because a node remain in sleep mode, it only turns on whenever it has to transmit data. This saves significant energy and enhance the network lifetime. However, its performance is decreased due to synchronization need of nodes. Other TDMA based protocol is Preamble based TDMA(PB-TDMA),Body-MAC (BMAC) and Med MAC [6], [7]

1.6 Energy Efficient MAC Protocols for WBAN

This section describes the efficient protocols for MAC in WBAN

1.6.1 Okundu MAC Protocol

In [8] Okundu et al presents a MAC protocol for WBANs. It utilizes energy efficiently. Protocol has three parts: wakeup service, link establishment and alarm process. The sleep time, wakeup time and wakeup fall back time(WFT) are centrally controlled which contributes to save energy. If time slots are continuous, it causes collision. To avoid these collision, WFT mechanism is used.This mechanism is defined as, suppose a node has data and node want to transfer to master node and master node is not available at that time, then communication between node and master node gets fail, In that case, the node switch back to sleep mode and this sleeping time is calculated by WFT. Nodes has the buffering capability and they buffer the data in sleeping time. This mechanism give chance to every node to transfer its data to master node in predefined time slots even node fails to transmit earlier. The central management to control traffic encourges to overcome the idle listening problem and over hearing issues. only eight nodes can become the member of master node in one cluster. All the communication in the network is started by the master node. The drawback of this scheme is that it only allow one slave sensor node to connect with network at one instant.

1.6.2 Med Mac Protocol

Med MAC, a TDMA MAC protocol is proposed by N. F. Timmons et al. This protocol utilizes two schemes to save energy expenditures, these schemes are Drift Adjustment Factor (DAF) and Adaptive Guard Band Algorithm(AGBA). Coordinator and slave nodes are synchronized through AGBA scheme with time stamp. A guard Band(GB) is used between time slots which enables nodes to sleep for longer period of time. This GB is used to synchronize slave nodes with coordinator. The gaps due to GB between time slots are different in size, vary according to application. To avoid overlapping of GB between time slots Med MAC implements DAF scheme which adjust the GB according to application and practical situation. Proposed protocol perform better than IEEE 802.15.4 for Class 0 which is used for health monitoring at low data rate, medium data is class 1 which measure EEG signals. A guaranteed Time Slot(GTS) mechanism is introduced to avoid collision which play an important role to save energy. This protocol is not suitable for high data rate applications, it only perform well in low data rate applications. The applications of WBAN for in body and on body has high data rate.

1.6.3 Low Duty Cycle MAC Protocol

In [9] a MAC protocol is presented for WBANs. The slave node perform analog to digital conversion whereas master node perform complex operations like digital signal processing. To remove overlapping problem between continuous time slots, a Guard Time(Tg) scheme is proposed. A network control packet is utilized after every T frames for general information about network. A reliable TDMA scheme implementation reduces the energy expenditures. Low duty cycle protocol efficiently utilize energy because it sends short bursts of data. This Protocol also use TDMA mechanism to avoid collision. This protocol autonomously monitor patient with minimum energy consumption and send data to coordinator, it certainly minimize the burden on medical persons. WBAN is dynamic network and TDMA topology is not suited for such networks. TDMA only works good for static networks.

1.6.4 Ta-MAC Protocol

In this protocol, information of traffic encourges to attain communication with minimum energy utilization. This protocol presents two wakeup schemes: a wakeup radio mechanism and a traffic based wakeup mechanism. first mechanism make use of traffic patterns of nodes to facilitate normal traffic and the radio signal scheme is used for emergency data and on demand data. Traffic patterns are used in traffic based wakeup mechanism. The coordinator initiate traffic pattern at startup and can be changes after. A traffic based wakeup table is created where all nodes are organized with respect to their traffic patterns. Wakeup radio mechanism use a separate channel for controlling radio signals.

1.6.5 S-MAC Protocol

A MAC protocol for WBAN is proposed In [10]. The solution of idle listening is addressed in this protocol. It utilizes fix duty cycle. Coordinator assigned a wakeup time to all nodes, all nodes wakeup in its own time schedule, forward data and then switch back to sleep mode. The network is synchronized which helps to avoid collision. This protocol has a very low delay.

1.6.6 T-MAC Protocol

Mihai et al [11] proposed a Time-out MAC. Increased efficiency in energy is achieved with flexible duty cycle. The nodes wakeup in its allocated time slot and then send awaiting data packets. if the node found no activity, it switch back to sleep mode. if a slave node transmit a RTS signal and not received the CTS, it transmit two more RTS signals. The main drawback of this scheme is sleeping activity of nodes.

A key concern in WSN technology is to enhance the lifetime of network and to trim down the energy usage of the sensor network. Wireless sensors are dispersed typically in remote areas to examine earthquake, industrial environment,battle field, to monitor habitant [12], agriculture and land monitoring [13], and physical atmosphere conditions. Wireless Sensor get data from sensing field, gather information and transfer to BS through wireless link.

A Wireless Sensor Network has hundred or thousands of sensor nodes. A sensor node may have either a single sensor or multi sensors, a microcontroller, RF transceiver for communication and a battery source. Sensor unit takes related measurements from environment. This measured data is then converted into electrical signal and analogue to digital converter(ADC) transform this electrical signal into digital pulses. This digital data is then processed by the microcontroller. finally, RF transmitter transmit sensed data to sink node. A great number of protocols are available which forward scrutinize data to BS. Lifetime of network is more often than not important in monitoring of environment and other fields.

The escalating in Micro-Electro-Mechanical System technology, makes it possible to set up a network of millions sensors. The intense employment of wireless sensors makes it very thorny to restore sensor power sources. Therefore, a key subject for WSNs is to curtail energy expenditures of sensor nodes to prolong lifetime of network. Several protocols based on clustering topology [14], [15], [16], [17] [18], [19], [20], [21] are available and used in many applications. In these protocols, cluster heads collects data and then transfer to BS. The energy utilization in clustering based schemes is minimized by controlling the range of transmission. In this methodology, sensors are partitioned into undersized groups termed as clusters and every cluster has a master node called cluster head(CH). The CH manages the group communication with the BS. So, sensor nodes no longer directly communicate with BS, CHs receive the messages from all its group member, aggregates and then transfer to the BS.

As the entire nodes send their data to their corresponding CH, the CH deal out a Time Division Multiple Access (TDMA) schedule for each its member nodes to avoid collision. Each member node sends its data to CH only in defined allocated time slot so, sensor node turns off its transceiver otherwise. This saves energy of sensor nodes and they stay active for long period of time. As a rule each associated node transfer its data to nearby CH therefore; minimum energy utilization is require for node to transfer its data. CHs perform necessary processing on collected data and filter out the redundant bits, it reduce the amount of data that needs to be forward to the BS. Consequently, transmission energy consumption reduces to a significant amount. In this research work, we design a gateway based energy aware multi-hop routing protocol.

The impulse behind this research effort is to trim down the utilization of energy of sensor nodes by logically dividing the network into four regions. We use different communication hierarchy in different regions. One region communes direct to BS and one region communicates directly to gateway node. Other two use clustering hierarchy and nodes transfer their sensed data to gateway node through their CHs. Gateway node assists in defining clusters and creates a TDMA schedule for CHs. Each CH assigns its own TDMA schedule for its slave nodes.

WSNs are used to monitor certain parameters in many applications like environment monitoring, habitant monitoring, [12], [22] battle field, agriculture field monitoring and smart homes. These wireless sensors are dispersed in sensing area to monitor field. Wireless body area network (WBAN) is new promising sub-field of WSN. A key application of WBAN is health-care services [23]. Body sensors are implanted in the body or positioned on the body of the patient. These sensors monitor blood pressure, body temperature, pulse rate, glucose level et cetera [24], [25], [26]. Use of WBAN technology to monitor health parameter significantly reduce the expenditure of patient in hospital. Patient can be monitored at home for longer period. Sensors continuously sense data and forward to medical server.

The rapid growth in population of developed countries bring major challenges for health-care authorities and government. To counter health challenges and to provide patient monitoring at remote area, wireless technology provide cost effective, reliable and fast services to patient. Wireless Body Area Network (WABN) is new emerging technology which provide potentially great health care services. It provides easy diagnostic monitoring [27]. In WBAN, sensor nodes are operated with energy source constraints. It is required to use minimum power for transmitting data from sensor node to sink. Minimum energy utilization of energy source can preserve the battery life over longer period because recharging of batteries in WBAN is infrequent. One of the major obstacle in WBAN is to recharge the batteries. An efficient routing protocol is required to overcome this issue of recharging batteries. WSNs have many routing protocols [28], [29], [30], [31] which efficiently utilizes energy. However, WSNs and WBANs have different architectures, applications and operate in different conditions. It is impossible to port WSN routing protocol to WBAN. So, energy efficient routing protocol for WBAN is required to monitor a patient for longer period of time.

Our contribution is that we propose a high throughput, reliable and stable routing protocol for patient monitoring. We deploy sensor nodes on the body at fixed places. Sink is paced at waist. Sensors for ECG and glucose level are placed near the sink. Both these sensors have critical data of patient and required less attenuation, high reliability and long life so they always send their data directly to sink. Other sensors follow their parent node and transfer data to sink through multi hop. It saves energy of nodes and network work for longer time.

Chapter 2

Related Work

2.1 Related Work

Energy utilization and lifetime of network are the most important features in the field of the WSN. This study present clustering based routing for WSNs. A large number of the clustering protocols are homogeneous, for example LEACH [32],[12], PEGASIS [33], and HEED [34],ACH [35],[36]. As CHs collect data from its member or slave node, aggregates and than forward to faraway located BS, this process overload the CH and it consumes lot of energy.In LEACH, the CHs are selected periodically and consume uniform energy by selecting a new CH in each round. A node become CH in current round on the basis of a probability p . LEACH performs well in homogenous network but it performs shoddily in heterogeneous networks as shown by [37].
author in. [38] presents another clustering protocol(TL-LEACH). TL-LEACH describes a two level clustering scheme which perform well in terms of minimum energy consumption of network. There are two levels of CHs, level one luster heads connect with their corresponding member sensor nodes. CHs at second level create clusters from CHs of level one. TL-LEACH scheme is potentially more dispense therefore; the load of the network on the sensors is well shared out which results in long lived sensor network.
PEGASIS arrange nodes to form a chain, in chain formation process each node compute to connect with next node or BS assist nodes to form chain. The chain formation process require global knowledge of sensor nodes hence, it is very hard to work with this topology.
Another clustering based protocol is HEED in which CHs are selected on the base of a probability. The probability value of a node to become CH is related to the remaining energy of sensor. In HEED, it is possible that the nodes having less

residual energy acquire large probability value to elect as cluster head.
SEP protocol is designed for heterogeneous nodes and are two level of heterogenous nodes. Nodes in SEP are heterogenous in terms of their initial installed energy,normal nodes and advance nodes. The probability to become CH depend on the initial energy of the node. Performance of SEP in multi level Heterogeneous networks is.

An Energy Efficient Unequal Clustering (EEUC) protocol is presented which makes an effort to equalize the network energy utilization. EEUC divides the network field into unequal clusters. In EEUC, there are some nodes in network that are not associated with cluster, hence these nodes are cut down from the network. J. Kulik et al. [39] proposed Sensor Protocols for Information via negotiation(SPIN). In SPIN, when a node sense data, it advertise information about sensed data to its neighbors. A neighboring node which is interested in data will send a request to originating node. This makes the entire nodes in the network to acquire this data. The drawback of this approach is that, there is no guarantee that data will deliver to each node because if a sensor is interested in data from distant source node then data may not deliver to interested node. This protocol is not suited for applications where reliable data delivery priority is on top.

In WBAN technology, a great number of routing schemes were proposed. In this section, we present some proposed routing protocols. In [40] the author present a thermal aware routing protocol. each node select a minimum hop rout to sink. When a parent node gets heated, the children node select another optimal route. Latre *et al.* proposed a CICADA routing protocol which employ spanning tree structure [41]. CICADA use Time Division Multiple Access (TDMA) protocol to schedule transmission of nodes. The nodes near the root act as forwarder nodes or parent nodes, they collect data from their associated children and relay to sink. Due to this extra load on parent nodes, they deplete their energy fast.

In [42]. Quwaider *et al.* presents a routing protocol which tolerate to changes in network. They use store and forward mechanism to increase the likelihood of a data packet to reach successfully to sink node. Each sensor is facilitated with buffers to store a data packet. In source to destination route, each node store data packet and transmit to next node. storing a data packet and than retransmitting causes more energy to consume and longer end to end delay.

Ehyaie *et al* [43] proposed a solution to this problem. They deploy some non-sensing, dedicated nodes with additional energy source. while this technique enhance the network lifetime, however, additional hardware required which increase the cost of the network.

A clustering based protocol Anybody [44] is proposed. Feature of this protocol is to restrict the sensor nodes to transmit direct to sink. It improves the efficiency of network by changing the selection criteria of cluster heads.

In [45] Nabi *et al.* proposed a protocol similar to store and forward mechanism. They integrate this store and forward scheme with Transmit Power Adaption(TPA). To control transmission power consumption, all nodes get aware of their neighbours. Node transmit with minimum power with a stable link quality. A similar method was proposed by Guo *et al.* [46]. They also used Transmission power Control (TPC) scheme as Nabi *et al* proposed before. When a link quality of a node decreased, an Automatic Repeat request(ARR) is transmitted and retransmit the drop packer. Retransmission of lost packet increased the throughput of the network with the expense of energy consumption.

Tsouri *et al.* [47] [48] use creeping waves to relay data packet. They proposed this protocol to minize energy consumption of nodes while keeping the reliable on body link. In [49] a delay tolerant protocol was proposed. They compare their protocol with different existing protocols.

Chapter 3

M-GEAR: Gateway-Based Energy-Aware Multi-Hop Routing Protocol

3.1 Motivation

Due to the fact that clustering protocols consume less energy, these protocols for WSNs have gained extensive acceptance in many applications. Many on hand WSN protocols use cluster based scheme at manifold levels to minimize energy expenditures. CH in most cluster based protocol is selected based on a probability. It is not obvious that CHs are distributed uniformly throughout the sensor field. Therefore, it is fairly possible that the selected CHs will be concentrate in one region of the network. Hence, a number of sensor will not find any CHs in their environs. Similarly some protocols used unequal clustering and try to use recourses proficiently on condition that multi-hop routing.
Multiple level clustering hierarchy has following major drawbacks.

- In multiple level schemes, one CH forward data to other CHs which relay data to BS. If relay CH is far away than it is necessary for forwarder CHs to transmit with a bit higher power level.
- In clustering protocols, a member node decides itself whether to a CH or not. It is possible that some distant nodes are selected as CHs. Therefore, these nodes consume lot of energy to forward data to BS hence, they will die early

In this article, our goal is to design a gateway based energy aware multi hop routing protocol. This approach meets the following points.

- Network is divided into regions and aid of gateway node reduces the average transmission distance. Hence, it saves network energy and prolong network lifetime.
- As network is divided into four logical regions, CH selection in each region independent of other regions so there is definitely a CH exist in each region.

3.2 Network Model

In this article we assume S sensors which are employed randomly in a uniform manner over an immense field to incessantly monitor environment. We represent the *i-th* sensor by s_i and consequent sensor node set S= s_1, s_2,. s_n .We assume the following network model.

- we deploy the BS out of the sensing field. After deployment both the sensor and the BS stay stationary.
- A gateway is deployed in the same network field at the centre of the network.
- Gateway node is stationary after deployment and rechargeable.
- we use homogeneous sensor nodes with same computational and sensing capabilities.
- Each sensor has a distinctive identifier (ID).

we use first order radio model as used in [32], and [50], for energy model of sensor nodes. This model represents the energy dissipation of sensor nodes for transmitting, receiving and aggregating data. The transmitter dissipates more energy then receiver as it requires energy for the transmitter electronics and amplifier. on the other hand, in receiver only electronic circuit dissipate energy, as shown in Figure 3.1.

The energy required to transmit a data packet of k bits to a distance d and to receive a data packet of k bits the radio consume, respectively, the following energies:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$

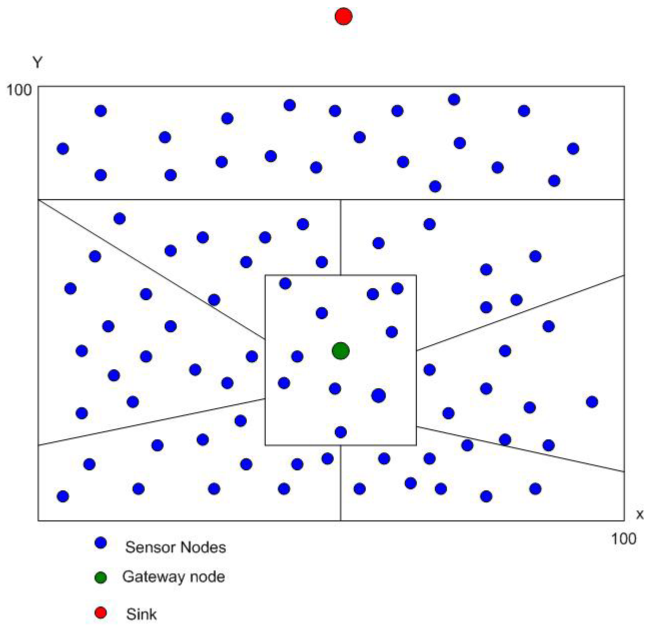

Figure 3.1: *Network Model*

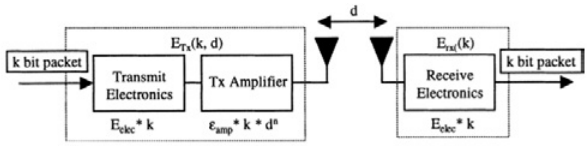

Figure 3.2: *Radio Model*

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2 \tag{3.1}$$

$$E_{Rx}(k) = E_{Rx-elec}(k) E_{Rx}(k) = E_{elec} \times k$$

$$E_{Rx}(k) = E_{elec} \times k \tag{3.2}$$

The energy values used are shown in table below.

Table 3.1: *Network parameter*

Parameter	**Value**
Eo	0.5j
E*elec*	5nJ/bit
E*fs*	10pJ/bit/m2
E*mp*	0.0013 pJ/bit/m4
Eda	5pJ/ bit
Packet size	4000 bits

3.3 The M-GEAR Protocol

In this section, we describe the detail of our proposed protocol. Nodes in sensor networks have too much sensed data for base station to process. Therefore, an automatic method of grouping data into a small set of momentous information is required [51], [52]. The process of Data grouping is termed as data fusion. In order to enhance the lifetime of network and throughput, we deploy a gateway node in the the middle of the network field. Function of gate way node is to collect data from CHs and from nodes near gateway, aggregation and sending to base station. Our results ensure that network lifetime and energy consumption improved with the expense of adding gateway node. We add rechargeable gateway node because it is on ground fact that the recharging of gateway way node is much cheaper than the price of sensor node.

3.3.1 Initial Phase

In M-GEAR, we use homogenous sensor nodes that are Dispersed randomly in network area. After employment of nodes, every node forwards its location to the BS. The BS calculates the distance of each node and save all information of the sensor nodes into the node data table. The node data table consists of distinctive node ID, Residual energy of node, and its distance to the BS and gateway node.

3.3.2 Setup Phase

In this segment, we divide the network field into logical regions on the basis of node's distance from gateway node and BS. BS divides the nodes into four different logical regions. Nodes in region-one use direct communication and send their data directly to BS as the distance of these nodes from BS is very short. Similarly nodes near gateway form region-two and send their data directly to gateway. Gateway node aggregates data and forward to BS. These two regions are referred to as non clustered regions. All the nodes away from the gate way node and base station are divided into two equal half regions based on their distance from gateway node, we call them clustered regions. Sensor nodes in each clustered region organize themselves into small groups known as clusters.

3.3.3 Cluster Head Selection

Initially BS broadcast a Hello packet and all sensor node forward its location, id an energy information to BS. The BS than transmit another packet which tells the node about their belonging region. After receiving this message, node knows their region information. Nodes near BS connect themselves with BS, similarly nodes near gateway connect themselves with gateway. Other nodes are divided in two regions and use clustering topology. CHs are elected in each region separately.Let r_i represent the number of rounds to be a CH for the node S $_i$, we call it epoch. each node elect itself as a CH once every r $_i$ = 1/p rounds. At the start of first round all node in both regions has equal energy level and has equal chance to become CH. After that CH is selected on the basis of the remaining energy of sensor node and with a probability p alike LEACH. in each round, it is required to have n x p CHs. A node can become CH only once in a epoch and the nodes not elected as CH in the current round feel right to the set C. The probability of a node to (belongs to set C) elect as CH increases in each round. It is required to uphold balanced number of CHs. At the start of each round, a node S_i belongs to set C autonomously choose a random number between 0 to 1. If the generated random number for node S_i is less than a predefined threshold T(s) value then the node is becomes CH in the current round.
The threshold value can be found as:

$$T(S) = \begin{cases} \frac{p}{1-p\times(rmod(1/p))} & \text{if } s \in C \\ 0 & otherwise \end{cases} \tag{3.3}$$

where P = the desired percentage of CHs and r = the current round, C = set of nodes not elected as CH in current round. After electing CHs in each region, CHs inform their role to neighbor nodes. CHs broadcast a control packet using a CSMA MAC protocol. Upon received control packet from CH each node transmit acknowledge packet. Nodes finds near CH, becomes member of that CH.

3.3.4 Scheduling

when some nodes are elected as cluster heads and other nodes become member of their corresponding cluster head, member node starts communication with CHs. CHs assign a time schedule to its member node. All the associated nodes transfer data to CH in its own scheduled time slot. Otherwise they are in idle mode. Node turn on only at times its transmission time, hence, it save certain amount of energy of individual sensor.

3.3.5 Steady-State Phase

In steady state phase, all sensor node transmits its sensed data during its time slot to CH. The CH collects data from member nodes, aggregates and forward to gateway node. Gateway node receives data from CHs, aggregates and forward to BS.

3.4 Performance Evaluation

We assess the performance of our proposed protocol and compare it with existing protocol in WSN, known as LEACH.

3.4.1 Simulation Setting

In order to appraise the performance of our proposed protocol, we simulated our protocol using MATLAB. We consider a wireless sensor network with N = 100 nodes distributed randomly in 100m X 100m field. A gateway node is deployed in the centre of the sensing field. The BS is located far away from the sensing field. Both gateway node and BS are stationary after deployment. We consider packet size of 4000 bits. We compare our protocol with LEACH protocol. To assess performance of our protocol with LEACH, we ignore the effects caused by signal collision and interference in the wireless channel. Table 1 shows the radio parameters used in our simulation.

3.4.2 Performance Parameters

3.4.2.1 Network lifetime

It is the time interval from the start of the network operation till the last node die.

3.4.2.2 Throughput

To evaluate the performance of throughput, the numbers of packets received by BS are compared with the number of packets sent by the nodes in each round.

3.4.2.3 Residual Energy

The residual battery energy of network is considered in order to analyze the energy consumption of nodes in each round. Residual energy ensures graceful degradation of network life.

3.4.3 Simulation Results and Analysis

3.4.4 Network Lifetime

In figure 3.3 we show the results of the network life time. Nodes are considered dead after consuming 0.5 joule energy. Our protocol obtains the longest network life time. This is because the energy consumption is well distributed among nodes. Network is divided into logical regions and two of them are further sub divided into clusters. we select the numbers of CHs in each region based on the density of the nodes in that region hence it better balance the load on CHs. On the other hand, in LEACH nodes dies quickly as stability period of network over. It is not evident that predestined CHs in LEACH are distributed uniformly throughout the network field. Therefore, there is a possibility that the selected CHs will be concentrated in one region of the network. Hence, some nodes will not have any CHs in their environs. Figure 3 shows interval plot of our proposed G-GEAR protocol and LEACH with 99% confidence interval. we note that, the results of G-GEAR protocol are statically different and perform well.

3.4.5 Throughput

Average packets sent to BS are assessed through extensive simulations. Our results have shown that network throughput is increased. Interval plots of M-GEAR and LEACH in figure 3.4 clearly depicts performance of both protocol. To calculate throughput, we assumed that CHs can communicate freely with gateway node. Our simulation results show an increase throughput of 5 times then LEACH.

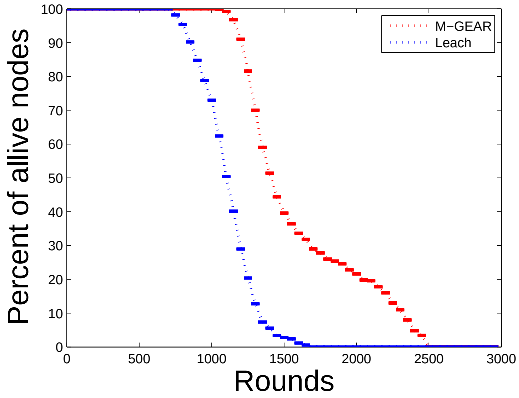

Figure 3.3: *Interval plot- Analysis of network lifetime*

Sensor nodes near gateway send their data directly to gateway; similarly nodes near BS transmit data directly to BS. Sensor nodes in both regions consume less transmission energy hence stay alive longer. More alive nodes contribute to send more sensed data to BS directly or through gateway. Hence, increased packets transfer to BS.

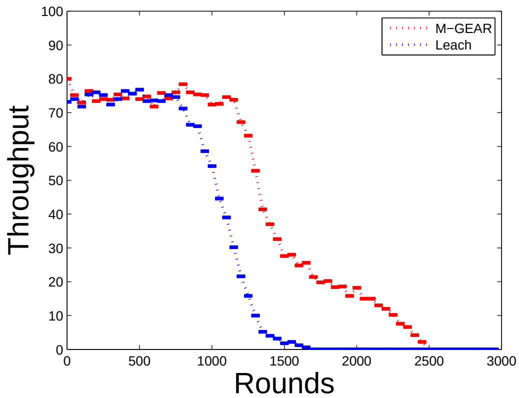

Figure 3.4: *Interval plot- Analysis of Throughput*

3.4.6 Residual Energy

Figure 3.5 shows average residual energy of network per round. We assume that a node has 0.5 joule energy so total energy of 100 node network is 50 joule. Our protocol yields minimum energy consumption then LEACH. Figure 3.5 clearly depicts that our protocol outperforms LEACH routing protocol in terms of energy consumption per round. Deployment of gateway node at the centre and high probability of CHs in all regions causes less energy to be consumed by sensor node. interval plots for statistical results of M-GEAR and LEACH shown in figure 3.5.

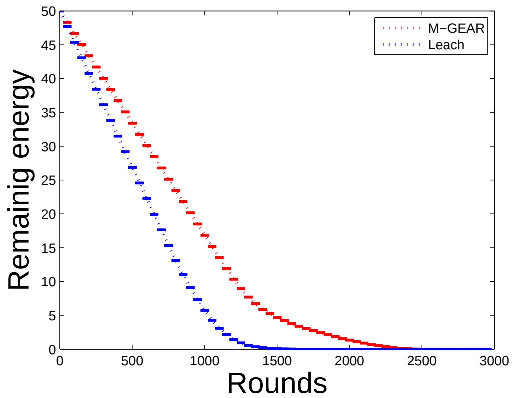

Figure 3.5: *Interval plot- Analysis of remaining energy*

Chapter 4

SIMPLE: Stable Increased Throughput Multihop Link Efficient Protocol For WBAN

4.1 Motivation

Wireless body area sensors are used to monitor human health with energy constraints. Different energy efficient routing schemes are used to forward data from body sensors to medical server. It is important that sensed data of patient reliably forward to medical specialist or server for further analysis. In [53] author present a opportunistic protocol. Proposed scheme facilitate mobility at cost of low throughput and additional cost of relay node. Whenever sink node goes away from transmission range of nodes, it uses a relay node which is used to collect data from sensor nodes. They deploy sink at wrist. As hands are used frequently, sink is mobile most of the time and keep away from the sensors for longer time. It will consume more power of sensor nodes and relay node. Due to the mobility of the sink on hands, more packets will drop, that causes important and critical data to loss. High throughput with limited energy source is one of the key issue in WBANs. To increase the throughput and reliable communication between sensors and sink, we propose a new scheme. Main advantages of our Proposed protocol are as follow.

- our proposed scheme achieve a longer stability time. Nodes stay alive for longer period and consumes less energy.
- The large stability period and less energy consumption of nodes, contribute

to a high throughput.

4.2 Mathematical Model for WBANs

4.2.1 Energy Consumption Model

In this topology design, we consider a WBAN scenario in which eight sensor nodes are placed on the human body as shown in fig 1 on next page. The placement of nodes is pre-determined and fixed. Let N is the set of nodes, f is the forwarder node and sink S. Ci is the capacity of the wireless link. The data generated by sensor is denoted by d_{is}, which is routed to sink by sensor node i. According to the position of the sensors and sink on the body, we define the following connectivity parameters,

$$A_{if} = \begin{cases} 1 & \text{if i establishes a link with f} \\ 0 & otherwise \end{cases} \tag{4.1}$$

$$A_{fs} = \begin{cases} 1 & \text{if f establishes a link with S} \\ 0 & otherwise \end{cases} \tag{4.2}$$

A_{if} represents the connectivity between i and f. similarly A_{fs} is the connectivity between f and S. F^{s}_{if} is the traffic flow between node $_i$ and forwarder. F^{t}_{fs} is the total traffic flow routed between forwarder node and sink. We use minimum energy consumption model presented in [54].

$$min \sum_{i \in N} E_t = \sum_{i \in N} E_i + E_f \tag{4.3}$$

where

$$\sum_{i\in N} E_i(Tx) = \sum_{i\in N} d_{if}A_{if}(ETX_{elec} + E_{amp} \times n \times D^n)$$
$$\sum_{i\in N} E_i(Rx) = \sum_{f\in N} d_{if}A_{if}(ERX_{elec})$$
$$\sum_{f\in N} E_f(Tx) = \sum_{f\in N} F^t_{fs}(ETX_{elec} + E_{amp} \times n \times D^n + Eda)$$
$$\sum_{f\in N} E_f(Rx) = \sum_{f\in N} d_{if}A_{if}(ERX_{elec})$$

subject to:

$$\sum_{i\in N} d_{is}A_{if}(E_{TX-elec} + E_{amp} \times n \times D^n) \leq E \tag{4.3a}$$
$$\sum_{i\in N} F^t_{is} \leq C_i \tag{4.3b}$$
$$\sum_{i\in N} F^s_{if} - \sum_{f\in N} F^t_{fs} = 0 \tag{4.3c}$$
$$A_{if} = 1 \quad \forall i \in N \tag{4.3d}$$
$$A_{fs} = 1 \quad f \in N \tag{4.3e}$$
$$F^t_{fs} \leq d_{is}A_{fs} \tag{4.3f}$$
$$A_{if}, A_{fs} \in [0, 1] \qquad i, f \in N \tag{4.3g}$$

The objective function in (4.3) represents the total energy consumption of network. We aim to minimize the total energy consumption (E_t) of network. Objective function (4.3) shows the energy consumed by sensor nodes (E_s) to transmit data to f and total energy consumed by the forwarder node (E_f) to transmit and receive data packets. F^t_{fs} and E_{da} are the flow variable and data aggregation energy parameters, respectively. Flow variable represents the total traffic flow between forwarder node and sink. Forwarder node collects data packets from sensor nodes, aggregates and transfers the to sink.

E in constraint (4.3a) is the available energy for each sensor node. It represents the energy capacity constraint on sensor nodes. All sensors have limited energy resources. Constraint (4.3b) is the capacity constraint on wireless link. Ci is the link capacity and the data routed on wireless link has not to exceed link capacity. Equation (4.3c) shows the flow balance constraint. Data flow from sensors to sink, however, the converse can not be true. Constraints (4.3d-4.3e) are coverage parameters. They ensure full coverage of the sensor network. If forwarder node is not connected with sink, then constraint (4.3f) ensures zero flow on the link between forwarder node and sink. Constraints in (4.3g) are the binary decision variables.

4.2.2 Throughput Maximization Model for WBAN

In this section, we present throughput maximization model for WBANs. The objective is to increase successful packet transfers to sink because continuous monitoring of patient is major concern in WBANs. The minimum energy consumption of sensor nodes is another issue with high throughput requirement. In our proposed protocol, the forwarder node collects data from its member nodes and forwards data to sink. A forwarder node with high data rate is required to maximize throughput. In this work, the parameter r_i represents current data rate. A sensor node stops transmission when its residual energy and data rate decreases below E_{min} and R_{min}, respectively. The physical link that carries data from node i to node j is represented by $L_{i,j}$ and the wireless channel capacity by C_i.

4.2.2.1 Problem Formulation

Let Z_i is a 0-1 integer which represents nodes with residual energy greater than E_{min} and E_i is the total available energy. If the residual energy of nodes decreases below E_{min}, the nodes stop sending data. We formulate maximum throughput problem. The optimization model for maximum throughput is given as follows

$$max \sum_{i \in N} d_{is}^{t} \tag{4.4}$$

subject to:

$$\sum_{(j)\in N} y_{ij} = 0 \quad \forall i \in S \tag{4.4a}$$

$$E_i \geq E_{min} \tag{4.4b}$$

$$y_{ij} \leq L_{ij} \quad \forall i,j \in N \tag{4.4c}$$

$$\sum_{i,j} \in N y_{ij} \leq C_i \quad \forall i,j \in N \tag{4.4d}$$

$$Z_i \geq r_i \quad \forall i \in N \tag{4.4e}$$

$$\sum_{(i,j)\in N} y_{ij} - \sum_{(i,j)\in E} y_{ji} = 0 \tag{4.4f}$$

$$A_{if} = 1 \quad \forall i,f \in N \tag{4.4g}$$

$$A_{fs} = 1 \quad f \in N \tag{4.4h}$$

$$A_{if}, A_{fs} \in [0,1] \quad i,f \in N \tag{4.4i}$$

The objective function in (4.4) represents the successful data transfer from node i to sink. we are aiming to maximize throughput of network.
The constraint (4.4a) presents that, there is no uplink traffic after the sink in the network. The constraint (4.4b) represents that if the residual energy of a node decreases below minimum residual energy level E_{min}, the node is considered offline and it stops forwarding data to sink. The constraint (4.4c) shows that the amount of data transfer on any link is bounded by physical link capacity [**?**]. Similarly, constraint (4.4d) provides upper bound on the nodes, and it ensures that the traffic flow in the network is always less than the channel capacity. Constraints (4.4e) ensures that data rate is assigned to nodes with residual energy equal to or greater than E_{min}. Constraint (4.4f) is the flow conservation on the outgoing and incoming data of node i. Since all data flows are originated from nodes and do not return to the nodes. All data flows will eventually reach the sink. Constraints (4.4g-4.4h) are the link parameters. In order to achieve high throughput, all nodes must have good communication link. Finally, constraint (4.4i) is the binary decision value.

4.3 Radio Model

A great number of radio models are presented in literature. We use first order radio model as proposed in [32]. This radio model consider d the separation between transmitter and receiver and d^2 loss of energy due to transmission channel. First

Parameters	nRF 2401A	CC2420	Units
DC Current(Tx)	10.5	17.4	mA
DC Current(Rx)	18	19.7	mA
Supply Voltage(min)	1.9	2.1	V
$E_{tx-elec}$	16.7	96.9	nJ/bit
$E_{rx-elec}$	36.1	172.8	nJ/bit
E_{amp}	1.97e-9	2.71e-7	j/b

Table 4.1: *Radio Parameters*

order radio model equations are given as.

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + E_{Tx-amp}(k,d)$$

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times k \times d^2 \tag{4.5}$$

$$E_{Rx}(k) = E_{Rx-elec}(k)E_{Rx}(k) = E_{elec} \times k$$

$$E_{Rx}(k) = E_{elec} \times k \tag{4.6}$$

where E_{tx} is the energy consumed in transmission, E_{rx} is the energy consumed by receiver, $E_{tx-elec}$ and $E_{rx-elec}$ is the energy required to run the electronic circuit of transmitter and receiver respectively, E_{amp} is the energy required for amplifier circuit and k is the packet size.
In WBAN, the communication medium is human body which contributes attenuation to radio signal. so we add path loss coefficient(n) parameter in radio model.so above equation of transmitter can be rewritten as.

$$E_{Tx}(k,d) = E_{elec} \times k + E_{amp} \times n \times k \times d^n \tag{4.7}$$

The energy parameters given in above equation depends on the hardware. we consider 2 transceivers used frequently in WBAN. The Nordic nRF 2401A is a single chip, low power transceiver and other transceiver is Chipcon CC2420. The bandwidth of both transceiver is 2.4GHz. We use the energy parameter of The Nordic nRF 2401A transceiver because it consumes less power. The energy parameter for this transceiver is given in Table 1.

4.4 System Model

In this scheme, we deploy eight sensor nodes on human body. All sensor nodes has equal power and computation capabilities. Sink node is placed in centre at waist. Node 1 is ECG sensor node and node 2 is Glucose sensor node. These two nodes transmit data direct to sink. Figure 4.1 shows the placement of nodes and sink on the human body.

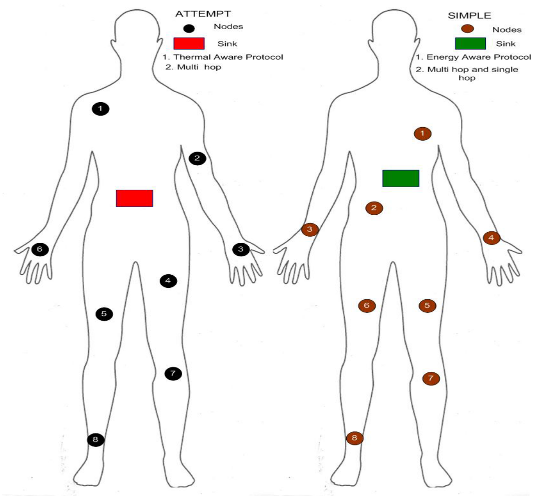

Figure 4.1: *Node deployment*

4.5 Protocol detail

In this section, we present a novel routing protocol for WBANs. The limited number of nodes in WBANs gives opportunity to relax constraints in routing protocols. keeping routing constrains in mind, we improve the network stability period and throughput of the network. Next subsections gives the detail of the protocol.

4.5.1 Initial Phase

In this phase, sink broadcast a short information packet which contains the location of the sink on the body. After receiving this packet, Each sensor node stores the location of sink. After that each sensor node broadcast a information packet which is a short message only contains node ID, its location and its energy status. In this way, all sensor nodes are updated with the location of its neighbours and sink.

4.5.2 Selection of Forwarder

In order to save energy and to enhance network throughput, we proposed a multi hop scheme for WBAN. In this section, we present selection criteria for a node to become next hop or forwarder. To weighing scale energy expenditure among nodes and to trim down energy consumption of network, we elect a new forwarder in each round. Sink node knows the ID, distance and residual energy status of the nodes. Sink computes the cost function of all the node and transmit this cost function to all nodes. On the basis of this cost function each node decides whether to become forwarder node or not. If i is number of nodes than Cost function of i nodes is computed as follows:

$$(C.F)_i = \frac{d_i}{(R.E)_i} \tag{4.8}$$

Where
d is the distance between the node and sink,
R.E is the residual energy of node and is
calculated by subtracting the current energy of node from initial total energy.
A bare minimum cost function node is preferred as a forwarder. All the neighbor nodes stick together with forwarder node and transmit its data to forwarder. Forwarder node aggregates data and send to sink. As forwarder has maximum residual energy and less distance to sink, hence, forwarder node consumes less energy to forward its children nodes data to sink. Two nodes for ECG and glucose monitoring can not be elected as forwarder because these two nodes has critical vital data. Both the nodes are placed near the sink and forward their data packet direct to sink.

4.5.3 Scheduling

when all the sensor nodes finds a forwarder or parent node, each forwarder node assigns a Time Division Multiple Access (TDMA) based time slots to its children nodes. All the children nodes transmit their sensed data to forwarder node in its own scheduled time slot. when a node has no data to send, it switches to idle mode. Nodes wakes up only at its transmission time, hence energy dissipation of individual sensor decreased.

4.6 Performance Metrics

4.6.0.1 Network Lifetime

It represents the total network operation time till the last node die.

4.6.0.2 Stability Period

Stability period is the time span of network operation till the first node die. After the death of first node, the time period till the network operate is termed as unstable period.

4.6.0.3 Throughput

Throughput is the total number of packets successfully received at sink.

4.6.0.4 Residual Energy

In order to investigate the energy consumption of nodes per round, we consider residual energy parameter to analyze energy consumption of network.

4.6.0.5 Path Loss

Path loss is the difference between the transmitted power of transmitting node and received power at receiving node. It is measured in decibels(dB).

4.7 Simulation Results and Analysis

4.7.1 Network Lifetime

Figure 4.2 shows the average network lifetime of proposed scheme. The proposed new cost function to elect forwarder node plays an important role to balance the energy consumption among the sensor nodes. A new forwarder node is selected in each round based on its computed cost function. Figure 1 clearly depicts that the proposed protocol has longer stability period. This is expected, due to the appropriate selection of new forwarder in each round. Hence, each node consumes almost equal energy in each round and all the nodes die almost equal time. In M-ATTEMPT, as temperature of forwarder nodes increases, nodes selects alternate longer path which consumes more energy. hence, these nodes die early.Our proposed protocol achieve 31% more stability period and .4% longer network lifetime.

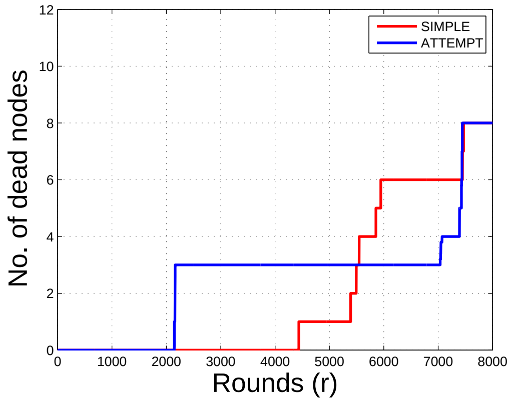

Figure 4.2: *Analysis of network lifetime*

4.7.2 Throughput

Throughput is the successful packet received at the sink. As WBAN has critical and important data of patient, so it requires a protocol which has less packet drop and maximum successful data received at sink. Our proposed protocol achieve high throughput than M-ATTEMPT, as shown in figure 4.3. Number of packets send to sink depends on the number of alive nodes. More alive nodes send more packets to sink which increases the throughput of network. The stability period of M-ATTEMPT is shorter than our proposed protocol which means number of packets sent to sink decreased, hence, throughput of M-ATTEMPT decreased. On the hand, our proposed protocol achieve high throughput due to longer stability period.

The figure 4.4 shows the number of total packets send to sink and figure 4.5 shows the number of packets dropped.

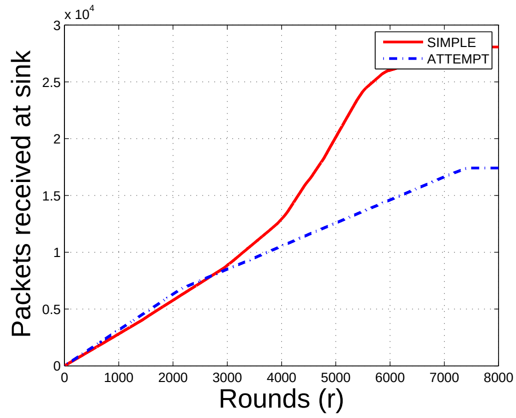

Figure 4.3: *Analysis of Throughput*

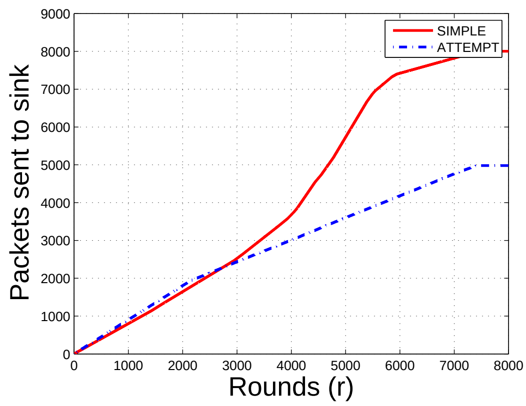

Figure 4.4: *Interval plot- Analysis of Throughput*

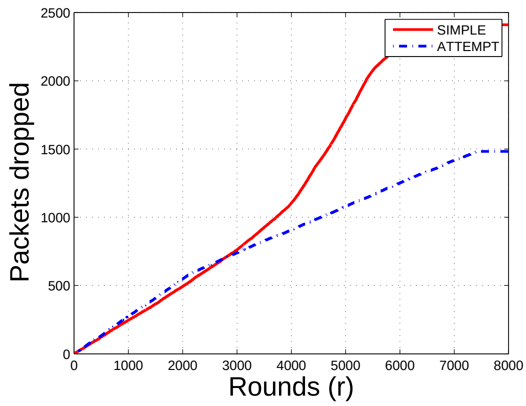

Figure 4.5: *Interval plot- Analysis of Throughput*

4.7.3 Residual Energy

The average energy of network consumed in each round is presented in figure 3. The proposed model use multi hop topology, in which each farthest node transmits its data to sink through a forwarder node. forwarder node is elected using aforementioned cost function, we elect new forwarder node in each round. Selection of appropriate forwarder in each round contributes to save energy. To transfer packets to sink, our multi hop topology use different forwarder node in each round, this restricts over loading of particular node. Simulation results shows that our protocol consumes less energy till 70% of simulation time. it means, in stability period, more nodes have enough energy and they transmit more data packet to sink. Hence, it also improves the throughput of the network. on the other hand, in M-ATTEMPT, some nodes exhaust early due to heavy traffic load.

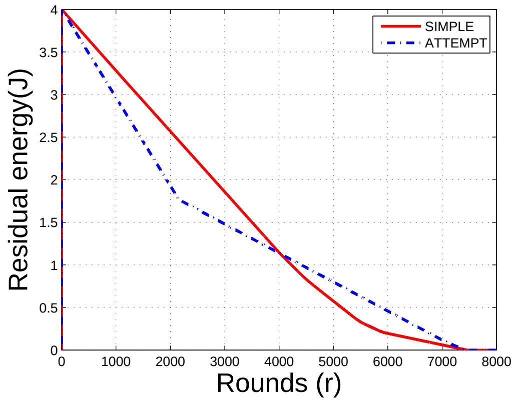

Figure 4.6: *Analysis of remaining energy*

4.7.4 Path Loss

Figure 4 presents the path loss of different sensors. path loss is a function of frequency and distance. Path loss shown in figure 4 is a function of distance. Path loss of each sensor is calculated from its distance to sink with constant frequency 2.4GHz. We use path loss coefficient 3.38 and 4.1 for standard deviation (). Proposed multi hop topology reduces the path loss as shown in figure 5. It is due to the fact that multi hop transmission reduces the distance, hence, minimum path loss. Figure 4 represents the results of both topology, initially our proposed protocol perform well. However, after 2000 rounds, path loss of M-ATTEMPT dramatically decreased because some nodes of M-ATTEMPT topology dies. Less number of alive nodes has less cumulative path loss. As our proposed protocol has longer stability period and more alive nodes has more cumulative path loss.

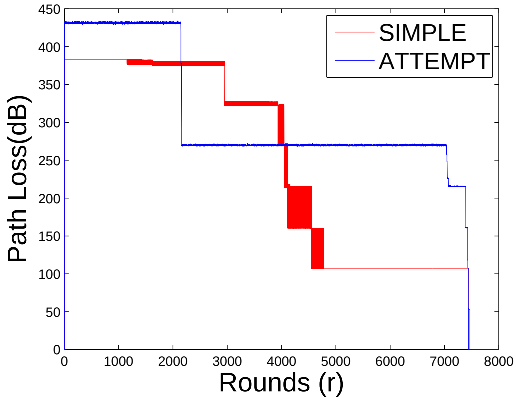

Figure 4.7: *network path loss*

4.7.5 Path Loss Model

Path loss represents the signal attenuation and is measured in decibels (dB). Path loss is the difference between the transmitted power and received power where antenna gain may or may not be considered. Path loss occurs due to the increasing surface area of propagating wave front. Transmitting antenna radiates power outward and any object between transmitter and receiver causes destruction of radiated signal. In WBAN, different human postures, movement of body, hands and cloths, affects the transmitted signal. Path loss is related to the distance and frequency and expressed as.

$$PL(f,d) = PL(f) \times PL(d) \tag{4.9}$$

The relation of frequency with path loss is expressed as

$$\sqrt{PL(f)} \propto f^k \tag{4.10}$$

Where k is frequency dependent factor and it is related to the geometry of the body. The relation of distance with path loss is given as

$$PL(f,d) = PL_o + 10nlog_{10}\frac{d}{do} + X\sigma \tag{4.11}$$

Where , PL is received power at distance d, d is the distance between transmitter and receiver, do is the reference distance, n is the path loss coefficient and its value depends on the propagation environment. In free space its value is 2, for WBAN, n varies from 3-4 for line of sight (LOS) communication and 5-7.4 for non line of sight (NLOS) communication. X is a gaussian random variable and σ is standard deviation [55]. PL0 is received power at reference distance do and it is expressed as

$$PL_o = 10log_{10} \frac{(4\pi \times d \times f)^2}{c} \tag{4.12}$$

Where f is frequency, c speed of light and d is distance between transmitter and receiver. The value of reference distance do is 10cm. In reality it is difficult to predict strength of signal between transmitter and receiver boundary. To solve this issue, we use a deviation variable Xσ.

Chapter 5

Conclusion

We describe an energy efficient multi-hop routing protocol using gateway node to minimize energy consumption of sensor network. In this work we divided the network into logical regions. Each region use different communication hierarchy. Two regions use direct communication topology and two regions are further subdivided into clusters and use multi-hop communication hierarchy. Each node in a region elects itself as a CH independent of other region. This technique implies better distribution of CHs in the network. Simulation and result evaluation section shows that our proposed protocol performs well compared to LEACH.

In this thesis, we propose a mechanism to route data in WBANs. The proposed scheme use a cost function to select appropriate route to sink. Cost function is calculated based on the residual energy of node and its distance from sink. Nodes with less value of cost function are elected as parent node. Other nodes become the children of that parent node and forward their data to parent node. Two nodes for ECG and Glucose monitoring forward their data direct to sink as they are placed near sink, also these two nodes can not be elected as parent node because both sensor node has critical and important medical data. It is not required that these two node deplete their energy in forwarding data of other nodes. Our simulation results shows that proposed routing scheme enhance the network stability time and packet delivered to sink.

In future work, we aim to use ETX metrics to describe the link efficiency as demonstrated in [56], [57], [58].

Publications

Conference Proceedings

1. **Q.Nadeem**, N. Javaid, S.N.Muhammad, M.Y.Khan, S.Sarfraz ”SIMPLE: Stable Increased-throughput Multi-hop Protocol for Link Efficiency in Wireless Body Area Networks,” Accepted in eighth International Conference on Broadband and Wireless Computing, Communication and Applications (BWCCA-2013), Paris, France

2. **Q.Nadeem**, N. Javaid, Y.Maqsood, A.Din, Z.A.Khan, ”M-GEAR: Gateway-Based Energy-Aware Multi-Hop Routing Protocol for WSNs,” Accepted in eighth International Conference on Broadband and Wireless Computing, Communication and Applications (BWCCA- 2013), Paris, France.

3. B. Manzoor, N. Javaid, O. Rehman, M. Akbar, **Q. Nadeem**, A. Iqbal, M. Ishfaq, ”Q-LEACH: A New Routing Protocol for WSNs”, International Workshop on Body Area Sensor Networks (BASNet-2013) in conjunction with 4th International Conference on Ambient Systems, Networks and Technologies (ANT 2013), 2013, Halifax, Nova Scotia, Canada.

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