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Research paper

Towards Developing a MAC protocol for outer-WBAN communication for pilgrims' health monitoring during hajj: A feasibility study

Shah Murtaza Rashid Al. Masud [1] *, Asmidar Abu Bakar [2], Salman Yussof [2]

[1] College of Graduate Studies, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000, Kajang, Selangor, Malaysia
[2-]College of Computer Science and Information Technology, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000, Kajang, Selangor
**Corresponding author E-mail: smramasud@gmail.com*

Abstract

Due to lack of deployment of information and communication technology (ICT) for real-time pilgrims' health monitoring during Hajj, many pilgrims left untreated, get lost and suffer from severe health problems which sometimes end with injury, traum and even death. WBAN is an emergent healthcare technology and can be deployed at Hajj ritual sites for pilgrims' health monitoring. WBANs body co-ordinator or gateway as an aggregator collect data from body nodes or sensors, store them and then forward to the healthcare stations for analyzing the data through outer-WBAN communications. Currently, most of the existing research works focused on intra-WBAN communications while the technical issues, problems, opportunities and standard correlated to outer-WBAN are not well discussed and mentioned. Since, medium access control (MAC) protocol is responsible for channel access, lower delay, and energy efficient transmission of data packets. Therefore, designing of an efficient and reliable MAC protocol is the earnest research demand to alleviate the aforementioned obstacle. In this research, a feasibility study has been completed to identify the problem and a proposal has been made to develop a suitable MAC protocol for outer-WBAN communication for pilgrims' health monitoring during Hajj.

Keywords: *Energy Efficient; Hajj; Health Monitoring; MAC Protocol; Outer-WBAN Communication; Pilgrims*

1. Introduction

Every year during Hajj, the largest religious mass gathering, an amount of 2 to 3 million pilgrims from all around the world congregate in Haram at Makkah in Saudi Arabia, and the number of pilgrims is increasing every year at the rate of about 3.5 percent. During the Hajj period, the crowd density can increase to seven individual per m^2 which is an indicator of overcrowding and one of the leading causes of lost of pilgrims and injury. Moreover, during Hajj in Makkah, the high air temperature and comparatively low humidity fluctuate rapidly thus favour heat stroke, heat exhaustion along with the development of various communicable (infectious), chronic and non-communicable diseases. During pilgrimage, the pilgrims are obliged to spend their times at Masjid-ul-Haram with an area of 4.5 sq. Km. And which can hold 250,000 pilgrims at a time, at Mina with an area of 2.5 sq. Km., at Muzdalifa with an area of 6.8 sq. Km., and at Arafat with an area of 13.6 sq. km. Hajj is a dynamic system which implies continuous movement and travel in ritual sites. Hence, it is a vital issue and a big challenge to provide best healthcare facilities and services for pilgrims and their real-time monitoring during Hajj [1].

Since pilgrims' health monitoring during Hajj is a vital issue but there is a few efforts so far have been shown by the research community. Pilgrims' monitoring and tracking systems have been proposed by some researchers in [2-3], but these systems do not focus on pilgrims' healthcare issues.

Wireless body area networks (WBANs) are modern and prominent technology has been proposed by IEEE community for real-time health monitoring for patients. IEEE 802.15.6 TG6 or WBAN) or body sensor network (BSN) is a subset of wireless personal area network (WPAN) which was formed in November 2007 offered the quick monitoring and evolution in patients' medical and life critical data and thus providing proper healthcare services [4]. To fully exploit wireless technology for healthcare, telemedicine, and m-health, Van Dam et al. first introduced the concept of WBAN in 2001. Original motivation and advanced development of BSNs for healthcare were first demonstrated by Prof. Guang Zhong Yang of Imperial College in the early 2000s and then illustrated in his book 'body sensor networks' in 2006.

Data transmission from body sensors to a healthcare station or remote server is the main principal of WBAN system. However, other advantages what WBAN and associated suitable communication network can provide are the mobility and flexibility of patients due to use of transferable or portable monitoring devices and the location independent monitoring facility. By using modern ICT, a WBAN may connect itself to the Internet to transmit data and efficiently administer the proper delivery of healthcare services among the pilgrims during Hajj. Therefore, integration of the medical technology and ICT in the healthcare sector is a prominent research issue especially for WBAN. It is also significant that the coverage of a WBAN is limited to about 1 to 2 meter, in some cases 2 to 5 meter. Hence, to largely extend its coverage area it should interwork with other wireless networks which will facilitate connectivity between WBANs gateway or coordinator and the outside world.

WBAN consists of a number of tiny sensors and a coordinator. WBAN on body coordinator is responsible for data collection

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from sensor nodes, processing the data, storing the data, controlling the nodes and transmitting data to the access points (APs) or base stations. Upon receiving data APs forward them through the Internet to the medical stations for further investigations by the medical personnel. WBAN communication is mainly divided in to two types: intra-WBAN communication and outer-WBAN or inter-WBAN or extra-WBAN or beyond-WBAN communication. In intra-WBAN communication sensor nodes send the sensed data to the coordinator. In outer-WBAN communication a coordinators or gateway node sends the received data to the access points (APs) or sink node for further transferring to the medical stations or healthcare centres for analysis. In WBANs system, the APs are considered as part of the infrastructure. APs can be deployed strategically in a dynamic environment to handle emergency situations [5-7]. Though, IEEE 802.15.6 standard is so far concerned about intra-WBAN communication there is no standard available for outer-WBAN communication. But, it is important that time-critical WBAN data arrives at its destination quickly. To successfully transfer the medical data, a reliable wireless communication network is needed. Hajj itself is a dynamic system. Indeed, if patients monitoring and medical care can be performed wirelessly, the patient is no longer constrained in his movements thus reducing the mortality rate. It is notable that, the mortality rate during Hajj is higher due to certain non-communicable health hazards [1] [7-8].

One of the major challenges during Hajj is to monitor a large number of pilgrims' health conditions by enabling a complete wireless network from body sensor nodes to coordinator and from coordinator to healthcare stations with low power consumption, and collisions avoidance. Therefore, in this research a systematic literature review was performed on existing research studies to identify the obstacle surrounding outer-WBAN communication. Initial literature review discloses that, communication standards like ZigBee, Wi-Fi, Bluetooth are widely being used for outer-WBAN communication, where ZigBee is better among other standards due to its small-sized (low data rate and low distanced) data transmission and low power consumption. In addition, ZigBee is widely being used in hospital and residential based medical applications and lead to the severe collision problem due to concurrent transmissions of packets to one receiver via ZigBee and lower throughput. ZigBee is appropriate for short range data transmission and not suitable for the emergency applications where the network size is bigger in the sense of lots of nodes and heavy traffic. It has also been observed that, the energy efficient, collision avoidance data communication in wireless sensor network particularly WBAN applications are controlled by the data link layer (DLL) protocols which is medium access control (MAC) protocol. MAC protocol provides greater flexibility in optimizing and designing communication system. MAC protocols are applications sensitive and varied due to the requirements of applications. The main objective of this research paper is to monitor pilgrims' health during Hajj using WBAN. Therefore, we study the suitability of developing a MAC protocol for outer-WBAN communication in order to efficiently monitoring pilgrims' health in Hajj particular application. In our paper, we focus on the transmission system of medical data or healthcare information in outer-WBANs instead of the commonly argued intra-WBANs or inter-WBANs communications.

1.1. Problem description

Every year during Hajj, many pilgrims suffer from both communicable and non-communicable diseases along with some other emergency issues [1]. Monitoring pilgrims' health and providing healthcare facilities during Hajj is an important issue but, the matter has not been addressed, and there is no technology has been proposed by the research community [2-3]. Wireless body area network (WBAN) is an emerging technology for healthcare [4] enabling intra-WBAN and outer-WBAN communication [5-7] as presented in Figure 1.1 can be deployed for pilgrims' health monitoring during Hajj. But, due to the lack of a standard for reliable outer-WBAN communication (WBAN coordinator to the access points-APs), which is mainly application specific, it may difficult to deploy in Hajj particular application.

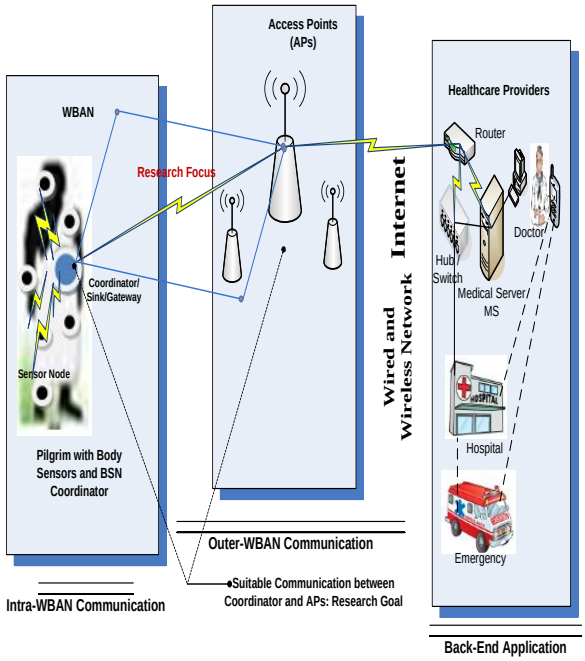


Fig. 1.1: Research Focus on Outer-WBAN Communication

Because of the specific requirements of real-time and distant healthcare services, the outer-WBAN communications cannot be realized merely by any prevailing wireless technology, such as ZigBee, Bluetooth, traditional cellular networks, or Wi-Fi and may not be directly implemented to outer-WBAN communications. The reason is that, in outer-WBANs, APs or gateways have much stronger computation, much higher storage capabilities than sensors and coordinators in intra-WBANs or inter-WBANs.

Initial literature review shows that, currently, ZigBee, Bluetooth, Wi-Fi are widely being used in hospital and residential based outer-WBAN communication. Theoretically Wi-Fi consumes 100mW-1000mW energy at the data rate 10Mbps-100Mbps, communication range is between 10-100 meters, network lifetime is few hours to 5 days. Bluetooth consumes 2.5mW-100mW energy at the data rate 1Mbps-10Mbps, communication range is between 1-10 meters, network lifetime is 1-7 days. ZigBee consumes 1mW-50mW energy at the data rate 100Kbps-250Kbps, communication range is between 10-100 meters, network lifetime is several days-several weeks. Bluetooth and Zigbee are suitable for low data rate applications which is merely acceptable for real-time and large scale networks applications. On contrary, Wi-Fi is suitable for high data rate applications but it consumes high energy which is not acceptable in medical applications. According to the study [10-12], ZigBee consumes low power and is suitable for low data rate, low distanced communication thus found the most useful technology as compare to Wi-Fi, and Bluetooth. Moreover, it has also been observed that ZigBee does not support perfectly at random and dynamically deployment of network topology thus it is evident not to deploy ZigBee for emergency applications or when the network size is comparatively larger (long distanced, lots of nodes and heavy traffic). ZigBee, Bluetooth, Wi-Fi have their own MAC protocols of DLL layer which are responsible for medium access, energy consumption, network lifetime and collisions. Since, none of these technologies is suitable for WBAN centric applications especially for outer-WBAN communication, so there is a need for developing a suitable MAC protocol.

The primary responsibility of MAC protocol is regulating access to the shared medium for transmitting data packets and providing the successful operation of the network. MAC protocol creates a basic network infrastructure and directly controls the activities of

the radios. As of preliminary study, two elementary tasks of the MAC protocol are to ensure energy efficient data transmission and to avoid collisions. In wireless sensor networking, the main reasons of energy inefficiency are idle reasoning and collisions. MAC protocol is highly an application specific thus one particular protocol cannot be appropriate for every probable application. Therefore, for designing a good MAC protocol for outer-WBAN communication, we have to consider these attributes including energy efficiency, scalability, collision avoidance, lower delay and higher throughput.

Moreover, MAC protocol for outer-WBAN communication should consider the dynamic allocation of network topology on the basis of network size and nodes density. Medium access control, channel assignments are the important issues considering the highly density environment, dynamic allocation of network topology and mobility in the network. There are numerous MAC protocols that have been designed, proposed and developed for wireless communication. Some typical examples including contention free or schedule based (TDMA) and contention based (CSMA/CA) protocols. Schedule based approaches are tightly synchronized and do not support network mobility and random deployment of network topology. Contention based protocols are suitable to support autonomous networking and are helpful when the network topology is random. CSMA/CA is a major cause of collision where TDMA is a major cause of delay.

In addition, using of single-radio MAC protocol for medical applications may result in unavoidable interference, channel collision and energy inefficiency. Multi-radio MAC protocol has higher data delivery rate, lower delay, and perform well in case of mobility and interference, but it consumes higher energy.

Study indicates that one particular standard of MAC protocols may not be implemented for the solution of the research problem or available protocols for wireless sensor network are not easily be portable for outer-WBAN centric medical application. Therefore, to effectively monitoring pilgrims' health during Hajj, we propose to develop a suitable MAC protocol that can easily deal with the collision avoidance and energy efficient issues for outer-WBAN communication. The flow of problem statement of this research is illustrated in Figure 1.2.

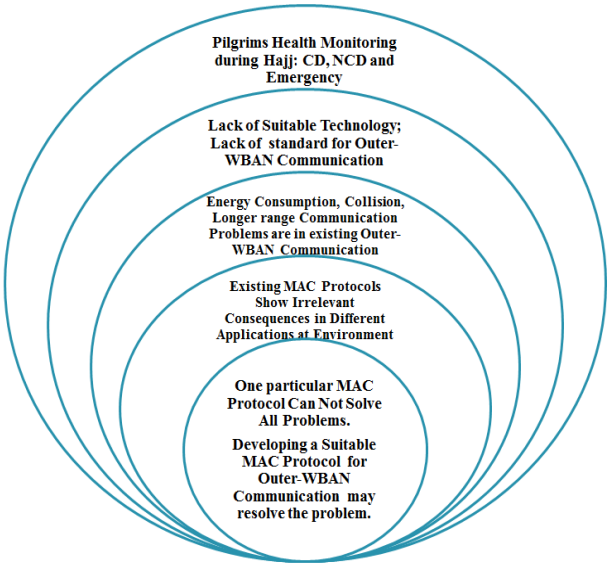


Fig. 1.2: The Flow of Problem Statement.

2. Feasibility study in designing suitable MAC protocol for outer-WBAN considering hajj environment

2.1. Background

The aim of this research is to monitor the pilgrims' health conditions during Hajj using WBANs. Thus, designing a MAC protocol for outer-WBAN communication to smoothly monitoring pilgrims' health during Hajj is an important issue. MAC protocol of DLL layer primarily is responsible for integrating with other network technologies, energy efficiency, prolonging network lifetime, higher throughput, lower delay and collision free communication. To identify the significance of deploying current information and communication technology (ICT) and limitations so far existing in literature to design a suitable MAC protocol outer-WBAN communication for efficiently monitoring pilgrims' health at Hajj ritual sites a in this research a preliminary literature review has been conducted and presented at the end of the paper.

2.2. Hajj and healthcare issues during pilgrimage

Hajj is the second out of five obligatory pillars in Islam. Every year during Hajj, millions of pilgrims from all around the world congregate in Makkah, Saudi Arabia. During the pilgrimage, the pilgrims are obliged to spend their times at Masjid-ul-Haram with an area of 4.5 sq. Km. which can hold 250,000 pilgrims at a time, at Mina with an area of 2.5 sq. Km., at Muzdalifa with an area of 6.8 sq. Km., and at Arafat with an area of 13.6 sq. km. According to the study as presented in Figure 2.1 [1] it is notable that during Hajj 62.5% chronic or non-communicable diseases and 37.5% infectious or communicable diseases are being encountered by the pilgrims. Other than diseases, overcrowding at religious sites also cause other noteworthy troubles such as missing and lost pilgrims, trauma, and even death.

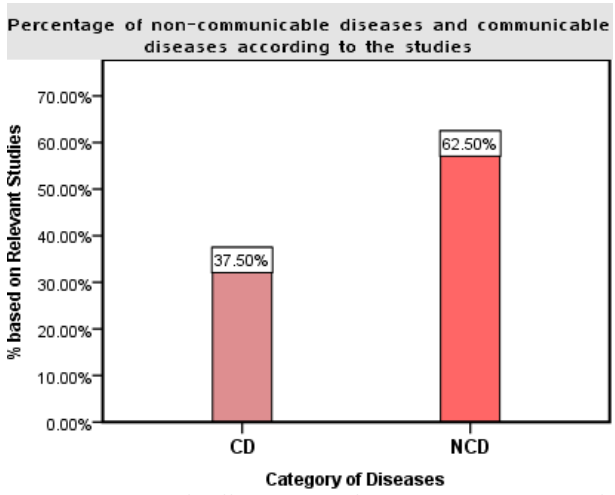


Fig. 2.1: Percentage of Different Types of Disease in Hajj. A Total of 30 Studies Related To Communicable Diseases (CD) or Infectious Diseases and Non-Communicable Diseases (NCD) or Chronic Diseases Were Used for Analyzing the Result [1].

2.3. Current technology for monitoring pilgrims

In our previous research work [4] a total of 15 studies have selected to define the key health issues during Hajj and are further categorized into four major types of healthcare facilities based on the current literature review. From the research it is revealed that 40% research focused on health record and guideline facility, 27% research focused on Pilgrims' tracking to avoid risks, crowd and accidents. Moreover, in the same research, it is shown that 20% research described the infectious diseases surveillance or prevention systems and 13% research focused on pilgrims' stress monitoring, pilgrims health condition e.g. pulse and temperature monitoring as shown in Figure 2.2.

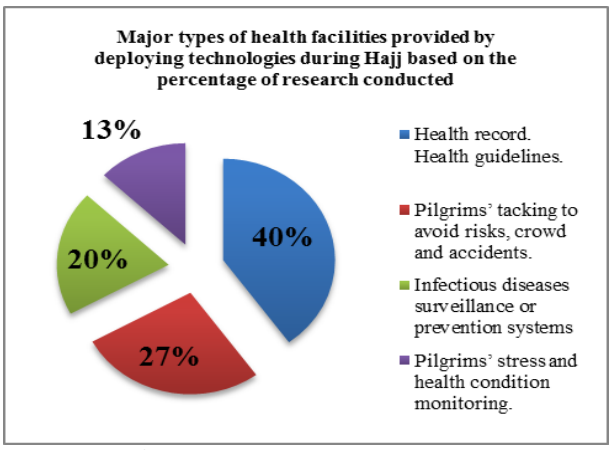


Fig. 2.2: Types of Health Facilities Provided by Deploying Technologies during Hajj Based on the Percentage of Research Conducted

During the review of literature, we found that various types of technologies have been proposed or deployed for healthcare facilities for pilgrims as described before. The following Table 2.1 shows the deployment of different technologies with respect to the four major types of health facilities during Hajj.

Table 2.1: Different Technologies Have Been Proposed in Respect to the Four Major Types of Health Facilities during Hajj in Current Literature

Major types of health facilities provided by deploying technologies during Hajj	Name of Technologies deployed
Health record. Health guidelines.	Mobile phone, GPS, IT, WSN
Pilgrims' tracking to avoid risks, crowd and accidents.	RFID, BSN, WSN
Infectious diseases surveillance or prevention systems	Mobile phone, GPS, GIS
Pilgrims' stress monitoring.	Mobile phone, Wearable device, GPS, GSM, Pulse and Temperatures sensors
Pilgrims health condition e.g. pulse and temperature monitoring.	

2.4. WBAN and communication phases

WBAN is a prominent technology for healthcare. The major advantages of deploying WBAN in healthcare sectors are location independent monitoring facility; providing mobility and flexibility of patients due to use of transferable or portable monitoring devices; and association with suitable communication network for ling distant data transmission. It is also significant that the coverage of a WBAN is limited to about 1 to 2 meter, in some cases 2 to 5 meter. Hence, to largely extend its coverage area it should interwork with other wireless networks which will facilitate connectivity between WBANs gateway or coordinator and the outside world [4]. Comparison between WBAN and WSN is presented in Table 2.2.

Table 2.2: Compariosn between WBAN and WSN

Attribute	WBAN	WSN
Power	Low	Low to High
Self-organization	No	Yes
Topology used	Star, single hope	Mesh, Multi hop
Duty Cycle	Low	Traffic dependent
Network	Variable, Heterogeneous	Static, Homogeneous
Supporting Wireless Technology	ZigBee, Bluetooth, MAC Protocol	ZigBee, Bluetooth, MAC Protocol

WBAN consist of a number of tiny sensors or body nodes and a coordinator. WBAN coordinator is responsible for data collection from sensor nodes, processing the data, storing the data, controlling the nodes and transmitting data to the access points (APs) or base stations for further investigations by the medical personnel [5]. WBAN communication is mainly divided in to two types: intra-WBAN communication and outer-WBAN communication [7] [10] or inter-WBAN [5] or extra-WBAN [6] [10] or beyond-WBAN communication. Body sensor nodes send the sensed data to the coordinator through intra-WBAN communication; and in outer-WBAN communication, coordinators or gateway node send the received data to the access points (APs) or sink node for further transferring data to the medical stations or healthcare centres for processing, analysis and investigation. In WBANs system, the APs are considered as part of the infrastructure, and can be placed strategically in a dynamic environment to handle emergency situations. At present, WLAN/ Wi-Fi, Bluetooth, and ZigBee are widely being used in off-body or outer-WBAN communication [5] [8]. WBAN based health monitoring system has been proposed in [9]. In this work, authors propose ZigBee, GPS module and Wi-Fi module for sensor and coordinator nodes, where, each node consists of various sensors, a GPS module and a ZigBee wireless modem. The coordinator or the base station consists of a receiving ZigBee modem and a Wi-Fi module. Authors in another research [10], random room mobility model has been proposed for extra-WBAN communication. Due to the lack of attention in communication issues for extra-WBAN, authors assumed that the coordinator could employ an existing high power network infrastructure e.g., Wi-Fi or cellular networks for transferring medical data to the healthcare centres.

2.5. Existing communication technologies for outer-WBAN and their limitations

According to the study as focused in [8] [11], theoretically Wi-Fi consumes 100mW-1000mW energy at the data rate 10Mbps-100Mbps, communication range is between 10-100 meters, network lifetime is few hours to 5 days. Bluetooth consumes 2.5mW-100mW energy at the data rate 1Mbps-10Mbps, communication range is between 1-10 meters, network lifetime is 1-7 days. ZigBee consumes 1mW-50mW energy at the data rate 100Kbps-250Kbps, communication range is between 10-100 meters, network lifetime is several days-several weeks. The comparison between ZigBee, Bluetooth and Wi-Fi technologies is presented in Table 2.3. Bluetooth and Zigbee are suitable for low data rate applications which is merely acceptable for real-time and large scale networks applications. On contrary, Wi-Fi is suitable for high data rate applications but it consumes high energy which is not acceptable in medical applications. However, due to small-sized data transmission (low data rate and low distanced) and low power consumption ZigBee is differentiated from other communication standards like Wi-Fi, and Bluetooth. Therefore, ZigBee is found the most useful technology in the wireless sensor network especially for hospital and residential based medical applications.

Table 2.3: The Comparison Between Zigbee, Bluetooth and Wi-Fi

Standard	Bluetooth	ZigBee	Wi-Fi
Data Rate	1Mbps-10Mbps	100Kbps-250Kbps	10Mbps-100Mbps
Nominal Range	1-10 m	10-100m	10-100m
Energy Consumption Rate	2.5mW-100mW	1mW-50mW	100mW-1000mW
Network Lifetime	1-7 days	Days-several weeks	Hours-5 days
Max Nodes	8	>65000	2007

ZigBee is mainly deployed in hospital and residential based medical applications and lead to severe collision problem due to concurrent transmissions of packets to one receiver. It has been observed in [12] that collision in mesh and star topology-based ZigBee is higher because packet dropped rate is more compared to cluster or tree-based topology. In cluster-based topology, the network load in the system is mutually shared with a fully functional device which diminishes the load, and in turn, it diminishes the collision. In another research [13], the authors did some experiments to determine the reach and limitations of ZigBee technology. It showed that the actual bandwidth for a ZigBee network is 157 Kbps out of the theoretical value of 250 Kbps and in reality the

bandwidth is 8.3 Kbps for a maximum message size. Again, theoretically, the maximum size of ZigBee network is over 65000 nodes but, the star network hubs are not able to handle more than 1650 packets. The authors also showed that the average retransmission time is about 17.25 ms and it constitutes considerable overhead as the network grows, and more hopes are introduced. However, the authors also suggested not deploying ZigBee for emergency applications or when the network size is bigger (lots of nodes and heavy traffic). It is also mentioned that the possibility of collision will be less when the network size is small with 1000 nodes where one message can be sent in every second. Researchers in [14] observed that in the presence of human bodies, walls, large shrubby environment and with interference the strength of ZigBee signal falls faster over short distance compare to clear environment. Moreover, ZigBee signals are measurable until 30-meter distance as compare to a typical or healthy environment. There is clear sign that whenever implementing a WSN or WBAN some of the parameter needs to be considered such as physical obstruction, line of sight, and signal interference or meddling from other devices.

2.6. MAC protocol

Medium access control (MAC) protocol is a sub-layer of data link layer (DLL) which is layer 2 of Open Systems Interconnection (OSI) model. Channel access control mechanism, radio control, collision avoidance, energy efficiency are the important features of MAC protocol. M Contention-free MAC and contention-based MAC are two major types of MAC which are also known as often use Time Division Multiple Access (TDMA) or Carries Sense Multiple Access with Collision Avoidance (CSMA/CA) respectively [15]. These two standards are widely use in WBAN and WSN communication for fair and reasonable access of shared medium.

MAC protocols requirements for communications in wireless networks particularly in WBAN and WSN differ because the network is optimized for specific applications. Since, WBAN system and its operation is application specific thus one particular standard of MAC protocol will rarely be suitable for every possible application. For outer-WBAN applications the MAC protocol must be optimized for energy efficient to maximize network lifetime, collision avoidance for efficient and smooth data transmission, and lower data delay for reliable and faster data transmission. Moreover, according to the network size, it should be scalable; should regulate and adjust to changes in the network such as an addition of new nodes. A MAC also should guarantee a random deployment of new devices in the environment. Furthermore, depends on the applications wireless body area network must support mobility in the network.

2.6.1. Contention-based MAC protocol

Authors in [16] presented that if wireless sensor network enabling one radio in a node cannot support mobility in the network, and unable to transmit and receive data concurrently thus may result in higher delay and channel inefficiency. Authors also recommend that for random deployment of network topology (when the network topology is random) the contention-based (CSMA) approaches are helpful. In CSMA, application requirements are not delay constrained and there is no mechanism to ensure tight synchronization but, there is a significant scope of data collision.

One of the initial attempts to significantly reduce idle listening, collisions, and overhearing in WSNs is the design of the contention-based Sensor-MAC (S-MAC) [15]. S-MAC uses the ready to send and clear to send (RTS/CTS) handshake scheme with acknowledgment (ACK)/ DATA scheme (by putting nodes in listen and sleep periods.) for unicast packets and collision avoidance. Some of the drawbacks of S-MAC are it is rigid and optimized for a predefined set of workloads; not able to adapt the length of listen and sleep periods with changing traffic conditions; has severe impact on system latency.

2.6.2. Contention-free MAC protocol

The authors in [16] show that schedule-based or contention-free (TDMA) MAC approaches are more energy efficient and collision avoidance if deployed network topology is not random and synchronized. But, there is a significant scope of delay. In TDMA schemes (preferred as scheduling methods for WSNs.) the system time is divided into slots and a node can only access its allocated time slot. All the time slots in this scheme are allocated to all the nodes in the neighbourhood and do not need any contention with its neighbours. Moreover, the schedule can be fixed or computed on demand (or a hybrid) and is normally regulated by a central authority (coordinator).

In [17], authors presented TDMA based energy efficient MAC protocol for short range, very low power and fixed nature of WBAN. Comparison between TDMA MAC and CSMA/CA MAC protocols are presented in Table 2.4.

Table 2.4: Comparison between TDMA and CSMA/CA

Standard	TDMA	CSMA/CA
Power consumption	Low	High
Preferred traffic level	High	Low
Bandwidth utilization	Maximum	Low
Scalability	Poor	Good
Effect of packet failure	Latency	Low
Synchronization	Required	Not Applicable

2.7. Single channel and multi-channel MAC protocol

Multi channel MAC protocols provide timely data communication features over single channel MAC as a result considerably improve energy efficiency and throughputs. So far, widespread researches on the designing of MAC for WBAN put emphasis on single channel which may result in unavoidable interference; bring channel collision and energy inefficiency. A TDMA based single channel MAC protocol has been proposed in [18] where the operation is not dependent on network coordinator. Moreover, based on local information the nodes in the network are capable of choosing their own time slot. A contention window (CW) adjustment CSMA/CA scheme based energy efficient and lower delay multi channel MAC has been proposed in [19] for WBAN. In this multi channel scheme, channels are categorized into the control channel and data channel to avoid interference, collision and the packet delay. Authors in [20] presented TDMA based multi channel MAC protocol for WBAN. The coordinator or central node (CN) of this protocol alternatively changes the time slots or the communication channel to reduce collisions. The main differences between single channel and multi channel MAC protocols are depicted in Table 2.5.

Table 2.5: Major Comparison between Single Channel and Multi-Channel MAC Protocols

Attribute	Single Channel	Multi Channel
Energy Consumption	High	Low
Collision management	Poor	Well
Mobility or interference	Perform poor	Perform well

2.8. Single radio, multi radio MAC protocol

Authors in [21] showed that using of single radio single channel MAC protocol for medical applications may result in obvious interference, channel collision, higher delay and energy inefficiency. Implementable single-radio multi-channel energy efficient TDMA based MAC protocol (ISRMC-MAC) is proposed in [22] using unbalanced star and mesh combined topology but it has more interference effect, more end-to-end delay, and less data delivery rate. WBANs employs star topology thus utilizes single radio single channel contention based MAC protocol which ultimately duplicates data due to a single-channel and leads to energy inefficiency.

To achieve high communication performance multi-channel MAC (Cluster On-demand Multi-channel MAC Protocol) has been dis-

cussed in [23], where the coordinator node or sink node uses multi-radio because the authors assume the coordinator node has a powerful transceiver and infinite battery which is not realistic in wireless sensor network applications. A multi-radio MAC protocol with a dedicated radio for control messages and the other radio for data transmission has been proposed in [24]. The proposed protocol can always monitor the control channel because each node has two transceivers. This protocol is designed for low spectrum utilization, and the main drawback is higher energy consumption. Collision free RTS/CTS based multi-channel MAC (AM-MAC) is proposed by [25] for single transceiver node. The main feature includes its efficient utilization of the medium and energy efficiency without the need for time synchronization is discussed in this research paper but the result is not provided for energy efficient transmission. Comparison between single radio MAC and multi radio MAC is presented in Table 2.6.

Table 2.6: Comparison between Single Radio and Multi Radio MAC Protocols

Attribute	Single Radio	Multi Radio
Data Delivery Rate	Low	High
End to end delay	High	Low
Topology used	Star, single hope	Mesh, Multi hop
Mobility or interference	Perform poor	Perform well
Energy consumption	Low	High
Collision management	Poor	Good

For WSNs, a dynamic multi-radio multi-channel (DMMA) MAC protocol has been proposed in [26]. A sleeping mechanism has been proposed for supporting less energy consumption, and also is able to choose the channel dynamically thus make the network more robust. Another power-saving multi-channel (PSM-MMAC) MAC protocol has been developed for WLAN and presented in [27]. PSM-MMAC protocol as described can reduce collision probability and the waiting time of a node at awaking state resulting in better throughput, and lower delay performance. Though, energy efficiency is one of the key features of the protocol of sensor network, but no mechanism has been discussed to handle with a heterogeneous multi-radio networking system. Multi-radio, multi-channel (MRMC) based MAC protocol have been designed and proposed in [28] for WSNs based application but it consumed more energy. For example, MRMC based MR-MAC consumes 10-15 mW energy and B-MAC consumes 10-70 mW energy at the data rate of 1000 bytes. In both cases, the power consumption kept increased due to the growth of data rate and data transmission distance and resulting in network life of only a few days of operation in WSNs.

To improve performance, especially energy efficiency, a sleep-wake up cycle mechanism is employed in traditional MAC protocols using duty cycling. However, this mechanism cannot manage emergency traffic and suffers from overheads such as, idle listening, and overhearing. In this mechanism, for transmitting an emergency data, a node has to wait until the receiver is awake. Hence, to handle prompt communication in WBANs system an external radio-triggered wake-up mechanism has been proposed in [7]. In this mechanism a wake up radio handles the wake up process and by using on-demand scheme it can reduce the overheads thus improve the performance. In another research [29] a wake up radio for channel monitoring feature is discussed for WBAN. It improves energy efficiency because it allows power efficient listening to wireless channel.

Different schemes are proposed for TDMA and CSMA/CA based MAC protocols for data collision management. TDMA based MAC protocols use scheduled based scheme, where frame is divided into time slots and then time is allotted to each channel for communication. But, CSMA/CA based MAC protocols are utilizing ready-to send and clear-to-send (RTS/CTS) handshake scheme with ACK (NACK) and DATA scheme to manage the collision. But both mechanisms have different drawbacks when they are being used for different environments and applications. However, both TDMA MAC protocols and CSMA/CA MAC protocols are using listen-sleep or sleep-wake up mechanism for energy efficient communication. The comparison between these schemes is illustrated in Table 2.7.

Table 2.7: Comparison between Energy Consumption and Collision Management Schemes in TDMA and CSMA/CA Based MAC Protocols

Attribute	TDMA	CSMA/CA
Energy Consumption	Listen-Sleep or Sleep-Wake up	
Collision management	Scheduled based	RTS/CTS/ACK/DATA

2.9. Summary

A number of literatures have been explored in this research in order to identify the real problem in monitoring pilgrims' health during Hajj as illustrated in Table 2.8. We propose to design a suitable MAC protocol for outer-WBAN communication and for this various MAC protocols, their merits and demerits have been discussed. It is noticeable that the selection of a proper MAC protocol mostly depends on the applications although a bounty of MAC protocols have been proposed over the last years.

3. Conclusion

So far there is no information and communication technology has been designed and proposed for pilgrims' health monitoring during Hajj and there is no standard available for outer-WBAN communication. Hence there is a need for designing a suitable medium access control (MAC) protocol for reliable data communication considering energy efficient and collision avoidance issues. Information presented in this literature review suggests that for random deployment of network topology (when the network topology is random) the contention-based (CSMA) approaches are helpful. In CSMA, application requirements are not delay constrained and there is no mechanism to ensure tight synchronization but, there is a significant scope of data collision. It also shows that schedule-based or contention-free (TDMA) MAC approaches are more energy efficient and collision avoidance if deployed network topology is not random and synchronized. But, there is a significant scope of delay. In this research we observed that, due to the dynamic and random deployment of network topology, there is a significant drop in data delivery in single-radio due to single channel assignment to radio. In contrary, multi-radio mechanism has low delay, significant throughput (more data delivery rate) and can perform well in case of mobility. Moreover, multi-radio mechanism has more interference reduction as compared to single-radios. Unlike single radio based MAC protocol, in multi radio MAC protocol, control channel and data channel can be separated for control radio and data radios respectfully thus synchronization can be omitted in designing dynamic and robust MAC protocol. But, there is high scope of energy inefficiency in deploying multi-radio MAC protocol. Designing a MAC protocol is application specific. In this research, we propose to develop a suitable MAC protocol for outer-WBAN communication for monitoring pilgrims' health during Hajj.

Table 2.8: Theory and Significant Findings through the Literature Review

Author/Year	Title	Theory/Standpoint	Domain	Significant Findings
Geabel A et al. (2014)	Pilgrim Smart identification using RFID technology	Although, providing proper healthcare facilities for pilgrims' during Hajj is an important issue but the matter has not been addressed.	Pilgrims' identification during Hajj	This paper describes radio frequency identifier (RFID) based pilgrims identification system
Mohandes M et al. (2013)	Pilgrim tracking and identification using wireless sensor	There is a need for monitoring pilgrims' health conditions during pilgrimage at Hajj ritual sites. Because, during Hajj many pil-	Pilgrims' tracking and identification during Hajj	Pilgrims tracking and identification systems is presented in this paper based on wireless sensor networks (WSNs) and

	networks and GPS in a mobile phone	grims suffer from both communicable and non-communicable diseases along with some other emergency issues and these topics have not been discussed.		GPS system in a mobile phone.
Mahtab Alam et al. (2014)	Surveying Wearable Human Assistive Technology for Life and Safety Critical Applications: Standards, Challenges and Opportunities	Medium access, radio deployment, contention-based CSMA/CA and contention-free TDMA requirements for designing suitable MACs for both intra-WBAN communication and outer-WBAN communication are the utmost important factors. For hospital and residential based outer-WBAN communication there has been described enough but for overcrowded and harsh environment there has been a little written to define the concept where energy efficiency, low delay, higher throughput and collision free MAC design is a vital issue.	A review on WBAN for health applications	Wireless body area networks (WBANs) requirements and characteristics for inter-intra and beyond WBAN with some limitations are discussed, evaluated and analyzed for both medical and non-medical applications.
Linghe Kong (2015)	mZig: Enabling Multi-Packet Reception in ZigBee	Since in ZigBee enabled wireless communication system, collision is higher in star and mesh based topology than tree or cluster based topology but to design medium access control (MAC) protocol with higher throughput and no collision for medical applications which is based on star topology is a critical research issue for outer-WBAN communication especially for Hajj particular application.	Wireless communication e.g. Wireless sensor networks	Although ZigBee outperforms Bluetooth, Wi-Fi, UWB for medical application in many reasons e.g. short-range and limited data transmission, energy-efficiency etc, but limitations including lower throughput due to packet collisions, etc. are still exist. In this paper authors represent mZig to enable multi-packet reception (MPR) in ZigBee., where PHY motivates a more aggressive MAC in ZigBee to increase throughput by exploiting concurrent transmissions.
E. Dalila Pinedo-Frausto et al. (2008)	An Experimental Analysis of ZigBee Networks	To handle emergency medical and non-medical situations at harsh and overcrowded environment the systems requires larger network size with lower delay and higher throughput. In practical ZigBee is able to manage 1650 packets at a time where theoretically the network size is more than 65000. Thus we need to design a suitable medium access control protocol to overcome these limitations.	Wireless sensor network based industrial applications	Several aspects concerning the reach and limitations of the ZigBee technology have been analyzed and discussed.
Mujahid Tabassum et al. (2015)	Performance Evaluation of ZigBee in Indoor and Outdoor Environment	Hajj ritual sites are of several square kilometers are in size where millions of pilgrims congregate to perform the Hajj. Hajj is a dynamic system in nature. To cope with pilgrims' health monitoring issues in such overcrowded environment using modern ICT is a big challenge. MAC protocol provides features to handle such obstacles in communication. Dynamic, heterogeneous, robust, mobility, long distance communication with high data rate are the key features to suitably design MAC for outdoor wireless communication particularly for outer-WBAN communication.	WSN based applications under various conditions such as indoor, outdoor, co-existence of Bluetooth	In this paper, researchers observed that in the presence of human bodies, walls, large shrubby environment and with interference the ZigBee signal strength drops faster over short distance compare to clean environment and ZigBee signals are detectable until 30-meter distance as compare to a normal environment.
Joseph Kabara et al. (2012)	MAC protocols used by WSN and a general method of performance evaluation	Communication problems may occur in larger and harsh environment with random deployment, periodic data transmission and non-deterministic applications because it is not always possible to ensure that all slave nodes (WBANs coordinators in outer-WBAN communication) are within the range of the master (access point for outdoor communication). Due to the lack of standard for outer-WBAN communication it is difficult to evaluate and select a protocol, even if the requirements of a particular application are known. In addition, medium access control (MAC) protocol requirements for communications in wireless communication vary because the network is usually optimized for specific applications. Thus, one particular standard will hardly be suitable for every possible application considering the energy efficiency, collision, delay, throughput requirements.	Wireless communication	In wireless communication particularly, wireless sensor network enabling one radio in a node cannot support mobility in the network, unable to transmit and receive data concurrently and thus may result in high data latency and channel inefficiency. In this paper the characteristics and limitations of both contention-based (CSMA) and contention-free MAC (TDMA) protocols have been discussed. Authors emphasized that, CSMA is a major cause of collision where TDMA is a major cause of delay. It is also mentioned that, CSMA is suitable for random deployment of network topology, where TDMA is suitable for scheduled based application where the base stations should deploy with high power transmitters.
Nabil Ali Alrajeh et al. (2013)	Multi Channel Framework for Body Area Network in Health Monitoring	Single radio single channel MAC protocol for medical applications may result in unavoidable interference and bring channel collision and energy inefficiency. This concept is applicable both for in and off body communication in WBAN applications.	Wireless body area network, particularly intra-WBAN communication.	To achieve high communication performance multi channel MAC has been proposed for WBANs intra-WBAN communication. In this protocol ZigBee is used to communicate mobile systems and physiological devices.

		Issues related to energy efficient and collision free outer-WBAN communication has not been discussed.		
Cheng L et al. (2008)	A Cluster Based On-demand Multi-Channel MAC Protocol for Wireless Multimedia Sensor Networks	WBAN consists of tiny nodes along with a coordinator. For Medical applications nodes should consumes less energy to prolong its battery life. Since, coordinator or sink node is situated in the center of the star topology based network and responsible for in and out body data communication, thus we assume coordinator may have powerful transmitters but energy efficient.	Wireless communication	Cluster on-demand multi-channel MAC protocol has been proposed. In this system the coordinator node or sink node uses multi-radio because the authors assume the coordinator node has powerful transceiver and infinite battery which is not applicable in sensor network particularly in medical applications. A scheduled multi-channel medium access is used to achieve energy efficiency and a contention-free mechanism is used for collision free data transmission. Scheduled based mechanism is highly deterministic and not applicable for random deployment of network topology.
S. Wu et al. (2000)	A New Multi-Channel MAC Protocol with On-Demand Channel Assignment for Multi-Hop Mobile Ad Hoc Networks	Channel assignment and medium access are the important issues considering dynamic allocation of network topology and mobility. Channel assignment is to decide which channels to be used by which hosts, while medium access is to resolve the contention/collision problem when using a particular channel. Applying these two concepts using single radio may cause huge delay and thus result in reducing throughput and energy inefficiency.	Mobile ad-hoc network	A multi-radio MAC protocol with a dedicated radio for control messages and the other for data transmission has been proposed.
Duy Nguyen et al. (2009)	Collision-Free Asynchronous Multi-Channel Access in Ad Hoc Networks	Though energy efficiency is an important issue but mechanism to do so has not been discussed.	Wireless communication particularly for ad-hoc network	Collision free RTS/CTS based multi-channel MAC protocol is proposed for single transceiver node. The main feature includes its efficient utilization of the medium. Although energy efficiency without the need for time synchronization is also addressed.
Zhiwu Liu et al. (2010)	A Dynamic Multi-radio Multi-channel MAC Protocol for Wireless Sensor Networks	To dynamically negotiate multiple radios for an appropriate channel is a good approach for MAC considering lower power consumption and no collision. Periodically and on-demand sleep-wake up mechanism is an effective approach for reducing energy consumption. Unlike single radio based MAC, in multi radio MAC, control channel and data channel can be separated control and data radios thus synchronization can be omitted in designing dynamic and robust MAC. Since, in multi radio MAC both types of radios are independent hence, they will not interfere each other activities particularly at the time of data transmission and cope with random deployment of network topology where network size is larger.	Wireless sensor network	A dynamic multi-radio multi-channel MAC protocol has been proposed. A sleeping based mechanism has been proposed for energy consumption, and it can choose the channel dynamically according to the changing of spectrum environment thus making the network more robust to the interferences.
Jianfeng Wang et al. (2006)	A Power-Saving Multi-radio Multi-channel MAC Protocol for Wireless Local Area Networks	CSMA base RTS/CTS mechanism has been used for collision free data transmission, while proper mechanism for energy efficiency has not been discussed.	Wireless communication particularly in wireless local area network	Power-saving multi radio multi-channel MAC protocol has been developed for WLAN. This protocol is capable of reducing the collision probability and the waiting time in the 'awake' state of a node, resulting in improved throughput, delay performance.

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