International Journal of Engineering & Technology, 7 (4) (2018) 5178-5187

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i4.22270
Research paper

WMNs enabled WBANs system for pilgrims' health monitoring at overcrowded environment during hajj in Saudi Arabia: a feasibility study

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Abstract

Due to the hardship of expedition, instability, overcrowded environment and fluctuation of rough weather, continuous walking, hassle and mental stress during the Hajj at Makkah in Saudi Arabia, many pilgrims get injured, sick and tired. Besides, those who are suffering from various chronic diseases may also contract severe heart, chest, abdominal, and kidney diseases along with some infectious diseases like influenza and thus complicate the overall physiological functions of the patients. Other than the problems of physical sickness and diseases due to harsh and overcrowding at ritual sites also causes numerous problems which may end with the physical injury, trauma and even death along with missing or lost pilgrims. Therefore during Hajj, it is a crucial matter and a significant challenge to ensure the best healthcare services and facilities for pilgrims' real-time health monitoring. Wireless body area networks (WBANs) is a modern and promising healthcare technology which coverage is limited to 1-2 meters. Hence, to extend the network coverage area for WBANs at Hajj ritual sites we have proposed wireless mesh networks (WMNs) to integrate with WBANs due to its self-expandable, self-configuring and self-healing nature. In this research, an extensive literature review is conducted, and a feasibility study is performed to identify the way to transmit pilgrims' health information to the healthcare centres by integrating WBANs with WMNs.

Keywords: *Hajj; Pilgrims; Health Monitoring; Overcrowd; MAC Protocol; WBANs; WMNs.*

1. Introduction

Hajj is one of the biggest yearly religious congregations in the world. Every year during Hajj, several million pilgrims from all around the globe assemble in Makkah, the kingdom of Saudi Arabia. Due to the adversity of expedition, unsteadiness, and fluctuation of rough weather, continuous movement around the ritual sites, hassle and mental stress, many pilgrims get injured, sick and tired. Besides, those who are suffering from various chronic diseases may also contract severe heart, chest, abdominal, and kidney diseases along with some infectious diseases like influenza and thus complicate the overall physiological functions of the patients [1]. Other than the problems of physical sickness and diseases, overcrowding causes other noteworthy problems and difficulties which may end with the physical injury, trauma and even death along with missing or lost pilgrims. Therefore, it is a crucial matter and a significant challenge to ensure the best healthcare services and facilities for pilgrims' real-time health monitoring during Hajj [2].

Scalability, energy efficiency, network lifetime, latency, throughput, delay, collision, and mobility are the essential requirements for sensor networking especially for both wireless sensor networks (WSNs) and wireless body area sensor networks (WBASNs) that need to handle carefully. However, the order of priority of some of these requirements is often different in WBANs in comparison to WSNs. One of the most important criteria for a WBAN is to establish and maintain energy efficient data transfer between the body sensor nodes, coordinator and the health care centre since these networks mainly deal with vital human signs [3]. Being unable to send or receive interpretive human vital signs, or receiving the information with long delays, might be the difference between life casualty and death. For example, it might be necessary during Hajj to provide regular health care and monitoring for pilgrims especially those who are elder and suffering from various chronic diseases. To maintain their independence without the need for constant supervision or the presence of caregivers, WBANs provide a reasonably safe and low-cost solution with minimal maintenance [4]. In such scenarios, the pilgrims are free to go about their daily routines to perform their religious activities and, since many pilgrims live in densely environments at Hajj ritual sites, WBANs are always being faced with a reliable and an energy efficient data transmission, an ever-changing interference background. Providing suitable communication network between WBANs and healthcare providers via the coordinator node or gateway to the access point (AP) is a challenging issue. Modern information and communication technology (ICT) can make it possible that WBANs will connect itself to the Internet to transmit data and proficiently control the accurate delivery of healthcare facilities and services among the pilgrims [5]. Therefore, integration of the ICT and medical/ healthcare technology is an outstanding research topic, especially in the field of WBANs and WSNs.

It is to be noted that, wired communication cannot be extended and expanded for wide or long distances and is restricted for short-range communication due to various reasons e.g. economic and reliable communication. Thus wireless in-on-off body sensor deployment for health monitoring is a novel topic of argument among researchers. In addition, existing WBANs differ from conventional WSNs because it consists of a diverse network environment related to the human body aiming to monitor the functions of

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the human body and surrounding environment continuously in a real-time fashion [6]. In addition, due to the characteristics of the body, and the devices attached to the body those are mobile and movable a wireless network environment for the human body may have numerous properties including limited and inconsistent bandwidth that is prone to more interference, limit to short and long range communications, heterogeneous and energy-dependent nodes, and each node should consume minimal transmission power due to radio frequency (RF).

Notwithstanding the information presented earlier, it is also important that the network coverage area of a WBAN is limited to about 1 to 5 meter. Hence, to facilitate connectivity between sensor devices or nodes of WBANs and the outside world it is necessary to expand its coverage area particularly while interworking with other wireless networks which forms special purpose wireless-sensor network enabling remote monitoring system for various medical environments [7] [8]. WBAN RF signal propagation, its environment at data link level and realistic channels on network level need to characterise extensively for more effective life-saving network architecture. Hence, one of the significant challenges of WBAN is to monitor a great number of pilgrims at pilgrimage sites and to provide proper health care facility when required. Therefore, WBAN needs a collision free and interference free complete wireless network infrastructure.

For example, for residential environment (e.g. hospital, clinic, or patients' resident) healthcare system with limited range does not need wireless communication platform with full meshing capability. However, for the long range and crowd environment like Hajj ritual sites, the communication infrastructure must be expanded and extended so that the site or location is fully covered.

Due to the limitations of self-management nature including self-expandable, self-configuring and self-healing of other existing conventional wireless communication technologies wireless mesh network (WMN) is the suitable and potential communication technology for monitoring pilgrims at the over crowded environment and transferring vital health information to the healthcare centers at Hajj ritual sites. In WMNs, wireless backbone network (WBN) is formed by integrating wireless mesh routers (MRs) and Internet gateways (IGWs) through which a mobile client (MC) can access the Internet. In WMN enabled system, IGWs act as a communication bridge and MRs act in a multi-hop manner. The elements of WMNs have the ability to simultaneously using multiple interfaces for packet transmission and reception in numerous non-overlapping channels that ultimately enhances the network capacity. Furthermore, WMN routers connect to other routers and clients forming a multi-hop transmission path to route data through mesh routers towards the healthcare and emergency centres [12] [13]. For Example, WMNs consist of several nodes called as mesh nodes act as a mesh router and work differently by rerouting data to another hop which it is connected. The way of data transmission in WMNs is different if we compare with a Wi-Fi or WLAN access point (APs) where service can be provided only within reach of the signal, and when it is turned off, the connection is gone. Therefore, WMN, due to its self-expandable nature can be deployed with WBAN during Hajj for pilgrims' health monitoring which requires extending the coverage of the environment. Thus,the kry objective of this research is to design a conceptual healthcare system for pilgrims' health monitoring during Hajj by integrating WBAN and WMN technologies.

One of the major concerns in wireless networks, in particular, WBANs and WSNs, is low energy consumption. The life of a WBAN depends on its nodes lifetime, where nodes life is its battery life and its transmission power. Life of node's battery differs and depends on different physiological data collection, amount of data size to be processed by sensors' processors, the number of transmissions, the distance we want to transmit, MAC protocols and transmission channel conditions. It has been shown that sensors lifetime is inversely proportional to the amount of data processed in the sensors processor, duration of operation, high data rate and increasing number of nodes in a network. Whereas, sensors lifetime is directly proportional to the amount of energy is being consumed during data transmission between the sensors and WBAN coordinator, e.g. gateway or between sensors and access points via the gateway node. All sensors work with low power consumption has a long lifetime compared to work with high power consumption, which has a short lifetime. It is compulsory to reduce power consumption as much as possible to lengthen the network lifetime because, longer battery life decreases WBAN operational costs and enhances patients comfort hence [9-10] [13]. Hence, in WBANs, a battery should consume minimal energy thus last for a long time and also be able to avoid internal body tissue heating and damage. Moreover, different types of medical applications, transmission environment and data retransmission also influence the power consumption of WBANs and require additional energy requirements of a transmitter. In sensor network, the protocols of data link layer (DLL) such as medium access control (MAC) protocol controls the battery lifetime of WBANs because, MAC protocols direct and control the packet transmission schedule and the transmission channel access which ultimately influences the battery lifetime [11] [12]. It is notable that, WBANs consist of several body nodes each of which has a processor with memory, a power unit and a transceiver along with a coordinator or body gateway device, which should place on the body of a patient. The primary functions of coordinator are to communicate body sensors/actuators, process the gathered data and broadcast to the access point. Gateway is capable of performing some tasks like reliable data routing, improving data fusion, spectrum sensing (between nodes and coordinator), network configuration or reconfiguration and wireless connectivity with APs [13]. Functions that can be incorporated in between sensor nodes and AP via the gateway must be supported by highly reliable and energy efficient MAC protocol taking into consideration of gateway parameters such as mobility and location, battery life, working, calibration and end-to-end connectivity. Hence an energy efficient MAC protocol with low delay and reliable transmission should be selected for a WBAN when sensor nodes send its data to distant healthcare providers.

Moreover, MAC protocol should support parallelism so that multiple WBANs might work in parallel. MAC protocols should consider the movement of body sensor while there is a movement of body. The MAC protocols in emergency applications and situations must allow quick access to its channel in order to transmit vital or life critical traffic or data to the coordinator or gateway of the network. The MAC protocol must be scalable and dynamic to the body sensor nodes for medium access control and should not perform static assignments. MAC should support heterogeneity, interoperability and integration of multiple networking technologies. Therefore, we focus on the reasons for the modification of the existing MAC protocol of WBANs considering the issues related to Hajj. In this research, an extensive literature review is conducted, and feasibility study is performed to identify the way to transmit pilgrims' health information to the healthcare centres by integrating WBANs with WMNs.

2. Material and method

As mentioned earlier, WBAN in healthcare environment has become a promising, and pervasive technology. To apply WBAN at overcrowded Hajj ritual sites requires extra coverage area. Therefore, our current research aims to study through literature review whether it is feasible to design WMNs enabled WBANs system for real-time monitoring og pilgrims' health during Hajj. In WBAN technology, MAC protocol is accountable for integrating of other network technologies, energy efficiency and prolonging network lifetime. Therefore, we reviewed numerous literatures to identify the limitations and possibilities among the information and communication technology (ICT) that can be installed at overcrowded Hajj ritual sites and developing the MAC protocol for smooth data communication. Finally, this study will emphasis on finding the method to bridge the gaps by proposing some in-

ventive ideas based on modern information and communication technology.

In [14], the authors presented a routing technique for wireless body area mesh networks considering different link quality for WMNs. In this research, the authors examined a single channel routing metric for WMN. However, mesh nodes suffer from overloaded data transmission collisions and capacity constraints while operating on a single channel [15]. Furthermore, authors in [14] did not focus on wireless radio and hop or link metrics that are essential for reducing interference and providing enhanced utilisation of frequency spectrum in a mesh network. For greater utilisation of frequency spectrum and fewer interference a multi-hop wireless networks with various interfaces (radios) was proposed in [16]. Authors in [17] presented an extension to the well-known ad-hoc on-demand distance vector (AODV) routing protocol [18] called multi-link AODV (AODV-ML) with the objective to determine and utilize multiple communication links in WMNs to optimally balance traffic in the network and reduce the burden on transmission links.

Authors in [19] presented a system based on single hop wireless sensor network to maximise information content and minimise wireless information loss of the system by deploying sensors as well as to gather data from them in a single hop indoor sensor network. They also focused on a network constitute of numerous sensors that endlessly sense the surrounding environment and transmit data packets to the base station. Thus, sensor network naturally generates massive traffic and applies to monitoring continuous variables for hazard aware environments. However, this paper did not focus on the advantages of using multi-hop wireless communication system in the sense of lower traffic, data aggregation, and efficient as well as energy-aware data communication problems.

Authors in [20] discussed that due to the continuous increment of sensors on a human body, rapid human movement in the environment and highly dynamic network topology, several significant challenges including the quick growth of channel conflicts may occur in single-hop wireless communication system. In [21], the authors showed that energy-efficient multi-hop networks are obligatory when applied close to the human body with intrinsic propagation loss. The authors in [21] also presented a multi-hop approach to MAC protocol and routing approaches for WBANs. However, wireless mesh network backbone with interference reduction scheme was not discussed in the paper. For minimum energy consumption, maximum throughput and longer network lifetime in WBAN, it is vital to deploy multi-hop wireless topology [22].

A real-time pilgrims' monitoring and health control, the health status of the people who fall into a dangerous situation with various diseases that could warn and threaten their health, life and localization system using wireless sensor network are proposed in [23]. The authors described WBSN as a specific application of WSNs where the agents dispatched to several areas at Hajj ritual sites. The model has been presented for limited space, but can be extended and simulated for a larger area of Hajj ritual sites. However, the author did not point out how to transfer life-critical vital information arising from the WBSN to the backbone network considering energy efficiency, high throughput, and a few data path loss. In [24] the authors presented agent-based wireless sensor mesh network (WSMN) for health application. However, they did not discuss critical issues related to WSMN such as energy efficient routing, link collision, and channel interference.

There are also other relevant works for example TDMA MAC protocol that focused on a single-radio multi-channel scheme[25], multi-radio multi-channel framework [26], WASP [27] cross-layer protocol, and CICADA [28] tree based TDMA protocol aiming to achieve high network reliability, efficient communication among devices in WBAN, high throuput, low data latency, lower delay, high reliability, and higher energy efficiency. However, authors in [25-28] did not consider some significant characteristics as mentioned in [29] including balancing power consumption among interconnected nodes, link efficiency, and energy-efficient communication.

For WBANs, numerous studies can be found in the literature those focus on MAC protocols [30-34], and energy efficient issues [35-38]. Several studies are discussed about the theoretical and practical medical data-gathering applications [39-47]. Buddhika et al. [48] examined the interference effect for WBANs when they are placed in the same area. A TDMA-based energy efficient MAC protocol has been presented by Marinkovic et al. [49] that was particularly designed for inter-WBAN communication. Energy efficient MedMAC was proposed by Timmons et al. [50]. Fang et al. [51] proposed BodyMAC for WBANs based on advanced TDMA. A multi-channel management protocol has been offered by Lee et al. [52]. WiseMAC was proposed by El-Hoiydi et al. [53] that was based on CSMA. Bayilmis et al. [54] presented a gateway leader selection approach for balancing energy among sensor nodes. Ismail et al. [55] offered a novel energy-efficient and adaptive MAC protocol namely isMAC (intelligent sensor MAC). The proposed protocol was designed to extend the WBAN lifetime and avoidance of collisions during packet transmissions that were based on multi-channel communication infrastructure. However, authors in [55] did not focus on multi-hop infrastructure for broader environment.

A promising solution for offering Internet connectivity among the mobile nodes (MNs) in larger environments is the wireless mesh networking technology that supplements wired infrastructure with a wireless backbone network. But, mesh technology has challenges on the issues especially in the MAC and routing layers [56]. Currently applied MAC protocols are designed for single hop mesh network which does not work well with IEEE 802.11s WMNs [57]. The authors in [58] presented a MAC protocol projected to offer multi-hop WMNs with a higher throughput. The proposed MAC was designed for single radio devices thus did not concentrate on energy efficiency or power consumption issues in the system. However, in order to considerably improve the capability problem and enhance the aggregate bandwidth available to the network it is evident that equipping mesh routers with multiple radios using multiple non-overlapping channels can be a good option. The overall limitations so far existed in current literature are presented in Figure 1.

3. Result and discussion

This section provides state-of-the-art issues and trends to integrate WBAN with WMN for transmitting pilgrims' physiological health information during Hajj. Different perspectives have been analysed and proposed an integrated model through a brief feasibility study.

3.1. WBANs perspective

For a WBAN explicitly targeting health care in a vast and crowded environment like Hajj ritual sites so far there is no available standard. WBANs should be able to boost the co-existence of sensor nodes with other networked devices and reduce interference among the co-existence wireless infrastructure. In WBAN, power consumption, delay management, throughput and data rate increase with each data processing level starts with individual body sensor node and progress through communication with existing wireless communication technologies via the Internet. To mitigate wireless interferences, improve throughput and delay performance several techniques can be used including multiple radios in nodes of wireless communication networks [62].

For example, for residential environment (e.g. hospital, clinic, or patients' resident) healthcare system with limited range does not need wireless communication platform with full meshing capability. However, for the long range and crowd environment like Hajj ritual sites, the communication networking infrastructure must be expanded and extended so that the site or location is fully covered [63]. Hence, multi-hop based routing of wireless commu-

nication is the best solution that provides the required range of the application. Therefore, multi-hop channels are obligatory to assure both reliable data routing and low power for data transmission [64].

Nevertheless, existing patients' health monitoring systems using WBANs which are mainly based on residential environment such as ZigBee (IEEE 802.15.4) with range 30 to 100 meters that usage short-range wireless systems, WLANs (IEEE 802.11a/b/g) range 0-100 meters, GSM, Bluetooth (IEEE 802.15.1) range 10-100 meters, Wi-Fi (IEEE 802.11a/b/g->IEEE 802.11n) range 100 meters [68]. And can able to transmit data from WBANs coordinator to medical server (MS) via the personal server (PS).

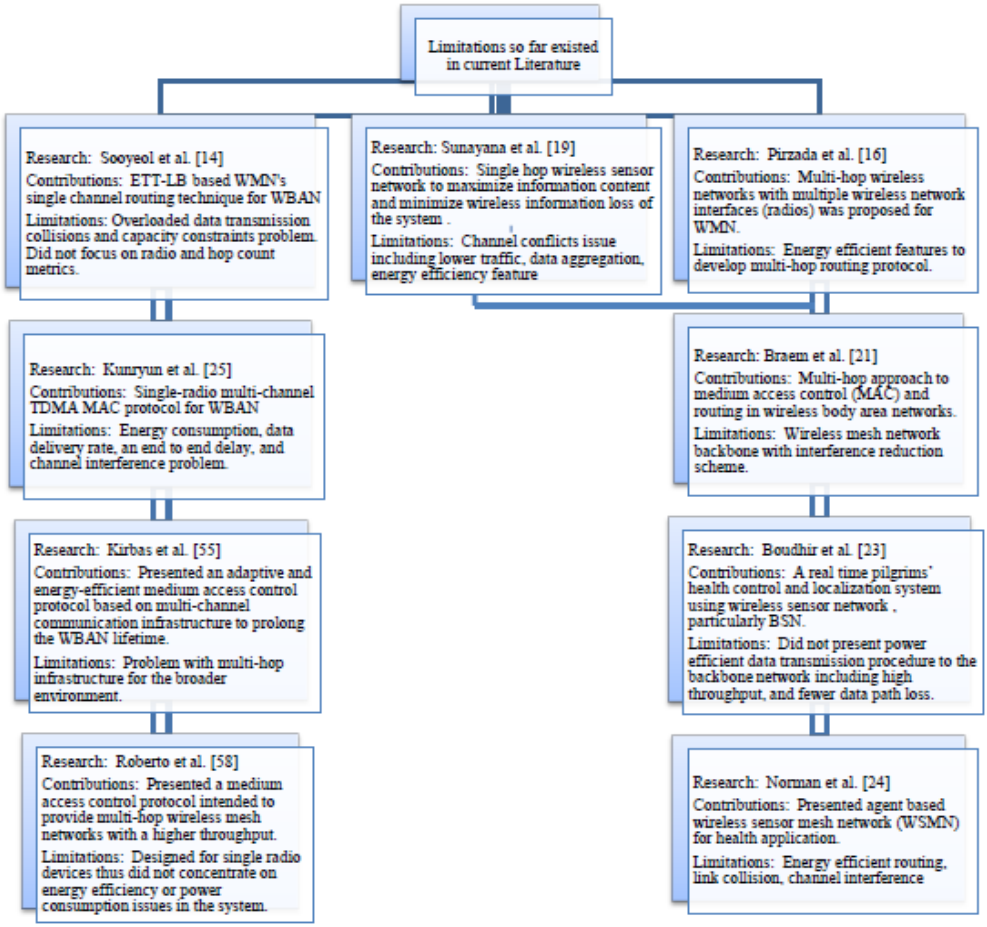


Fig. 1: Exploring Limitations in Order to Deploying WBANs with WMNs at Hajj Ritual Sites.

But, for the medical and health environment like Hajj ritual sites, the WBANs gateway devices should be planned and established in such a way that should facilitate both short-range and long-range wireless links. Moreover, the short-range wireless connection must incorporate I: between the WBANs coordinator (sink node) and the control unit also named as PS (PDAs) via network coordinator (NC) (using ZigBee or Bluetooth interface). II: Between PS and an AP or between the PS and the home server (HS) (using WLAN, Wi-Fi, ZigBee interface). It is notable that, if the PS supports more technologies than a WBAN can easily integrate with other applications. III: Finally, the long-range wireless link must unite with the AP (HS) and the MS through Internet backbone network (using IEEE 802.11s WMNs or WWAN, WiMAX) [65] [66] [67] [69] [70]. It is observed that IEEE 802.15.6, IEEE 802.15.1 and IEEE 802.15.4 have comparatively smaller coverage area than IEEE 802.11a/b/g, and IEEE 802.11a/b/g has relatively shorter coverage than IEEE 802.11s. IEEE 802.15.6 and IEEE 802.16.4 are mainly used in wireless sensor networking especially for managing smart and real-time healthcare environment [71].

Wireless technologies for communication from PS to AP (or HS) are WLAN, Bluetooth, ZigBee, cellular, Wi-Fi, and 3G, etc. If the PS supports more technologies, then a WBAN can easily integrate with other applications. WLAN or IEEE 802.11-based ad-hoc systems use only a single channel thus cannot access wireless last-mile network. Due to the low transmission power and low data rate IEEE 802.15.4 technology, e.g. ZigBee is considered the most popular wireless sensor networks system but suffer from the strong interference by some other wireless network standards, e.g. WLANs which share the same 2.4 GHz ISM band [72]. WLANs are widely implemented to provide hotspot and short-range coverage and are managed by an access point (AP) to integrate with other networks in the environment.

Moreover, WBANs should guarantee energy efficiency, reliability, lower delay, smooth data transmission, low latency and no interference. WBAN is an emerging medical technology consists of tiny sensors which are made up of a single transceiver and consider only a single-channel (data channel) and a single radio (control channel) for transmission at data link layer more specifically at MAC layer. WBANs consider single-hop communications between the sensors and the sink. Therefore it may raise problems such as interference, collision, energy inefficiency and significant latency or delay [73]. Hence, WBANs lead to degradation of performance is categorized as when I. the number as well as the density of sensors increases. II. Interaction between the sensors with WBANs in the same or different environment increases. III. Interaction between the WBANs with other networking technologies in neighbouring environment increases. IV. Information delivery from WBANs (and/ or other wireless or monitoring devices) to a distant gateway of other wireless or wired networking in different environment increases.

WBANs are regarded as dynamic because the body may sometimes in motion walking, running. Hence, reliable communication from WBANs to the personal server (PS) and from PS to medical server (MS) or medical centres or emergency stations through

access points (APs) using various networks for example in short-range communication cellular networks, ZigBee, Wi-Fi, Bluetooth. And for long-range communication for example Internet, or more specifically WLAN, WMAN, or particularly WMN and therefore Internet and its associated technologies are considered as a part of WBANs infrastructure and can be placed in a dynamic environment to handle emergency situations as illustrated in Figure 2.

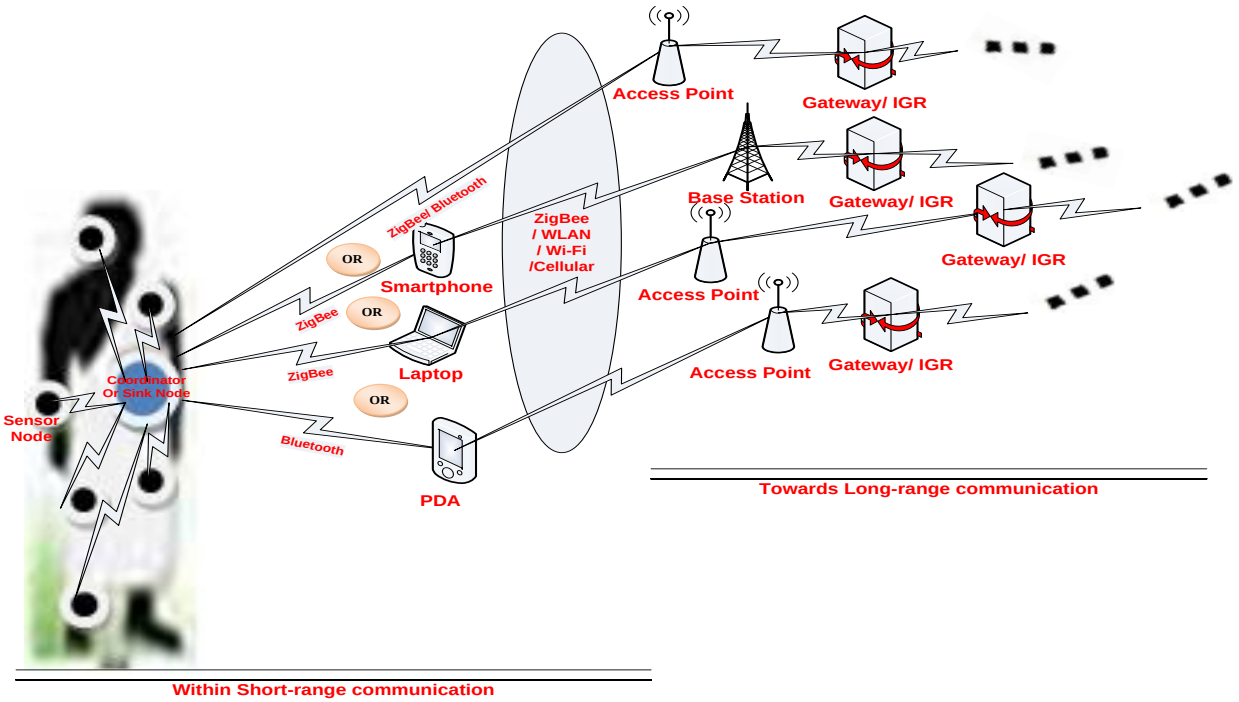


Fig. 2: WBANs Design Perspective.

3.2. MAC perspective

However, MAC provides channel access control mechanisms within a multiple access network, therefore, improving existing MAC protocol with through cooperation at data link layer level will help to encounter these performance degradation problems as mentioned earlier. And it will support and cooperate with WBANs for data transmission in a multi-hop fashion. It will also support WBANs to coordinate with other network technologies and devices in a crowd, and the distant environment in energy efficient and reliable way thus could provide an infrastructure to manage the data traffic route from multiple different sources. Also, this will improve the interaction between WBANs and other networks environment concerning data transmission [74].

WBANs uses RF spectrum require MAC protocol for life-critical data transfer; hence MAC should be energy-efficient for a more extended battery lifetime of tiny nodes, and reliable data transmission. Moreover, a human body having body sensors can represent an obstruction itself for the radio propagation. Also, communications near biological tissue, implanted or in-body; on-body and off-body propagations with inefficient energy MAC can also severely affect body tissues [75].

However, existing MAC protocols presented in [25]-[34] [49]-[50] cannot fully satisfy energy efficiency issue regarding multi-radio (MR), multi-channel (MC) wireless perspectives. An energy efficient TDMA MAC protocol based on single-radio (SR) and multi-channel (SC) was proposed in [25]. This protocol is proposed using unstable star + mesh topology hence it has more end-to-end delay, more interference effect, lower latency, and less throughput or less data delivery rate. Single radio and single channel contention based MAC protocol for WBANs has been proposed in [76]. Although this protocol employs star topology but leads to energy inefficiency. Contention-free single radio and single channel (SRSC) and multi-radio and multi-channel (MRMC) based TDMA MAC protocols have been proposed for WSNs [77] [78] [79]. Also, Dynamic MRMC MAC protocol has been proposed for WSNs [80]. Since the sink node of MAC protocols as stated before is equipped with multiple radio transceivers so it is thought that they can communicate data concurrently and simultaneously on multiple channels. Hence, it can guarantee efficient communication.

WBANs sensor modules consist of a single radio transceiver; hence the MAC protocols proposed for conventional WSNs cannot be implemented for WBANs. As a result, there is a need for MRMC MAC for WBANs. The single-radio mechanism of MAC protocol shows many disadvantages over multi-radio mechanism [26] such as; I. As compared to multi-radio the single-radio mechanism has less data delivery rate II. As compared to multi-radio the single-radio mechanism has more end to end delay. III. As compared to the multi-radio mechanism the single-radio mechanism cannot perform well in case of mobility or interference IV As compared to the long-range transmission of the multi-radio mechanism the single-radio mechanism supports for short-range communication. But, there is only one disadvantage in a multi-radio mechanism, which is V. As compared to single radio mechanisms energy consumption of multi-radio multi-channel mechanism is higher. However, issue V is not applicable for WBANs. Hence it requires energy efficient multi-radio multi-channel infrastructure for MAC. And, so there is a smoldering research issue of developing power efficient as well as reliable MAC for WBANs.

3.3. MAC perspective

Health monitoring in a broad and crowded environment like Hajj ritual sites requires seamless data transmission. Hence, WBAN derived from wireless personal area network (WPAN) requires a multi-hopping wireless medical system for a longer wireless communication incorporate with ICT (Information and communication technologies) infrastructure by extending WLAN to wireless mesh network (WMN IEEE 802.11s) having multi-hop network topology [81]. In WMNs, Internet gateways (IGWs) and wireless mesh routers (MRs) formed wireless backbone network (WBN) through which a mobile client (MC) can access to the Internet where, IGWs act as communication bridges and MRs are interconnected in a multi-hop method [82]. Also, people with chronic diseases it is urgent to continuously monitoring of their

physiological parameters and transferring medical data without range limit. Moreover, due to the radio propagation the human body may represent an obstruction especially when the nodes are implanted. Hence, multi-hop wireless connectivity is one of the primary needs for such critical applications which can extend the communication coverage even if the environment is overcrowded [71] [83].

On the other hand, self-organized, self-healing and self-configured WMN system consists of nodes, e.g. mesh router which communicates using the wireless medium to provide connectivity. To connect the Internet and access through multi-hop path that is established in the wireless backbone, all the nodes and networks infrastructure of WMN communicate in a mesh manner [84] [85].

Hence one of the promising configurations will be the integration of WBAN and WMN, where WBAN can route data towards one or multiple sinks. Under this combined configuration, WMN, communicate in a distributed manner, can provide a gateway for WBANs as well as WSNs and other smart objects as it allows for more bandwidth, and throughput than short-range communication systems such as Bluetooth and ZigBee. In WMN, mesh routers in most cases obligatory to accomplish as the universal and widespread kind of connectivity to have multiple interfaces with numerous wireless network technologies including IEEE 802.11, IEEE 802.15, and IEEE 802.16, cellular techniques which are not restricted to any one technology or protocol [86]. Furthermore, WMN routers connect to other routers and clients using a multi-hop communication and routing protocol to route data through mesh routers towards the healthcare and emergency centers, database and management servers. Thus, the primary functionality of this system is the capability to route data consistently from WBAN to the healthcare and emergency centers, database and management servers.

Also, mesh users are WBANs and relevant ICT attached with pilgrims and ICT of healthcare providers. A backbone mesh network can make connectivity to WLAN, Wi-Fi, WAN, wireless cellular networks and wired networks with gateway bridges that enable the integration of WMNs with other network infrastructures. WMN backbone is connected to wireless mesh users which send data to the mesh router in the range and the mesh router will forward the packets to the next until it reaches to the destination for further processing of the data. The multi-hop fashion of mesh routers allows all the mesh clients to access the internet even if the clients are out of radio frequency (RF) range [87]. This scalable and multi-path routing characteristic of backbone WMN, therefore, could be applied to exploit these mesh connections thoroughly. In this point, from one side pilgrims with WBANs or wireless clients or mesh clients will be able to connect and communicate to the Internet and send their life and time critical data through the web and from other side healthcare providers or wireless clients or mesh clients will be able to access the pilgrims' data.

To boost the signal and sustain signal strength by intermediate nodes which are also responsible for forwarding data packages the mesh architecture makes a series of shorter hops by breaking the long distance. Also, forwarding data from node to node until it reaches the destination such mesh architecture allows steady and relevant reconfiguration and connections around blocked or broken paths. Furthermore, it offers a cost effective; flexible and reliable deployment thus provides high-bandwidth Internet access [88] [89].

Multi-radio WMN is a promising technology that improves the network capability and capacity and reduces interference by utilizing multiple radio channels concurrently thus accurately determines the traffic distribution over links and channels [90] which help reliable data transmission in the over-crowded environment [91]. Therefore, using multi-radio multi-channel mesh routers as WMN backbone is a promising approach which may lead to the further deployment of various wireless networking technologies for example WBAN along with WMN. To optimise the performance of WBAN cautions with using a mesh backbone must address carefully, because at the end this combines WBAN with WMN. In a WMN enabled system, mesh routers form the WMN communicate with the gateway, while sensor nodes form the WBANs connect to the mesh router.

As illustrated in Figure 3, WMNs configuration is comprised of I. least mobility or static wireless mesh routers (WMRs), also called as mesh capable node or mesh points (MPs). For wireless communication, MPs use IEEE 802.11 MAC. MPs support automatic topology and route discovery, effective data packet forwarding. II. Mobile or static wireless mesh clients (WMCs) also called non-mesh stations or stations (STAs) or terminal devices, e.g. smart phones, laptops, and tablets. The basic job of STA is to associate with one of its nearest MAPs, and accesses the Internet. III. Mesh access points (MAPs) equipped with a WLAN AP function are MPs that support the AP function and provides access for STAs. IV. Mesh router with gateway or Internet gateway router (IGR) also called as backbone mesh capable node or mesh point portals (MPPs). Primarily, MPP is an MP that connects to a WMN or similar type of network, e.g. WLAN. MPs together with MAPs and MPPs construct a multi-hop wireless backbone and enables mesh nodes to communicate with external networks, e.g. Internet.

3.4. Integrating WBANS with WMNs

At present, considering various medical and healthcare applications, the development and deployment of WMN enabled WBAN technology for Hajj pilgrims' health monitoring is an exciting and challenging research topic. Thus, the study of MAC protocol of wireless network with high throughput, energy efficiency, and lower delay, has become the critical point in WBAN applications. However, MAC protocols for WBANs communication until recent time are built using short-range, e.g. ZigBee, IEEE 802.15.4, or Bluetooth standards with different power consumption rate [92] which do not support long-range communication hence there is a need for modifying or enhancing the existing MAC protocols for WBANs.

This new WBAN standard can then support multi-radio multi-channel mesh routers (WMN backbone) with a focus on energy efficiency, interference reduction. Thus, WMN can be used to transmit vital information arising from the WBAN to the backbone network. Energy consumption is one of the significant issues of sensor nodes, and this must be as minimal as possible so that the nodes acquire longer life. So, it is in the hands of MAC algorithms to reliably access the channel without collision and interference to ensure energy efficiency and high data rate. Also, the RF part of the WBANs sensors consumes most of the energy. Therefore, MAC protocol can play a significant role in controlling RF module to reduce power consumption [93] [94] [95] hence there is a need for enhancing or modifying existing WBAN MAC protocol which can support multi-radio multi-channel mesh routers with focus on energy efficiency, interference reduction, high throughput, and less latency.

Therefore, deploying WBANs with WMNs for pilgrims health monitoring during Hajj, the cycle may recall as WBAN (sensor nodes and coordinator/sink, interface ZigBee/ Bluetooth) –> WPAN (personal server, Interface Wi-Fi/3G/ GSM/ZigBee/Bluetooth/WLAN/WAN/WiMAX) –> WLAN (LAN) (access points –> Internet gateways) –> WWAN (long-range Internet, Interface WMN/WMAN) –> end-user healthcare monitoring application (through internet gateways –> access points –> emergency healthcare service providers), as depicted in Figure 4.

3.5. Discussion

Mesh users are WBANs and relevant ICT attached with pilgrims and ICT of healthcare providers. A backbone mesh network can make connectivity to WLAN, Wi-Fi, WAN, wireless cellular networks and wired networks with gateway bridges that enable the integration of WMNs with other network infrastructures. WMN backbone is connected to wireless mesh users which send data to the mesh router in the range and the mesh router will forward the

packets to the next until it reaches to the destination for further processing of the data. The multi-hop fashion of mesh routers allows all the mesh clients to access the internet even if the clients are out of radio frequency (RF) range [87].

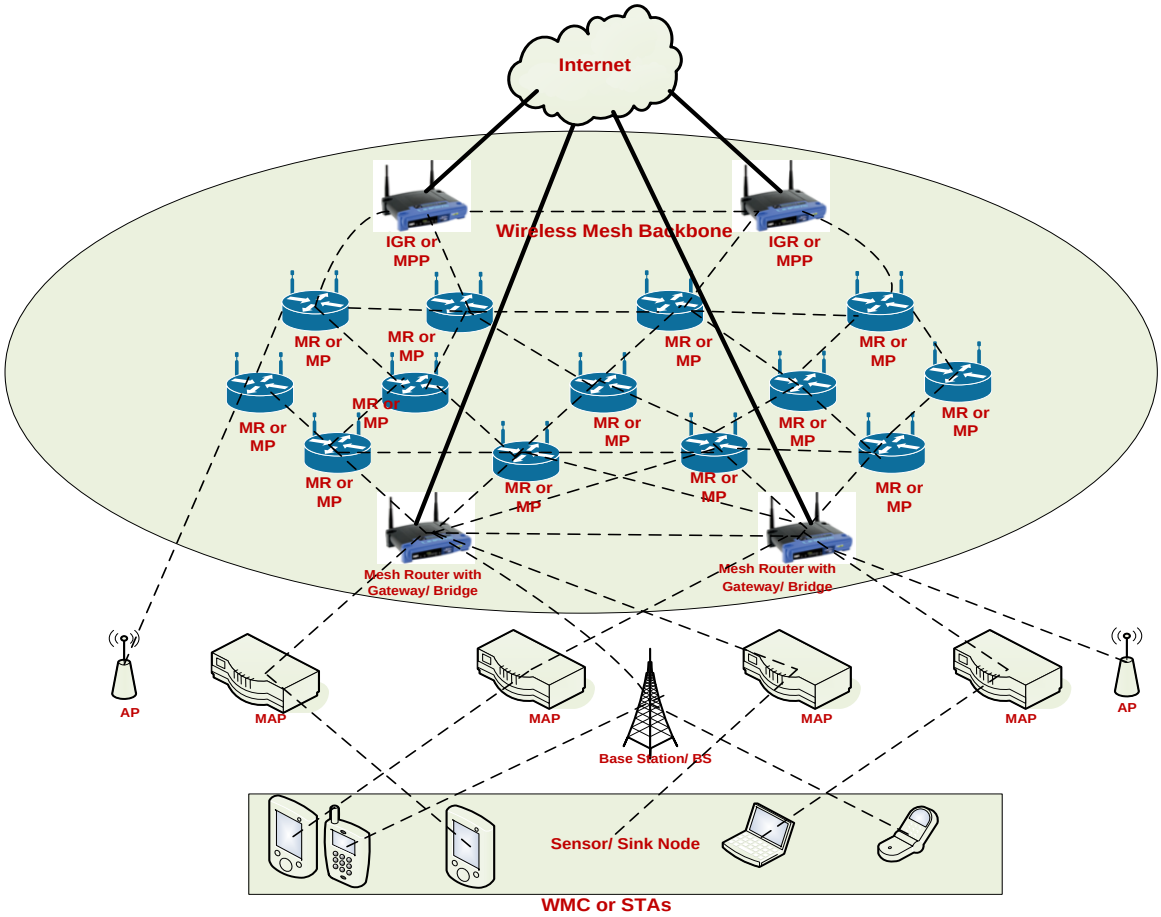


Fig. 3: WMNs Design Perspective.

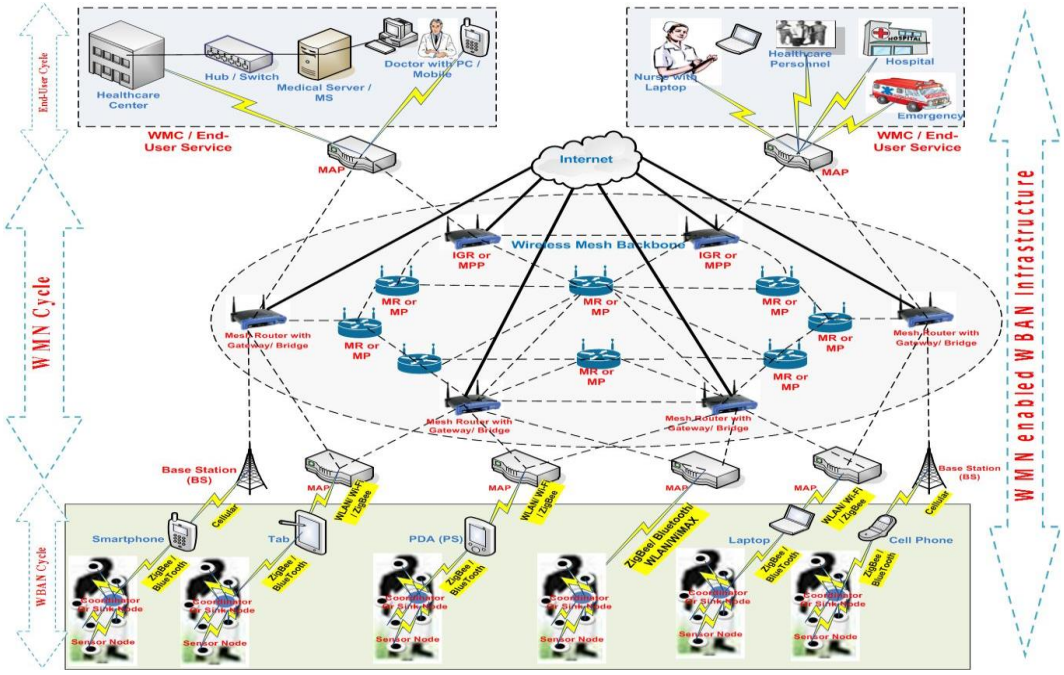


Fig. 4: Proposed model to integrate WBANs with WMNs.

In this point, from one side pilgrims with WBANs or wireless clients or mesh clients will be able to connect to the Internet and send their life and time critical data through the web and from other side healthcare providers or wireless clients or mesh clients will be able to access the pilgrims' data.

Besides, using of multi-radio is a promising technology that improves the network capability, capacity and reduces interference by using multiple radio channels concurrently thus accurately determines the traffic distribution over links and channels [90] which help reliable data transmission in the over-crowded environment [91]. Therefore, using energy efficient multi-radio multi-channel approach at WBAN MAC level may lead to the further deployment of WBAN at Hajj ritual sites with WMN.

4. Conclusion

A literature review and feasibility study have been conducted in this research in order to design a WMNs enabled WBANs system for monitoring pilgrims' health condition during Hajj at overcrowded environment. For smooth and uninterrupted data communication between WBANs nodes and access pints (APs) through the gateway or coordinator node, an energy efficient MAC protocol is proposed for WBANs. A discussion part with future research direction is also presented in this research paper.

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