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Performance Comparison of Different MAC Protocols over Wireless Body Area Networks (WBAN)

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ABSTRACT

Wireless Body Area Networks (WBAN) is referred to as a body sensor network (BSN), is a wireless network of wearable computing devices. Various MAC protocols with objectives have been proposed for WBANs. In this paper is evaluate, analyzing, and comparing the performance of three types of MAC protocols: Tunable Medium Access Control (TMAC), IEEE 802.15.4 (ZIGBEE MAC) and IEEE 802.15.6 (BASELINE MAC), as they are used on wireless body area networks for different performance metrics. The performance evaluation and analysis of the MAC protocols (TMAC, ZIGBEE MAC, and BASELINE MAC) are carried out under different network conditions in order to find the best MAC protocol which is the most suitable for this type of network and also to find how to improve the performance within these type of networks.

INTRODUCTION

Wireless Body Area Networks (WBAN) has emerged as a key technology to provide real-time health monitoring of a patient and diagnose many life threatening diseases (Gopalan, and Park, 2010; Sharavanan *et al.*, 2015). WBAN consists of portable and small sensor nodes, which can be used for long time health monitoring. Using sensing capabilities, these small energy constrained devices measure human body parameters and communicate with some external monitoring station for diagnose and for further analysis as shown in figure 1. WBAN operates near or inside a human body and supports a variety of medical and non-medical applications (Hussain, and Kwak *et al.*, 2009; Sharavanan *et al.*, 2015). Data streaming from human body to monitoring station using wireless communication channel is an energy consuming process. Low power signal processing and energy efficient communication mechanisms prolong lifespan of these small devices (Rahim *et al.*, 2012).

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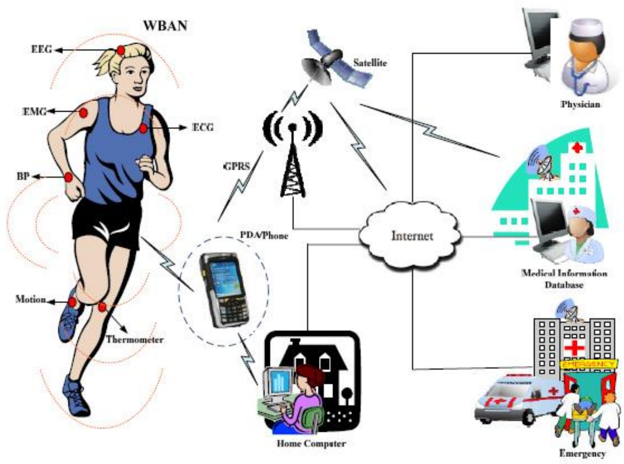

Fig. 1: WBAN Architecture of Medical Applications

In WBANs, sensor nodes of small size with low power and limited computational capabilities are attached or implanted to human body for measurement of physiological signs. These physiological signs include; respiratory patterns, heartbeat, temperature, posture, breathing rate, Electro Cardio Gram (ECG), Electro Encephalo Graphy (EEG) and many more. Transmission data rates for these physiological parameters vary from 1Kbps to 1Mbps. Sensor nodes collect information from human body and communicate with a central device called Coordinator.

Energy efficiency is the most important requirement of a good MAC protocol for WBANs. To improve energy efficiency of WBANs, a versatile MAC protocol should have the capabilities to reduce power dissipation due to collision of packets, overhearing of nodes, idle listening to receive probable data packets and control packet overhead of communication. Similarly, Quality of Service (QoS) is an important goal to achieve in WBANs. This includes latency, jitter, guaranteed communication and security (Rahim *et al.*, 2012; Sruthi, 2016).

The most important parameter in wireless body area networks (WBANs) is the energy efficiency of the system. A medium access control (MAC) layer is the most suitable level to address the energy efficiency (Zheng *et al.*, 2005; Chiras *et al.*, 2005; Barroso *et al.*, 2005; Miller *et al.*, 2005; Sruthi, 2016). This layer is used to coordinate node access to the shared wireless medium. The MAC is the core of communication protocol stack, which provides the basis for achieving Quality of Service (QoS) in any wireless networks. A versatile MAC should support diverse applications and different types of data such as continuous, periodic, burst and non-periodic data along with high level QoS. MAC plays a major determining factor in improving overall network performance. The fundamental task in MAC protocol is to avoid collisions and to prevent simultaneous transmissions while preserving maximum throughput, minimum latency, communication reliability and maximum energy efficiency. It is important to note that while designing MAC protocols one should keep in mind that nodes are prone to failures, constrained capabilities and restricted energy resources (Abidi *et al.*, 2017).

MAC protocols for Wireless Sensor Networks (WSNs) and other short-range wireless technologies use Time Division Multiple Access (TDMA) or Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). Due to complex hardware and high computational power requirements, Frequency Division Multiple Access (FDMA) and Code Division Multiple Access (CDMA) are not suitable approaches for medium access in sensor networks [8]. CSMA/CA approach out performs in dynamic networks. It is presumed that WBANs are not dynamic. TDMA approach is well suited for WBANs. However, TDMA based MAC protocols require extra energy consumption for synchronization (Marinkovic *et al.*, 2009; Bhandari and Moh, 2015).

Therefore, the objective of this paper is to analyze, evaluate, and compare different MAC protocols on WBAN. Many parameters need to be taken into consideration when evaluating and analyzing the performance of MAC protocols, such as power consumption, packet delivery ratio, and packet loss ratio.

Related Work:

Many studies have been undertaken to analyze and evaluate the performance of WBAN under various network environments. This section surveys the most pertinent studies presented in recent years. The core set of application, functional and (Patel, and Wang, 2010) had presented technical requirements of BAN. This study showed that the fundamental challenges of BAN such as scalability (in terms of data rate, power consumption and duty cycle, antenna design, interference mitigation, coexistence, QoS, reliability, security, privacy and energy efficiency. In addition, several candidate technologies had been figured out which poised to address the emerging BAN market, and their merits and demerits are highlighted. On the other hand, a brief overview of standardization activities that related to BANs had been presented in this study.

A comprehensive survey of recent energy-efficient medium access control (MAC) protocols for wireless body area networks (WBANs) presented by (Gopalan, and Park, 2010; Abidi *et al.*, 2017). This study demonstrated a comparison of the various approaches pursued. It outlined the crucial attributes for a good MAC. Several sources that contribute to the energy inefficiency are identified. Then, it investigated a few MAC protocols devised for WBAN by emphasizing their salient features. As a conclusion, this study put forward a number of open research challenges with regard to prospects of medium access techniques and other issues.

IEEE 802.15.4 is a current major technology for low-rate low-power wireless networks. The applicability of IEEE 802.15.4 over a wireless body area network (WBAN) studied in (Li *et al.*, 2009). This study presented an evaluation of three different access schemes' performance of IEEE 802.15.4 over a wireless body area network (WBAN). Considering the coexistence of contention access period (CAP) and contention free period (CFP), it also studied the mutual influences of these two traffics. The results of this study showed that the unslotted mode has better performance than the slotted one in terms of throughput and latency but with the cost of much power consumption. In addition, the guaranteed time slot (GTS) in CFP cannot guarantee the successful transmission of the CFP frames without sufficient GTS allocation. Finally, this study gave the suggestions for the novel medium access control (MAC) design for a WBAN.

Use of a WBAN will also allow the flexibility of setting up a remote monitoring system via either the internet or an intranet. For such medical systems, it is very important that a WBAN can collect and transmit data reliably, and in a timely manner to the monitoring entity. An evaluation of the performance of an IEEE802.15.4/ Zigbee MAC based WBAN operating in different patient monitoring environment is presented by (Khan *et al*., 2008). This research studied the performance of a remote patient monitoring system using an OPNET based simulation model. The simulation results of this study showed that it is possible to monitor patients from remote locations using the WBAN over the internet without reasonable delay. For a remote patient monitoring, two design issues are highlighted in this study. First, a WBAN should not be directly connected to a main hospital network via the service node. With a directly connected WBAN, the service node will continuously transmitting short packets, which reduce the transmission efficiency of network, and increases the transmission delay (Sharavanan *et al*., 2015).

WBAN MAC Protocols:

The most important requirements of WBANs are the energy efficiency of the system, Quality of Service (QoS), and reliable data transmission (Zheng *et al*., 2005; Naik and Sivalingam, 2004). A medium access control (MAC) layer is the most suitable level to address the energy efficiency and effective data transmission while preserving QoS since it is responsible about node access to the shared wireless medium. The main aim of MAC protocol is to avoid simultaneous transmissions while preserving maximum throughput, minimum latency, communication reliability and maximum energy efficiency. The MAC protocol should be able to support different applications and various types of data such as continuous, periodic, burst and non-periodic data along with high level QoS since it plays a major determining factor in improving overall network performance (Sahooa and Sheu, 2017). The next sections demonstrate some of well-known existing MAC protocols proposed for WBANs (Miller *et al*., 2005).

Tunable MAC (TMAC):

Tunable MAC (TMAC) can be known as Timeout MAC, which transmit all messages in bursts of variable length and sleep between bursts. It consists of RTS/ CTS/ ACK Scheme. Its synchronization is nearly similar with the S-MAC. However, it is more save energy than S-MAC (Bhandari and Moh, 2015). Since idle listening is a major source of overhead, TMAC, similar to S-MAC, maintains a sleep-sense cycle. However instead of having a fixed duty cycle like in S-MAC (say 10% sense and 90% sleep), it has a variable duty cycle. The idea is similar to that of a screen-saver. Just as the screen-saver starts after a certain period of inactivity, the node switches itself to a sleep mode when no activation event has occurred for a predetermined period. The activation event can be a reception of some data, expiration of some timer, sensing of the communication, knowledge of an impending data reception through neighbors' RTS/CTS and so on. Synchronization of the schedules is achieved in an exactly similar manner as S-MAC through the scheme dubbed as virtual clustering (Naik and Sivalingam, 2004). T-MAC uses a fixed contention interval to send an RTS. A special case arises in the RTS transmission due to the dynamic duty cycle. When a node sends an RTS, it may not get CTS back if that RTS was lost or if the receiving node could not transmit because one or more of its neighbors were communicating. In this case, the sender node might go to sleep if it does not hear CTS for the predetermined time, resulting in a reduced throughput. To correct this problem, T-MAC specifies that the RTS be sent twice before the sender gives up (Naik and Sivalingam, 2004). Due to the "early problem" of T-MAC, it will limit the maximum output and will cause problem in transmitting data. Further testing on real sensors is needed for this T-MAC.

IEEE 802.15.4 MAC (Zigbee MAC):

IEEE 802.15.4 is a new standard to address the need for low-rate low-power low-cost wireless networking. IEEE 802.15.4 is a standard, which specifies the physical layer, and media access control for low-rate wireless personal area networks (LR-WPANs). The IEEE 802.15 working group (Ranjan, 2016) maintains it. The goal of IEEE 802.15.4 is to provide a physical-layer and MAC-layer standard with ultra-low complexity, cost, and power for low data-rate wireless connectivity among cheap fixed devices (Xin, 2012). The IEEE 802.15.4 standard supports multiple network topologies, including both star and peer-to-peer networks depending on the application requirements.

The MAC protocol in IEEE 802.15.4 can operate on both beacon enabled and non-beacon modes. In the beaconless mode, the protocol is essentially a simple CSMA-CA protocol. Since most of the unique features of IEEE 802.15.4 are in the beacon-enabled mode (Ranjan, 2016).

The MAC sub layer provides two services: the MAC data service and the MAC management service interfacing to the MAC sub layer management entity (MLME) service access point (SAP) (MLMESAP). The MAC data service enables the transmission and reception of MAC protocol data units (MPDU) across the PHY data service (Ergen, 2004; Yassein *et al*., 2016).

The features of MAC sub layer are beacon management, channel access, GTS management, frame validation, acknowledged frame delivery, association and disassociation.

IEEE 802.15.6 MAC (BASELINE BAN MAC):

IEEE 802.15.6 is a bit elusive, but some of the available information points to some kind of wireless BANs. It is possible that it is meant to be the WBAN Study Group Medical Body Area Networks (SG-MBAN), but that group has not yet released any standards. SG-MBAN’s meeting minutes from their meeting in Montreal, May 2007 indicates that the group name has not been clarified as one of their members asked if the group title will be 15.5x or 15.6 without getting an answer (Astrin *et al.*, 2009; kohno *et al.*, 2008; Kaur, 2016).

According to their meeting minutes from San Fransisco, July 2007 and the Montreal meeting minutes, the frequency band has not yet been clarified (Kwak *et al*., 2010).

IEEE 802.15.6 will define both PHY and MAC layers. The current IEEE 802.15.6 standard defines three PHY layers, i.e., Narrowband (NB), Ultra wideband (UWB), and Human Body Communications (HBC) layers. The selection of each PHY depends on the application requirements. On the top of it, the standard defines a sophisticated MAC protocol that controls access to the channel (Kaur, 2016).

For time referenced resource allocations, the hub (or the coordinator) divides the time axis (or the channel) into a series of super frames. The super frames are bounded by beacon periods of equal length. To ensure high-level security, the standard defines three levels (Saleem *et al*., 2011):

- Level 0 - unsecured communication
- Level 1 – authentication only
- Level 2 - both authentication and encryption.

Network Modeling and Simulation Setup:

OMNeT++ ver. 4.1, (Varga, 1999) is used to model the WBAN evaluation scenarios. The designed models with an extensive set of parameters are performed to evaluate and analyze the performance of different MAC protocols over WBAN, in order to find the best protocol, which can be used in this type of networks. The evaluation of the WBAN using different MAC protocols is done with the following model specifications:

- 5, 10, 15, 20, and 25 sensors are distributed randomly on human body in different positions.
- All sensors streaming its data to a monitoring station located 10m away from the human body.
- The size of data packet is 8 byte.
- The values of data rate used are 5,10,15,20 and 25 packets / second.
- All the nodes using UDP traffic sources.
- Data transfer rate is 54 Mbps.
- All experiments tested for 250 seconds simulation time.
- Radio TX Output Power is set to be -15dBm.
- Tunable MAC (TMAC), IEEE 802.15.4 MAC (Zigbee MAC), and IEEE 802.15.6 MAC (BASELINE BAN MAC) are used as a MAC protocols.

4.1. Evaluation Scenarios:

Two evaluation scenarios are carried out under different network environments to compare, evaluate and analyze the performance of different MAC protocols for the Wireless Body Area Network (WBAN); these are:

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A. Varying network density by changing BAN number of nodes, to evaluate the effects of contention on power consumption and packet delivery ratio (PDR).

B. Varying packet rate to evaluate the effects of offered load on the performance of BAN.

4.2. Analysis Metrics:

The metrics, which are selected to compare and analyze the performance of different MAC protocols for the Wireless Body Area Network (WBAN), are:

- Power consumption: represent the amount of the power consumed by the node to perform the networking process (reading the data from the human body, handshaking, processing the data, and transmission the data).
- Packet Loss -- represents the difference between the number of packets sent by the source node and the packets received at the destination node.
- Packet Delivery ratio (PDR) -- represents the ratio between the numbers of packets received by the destination to the number of packets sent by the source.

RESULT AND DISCUSSION

Two types of experiments were carried out to evaluate and analyze the impact of number of nodes variations and packet rate variation on the performance of different MAC protocols over wireless body area network. Both experiments are performed to find the best MAC protocol, which can be used in WBAN and how to improve the performance of these protocols over WBAN. These experiments are:

Figure 2 shows the power consumption versus the number of nodes. There are three plots, each corresponding to a different MAC protocol. Figure 2 shows that the power consumed is inconsistently changing due different capability of nodes. Moreover, the figure shows that the power consumption of TMAC is the lowest than BMAC by 45.6% and ZMAC by 82.4%. This is because that the TMAC, maintains a sleep-sense cycle, however instead of having a fixed duty cycle, it has a variable duty cycle and the nodes switches itself to a sleep mode when no activation event has occurred for a predetermined time period which leads to saving the power.

Figure 3 shows number of lost packets versus the number of nodes. There are three plots, each corresponding to a different MAC protocol. Figure 3 show that the number of lost packets at using ZMAC is the lower than number of lost packets at using TMAC by 69.6% and BMAC by 84.2%. This is because ZMAC can operate on both beacon and non-beacon modes which lead to improve the ability of this protocol to deals with packet collision.

On the other hand, Figure 4 shows that the packet delivery ratio is inconsistently changing due to the occurrence of packet collision or packet dropped. The figure demonstrates that the performance of ZMAC in BAN is better than TMAC by 12.8% and BMAC by 29.7% with respect to the number of lost packets while changing BAN node number.

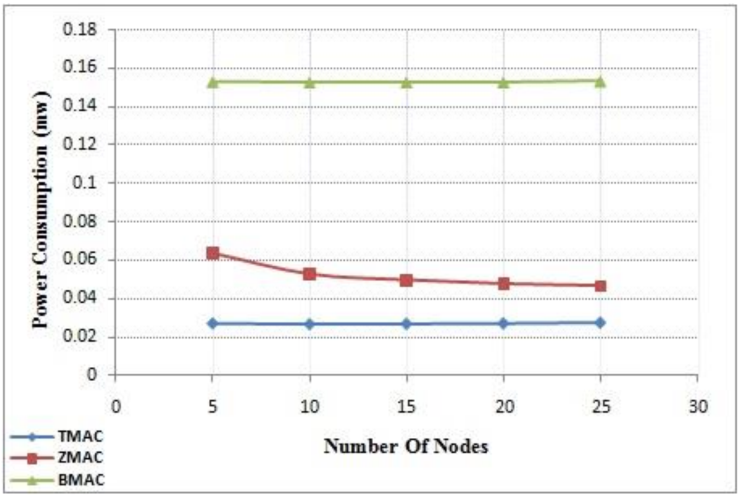

Fig. 2: Power Consumption vs. Number of Nodes for Different MAC Protocols over WBAN

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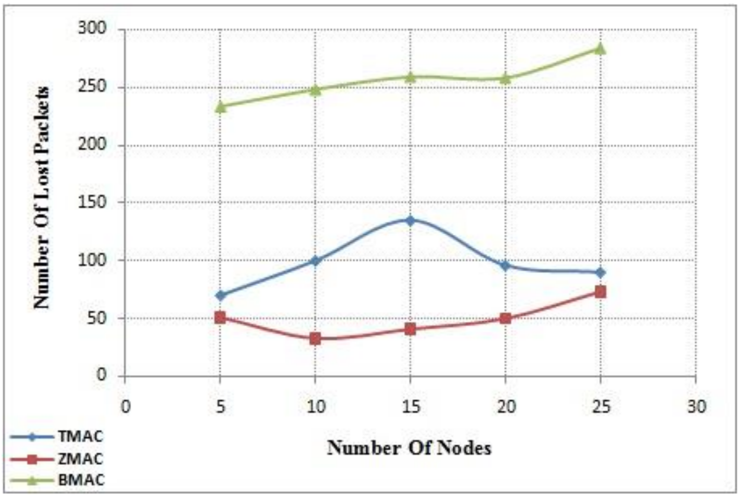

Fig. 3: Number of lost Packets vs. Number of Nodes for Different MAC Protocols over WBAN

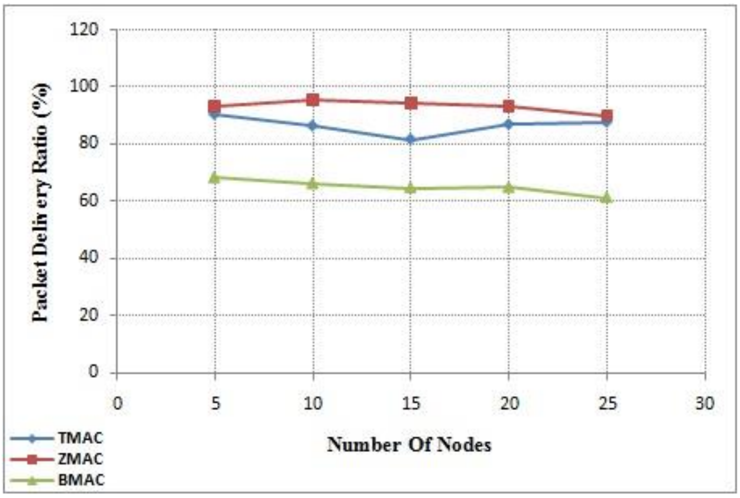

Fig. 4: Packet Delivery Ratio vs. Number of Nodes for Different MAC Protocols over WBAN

Conclusion:

In this paper presents a review of three types of MAC protocols for WBAN, the aim of performance assessment of these protocols mechanisms (TMAC, ZIGBEE MAC, and BASELINE MAC), is to provide a suitable and appropriate wireless technologies for such network. The simulation results show that the ZMAC is better than TMAC and BMAC in term of the number of lost packet and the packet deliver ratio. TMAC is better than ZMAC and BMAC in term of the power consumption which the last has an overeating problem doesn't solve and increases the power consumption so is good for normal traffic application, even TMAC is suffering from sleeping problem, TMAC has good adaptabilities to charging traffic condition. Overall, our resulting indicate that there are important tradeoffs that should be seriously taken in to consideration when choosing a protocol for WBAN.

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