An Analysis of Energy Efficient Wireless Body Area Sensor Networks of MAC Protocols

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Abstract— *In this paper, we provide a survey of energy-efficient medium access control (MAC) protocols for wireless body area networks (WBANs). The bottleneck of WBAN is the MAC protocols which are designed to achieve high reliability, energy minimization, low power consumption and reduction of latency. For this purpose, different approaches and techniques of energy-efficient MAC protocols like Low Power Listening (LPL), Schedule Contention, PCM, Duty Cycling, CDMA & TDMA are elaborated due to their significance in solving issues of energy dissipation, traffic control mechanisms for collision avoidance and power consumptions, etc. The survey suggests that there are so many techniques employed to make WBANS energy efficient like LPL, schedule and contention and TDMA. However, the web layer, physical layer, and radio frequency communication need to be considered for energy minimization.*

Keywords— *Energy Efficiency, Medium Access Control Protocols, Wireless Body Area Network*

1. Introduction

Wireless body area networks (WBANs) are a particular type of sensor network using wireless sensor nodes on a per- son's body to measure physiological parameters such as blood pressure, body temperature, heart rate, and blood sugar level, enabling a patient's health to be monitored remotely [1]

With the rapid growth and development of WBAN, persistent health monitoring has become a wide area of research. Continuous monitoring of physiological parameters and detecting the emergencies improves the patient's health status data log and quality of liveliness.
There are three stages in WBAN; The First stage is low-power sensors that are based on battery, sensor nodes must be run for a long duration of time without maintenance and repair [2]. Second is the master node which is the coordinator or the gateway node which contains multiple small nodes. Its energy requirement must be more vulnerable than nodes due to its suppleness [3]. The last stage is the metropolitan area or network that provides health monitoring purpose[4]. As is shown in Fig .1 the best manner to save power, optimize and enhance energy efficiency is the MAC protocol that operates at the data link layer. The major sources of energy wastage are a collision of packets, idle listening, traffic fluctuations, over-emitting, overhearing and control overheads, etc. [5]

As is shown in Fig .2 most of the power is consumed during the communication process because of the data that is transmitted from the nodes to the master node which cause collision of packets, delay in packets as well as traffic fluctuation. With regard to enhance and boost the reliability and the performances of the network MAC protocol's different wake-up mechanisms are applied.

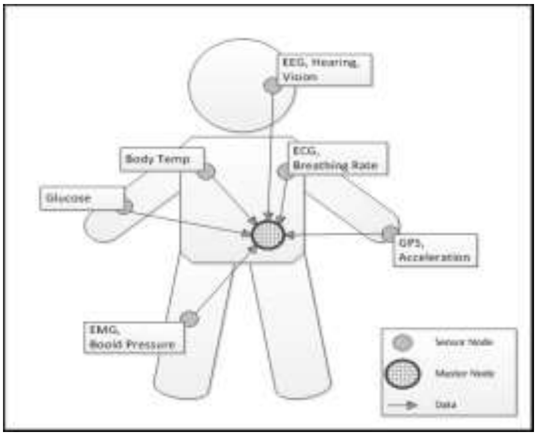


Figure 1. An Example of WBAN Constitution

2. Literature Review

Ullah, F., et al [6] discussed about the four different types of MAC protocols, namely energy efficient Medium Access Control (MAC), Med MAC, Low Duty Cycle MAC, and Body MAC. Some important core sources of wastage have been considered in this paper and scores of work has been made in the network layer, cross layer and data link layer.
Salim . A in [7] has also discussed about the design challenges of three MAC protocols, techniques for the data traffics including energy minimization techniques, frame Structures and network architecture.
Longman . E in [8] discusses and provides the techniques for MAC energy efficient protocols for WBAN that are Low power Listening (LPL), Time Division Multiple Access (TDMA) and Schedule Contention.
The Five major approaches that are applied for energy efficient mechanisms are Low Power Listening, Schedule Contention, PCM; PCMA; CDMA & TDMA.

2.1 LPL

Low Power Listening is the process in which the node awakes for a little period of time and checks the action of the channel, if the channel is inoperative, then it will transmit the data at once and if the channel is non operative it will remain in an inactive state, which obtains information from nodes and return to sleep mode if no activity is observed. It is very robust; there is no synchronization and instant recovery after channel disruption. This is also called channel polling [9]. If a sender wants to transmit a message, it sends an extended preamble to make sure that the receiver is listening for the packets. The preamble is the size of the sleep period. Low power listening is responsive to traffic routes which causes attenuation and affects the performance of the system.

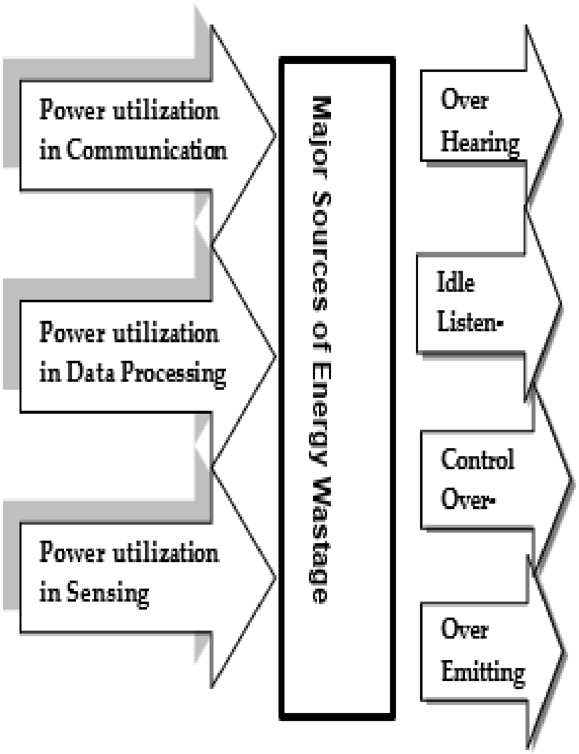


Fig. 2. Sources of Power Consumption

Wise Mac Protocols are based on low power listening. This protocol reduces the idle listening through non-persistence strategy of CSMA and preamble sampling techniques [10].
CSMA is the carrier sense multiple access, Fig. 3 & Fig. 4 shows that chances of collision reduce by sensing the medium before transmitting whereas propagation delay hinders the elimination of collisions. The non-persistent strategy defines procedure for a station that senses a busy medium.

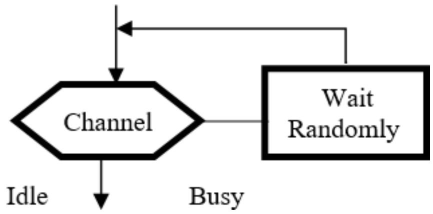


Fig. 3. Non-persistent strategy

2.2 Schedule Contention

Schedule contentions are the combinations of schedule and contention mechanisms that reduce effectively the collisions and scalability problems. In contention based, the nodes try to transfer data that caused the channel to disrupt and results in access failure and then the probability of chances of collision increases rapidly for the packages. Contention is based on CSMA/CA which is carrier sense multiple access collision avoidance that is performed by the CCA carrier channel assessment before transmitting data [11]. In contention based if the channel is full of activity the nodes defer its transmission till it becomes idle. It holds a good adaptability for traffic fluctuation [12].

Scheduling means that the sensor nodes have a schedule for transmission of information in the form of bandwidth or time slots. Channels are separated into fixed or variable timeslots which are assigned to nodes that transmits during its time period. It is free of Idle Listening, overhearing and collision of packets because of lack of medium competitors.

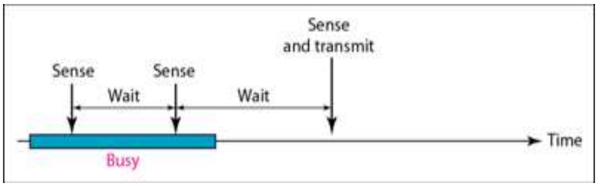


Fig. 4. Non-persistent strategy

Examples of scheduling include TDMA FDMA and CDMA on the other hand FDMA and CDMA are not widely used strategies due to computational load and frequency limitations. This requires time synchronization. In a time division multiple accesses are the most efficient scheduling mechanism but requires more power consumption due to synchronization.
Shaker A.S. et al. in [13] introduces S-MAC (sensor medium access control). In this all nodes pursue coordinated inactive mode among their adjoining nodes, because the low duty cycle is set as the pre-selected mode. This increases the chance of the response time. All nodes choose and announce for awake schedule synchronization is must for the awake schedules for the adjoining nodes.

This reduces the idle listening, overhearing and collision of packets Fig. 5 shows that the nodes turn on for transmission otherwise remains in sleep state to S-MAC users in-channel signaling. Whereas, in-channeling reduces the overhear issues and prevents the use of extra channel resources. Sensor MAC reduces latency up to 50% of intense traffic and saves more power for low traffic. It causes the traffic condition, according to its latency and energy.

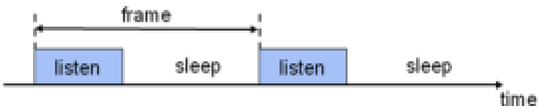


Fig. 5. The nodes scheduling frames

2.3 TDMA

In TDMA, the bandwidth of the channel is just Timeshared; it is a data link layer protocol that uses TDM at the physical layer. The time slots are assigned to the sensor nodes by the master node. Traffic rate is the key source that allows the nodes to coordinate with each slot time for the contending and scheduling nodes. Whoever the synchronization degrades the performance in relation to power consumption, but it has highly clock wandering which reduces the throughput. TDMA enables dynamic and flexible slot allocation in a collision free environment. It applies the channel traffic rate and adapts better heterogeneous traffic. Preamble based TDMA protocols [14] are one of the types of TDMA. The relationship of TDMA and CSMA/CA is shown in Table I.

	TDMA	CSMA/CA
Power Consumption	Low	High
Traffic level	High	Low
Scalability	Poor	Good
Effect of packet crash	Latency	Low
Bandwidth utilization	Maximum	Low
Synchronization	Required	Not applied/valid

Table I. TDMA VS CSMA/CA

2.4 *CDMA*

Code Division Multiple Access (CDMA) is based on DSSS, which is called a direct sequence spread spectrum encoding technique. In CDMA one channel carries all transmissions simultaneously. It varies from FDMA and TDMA because only one channel engages the entire bandwidth and all stations can send data simultaneously. In CDMA systems [15] all users contribute to the same frequency, but every sender and receiver is allocated a Pseudo Random Noise (PN) code [16]. Before transmissions the data packets get Exor-ed with the PN code and then again Exor-ed with the PN code at the receiver side for proper decoding.

Every signal is allocated a unique code; therefore, every same code will occupy the same channel. Yet, there is some deficiency in CDMA, which degrades the performance of a network throughput and data traffics.

Orthogonal codes are wasted in this situation, but CDMA can't reduce the probability of idle listening because idle listening consumes a high sum of vitality and in CDMA there is also limited data transmission rate.

2.5 *PCM*

Power control MAC in [17] proposed that the packets that are transmitted should be selected with respect to power, In PCM the request to send and clear to send packets are transmitted with power maximum Pmax. Packets are sent at low power level in order to prevent collision of packets figure 6. Packets are acknowledged for a minimum level of power to save the system from causing degradation in signals to reach the nodes. It periodically increases power levels and melt off the collision of packets with less energy levels as shown in figure 7

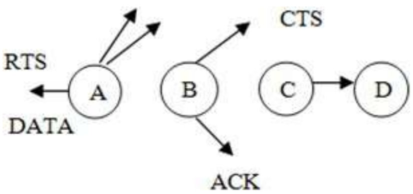


Fig. 6. PCM scheme

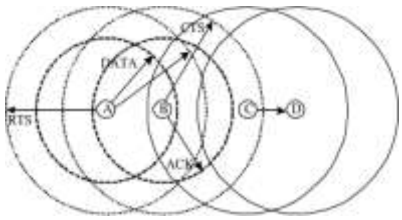


Fig. 7. Data packets transmitted periodically

2.6 PCMA

Power Controlled Multiple Access is an efficient and flexible "bounded variable power control" which is the suppression of collision that allows variable power stages to send on a per packet base. PCM plays a critical role with the use of APTS or RPTS which is the Acceptable Power to Send or Request Power to Send. PCMA involves another channel which is the busy signal used for advertisement of noise tolerance[18]. During each interval of time the parcels that are shipped to the receiver periodically sends a busy signal to advertise the maximum tolerance level of the additional noise. PCMA uses this technique to bind the transmission level of the neighboring nodes. The goal of the PCMA is to reach at a desired level of SINR which is signal to interference noise ratio, thus a link is established between nodes for communication.

2.7 DCA-PC

The multi-channel MAC protocol which is Dynamic Channel Assignment (DCA) strategy which controls power proposed in [19]can solve the problem of channel assignment, medium access and force control. Firstly, it firmly assigns channels to nodes in an 'On Demand' manner. The origin and destination nodes use RTS/CTS at which power level will transfer the information. To reserve data channels RES messages are used, then the packets of data and ACK acknowledgments are sent along the reserve data channel. By utilizing multiple data channels, it reduces the normalized propagation delay of packets and increase throughputs of energy efficiency without power consumption mechanisms.

2.8 DTDMA & PB-TDMA

PB-TDMA was proposed in [20], a TDMA contains a preamble time slot for transmission of packages. With this preamble the node receives a dedicated subs slot and uses it to send to the id node to the goal. Neighboring nodes listens to the preamble and maintain records for the time slots to receive packets so as to ward off unnecessary power use.

In fig. 8 this preamble is implemented in the middle of the data structure which applies to all nodes. Each node writes the destination identity into its sub slot in the preamble for a packet to send at the beginning of the frames. Every node contains the preamble of the transmission slot whether the data has sent or not, to determine whether the packets are picked up in the other slots.

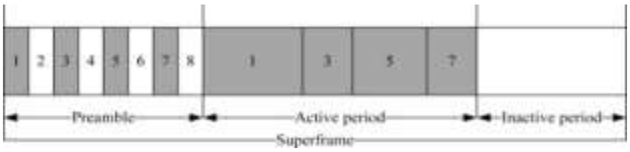


Fig.8. PB-TDMA Super Frame Structure

The Reserved based Dynamic TDMA (DTDMA) was suggested in [10] which also practice time slots for data transmitting [21]. This approach has a large amount of requirement for WBAN that includes limitation of power consumption.

In DTDMA, the channels used super frame structures. Every super frame uses a beacon at each frame and at each channel allocation; there is a CFP which is a configurable period for data transmission. A CAP period (Contention Access Period) are used in the Slotted aloha protocols, and in inactive slot time configurable period to save energy. The DTDMA uses CFP duration of the CAP period in order to transmit information at the CFP traffic time earlier than CAP. If there is no CFP period available, then the inactive time period will not increase. The super frame structure is given by fig. 9.

The subjects that are designed for DTDMA are as follows:

(a) Properly responding to various conditions like regularity of traffic, on demand conditions and emergency
(b) Minimization for successful packet propagation delay
(c) By using Dynamic channel allocation scheme, Improvements in the channel utilization rate
(d) Keeping duty cycle of sensor nodes as well as power consumption at minimum level and lengthening the life.

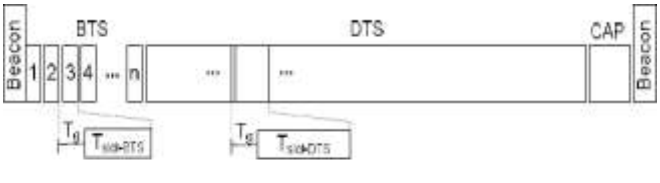


Fig. 9. DTDMA Structure frame using Beacons, CAP period and CFP periods

2.9 Adaptive Reliable MAC

Rahim et al proposed in [22] an adaptive and reliable MAC that is practiced to avoid collision, adaptive guard bands are put through. It utilizes a star topology with a middle node with the channel access TDMA approach. This attack is based on Synchronization, and the nodes used dedicated path to build a communication link. AR-MAC is based on Time Division Medium Access approach to reduce energy usage. It allocates GTS which is guaranteed time slot to every sensor node for communication.

This can reduce over-hearing and idle listening between nodes when communication goes. According to nodes requirement, it uses periodically sleep and wake up mechanisms, it creates a star topology between the child nodes and key nodes (CN) and communication with a base station (BS) through Access point (AP). As in Fig. 10. A total time (T) frame is assigned to all the nodes having three components including Contention Free Period (CFP), Contention Access Period (CAP) to provide emergency on need basis and time for communication (T) of the master node.

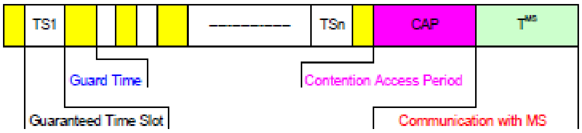


Fig. 10. Time Slot Assignment and GTS

In Channel selection, the CN has to scan the RF channel signal first, if it is busy then switches to another RF channel. If founds free then successful transmission. If the channel is active, it will wait for the (T) packets of the channel. If nodes don't receive packets, then again switches to the next channel. After the reception and transmission, they will (ACK) acknowledged packets for the CN.

In time slots assignments after receiving the packets from the channel it sends out a (TSR) time slot request packets to CN.TSR contains time slot information as easily as data rates of the sensor nodes. Author in [23] proposed fixed length of time slots and set up a time for the guard bands Tgb.

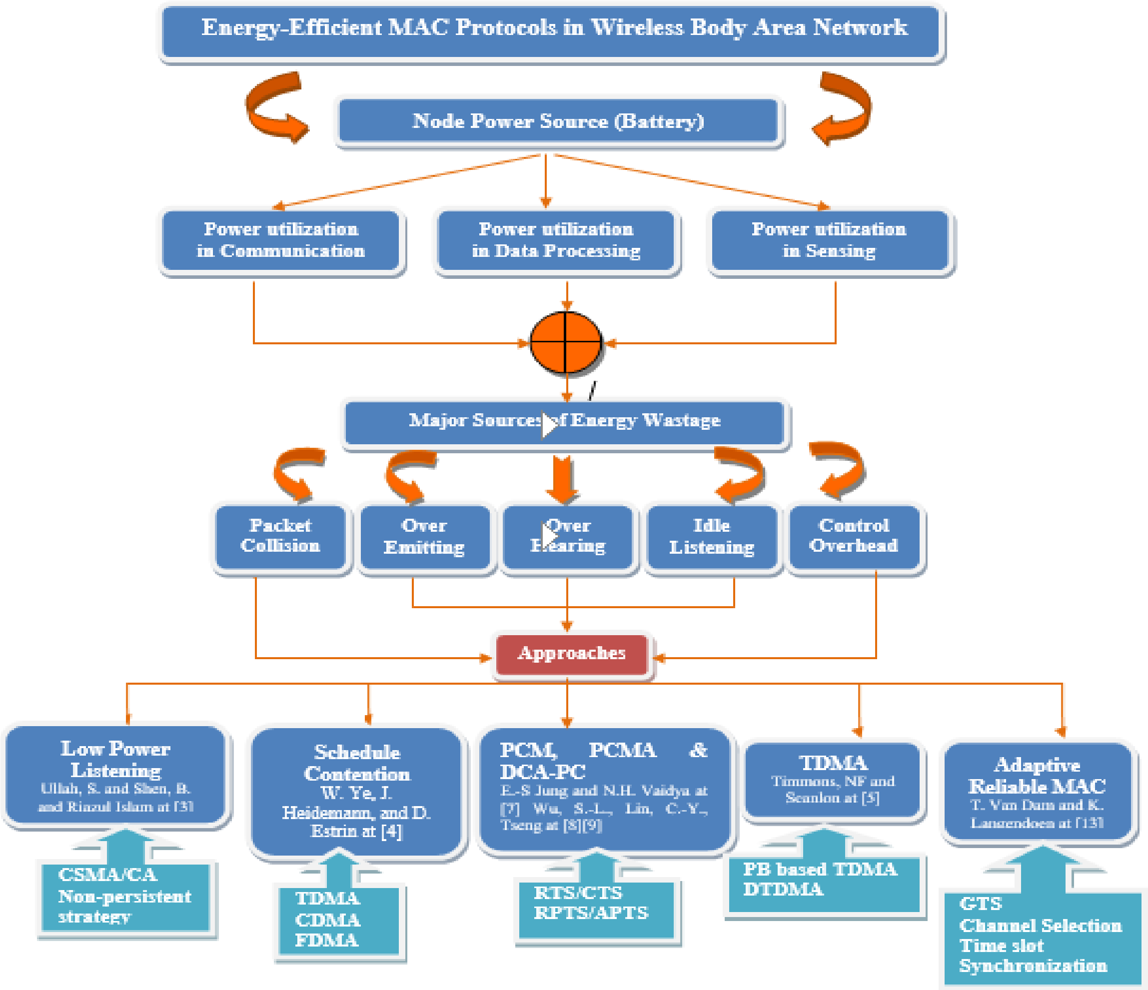
Adaptive reliable MAC uses adaptive time slot schemes for the time slots (TS) and GBT time. Child nodes allocate time slots and carry the time slot request reply which is denoted by (TSSR), these time slots are of varying length depending on the necessity of the sensor nodes. So, by assigning time slots and acknowledgements it responds to more capital and efficient transmissions for the nodes in the communication link. Guard band time is introduced due to avoid interference which is done by the wandering of the clock of the sensor nodes. Mathematics of the Guard band time is accomplished by

$$T_{n,n+1}^{GB} = \frac{F}{100} \times \frac{1}{2}[TS_n + TS_{n+1}] \quad (1)$$

$$T_1^{GB} = \frac{F \times TS_1}{100} \quad (2)$$

$$T_n^{GB} = \frac{F \times TS_n}{100} \quad (3)$$

3. Literature Map



4. Key Findings

In wireless body area sensor network there are three roots of power expenditure, i.e. power consumption in communication, data processing, and sensing. And there are five major sources of power wastage in WBANS that are packet collision, over emitting, idle listening, overhearing, and control overhead. In this respect, there are some techniques to resolve these problems i.e. LPL, Schedule contention, PCM, PCMA, CDMA & Dynamic TDMA PB-TDMA as well as other efficient MAC protocols include wise MAC, AR-MAC, Body MAC, MED MAC to avoid energy and power sources to increase efficiency and reliability in communication link established between the clients.

LPL is a type of polling. In LPL, if the sensors have data to send then sensor nodes awakes for a little period of time and sense the channel to carry that data, if the channel is idle it sends the data and if the channel is not idle it goes back to the snooze mode. This cuts down the idle listening.

Whereas, Schedule Contention is a blend of schedule and contention mechanisms that reduces the collision problems. For which there are three techniques like TDMA, FDMA, and CDMA.

FDMA and CDMA are not widely practiced because of bandwidth limitations and computational burden. In TDMA limited bandwidth is split up into time slots and data will transmit through these time slots therefore the problem of collision reduces.

In S-MAC (Sensor Medium Access Control) all nodes follow coordinated sleeping mode among their adjoining nodes, because the low duty cycle is set as the default style. This increases the chance of the response time. All nodes choose and announce for awake schedule synchronization is must for the awake schedules for the adjoining nodes.

We see four different cases of MAC protocols, namely energy efficient MAC, MED MAC, Low Duty Cycle MAC, and Body MAC. Close to important key sources of wastage has been hashed out in this paper and a lot of study has been performed in the network layer, cross layer, and data layer.

In PCM the request to send and clear to send packets are carried with maximum power. Packets are sent at low power level in order to prevent collision of packets.

The Power Controlled Multiple Access (PCMA) is an efficient and flexible "bounded variable power control" which is the suppression of collision that allows variable power stages to send on a per packet base. PCM plays a critical role with the use of APTS or RPTS which is the Acceptable Power to Send or Request Power to Send) for the minimum transmission of power required to broadcast the data at the recipient.

In DCA-PC Dynamic Channel Assignment Strategy the source and destination nodes use RTS/CTS at which power level will transfer the information. To reserve data channels RES messages are used, then the packets of data and ACK acknowledgments are sent along the reserve data channel.

By utilizing multiple data channels reduces the normalized propagation delay of packets and increase throughputs of energy efficiency and no power utilization mechanisms involved.

In PB-TDMA contains a preamble time slot for transmission of packages. With this preamble the node receives a dedicated subs slot and uses it to send the id node to the goal. Neighboring nodes listen in the preamble and maintain records for the time slots to receive packets so as to ward off unnecessary power use.

In adaptive, reliable MAC that is practiced to avoid collision, adaptive guard bands are put through. It utilizes a star topology with a middle node with the channel access TDMA approach.

Adaptive reliable MAC uses adaptive time slot schemes for the time slots (TS) and GBT time. Child nodes allocate time slots and carry the time slot request reply which is denoted by (TSSR), these time slots are of inconsistent length depend on the necessity of the sensor nodes.

So by assigning time slots and acknowledgements it responds to more capital and efficient transmissions for the nodes in the communication link. Guard band time is introduced to avoid interference which is done by the wandering of the clock of the sensor nodes.

5. Open Area

The predominant concern in WBANs pertains to energy efficiency, standing as the primary goal to achieve within this domain. A multitude of approaches are implemented to enhance the energy efficiency of WBANs, encompassing methods such as Low Power Listening (LPL), scheduling, contention, and TDMA. However, achieving optimal energy conservation necessitates the comprehensive assessment of factors spanning the web layer, physical layer, and radio frequency communication.

6. Conclusion

The objective of this type of research is to introduce MAC protocols for WBANs, focusing on reducing energy consumption. These specific exercises aim to prolong the lifespan of WBANs while ensuring dependable communication, adaptability, equitable management, and Quality of Service (QoS). However, MAC protocols based on random access and Low Power Listening (LPL) are insufficient for addressing urgent and on-demand traffic. Conversely, Time Division Multiple Access (TDMA) emerges as a crucial strategy for channel utilization in WBANs. Due to varying application requirements and hardware constraints, no single protocol has been identified as a definitive solution.

REFERENCES

1. Yaghoubi, M., K. Ahmed, and Y. Miao, *Wireless body area network (WBAN): A survey on architecture, technologies, energy consumption, and security challenges.* Journal of Sensor and Actuator Networks, 2022. **11**(4): p. 67.
2. Iftikhar, A., et al., *Efficient Energy and Delay Reduction Model for Wireless Sensor Networks.* Comput. Syst. Sci. Eng., 2023. **46**(1): p. 1153-1168.
3. Bhattasali, T. and R. Chaki. *A survey of recent intrusion detection systems for wireless sensor network*. in *Advances in Network Security and Applications: 4th International Conference, CNSA 2011, Chennai, India, July 15-17, 2011 4*. 2011. Springer.
4. Jabirullah, M., et al. *Development of e-health monitoring system for remote rural community of India.* in *2020 7th International Conference on Signal Processing and Integrated Networks (SPIN)*. 2020. IEEE.
5. Pradha, S.E., et al., *Scheduled access strategy for improving sensor node battery life time and delay analysis of wireless body area network.* IEEE Access, 2021. **10**: p. 3459-3468.
6. Ullah, F., et al., *Medium access control (MAC) for wireless body area network (WBAN): superframe structure, multiple access technique, taxonomy, and challenges.* Human-centric Computing and Information Sciences, 2017. **7**: p. 1-39.
7. Salim, A., *An Approach for Data Routing in Wireless Body Area Network.* Wireless Personal Communications, 2023. **130**(1): p. 377-399.
8. Longman, E., *Multihop wireless networking with RF wake-up enabled intermittently-powered nodes*. 2023, University of Southampton.
9. Chen, D., et al., *A hybrid scheme for disaster-monitoring applications in wireless sensor networks.* Sensors, 2023. **23**(11): p. 5068.
10. Gamage, A., et al., *LMAC: Efficient carrier-sense multiple access for LoRa.* ACM Transactions on Sensor Networks, 2023. **19**(2): p. 1-27.
11. Baiocchi, A. and I. Turcanu, *On Flow Control and Optimized Back-Off in Non-Saturated CSMA.* IEEE/ACM Transactions on Networking, 2023.
12. Sree Nidhi, S. and D. Sridharan, *ENERGY EFFICIENT MAC PROTOCOL FOR PRIORITY BASED TRANSMISSION IN WBAN.*
13. Shaker, A.S., et al., *SEEK Mobility Adaptive Protocol Destination Seeker Media Access Control Protocol for Mobile WSNs.* Iraqi Journal For Computer Science and Mathematics, 2023. **4**(1): p. 130-145.
14. Kosunalp, S. and Y. Kaya, *IoT-TDMA: A performance evaluation of TDMA scheme for wireless sensor networks with Internet of Things.* Concurrency and Computation: Practice and Experience, 2022. **34**(21): p. e7063.
15. Buehrer, R.M., *Code division multiple access (CDMA)*. 2022: Springer Nature.
16. Yang, T., Q. Zhang, and P. Li. *Pseudo-random noise generator based on FPGA*. in *Journal of Physics: Conference Series*. 2022. IOP Publishing.
17. Jung, E.-S. and N.H. Vaidya. *A power control MAC protocol for ad hoc networks.* in *Proceedings of the 8th annual international conference on Mobile computing and networking*. 2002.
18. Preethichandra, D., et al., *Wireless Body Area Networks and Their Applications–A Review.* IEEE Access, 2023.
19. Wu, S.-L., et al., *A multi-channel MAC protocol with power control for multi-hop mobile ad hoc networks.* The computer journal, 2002. **45**(1): p. 101-110.
20. Pourmohseni, B. and M. Eshghi, *Reliable energy-efficient dynamic-TDMA MAC protocol for wireless body area networks.* Int. J. Appl. Innov. Eng. Manag, 2013. **2**: p. 393-402.
21. Li, C., H.-B. Li, and R. Kohno, *Reservation-based dynamic TDMA protocol for medical body area networks.* IEICE transactions on communications, 2009. **92**(2): p. 387-395.
22. Rahim, A., et al. *Adaptive-reliable medium access control protocol for wireless body area networks*. in *2012 9th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON)*. 2012. IEEE.
23. Tseng, Y.-C. *A new mutli-channel MAC protocol with on-demand channel assignment for mobile ad hoc networks*. in *Int'l Symp. on Parallel architectures, Algorithms and Networks (I-SPAN), 2000*. 2000.