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Energy Efficient MAC Protocols for Wireless Body Area Networks (WBANs)

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Abstract

The Wireless Body Sensor Network (WBSNs) is useful in providing the medical services for people who need continuous monitoring and caring and specially aged people, which are small devices implant or placed inside the human body. It works by batteries but these batteries must have high efficiency and should work through the whole age and not be replaced unless after a long period. This paper will mention energy efficient MAC protocols SensorMAC, Timeout-MAC, WiseMAC, DSMAC and Zebra-MAC which are used in WBSN's networks that work on increasing the efficiency of energy and reduce its loss.

Keywords: Sensor Networks; Wireless; Medium Access Control protocols (MAC) Protocols; Wireless Networks.

Kablosuz Vücut Alan Ağları için Enerji Verimli MAC Protokolleri (KVAA)

Öz

Kablosuz Vücut Ağları (KVAA), sürekli izleme ve bakıma ihtiyaç duyan ve özellikle yaşlı insanların sağlık yönünden takipleri için insan vücuduna yerleştirilerek bu hastaların takiplerinin ve sağlık hizmetlerinin güvenli bir şekilde yapılabilmesi amacıyla sıklıkla kullanılmaktadır. Bu küçük sensörlerin enerji ihtiyaçları piller tarafından sağlanır. Ancak bu piller sensörlerdeki protokoller tarafından verimli bir şekilde kullanılmalıdır. Bu çalışmada, enerji verimliliğini artırmaya ve kayıplarını azaltmaya çalışan ve KVAA'larda kullanılan enerji verimli MAC protokollerinden olan SensorMAC, Timeout-MAC, WiseMAC, DSMAC ve Zebra-MAC protokollerinden bahsedilecektir.

Anahtar Kelimeler: Kablosuz ağlar, Ortam erişim protokolleri, Sensör ağlar

1. INTRODUCTION

WBANs consist of many nodes may access to thousands of nodes. They configure more commonly in laptops, cell phones, PDA, GPS devices and smart electronics. As well as, they became cheaper, more ability on movement and more prevalent in daily life. The sensor node can work by energy through AA batteries which may extend to several years with the decline of 1% for a full cycle.

The wireless sensor networks always involve hundreds of nodes and such connection through wireless channels can facilitate data and information exchange, equipping and publish on global scale for many purposes include environment monitoring, study the situations in battles, military monitoring, environments arising from research and factories, monitoring the healthy institutions, infrastructure, smart homes and patients monitoring devices. Also, it has defects include ease to penetrate which need to high security, relatively low speed in communications and still expensive in general. Also, the most important defects of these networks are the damage or loss in the energy efficiency resulting of many reasons include collisions, overhearing and idle listening.

We will mention many MAC protocols which are used in wireless sensor networks and these protocols have a vital role in reducing the loss of data that lead to the weak in the energy efficiency of WBANs. We will work on describing the optimal MAC protocols that work in reduce the loss of data with mentioning the characteristics and defects of these protocols and we will compare between these protocols in terms of use and work.

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2. BACKGROUND

The energy inefficiency results from many sources that widely addressed in the literature and include overhearing, idle listening, traffic fluctuations, collisions, over-emitting and control packet overhead. However, the main source of energy inefficiency is collisions. Collisions occur when two or more sensor nodes trying to send data packets at the same time. Idle listening occurs when a node attends to an idle channel in order to obtain the traffic which is possible. Overhearing occurs when a specific node receives a packet of data which was attended to be sent to another node. When one receives a data packet that is attended to be sent to other nodes the overhearing occurs. When the target node is not ready to get the message as a result of the prolonged transmission the over emitting occurs. The overhead of the control packet means that data transmission should use the minimal number of control packets. The energy consumption of control packets is caused by sending, receiving and listening. Because of that control packet does not transfer the data directly, they decrease the effectivity of the throughput. Nevertheless, idle listening, overhearing and collisions in WBAN can be decreased considerably by using of Clear Channel Assessment (CCA) link scheme/master-slave architecture with Time Division Multiple Access (TDMA). This system can considerably lead to power saving because it decreases the probability of idle listening and collisions. In order to significantly decrease the control packet overhead, idle listening, overhearing, and collisions it is required the availability of power-efficient techniques and flexible duty cycle [1].

There are numerous characteristics that need to be taken into consideration when designing an energy-efficient WBAN MAC protocol. The energy efficiency is the main attribute. The devices of WBAN which work using batteries need rigid constraints in using the resources of energy. Thus, in order to accomplish this objective, it requires designing communication protocol of energy-aware. The wastes of energy which identified below must be minimized in order to maximize the energy efficiency. Nevertheless, WBAN is proposed to support critical applications of lifesaving. Thus, the significant metrics in addition to the energy efficiency are the security, safety and reliability. As well as, the Quality of Service (QoS) is another significant factor of a good MAC protocol. The other importance factors comprise latency, jitter, bandwidth utilization, adaptability to changes in network, topology, throughput and scalability. Jitter, latency and throughput necessities rely on nature of the application. In the case of consumer electronics (CE) applications, latency and jitter should not be equal or more than 50ms and 250ms, correspondingly while in the case of health applications, latency should not be equal or more than 125ms for QoS packet [2]. Finally, besides the QoS the good MAC protocol should contain another attributes include reliability, heterogeneous traffic, security, energy-efficiency, and safety [3].

3. RELATED WORK

Recently, many articles have reviewed and detailed the aspects of wireless sensor network. Heidemann et al. [4] offers sensor-MAC (S-MAC), a new medium access control protocol clearly planned for the networks of the wireless sensors. While dropping power, feeding is the primary goal in the plan; the protocol has decent ability of changing the size and capable of escaping from collision. It achieves these by using a collection of scheduling and contention scheme. In [5], reviews the synchronization of the time issue and the requirement for synchronization of the time in sensor networks, after that presents in detail, the synchronization of the time in the basic form approaches clearly designed and proposed for sensor networks. In [6], the availability of WSN nodes are considered that can be addressed by indulging the distant testing and fixing the substructure for separate sensor nodes using COTs components, they built and evaluated the system level examination interface for distant testing repair and software update. This also covers contents regarding the plan methods which were carried to explore the difficulty using the projected infrastructure. The wireless broadcast can be used in easy way in various testing with optimum cost. In [7], reviews new routing protocols for sensor wireless networks and grants a cataloging for the several methods pursued. The Datacentric, the hierarchical and position-based are three important classifications that are inspected in this paper. The network flow and the quality of service modeling are discussed also. In [8], suggests the unwanted EA's performance when dealing with grouped routing problem in WSN by framing a new fitness role that incorporates two clustering parts, viz. cohesion and separation error. As a result of the paper, simulation over 20 random heterogeneous WSNs shows that evolutionary based clustered routing protocol (ERP) extends the network lifetime and spend less energy as compared to LEACH, SEP, and HCR protocols. In [9], the modified superframe structure of IEEE 802.15.4 based MAC protocol is proposed which addresses the problems and improves the energy consumption efficiency. Moreover, priority guaranteed CSMA/CA mechanism is used where different priorities are assigned to body nodes by adjusting the data type and size. In [10], presents an energy-efficient cooperative MAC (EECO-MAC) protocol using power control in mobile ad hoc networks. Cooperative communications improve network performance by taking full advantage of the broadcast nature of wireless channels. As a result of the paper, EECO-MAC consumes less energy and increases the network lifetime compared to IEEE 802.11 DCF and CoopMAC at the cost of delay.

4. MAC LAYER PROTOCOLS

4.1. Sensor-MAC

The simple thought from the Sensor-MAC (S-MAC) protocol is to manage locally the synchronization and the schedules of periodic sleep–listen depending on this synchronization [11]. So that, in order to set up a communal sleep schedule, the adjacent nodes forming the virtual clusters. Two adjacent clusters wake up at the listen period if they reside in two different virtual clusters. The S-MAC defect is the probability of follows two distinct schedules that resulted in further energy consumption across overhearing and idle listening. The exchanges schedule is completed through the periodic packet broadcast of SYNC to the instant neighbors. The SYNC packet is sent by the period every node and so-called the period of the synchronization. Moreover, CTS/RTS exchanges of the packet are used for the unicast-type packets of data. As well as, S-MAC comprises message passing where the message long is separated into the frame and will be sent as a form of burst. This method can achieve the safety of energy by decreasing the overhead of the communication at the unfairness expense in the medium access. The high latency might cause by the sleep of periodic exclusively for the multihop routing algorithms because the entire intermediary nodes have their own schedules of sleep. Through the periodic sleeping, latency causes the sleep delay [11]. The method of adaptive listening has been suggested in order to promote the delay of sleep and therefore the whole latency. In this approaches, when the communication ends, the node which overhears the communication of its neighbors wakes up for a short time. Therefore, the node neighbor may pass data directly if the node is in the next-hop. The duration field of RTS/CTS announces the end of the communication. The sleep schedules are decreased the idle listening which causes the waste of energy. In addition to the simplicity of implementation, the announcement of the sleep schedule may prevent the time synchronization overhead. RTS/CTS that maximize the probability of collision does not be used by the broadcast data packet. Adaptive listening incurs idle listening or overhearing if the packet has not been destined to the listening node. The sleep and listen periods are constant and predefined that minimize the algorithm effectiveness under an inconstant traffic load.

4.2. Timeout MAC

TMAC which is showed in Figure 1 is also based on MAC layer protocol which depends on SMAC basic features in enhancing the effectiveness of power by sleeping during inactivity of the periodic network [12]. Nevertheless, TMAC is unlike SMAC by following the dynamic schedule of sleep. The protocol of TMAC minimizes the idle listening overhead by introducing an active timeout mechanism which adjusting dynamically the active period in accordance with the network traffic loads. When all the traffic of the network has accomplished, TMAC tolerates the nodes to sleep. After observing the idle channel for an adaptive timeout (TA) period, the traffic end is signaled. The node switches its radio and leaves to the status of sleep if no movement occurs for the duration of the timeout. The period of TA must be adequately great in order to ride the early sleep issue because the node will go the status of sleep when its neighbor still has some packet to be sent. FRTS (Future Request to Send) technique is also introduced by TMAC with the priority of full buffer in order to avoid the problem of initial sleeping for the converging type of data communication. Also, the FRTS is broadcasted when the node has data to be sent overhears the packet of CTS. The FRTS packets store the data duration and the FRTS receiver sets the NAV and leaves to sleep. After the end of the telecommunication, the node wakes up again in order to receive data from the FRTS sender. In full buffer property, if the sending buffer of a node is completed and it obtains RTS from a node rather than responding with CTS, RTS which has the priority will be sent by the node. When the data sending is completed, only then it responses with the CTS to the original demand of RTS which it received. Therefore, this technique is introducing control of flow in the flow of data. The property of full buffer is employed only in the mechanism of converging type and not in telecommunication of ad-hoc.

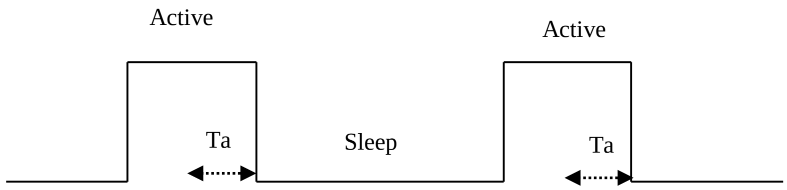

Figure 1. TMAC Protocol [13]

4.3. Wise MAC

WiseMAC protocol (Figure 2) is used the preamble sampling technique to reduce the consumption of energy [14]. The WiseMAC protocol adds the preamble in front of every packet of data in order to notify the recipient to not going to the mode of sleep until the current frame is received. However, the recipient should stay in the mode of a wake-up for the transmission of the upcoming frame too. The Sampling of the Medium means the listening to the wireless channel for the short time period. TW represents the constant period where the whole nodes of sensors sampling the medium in the network of the sensor. The process of sampling, in order to send data, the nodes of sensor checks the medium periodically to check the channel obtainability. The node of the sensor listens to the channel if the medium of the sampled is busy until receives the frame of data or the medium became idle. Beside the transmitter, the wake-up preamble of the same size to the period of the sampling been added in the opposite of each frame of data to certify that receiver will be aware when the data packet segment reaches. WiseMAC protocol offers an impression in order to learn the direct neighbors sample schedule which used to decrease the preamble wake-up size. The node can send the duration preamble T to get neighboring node sampling interval in case if the node does not have any knowledge of its neighboring node. If the frame is received successfully, the wake-up pattern of the received node is piggybacked in its message of the acknowledgment. In order to keep the relative schedule of the neighboring node offset from the wake pattern of the node, a table is conserved. This table enables the node from determining the next wake-up for the whole of its relevant neighbors and decrease the preamble length of the whole coming frames of future. Through this simple table, it can offer a high enhancement to the protocols of basic preamble sampling. WiseMAC appends on the Medium Reservation Preamble (TMR) in front of the preamble of the wake-up and uses to avoid the collisions that occur between dissimilar nodes which are necessary to send the frame of data to the same destination. The data frame of WiseMAC comprises a Start Frame Delimiter (SFD) and a bit SYNC preamble (SYNC) after the preamble of the wake-up. The preamble wake-up duration of WiseMAC is symbolized by TP and divided into two parts: the medium reservation preamble of length TMR and the clock drift compensation preamble of duration TCDC.
Therefore, the preamble of wake-up is computed as,

$$TP = TMR + TCDC \tag{1}$$

The preambles of wake-up in the simple preamble sampling approach (long) can maximize the extra power consumption overhead and cause the throughput of the limitation in response and transmission. The WiseMAC decreases the node energy and cost if it is compared to the simple preamble sampling technique because it decreases the long length of the wake-up preamble. We mentioned below the advantages and limitations of WiseMAC protocol according to the references of different reviewed papers [15].
The performance of WiseMAC protocol is much better than SMAC protocol in the variable traffic conditions:

- Since WiseMAC protocol exhausts low power, it delivers better lifetime for battery.
- WiseMAC protocol offers a good throughput in the variable traffic rates in comparison to the layer of other MAC protocols.
- The external time synchronization requirement is qualified via the protocol through holding the clock drift very well.
- In order to get better results in various applications, WiseMAC protocol can be joined easily with other MAC protocols.

The Limitations of WiseMAC protocols are:

- The scheduling scheme of sleep-listen in WiseMAC is a decentralized system which results in different wake-up times and sleeps to every neighbor of the node.
- Communications with the type of broadcast the neighbors are buffering different packets in the sleep mode and supplied many times as each neighbor wakes up and that resulted in needless power consumption and higher latency.
- The collision happens at the beginning of the preamble to the node according to the hidden terminal problem.

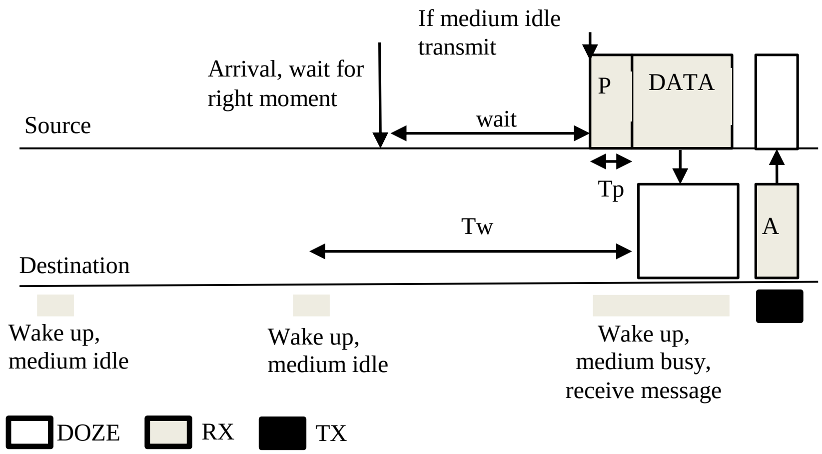

Figure 2. WiseMAC Protocol [15]

4.4. DSMAC

The constant duty cycle design of SMAC as mentioned above trades of latency in order to save the waste of energy. Therefore, SMAC is efficient in consumption of energy, so SMAC is considered not appropriate for the delay sensitive sensing applications that need a quick reply from the sensor devices. In a DSMAC-enabled network, all the defined functionalities are assumed by each sensor in S-MAC protocol. According to the average of latency which passes by the sensor and the efficiency of current energy use, the DSMAC protocol tries to dynamically regulate its sleep-wake up cycle time. The DSMAC protocol defines the latency of one-hop between the packet which gets inside the queue and sends it out successfully. The sending sensor node records the value in the header of the packet and regained it by the receipt node. The receipt sensor average of latency represented by the value of average for the whole one-hop latency values which composed in the synchronization present period. This value of the average latency assists the approximate assessment of the present traffic condition and an indicative parameter for the reception node. Furthermore, all receivers keep track of their own level of energy waste. At the beginning, the whole node adopts the common elementary service duty cycle.

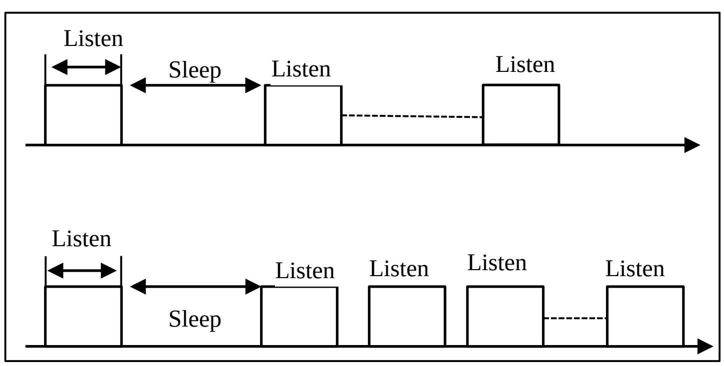

Figure 3. The adoption duty cycle of DSMAC [16]

If notices that latency becomes insufferable in the receiver sensor node, it makes a decision unilaterally in order to double the original duty cycle by restricting the sleep time period length consequently without varying the listen time period as clarified in Figure 3. Consequently, nodes that maximize their cycle of duty have the ability to get more probabilities to receive packets rather than blocking the other senders while sleeping [16]. It doubles its cycle of duty by restricting its length of the sleep period, without changing its period of listening.

4.5. Zebra-MAC (Z-MAC)

Z-MAC has considered an efficient hybrid protocol substitutes the protocols of TDMA and CSMA. In low channel contention Z-MAC protocol uses CSMA and in high channel contention, it switches to TDMA. Z-MAC [17] protocol depends on B-MAC [18] and utilizes CSMA as the baseline MAC scheme. Nevertheless, Z-MAC protocol depends on the schedule of TDMA as a hint in order to improve the contention resolution. There are two modes where Z-MAC operates which are the set-up mode and transmission mode. Each node assigns time slot through the set-up mode. For a given slot, symbolized by "owner", the node to which that slot is assigned while all the other nodes are symbolized by "non-owners". In order to assign slots to nodes, Z-MAC utilizes DRAND [17]. Through the set-up stage DRAND is run and assurances that no two nodes within the neighboring of two-hop be assigned the same time slot. The time is split into slots during the transmission mode. Through the set-up mode of Z-MAC, the assignment of the time slot is implemented a higher overhead. The philosophy design of Z-MAC is the high initial overhead which is remunerated across the long period of the network process, ultimately recompensed by enhancing the effectiveness of the energy and throughput. Z-MAC is dissimilar to TDMA where the node may communicate through any time slot. Through the slot and before the node transmits, the node always implements carrier-sensing and tries to transmit a packet when the channel is free. Nevertheless, the priority of accessing the channel is always for the owner of that slot than other non-owners. The importance is employed by regulating the primary contention window size in such a method where the earlier chances are given to the owner in the transmission than non-owners. When mixing the thoughts of TDMA and CSMA, the protocol of Z-MAC becomes robustly to the slot assignment failures, conditions of the time-varying channel, timing failures topology and changes than a standalone TDMA; in the worst case, it constantly falls back to CSMA. Z-MAC permits nodes in a one-hop neighborhood to contend for a neighbor's slot when that neighbor does not use its own slot in HCL mode? And is it better to these slots to be assigned to the neighbors or not? In order to argue this difficulty, consider a three-node chain in the mode of HCL: A--B--C, assigned slots 1, 2 and 3 correspondingly as illustrated in Figure 4. If the slot is 2, and the owner (B) does not transmit its data, then both A and C could contend for the same slot and transmit, since they are both in the one-hop neighborhood of B. That may cause a hidden terminal problem.

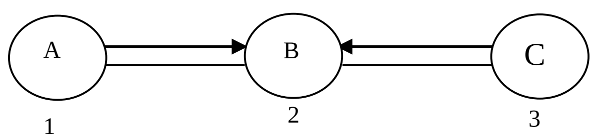

Figure 4. The terminal problem of hidden and its effect on Z-MAC [17]

5. CONCLISION

Many MAC protocols of WBANS have been analyzed with the focus on energy consumption issue in order to achieve different requirements include energy efficiency, fairness, scalability, reduced synchronization overhead and quality of service. SMAC protocol saves the energy consumption but the feature of permanent sleep in each node leads to lack of well adapt to the changes in traffic movement in the network which lead to consuming unnecessary energy. TMAC protocol saves the energy consumption and increases the age of the network if compared with SMAC. Whereas, DSMAC protocol can adapt with the changes occur in network traffic movement because it adjusts ineffective time listening for SMAC. SMAC, TMAC, and DSMAC are all of the kind CSMA. While WiseMAC is much better than SMAC in providing energy under the changing of traffic in the network and it is of type NP-CSMA. ZMAC protocol is a protocol which collects between two strengths of TDMA and CSMA and it is characterized by the ability to adapt to the changes of traffic movement in the network. The researches trends in the future are to analyze the simulation of comparison performance of protocols.

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