Proposing a New MAC Layer Schedule with the Aim of Reducing Energy Consumption in Wireless Sensor Networks

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ABSTRACT
Recent advances in the field of electronics and wireless telecommunications have created the capability and potential for designing and manufacturing sensors which have low power consumption, small size, reasonable price and various applications. These small sensors, which based on their type, can perform different tasks such as receiving environmental information, processing it and then sending that information, have shaped an idea to create and expand networks known as wireless sensor network (WSN). A sensor network consists of a large number of sensor nodes which are widely distributed in the environment and are engaged in collecting information. The sensors have significant limitations, and one of the most important limitations is the low capacity of these sensors' battery, which makes the efficient use of the energy a vital issue. When the energy in the battery ends, the sensor, functions completely stops. This would result in the loss of a part of the network. Moreover, in most of the sensor, applications, replacing the battery is impossible either because the evaluated area is too large or because it is unsafe. Therefore, minimizing the energy consumption, by designing communication protocols and applications for these networks, is one of the most important issues. So designing a MAC Layer schedule to reduce energy consumption in wireless sensor networks which can significantly reduce power consumption but also would be compatible with IEEE 802.15.4 is an important and unavoidable challenge.

KEYWORDS: Wireless Sensor Networks, MAC Protocol, Power Consumption, Duty Cycle, Scheduler.

1. INTRODUCTION

A wireless sensor network is a network of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, motion, contamination etc. in different locations within a specific range. The development of wireless sensor networks was motivated by military applications such as battlefield surveillance; today such networks are used in many industrial and non-military applications such as industrial process monitoring and control, machine health monitoring, house or perimeter monitoring, Health care monitoring, smart homes and traffic control. Despite advances in this type of networks, sensor nodes are still dependent on small batteries for their energy supply since their application involves characteristics such as large number, small size and contingency placement. Usually there is no possibility of recharging or replacing the sensor nodes because they are often used in harsh and inaccessible environments. Therefore, a severe limitation in energy supply is one of the most important challenges in wireless sensor networks. Also, since the performance of sensor networks strongly depends on their lifetime and coverage, it is vital to consider energy saving algorithms in the design of long term sensor networks.

Generally, wireless sensor networks are idle for most of the time and only occasionally send data. Meanwhile, the amount of energy required to listen to an idle channel (without use) is equal to the energy consumption when data is being sent and received, And it is much more than the energy consumed in sleep mode.

The main objective of the sensor networks is wise and rational management of energy resources. So, first it is necessary to know where the energy is consumed. Some of the energy consumption in sensor node may be helpful and productive such as: 1- sending or receiving data, 2- Processing query requests, and 3- Sending queries and data to neighbor nodes.

However, some energy consumed in the sensor node is wasteful and useless such as: 1-Passive listening, i.e. listening to an inactive channel for possible traffic, 2- Collision, i.e., when a node receives more than one packet at a time, Even when it receives two packets only partly in the same time. All packets that cause collision must get discarded and sent again, and resending packets increases energy consumption, 3-Overhearing, i.e., when a node receives packets sent to other nodes 4-control packets overhead, which is the number of control packets for data transmission and must be minimized, 5- Sending a message when the destination node is not ready to receive.

Considering the mentioned factors, many research and procedures have been carried out with the objective of saving energy, which have been particularly involved with utilizing the MAC layer. In fact, since the MAC layer is responsible for managing channel access control mechanisms, it enables us to have direct access to radio transmission functions without any changes in the standards.

Developing a scheduled plan and effectively using sleep / wake scheduling techniques, can reduce energy loss in the idle mode and increase the efficiency.

Proper adjustment of node's duty cycle is a very interesting approach in this regard; in this approach the nodes switch their status between the off and on-state, according to a predefined schedule. In this study, we use asynchronous scheduling which enables us to significantly save energy in nodes using duty-cycle scheduling.

Thanks to this scheduling, each node will already know when neighboring nodes would transfer data. Using this local scheduling information, the radio transceiver will be adjusted according to active and inactive status, and radio transceiver will be active at the time of data transmission; this approach reduces the energy consumption associated with the phenomenon of idle listening, there by extending the lifetime of the network.

2. THE RESEARCH CONDUCTED IN THIS FIELD

Many protocols have been presented to increase the energy efficiency of the networks and many other protocols have been provided to decrease competition and congestion in a wireless sensor network. These protocols are classified as follows:

1-Protocols which manage the challenges associated with competition and congestion.

2-Protocols which try to increase the network energy efficiency.

2.1. Protocols Which are Based on Competition and Congestion

Competition and congestion are problems that naturally form in wireless sensor networks because of their design. Competition occurs when multiple nodes try to send their packet to a forwarder node.

Congestion also occurs frequently in wireless sensor networks. Many protocols have been presented to diagnose, control and possibly avoid competition and congestion. ECR-MAC Protocol [1] uses dynamic mechanism forwarder selection (DFS). This mechanism is also a mechanism to avoid congestion, because it helps avoiding competition by giving more options to nodes to send their data. Pump Slow Fetch Quickly (PSFQ) Protocol [2] is another protocol that uses this mechanism for avoiding congestion.

The purpose of this protocol is to minimize the number of resends to detect the loss of data. PSFQ protocol disadvantage is that the pumping operation may be slow and lead to a big delay. Event To Sink Reliable Transport (ESRT) Protocol [3] is presented to achieve a high reliability in transporting event to sink. ESRT tries to achieve a reliable event detection using energy efficiency and congestion control techniques. ESRT defines five states for congestion:

No congestion-low Reliability, No congestion-high Reliability, Congestion-high Reliability, Congestion-low Reliability, and Optimal operational region.

CODA protocol [4] uses a combination of the present and past channel loading conditions and the current buffer occupancy to infer accurate detection of congestion at each receiver with low cost. In the event of persistent congestion, this protocol can also assert congestion control over multiple sources from a single sink. Lightweight Medium Access Control (LMAC) Protocol [5] is a MAC protocol based on Time Division Multiple Access (TDMA). LMAC reduces competition in the network by organizing time into time slots and then assigning each time slot to a node. The disadvantage of this protocol is that all the nodes will always listen to all the sent messages and that is a waste of energy. Rhee et al, have presented (Z-MAC) protocol which uses TDMA and CSMA [6].

Z-MAC protocol monitors the competition in the network and uses the CSMA when the competition is low, but uses TDMA when the competition in the network is high. Funneling-MAC protocol is another protocol based on TDMA which only tries to counter the congestion in the vicinity of base station by using the TDMA around the base station [7].

2.2. Protocols Which Increase Energy Efficiency

Since energy efficiency is an important criterion in wireless sensor networks, different strategies have been adopted to try to prolong the lifetime of the network. Strategies that are used to extend the lifetime of the network can be classified as follows:

1-Duty cycles strategy
2-Topology control strategy
3-Clustering and grouping strategy

2.2.1. Duty Cycle Strategy

Based on this strategy, energy-based protocols can be divided into 3 categories: Preamble-sampling, scheduling, and hybrid methods.

Preamble-sampling MAC Protocols [8], [9] use the Low Power Listening [10] (LPL) to sample the initial data packets.

B-MAC [8] is a link layer protocol And provides the interface with the upper layer that is CSMA based on protocol that provide Low power listen states to low power consumption.

Wise MAC [9], [10] is based on the preamble sampling technique. This technique consists of regularly sampling the medium to check for activity. By sampling the medium, we mean listening to the radio channel for a short duration. If the medium is found busy, a sensor node continues to listen until a data frame is received or until the medium becomes idle again. At the access point, a wake-up preamble of size equal to the sampling period is transmitted in front of every data frame to ensure that the receiver will be awake when the data portion of the packet arrives.

This technique provides a very low power consumption when the channel is idle. The disadvantages of this technique are that the (long) wake-up preambles cause a throughput limitation and large power consumption overhead in reception. The overhead in reception is not only born by the intended destination, but also by all other nodes overhearing the transmission.

X-MAC [11] is a low power MAC protocol for wireless sensor networks (WSNs). Standard MAC protocols developed for duty-cycled WSNs such as BMAC, which is the default MAC protocol for TinyOS, employ an extended preamble and preamble sampling. While this “low power listening” approach is simple, asynchronous, and energy-efficient, the long preamble which introduces excess latency at each hop is suboptimal in terms of energy consumption, and suffers from excess energy consumption at non-target receivers.

X-MAC proposes solutions to each of problems by employing a shortened preamble approach that retains the advantages of low power listening, namely low power communication, simplicity and a decoupling of transmitter and receiver sleep schedules.

SMAC protocol [13], is based on sleep, a node sleeps for a period and after waking up listens to channel and receives the packets. Basically, a node periodically follows the path that includes Listening and sleep interval. SMAC avoids hidden terminal problem using RTS/CTS packet.

DMAC [15] is designed to deal with specific information and collected needs of Wireless sensor network and store energy with sleep mode. DMAC works by creating a tree of information، The main station is the root of the tree; the tree makes a frequent awakening from the source to base station.

ECR-MAC protocol is another method which uses the duty cycles [16]. Zhou and Medici have designed this protocol to improve energy efficiency and delay.

ECR-MAC protocol uses a mechanism called dynamic forwarder selection (DFS). DFS mechanism provides more flexibility in forwarding packets that leads to improved energy efficiency and delay. Pipelined Tone Wakeup (PTW) has been suggested to deal with the threshold between energy efficiency and overall delay. PTW [17] uses pipeline technique to help shorten the time it takes to wake nodes for sending data, but it also maintain energy efficiency.

2.2.2. Topology Control Strategy

Given the large number of nodes in a wireless sensor network, there are some redundant nodes in any given area of a region. With regard to this phenomenon in the wireless sensor networks, controlling the topology of the network is another popular method to reduce energy consumption.

SPAN protocol was one of the first sleep based topology control techniques for ad hoc wireless network. SPAN protocol tries to reduce energy consumption without affecting the connections and topology of network. SPAN tries to minimize the number of coordinators in order to reduce the delay time. In this protocol, the decision of a node to become a coordinator is based on local data gathered from locally broadcasted messages.

2.2.3. The Strategy of Clustering / Grouping

Grouping or clustering nodes together is another strategy which is often used to create energy-efficient protocols. LEACH protocol puts nodes that are close to each other into a cluster and then selects one of the nodes from the cluster as the cluster head. The cluster head node acts as a local base station for that cluster. So anything that cluster head node receives from the rest of the cluster members will be sent directly to the base station [19]. PEGASIS protocol is very similar to LEACH protocol and utilizes the cluster heads, but instead of having a direct communication between each cluster head and base station, it forms a path of cluster heads toward the base station [20]. Geographical Adaptive Fidelity (GAF) protocol has been suggested to help reducing the energy consumption in Ad-Hoc wireless network [21]. GAF protocol uses nodes’ location data and decides which nodes should continue their work while also maintaining throughput of network connections.

3. METHOD

In each period of the duty cycle, a node wakes up to send and receive data, but the receive-wake ups, will be scheduled according to send-wake ups of the neighboring nodes. By using the information collected during the initial phase, each node only activate its radio transceiver when it wants to receive or send data to its neighbors. This schedule can reduce unnecessary wake ups associated with idle listening. Announcement Packet (PktANN) is a signal packet which is used by a node when it joins the network. It is used to announce the presence of node and the time of its next send-wake up. Waking table (WTBL) is a data structure in which a node stores the send-wake up schedule of its neighbors. In the initial setup of the network, all nodes exchange information about their transmission time using PktANN. When such message from an unknown neighbor is received, the proposed schedule updates WTBL table by storing a new entry. But before storing, Information of neighbor's transmission time is converted to an offset which refers to the duration between the start of the duty cycle and the moment when the neighbor sent the packet (in seconds). Each node randomly selects its own transmission time within an appropriate range, considering the choice that is made by neighbors. This difference in neighboring nodes ending schedule leads to reduced competition for access to the channel.

In more detailed explanation, If WTBL is empty, then transmission time will be randomly selected from a time interval obtained from Eq.(1), where "TC" is the current time, "Wake Time" is the time window assigned for data transmission, "Turn Around Time" is the amount of time required by the radio to switch state. If the table is not empty, then it will try to set its transmission time to a value different from its neighbors, to avoid collision caused by simultaneous transfer. A node checks to find out if two consecutive entries in the table exist, (i and i+1) and then compare their offsets difference to Eq.(2), and if it is greater than the Eq. (2) then transmission time will be selected according to Eq.(3) interval. If there is only one entry in the WTBL table, then transmission time will be selected according to Eq. (4).

$$[T_c, T_c + T_0 – (\text{wake Time} + 2*\text{TurnAroundTime})] \quad (1)$$

$$2*\text{wakeTime} + 4*\text{TurnAroundTime} \quad (2)$$

$$[\text{offset}[i] + D, \text{offset}[i+1]-D] \quad (3)$$

$$[\text{offset}[0], T_0 - D] \quad (4)$$

D=WakeTime+2.TurnAroundTime

With further analysis of the protocol, it can be said that there are basically five sub-statuses based on the condition of radio transceiver: Idle or listening to channel (IDLE), competing for the channel (CCA), transmitting (TX), receiving (RX) and off (OFF).

If we assume that in some points the physical layer is in off status, when the transmission timer expires, node schedules the next transmission after n seconds, wakes up (Physical layer and MAC are in idle status), check for the packet in line for transmission, and if necessary, starts to compete for access to the channel (Physical layer and MAC are in competing for the channel status). If it wins the competition, then transmission will start (Physical layer and MAC are in transmitting status). As soon as the packet transfer ends, node switches to idle mode and waits for an acknowledgment message from the receiver it had tried to connect. If MAC layer does not receive the acknowledgment message before a specified time, then the message must be sent again. In case of receiving acknowledgment message, node switches to receive mode and receives the packets, then switches to idle mode and check for packets that must be transferred. If it finds any, the process repeats, otherwise, it remains in idle mode until the sending or wake up schedule. When the wake up time expires, node will turn off the radio transceiver.

Fig.1 shows a diagram of the physical layer status and highlights the main operations that change the status.

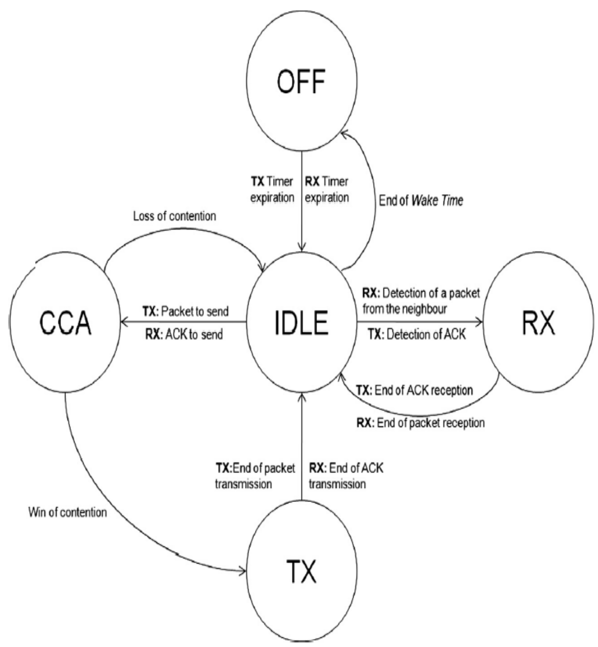

Fig. 1. The Diagram State

3.1. Real-Time Packets

The Challenge which we will review in the proposed schedule design is the Real-time packets. In a network and especially in a wireless sensor network in which time of data transfer to the base station is most crucial, we must pay special attention to real time packets and plan a strategy to transfer these packets to the base station with high speed, low power consumption and high precision. For this purpose we change the scheduling algorithm to a different form. Real-time packets have a high priority and their data is very important for decision-making and performance of the network, and if they are delayed they will be useless. In the proposed design, each node sends the Real time packet as soon as it sees it. CSMA / CA method is used for scheduling real-time packets. Thus, with this method, all nodes are warned not to send or receive anything in the range of sender, receiver, or both during this exchange of information. In Fig.2, you can see the CSMA used in this scheduling method.

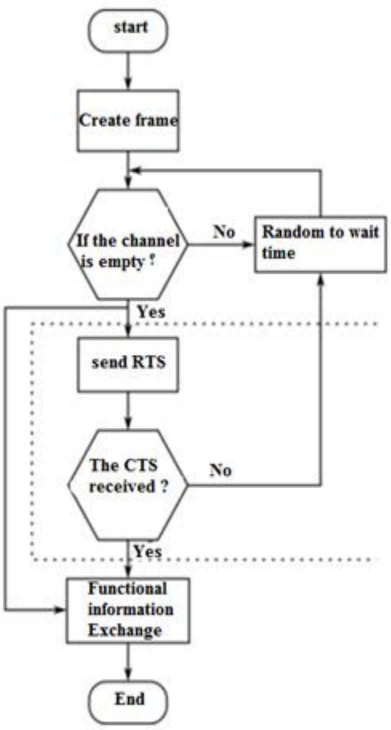

Fig. 2. The procedures protocol CSMA/CA

3.2. Location of the Base Station

In this section we discuss the impact of base station location on the efficiency of wireless sensor network. What is desirable in a wireless sensor network is reducing energy consumption and thus extending the life of the network. It is clear that changing the location of base station greatly changes the network performance.

Location of the base station proposed in this plan is shown in Fig.3.

Fig. 3. The Location of the base station in proposed design

In the proposed design, coordinates of the base station can be obtained from Eq. (5) where xi and yi are the coordinates of the node number i, and N is the number of sensor nodes. This equation can be used to determine the optimal location for base station.

$$X=(\sum X_i)/N \quad , i=1,2,3,\ldots,n \qquad (5)$$

$$y=(\sum y_i)/N \quad , i=1,2,3,\ldots,n$$

3.3 .Energy consumption

Data must converted from the digital to a signal which can be sent. This process is done in the transfer electronic circuit. This signal is then delivered to an amplifier circuit. As can be seen in Fig.4 energy consumption in the transport section of electronic circuit is Eelec * k and it is Eamp * k * d^2 in the amplifier circuit. In these equations, k represents the number of bits that must be sent, and d represents the distance that these bits should travel. Upon arriving to destination, signals then will be converted back to digital data by the receiver circuit. The energy consumed for this process equals Eelec * k. where k represents the number of bits.

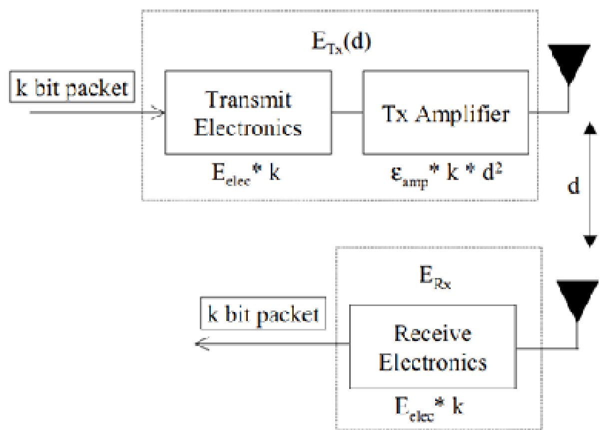

Fig. 4. The Energy consumption component for send and receive

Generally, the equation of energy consumption is as follows. In this equation, Etx represents the required energy for k number of bits to travel the distance of d, and Erx is the energy required for receiving k number of bits. Etx and Erx can be obtained from Eq.(6) and Eq.(7). If the transmission distance would be greater than a certain threshold, then more energy must be spent to send the data. This threshold is represented by “do”. Where do is do=√ ((Efs/Emp))

$$Etx = \begin{cases} Eelec * k + Emp * k * d^2 & if\ d < do \\ Eelec * k + Efs * k * d^4 & if\ d > do \end{cases} \qquad (6)$$

$$Erx = Eelec * k \qquad (7)$$

4. RESULTS AND DISCUSSION

In our simulation, packet rate was 0.1 packets per second and T0 was 20 seconds. Diagrams shown in Fig. 5, Fig. 6 and Fig .7 represent power consumption in network implementation, delays, and delay of real-time packets respectively. From these diagrams, we can conclude that our proposed method consumed less energy than the AS-MAC2 method. In addition, Fig.6 shows the delay of packet arriving to the base station which was lower in the proposed method compared with AS-MAC2.Also as shown in Fig.7, the delay of real-time packets in the proposed method was much lower than that of AS-MAC2 method. In general it can be said that based on the criteria measured in this scenario, the proposed method performed better than AS-MAC2**.**

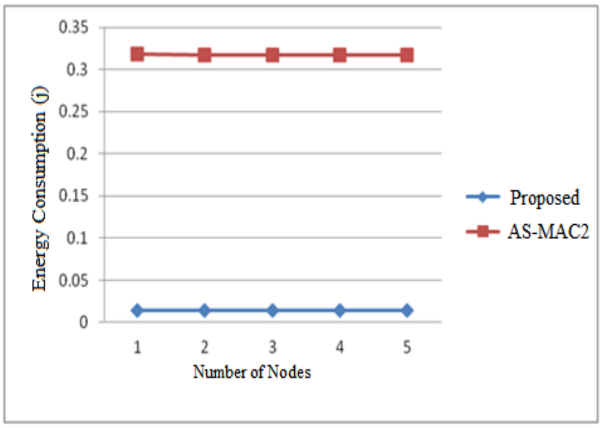

Fig. 5. The Power consumption

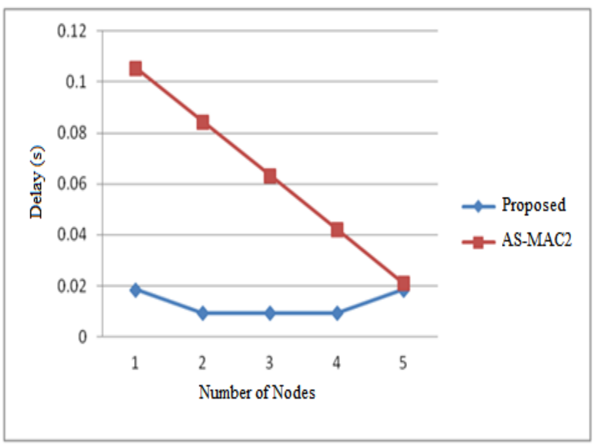

Fig. 6. The Delay of packets

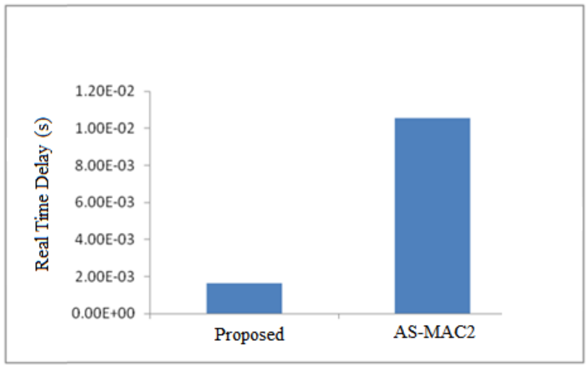

Fig. 7. The Delay of real-time packets

5. CONCLUSION

The proposed MAC protocol is able to reduce energy consumption in wireless sensor networks and is compatible with IEEE 802.15.4. This protocol is based on an efficient cycle and uses each node's information about the periodic transfers of its neighbors to schedule its own waking periods on the basis of this information and to avoid useless wake ups.

Proposed solution is powerful because it is sensitive to changes in network, and nodes update the stored information as soon as they feel a change in the network. This Protocol is designed by MATLAB and with respect to the current MAC protocol, which is ZigBee.

Evaluation of the proposed protocol in a more complex and dynamic scenario with the aim of developing these studies can be one of the further studies.

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