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Research Article

Performance of a Wireless Sensor Network MAC Protocol with a Variable Sleep Interval

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Abstract: A MAC protocol specifies how nodes in a sensor network access a shared communication channel. Medium access control protocols for wireless sensor networks are almost always designed to be energy efficient. Desired properties of such MAC protocol are: it should be distributed and contention-free. This study addresses low power MAC protocols utilize energy in efficient manner in wireless sensor networks. We are interested in the trade-off between power consumption and transmission delay, focusing on low traffic in EM-MAC. In EM-MAC, a significant proportion of the nodes may have to stay awake much longer than envisaged. We describe RRMAC protocol (Receiver-Reservation MAC protocol), a new protocol for the Collision avoidance and energy loss due to retransmissions and increase the life span of a wireless sensor networks. This study concludes with the result of simulation studies which indicate that the use of the proposed RRMAC protocol is expected to increase the life time of wireless sensor networks significantly.

Keywords: Duty cycling, energy efficiency, interference, medium access control

INTRODUCTION

Wireless Sensor Networks (WSNs) constitute a special class of wireless data communication networks. A node in a wireless sensor network is a low cost, resource constrained device. Sensor nodes are typically deployed in large number and are often positioned randomly. Sensor nodes are generally battery powered. A sensor network is comprised of a large number of limited power sensor nodes which collect and process data from a target domain and transmit information back to specific sites. A Medium Access Control (MAC) protocol specifies how nodes share the channel and hence plays a central role in the performance of a sensor network. Sensor networks contain many nodes, may turn on and off in order to conserve energy. Contention occurs when two nearby sensor nodes both attempt to access the communication channel at the same time. Most of these protocols have energy conservation as an objective. The pattern of energy use in the sensor nodes, however, depends on the nature of the application. As the range of applications which use WSNs is large and diverse, the proposed protocols display much diversity.

To design a good MAC protocol for the wireless sensor networks, we have considered the following attributes. The first is the energy efficiency. As stated above, sensor nodes are likely to be battery powered and it is often very difficult to change or recharge batteries for these nodes. In fact, someday we expect some nodes to be cheap enough that they are discarded rather than recharged. Prolonging network lifetime for these nodes is a critical issue. Another important attribute is the scalability to the change in network size, node density and topology. Some nodes may die over time; some new nodes may join later; some nodes may move to different locations. The network topology changes over time as well due to many reasons. A good MAC protocol should easily accommodate such network changes. Other important attributes include fairness, latency and throughput and bandwidth utilization. These attributes are generally the primary concerns in traditional wireless voice and data networks, but in sensor networks they are secondary.

An energy efficient wireless MAC protocol should minimize the four sources of energy waste (Joseph *et al*., 2004) idle listening, overhearing, collisions and protocol overhead. Idle listening refers to the active listening to an idle channel, waiting for a potential packet to arrive. Overhearing refers to the reception of a packet, or of part of a packet that is destined to another node. Collisions should of course be avoided as retransmissions cost energy. Finally, protocol overhead refers to the frame headers and the signaling required by the MAC protocol (Chieh-Jan *et al*., 2010). As the power consumption of a transceiver in receive mode is far from being negligible, idle listening can become the main source of energy waste, especially in low traffic conditions. To reach a low average power consumption,

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the transceiver must be shut down part of the time (i.e., duty cycling).

The medium access control is a broad research area and many researchers have done research work in the new area of low power and wireless sensor networks. The standardized IEEE 802.11 Distributed Coordination Function (DCF) (Amre and Decotignie, 2004) is an example of the contention-based protocol and is mainly built on the research protocol MACAW. It is widely used in ad hoc wireless networks because of its simplicity and robustness to the hidden terminal problem. However, recent work has shown that the energy consumption using this MAC is very high when nodes are in idle mode. This is mainly due to the idle listening. PAMAS made an improvement by trying to avoid the over hearings among neighboring nodes. A protocol proposed by Ye *et al*, named S-MAC (Ye *et al*., 2004), is a robust medium access control (MAC) protocol for wireless sensor networks. Owing to its success in significant reduction in energy consumption and its robustness, S-MAC has been used in many Wireless Sensor Networks (WSNs). It is one of the networking protocols included in Tiny OS, a popular operating system for a number of platforms available as WSN nodes (Gang *et al*., 2006). Many other MAC protocols have been proposed recently which are based on, or inspired by, S-MAC.

S-MAC reduces energy consumption by allowing the nodes to periodically turn off their radio receivers (and any other resources that have no work to do) and enter a low power sleep state. The duty cycle of a node is the ratio of the time it is awake (i.e., not in the sleep state) to the total time. The lower the duty cycle, the lower is the power consumption of a sensor node. In S-MAC the channel access is contention based, using a scheme similar to the IEEE802.11 distributed coordination function. However, unlike the IEEE 802.11 MAC protocol, the intervals when contention can occur are scheduled (Hui *et al*., 2006). S-MAC, therefore, combines the features of both contentions based as well as time scheduled protocols. Even though the contention interval in S-MAC is scheduled, S-MAC requires much looser time synchronization than TDMA based protocols. This allows the S-MAC nodes to use inexpensive timing hardware and simpler synchronization algorithms (Lei *et al*., 2003). Furthermore, S-MAC does not suffer from the limited scalability generally associated with TDMA schemes.

In the common control channel, using the channel selection mechanism between the sender and the receiver and using the control frames and data structures discussed earlier, the best data channel to be used for communication is selected. Firstly, the sender node gets its CIT, for an ascending ordered list of channels based on the load in the channels. This list is sent by the sender as part of the IRTS with an entry for channel list in it (Michael *et al*., 2006). Now at the receiver, the node gets its CIT for an ascending ordered list of channels based on the load in the channels and matches the first channel from the sender's list having the highest rank based on its own ranking list of channels which it has got. In a case where some of the channels are having the same information, then the highest ranked channel from the sender's list is taken. Since the channel has been selected at the end of this phase, it is important to inform the sender and the neighbors of the receiver about the selected data channel for data communication, which is done when the receiver sends the ICTS, with an entry for channel ID (Rajendran *et al*., 2003). Once the ICTS is received by the sender, it transmits the CSM in order to inform the neighbors of the sender about the chosen data channel for communication. In addition to informing the neighbors of receiver and sender by means of ICTS and CSM respectively, they also help in maintaining an updated CIT for a node (Redi *et al*., 2008). Whenever an ICTS or CSM is transmitted the corresponding neighbors insert or update their list of CIT with the nodes and channel information part of those messages. In order to get the latest channel usage snapshot in the CIT, the nodes are timed out of the data channel once they use up the system wide time constant T, which is the maximum time nodes, can spend on the selected data channel for their communication. These frames also help in solving the hidden node problem at the common control channel. IRTS and ICTS function as a way to control access of the common control channel, so neighboring nodes which receive an IRTS or ICTS sets its Network Allocation Vector (NAV) to the duration fields in the corresponding frames and delay access to the common control channel by the time required to exchange the ICTS and CSM as mentioned in the IRTS and ICTS (Jingbin *et al*., 2007). The duration fields part of the IRTS and ICTS do not include the time for data communication. Also, they use the binary exponential back off times, randomly chosen from a collision window which has the minimum and maximum window limits same as in IEEE 802.11 (Joris *et al*., 2010). Data frame is dropped by the sender after retransmitting IRTS seven times after failure to receive an ICTS.

RESEARCH METHODOLOGY

In RR-MAC (Receiver reservation MAC), there are multiple channels available for transmissions. Each node in the RRMAC uses a pseudorandom sequence to determine its wake-up channel (channel in which it becomes active) and another pseudorandom sequence to determine its wake-up time (time at which it has to become active in the wake-up channel). The nodes of RR-MAC can look into the pseudorandom sequences of any other node (Rajesh *et al*., 2008). In other words, the nodes are initially fed about the other nodes in the network and what pseudorandom sequence is pursued in each node to obtain the wake-up channel and time (Prabal *et al*., 2010; Chieh-Jan *et al*., 2010). Thus a sender S which has to transmit data to a receiver R will actually imitate the receiver's pseudo

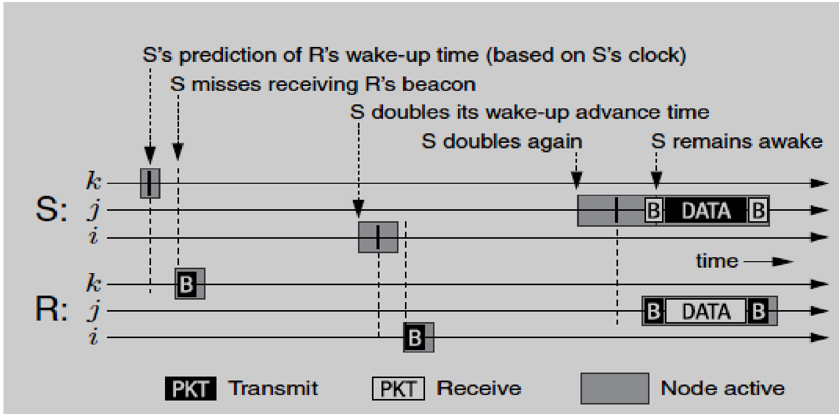

Fig. 1: Sender *S* sends data packets to receiver *R* using EM-MAC

function to know where the receiver is active in terms of channel and time. Then the sender will also wake-up in the same channel at the same time as the receiver. When no data is there to transmit, then the node simply goes with its own pseudorandom sequence to wake-up in the channel and time obtained with its pseudo sequence, expecting data from prospective senders, if any (Fig. 1).

Only three of the channels are shown here, labeled *i*, *j* and *k*. At the time of *R*'s second beacon, no node has a packet waiting to send to *R*. When there are two senders S1 and S2 to transmit data to receiving node R, then both senders imitate the pseudo sequence at the receiver node to obtain the receiver's next wake-up channel and next wake-up time. Since, there is no control channel here, both senders are unaware of each other They may both imitate the receiver and wakeup simultaneously at the receiver's channel time (little earlier than actual wake-up time so as not to miss the receiver's-Ready beacon). When the receiver wakes up in the channel, there are also two senders waiting out there to reach the receiver (Paramvir *et al*., 2004). The receiver follows the standards of transmission, wherein, it sends a-Ready beacon first to indicate it's availability to any prospective senders. The two senders upon getting this-Ready beacon from the receiver come to know the active existence of receiver and begin their transmission. This leads to collision of packets from the two senders. In EM-MAC the collision is attempted to be resolved by exponential back-off algorithm. Upon a collision, the senders will back-off and retransmit the packets after their respective back-off time. The back-off time is calculated individually at each sender. Thus the two senders are likely to retransmit after different back-off time intervals and collision is avoided. This technique serves well under low traffic conditions. Under high traffic there can be large number of senders to one receiver. Upon collision, all of them back-off and reattempt transmission. There is a high probability that after first back-off, still some nodes undergo collision or sense the channel busy and again back-off second time. Gradually, as the back-off continues each sender will be able to access channel without collision and close the transmission one by one. As it can be seen, the senders undergoing collision have to attempt back-off and retransmit. Under high traffic, a sender may have to back-off several times, before succeeding in its transmission. This also adds time delay along with energy drain for iterative retransmissions.

Energy waste and time delay due to back-offs are major drawbacks of EM-MAC. RR MAC aims at minimizing these 2 sources of energy waste. Every node in RR MAC also uses the pseudorandom sequence as in EM MAC to decide its frequency and wakeup time. In addition it can also imitate the pseudorandom sequence of other nodes to identify the frequency channel and wake up time of other nodes. Based on this imitation, a sender will identify the frequency and wake up time of the receiver node. When the receiver wakes up, the sender also wakes up to transmit the data. However, unlike EM MAC where back offs normally occur if many senders wake up to transmit data to same receiver, RR MAC incorporates an orderly approach for the senders. RR MAC maintains a central registry wherein each sender upon imitating the receiver's wake up channel and wake up time, will register its Reserve for Transmission (RFT) for that receiver. Each sender before registering it's RFT will verify there is reservation from any other sender. If so, it will reserve the time after the last sender. In short the receiver's wake up time is shared by the senders with each sender completing its transmission and succeeded by the next sender. The succession proceeds according to the RFT registered in the central registry. In this way, the wake up time of the receiver is shared by the senders. In other perspective, it enables time division of the receiver's wake up time based on the RFT registered on the central registry:

- A Sender S1 contains data to transmit to a receiver R

- S1 imitates the pseudo sequence of R to identify R's wake up channel fr and wake up time tr
- S1 registers a RFT (Reserve For Transmission) for the receiver R from time tr till (tr+ts1), where ts1 depends on the size of data at S1
- Another Sender S2 also contains data to transmit to same receiver R
- S2 imitates the pseudo sequence of R to identify receiver's wake up channel fr and wake up time tr
- S2 verifies the central registry for already registered RFTs from other senders and registers its RFT from time (tr+ts1) till (tr+ts1+ts2), where ts2 depends on the size of data at S2
- The next sender, if any, makes reservation into the registry for its transmission respectively
- When R wakes up the Senders complete their transmission one after another in the order of the RFT registered

RR MAC is implemented with a typical network comprising of two sources transmitting to a receiver. MATLAB simulator is used.

RESULTS AND DISCUSSION

The proposed protocol and existing protocol are applied onto the network with above parameters (Table 1) to obtain the number of packets transmitted in course of time. The below plot is made for RR-MAC vs. EM-MAC for the packets transmitted.

As can be seen in Fig. 2 more packets are transmitted in RR MAC for the same time as compared to EM-MAC protocol (Kirubakaran and Shankar, 2012).

Table 1: RR_MAC network parameters

Attribute	Value
Number of nodes	3
Transmission speed	100 kbps
Sleep interval	1000 to 3000 ms

When more senders transmit data to a receiver, the RR MAC gives still better results (Youngmin *et al*., 2008). This can be accounted by the fact that, when collision occurs all four sources back-off and reattempt to transmit independently. It takes course of time for all four nodes to pick up the channel when it is free and complete transmission to the receiver. In RR-MAC, the four nodes complete their transmission without any back-off, each completing the transmission as per the reservation made on the receiver. The packets transmitted in the four source network are shown in Fig. 3 (Kirubakaran and Shankar, 2012).

In EM MAC, back off makes a significant source of energy drain. This becomes a further problem when there are more senders giving remarkable time delay before all the collided senders complete their transmission in subsequent reattempts and backing off (Xu *et al*., 2005). If the sleep interval is small the nodes can wake up frequently, then the senders can reattempt quickly as they wake up more number of times than it was with long sleep intervals. Also receiver will be available frequently, benefitting the reattempting senders and all senders can complete the transmission early as compared to long sleep interval. In order to study the behavior of EM MAC and RR MAC with frequent wake ups, the sleep interval was shortened.

Hence, it makes an interesting point here to analyze the behavior of both the protocols when the sleep interval of the nodes is kept small. Keeping the sleep active much longer than they were active previously

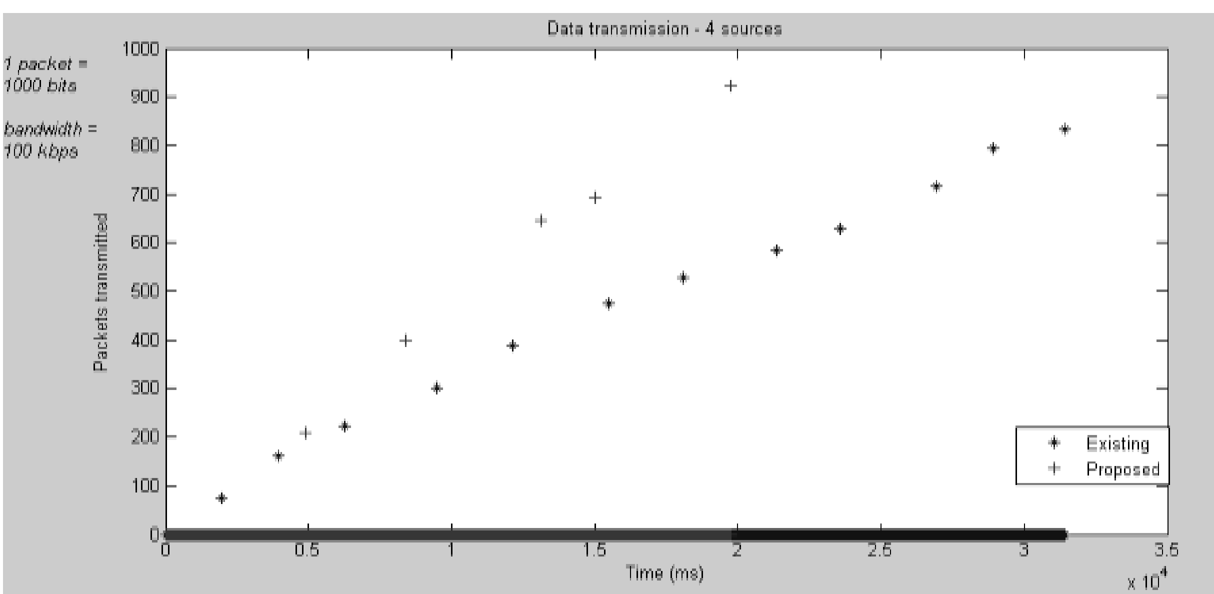

Fig. 2: Two sources transmitting packets to receiver

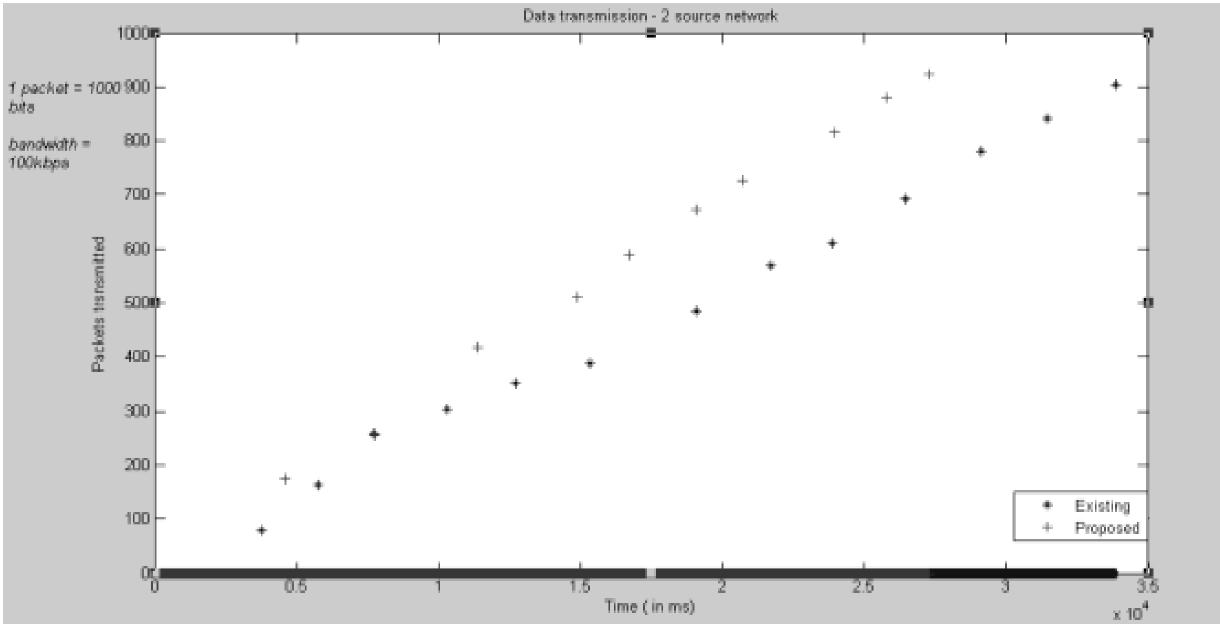

Fig. 3: Four sources transmitting packets to a receiver

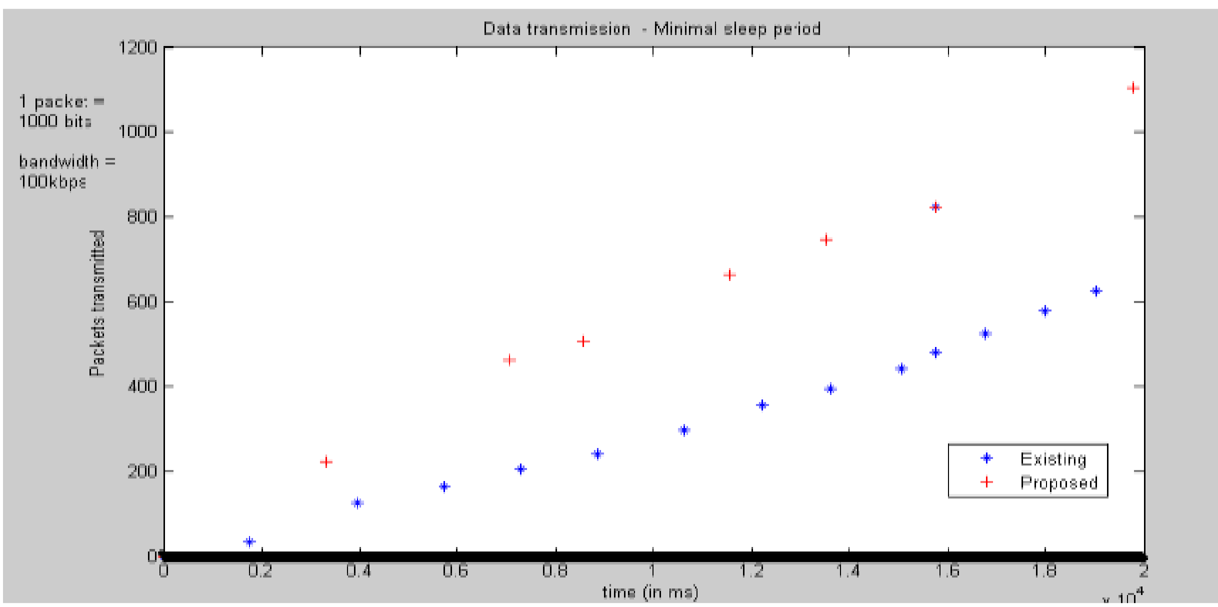

Fig. 4: Four sources transmitting packets with short sleep interval

(Tie *et al*., 2009). Smaller sleep interval will give a better kick-back on the data transmission for the EM-MAC protocol. This will cause more packets transmitted in a given time than they would be transmitted with longer sleep interval. A comparison was plotted in Fig. 4 between the EM-MAC and RR-MAC in the same four node network, but now with the sleep interval of the nodes shortened between 1000 ms to 1500 ms. As observed, the EM-MAC transmits more packets than it did previously with longer sleep interval. This can be seen on comparing Fig. 3 and 4. This is because, the nodes wake up more number of times and sender nodes can back-off more number of attempts in a given time in order to reach the receiver. However, shortening the sleep intervals also favors the RR MAC (Yafeng *et al*., 2008). The efficiency of RR MAC has only improved on shortening the sleep intervals. The RR-MAC still outperforms the EM-MAC by transmitting more packets since the nodes follow an orderly approach to reach the receivers. Smaller sleep interval had favored both the EM-MAC and RR-MAC protocol equally well and RR-MAC continues to perform better than the EM-MAC with smaller sleep intervals also.

CONCLUSION

By adapting time division on the receiver wake up time, sender nodes make a regulated transmission to the receiver. It is a win-win situation for both the senders and receiver. In future study, this study will extend the use of central registry further to proactively decide if a receiver has to wake up in its next wake up time or can skip the next wake up when no reservation is made by any sender. This will save energy at the receiver node by eliminating unnecessary wake ups especially in low-traffic.

A bursting algorithm is also to be devised so that a sender can transmit data partially to the receiver and transmit the remaining packets to the receiver in the next wakeup. This algorithm will be proactively adopted especially when there is high data traffic and the data size is huge at the sender. In such scenario, one sender may reserve the receiver for a very long time to complete its huge data transmission. This will cause the receiver potentially unavailable to other senders for a long duration. This algorithm will enable to handle such data transmissions efficiently.

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