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Research Paper

ENERGY USAGE REDUCTION IN WIRELESS SENSOR NETWORKS USING ASYNCHRONOUS DUTY CYCLE MAC PROTOCOL

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Recent advances in Wireless Sensor Networks (WSN) have led to many new protocols specifically designed for different kinds of applications where energy efficiency is an essential consideration. Most of the attention has been given to the Medium Access Control (MAC) protocols since they play an important role in wireless communications. The sensor networks are efficient, when the nodes are inactive for long time but becoming suddenly active when something is detected. These sensor nodes majorly depend on batteries for energy, which get depleted at a faster rate because of the computation and communication operations they have to perform. Wireless sensors networks performance are strictly related to the medium access mechanism. Therefore, to prolonging the network lifetime, we are in need of a Medium Access Control (MAC) protocol that is able to improve energy efficiency by minimizing idle listening. Duty cycling is a widely used mechanism to reduce energy consumption. In this paper, we propose a Wake up Time-Aware (WTA) asynchronous duty cycle MAC protocol in wireless sensor networks. The proposed protocol provides a solution for reducing idle listening time. It adopts a data arrival rate to determine the next wake up times. As the next wake up time of the receiver is known in prior then there is no need for a sender to wake up for a long time. The performance of proposed protocol is compared with that of RI-MAC and pseudo random asynchronous duty cycle MAC protocol.

Keywords: Wireless sensor networks, Medium access control, Data arrival rate, Energy efficiency, Idle listening time

INTRODUCTION

Wireless sensor networks is an emerging technology that has a wide range of potential applications which require constant monitoring and detection of events such as environmental monitoring, area monitoring, vehicle detection. This network consists of large numbers of distributed sensor nodes that organize

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themselves into a multi-hop wireless network. Sensor nodes are made up of small electronic devices which are capable of sensing, computing with other connected nodes in the network and transmitting data from harsh physical environment. Various issues in wireless sensor networks design are energy consumption, infrastructure setup, computational speed, communication bandwidth, etc. Among these energy conservation is the most important factor in wireless sensor networks, since sensor nodes are usually powered by batteries, it is difficult to recharge or replace the battery of each sensor node. Energy is consumed by a sensor node either for sensing purpose and processing the data or communications. The radio transceiver is the most power consuming component in a sensor node. A typical radio transceiver consists of four possible modes with different power consumption: transmitting, receiving, listening, and sleeping. The first three modes are called active or wakeup modes. Idle listening means that a sensor node turns on the radio to monitor wireless medium but do not receive any packets. MAC protocols are used to turn the radio into sleeping mode as long as possible to ensure a long-lived network of wireless communicating sensors. However, the radio should be scheduled to be in wakeup mode periodically to monitor, send or receive data packets. In this paper we propose a new asynchronous duty cycle MAC protocol based on data arrival rate.

MAC PROTOCOL—AN OVERVIEW

A Medium Access Control (MAC) protocol has an important role to enable the successful operation of the network. Energy efficiency, scalability, throughput and fairness are some of the attributes be considered for designing a good MAC protocol in wireless sensor networks. Although energy conservation in communication can be performed in different layers of the TCP/IP protocol suit, energy conservation at MAC layer is found to be the most effective one due to its ability to control the radio directly. The four major sources of energy loss are collisions, control packet overhead, overhearing, and idle listening. Control packets may have to be received by all nodes within radio range of the sender, resulting in power drain. Overhearing means reception of packets destined for others, it increases energy consumption. Idle listening means, a node’s radio consumes the same amount of power for simply monitoring the channel when there is no traffic destined for it, and then power is wasted. MAC protocols are used to improve energy efficiency by maximizing sleep duration, minimizing idle listening and overhearing, and eliminating hidden terminal problem or collision of packets, so that two interfering nodes do not transmit at the same time. In wireless sensor networks, MAC protocol employs the duty cycling technique, in which sensor nodes turn their radio on and off repeatedly, to save energy. There are two types of duty cycle MAC protocols: synchronous and asynchronous.

Synchronous Duty Cycle MAC Protocol

In synchronous duty cycle MAC protocol sensor nodes wake up and sleep at the same time, it requires timing synchronization.

Timing synchronization causes control message overhead, it makes sensor nodes more complex and expensive. In this protocol sensor nodes are align their sleep/wake up period with the neighboring node, if the neighboring nodes have different wake up schedule then the sensor nodes wake up multiple times. Here unnecessary power consumption takes place on synchronization message exchanges. Examples of synchronous duty cycle MAC protocols are S-MAC and T-MAC.

Asynchronous Duty Cycle MAC Protocol

Asynchronous MAC Protocols are also called as Random Access MAC Protocols. Here randomization is used. Nodes do not synchronize in time and contend for access to the radio channel. In this protocol, sensor nodes wakes up and sleep independently. So that time synchronization is not necessary. These protocols adopt a random wake up interval in order to avoid repeated collisions. When several nodes wake up at the same time, collisions may occur due to simultaneous transmissions. Whenever the sensor nodes wake up and try to send data, collisions may occur repeatedly, if these sensor nodes adopt the same wake up interval. The sensor nodes wake up at different times with random wake up intervals, it is necessary to ensure that a sender and the intended receiver are active at the same point in time to transmit data. For these, preamble based protocols were used. Preamble based protocols occupies the wireless medium for a long time. These protocols typically employing a Low Power Listening (LPL) in which, sender transmits a preamble lasting at least as long as the sleep period of the receiver. These protocols achieve higher energy efficiency and remove the synchronization overhead required in synchronous duty cycle approaches. Examples of the asynchronous duty cycle MAC protocols are B-MAC, X-MAC, Wise-MAC. However, preamble transmission occupies the wireless medium for a long time, which decreases throughput and increases delay. RI-MAC reduces this cost by using beacon frame instead of preamble transmission.

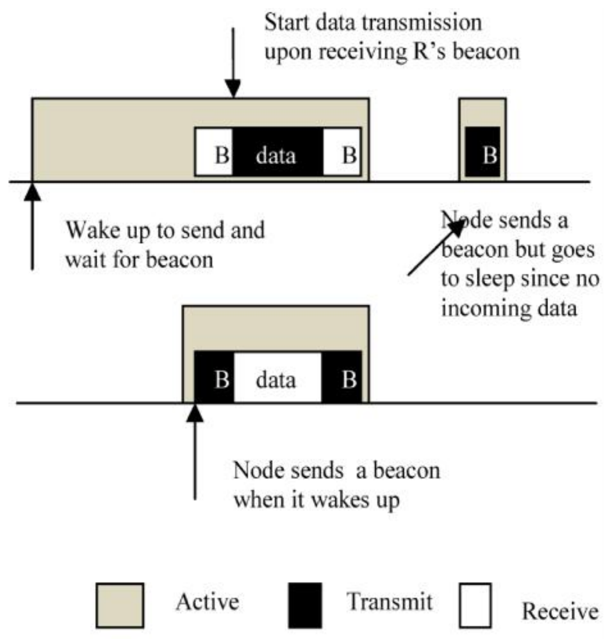
RI-MAC—AN OVERVIEW

In this paper we propose a WTA-MAC which is evolved from RI-MAC. The proposed protocol operation is similar to the RI-MAC but it includes wake up time calculation to reduce idle listening time. Compare to the other asynchronous duty cycle MAC protocol, RI-MAC gives better energy efficiency by using receiver initiated operations.

Figure 1 gives an overview of RI-MAC, in which a data transmission is always initiated by the intended receiver node. In RI-MAC, a sender wakes up and remains active until the intended receiver sends a base beacon. The receiver sends a base beacon whenever it wakes up. After the sender receives the beacon, data transmission is started.

Though this protocol improves preamble-based protocols in terms of energy consumption and delay, the idle listening time is considerable nonetheless. Even though the receiver is initiated the transmission, sender should remain for long time. So that idle

Figure 1: Design of RI-MAC



listening time of sender is high. To overcome this, we propose a new MAC protocol based on RI-MAC. The key feature of our protocol is that, if the sender knows the wake up schedule of receiver in advance then there is no need for the sender to active for a long time. Based on this concept WTA-MAC protocol is proposed. The contribution of this work are as follows:

- We present a new asynchronous duty cycle MAC protocol called WTA-MAC protocol based on receiver initiated transmissions.
- Wake up time of receiver is calculated based on data arrival rate.
- Due to the receiver initiated design, it reduces overhearing and also achieves lower collision probability and recovery than other existing MAC protocols.
- Finally we compare the proposed protocol with some of the previous protocols in terms of energy consumption and delay.

PROPOSED WORK

We propose a Wake up Time- Aware Energy efficient MAC (WTA-MAC) protocol based on data arrival rate. The proposed MAC protocol differs from the existing work in terms of wake up time determination. The design goals of the WTA-MAC protocol for duty cycled wireless sensor networks are reducing idle listening time, achieves high energy efficiency, low end to end delay.

WTA-MAC Protocol Design

WTA- MAC protocol works based on RI-MAC. The novel idea of the proposed protocol is to reduce idle listening by the calculation of wake up interval. This protocol significantly reduces the amount of time a pair of nodes occupy the medium before they reach a rendezvous time for data exchange, which is similar to RI-MAC. In RI-MAC, the sender remains active and waits silently until the receiver explicitly signifies when to start data transmission by sending a short base beacon frame. So that idle listening time of sending node is high which yields high energy consumption. The proposed protocol includes wake up time calculation for reducing the idle listening time of sensor nodes. As the next wake up times of receiver is known in advance, sending nodes do not need to remain active until their intended receivers wake up. Hence, sending node has wake up just before the receiver wakes up. So that listening time is reduced in the proposed scheme as compared to the existing work.

We propose an efficient method based on data arrival rate to determine the wake up interval. Sensor node *i* calculates the wake up interval as follows:

$$F_i(n) = \mathrm{mod}\left(Hash\left(n \oplus ID_i\right), T_{range}\right) - T_{dr} \qquad ...(1)$$

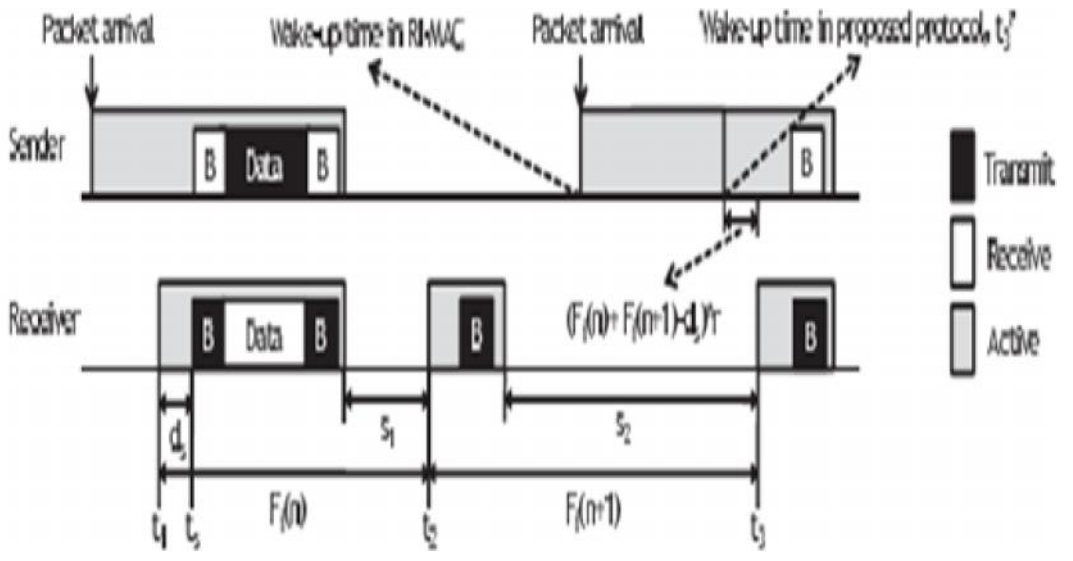
where n is a sequence number for each sensor node, which is incremented at each wakeup of sensor node i, ID is the identification number of a particular

Sensor node, $\oplus$ is the exclusive OR operation, T_{range} is the range of the wake up interval and T_{dr} is the data arrival rate at that particular sensor node. In this, wake up interval is computed by taking data arrival rate as a metric instead of random wake up interval in the previous work. By this, the sensor nodes are wake up just before the packet arrives. So that, idle listening time is reduced.

Operation of the Proposed Protocol

Whenever a packet arrives at a sender, it wakes up and remains active until the intended receiver i sends a base beacon. After turning on its radio, the receiver node sends a base beacon as an invitation for data transmission. As shown in Figure 2, the receiver node wakes up at t_1 and sends a base beacon at t_s, after performing a short backoff followed by the CCA check to avoid collisions from simultaneous transmission of beacon transmission. Then the receiver node waits to receive packets from the sender until a Time-Out (TO) period occurs. The receiver goes to sleep if it detects the channel busy or no packets arrived after TO occurs. If a sender receives the base beacon, it starts sending data immediately. The successful reception of the packets from a particular sender is acknowledged through another beacon denoted as ACK beacon. This ACK beacon's role is twofold: first it acknowledges the correct receipt of the sent data frame, and second, it invites a new data frame transmission to the same receiver. If there is no incoming data after broadcasting a beacon, the node goes to sleep. Unlike RI-MAC, the proposed scheme includes a sequence number n and the time difference between the wake up time (t_1) and the start time if base beacon transmission (t_s), denoted by d_s. By using $t_1 = t_s - d_s$, sender can calculate the last wake up time of the receiver. Then both the sender and receiver calculate

Figure 2: Operation of the Proposed Protocol



the next wake up times of the receiver i by $t_2 = t_1 + F_i(n)$, $t_3 = t_1 + F_i(n) + F_i(n + 1)$ continuing as far as is necessary. So that the sender recognizes all of the wake up times of the receiver in future. Thus, when a packet arrives later the sender does not wake up immediately, because it has the wakeup schedule of the receiver. Hence, it wakes up just before the receiver wakes up in order to save energy. This approach significantly reduces the idle listening time with very low additional overhead.

Handling Clock Drift

A clock in each sensor node runs at a different speed is referred to as clock drift. In the proposed scheme, senders must wake up slightly earlier than the calculated wake-up time of receiver i. Receiver i wakes up at every (k > 1), while the senders wake up at t_k'(k > 1) if they have data to send, as follows:

$$t_k' = t_s + (1 - r)\left\{\sum_{m=0}^{k-2} F_i(n+m) - ds\right\} \quad ...(2)$$

$$t_2' = t_s + \{F_i(n) - ds\} - \{F_i(n) - ds\} * r \quad ...(3)$$

$$t_3' = t_s + \{F_i(n) + F_i(n+1) - ds\} - \{F_i(n) + F_i(n+1) - ds\} * r \quad ...(4)$$

where r is the upper bound of clock drift. The upper bound of clock drift in Berkeley motes is 40 ppm, where t_2 and t_3 are the wake up times of the sender and t_2' and t_3' are the wake up times of the receiver.

SIMULATION EVALUATION

We perform extensive simulation of our work using NS-2 simulator. In this work, the proposed protocol is compared with RI-MAC and Pseudo random asynchronous MAC protocol. We deploy 50 sensor nodes randomly in 1000 m * 1000 m area and two ray ground model is used as a channel model. All sensor nodes except the sink independently generate packet s and send them to the sink through multi-hop transmissions. Each node generates packets according to a Poisson process, i.e., the packet inter-arrival time is exponentially distributed.

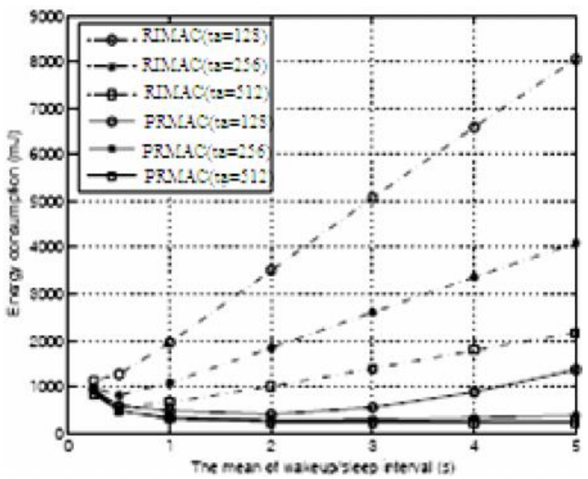
Table 1: Simulation Parameters

Data packet size	128 bytes
Beacon size	12 bytes
Transmitting energy	24.75 mw
Receiving energy	13.5 mw
Transmitting range	250 m

RESULTS

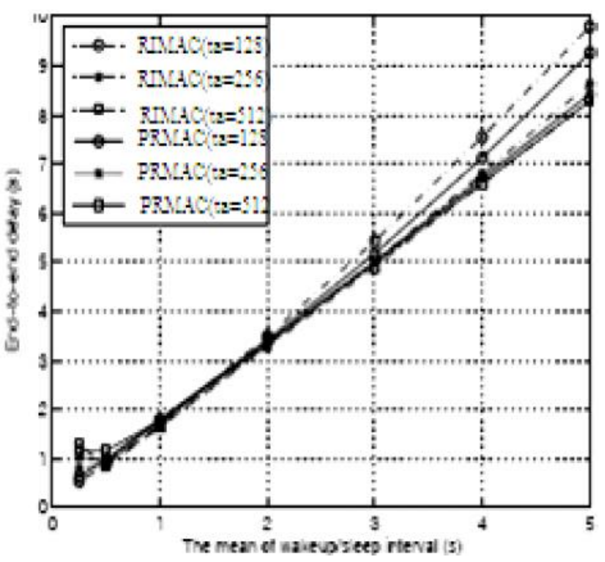
RI-MAC and pseudo random MAC protocols are implemented by considering mean of the wake up/sleep interval as 0.25, 0.5, 1, 2, 3, 4, 5. As shown in Figure 3, pseudo random MAC is compared with RI-MAC protocol in terms of mean of sleep/wakeup interval and energy

Figure 3: Energy Consumption According to Wakeup/Sleep Interval



consumption. In Figure 4, the two protocols are compared in terms of mean of wakeup/sleep interval and end to end delay.

Figure 4: End to End Delay According to Wakeup/Sleep Interval



WTA-MAC protocol is partially implemented and we are going to compare this protocol with existing MAC protocols by considering energy consumption and end-end delay as a parameters.

CONCLUSION

Energy conservation has been considered as the most striking issue in wireless sensor networks. Developing an energy efficient MAC protocol has been a hot research area in WSN. In this paper, WTA asynchronous duty cycle MAC protocol has been proposed to solve the problem of idle listening in wireless sensor networks. Energy efficiency is the primary goal in the protocol design. Duty cycling mechanism is used in our work to achieve lower energy consumption. This protocol employs the data arrival rate to determine the next wake up time of the receiver. Then the sender recognizes all of the wake-up times of the receiver in future then there is no need for the sender to be active for long time. Due to the reduction of idle listening time, energy Consumption is minimized. Further results on network scenarios incorporating high number of nodes over a larger area as well as biggest packet sizes.

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