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An application-specific duty cycle adjustment MAC protocol for energy conserving over wireless sensor networks ☆

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ABSTRACT

Wireless sensors are battery-powered sensing and computing devices. Comparing with wired sensors, wireless sensors have limited battery life that restricts the communication rage and working time of sensor nodes. Duty cycle adjustment affects the energy consumption and data transmission of wireless sensors. The long duty cycle makes the sensors can have more time to transmit data, and low duty cycle makes the sensors can conserve battery energy. In this paper, we propose an application-specific duty cycle adjustment MAC protocol (i) to conserve energy on sensors with low data traffic and (ii) to decrease transmission latency on sensors with heavy data traffic. In the proposed scheme, nodes are not required to follow a single generic duty cycle. Each node can have different listen and sleep schedules with different duty cycles.

1. Introduction

In wireless sensor networks, applications such as surveillance or monitoring will be retained for a long period [1,2]. In such applications, an individual node remaining largely inactive until an event is detected. If no sensing event happens, nodes are in idle for a long time. When nodes are in idle, the energy is still being consumed. In traditional wireless sensor networks, sensors need to be in listening for sensing data transmission, which drains the battery life [3,4]. In order to reduce the energy consumption when nodes are in idle listening, duty-cycle based MAC protocols are introduced to let nodes go into sleep mode periodically or aperiodically [5–9].

Traditional MAC protocols, such as 802.11, are not suitable for data delivery of wireless sensors with low duty cycle [6]. Idle listening in 802.11 consumes as much energy as it does when receiving data. Idle listening wastes energy when a node is active, but there is no meaningful task on the radio channel. MAC protocols that support a duty cycling mechanism can eliminate idle listening, hence the energy consumption can be reduced. S-MAC [7], T-MAC [10], and U-MAC [11] are duty-cycle based MAC protocols that can specify when nodes are awake and asleep within a frame. In S-MAC, neighboring nodes form virtual clusters to synchronize the working schedules. Nodes periodically wake up, receive and transmit data, and then return to sleep to reduce energy consumption. Within a virtual cluster, a node exchanges synchronization and schedule information with its neighbors to ensure that the node and its neighbors wake up at the same time. After the schedule is synchronized, nodes with data can transmit packets when the receive nodes are awake. Nodes without data will be in idle for waiting connection until the end of the awake period and the nodes then enter into sleep mode. S-MAC uses a SYNC packet to accomplish the synchronization of working schedules. When a node receives the SYNC packet, the node will adjust its timer immediately. In S-MAC, the period of a regular cycle consists of a listen and a sleep state. The duty cycle is defined as the ratio of the node in listen state respective to the period of a regular cycle. A 20% duty cycle means that it is capable of listening to 20% of a specified time period and turned off for the remainder.

In a wireless sensor network, nodes may take on different roles, e.g., data source nodes, intermediate nodes, and sink nodes, according to their tasks. Different types of nodes have different transmission behaviors and traffic loads. Even data source nodes with same tasks may have different data collecting time and sending time. In S-MAC, a uniform duty cycle is assigned across the whole network, which is not suitable for all sensors. If the uniform duty cycle is set too long, it may cause energy wastage on nodes with low data traffic because the nodes are in idle listening. If the uniform duty cycle is set too short, it may increase transmission latency on nodes with heavy data traffic because the nodes don't have enough time to transmit all collected data [12].

In this paper, we propose an application-specific duty cycle adjustment MAC protocol named OD-MAC to decrease the probability of schedule misses of nodes. The goals of the proposed MAC protocol are twofold: (i) to conserve energy on nodes with low data traffic, and (ii) to decrease transmission latency on nodes

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with heavy data traffic. In the proposed scheme, nodes are not required to follow a single generic duty cycle. Each node can have different listen and sleep schedules with different duty cycles. Additional wake-up periods can be added on the receiver node, scheduled such that the receiver is in listening exactly when the data source node is ready to send the data packet. We develop algorithms for data scheduling to allow nodes to minimize energy consumption and transmission latency. Initially, each node only has a timetable without any schedule. The synchronizer broadcasts a generic synchronization packet and establishes the generic schedule for all nodes. After all nodes follow the generic schedule, a node that collects data periodically can send an application-specific synchronization packet for the on-demand data schedule. When a node receives the specific synchronization packet, the node adds a specific schedule into its timetable as that sent by the sender. When a node receives a another schedule from other nodes, it adjusts its timetable to satisfy the request if there have available time periods can be arranged. Some neighboring nodes may be failed to send data to the receiver at active time due to signal collisions on the radio channel, the sender will go to sleep state for energy conserving and wait for next wake-up time to try to transmit data again.

The remaining parts of this paper are organized as follows: Section 2 introduces some related works of duty-cycle based MAC protocols. Section 3 describes the duty cycle design consideration of MAC protocols for wireless sensor networks. Section 4 presents the proposed on-demand MAC control mechanism for wireless sensor networks. Section 5 gives the simulation results and performance analysis of the proposed on-demand MAC control mechanism for wireless sensor networks. Section 6 has the conclusion remarks.

2. Related works

In wireless sensor networks, duty-cycle based MAC protocols can be classified into synchronized, asynchronous, and hybrid approaches. This section provides a brief overview of existing duty-cycle based MAC protocols.

S-MAC [7], T-MAC [10] and U-MAC [11] are synchronized protocols which can specify when nodes are awake and asleep within a frame. In S-MAC, neighboring nodes form virtual clusters to synchronize the working schedules [7]. Nodes periodically wake up, receive and transmit data, and then return to sleep to reduce energy consumption. Within a virtual cluster, a node exchanges synchronization and schedule information with its neighbors to ensure that the node and its neighbors wake up at the same time. After the schedule is synchronized, nodes with data can transmit packets by sending medium reservation through RTS (Request To Send) and CTS (Clear To Send) frames when the nodes are awake. Nodes without data will be in idle for waiting connections until the end of the awake period and the nodes then enter into sleep mode. S-MAC uses a SYNC packet to accomplish the synchronization of working schedule. When a node receives the SYNC packet, the node will adjust its timer immediately. In S-MAC, the listen interval is divided into two parts: (i) interval for receiving SYNC packets and (ii) interval for receiving RTS/CTS packets. Fig. 1 shows the illustration of S-MAC frame structure.

In [10], Dam and Langendoen proposed the T-MAC protocol that enhances the design of S-MAC by listening to the radio channel for only a short time, and nodes enter into sleep mode if no data is received during that time. After synchronization, T-MAC shortens the awake period of a node if the radio channel is idle for a short time. If data are received, the node remains awake until the transmission is finished or the awake period ends. By using adaptive duty cycling, T-MAC can reduce energy usage for transmitting data. However, in return for gaining energy, the costs are the reduced data throughput and the increased transmission latency.

In [11], Yang et. al. proposed the U-MAC protocol that tunes duty cycle according to the traffic loads of sensor nodes. In wireless sensor networks, making nodes asleep for a long time to lower the energy consumption may result in higher transmission latency. U-MAC tries to solve the problem by tuning duty cycle according to the traffic loads. To reflect the traffic loads, U-MAC adopts a utilization function to calculate the load of each node. Upon synchronization, a node calculates its traffic utilization since the last synchronization time. The node adjusts its duty cycle according to the calculated utilization, and then broadcasts the new schedule to its neighbors.

B-MAC [13], WiesMAC [14], and X-MAC [15] are asynchronous protocols that utilize adaptive preamble sampling schemes to reduce duty cycle and minimize idle listening. In B-MAC, nodes are awake and asleep asynchronously. When a sender has data, the sender sends a packet with a preamble that is longer than the sleep period of the receiver. When the receiver wakes up and detects the preamble, it stays awake to receive the data. B-MAC equips periodic channel sampling, called Low Power Listening (LPL), to enable low power communication without the need of explicit synchronization among the nodes. The receiver only wakes for a short time to sample the medium, which reduces the time of idle listening and energy consumption.

In [14], El-Hoiydi and Decotignie proposed the WiseMAC protocol for the downlink channel of infrastructure wireless sensor networks. WiseMAC is also based on the preamble sampling technique [16]. By sampling the medium, WiseMAC listens to the radio channel for a short duration, i.e., the duration of a modulation symbol, to check for network activity. Nodes sample the medium with the same constant period. In WiseMAC, the access point learns the sampling schedule of all sensor nodes. Having the sampling schedule of the destination, the access point starts the transmission just at the right time with a wake-up preamble. To reduce the length of the extended preamble, the receiver sends the time of its next awake period in the data acknowledgment frame. As a result, the sender can begin the preamble only a short time before the receiver will awaken. By using the preamble sampling technique, WiseMAC can reduce energy usage for transmitting data. However, it is not suitable for long distance multi-hop data transmission.

In [15], Buettner et al. proposed the X-MAC protocol that uses a shortened preamble approach for retaining the advantages of low power listening. In wireless sensor networks, long preamble introduces excess transmission latency at each hop and suffers from excess energy consumption at non-target receivers. Instead of sending a long preamble stream, X-MAC inserts small pauses in the preamble stream, which forms a series of short preamble streams. These gaps enable the receiver to reply an early acknowledgement packet back to the sender during the short pause between preamble streams. When a sender receives an

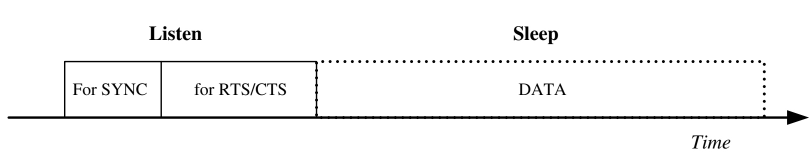

Fig. 1. S-MAC frame structure.