PRIORITY AWARE DATA COLLECTION MAC PROTOCOL IN WIRELESS SENSOR NETWORKS

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Abstract —Data packets generated by sensor nodes are generally routed and transferred to the sink nodes in a wireless sensor network. Since a large number of data packets may be transmitted to the sink node simultaneously, significant packet collisions may be occurred around the sink node and severe latency can be caused. In this paper we proposed a priority aware data collection MAC protocol (PADC-MAC). The basic idea of this protocol is to reduce the duplicated data packets before they are sent to their neighbor nodes. In PADC-MAC protocol, a node uses data signal length and data receiving direction to determine whether the received data packets are redundant or not. Furthermore, the high priority data packets are transmitted immediately to the next node in PADC-MAC. The comparative analysis of the simulation test results shows that PADC-MAC outperforms other related protocols in terms of node energy consumption and transmission delay, especially on the transmittal of priority data packet. Simulation results show that the performance of PADC-MAC is improved up to 23.3% in packet transmission delay and 36.6% in node energy consumption com-pared with related protocols.

Keywords— Wireless Sensor Networks, Multiple Access Control (MAC), energy efficiency, delay, priority

1. INTRODUCTION

Wireless sensor networks (WSNs) have been widely used in many applications such as those in environment monitoring, health care, wild animal tracking, and fire detection. WSNs consist of a large number of small sensor nodes with a limited energy capacity and computing power. Since each sensor node is generally powered by battery, the battery may not be easy to be replaced. So it is very important to save sensor node's energy for extending the network's life time. Many research works have been suggested to limit sensor node energy consumption [1-5]. One of the most efficient ways to increase a sensor node's energy efficiency is to adapt low power scheme at MAC (Medium Access Control) layer. That is because the MAC protocols take charge of the radio module operation. The radio module usually consumes much node energy. Another source of energy consumption at sensor node is idle listening. During idle listening state, a sensor node is listening to the link without transmitting and receiving data packets. But the same

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amount of energy may be consumed by a sensor node during transmitting or receiving state. Many solutions to reduce energy consumption due to the idle listening have been proposed. The MAC protocols may be classified into three categories: contention-based protocols [1][2], TDMA schedule-based protocol or reservation based protocol [6], and Hybrid protocol [7]. Contention-based MAC protocol adapts the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) protocol. The main idea of this protocol is that when a node wants to send data packet, it will compete with other nodes for wireless channel. Contention-based protocols demand no coordination among the nodes within a virtual cluster to access the wireless channel. The simple implementation and the flexibility to accept nodes are the important advantages of contention-based protocols. On the other hand, the schedule-based TDMA protocol supports collision free mechanism by assigning time slots for all intending nodes to transmit or receive data packet. The unique characteristics of the schedule-based TDMA protocol is the energy efficiency by reducing packet collisions, overhearing, and idle-listening. Finally, the Hybrid MAC protocol was developed to solve the disadvantages in both scheduled and contention-based-MAC protocols. The hybrid protocols modify the operation of MAC protocol between the contention-based CSMA protocol and the schedule-based TDMA protocol based on the contention level in the network. The main excellence of the hybrid MAC protocols is easy implementation to network conditions that may reduce a lot of energy consumption. To reduce energy consumption by idle listening, many MAC protocols employ duty-cycle mechanism [8][9][10][16]. Each sensor node using duty-cycling stays in ON mode and OFF mode periodically. When a node stays in ON mode, the node can transmit or receive data packet. Otherwise, the sensor node turns its radio off to reduce energy consumption. On the contrary, in the OFF mode, a sensor node cannot transmit or receive data packet. Consequently, using the duty cycling technique causes significant delay in packet transmission, especially in a multi-hop data packet environment. When many data packets are received at a relay node, the node cannot send all the packets during one operational cycle. A relay sensor node must wait until the next operational cycle to transmit its data packet to a neighbor node. As the number of applications using WSNs increase, there are more things to consider. Among them is the great demand for QoS (Quality of Service) [12][17]. As mentioned earlier, WSN has been widely used on various applications such as object tracking, environment monitoring, military, health-care industry, and fire surveillance. The sensor nodes are distributed in the measuring field randomly or intentionally. The distributed sensor node then detects, measures, or senses the intended target objects. A sensor node then sends data packets generated from measuring field to a sink node or a final destination. The sensor nodes near the sink node typically consume more energy than sensor nodes further away from the sink node. This is because the data packets generally converge to the sink node. The sensor node near the sink node may deal with a large number of data packets. Such a phenomenon shortens the operational lifetime of the overall WSNs. To deal with this problem, load balancing data transmission mechanism is required. Furthermore, in the object tracking applications such as animal access, wild animal appearance, and the flight appearance an event occurrence is not common. When such an event occurs, several sensor nodes can detect the same event and want to send their measured data packets to a sink node simultaneously. Many duplicated packets may be generated and be transmitted. These duplicated packets can increase the packet transmission delay. To reduce the packet transmission latency the duplicated packets need to be discarded at the relay node before transmitted. To deal with these duplicated data packets and congestion problem in sensor networks, many research works have been proposed [13-15]. In this paper, we proposed a priority aware data collection MAC protocol. The important contribution of this paper is to reduce the duplicated data packets before being transmitted and to prioritize the transmission of urgent data packets. The remainder of this paper is structured as follows: The detailed design of the proposed PADC-MAC protocol is presented in Section 2. In Section 3, we

analyzes the performance of the proposed PADC-MAC protocol in comparison with the other related protocols and Section 4 discusses the conclusions of the study.

2. DESIGN OF PADC-MAC PROTOCOL

2.1. OVERVIEW

One of the major problems to solve with WSN is increasing the lifetime of network. If any node fails to send its information to other node, then the network is considered dead. In the collecting or aggregating processes in WSNs, a protocol must be able to eliminate redundant data packets from several sensor nodes and to reduce energy consumption of relay node. Many studies have been conducted to further extend network lifetime with data aggregation technique [13]. Those techniques are generally divided into two groups: a structure based scheme [14] and structure-free scheme [15]. Various structures of the sensor nodes in structured data aggregation scheme are formed to collect, aggregate, and transmit the data packets to their sink node. They may be designated as leader nodes, root nodes, and cluster heads. The advantage of the structured data aggregation is low maintenance overhead for static traffic pattern. But the over-head of design and maintenance of the structure may be increased in event-driven applications such as object appearance detection. Since the numbers of child nodes are not fixed to receive data packet in structure-free data aggregation, an efficient scheduling scheme is needed to avoid entire network congestion and to increase throughput. In priority handling aggregation technique [19], a hybrid scheme was suggested. The scheme uses priority queues to support High Priority Packets (HPP) to be transmitted in a required time. Furthermore, the scheme does not reduce data size and appends data from in-coming packets to reduce energy consumption. The real-time transmission for the high priority packets in the scheme is done by directly forwarding the packets in the scheme.

2.1. DESIGN OF PADC-MAC PROTOCOL

In this paper, we consider an environment where normal and abnormal data packets may be collected simultaneously. The proposed protocol provides transmission priority on these data packets according to their transmission urgency. Here, abnormal or delay sensitive data packet is given higher priority [21]. These data packet are generated when an event occurs, such as fire, appearance of the animal, and wild animal appearance. And the lower priority traffic is the normal data which may be periodic or normal data which is collected periodically by sensor nodes. To support priority transmission in the PADC-MAC protocol, the modified Tx-beacon and Rx-beacon frames of the QAEE-MAC [17] are used. If a sender node tries to transmit its data packet, the node first transmits a Tx-beacon to its receiver, and then receives a beacon frame from the receiver node. The receiver node wakes up first and receives all the beacon frames from the sender nodes. The receiver node then determines which sender node will transmit its packet first. After deciding the packet transmission order among sender nodes, the receiver node broadcasts its beacon frame to all the sender nodes. The beacon frame sent by the receiver contains the sender's address, NAV value, and transmission priority level. After receiving the beacon frame from receiver, all the other sender nodes enter sleep mode for a while except the sender node selected and notified by the receiver node. The receiver node always waits for sender node's beacon frames. After receiving all the sender node's beacon frames, the receiver node then determines which sender node will transmit first, depending on the priority bit value. Furthermore, to save each node's energy, the receiver node tries to send its beacon frame immediately after receiving a sender's beacon frame with higher priority. If any node does not transmit a sender's beacon frame for some time, the receiver node stops to receive sender's beacon frames and transmits its beacon frame to its neighbor nodes.

Fig. 1 Beacon Frame Formats

The formats of beacon frames used in the PADC-MAC protocol are shown in the Figure 1. It can be seen that the sender's beacon frame is different from that of the receiver node. In the sender's beacon frame format we added two fields in the IEEE 802.15 specification; a priority bit and NAV field. The priority bit is set by original sender node that detects the event occurrence. Using this priority bit field, a sender node can inform the packet's priority level information to the receiver node. Using this priority information, the receiver node can determine the packet transmission priority level. In other words, if a receiver node receives many sender's beacon frames, the receiver node then selects one sender node whose priority field bit set 1. So an abnormal data packet can be transmitted faster than a normal data packet. Furthermore, a sender node can inform all the other receiver nodes the information of amount of data packets transmitted. The information of amount of data packets trans-mitted is contained in NAV field of beacon frame. The NAV field plays the same role as that of RTS/CTS packets in IEEE 802.11. Figure 2 shows an environment when only a signal strength is used to determine whether the received data packets are duplicated or not. In this figure the node B and the node C detect different event occurrences each other. If the node B and the node C use almost the same transmission power and are located at the almost same distance from the relay node A, the received signal strengths at the node A are almost the same. So the intermediate node A may not distinguish the data packets received nodes B and C. Therefore, the intermediate node A may consider that the packets are duplicated ones and discard one of them. To solve this problem, data packet collected direction is used to distinguish duplicate data packets [18].

Fig. 2 A sample diagram of a signal strength only based protocol which incorrectly decides that the data packets are duplicated

Figure 3 shows the same environment as Figure 2. But in this case data packet direction is used to identify duplicate packets. As shown in the figure, nodes B and C are located in the different virtual clusters but in the almost same monitoring direction.

Fig. 3 A sample diagram of a signal strength only based protocol which incorrectly considers two different events as one

The two nodes in this case detect different event occurrences. But intermediate or relay node A may consider the two different events as the same one. So it may also drop one of packets. The PADC-MAC can solve the above mentioned problem. The proposed mechanism considers the packet signal length, the packet direction, and the packet priority simultaneously. Therefore, if the same situation as Figure 3 happens, the PADC-MAC can distinguish event 1 from event 2. So an efficient data packet gathering or collecting can be achieved. After transmitting all the higher priority data packets, the intermediate node A send data packets with lower priority. Like this the PADC-MAC protocol can support priority data packet transmission. The data packets with priority bit 1 may be created by nodes when an event occurs. These data packets with higher priority are generally very sensitive to transmission delays. If a relay sensor node receives these delay sensitive data packets, the node has to transfer them first. To illustrate the operation, we consider here a case when the higher priority data packets and the lower priority packets coexist. As shown in the Figure 3, the node B collects normal data and the node C detects event occurrence. The data packets collected by node C get higher priority level. After collecting data packet, both nodes send the data packets to the relay node A. After receiving the packets from node B and node C, the relay node A puts the data packets from node B into lower priority packet queue, and puts the data packets from node C into the higher priority packet queue. In other words, the relay node can separate both packets with the same signal strength and packet direction. The architecture of the queue management system used in PADC-MAC is shown in the Figure 4. As shown in the figure, the packet classifier checks the priority bit to put data packets into appropriate queue. The operation of the queue management is described in [17].

Fig. 4 The Architecture of PADC-MAC Queue Management

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1: SENDER: Data Measuring & Receiving
    {event detect    priority bit set}
    {aggregating packets: signal strength/data direction}
2: SENDER: Channel Sensing
3: SENDER: if channel == busy
    {wating}
4: SENDER: else if channel == idle
    {TxBeacon frame Transmission
    TimeSenderNo = TxBeacon time}
    {waiting RxBeacon frame}
5: SENDER: if ReceivedNode == Sink
6: SENDER: if ReceivedBeacon == TxBeacon
    {witing RxBeacon frame}
7: SENDER: elsief ReceiveBeacon == RxBeacon
    {TimeSink = RxBeacon time
    TimeTransferSlottime = TimeData - (TimeSenderNo-TimeSink)}
8: SENDER: if Time! = TimeTransferSlottime
    {sleeping}
9: SENDER: elseif {data packet transmission}
10: SENDER: else if ReceivedNode == Receiver
11: SENDER: if SenderControl == RxBeaconDelete
    {Deleted SenderBuffer = null}
12: SENDER: else {data packet transmission}

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Fig. 5 Sender Node Packet Transmission Algorithm

Figure 5 shows the algorithm of packet transmission process by a sender node. A Sender node first checks whether the data packets were generated from an event or not. If the data packets were generated from an event, then the packet's priority bit is set to 1, otherwise the priority bit is set to 0. Then the sender node determines whether the received data packets are duplicated or not according to the signal strength and data packet receiving direction.

3. PERFORMANCE AND EVALUATION

The overall performance of the PADC-MAC is evaluated in terms of energy consumption of sensor node and the packet transmission delay. Table I shows the values of the network environments and the energy parameters of each sensor node used in the simulations. We assumed here that all sensor nodes are randomly arranged and maximum hops to the sink node are 3. And there are 30 nodes randomly located around the measuring field. All the data packets from sender nodes are directed to the sink node. It is assumed that the sink node is located at the middle of the network structure. The simulation is performed according to the number of packets generated from a node.

Table I. Networks Parameters

Parameter	Description Value	Value
	Regular	Bold
PTX	Power consumption in TX	57.6mA
Pidle	Power consumption in idle	10mA
Psleep	Power consumption in sleep	10 μ A
PRX	Power consumption in RX	10mA
Tdata	Data packet transfer time	7.744ms
Data_Rate	Data rate	250kbps
Bcapacity	Battery capacity	1000mAh
Beacon	beacon size	44byte
Data	data packet size	220byte
SIFS	Short Interframe Space	192 μ s
ACK	Acknowledgement size	5B
Preamble	Short preamble size	6B

We ran ten simulation tests and calculated the mean value of each network performance parameters. Figure 6 shows the result of a comparison of the average packet transmission delay according to the number of generated data packets from a node. It can be shown that the PADC-MAC protocol outperforms other related protocols in packet transmission latency between sender nodes and the sink node. As the number of nodes increases, the performance difference increases. A comparison of the average node energy consumption according to the number of data packets created from sensor node is shown in the Figure 7. The Figure 7 shows that the proposed protocol also outperforms other related protocols in terms of average energy consumption of sensor node. Under heavy traffic condition, in PADC-MAC a node consumes energy less by more than 40% on average. As number of packets generated by a node increases, more duplicated data packets may be removed at the relay node before being sent to the sink nodes. We evaluated the higher priority data packet transmission delay of the PADC-MAC.

Fig. 6 Average Packet Delay versus No. of packets

Fig. 7 Average Node Energy Consumption versus No. of packets

Figure 8 shows that as the number of packets created by a sensor node increases, the PADC-MAC outperforms other proto-cols in higher priority data packet transmission delay. Because other protocols do not have priority data packet supporting mechanism, PADC-MAC shows better performance in the average packet transmission delay.

Fig. 8 Average High Priority Packet Transmission Delay versus No. of packets

4. CONCLUSION

In this paper, we presented a Priority Aware Data Collection MAC protocol in Wireless Sensor Networks. The PADC-MAC uses signal strength, the receiving direction of data packet, and packet priority level simultaneously to determine whether the received data packets are duplicated packets or not. Only the adequate data packets are transmitted to the final destination node through the relay sensor nodes. The proposed scheme can discard many duplicated packets generated from the same event or environment by many sensor nodes. The PADC-MAC can also prevent unnecessary removal of data packets that can be caused by misjudgment. Furthermore, a queue management mechanism for priority data transmission is used in the PADC-MAC. This mechanism supports Quality of Service (QoS). By using these properties, the protocol can reduce the packet transmission delay and node energy consumption, from sensor node to the final destination, a sink node. Simulation results show that the performance of PADC-MAC is improved up to 23.3% in packet transmission delay and 36.6% in node energy consumption compared to other related protocols. Under heavy traffic condition, a node in PADC-MAC consumes energy less by more than 40% on average. This is because

more redundant data packets can be removed before being sent to its sink node from the relay nodes as the number of packets created by the node increases. In conclusion, PADC-MAC improves packet transmission delay and node energy consumption especially in priority packet transmission in our simulation.

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