QA-MAC: QoS-Aware MAC Protocol for Wireless Sensor Networks

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Abstract— **In this paper, we present a QoS-aware MAC protocol (QA-MAC) for cluster based wireless sensor networks (WSNs). QA-MAC is a TDMA-based scheduling protocol that minimizes the energy consumption in multi-hop WSNs and provides Quality of Service (QoS). A dynamic scheduling algorithm according to the number of member nodes, node traffics, and traffic priorities is suggested. The selected cluster head allocates time slots for all member nodes in the first TDMA schedule period of each round. During the second schedule period in each round, the cluster head makes a schedule for all data transmission. The proposed QA-MAC (QoS-Aware MAC) could save energy, reduce transmission delay, and support QoS.**

Index Terms— **Wireless Sensor Network, MAC protocol, TDMA, QoS**

I. INTRODUCTION

Wireless Sensor Networks (WSNs) is an exiting new technology with application to environment monitoring, factory monitoring, agriculture, medical care, and military applications. WSNs are composed of many sensor nodes and each sensor nodes have limited power resources. And sensor nodes are usually deployed in widely environment which makes it hard to recharge and replace their individual batteries. Therefore limited power resources must be managed for prolonging network lifetime [1]. So energy saving is one of the primary concerns. To use power resource effectively, there are a lot of researches in various fields. Major sources of energy consumptions of the sensor nodes are idle listening, collision, overhearing and control overhead [2]. Idle listening is a dominant factor in most sensor network applications. MAC protocols for WSNs are usually divided into two categories, contention-base and contention-free. Contention-based protocols usually require sensor nodes to keep their radios on to monitor possible incoming messages. So such protocols are not energy-efficient due to idle listening. So many researches are focusing on lowering the radio duty cycle by turning the radio off part of time. But contention-free protocols, known as scheduling-based protocols, try to detect the neighboring radios of each node before allocating collision-free channels to a link. Clustering solutions are often combined with TDMA-based protocols to reduce the cost of idle listening. Cluster based wireless sensor network is composed of many clusters. In each cluster, there are two types of node, one is a cluster head and another is member node. All of nodes in cluster have to be a cluster head or a member node. After cluster is formed, member nodes send their sensing data to cluster head. Cluster head integrates data received from member nodes and then send it to sink or BS (Base Station) [3]. In cluster based wireless sensor network, there exist various MAC protocols using TDMA-based [4]. Cluster head sends scheduling message to member nodes after forming cluster in TDMA-based MAC protocols. In a schedule message, there is information that tells member nodes about the time slot for transmitting their sensing data. Member nodes switch radio on and transmit their sensing data during their allocated time slot. And all other times, member nodes switch radio off and sleep until next frame [5].

In this paper, we present QoS-aware MAC protocol for cluster-based wireless sensor networks. QA-MAC could change the number of frames in proportion as information about member node's traffic load and the number of cluster member nodes. Through mathematical analyzing, we prove that the proposed protocol reduces energy consumption and transmission delay in compare to the previous related works.

The remainder of this paper is organized as follows: In Section 2 we present a short of related works. Section III describes the QA-MAC algorithm in detail. In Section 4 the proposed algorithm is evaluated. Finally, Section 5 concludes the paper.

II. RLATED WORKS

MAC protocol for WSNs can be divided into two categories: schedule-based (or contention-free) and contention-based protocols. Schedule-based MAC protocols use distributed algorithms that schedule the medium access among nodes in WSNs. So collisions can

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be avoided. TDMA protocol is a major research area for schedule-based MAC. In contention-base protocols, a medium is shared by all sensor nodes. A classical example is the carrier-sense multiple access (CSMA) protocol. In CSMA, a node listens to the channel before transmitting. If the channel is busy, it delays to send its data. Most MAC protocols for cluster based wireless sensor network have been based on TDMA. They expect to save power resources and reduce transmission delay. There are many researches to accomplish that purpose using TDMA-based. LEACH [6] is one of famous cluster-based routing protocols in WSN. The cluster head relays the data to the global base station. Cluster head is selected randomly and periodically in LEACH protocol. Georgios et al. proposed BMA algorithm [7]. BMA (The Bit-Map-Assisted) MAC protocol is also TDMA based. BMA is intended for event-driven sensing applications, that is, sensor nodes forward data to the cluster head only if significant events are observed. The contention period operates like TDMA based schedule. In BMA, each node transmits 1-bit control packet data to the cluster head during its allocated time slot when node has data to send. After cluster head receives all member nodes' control packet data, cluster head allocates time slot to nodes which have data to transmit and otherwise allocates idle slot. Nodes which have data to transmit switch radio on and send data to cluster head in its allocated time slot and switch radio off at all other time slots. Node which doesn't have data to transmit switch radio off until next session and cluster head also switch radio off in idle period to save its energy. But BMA costs unnecessary energy in contention period because all member nodes have to switch radio on during that time and also BMA makes delay due to idle listening.

EC-TDMA is shown in [8]. In EC-TDMA protocol the length of TDMA frame is changed in proportion to the number of sensor nodes and their traffic loads. In EC-TDMA, frame size is not fixed because they assume that all nodes don't have enough data to send. In the first schedule period of each round, cluster head allocates time slots to all member nodes. Other time cluster head allocates different time slots in proportion to the number of sensor nodes and sensor node traffic load. Member nodes transmit not only data but also expected traffic loads of next frame to cluster head in data transmission period. Then cluster head could make a TDMA schedule using information about sensor node expected traffic load. EC-TDMA could reduce idle listening and improve channel utility, but has overhead to operate schedule period at all frames and also make delay for scheduling.

III. QA-MAC

Frame structure of the QA-MAC is shown in figure 1. The QA-MAC could change the number of frames according to information about member node's traffic load and its priority.

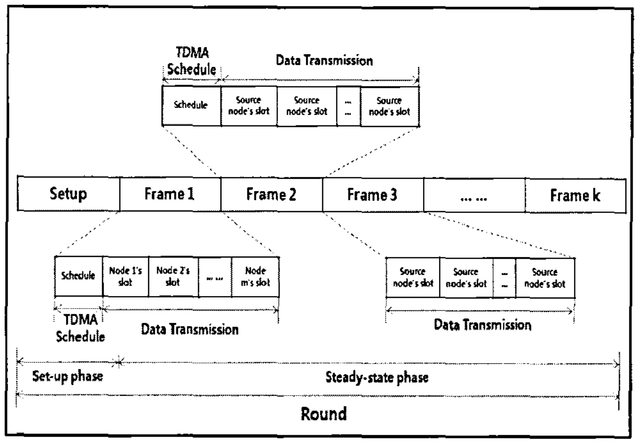

Fig. 1. Super Frame Structure of QA-MAC

QA-MAC frame structure is composed of rounds. Each round is divided into two parts. One is set-up phase and the other is steady phase. The round is divided into k frames. The cluster head allocates time slots for all member nodes in the first TDMA schedule period of each round. During the second schedule period in each round, the cluster head makes a schedule for all data transmission. The cluster head could change the number of frames in proportion to the number of member nodes and node traffics dynamically. In QA-MAC the cluster head allocates time slots to all member nodes in the first schedule period in every round. Member nodes send data, anticipated traffic loads, and data priority to their cluster head in its allocated time slot. During the second schedule period, the cluster head sends out schedules to member nodes. We assume that all member nodes have enough data to send. We also assume here that there are two kinds of data priority. Each node determines its data priority. Data above predefined threshold value will have higher priority. Cluster head will first assign time slots to the nodes with higher priority data. An example of schedule process of the QA-MAC algorithm is shown in the Fig. 2. We assume that there are one cluster head and five member nodes in the cluster. Node A has five data packets, node B and C have two each, node D owns four and node E has three data packets.

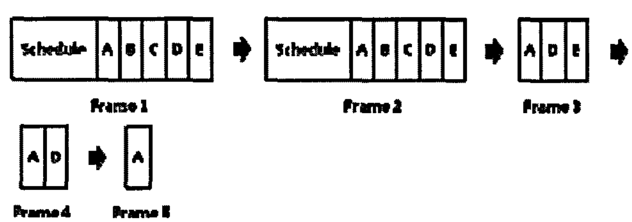

Fig. 2. Process of Schedule Method of QA-MAC

During a schedule period of the first frame, cluster head allocates time slots to all five nodes. Five member nodes transmit the sensed data and anticipated traffic loads and their priority to the cluster head. When the second frame starts, the cluster head determines the maximum number of frame (k), where k will be 5. In this example node A has the largest amounts of data compared to other nodes. The first and second frame is divided into 5 time slots since all member nodes have data to transmit in that frames. But at the third frame, node B and C don't have data to send. So the third frame is composed of 3 time slots. At the fourth frame, there are only two nodes (A and D) have data, so the frame is divided into 2 time slots. In the above figure we don't consider data priority. There are two ways to support the data priority.

1) Fix the frame size and allocates the remaining slots to the higher priority data.
2) Allocate all slots to the higher priority data in maximum frame size, then changes the frame size as above.

Energy Consumption

One example of a transmission progress is shown in the Fig. 2. The proposed algorithm in this uses only two schedule periods while all member nodes transmit their data in a round. So QA-MAC could save power resources and reduce transmission delay.

Energy consumption of QS-MAC in a round is given by,

$$(2 * E_{shchedule}) + \{n_i * E_{transmission} * (S_{data} * S_{\inf o})\} + \{(\sum_{n=1}^{N} P_{n_i} - n_i) * E_{transmission} * S_{data}\} \quad (1)$$

n_i stands for i_{th} member node, P_{n_i} intends n_i 's anticipated traffic load. k denotes maximum number of frames. $E_{schedule}$ denotes a energy consumption at a schedule period and $E_{transmission}$ means energy consumption for data transmission period per byte. S_{data} denotes a general sensing data and $S_{\inf o}$ means a control packet data that have information about anticipated nodes' traffic load and its priority. There exist only two schedule periods, so $E_{schedule}$ is required two times. And all member nodes transmit general data and control packet in the first frame. So each member node consumes energy to transmit both data, S_{data} and $S_{\inf o}$ to a cluster head. In other frames, member nodes consume only transmission energy for data they have.

But BMA needs more overhead as the number of frames gradually increases. It causes unnecessary energy consumption. The energy consumption of the BMA is calculated as,

$$(k * E_{contention}) + (\sum_{n=1}^{N} P_{n_i} * E_{transmission} * S_{data}) \quad (2)$$

In same way the energy consumption of the EC-TDMA can be described by

$$(k * E_{schedule}) + \{\sum_{n=1}^{N} P_{n_i} * E_{transmission} * (S_{data} + S_{\inf o})\} \quad (3)$$

The EC-TDMA needs $E_{schedule}$ k times and also consumes energy for general data (S_{data}) and control packet data ($S_{\inf o}$) transmission.

Transmission Delay

As described above, QA-MAC needs only two schedule periods ($T_{schedule}$) during each round and cluster head allocates time slots (T_{slot}) to member nodes. Therefore the QA-MAC makes less transmission delay than other algorithms. The transmission delay of QA-MAC can be obtained as follows:

$$(2 * T_{schedule}) + (\sum_{n=1}^{N} P_{n_i} * T_{slot}) \quad (4)$$

But the transmission delay of BMA can be given by the following expressions,

$$(k * T_{contention}) + (k * n_i * T_{slot}) \quad (5)$$

And the transmission delay of the EC-TDMA is given by the following expressions,

$$(k * T_{schedule}) + (\sum_{n=1}^{N} P_{n_i} * T_{slot}) \quad (6)$$

IV. PERFORMANCE EVALUATION

In this section, the performance of the QA-MAC is compared to other related protocols, BMA and WC-TDMA. Both protocols are based on the cluster-base TDMA protocol as described before.

Energy Consumption

The energy parameters are specified in table 1. For comparison, we use the same parameters used in [9][10].

TABLE I
ENERGY PARAMETER[9][10]

Parameter	Value	Meaning
S_{data}	1452byte	Size of General data
S_{info}	20byte	Size of Info. data
$E_{transmission}$	0.4μj/byte	Energy Consumption for Data Transmission period
$*E_{schedule}$	580μj	Energy Consumption in Schedule period
$**E_{contention}$	1020μj	Energy Consumption in Contention period

$$*E_{schedyke} = S_{data} * E_{transmission}$$

$$**E_{contention} = S_{info} * \sum_{i=1}^{N}(1 + E_{integrates}) + E_{schedule}$$

Figure 3 shows the average energy consumption in a round. QA-MAC protocol shows more energy efficient than other algorithms. BMA needs contention period and idle listening in every frames and EC-TDMA needs schedule periods in every frame while our algorithm needs schedule period only two times.

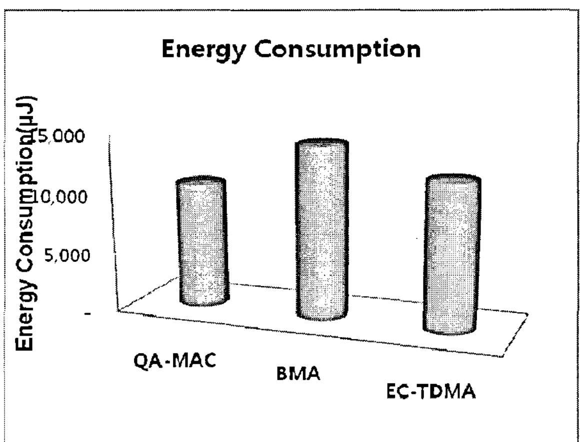

Fig. 3 Comparison of average energy consumption

Transmission Delay

The parameters used for transmission delay are shown in table 2. Total transmission delays can be obtained from equation (4), (5) and (6).

TABLE II
TRANSMISSION DELAY PARAMETER[8]

Parameter	Value	Meaning
$T_{transmission}$	46ms	Size of contention period
$T_{schedule}$	40ms	Size of schedule period
T_{slot}	9.2ms	Size of time slot

Figure 4 shows the average delay comparison in a round. QA-MAC protocol needs less average transmission delay than those of BMA and EC-TDMA protocols.

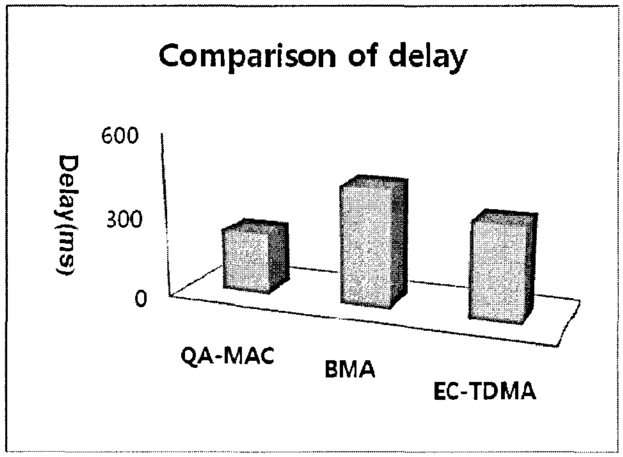

Fig. 4 Comparison of average delay

As described before, the proposed algorithm can support QoS. We assume here that only node A has abnormal sensing data. So cluster head needs to send A's data first to the BS. Figure 5 shows the comparison of transmission delay for node A and E. As expected, the transmission delay of node A was reduced about 28% while the transmission delay of node E was increased about 10%.

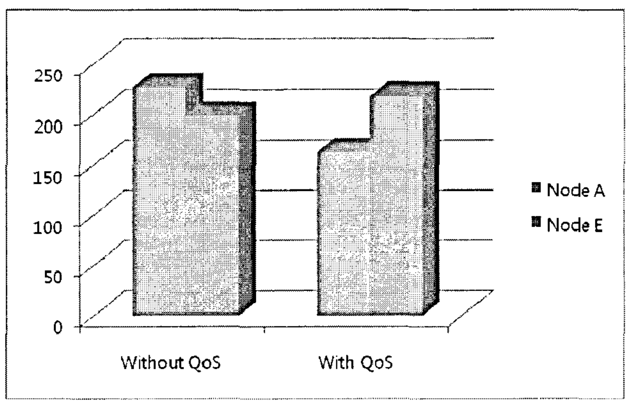

Fig. 5 Comparison of transmission delay with QoS

V. CONCLUSIONS

In this paper, we proposed an efficient TDMA scheduling algorithm to support QoS (Quality of Service) for a clustered Wireless Sensor Network. Previous related works have some problems requiring more overhead or scheduling period. Those may cause some unnecessary energy consumption and transmission delay. In the proposed efficient dynamic scheduling algorithm, scheduling period was reduced and data priority can be provided using modified control packet between cluster head and member nodes. Cluster head could schedule dynamically using information from member node's traffic load, the number of cluster member nodes, and data priority. We showed that QA-MAC required less average energy consumption and transmission delay than those of the previous researches algorithms.

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