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AN EFFICIENT MAC PROTOCOL FOR SUPPORTING QOS IN WIRELESS SENSOR NETWORKS

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ABSTRACT

Wireless sensor network can be employed in wide range of application areas, such as target detection and tracking, military, and environmental monitoring. Media access control protocol is one of the most critical issues for wireless sensor network. A lot of efforts have been dedicated to MAC protocol and many MAC protocols have been proposed for different purposes. In this paper, a modified TDMA based MAC protocol is proposed. The proposed protocol support three different types of traffics and can assign slots for them flexibly. The proposed MAC protocol employs slots reuse scheme to dynamically use slots to transmit traffics and dynamically employs sleep and wake up scheme to reduce radio energy expenditure and then to extend lifetime of WSN network. Simulation results on numerous problem instances show efficiency of the proposed MAC protocol.

Keywords: *Wireless Sensor Networks, Media Access Control, QOS*

1 INTRODUCTION

With the development of sensing, embedded computing and wireless networking, wireless sensor network (WSNs) have emerged as an important technology. WSNs are large networks which consist of small sized battery powered embedded devices [1, 2]. A sensor node is made up of four basic components: sensing unit, processing unit, transceiver unit, and power unit. Sensing units are usually made up of three subunits: sensor, processing unit and communication unit. There are hundreds or thousands of sensor nodes spread across a geographical area coordinate to perform sensing tasks and to monitor the environment. Data are routed back to the sink by a multi-hop infrastructure through the sink. Sink may be a full of powerful abilities stationary sensor node or mobile hardware device carried by users to gather all sensing messages transmitted from multiple sensor nodes. As sinks gather messages successfully, they process and forward essential data to administrators through Internet or wireless communication infrastructure.

A WSN has many attractive characteristics including low cost, easy deployed, context-aware capability and fast ad-hoc networking configuration, so that it can be widely used in various applications such as border detection, environment monitoring, smart home, and military surveillance. In academia, there are also many issues preventing the ubiquitous use of wireless sensor network.

Media Access Control (MAC) is an important issue in wireless sensor networks. Since wireless sensor network works in a broadcast way, it requires a MAC protocol to resolve contention to make it work more efficiently. In WSN, sensor nodes operate on the battery power. Also, an efficiently MAC protocol make power usage efficiently and may extend the lifetime of the utilization of the sensor nodes. Various MAC protocol have been proposed to improve the performance of WSN network. S-MAC [3] was an important MAC protocol designed for wireless sensor networks. It is also one of the most popular MAC protocols used for research on and implementation of wireless sensor networks. S-MAC operates in a duty-cycled fashion, i.e., sensors sleep and wake up periodically. Reference [4] proposes a schedule-based protocol called FlexiTP to handle periodical traffics. Unfortunately, sporadic traffics are not addressed. Several MAC protocols have been proposed to handle event-reporting traffics. These protocols exploit spatial correlation of sensor readings to reduce redundant reports. Unfortunately, these protocols cannot handle periodical traffics well. TRAMA [5] is a schedule-based TDMA MAC protocol. It allows a node with heavier traffics to borrow slots from nodes with lighter traffics. So, it can also handle on-demand traffics well. But

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TRAMA is not tailored to convergecast and event-reporting traffics. In [6], a multi-channel MAC protocol called MC-LMAC is proposed. The protocol employs parallel transmission on multi-channel to extend the throughput of WSN. DGRAM [7] is a TDMA-based protocol which is designed to provide delay guaranteed service in an energy efficient manner. The protocol exploit slot reuse scheme to reduce delay of a node in access the medium, in the same time, it can ensure the medium access is contention free. MRMAC [8] is an efficient MAC protocol that can reduce end to end delay and use energy efficiently. It is implemented by informing the destination node next packet arrival time and medium reservation information to reserve the medium in advance.

The rest of the paper is organized as follows. Section Ⅱ describes the proposed MAC protocol for supporting, QoS. Computational results are presented in section Ⅲ. Some concluding remarks are given in section Ⅳ.

2 PROPOSED SCHEME

In this paper, the network topology of WSN is considered as a hierarchical architecture. A WSN consists of sensors nodes, cluster heads and a sink. Sensor nodes are used for monitoring environments and send data to cluster head. The function of cluster heads is to collect data from sensor nodes and send them to sink. Cluster nodes are located at the center of different areas and sensors nodes surround the nearest cluster head. Each cluster head can communicate with sink directly.

In this paper, three types of traffic are considered as follows:

Event reporting traffic: sensors send unusual events to sink. These traffics are real-time service.

Data traffic: sensors periodically send their data to sink. These traffics can be temporarily suspended by other traffic under emergency conditions.

Control traffic: these traffics consist of local gossip, broadcast and query packets. These traffics are non-real time service.

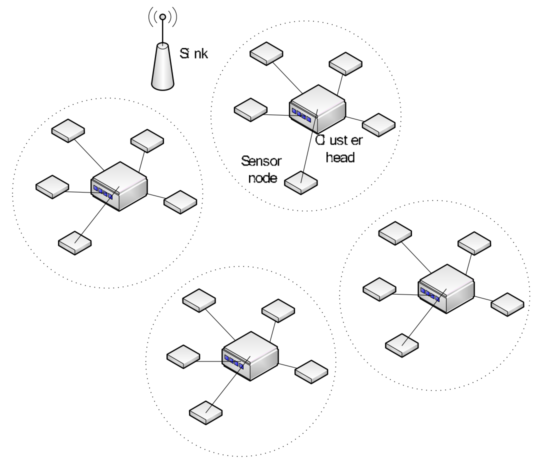

Figure 1. WSN Network Architecture.

In this paper, we propose a TDMA based Media access control scheme to handle these three types of traffics. In the scheme, time is divided into frames. Figure 1 shows structure of the frame. Each frame is led by a control overhead which is used for control and management purpose and is followed by n slots which can be used to transmit event reporting traffic and data traffic. Contention cycle is used to perform contention resolution and backoff mechanisms. In the frame, the data traffic slots and event reporting slots can be exchanged. In order to achieve a low event reporting delay, the event reporting slots can occupy the data traffic slots.

The proposed MAC protocol includes the following four parts: data transfer scheme, event reporting scheme, slot reuse scheme and lifetime extension scheme.

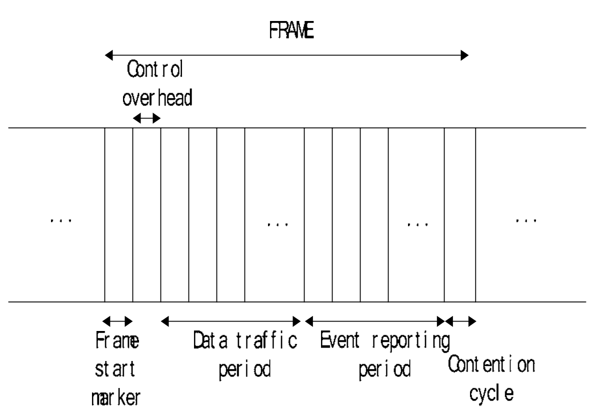

Figure 2. Frame Structure Of The Propose MAC Protocol

2.1 Data Transfer Scheme

To transmit event-reporting traffics, we propose a scheme to assign slots to each sensor node. The proposed scheme assigns data slots to each node and also determines the number of slots for data transfer

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period. Our scheme can assist data aggregation and reduce event reporting latency. The scheme works as follows.

Step 1: For each node v in a cluster head, we will compute a number n(v) for v as the smallest positive number that has not been used by any of v's neighbors in the same cluster.

Step 2: We then traverse nodes of the same cluster in a random manner. For each node v being visited, we try to increase the value of n(v) such that n(v) is less than the value used by v's parent and n(v) has not been used by any of v's neighbors.

Step 3: Let m1 = min{n(v)} and m2 = max{n(v)}. The length of the data traffic period will be m2-m1+1 slots. Also, for each node v, we let s(v) = n(v)-m1+1 be the data traffic slot of v.

2.2 Event-Reporting Scheme

This scheme consists of two parts. First, we propose a distributed slot assignment algorithm to allocate event reporting slots to each node. Then we show how nodes use these slots. The result will also determine the length of the event reporting period. The slots assignment algorithm works as follows. A node can select slots that are used by its neighbors. Allowing a node to share the same slots with its neighbors can reduce redundant reports of the same event. Since neighboring nodes may share the same slots, backoff is needed to access event reporting slots. The event reporting scheme works as follows.

Step 1: Define an array A length of F;

Step 2: Setting a pointer points to the first place of A;

Step 3: Use top-down tree traversal with depth-first, and assign continuous time slot according to the level of node;

Step 4: Time slots are assigned starting from the pointer, if level(node)>4, the time slot ID will be assigned from the pointer in front of (level(node)-3);

Step 5: After each node assigning continuous time slot, pointer points to the smallest time slot ID of A that still not be occupied;

Step 6: Repeat step 3 to step 6, until each node in the tree has its own time slots;

There are two states of nodes for event reporting traffic: source state and non-source state. Originally, all nodes are in non-source state. When a sensor node detects an event, the state of the sensor node turns to be source state and the node will allocate slots for event reporting.

A node in the ES mode overhearing an event-reporting packet will check its buffered packets and delete those packets with high similarity as the overheard packet. On the other hand, nodes in the NES mode will help to relay these event-reporting packets in any of the event-reporting slots. When a node in the ES mode does not have any event-reporting packet in its buffer, it will return to the NES mode in the next frame. Intuitively, in the event area, nodes will be partitioned into several sub-areas, each sub-area contains some neighboring nodes sharing the same event-reporting slot. From each sub-area, only few packets are expected to report the same event. Further, reports from different sub-areas are expected to leave the event area at different time slots (because two-hop neighbors should not share the same slot) and thus form "pipeline-like" flows leaving for the sink.

2.3 Slot Reuse Scheme

To get QoS and efficiently use slots, we propose a scheme to dynamically use slots. In this scheme, it permits sensor nodes to borrow and return slots according to traffic load.

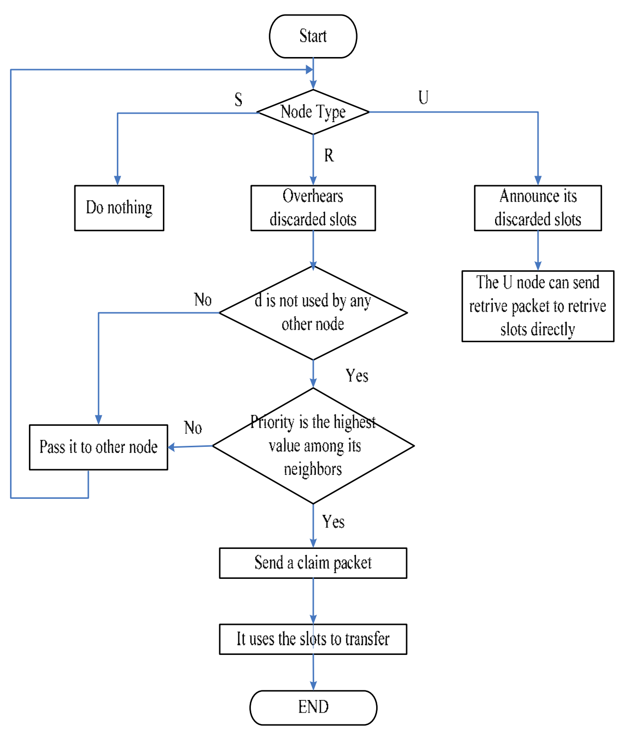

Figure 3. Flow Chart Of Slots Reuse Scheme

Figure 2 shows the flow chart of the slot reuse architecture. First, we classify nodes into three states, the sufficient nodes (S-node), the redundant nodes (R-node), the unsatisfied nodes (U-node). According to the number of packets stored in each

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node's buffer, it determines its state. An S-node will do nothing. An R-node will announce their discarded slots as early as possible by transmitting a Discard packet. When a U-node overhears a discard packet, it needs to check whether it can use the slots. By this slots reuse mechanisms, nodes can reuse the slots more flexibly.

2.4 Lifetime Extension

Lifetime extension is an important issue in wireless sensor networks. In this paper, we also propose a lifetime extension scheme which is shown as follows:

Before a node wake up, it needs to listen to the channel for a short period in the beginning of all the event reporting slots. During these slots, if there is no packet transmitted, the node can go to sleep. According to these rules, idle listening will be reduced and the lifetime of the network will be extended. There is a trade-off between the transmission delay and lifetime of WSN. Nodes should keep sensitive by waking up to listen to the channel frequently to achieve low transmission delay, such that the lifetime of WSN will be reduced.

3 SIMULATION RESULTS

To investigate the effectiveness of the proposed MAC protocol, we implemented a network with 500*500 units sensing area in which 500 nodes and N cluster heads are uniformly distributed. The simulation parameters are set as follows: transmission range is 50 units, packet length is 64bytes, bit rate is 250 Kbps, slot size is 150ms, and simulation time is 6000 seconds. In the simulation, all the traffics are triggered at the beginning of the simulation. In the proposed MAC protocol, each sensor node maintains three different buffers. In the TDMA scheme, each sensor node only maintains a FIFO buffer.

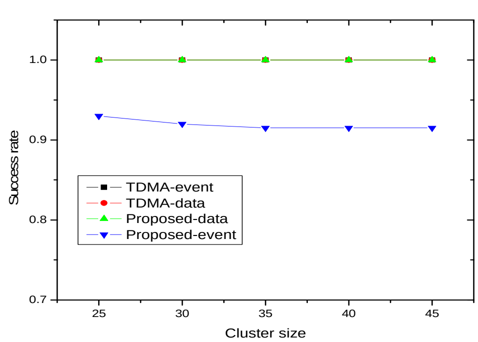

Figure 4. Success Rate Versus Cluster Size

Figure 4 shows the comparison of the success rate between the proposed MAC and TDMA scheme. Success rate is the ratio of the number of packets received by the intended receiver to the number of packets transmitted by the sender per pair. From the figure, we can see that TDMA achieves the best results because it is collision-free transmission, all event reporting and data packets can be received by the sink. The success rate of event reporting in our proposed protocol only achieves 92% because nodes in the NES mode will contend any of the event reporting slots to send. However, for event reporting traffics, it is tolerated to have some packet loss, because of the redundancy of the event reporting traffic. The success rate of the data traffic of the proposed protocol is almost 100% as TDMA scheme which is a collision free scheme. The proposed MAC protocol can achieve good performance almost as TDMA protocol.

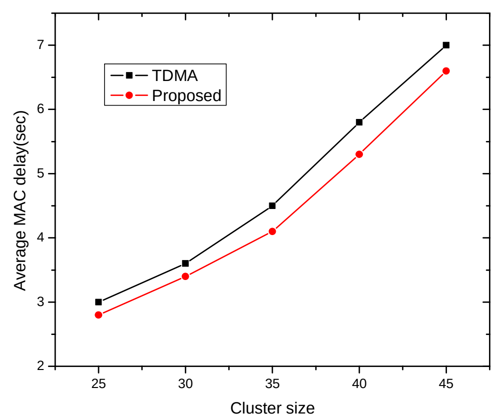

Figure 5. Average MAC Delay Versus Cluster Size

Fig. 5 shows the comparison of the average MAC delay between the proposed MAC and TDMA. The average MAC delay increases as the cluster size increase for both protocols. The proposed MAC is better than TDMA in terms of average MAC delay. This is because the proposed MAC uses slot reuse scheme which let different priority sensor nodes dynamically use slots to transmit different types of traffics, so the channel contention probability can be reduced and sensor nodes can send packets as soon as possible.

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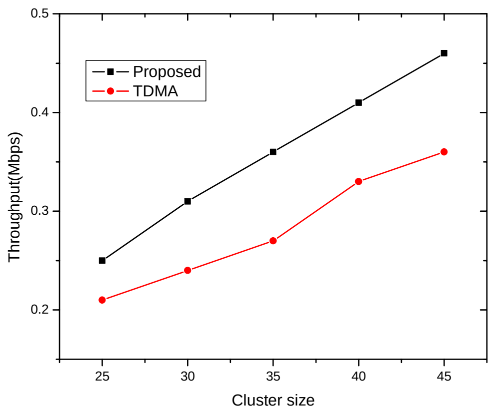

Figure 6. Network Throughput Versus Cluster Size

Figure 6 shows the comparison of the throughput of the proposed MAC with that of TDMA under different cluster sizes. From the figure, we can see that the proposed MAC is better than TDMA in terms of throughput. This is because that the proposed MAC uses borrowing and returning slots to transmit traffics, so that time slots can be used effectively. As a result, the scheme can get a higher throughput.

4 CONCLUSIONS

In this paper, we have studied the problem of MAC protocol in WSN networks. A new MAC protocol was proposed. The protocol could allocate slots according to type of differentiated traffics and slots reuse scheme was proposed in the protocol to exploit spatial reuse dynamically. The performances of the proposed MAC protocol are compared with TDMA protocol through simulation. Simulation results showed that the proposed MAC protocol can achieve good performance in terms of success rate, average MAC delay and network throughput from source to destination nodes.

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