Data Transmission Scheduling based on RTS/CTS Exchange for Periodic Data Gathering Sensor Networks

Takashi Matsuda, Masumi Ichien
Graduate School of Science and Technology
Kobe University
Kobe, Japan
matsuda@cs28.cs.kobe-u.ac.jp

Shinji Mikami
Graduate School of Natural Science and Technology
Kanazawa University
Kobe, Japan
mik@cs28.cs.kobe-u.ac.jp

Hiroshi Kawaguchi, Chikara Ohta, Masahiko Yoshimoto
Department of Computer and System Engineering
Kobe, Japan
yosimoto@cs.kobe-u.ac.jp

Abstract— **One challenging issue of sensor networks is extension of overall network system lifetimes. In periodic data gathering applications, the idle time is longer than transmission time in the state of a sensor node. Consequently, it is important to decrease wasteful power consumption during idle time. In this study, we propose a scheduling algorithm based on the history of RTS/CTS exchange during the setup phase. Scheduling the transmission during transfer phase enables each node to turn off its RF circuit during idle time. By tracing ongoing RTS/CTS exchange during the data transfer phase, each node knows the progress of the data transfer process. Thereby, it can wait to receive packets for data aggregation. Simulation results show a 220% longer system lifetime of our scheduling than of existing "power scheduling."**

Keywords- data gathering; scheduling

I. INTRODUCTION

Recently, advances in technology, low-power electronics, and low-power radio frequency design have enabled the development of small and low-power sensor nodes. Wireless sensor networks comprising such sensor nodes have attracted attention for extracting information from a wide range of sources. Generally, the sensor node works with a battery. However, numerous nodes are deployed in a sensing area, so it is necessary to reduce the battery exchange frequency. Therefore, extension of the system lifetime is the hurdle to achieve wireless sensor networks. Important issues for system lifetime extension are the following.

- Idle listening: The RF circuit operates while the sensor node is not communicating. The RF circuit consumes as much power when the sensor node does not receive data as when it does.
- Retransmission by collision: The sensor node should retransmit data and will consume power when the data transmission fails because of collision.

We approach cross-layer design of the application, network, and MAC layer for the above issue to achieve the system lifetime extension. We realize scheduling to learn application-level transmission timing in the network layer by MAC with an RTS/CTS exchange function for collision avoidance [8].

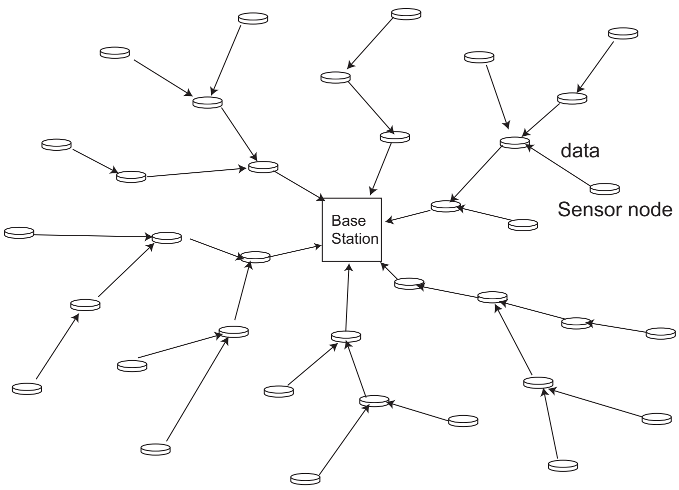

Figure 1. Sensor network tree for data gathering application.

In this study, we target the periodic data gathering application, which periodically observes such as temperature and humidity. In this application, the base station collects sensing information from the sensor nodes.

In such an application, the network tree is composed for data collection (Fig. 1). This tree is recycled and used two or more times. Consequently, the sensor node records and schedules the data transmission timing during the first time; thereby the idle listening can be decreased from the second occurrence. Moreover, the number of RTS/CTS collisions decreases by deciding the transmission timing in the network layer, so the retransmission overhead decreases.

As described later, the existing scheme schedules communication timing based on time. The sensor node should not retransmit the data packet so as not to disarrange scheduling timing if the data error occurs while the sensor node is transmitting a data packet. Moreover, time-based scheduling cannot be used in the case of disturbance of synchronization among sensor nodes. In this study, we propose an event-based scheduling scheme based on an RTS/CTS exchange scheme to prevent hidden terminal problem.

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Another characterization is that our scheduling scheme uses data aggregation for scheduling in this work. The existing scheduling scheme does not make active use of data aggregation. The proposed scheme also schedules data aggregation when identical routes are used for data collection.

II. RELATED WORK

Some protocols for periodic data-gathering applications have been studied: Low-Energy Adaptive Clustering Hierarchy (LEACH) [1], Power-Efficient GAthering in Sensor Information Systems (PEAGASIS) [3], etc. Power Scheduling (PS) is a scheduling scheme for periodic data gathering [2]. The PS scheme lowers power consumption by scheduling the send and receive times and turning off the RF circuit when not either sending or receiving.

The PS scheme has two phases: the setup phase and the steady phase. First, sensor nodes communicate a data packet using CSMA with RTS/CTS exchange in the setup phase. In this regard, the sensor node records the communication beginning time in the list when the data packet is sent correctly. Here, the communication beginning time that is recorded in the list is the transmission beginning time of the RTS packet. Figure 2 shows an example of a schedule in the case of sensor nodes sending their own sensing data to a base station using a multi-hop. In this list, the character on the left of each element shows the event type: the sender sends data (STD) and the receiver receives data (RRD). The right figure shows the communication beginning time. The sensor node sends data after the t_0 seconds from the data collection beginning time if the element in the list is SSD-t_0. The element's addition to the list is according to the following.

- When the node transmits: The sensor node records the transmission event (STD) and the transmission beginning time.
- When the node receives: The sensor node records the reception event (RRD) and the reception beginning time.

Fig. 2 depicts the flow of the schedule-making. First, node 1 transmits a data packet to node 3 so that node 1 takes sensing data to the base station. At that time, node 1 records the information of sending data (STD) and the transmission beginning time (t_0) in the list (node 1 – list 1). Then, node 3 records the receiving data (RRD) information and the reception beginning time (t_0) in the list (node 3 – list 1). Actually, a propagation delay pertains between the sending and receiving time. However, for simplicity, we show it as the same time. Next, node 3 relays the node 1 data to the base station. Node 3 records the information of sending data (STD) and the transmission beginning time (t_1) in the list (node 3 – list 2). These nodes add events to the list as well as ahead when node 2 sends its own sensing data to the base station.

Next, in the steady phase, no sensor nodes use RTS/CTS exchange because the transmission time of each node is decided. To the greatest degree possible, sensor nodes turn off the RF circuit power. This *Sleep* process turns off the RF circuit of the sensor node. The sensor node turns on the RF circuit immediately before the transmission beginning time of

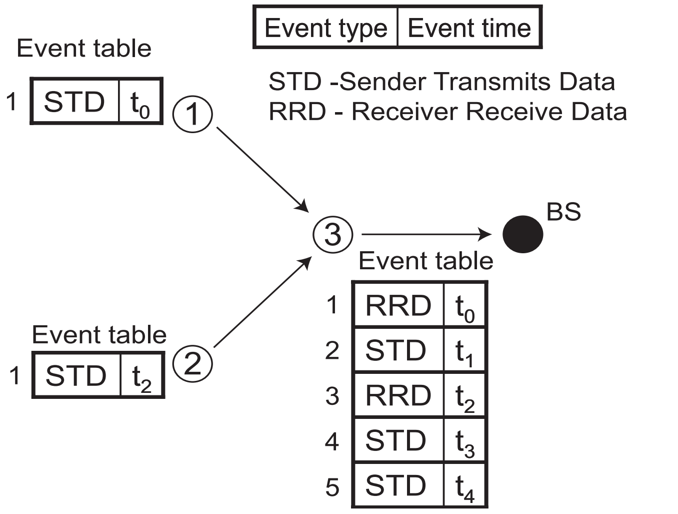

Figure 2. A 3-node sensor network with a base station and an exemplary schedule by power scheduling.

the list that was made in the setup phase; it sends data immediately. After the sensor node sends data, it sleeps until the time of the next gathering period. The sensor node turns on the RF circuit immediately before the time of the reception time that is recorded in the list. The sensor node then sleeps until the time of the following event when the sensor node finishes receiving data. In that manner, the PS scheme extends the system lifetime by obviating idle listening.

However, because of time-synchronization gaps among sensor nodes, it might not be possible for them to communicate with each other. For example, if the inner clock of node 1 shifts in relation to those of other nodes, node 1's transmissions would interfere with those of other nodes. In the PS scheme, sensor nodes cannot transmit again because sensor nodes do not know the schedules of other nodes. The PS method does not positively aggregate data. It is necessary to prepare a special node that can serve the same role as the base station if data aggregation is needed.

The PS scheme has three drawbacks. One is that the PS scheme cannot retransmit data because retransmission would jumble the schedule and thereby create a data transmission error. Another is that synchronization must be maintained among nodes because of its use of time-based scheduling. Finally, the PS scheme might not make the best use of its possible aggregation. If a route is consistently available to send data to the base station, each node should retain a schedule that is decided once, and then perform transmissions separately.

III. PROPOSED METHOD

We propose Multi-layer Scheduling (MS), which schedules based on RTS/CTS exchange. The MS scheme has two phases that resemble phases of the PS scheme: the setup phase and steady phase. Two major differences exist with the PS method. One is the ability to retransmit data because of event-type scheduling and RTS/CTS exchange at the steady phase.

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Another is the ability to aggregate data of all sensor nodes. Details of the operation at each state are described as follows.

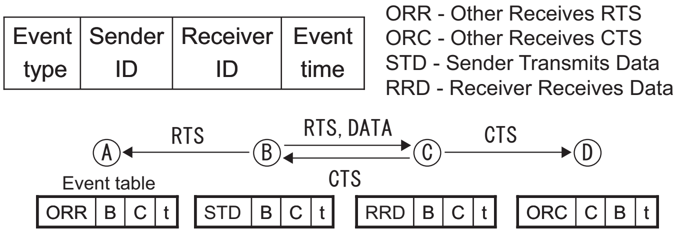

Figure 3. Making list at each node when node B sends to node C

A. *Setup Phase*

Both the PS scheme and MS scheme are independent of the route-decision method. However, in this work, sensor nodes collect data to the base station in accordance with Tiny Diffusion, which is a simplified Directed Diffusion method [5, 7]. In Tiny Diffusion, the base station broadcasts an interest packet to the entire network. Each sensor node that is targeted for the interest packet sends sensed data to the base station. In our target application, we assume that all sensor nodes are targeted for the interest packet and send data to base station. The MS method procedure is shown as follows.

First, the base station broadcasts an interest packet to the entire network, which has an interval of data collection and a data collection frequency in steady phase. Moreover, the interest packet has the number of minimum hops from the base station. The number of minimum hops for interest packets that are transmitted from the base station is 0. The sensor node receiving the first interest packet updates the number of minimum hops by adding one and forwards it to neighbor nodes. The sensor node compares the number of minimum hops in the interest packet with that of itself when the sensor node receives two interest packets or more. The sensor node updates the number of minimum hops and forwards the interest packet again if the number of minimum hops in the interest packet plus one smaller than that of the sensor node. If that is not so, then the sensor node does not forward the interest packet, thereby limiting the volume of interest traffic.

Next, each source node sends sensed data to the base station or to a relay node that is nearer the base station. The relay node is that which can send the interest packet to the source node earliest with minimum hops. The node relays it to its relay node, as described above, when the node receives a packet from the other node. In the first collection, sensor nodes transmit sensing data simultaneously because it is not understood whether there are relay data or not. From the second time of collection, sensor nodes can aggregate data because they know when the last of the relay data arrives. This method is described in paragraph 3.B.

The MS scheme uses RTS/CTS exchange for collision avoidance, just as the PS scheme does. Neighbor nodes that received RTS/CTS packets sleep; the time is included in RTS/CTS packet like Power Aware Multi-Access protocol with Signaling (PAMAS) [6]. Consequently, the power consumption is reduced because sensor nodes can avoid listening activities.

In the MS scheme, sensor nodes determine the timing to send a packet based on RTS/CTS packets used in this MAC

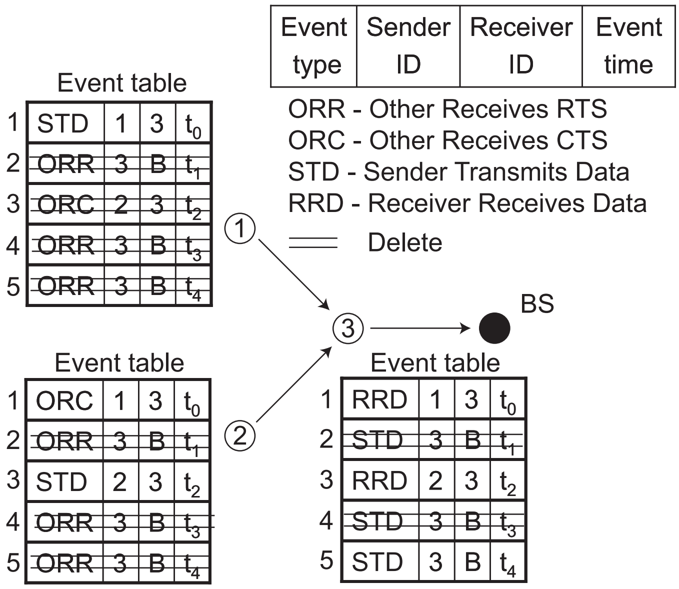

Figure 4. Example of a 3-node sensor network with a base station and a possible schedule using multi-layer scheduling.

protocol. Sensor nodes receive RTS/CTS packets with the recorded packet type, with the transmission/reception beginning times of these packets, and the sender and receiver addresses in the list. Fig. 3 shows an example of list production of the node for transmission from node B to C. The character at the left of each element in this list shows the event type, which is one of the following: other receives RTS (ORR), other receives CTS (ORC), sender transmits data (STD), and receiver receives data (RRD). The second and third figures from the left of each element respectively show sender-node and receiver-node addresses. The rightmost figure of each element shows

the transmission or reception beginning time of the packet. The condition of adding the event to the list is as follows.

- When the node transmits data: The sensor node records the transmission data event (STD) and the beginning time of transmission (node B).
- When the node receives data: The sensor node records the reception data event (RRD) and the beginning time of reception (node C).
- When the node receives RTS: The sensor node records the reception RTS event (RRD) and the beginning time of reception (node A).
- When the node receives CTS: The sensor node records the reception CTS event (RRD) and the beginning time of reception (node D).

If a sensor node receives the above events again from the same sender, the sensor node deletes the old event and adds a new event to the end of the list.

This is done to send data to the next node that are aggregated with other data from further nodes from base station in the steady phase. Moreover, the sensor node turns the radio off after sending data; it subsequently deletes events in the list.

Fig. 4 portrays an example of list-making using the MS method. First, node 1 sends its sensed data to node 3 for subsequent relay to the base station. Node 1 exchanges a RTS/CTS packet with node 3. Node 2 receives this CTS packet from Node3, and records this information of the CTS packet in the list (node 2 – list 1). Node 1 and node 3 also respectively record transmit and receive information of the list (nodes 1 and 3 – list 1). Next, node 3 forwards node 1's data to the base station. In this case, node 3 exchanges an RTS/CTS packet with the base station similarly, and node 1 and node 2 receive the RTS packet from node 3. Then, node 1 and node 2 record CTS information in each list (node 1 and 2 – list 2). Node 3 records information of sending data in the list (node 3 – list 2). Similarly, node 2 sends its sensed data to node 3 to be relayed to the base station. In this case, node 2 exchanges an RTS/CTS packet with node 3 as well as ahead. Node 1 receives node 3's CTS packet and records this information in the list (node 1 – list 3). Nodes 2 and 3 record transmit and receive information in the list (nodes 2 and 3 – list 3). Next, node 3 forwards node 1's data to the base station. Node 1 and node 2 receive the RTS packet from node 3. Nodes 1 and 2 have received the RTS packet from node 3 before, so they delete old information (node 1 and 2 – list 2) and add new information (nodes 1 and 2 – list 4) in the list. Node 3 also deletes old information (node 3 – list 2) and adds transmit information in the list (node 3 – list 4). Finally, node 3 transmits its own sensed data to the base station. Nodes 1 and 2 delete old information (nodes 1 and 2 – list 4) and add new information (node 1 and 2 – list 5) to the list again. Node 3 deletes old information (node 3 – list 4) and adds transmit information to the list (node 3 – list 5). Each sensor node maintains this list until the next setup phase.

B. Steady Phase

In the steady phase of the MS scheme, each sensor node sends data based on its list that was produced in the setup phase. First, sensor nodes with elements of data transmission at the top of the list send data. In the MS scheme, sensor nodes exchange RTS/CTS packets differently from PS scheme, so neighbor nodes receive RTS/CTS packets and check elements the list. Sensor nodes that have transmission as the unchecked top element in the list prepare to send data shortly after sleep by RTS/CTS. Nodes that finish transmission sleep until the next data collection.

Fig. 4 shows an illustrative example of the MS method flow. First, node 1, with the data transmission element at the top of the list among tree nodes, sends data to node 3. In the MS method, node 1 exchanges an RTS/CTS packet with node 3, and node 2 receives the CTS packet. Then nodes 1, 2 and 3 check the first element in the list. After node 1 finishes sending data, node 1 goes to sleep until the next data collection. Next, node 2 with unchecked top element of transmission in its list sends its sensed data to node 3. Then nodes 2 and 3 check the second element in their respective lists. After that, node 2 goes to sleep. Finally, node 3 sends aggregated data to the base station and sleeps until the next data collection. In this manner, sensor nodes aggregate data and send data smoothly to avoid collision.

Sensor nodes cannot check the list and send data if sensor nodes cannot receive RTS/CTS packets because of interference

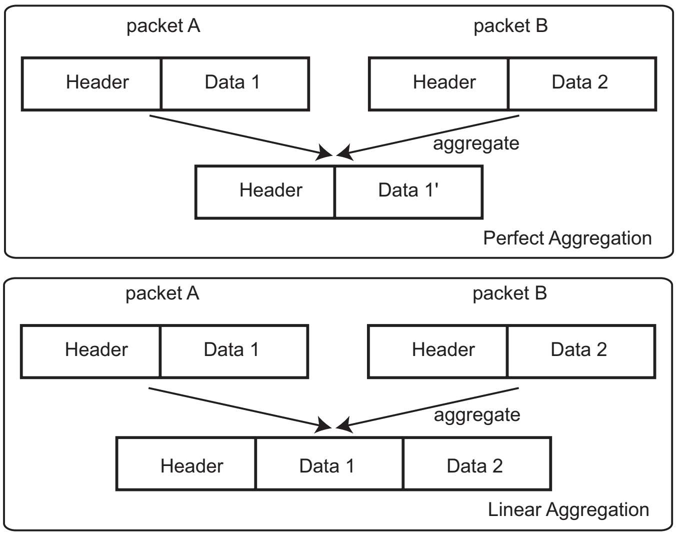

Figure 5. Data aggregation type: perfect aggregation and linear aggregation.

and collision. Then, if the sensor node cannot send data at the previous transmit time and receive all data that should be relayed, the sensor node aggregates these data and sends them to next hop node immediately. If the sensor node was unable to send data at the previous transmit time and did not receive all relay data, the sensor node waits some time and sends aggregated data to the next hop node. This node waits some time after it sends data. If the node still does not receive new relay data, it then goes to sleep.

In the MS scheme, sensor nodes exchange RTS/CTS packets in a steady phase unlike the PS scheme, so sensor nodes can retransmit data to avoid collision. In the PS scheme, the sensor node cannot retransmit data for its time schedule and collision.

IV. SIMULATION RESULT

We used a QualNet simulator to evaluate our scheduling. We simulated 100 sensor nodes and a single base station. Sensor nodes were deployed in a 100 m × 100 m rectangular area uniformly. The transmission range is assumed to be circular with a 25 m radius. We assume that the transmission power is 800 μW, the reception power is 800 μW, and the sleep power is 0.5 μW. We assume that the battery capacity of each sensor node is 500 mJ. We assume that the header of each packet is 32 bytes. The sample period of the Low-Power Listening (LPL) is 50 ms. The data gathering period is 900 s. We assume that header aggregation eliminates headers of two or more packets for the same destination. The base station broadcasts an interest packet every 10 rounds and reconfigures the routing tree.

Next, we explain the aggregation method used for this simulation. Two methods of data aggregation exist: perfect aggregation and linear aggregation. The features of each aggregation method are as follows (Fig.5) [4].

- Perfect aggregation: For applications that require only the maximum, minimum, and mean of measurements of the sensor, sensor nodes receive all packets, operate, and forward one packet. Although this method is used by many proposed protocols, it is not practicable because applications are limited.
- Linear aggregation: The sensor node aggregates data to the same target node in one packet and forwards it. The sensor node then deletes the header of each datum and brings them together, thereby reducing traffic. It is possible to apply this to any application.

The MS scheme does not depend on the aggregation method. We validate it using linear aggregation with wide applications in this simulation. The MS scheme, which positively aggregates data, is more advantageous than the PS scheme when it is possible to aggregate data completely.

The MS scheme uses LPL as its medium access control for data communication to reduce power consumption. Fig. 6 shows the LPL operation. In LPL, the radio periodically samples the channel. If there is nothing to receive, the radio powers off, otherwise it wakes up from LPL mode to receive the incoming packet. For that reason, the radio on-time is short. Therefore, the power consumption of the LPL method is very low. If the sensor node needs to send data, the sensor node sends a preamble that is as long as the radio channel sampling interval (*T*). Then the neighbor nodes contain destination node wake up radio to prepare to receive incoming packet. However, because the sensor node sends data immediately after the preamble, it may cause a hidden terminal problem and overhearing. Consequently, we use LPL with the RTS/CTS exchange function to obviate that problem. The sensor nodes that receive the RTS/CTS packet turn the radio off for the duration described in RTS/CTS packet, as in the Power Aware Multi-Access protocol with Signaling (PAMAS) [6]. This feature resolves problems of overhearing, so the radio power consumption is conserved. Fig. 7 shows the operation of LPL with RTS/CTS exchange.

Fig. 8 shows the number of nodes that are alive by simulation time for the MS scheme, the PS scheme, and a non-scheduling scheme. The packet payload is 16 bytes. As this figure shows, the MS scheme has the longest time of all nodes live among the tree scheme. The PS scheme reverts to the MS scheme at 300 000 s. However, sensor nodes near the base station typically run down their batteries, so the base station becomes unable to receive data from distant nodes. Therefore, we assume the system lifetime as that when the first node exhausts its battery power. The lifetime of the MS scheme is 3.5 times as long as that of non-scheduling, and two times as long as that of the PS scheme. A major contributing factor is the effect of reduction of consumption energy by data aggregation. Another possible factor is that sensor nodes turn off their radios shortly after finishing data sending. However, sensor nodes turn their radios off periodically using LPL, so the influence by the second factor is small.

Next, Fig. 9 shows a comparison of lifetimes when the payload size is changed. In this figure, the smaller the payload size, the larger the effect of MS scheme. Conversely, for larger payloads, the difference between MS scheme and PS scheme decreases because the effect of consolidation shrinks as the payload size grows. Generally, the sensing data are smaller than the header. For that reason, it can be said that scheduling that considers aggregation is important.

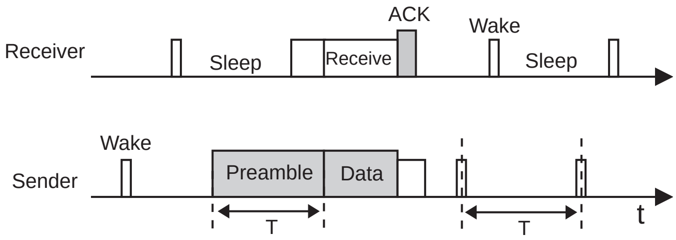

Figure 6. Timing chart of Low-Power Listening.

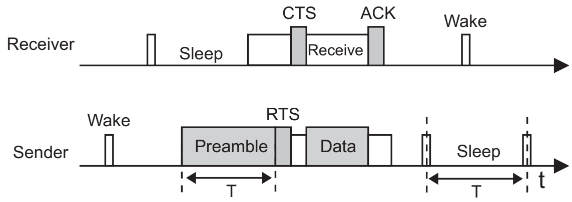

Figure 7. Timing chart of Low-Power Listening with RTS/CTS exchange.

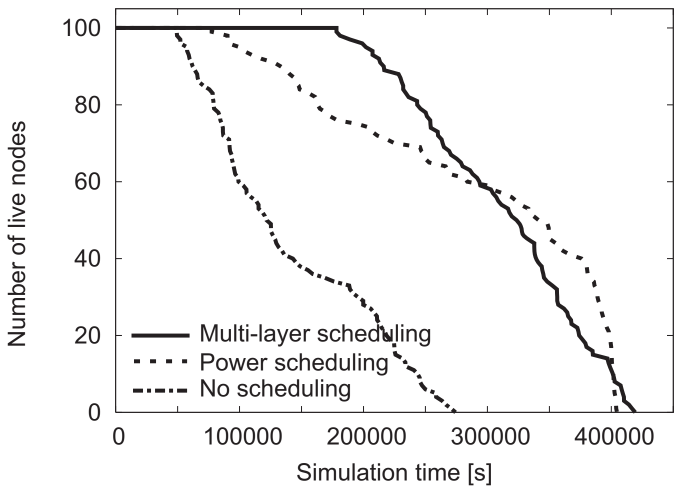

Figure 8. Comparison between power scheduling and multi-layer scheduling at lifetime

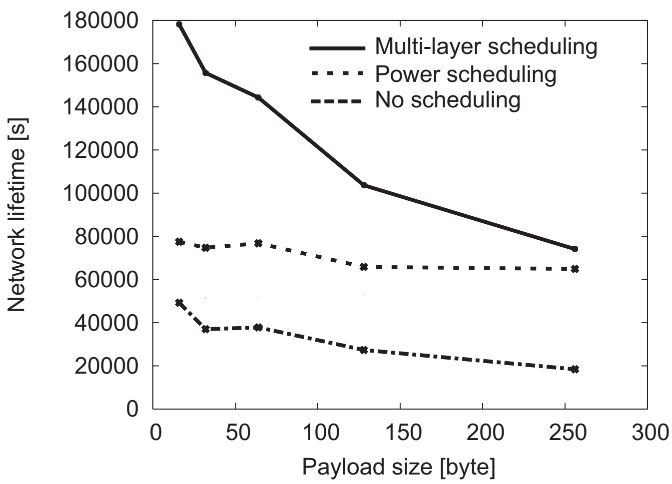

Figure 9. Lifetime when payload size is changed

V. CONCLUSION

In this work, we proposed a scheduling scheme based on RTS/CTS exchange and evaluated our scheme through simulation. Comparison of the results achieved using the proposed scheme with PS shows a prolonged system lifetime through the use of our scheme. It is important to determine the schedule considering data aggregation.

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