Multipath Routing using Isochronous Medium Access Control with Multi Wakeup Period for Wireless Sensor Networks

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***Abstract*— The cycled receiver MAC protocols reduce idle listening by periodically putting nodes into sleep state. Conventional cycled receiver protocols, however, have problem such as overhearing and high latency. In this study, we propose Isochronous MAC with multi wakeup period which can reduce the power consumption due to overhearing without delay increased. To exploit this benefit, we combine it with multipath routing. Simulation results show a 12% longer system lifetime and a 87% lower delay of our proposal scheme than that of the conventional scheme.**

I. Introduction

In wireless sensor networks, sensor nodes consume measurable power due to idle listening, in which receivers are activated even when they receive no data. Cycled receiver MAC protocols which reduce idle listening by making sensor nodes periodically turn their RF circuit off have been developed. With cycled receiver MAC protocol, a sensor node sends preamble to neighbor node before transmitting data. The preamble makes the neighboring nodes including the intended receiver notice the sender trying to send data. This kind of MACs can be classified into two categories: "asynchronous" and "synchronous." Low Power Listening (LPL) is one of the asynchronous [1]. In LPL, senders need to transmit enough long preamble to wake their neighbors up. Long preamble, however, consumes power.

To reduce this power consumption, Isochroous MAC (I-MAC) has been proposed [2]. In I-MAC, nodes synchronize with each other by using by a long-wave standard time code, which is available in America, Europe and Japan. One-chip LSI for this service, which consumes only 90 μW for time synchronization, has been developed for small watches (MIL6191-A03; OKI [3]). The synchronousness makes a sender it easy to predict when the neighboring nodes wake up, so that the length of the preamble is shorten. Consequently, the power consumption of I-MAC is smaller than that of LPL.

Cycled receiver MAC inherently or still has two problems. One is delay. The longer the wakeup period, the longer delay time before transmission. The other is overhearing which caused by listening to packets intended to other nodes.

In this work, in order to mitigate these problems, we propose I-MAC with multi wakeup period (I-MAC-MWP). I-MAC-MWP can reduce the power consumption due to overhearing without delay increased. To exploit this benefit of I-MAC-MWP, we combine it with multipath routing. In this paper, we estimate the system lifetime and the delay by simulation and show the effectiveness of proposal scheme.

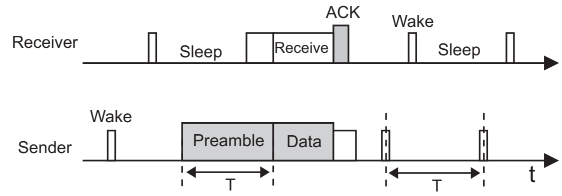

Fig. 1. Time diagram of transmission and reception in Low Power Listening.

II. ISOCHRONOUS MEDIA ACCESS CONTROL

Some protocol for asynchronous MAC Protocol have been studied: Low Power Listening (LPL) [1], Wise MAC [4], etc. Fig. 1 shows the time diagram of transmission and reception in Low Power Listening. Each sensor node enters a receiving mode only during a specific wakeup duration time, T_{on}, that occurs in every wakeup period, T. To send data, the sender first sends the preamble to wake up the neighboring nodes. The receiver which receives the preamble keeps operating the RF circuit, then the receiver can recieve data packet. After that, it sends the data. The receiver node returns the ACK data if the data are received correctly, and reverts to a sleep state. The preamble length must be sufficiently long for the other neighboring nodes, including the receiver node, to be able to be wake up. With LPL, the length of a preamble is set to the wakeup period. Consequently, the longer wakeup period causes the more power consumption of preamble transmission; that requirement conflicts with our goal to reduce the power consumption that is attributable to idle listening. The optimum wakeup period is dependent on the transmission frequency and the number of neighboring nodes to which the data are sent [2]. Overall, it is not easy to determine an optimum wakeup period for the entire network.

With synchronous MAC protocol, all nodes synchronize the wakeup duration time at every node. Isochronous-MAC (I-MAC) [2] is one of the synchronous MAC protocol. In I-MAC,

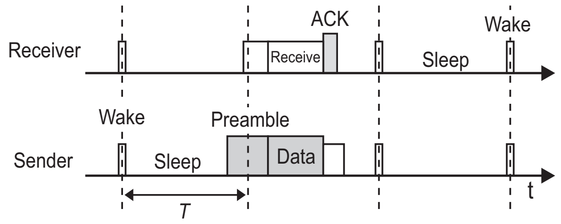

Fig. 2. Time diagram of transmission and reception in I-MAC

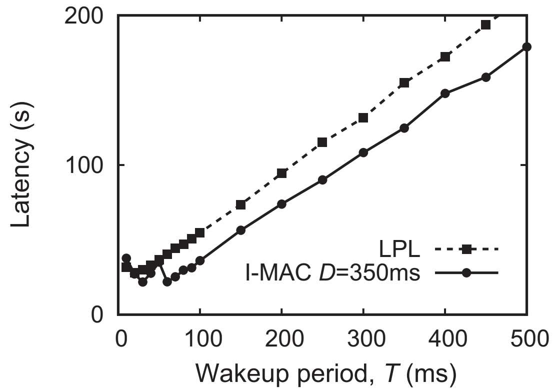

Fig. 3. Relation between latency and wakeup period.

the synchronization can be achieved using long-wave standard time code. Using I-MAC, since the synchronized wakeup time of every node can be known easily, the preamble length can be shortened. In I-MAC, as in the case of LPL, each node senses the channel status during the wakeup duration time, T_{on}, which happens within every wakeup period of T.

Fig. 2 shows the time diagram of transmission and reception in I-MAC. The sender node first sends the preamble before the neighboring nodes wake up. The preamble length is determined based on the time-synchronization timing and the amount of the clock drift. After that, it sends the data. The receiver node returns the ACK data if the data are received correctly, and reverts to a sleep state.

These cycled receiver MAC protocols greatly reduce idle listening. However, the cycled receiver MAC protocols has two problems. We explains a delay and a over hearing that is the problem of the cycled receiver MAC protocols.

A. Latency

Fig. 3 shows the relationship between latency and the wakeup period. The term "latency" is collection time of data. In this figure, longer wakeup period makes the collection time of I-MAC and LPL longer. In I-MAC, long wakeup period reduces power consumption. However, some application required low latency data transmission. For example, it is necessary to transmit the damage of the earthquake and the fire rapidly. To address the delay, some adaptive wakeup period MAC protocols are proposed [5], [6].

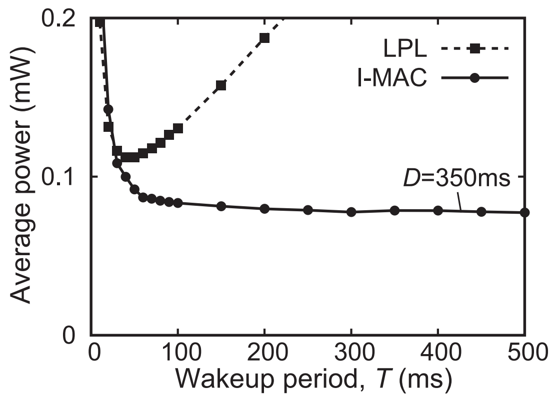

Fig. 4. Relation between average power and wakeup period

B. Overhearing

As described above, the cycled receiver MAC protocols require to transmit preamble to establish communication with neighbor nodes. The receiver which receives the preamble keeps operating the RF circuit, then the receiver can recieve data packet. However, it causes overhearing which non-destination nodes receive data packet.

III. Proposal scheme

A. Medium access control with multi wakeup period

With LPL, the length of the preamble depends on the wakeup period, so that LPL has an optimal wakeup period shown in Fig. 4. In contrast, with I-MAC, the length of the preamble is independent of the wakeup period. The longer the wakeup period, the lower the power. In this sense, I-MAC can have several periods. Proposal scheme has two modes in wakeup period: "low wakeup frequency (low) mode" and "high wakeup frequency (high) mode." Only the nodes on the data transmission path shift their mode from "low" to "high," and the other nodes stay in the low mode.

The benefit to introduce multi wakeup period is to reduce overhearing. Let us explain such effect using Fig. 5. Nodes A, C, and E relay data, and node B and D are not on the data transmission path. Since Node A, C, and E exist on the data transmission path, they are in high mode as shown in Fig. 5. Even though Node B and D are within the transmission radius of Node C, they get rid of the overhearing due to Node C because they are sleeping when Node C transmits. Thus, overhearing can be avoided, thanks to two wakeup periods.

B. Multipath routing

We also apply I-MAC-MWP to multipath routing. Fig. 6 shows an example of multipath route establishment. To have multiple relay nodes, each node stores the candidates of relay nodes using flooding in path finding phase. First, Node D initiates an interest packet, which is disseminated for all other nodes (Fig. 6(a)). Next, each node sets the route to transmit sensed data to Node D toward the neighbor which firstly sent an interest packet(Fig. 6(b)). In this case, Node A has two

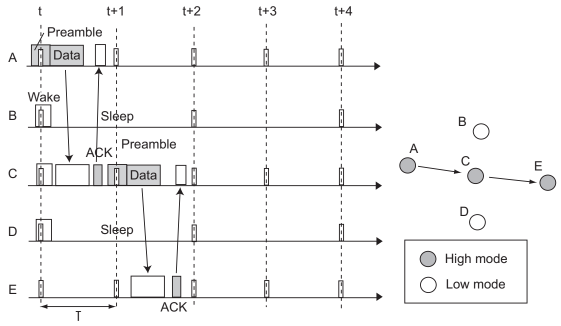

Fig. 5. Overhearing suppression using low and high mode.

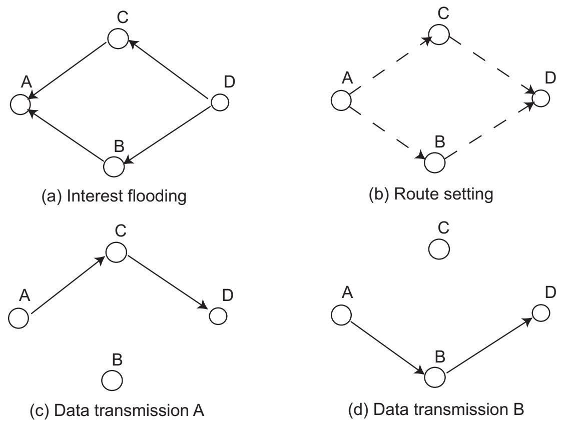

Fig. 6. Example of multipath route setting.

pathes to Node D (Fig. 6(c)(d)). In proposal scheme, Node A alternates the route to Node D every N_{alt} data transmissions. Suppose that Node A is using Node C as a relay node as shown in Fig. 6(c). To change the route, Node A needs to urge Node B to shift from the low mode to the high mode. Node A knows when Node B wakes up next time in the low mode. At the next wakeup time of Node B, Node A sends the data packet with the high mode request to Node B. As a result, Node B is activated to be in the high mode. Then the activated node will urge the next node, if any, on the alternative route to be in the high mode.

C. Features of the proposal scheme

The features of the proposal scheme are as follows.

- Latency can be reduced in the high mode comunication.
- Power consumption due to periodical wakeup can be reduced in the low mode.
- Overhearing of the low mode nodes can be reduced by multi wakeup period.
- Distributed traffic load thanks to multpath routing leads to distrbuted power consmiption among the nodes.

IV. Simulation

We used QualNet simulator to evaluate our proposal scheme [7]. 100 sensor nodes were deployed in a 100 m × 100 m sensing area uniformly, and a sink node is set up at the center

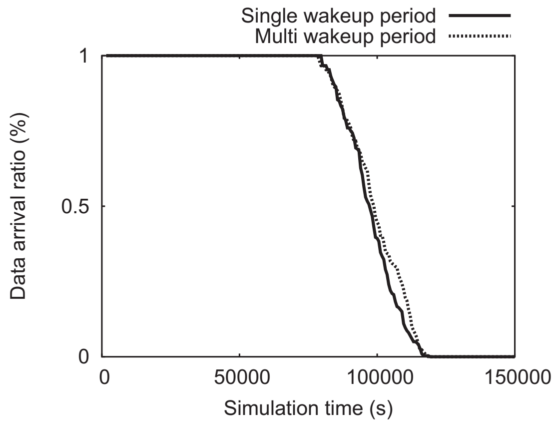

Fig. 7. Comparison of wakeup period (800 ms) and multi wakeup period (100 ms and 800 ms) at lifetime in single path routing.

TABLE I
NUMBER OF OVERHEARING.

	Number of overhearing
Single wakeup period ($T = 800$ ms)	30.4
Multi wakeup period ($T = 100/800$ ms)	8.5

of the field. We assume 10 source nodes chosen at random from among these 100 sensor nodes. The transmission range is assumed to be circular with a 20 m radius. The bit rate is 10 kbps. We assume that the transmission power is 24.75 mW, the reception power is 13.5 mW, the sleep power is 0.015 mW, and the time synchronous power is 0.09 mW [8]. Battery capacity is 4 J. Sensed data are regularly collected every 600 s. We assume that the header of each packet is 32 bytes, the packet payload is 64 bytes. Alternating route is excuted every 30 data gathering times. We assumed each 100 ms and 800 ms wakeup period in single path with LPL, and both wake period in proposal scheme. The simulation result is an average of 30 trials.

In this paper, we define a system life time as a duration for which a data arrival ratio is 90% or more.

First of all, we compare I-MAC and I-MAC-MWP in the case of single path routing (SP). Hereafter, we denote them as I-MAC/SP and I-MAC-MWP/SP, respectively. Fig. 7 shows comparison of system lifetime in I-MAC ($T = 800$ ms) and that in I-MAC-MWP ($T = 100/800$ ms). It is supposed that I-MAC-MWP ($T = 100/800$ ms) consumes more power than I-MAC ($T = 800$ ms) because of the high mode in I-MAC-MWP. However, it can be read from this figure that system lifetime of I-MAC-MWP is same as that of I-MAC. This result can be explained as I-MAC-MWP can surppress overhearing. Table I shows the average number of overhearing for 10 data transmissions per node in I-MAC and I-MAC-MWP. The average number of overhearing in I-MAC-MWP is 72% less than that in I-MAC. That is overhearing is remarkably reduced by I-MAC-MWP.

Next, we investigate how type of routing scheme affects system lifetime in the case of I-MAC ($T = 800$ ms). Fig. 8

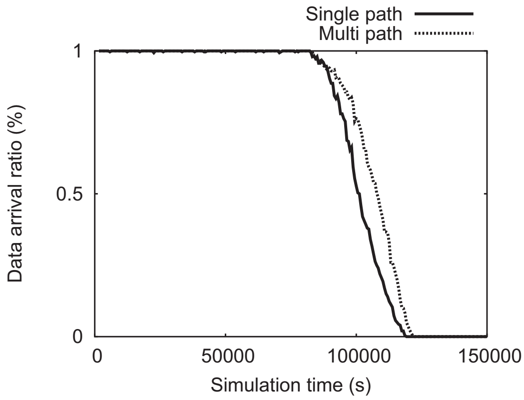

Fig. 8. Comparison of lifetime in the case of I-MAC/MP and that in the case of I-MAC/SP ($T = 800$ ms).

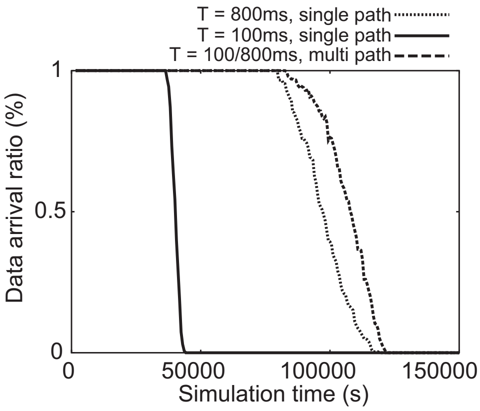

Fig. 9. Comparison of system lifetime in the cases of I-MAC/SP ($T = 100$ ms or $T = 800$ ms) and that in the case of I-MAC-MWP/MP ($T = 100/800$ ms).

shows comparison of lifetime in the case of single path routing and that in the case of multipath routing. As seen in this figure, the system lifetime in the case of multipath routing almost the same as that in the case of single path routing. That is multipath routing does not extend system lifetime enough alone.

Fig. 9 shows comparison of system lifetime in the case of the I-MAC-MWP and multipath routing (I-MAC-MWP/MP) ($T = 100/800$ ms) and that in the case of the conventional I-MACs ($T = 100$ ms and $T = 800$ ms) and single path routing (I-MAC/SP). The system lifetime in I-MAC-MWP/MP is 12% longer than that in I-MAC/SP.

Fig. 10 shows the latency of each round of proposal scheme and single path. Here, the round denotes the number of data collection from the beginning. Only the results are shown until one of the nodes is died first due to battery exhaustion. In I-MAC-MWP/MP, when the first data transmission or the changing data path phase, the delay grows for a moment because it operates in low mode (800 ms). However, the delay drops after that because the sensor node operate high mode (100 ms). Consequently, except the initial data transmission or

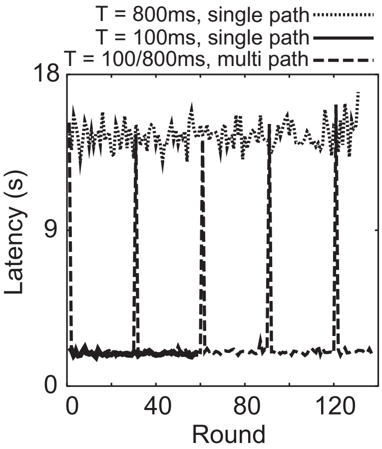

Fig. 10. Relationship between latency and round.

the route change, I-MAC-MWP/MP achieved the improvement of the delay time of about 87% compared with the single path with I-MAC/SP at 800 ms. This result gives a valuable insight that it is beneficial for the nodes on the data transmission path to dear to operate with wakeup period short.

V. Conclusion

In this work, we propose multipath routing using medium access control with multi wakeup period and evaluated our scheme through simulation. Simulation results show that the proposel scheme prolongs system lifetime and reduces data collection latency.

Acknowledgments

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