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Impact of Divided Static Random Access Memory Considering Data Aggregation for Wireless Sensor Networks

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***Abstract*—The most challenging issue of sensor networks is extension of overall network system lifetimes. It is important for the extension of system lifetime to determine the routing considering data aggregation. Data aggregation can reduce network traffic by the elimination of the redundant data. Though data aggregation is effective, sensor node needs a certain amount of RAM to aggregate data. RAM has standby energy, and its power consumption is one of the major factors in sensor node. In this work, we investigate the relationship among RAM capacity, data aggregation and power consumption. Then, we propose to use divided operating SRAM. Proposal method can reduce energy of sensor node even if RAM capacity is large.**

I. Introduction

Recent advancement in wireless communication technology and electronics has enabled the development of low power sensor network. In achieving wireless sensor networks, the most important issue is extension of the system lifetime. In general, the sensor node works with a battery. Numerous nodes are deployed in a sensing area, frequent battery exchange will be unacceptable burden. In order to reduce the battery exchange frequency, extension of the system lifetime is the hurdle to achieve wireless sensor networks.

Data aggregation is used as one solution of extension of the system lifetime[1]. Data aggregation can effectively reduce network traffic by the elimination of the redundant data. Many approaches are proposed by researchers. Data aggregation can be categorized into two classes: lossy and lossless[2]. Perfect aggregation and beam-forming are lossy aggregations[3], [4]. With perfect aggregation, a sensor node aggregates received data into one unit of data and then sends it to the next hop, where average, maximum, and count operations are examples of perfect aggregation functions[5]. Such an operation can remarkably reduce the amount of transmitted data. Perfect aggregation is quite efficient in this sense, whereas available applications are limited. Examples of lossless aggregations are linear aggregation and data funneling[6], [7]. Linear aggregation performs a simple operation: header aggregation. A sensor node concatenates the payloads of buffered packets whose next-hops are equal and then puts it into one packet. The efficiency of the header aggregation is lower than that of perfect aggregation, whereas lossless aggregation is versatile for all applications.

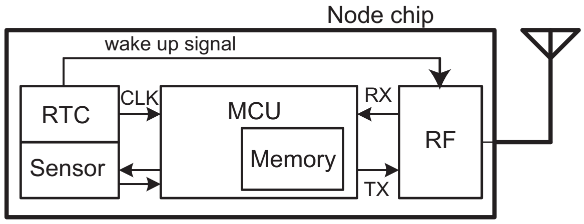

Fig. 1. Functional block diagram of typical sensor node

To aggregate data packet, each sensor node holds relay data temporarily and sends it at once. So, sensor node needs a certain amount of Random Access Memory (RAM) to aggregate data. RAM has standby energy which increases in proportion to memory capacity to hold data. RAM capacity is one of the major factors in low power sensor node. Therefore, there is tradeoff between RAM and data aggregation.

In this work, we investigate the relationship among RAM capacity, data aggregation, power consumption. In general, sensed data size strongly depends on a kind of applications. Thus it is difficult to prepare the optimum size of RAM in advance. In this paper, in order to increase flexibility toward various applications, we propose the usage of a divided SRAM (Static Random Access Memory) which operates partially on demand. Our simulation results shows the proposal approach achieves enough effect on power reduction compared with the usage of conventional SRAM.

The rest of the paper is organized as follows: Section II analyzes the energy consumption of typical sensor node. In Section III investigates a relationship between data aggregation and RAM from viewpoints of power consumption. In Section IV proposes the usage of divided SRAM which operates only the minimum part enough to record data packets. Proposal approach will be evaluated against conventional scheme in Section V. Finally, we summarize this paper in Section VI.

II. Analysis of the Module of Sensor Node

In this section, we explain about each module of a sensor node, and its power consumption.

Figure 1 shows a typical sensor node consists of five types of modules: Radio Frequency (RF), Random Access

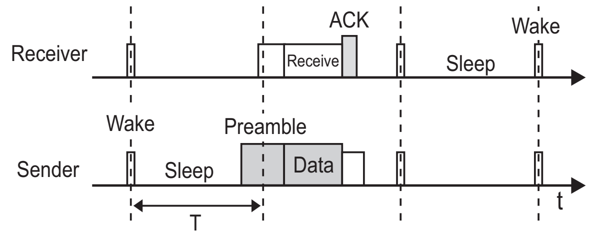

Fig. 2. Timing chart of I-MAC.

Memory (RAM), Micro Controller Unit (MCU), Real Time Clock (RTC), and Sensors.

First, we explain about RF module. RF is an important module to communicate via wireless. In wireless sensor networks, RF has short range and low bit rate communication for energy saving. This means that the transmission power can be reduced while the reception power can not be relatively negligible. RF consumes as much power when the sensor node does not receive any data as when it does. RF possibly operates even if the sensor node is not communicating. Such the state is called idle listening, and the power consumption of idle listening can be dominant factor in a sensor node. In order to reduce such power consumption, some types of cycled receiver MACs (Media Access Control) have been proposed, e.g., S-MAC, T-MAC, D-MAC, X-MAC, I-MAC[8], [9], [10], [11], [12]. Cycled receiver MAC can reduce power consumption of idle listening by long wakeup period. Figure 2 shows the timing chart of I-MAC, which is a kind of cycled receiver MACs. With these cycled receiver MACs, each sensor node senses carrier periodically. However, the delay increases as wake up period becomes longer. Moreover, even if duty cycle of RF is small, the power consumption will occupy most of the power consumption in sensor node with less communication frequency.

Secondly, we explain about RAM. RAM is an indispensable module to hold sensing data, received packets, and route information. In general, Static Random Access Memory (SRAM) and flash Read Only Memory (flash ROM) is used for the data logger. On the wireless sensor network where the reading and writing frequency of memory is low, the standby power of SRAM is dominant. SRAM standby power increases in proportion to memory capacity. Therefore, large capacity SRAM increases wasteful power consumption. On the other hand, flash ROM has no standby power even if it holds data. However, if flash ROM is used, it is difficult to make the sensor node a single-chip.

Thirdly, we explain about MCU. MCU has the role of the instruction of memory reading and writing, analysis and compression of received data, decision of following destination, and so on. Low power MCU is more necessary than high-performance MCU in wireless sensor networks. MCU operates at the same time when RF and the sensors operate. If MCU operates whenever RF operates, it requires a measurable amount of power. Then, the MAC controller which separate from MCU is used. In this scheme, only the MAC controller can process at preamble sampling of cycled MAC and handling the packet which is not sent for me. Moreover, some low power MCU for the sensor network is proposed.

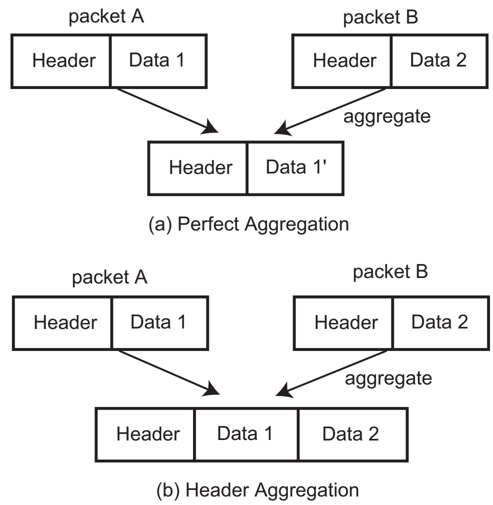

Fig. 3. Perfect aggregation and header aggregation.

Fourthly, we explain about RTC. RTC counts real time and wakeup or sleep timer. RTC is important module to know the time of sensing and synchronized communications on RF. Unlike other modules, RTC keeps operating, for a long time until the battery is dead since sensor node had been deployed. Therefore, it is one of the big factors to increase power consumption even though power consumption of RTC is smaller than other modules.

Finally, we explain sensor. Sensor is a module to acquire physical information around the sensor node. The power consumption of sensor strongly depends on the kind of sensor. Moreover, the kind of sensor is different according to the kind of application. Therefore, sensor is not considered in this paper.

III. Relationship between Data Aggregation and Random Access Memory

The data aggregation is an effective method that the communication traffic can be reduced in wireless sensor networks. To aggregate data, it is necessary to hold some data at each sensor node. Therefore, the memory for the data storage is needed. However, as described in the preceding section, SRAM has standby power to hold data. Therefore, the trade-off exists in the capacity of memory and data aggregation.

Some methods are proposed to the data aggregation. There are two classes of data aggregation: lossy and lossless. The typical method of lossy aggregation is perfect aggregation. For applications that require such as maximum, minimum, and mean of sensor measurements over all the sensor nodes, 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 (Fig. 3(a)). The typical method of lossless aggregation is header aggregation. Header aggregation that is one of the linear aggregations can reduce power consumption as the maximum number of aggregation packets increases. However, if a certain number of packets is exceeded, the effect becomes small. Figure 4 shows the maximum number of aggregation packets and the sending and receiving energy. Data packet

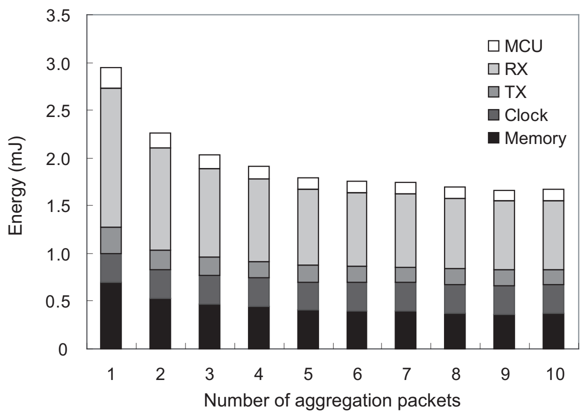

Fig. 4. Energy consumption which include MCU, RF (RX and TX), clock, and memory when the maximum number of aggregation packets is changed (RAM capacity = 8162 bit).

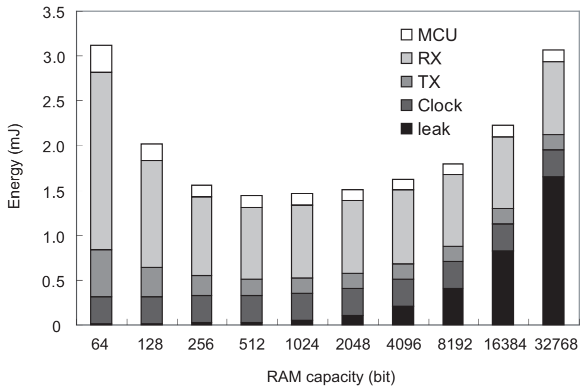

Fig. 5. Energy consumption which include MCU, RF (RX and TX), clock, and memory when RAM capacity is changed (maximum number of aggregation packets = 5).

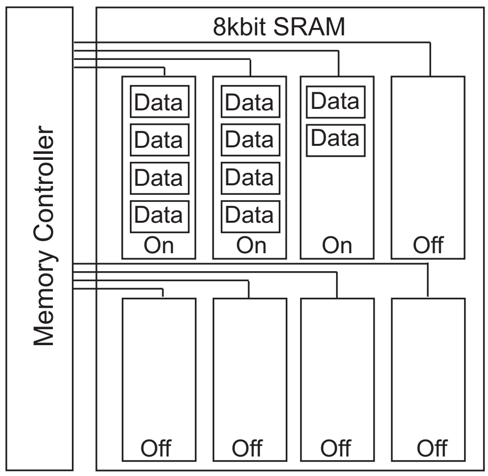

Fig. 6. Divided SRAM by same partition size

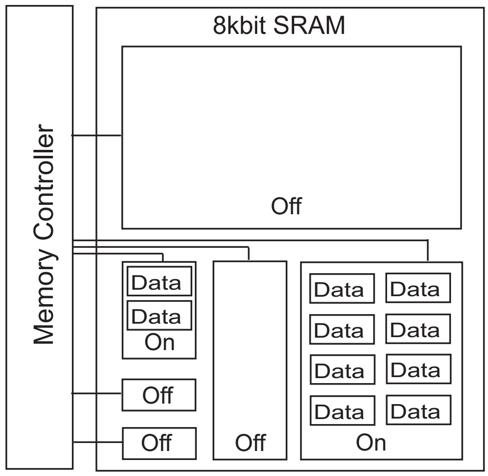

Fig. 7. Divided SRAM by multiplicative partition size

size is 6 bytes and header size is 4 bytes. A detailed parameter is described in Section V. TX and RX energy is reduced due to reduction of traffic for data aggregation. In addition, energy of memory is reduced too. As you see, the effect become small around in exceeded five data packet. If the ratio of header and data changes, the effect of data aggregation changes. The larger the header is, the more effective header aggregation method is. However, the error happens easily to the communication with a long aggregation packet.

Figure 5 shows the energy consumption of sensor node when the capacity of SRAM is changed. When the capacity of RAM becomes large, the energy consumption of sensor node becomes larger by the RAM standby power. Though the energy of RF is reduced for data aggregation, The energy of memory is larger than it. Therefore, the best capacity of SRAM to aggregate data exists.

IV. Divided SRAM Architecture

As described in the preceding section, suitable SRAM capacity for the data aggregation exists. However, it is difficult to prepare the best SRAM capacity. Then, we propose to use divided SRAM.

The proposal scheme divides SRAM into some partitions, and leaves only the necessary part on. Figure 6 is an image of the proposal SRAM. If the received data exceeds the one partition size, memory controller turns on the next partition. Reversely, the partition which not needs to hold data is turned off. Memory controller operates only when memory is reading or writing. So, power overhead of memory controller is quite small. Thus, power consumption can be reduced by turning on only the partition which hold data. Proposal method can also reduce power consumption by high-compression data aggregation like perfect aggregation. Because, the partition which has no data increases due to high-compression data aggregation.

A lot of partition is turned off and power consumption of most blank memory is reduced. On the other hand, power overhead of memory controller increases. Moreover, circuit design of memory controller becomes increasingly more complex. To combat this, we propose a variously-size partition RAM (Fig. 7). If we divide s bit RAM to n multiplicative size partitions, memory controller can control partitions by $\frac{s}{2^{n-1}}$ bit. In this paper, we did not evaluate variously-size partition RAM but same-size partition only.

V. Performance Evaluation

We used QualNet simulator to evaluate our proposal scheme[15].

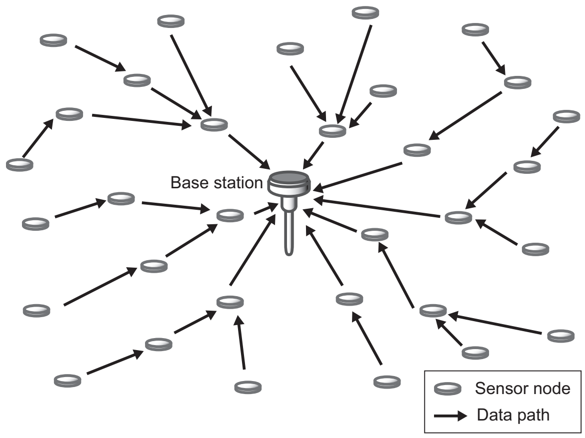

Fig. 8. Sensor network tree for data gathering application.

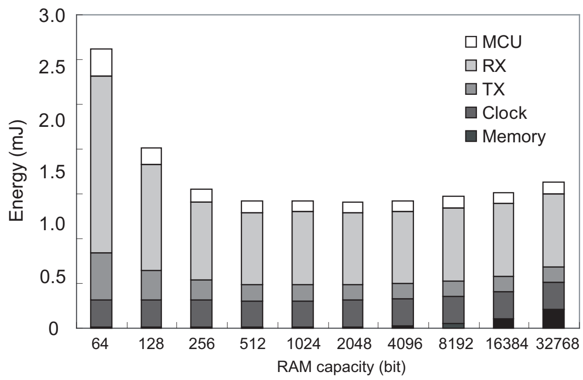

Fig. 9. Energy consumption which include MCU, RF (RX and TX), clock, and memory using proposal method (number of partition = 8, maximum number of aggregation packets = 5).

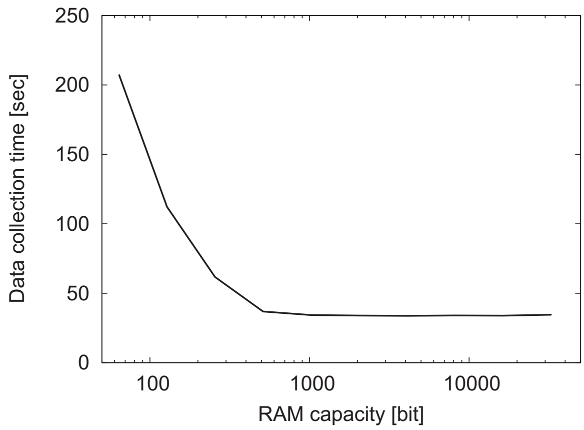

Fig. 10. The data collection time using proposal method (number of partition = 8, maximum number of aggregation packets = 5).

A. Simulation Condition

Sensor nodes were deployed in a sensing area uniformly. Proposal method is adaptable to any type of application, routing, MAC, and aggregation method. In this simulation, we assume following parameters. Sensor nodes collect data to the base station in accordance with Tiny Diffusion, which is a simplified Directed Diffusion method (Fig. 8)[13][14]. 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. For each parameter setting, 30 trials with different random seeds were executed and the average value of them are plotted in the following graphs. We use I-MAC for MAC protocol. The transmission range is assumed to be circular with a 20 m radius. The RF parameter is refered to[16]. We assume that the transmission power is 1.9 mW and the reception power is 3.7 mW. The clock power is 0.5 μW[17]. The Memory parameters are decided by circuit simulation. The memory write power is standby power is 1.5 nW/bit. The partition control overhead is 2 μW/bit and partition switching time is 10 ns. The MCU power is 0.5 mW, it is refered by 8051 processor[18]. We assume that the header of each packet is 32 bit. The default packet payload is 48 bit. The control packet size is 32 bit. The ACK packet size is 32 bit. The bit rate is 20 kbps. The sample period of the I-MAC is 500 ms. The data gathering period is 600 s. We assume that header aggregation eliminates headers of two or more packets for the same destination. Signal to noise ratio (SNR) threshold is 10 dB. If SNR threshold exceeds 10 dB, it is considered that the channel interference occurred. In this case, a sender node cannot receive ACK packet from a receiver node and sender node retransmits data.

B. Simulation result

Figure 9 shows energy consumption which include MCU, RF (RX and TX), clock, and memory using proposal method when RAM capacity is changed. The number of partition is eight and maximum number of aggregation packets is five. Using proposal method, best RAM capacity is 512 bit from the viewpoint of energy. However, proposal method reduce the overhead which sensor node has the large capacity compared with normal RAM (Fig. 5). For example, energy consumption of proposal scheme is 20% lower than that of conventional scheme on the condition that sensor node has 8192 bit RAM. Figure 10 shows the data collection time when RAM capacity is changed. The larger RAM capacity is, the shorter data collection time is. Proposal scheme can use large capacity of RAM with low power and low delay.

Figure 11 shows total energy consumption of sensor node when the number of partition is changed. The number of partitions exceeds eight, the effect of proposal scheme is saturated. Though it is effective to increase number of partition, the hardware design is difficult. Moreover, the overhead of the memory control increases.

Figure 12 shows the energy consumption of sensor node when maximum number of aggregation packets is changed. The effect of data aggregation using proposal scheme is saturated from five data aggregation as same as conventional scheme. The efficient of data aggregation changes depending on the ratio of header size and payload size. In this paper, we use header aggregation only. If we use high-compression data aggregation, proposal method is more effective. Figure 13 shows energy consumption when payload size is changed. Eight partition RAM of Proposal scheme is effective with any size of the payload.

VI. Conclusion

In wireless sensor network, memory standby energy is dominant parameter on sensor node. Considering data aggregation, sensor node needs large capacity of memory.

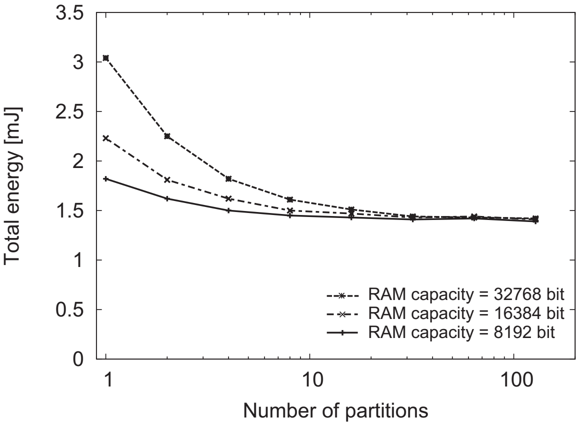

Fig. 11. Total energy consumption of sensor node when the number of partition is changed (maximum number of aggregation packets = 5).

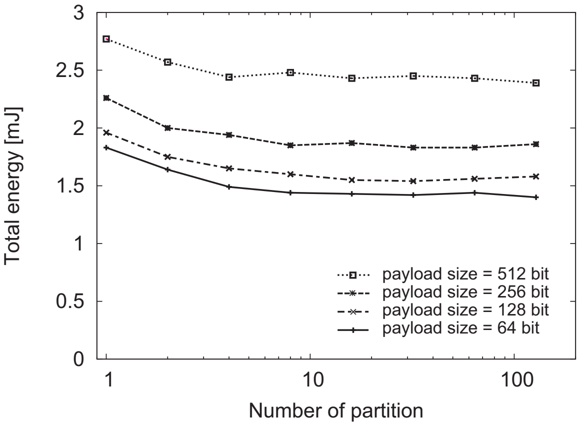

Fig. 13.

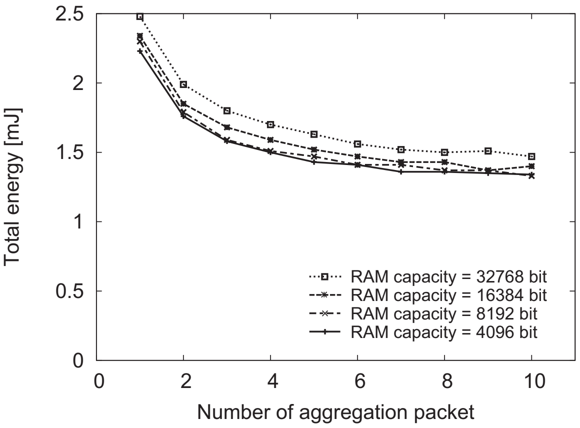

Fig. 12. Total energy consumption of sensor node when the maximum number of aggregation packets is changed (number of partition = 8)

In this paper, we propose to use divided operating SRAM for data aggregation. The necessary part of memory keeps power on and the unused part of memory cut off. Proposal scheme can reduce energy consumption even if sensor node has large capacity of RAM. However, if RAM is partitioned with same capacity, the overhead of RAM standby power becomes prominent by large capacity RAM. Therefore, our future work is that we devise means of dividing the memory.

Acknowledgment

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