2013 IEEE International Conference on High Performance Computing and Communications & 2013 IEEE International Conference on Embedded and Ubiquitous Computing

Performance Comparison of DASH7 and ISO/IEC 18000-7 for Fast Tag Collection with an Enhanced CSMA/CA Protocol*

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***Abstract*—ISO/IEC 18000-7 adopted Slotted ALOHA as MAC transmission protocol. However, this protocol cannot solve the collision problem when there is a need of collecting massive tags. To solve this problem, DASH7 adopted CSMA/CA for MAC protocol. It also proposed three kinds of collision avoidance models to implement the back off flexibly. AIND is the unsurpassed model as it can effectively use the contention period employing data transmission time back off. RAIND adopts random initialization and distribute access time of each tag in order to reduce the backoff. And the last, RIGD does geometric decaying slot backoff, minimizing the number of backoffs to reduce energy consumption. This paper presents tag collection scenario. We analyze the three CA models and Slotted ALOHA with tag collection time. We also suggest adaptive guard time method to improve the CA models. The aftermath of tag collection experiment is that CSMA/CA has exceptional performance than Slotted ALOHA. AIND has the best performance among CA models and its performance is 28.7% better than Slotted ALOHA. In addition, the adaptive guard time method enhances RAIND and RIGD which are based on random back-off. In particular, RIGD with adaptive guard time method(AG-RIGD) has similar performance as AIND. Besides, AG-RIGD is better than AIND in terms of energy efficiency because it consumes one third of energy than AIND during tag collection.**

Keywords—DASH7; ISO/IEC 18000-7;Tag collection;Slotted ALOHA;CSMA/CA;Anti-collision;Wireless Sensor Network

I. INTRODUCTION

In active RFID systems, each tag is equipped with its own battery and active RFID systems can be applied to a wide variety of industrial fields that require inventory information management, location tracking, process automation, and logistics. In such industrial fields, to manage information on applicable objects more efficiently in real time, an RFID reader should collect data from a massive number of RFID tags located within its communication range and provide the data to a system or user as soon as possible when triggered manually or periodically. This is referred to as tag collection. When active RFID tags are applied to moving objects, the tag collection procedure must be completed quickly so that the tags do not move out of the reader's communication range during tag collection. As the time required for tag collection increases, the battery consumption on each tag also increases, which is a major concern in active RFID systems where tags are powered by their own batteries. Consequently, in terms of the overall performance of active RFID systems, the speed at which the reader collects data from a massive number of tags is very important.

The main cause of poor performance of tag collection in RFID systems is the tag collision problem, which is caused by simultaneous responses from multiple tags. For that reason, a tag collection method based on an efficient anti-collision protocol to resolve the tag collision problem is important in improving the tag collection performance. However, the current standard for active RFID systems does not have enough capability to retrieve data from a massive number of tags in a timely manner.

ISO/IEC 18000-7 is the standard for active RFID systems and defines the air interface communications in 433MHz frequency. It operates in lower frequency compared to other existing communication technologies, such as 900MHz based Zigbee, 2.4GHz based IEEE 802.15.4 WPAN, Bluetooth, etc. So it has advantages of wide communication range and low power consumption. DASH7 is the new technology that maximizes the benefits of the 433MHz frequency band. It tends to support not only RFID systems but also wireless sensor network. Though it uses the same frequency band as ISO/IEC 18000-7, there are many differences between them. And their main difference is MAC transmission protocol.

Slotted ALOHA is the mandatory tag collection protocol in ISO/IEC 18000-7 standard. It can't resolve collision problem effectively. In contrast, DASH7 adopts CSMA/CA which has anti-collision mechanism and tends to improve the collection speed. It suggests three kinds of CA models (AIND, RAIND, RIGD) for different purpose. AIND and RAIND use constant backoff time for fixed length of packet. RIGD has an advantage of power consumption.

In this paper, we suggest a fast tag collection method based on enhanced CSMA/CA protocol. We analyze the three CA models and Slotted ALOHA [20] with tag collection time. And we propose the adaptive guard time method (AG) to reduce the waste of contention period. The performance is verified with a real-world testbed and composed of collection time and energy consumption.

This paper is organized as follows. In section 2, we introduce the DASH7 technology, tag collection algorithm in ISO/IEC 18000-7 and CSMA/CA research. Section 3 explains DASH7 CSMA/CA process, the role of guard time and adaptive guard time method. In section 4, we evaluate Slotted

*This work was supported by the Industrial Strategic technology development program, No. 10041947 funded by the Ministry of Trade, Industry & Energy (MOTIE, Korea).

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978-0-7695-5088-6/13 $31.00 © 2013 IEEE
DOI 10.1109/HPCC.and.EUC.2013.112

ALOHA and DASH7 CSMA/CA model with tag collection time. Also, we compare default guard time method with AG method. Finally, we present our conclusions.

II. RELATED WORKS

A. DASH7 Technology

DASH7 is the new communication technology based on 433MHz frequency band. It supports RFID systems and wireless sensor network. DASH7 is designed as OSI 7 layer. Main differences between ISO/IEC 18000-7 and DASH7 are described in TABLE I.

There are many channels in the DASH7 physical layer. ISO/IEC 18000-7 can use only one channel which has 433.92MHz as its center frequency. DASH7 presents multiple-channel to reduce collision. It divides the whole channel into maximum 8 segments. A DASH7 system can utilize maximum number of channel when its symbol rate is set to 55kbaud. On the other hand, when the symbol rate is 200kbaud, it can use 4 hi-rate channels.

DASH7 data link layer uses CSMA for MAC transmission protocol. ISO/IEC 18000-7 uses Slotted ALOHA and it has many problems. For example, it should recollect tags which collided. Recollection degrades the performance and increases energy consumption. To solve this problem, DASH7 applies CSMA/CA that is well-known in wireless standards. Tag collection process is simplified because of collision avoidance.

B. ISO/IEC 18000-7 Tag Collection Algorithm

ISO/IEC 18000-7 uses Slotted ALOHA for MAC transmission protocol. In Fig. 1, there is a single collection round which is composed of several discrete timeslots. Every node can send response packet only at the beginning of each timeslot. In a time slot, only one node can send the data packet. If many tags try to send a data at the same timeslot, a tag collision is occurred. The collision is the main problem which causes poor performance of tag collection. To solve this problem, ISO/IEC 18000-7 presents tag collection algorithm that repeats collection rounds until all the tags are collected. However, it causes an increase in the total tag collection time and battery consumption. So, extensive research has been done to reduce collision [7]–[9].

TABLE I. PHY AND MAC COMPARISON (ISO/IEC 18000-7 VS DASH7)

Layer	*Component*	*ISO/IEC 18000-7*	*DASH7*
PHY	Channel Size	500kHz	216kHz
	Channels	1	8
	Modulation	FSK ± 50kHz	GFSK ± 50kHz
	Encoding Options	Manchester	PN9, FEC
	Symbol Rate	55.6kbaud	Normal : 55.6kbaud Turbo : 200kbaud
	Packet Sync	Pulse width	Sync word
MAC	Access Methods	Slotted ALOHA	CSMA/CA
	Addressing	Unicast Broadcast	Unicast Broadcast Multicast Anycast
	Multi-hop Support	No	Yes

Fig. 1 shows the tag collection algorithm of ISO/IEC 18000-7. Firstly, a reader sends wake-up command to tags for switching their status from sleep to scan. Secondly, it sends a collection command in order to receive responses of the tags. When the tags have scan status, each tag receives the collection command, and then, it sends the collection response message. The tags use Slotted ALOHA for MAC transmission protocol and gets parameters to process Slotted ALOHA from collection command. The collection command lets each tag know a window size which determines a response time, and the tags can send response in specified time (57.3ms). The tags can calculate a slot size using the response packet length. The response of tag is conducted within each slot.

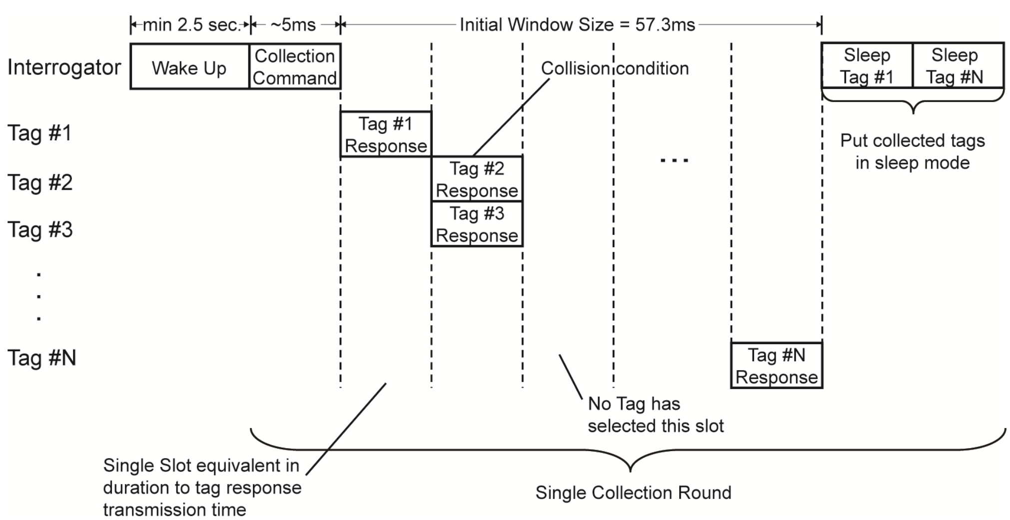

Fig. 1. ISO/IEC 18000-7 Tag Collection Algorithm [1]

Slotted ALOHA can cause tag collision because the tags cannot know selected slots. Therefore, it needs to use a sleep command and a round to retransmit the responses of tags which had been collided. The round means the sum of collection command and response period. Interrogator collects tags which cannot be received within one round. If the tag is already received, then it must not be collected in next round. So, interrogator needs to send sleep command to collected tags. The tag which receives sleep command turns its status to sleep and it is inactive until it receives a wake-up command. According to this algorithm, interrogator can collect all tags in several rounds. Also, the number of rounds executed is a factor that estimates collection performance.

C. CSMA/CA Research

CSMA/CA is collision avoidance, contention based MAC protocol which is used in wireless communication standards. In CSMA/CA research issues, CA algorithm is very important for MAC performance. It is the research to reduce the collision, and it should consider two factors.

Firstly, it considers back off method. Generally, in contention period, CA algorithm uses random back-off to avoid collision. However, it uses contention period ineffectively which decreases the MAC performance. To solve this problem, many researchers are working on 802.15.4 which is representative wireless sensor network system. Related to it, ECR(Enhanced Collision Resolution) and EB(Enhanced Backoff) is presented [10]. ECR increases backoff exponent according to clear channel assessment (CCA) result and packet transmission because a channel contention degree can be guessed by CCA results and packet transmission. EB mechanism shifts the range of backoff counters in order to reduce redundant backoffs and CCAs during a transmission. Additionally, it proposes hybrid mechanism of ECR and EB, and gives simulation results of their performances. Finally, the paper enhances the throughput of CSMA/CA. And Nilsson et al. [11] applies CSMA/CA to RFID system which simulates constant, linear, exponential back-off and presents transmission delay and energy consumption.

Secondly, it considers CCA. 802.15.4[3] uses non-persistent CSMA. This protocol does not observe channel continuously, it stops sensing when the channel is busy and restarts after a certain period of time. Because it is a low power sensing method, it is used extensively in wireless sensor network system. E. egea-lopez, et al. [13] estimates the performance of non-persistent CSMA for RFID systems, Wong, et al. [15] estimates it with exponential backoff scheduling and Kiryushin, A. et al. [14] evaluates the performance of CCA to get accurate value.

III. IMPLEMENTATION OF FAST TAG COLLECTION

DASH7 uses CSMA/CA for MAC transmission protocol. This section explains attributes of DASH7 CSMA, and it looks at functions of each CA model. However there isn't any tag collection algorithm like ISO/IEC 18000-7 with DASH7 CSMA/CA. So, this paper presents the massive tag collection method for DASH7 technology. Finally, it describes the adaptive guard time method to improve the collection performance of DASH7 CSMA.

A. DASH7 CSMA Process

Fig. 2 shows the flow chart of DASH7 CSMA/CA process. CSMA consists of several functions. One is channel sensing which checks busy status and another is guard time to avoid collision with other data transmission.

DASH7 performs clear channel assessment (CCA) to check the channel busy before the data transmission. When there is collision, the RSSI value is smaller than common signal value. RSSI value changes according to the RF settings and communication distance. So, threshold should be determined before using it through the experiment of free and busy channel signal. After defining the threshold, we can define CCA. If the RSSI value is bigger than threshold, CCA succeeds. And if the RSSI value is smaller than threshold, CCA fails.

DASH7 CSMA process performs two CCA. Basic CSMA protocol does only one CCA but it has a problem. A reader sends an ACK or sleep command right after data transmission.

If it does only one CCA, it can guard only the data. Therefore, the following ACK or sleep command will be collided with other responses. So, DASH7 performs two CCAs like 802.15.4. Between CCAs, there is a channel guard time to pass the other node's data transmission period. If second CCA succeeds, the node changes the RF state from IDLE to TX and is ready for data transmission.

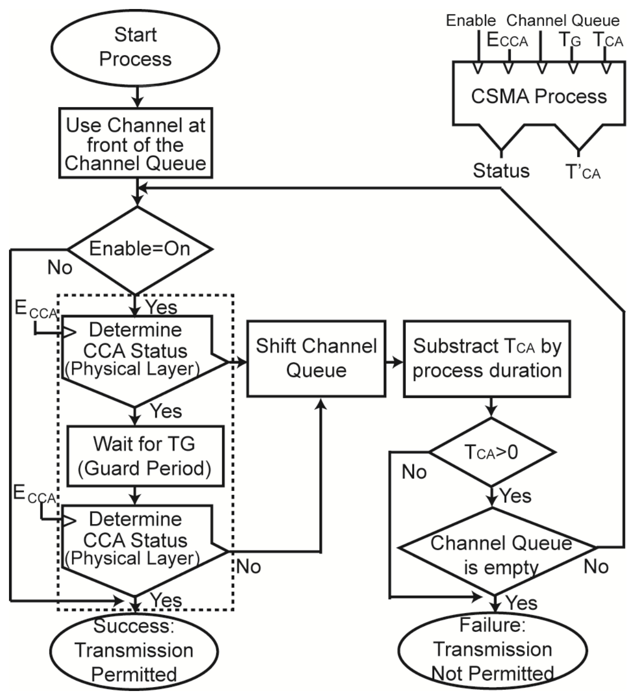

Fig. 2. DASH7 CSMA Process [5]

B. DASH7 Collision Avoidance Models

Fig. 3 is the flow chart of CSMA/CA. There are two components for CA models. One is congestion control and the other is flow control. This paper concentrates on congestion control and DASH7 suggests three CA models which have a different congestion control.

Fig. 4 explains the difference between DASH7 CA models. Node A and node B are assumed. Node A sends command and node B responds to it. In Fig. 4, collision avoidance time (T_{CA}) is the timeout for response from node B to node A. It also means contention period when multiple nodes responds to command of node A. CA model is the algorithm which occurs within T_{CA}, and each CA model has different attributes.

Fig. 4(A) is AIND (Initial insertion, Adaptive slotting, Linear slot back-off) model. Responses of every node start at the first T_{CA}. The most quickly accessed node that finished two CCA sends the data first and the others perform back-off because of CCA failure. AIND defines back-off length as the packet duration. After avoiding collision, if back-off for next CCA time is equal to the packet duration, back-off reduces wastage of T_{CA}, getting up on a regular basis. Therefore, AIND uses T_{CA} effectively and has good performance when there are massive responses. However, if every node performs same CCA and backoff, only one node can access in a free slot and others should do backoff until they succeed in CCA. Therefore, their energy consumption is increased.

Fig. 4(B) is RAIND (Random insertion, Adaptive slotting, Linear slot back-off). It is very similar with (A) but has random initial insertion time. At this time, the random value is calculated with the ID of each node. If the CA model uses random insertion, it can distribute its access time. As a result, it can perform back-off effectively, and reduce energy consumption. However, if random insertion occurs too late, a node is assigned very small contention period. It means that a node gets fewer opportunity for collision avoidance, and it decreases the performance of heavy competition systems like tag collection.

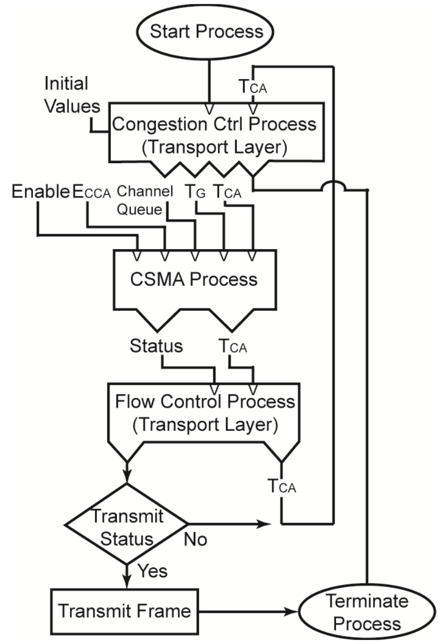

Fig. 3. DASH7 CSMA/CA Process [5]

Fig. 4(C) is RIGD (Random increase, Geometric decaying slot back-off). It has random back-off unlike (A) and (B). RIGD does not define random insertion with T_{CA}. It divides T_{CA} by two, and defines random insertion and repeats division and insertion when there is a CCA failure. It solves ineffective contention period allocation but decreases the opportunity to avoid collision because it has unsophisticated way to divide T_{CA}. However, every node can get same access opportunity unlike (B). As a result, it is not appropriate to the tag collection application. But, it is good for low power systems like wireless sensor network.

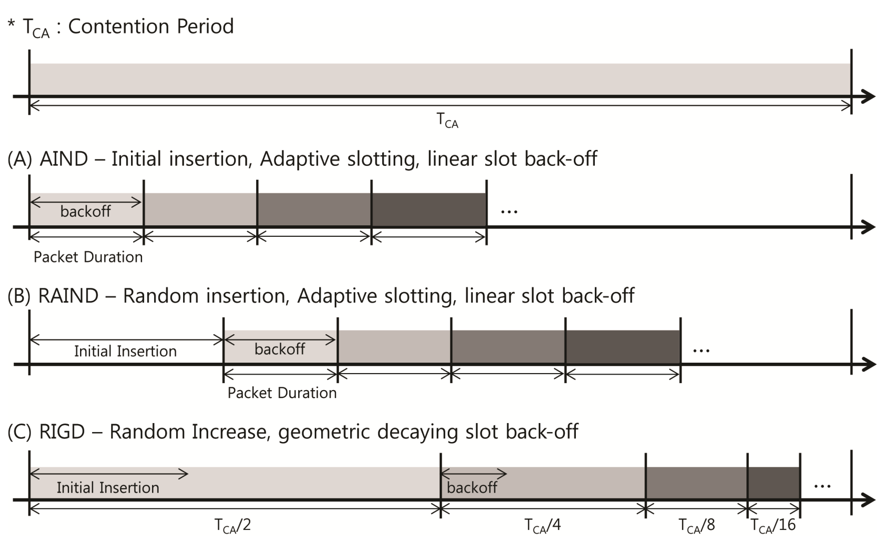

Fig. 4. DASH7 Collision Avoidance Models

C. Adaptive Guard Time method

Guard time (T_{GD}) which is placed between 2 CCAs in DASH7 is the time to guarantee the data transmission without any collision which is a very important value for CA. so DASH7 defines default value for it. It is set as 5ti(about 4.85ms) when the RF uses 55kbaud of symbol rate. This default value is defined by transmission time for 32bytes of data.

Fig. 5 shows data transmission events according to the DASH7 CSMA process. (A), (B), (C) represents basic events when a node transmits a data. If the channel is free, (A) can succeed two CCA continuously, and sends data immediately. But if the channel is busy, a node fails CCA and should repeat CCA again. (B) represents first CCA failure, and (C) represents second CCA failure. When CCA fails, a node tries CCA again within T_{GD}.

(D) and (E) assume that massive nodes optimally send data without collision. (D) is optimal data transmission when it uses default guard time of DASH7. In (D), T_{GD} is longer than packet duration. Because the data packet for collection is defined as 16bytes, data transmission takes shorter time than T_{GD}. It is not required for T_{GD} to use the longer time than packet duration in order to avoid collision. DASH7 default T_{GD} decreases the collection performance. If T_{GD} uses the same time as packet duration, the collection application can save contention period. As a result, the more tags can be collected within T_{GD}.

This paper presents a method like (E) and names it as adaptive guard time method (AG). AG is the method to set the channel guard time as same as packet duration. For example, in the tag collection application, collection command and response are smaller than 32bytes. In this case, the default guard time in DASH7 is 4.85ms, which is unnecessarily long. If the guard time is set as same as the packet duration, tag collection time can be reduced. AG has different improvements according to the CA model. If CA uses AG, the worst CA which wastes contention period a lot, can get much improvements. RIGD has the worst usage of contention period as it performs random insertion in each back-off division and distributes data transmission a lot. Therefore, RIGD gets the best improvement.

D. Tag Collection Scenario for DASH7

This paper compares the DASH7 collection performance with ISO/IEC 18000-7. However, DASH7 specification does not have any tag collection algorithm.

Therefore, at first, the super frame needs to be designed to apply CSMA protocol. To correctly estimate the performance, the superframe structure in Fig. 6 is designed on the same condition as in Fig. 1.

After designing frame structure, the next step is to define the time for tag collection. In case of ISO/IEC 18000-7, rounds are repeated for tag collection. The round implies collection command time and response time. Response time is defined by window size, and calculated as window size * 57.3ms. So, DASH7 also needs window size mechanism and should have a similar value of 57.3ms. Because the concept of tick has the value of 0.97ms, the contention period gets about 59ti.

The final step is to determine the end state. In ISO/IEC 18000-7, tag collection algorithm uses three continuous empty rounds to determine the end state. When no tags are collected for three rounds, it finishes collection and presents the result. Similarly, tag collection based on CSMA also needs to define the end state. To get a comparable scenario, it also uses the same end state.

IV. EXPERIMENT AND ANALYSIS

A. Experiment Evironment

Reader and tags which were used in this experiment are shown in Fig. 7. It uses MSP430f6137 core of Texas Instrument [6] which is ultra-low-power microcontroller system-on-chip with integrated CC1101 RF transceiver. Therefore, RF functions are controlled using predefined RF registers in MCU. As CC1101, the MCU has 64 bytes of RF FIFO register. It is connected with PC using UART interface to receive command and report experiment result. The collection performance of Slotted ALOHA refers to [20]. In the case of DASH7 CSMA, PC receives execution time from the DASH7 tag collection application and that is the performance value. For every tag set and CA model, we collected the data for 500 tag collections and calculated the average tag collection time.

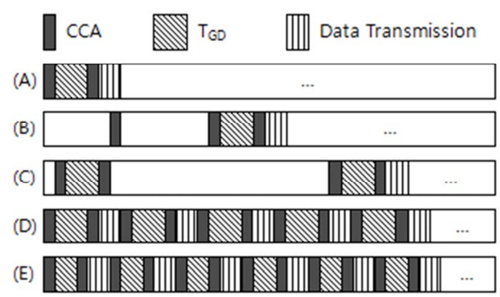

Fig. 5. DASH7 CSMA/CA Data Transmission Examples

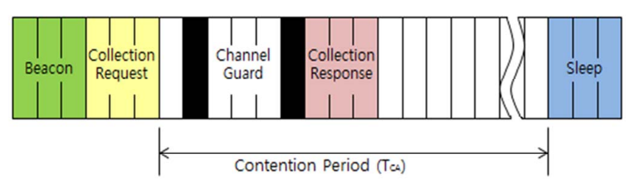

Fig. 6. Proposed Super Frame Structure for DASH7 Tag Collection

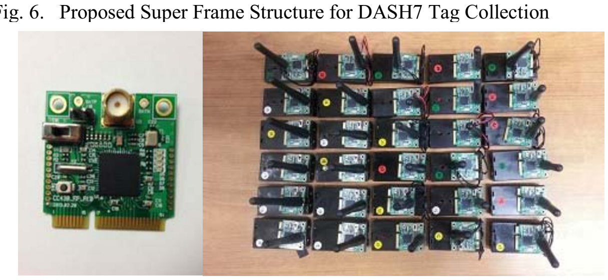

Fig. 7. DASH7 Reader and Tag

The tag collection application should define device configuration value according to the DASH7 specification before running it. The channel bandwidth is 216KHz, starts from 434.568MHz. Encoding method is PN9 and no FEC mode. Reader runs as gateway and tag runs as endpoint.

B. Performance Comparison

1) Slotted ALOHA and CSMA/CA

At first, this paper measures collection rate and time of three CA models using scenario 0 and it compares the result with the Slotted ALOHA experiment [20]. Tags were randomly placed one meter away from the reader. The experiment was done by testing from 5 to 40 nodes increasing 5 nodes on every testing. Each test was executed 500 times, and the result was calculated as average value of it.

Fig. 8 is the result that measured collection rate of each CA model before measuring collection time. The collection rate is average 97% at 5 tags and also has same value at 40 tags. There is no big difference in collection rate among three CA models. Each model only has difference in usage of contention period, and it does not affect collection rate.

Fig. 9 shows the collection time comparison. In this figure, we can see CSMA/CA has much better performance than Slotted ALOHA. Slotted ALOHA can-not detect collision because it should wait for the next collection round to retransmit collided data. The heavy collision can result in ineffective slot usage. Additionally, it increases collision probability, and the performance of Slotted ALOHA gets rapidly bad .On the other hand, CSMA can avoid collision because it detects busy channel with CCA, and retransmit data within contention period. According to the way CSMA/CA executes back-off, use of contention period is increased. So, CSMA can get better performance than Slotted ALOHA.

Among the CA model, AIND has the smallest collection time in Fig. 9. AIND does back-off as same as packet duration, so it has the most slots within the contention period. If a node has a lot of slot, it means that it has many opportunities to transmit a response packet. So, we can say that AIND has the best use of contention period. It also means, AIND has the best performance. The other two models have similar performance with AIND when the number of tags is less than 25, but they show worse performance as the number of tags increases. Because RAIND and RIGD use random method in their models, they can't use the contention period uniformly. They increase almost same until 40 tags are collected. The best case of RAIND has better performance than RIGD. If initial insertion is the first of contention period, it can operate as AIND. However, the worst case of RAIND only has one opportunity to transmit a packet and RIGD has more opportunity than RAIND. As a result, RAIND has similar performance as RIGD which regularly has the half of the best case RAIND.

2) Default and Adaptive Guard Time

The second test estimates the performance of adaptive guard time method (AG). This experiment also tests the same scenario, but defines a special parameter called guard time. By DASH7 specification, default guard time has 5ti for 32bytes of packet. In the tag collection, the data packet is 16bytes. So, we can reduce the guard time as 2.5ti. However the basic time unit in DASH7 specification is 1ti, so the adaptive guard time is set to 3ti, which is the multiple of the basic time unit.

Fig. 10 is the experiment result of RIGD with AG. RIGD shows drastic difference in performance among the 3 models. When the application collects 40 tags, its collection time was reduced to 11.2%. RIGD is affected by the guard time because it distributes access time for CCA by random insertion. When it applies AG, it decreases guard time and waste of contention period. Therefore, AG-RIGD gets over its limitation.

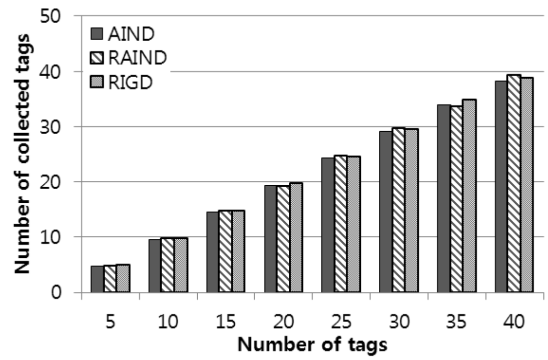

Fig. 8. Collection Success

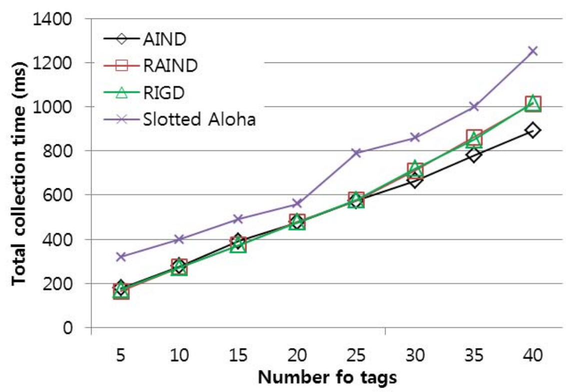

Fig. 9. Collection Time (Slotted ALOHA, DASH7 CA Models)

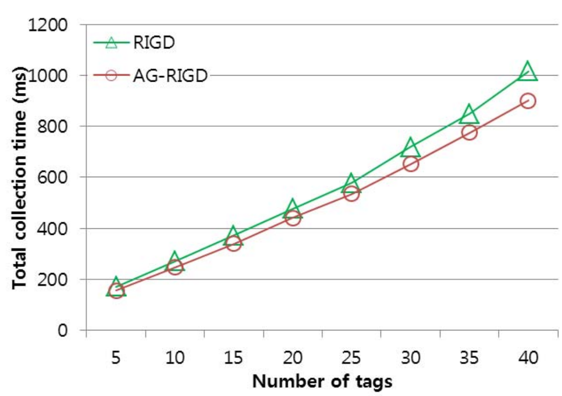

Fig. 10. Collection Time (RIGD VS AG-RIGD)

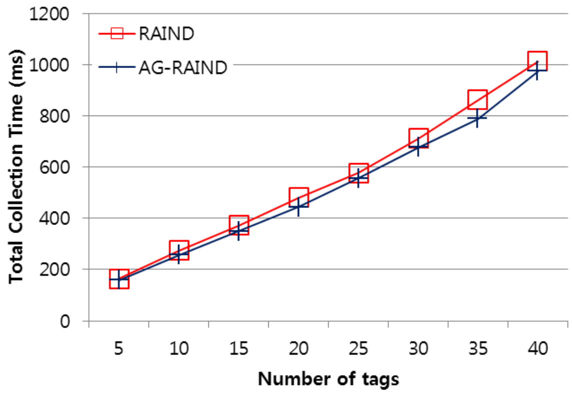

Fig. 11. Collection Time(RAIND VS AG-RAIND)

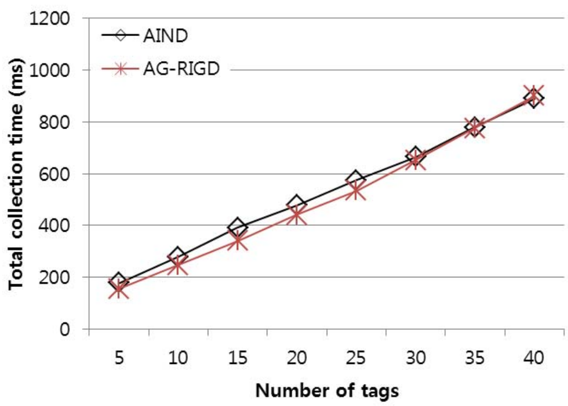

Fig. 12. Collection Time(AIND VS AG-RIGD)

Fig. 11 is the result of RAIND with AG. It has under 2% difference in its performance when compared with RAIND. Only initial insertion is defined randomly, RAIND does constant back-off after that. If constant back-off occurs, distribution of access time is decreased when it is compared to RIGD. As a result, influence of the guard time is reduced, and its improvement is less than RIGD. Similarly, AIND has no improvement because all the tags try CCA at the same time.

TABLE II. CURRENT CONSUMPTION OF EACH OPERATION

RF State	*Operations*	*Time Symbol*	*Current Consumption* [a]
SLEEP	Channel Guard	T_{GD}	0.1mA
	Backoff	$T_{backoff}$	
TX	Data Transmission	None	17mA
RX	CCA	T_{CCA}	17mA
	Contention Period (for Reader)	T_{CA}	

a. *current consumption in MSP430[6]*

According to the experiments, AG-RIGD has the best improvement and Fig. 12 shows that the AG-RIGD and AIND have almost same performances. In this case, using a low power model is better choice in wireless sensor network. In TABLE II. , we can see several operations within contention period. Channel guard operation has RF SLEEP state and it consumes little energy (0.1mA). However, CCA and collection response operations consume a lot of energy to receive and transmit data (17mA). Therefore, a model which performs those operations frequently within a contention period, will consume more energy and SLEEP can be ignored.

If AIND and AG-RIGD succeed in data transmission at one try, it is the best case and the two models have same energy consumption because they do the same operations. However, the worst case which fails in CCA continuously until the end of contention period, cause different energy consumption between two models. AIND does backoff with the length of constant packet duration and the maximum number of CCAs in a contention period can be calculated as Eq. (1). But, RIGD does backoff with half of the pervious backoff value, and the maximum number of CCAs in a contention period can be calculated as Eq. (2).

$$N = \frac{T_{CA}}{(T_{CCA} + T_{backoff})}, \qquad N = N_{AIND} \tag{1}$$

$$\sum_{i=1}^{N} (T_{CA} \times \frac{1}{2^i}) < T_{CCA}, \qquad N = N_{AG-RIGD} \tag{2}$$

While the tag collection was executed within the experiment environment, T_{CCA} took 1.2ms and $T_{backoff}$ took 2.9ms. If the tag collection has the worst performance in a round, N_{AIND} is 18, $N_{AG-RIGD}$ is 6 and N_{AIND} consumes 3 times more energy than $N_{AG-RIGD}$. Therefore, when the two models have same performance, AG-RIGD is the better algorithm, because it consumes less energy than AIND.

V. CONCLUSION

DASH7 is a wireless sensor network technology that uses 433MHz of bandwidth. Unlike ISO/IEC 18000-7, it uses CSMA/CA as MAC transmission protocol for enhancing the performance. Additionally, it presents many kinds of CA models depending on the application.

In this paper we compare with DASH7 MAC transmission protocol with ISO/IEC 18000-7 by experiments, and performances are measured with a large number of tag collection which is a well-known application in RFID system. The experiment result shows that DASH7 CSMA/CA has maximum 28.7% better performance than Slotted ALOHA. Among CA models, AIND has 12.3% better performance than the others. Moreover, when the application uses adaptive guard time method which is presented in this paper, the performance of AG-RIGD is almost same as AIND. Additionally, RIGD consumes less energy than AIND because AIND uses more operations which use transmit or receive state in RF transceiver. Therefore, we can use AG-RIGD as the best CA model which has good performance and energy efficiency for tag collection.

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