A Protocol Minimizing Missing Tags in a Moving RFID Tag Environment

Chul Wan Park, Ji Hyoung Ahn, and Tae-Jin Lee

***Abstract*—A collision caused by transmitting several tag IDs simultaneously reduces throughput and increases identification delay in Radio Frequency IDentification (RFID) systems. In a moving tag environment, frequent collisions may lead to a situation wherein unidentified tags may leave the reader's identification range. These missing tags lower the identification rate of tags in a moving tag environment. In this paper, we propose a new method to minimize the missing tags in a moving tag environment to increase the identification rate. The proposed method, ALOHA-based Minimizing the Missing Tags (AMMT), is designed to improve the identification rate by minimizing the missing tags. Simulation results show that AMMT provides better identification rate compared to Dynamic Framed Slotted ALOHA (DFSA).**

***Index Terms*—Anti-collision, DFSA, missing tag, moving tag, RFID.**

I. Introduction

Radio Frequency IDentification (RFID) is a non-contact identification technology to gather information from various objects using radio frequency [1], [2]. An RFID system consists of tags and a reader which collects information from the tags [3]. In an RFID system, a collision may occur due to simultaneous transmission of multiple tags. Since a reader cannot get any useful information from collided tags, collisions degrade performance of the system. Thus an anti-collision protocol to avoid collisions is required to increase the performance of an RFID system [4], [5]. Existing anti-collision protocols mainly consider the tags in a static environment, i.e., tags are immobile. For some applications of RFID systems, proper anti-collision protocols are needed to handle moving tags (see Fig. 1).

When tags move in a conveyor belt, the receiver occasionally fails to collect data due to channel errors and collisions. Sometimes the failure may last longer, and the long-lasting fault causes information loss, increase of the identification time, and inaccurate localization [6]. A missing tag is defined as an unidentified tag during the full identification process. The missing tag is caused by static and dynamic errors [7], [8]. The static error is caused by an obstacle disturbing communications between a tag and a reader. Since an RFID reader cannot know whether an obstacle exists in the identification range, the static error cannot be estimated. However, we can estimate the dynamic error since the missing tags caused by channel noise or collisions can be estimated using the probability of missing tags and the channel propagation model.

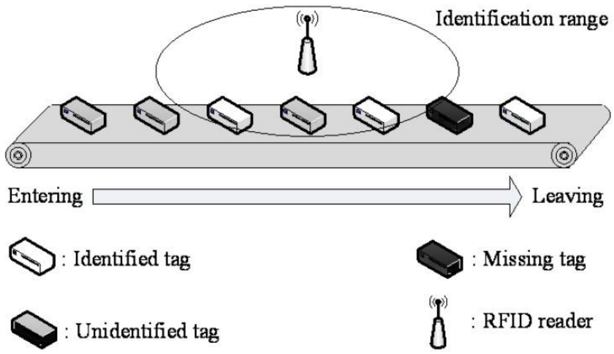

Fig. 1. An RFID system with moving tags.

Since missing tags decrease the reliability of an RFID system, the missing tag problem is one of the most important issues in a moving tag environment. In this paper, we propose an ALOHA-based Minimizing Missing Tags (AMMT) protocol to reduce the missing tags using the success probability and the channel state of an RFID system. The AMMT protocol estimates the missing tag probability by using the tag speed, the tag density, and the channel model and determines the next frame size to minimize the estimated probability of missing tags. By minimizing the number of missing tags, the AMMT can increase the identification rate and decrease the identification time. This paper is organized as follows. In Section II, we describe the proposed anti-collision protocol under a practical channel environment. Section III contains simulation results. Finally, we conclude in Section IV.

II. The ALOHA-Based Minimizing Missing Tags

We assume that the reader knows the speed and the line density of tags. The speed and the line density of tags is used to estimate the number of tags arrived at the prior frame. We assume that an obstacle to cause missing tags is not in the identification range. An entering tag during the current frame cannot try to transmit the information if it does not receive the query command from the reader at the start of the frame. Then it tries to transmit its ID in the next frame. The reader can estimate the number of arrived tags in a frame from the speed, the density, and the previous frame size.

We employ the channel model in [9] to develop the

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proposed AMMT protocol and calculate the Bit Error Rate (BER) $BER(d)$ using the signal to noise ratio $SNR(d)$ when the distance between the reader and a tag is d. Let M be the number of bits of a packet containing a tag's ID. The BER is calculated as follows.

$$BER(d) = 2Q\left(\sqrt{2^k \cdot SNR(d)}\right) \cdot \left(1 - Q\left(\sqrt{2^k \cdot SNR(d)}\right)\right), \quad (1)$$

where k is the line code index k (k=0, 1, 2, 3) defined in EPC standard [1].

The Packet Error Rate (PER) $PER(d)$ at distance d is

$$PER(d) = 1 - (1 - BER(d))^M. \quad (2)$$

Since tags may be located uniformly, the probability density function that a tag is located at the position from which the distance is d to the reader is

$$P(d) = \frac{1}{2r}, \quad (3)$$

where r is the identification range of the reader.

Then the average PER PER_{avg} in the identification range of the reader is calculated as follows.

$$PER_{avg} = \int_{-r}^{r} PER(d)P(d)dd. \quad (4)$$

Since the tags move with the constant speed of v_{tag} and the density of d_{tag}, some tags may enter and leave the identification range at every frame. Let t_{slot} be the time duration of a slot. The reader initiates the i th frame by broadcasting the query command, which includes the frame size L_i. The tags, which receive the query command, select slots randomly in the frame and transmit data in the selected slots. The number of tags which try to transmit in the current frame is the sum of the remaining unidentified tags from the previous frames and the tags arrived during the previous frame. Let N_i be the number of tags which try to transmit data at the i th frame. The probability of success slot $p_{succ,i}$ at the i th frame is

$$p_{succ,i} = \frac{N_i}{L_i}\left(1 - \frac{1}{L_i}\right)^{N_i - 1}. \quad (5)$$

The probability of idle slot $p_{idle,i}$ at the i th frame is

$$p_{idle,i} = \left(1 - \frac{1}{L_i}\right)^{N_i}. \quad (6)$$

So, the probability of collision slot $p_{coll,i}$ at the i th frame is calculated as

$$p_{coll,i} = 1 - p_{succ,i} - p_{idle,i}. \quad (7)$$

Let $N_{remain,i}$ be the number of the remaining tags at the end of the i th frame. The remaining tags at the i th frame are the collided tags at the i th frame. So $N_{remain,i}$ is calculated using the success probability.

$$N_{remain,i} = N_i - L_i p_{succ,i}. \quad (8)$$

In the moving environment, new tags enter the identification range every frame. The number of entering tags during the i th frame is

$$N_{new,i} = L_i t_{slot} v_{tag} d_{tag}. \quad (9)$$

Then, the number of tags to be identified at the (i+1) th frame is

$$N_{i+1} = N_{remain,i} + N_{new,i}. \quad (10)$$

To minimize the missing tags, the proposed protocol defines a missing tag probability. The entering tags at the i th frame may leave the identification range after some frames. Let R_i be the number of frames experienced by the entering tags $N_{new,i}$. Since the number of frames experienced by the entering tags is different every frame, we can approximate the number of frames experienced by the entering tags in a steady state as follows.

$$R_i = \left\lfloor \frac{2r}{L_i t_{slot} v_{tag}} \right\rfloor. \quad (11)$$

The probability of a success tag at the i th frame is calculated as

$$p_{tag,i} = \left(1 - \frac{1}{L_i}\right)^{N_i - 1}. \quad (12)$$

If a tag does not transmit data successfully due to a collision or a channel error during the frames experienced by the tag, it becomes the missing tag. When a channel error occurs, the reader recognizes it as a collision. The probability of an unidentified tag at the i th frame is calculated as follows.

$$p_{unid,i} = 1 - (1 - PER_{avg})p_{tag,i}. \quad (13)$$

The probability of a missing tag is the probability that a tag is not identified by the reader during the frames within the identification range $2r$. The missing tag probability $p_{miss,i}$ at the i th frame is then

$$p_{miss,i} = (p_{unid,i})^{R_i}. \quad (14)$$

We start from the initial frame size L_0. The reader can estimate the number of the remaining tags using the estimation method. In this paper, we use the Maximum Likelihood (ML) estimation method to determine the next frame size. To estimate the number of tags, the ML estimation method uses the number of idle slots [10]. The reader collects the statistics on the total number of idle slots and calculates the measured idle probability $\tilde{p}_{idle,i}$ under the frame size of L_i. Using the measured idle probability, the reader estimates the number of tags $\hat{N}_i$ at the i th frame and determines the next frame size.

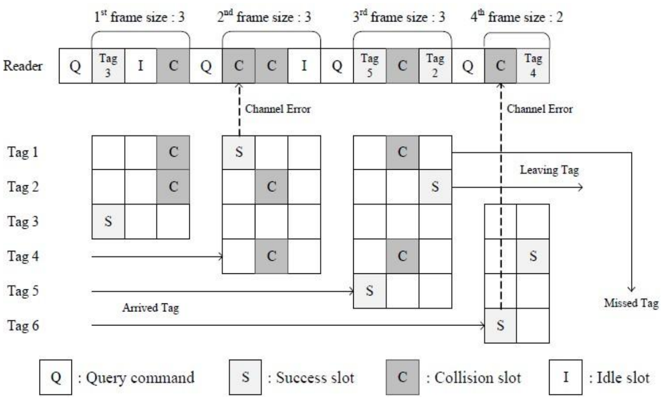

Fig. 2. The AMMT protocol in a moving tag environment.

TABLE I: SIMULATION PARAMETERS

Parameter	Value
Time duration of a slot	0.003 s
Transmission power of a reader	10 dBm
Antenna gain of a reader	0 dBi
Antenna gain of a tag	-6 dBi
Frequency	900 MHz
Bandwidth	500 kHz
Tag ID size	96 bits
Thermal noise density	-174 dBm/Hz

$$\hat{N}_i = \frac{\log \tilde{p}_{idle,i}}{\log(1 - 1/L_i)}. \quad (15)$$

Since there are no tags in the identification range initially, $\tilde{p}_{idle,0} = 1$, $\hat{N}_0 = 0$. Let $\tilde{N}_{succ,i}$ be the measured number of success tags. At the i th frame, the estimated number of remaining tags is then

$$\hat{N}_{remain,i} = \hat{N}_i - \tilde{N}_{succ,i}. \quad (16)$$

Note that $\hat{N}_{succ,0} = 0$. So, the estimated number of tags $\hat{N}_{i+1}$ to be identified at the $(i+1)$ th frame is

$$\hat{N}_{i+1} = \hat{N}_{remain,i} + N_{new,i}, \quad (17)$$

where $N_{new,i}$ is given in (9).

Since the probability of a missing tag is dependent on the frame size, the proposed protocol determines the next frame size to minimize the probability of a missing tag. From (11), (13), and (14), the probability of a missing tag is estimated as

$$\hat{p}_{miss,i+1}(L_{i+1}) = (1 - (1 - PER_{avg})\,\hat{p}_{tag,i+1})^{\left\lfloor \frac{2r}{L_{i+1} t_{slot} v_{tag}} \right\rfloor}, \quad (18)$$

where $\hat{p}_{tag,i+1} = (1 - 1/L_{i+1})^{\hat{N}_{i+1} - 1}$.

The optimal frame size $\hat{L}_{opt,i+1}$ at the $(i+1)$ th frame is determined as the value to minimize $\hat{p}_{miss,i+1}(L_{i+1})$. So

$$\hat{L}_{opt,i+1} = \left\lfloor \arg\min_{L_{i+1}} \{\hat{p}_{miss,i+1}(L_{i+1})\} \right\rfloor. \quad (19)$$

To process the entering tags, the frame size should satisfy

$$L_{i+1} t_{slot} > \frac{1}{v_{tag} d_{tag}}. \quad (20)$$

So the minimum frame size $L_{\min}$ is confined to

$$L_{\min} = \left\lfloor \frac{1}{t_{slot} v_{tag} d_{tag}} \right\rfloor. \quad (21)$$

The number of the entering tags by increasing the frame size affects the next frame size. When the frame size is higher than the threshold, a tag can leave the identification range as soon as it enters the identification range. The distance a tag travels during the $(i+1)$ th frame is

$$L_{i+1} t_{slot} v_{tag} < 2r. \quad (22)$$

Then, the maximum frame size $L_{\max}$ is limited to

$$L_{\max} = \left\lfloor \frac{2r}{t_{slot} v_{tag}} \right\rfloor. \quad (23)$$

Thus the next $(i+1)$ th frame size L_{i+1} is determined as

$$L_{i+1} = \min\left\{\max\{L_{\min}, \hat{L}_{opt,i+1}\}, L_{\max}\right\}. \quad (24)$$

At the first frame (see Fig. 2), there are three tags in the identification range and the reader broadcasts the query command. Tag 3 selects the first slot and transmits its ID. Tag 1 and Tag 2 select the third slot, so a collision occurs. So Tag 1 and Tag 2 are the remaining tags. Tag 4 enters within the identification range of the reader during the first frame and tries to transmit data at the second frame. The number of tags N_2 is 3 at the second frame. Tag 1 is not identified in the first slot of the second frame by channel error, and Tag 2 and Tag 4 collide. At the third frame, Tag 1, Tag 2 and Tag 4 retry to transmit data and Tag 5 enters within the identification range of the reader. Since only Tag 5 selects the first slot of the third frame, it transmits data successfully. At the second slot of the third frame, a collision between Tag 1 and Tag 4 occurs. Tag 2 selects the third slot of the third frame and transmits data successfully. Tag 1 and Tag 2 leave the identification range of the reader during the fourth frame. Since Tag 1 does not transmit data within the identification range of the reader, it becomes a missing tag. At the fourth frame, Tag 6 enters within the identification range of the reader and transmits data but experiences channel error at the first slot of the fourth frame. Tag 4 selects the second slot of the fourth frame and transmits data successfully.

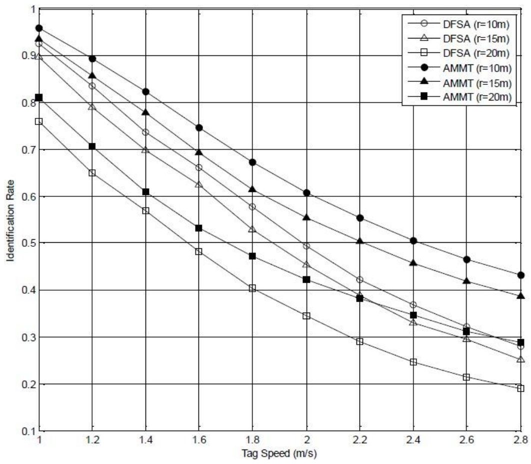

Fig. 3. Identification rate with variation of tag speed (d_{tag}=100 tags/m).

III. Simulation Results

Table I shows the parameters used in the simulation. The simulation parameters are set to follow the EPC global C1 G2 standard [1]. We compare our AMMT with Dynamic Framed Slotted ALOHA (DFSA). We define the identification rate R_{id} as the ratio between the number of the successfully leaving tags and the total number of the leaving tags. In the moving environment, the identification rate is considered as a key performance metric for an RFID system.

$$R_{id} = \frac{\text{Number of successfully leaving tags}}{\text{Number of total leaving tags}}. \qquad (25)$$

Fig. 3 shows that the identification rate of the AMMT protocol for varying speed of tags is higher than that of DFSA when the density of tag is 100 tags/m. The identification rate of AMMT protocol is 22.7% higher than that of DFSA when the transmission radius r is 10 m and the speed of tag is 2.6 m/s. Since the number of tags to be identified increases as the transmission radius and the speed of tags increases, the identification rate decreases. When the speed of tags is 1.8 m/s, the identification rate of the AMMT protocol $(r = 10m)$ is 33.6% higher than that of the AMMT protocol $(r = 20m)$ due to channel error.

In Fig. 4, the identification rate is shown to decrease by increasing the density of tags when the speed of tags is 2 m/s. The identification rate of AMMT protocol $(r = 10m)$ is 14.4% higher than that of DFSA when the density of tags is 100 tags/m. Since the number of tags increases as the density of tags increases, the number of the collided tags increases and affects the occurrences of missing tags. When the density of tags is 60 tags/m, the identification rate of the AMMT protocol $(r = 10m)$ is 34.2% higher than that of the AMMT protocol $(r = 20m)$ due to increasing number of collided tags.

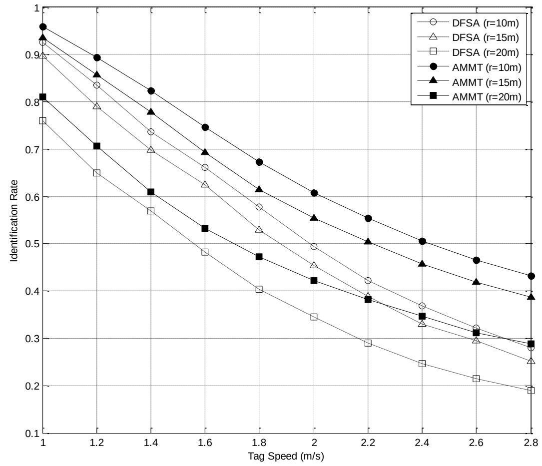

Fig. 4. Identification rate with variation of tag density (v_{tag}=2 m/s).

IV. Conclusion

The identification rate is an important performance metric for a moving tag environment since these may be missing tags. We have proposed the AMMT protocol to minimize the number of missing tags and to reduce the identification delay in a moving tag environment. Simulation results show that the AMMT protocol achieves better system performance than the DFSA protocol in terms of the identification rate.

References

[1] EPC global, "EPC radio-frequency identity protocols class 1 generation 2 UHF RFID protocol for communications at 860MHz-960MHz," Version 1.2.0, 2008.

[2] R. Want, "An introduction to RFID technology," *IEEE Pervasive Computing*, vol. 5, no. 1, pp. 25-33, Jan. 2006.

[3] C. Wang, M. Daneshmand, K. Sohraby, and B. Li, "Performance analysis of RFID generation-2 protocol," *IEEE Transaction on Wireless Communications*, vol. 8, no. 5, pp. 2592-2601, May 2009.

[4] L. Zhu and T.-S. P. Yum, "Optimal framed ALOHA based anti-collision algorithms for RFID systems," *IEEE Transactions on Communications*, vol. 58, no. 12, pp. 3583-3592, Dec. 2010.

[5] J. Myung, W. Lee, and J. Srivastava, "Adaptive binary splitting for efficient RFID tag anti-collision," *IEEE Communications Letters*, vol. 10, no. 3, pp. 144-146, Mar. 2006.

[6] C. Ma, J. Lin, and Y. Wang, "Efficient missing tag detection in a large RFID system," in *Proc. Trust, Security and Privacy in Computing and Communications*, pp. 185-192, Jun. 2012.

[7] K. Fyhn, R. M. Jacobsen, P. Popovski, and T. Larsen, "Fast capture-recapture approach for mitigating the problem of missing RFID tags," *IEEE Transactions on Mobile Computing*, vol. 11, no. 3, pp. 518-528, Mar. 2012.

[8] W. Luo, S. Chen, T. Li, and S. Chen, "Efficient missing tag detection in RFID systems," in *Proc. of International Conference on Computer Communications*, pp. 356-360, Apr. 2011.

[9] J. Park and T.-J. Lee, "Channel-aware line code decision in RFID," *IEEE* Communications *Letters*, vol. 15, no. 12, pp. 1402-1404, Dec. 2011.

[10] G. Khandelwal, K. Lee, A. Yener, and S. Serbetli, "ASAP: a MAC protocol for dense and time-constrained RFID systems," *EURASIP*

Journal on Wireless *Communications and Networking*, vol. 2007, no. 2, pp. 1-13, Jan. 2007.

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