

LETTER

Multi-Dimensional Channel Management Mechanism to Avoid Reader Collision in Dense RFID Networks

Haoru SU^{†a)}, Student Member and Sunshin AN^{††b)}, Nonmember

SUMMARY To solve the RFID reader collision problem, a Multi-dimensional Channel Management (MCM) mechanism is proposed. A reader selects an idle channel which has the maximum distance with the used channels. A backoff scheme is used before channel acquisition. The simulation results show MCM has better performance than other mechanisms.

key words: RFID, reader collision problem, MAC, multi-channel

1. Introduction

Radio Frequency Identification (RFID) is a promising technology for ubiquitous computing. From supply chain logistics to enhanced shop floor control, it presents many opportunities for process improvement or reengineering. However, when multiple mobile readers are present in a working environment, signal from one reader may reach others and cause interferences, which was explained in [3] as the reader collision problem.

There are many existing protocols to solve this problem. In ALOHA [2], each reader starts reading tags when it gets a request and retransmits if it collides. It is implemented easily, but the effectiveness is limited. In Color-wave [3], each reader chooses a random color (time slot) to transmit. If it collides, it selects a new color. It is simple and flexible, but it requires time synchronization. Also, it assumes readers can detect collisions that happen at tags, which may not be practical. Pulse [4] introduces a control channel. When a reader reads tags, it periodically broadcasts beacons through the control channel to prohibit reading of its neighbors. It mitigates collisions, but it cannot solve the hidden and exposed node problem. Further, beacon transmission consumes much energy. To solve these problems, DiCa [5] is proposed. Each reader contends the data channel with its neighbors by exchanging control packets. However, it needs sufficient time to exchange contention messages. RAC-Multi [6] considers the multi-channel environments. Reader randomly chooses an odd or even numbered data channel, and then sends beacons during reading like Pulse. It improves the reading throughput. However,

randomly selected channel may cause inter-channel interference. Also, periodical beacons consume plenty of energy. Moreover, immediate reading after channel selection may cause collisions.

In this letter, we improve RAC-Multi and propose a novel reader anti-collision mechanism called Multi-dimensional Channel Management (MCM) for multi-channel mobile RFID networks. The main idea of MCM is that a reader selects a channel with the maximum distance from used data channels instead of randomly selecting an odd or even numbered channel. MCM also provides a random backoff before channel acquisition to avoid collisions. Periodical beacon transmissions are omitted to reduce energy consumption. Simulation results show MCM outperforms the five other existing anti-collision mechanisms in the throughput, query efficiency, and energy efficiency.

2. Multi-Dimensional Channel Management Reader Collision Avoidance Mechanism

In this section, the proposed mechanism for multi-channel mobile RFID network is described after a mathematical analysis.

2.1 Mathematical Analysis

For RFID communications, international standards suggested the use of a frequency between 860 MHz and 960 MHz [1]. In Korea, a frequency ranging from 908.5 MHz to 914 MHz with 25 channels of 200 KHz bandwidth each was standardized for mobile RFID networks (908.5–908.75 MHz and 913.75–914 MHz are used for protection). The spectral mask of a channel transmission should follow the values shown in Fig. 1 [1].

To understand some properties of the reader collision

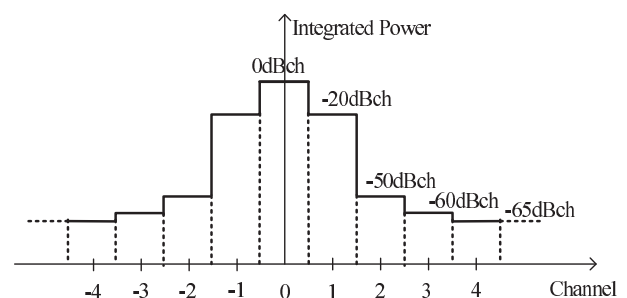


Fig. 1 Spectral mask of a channel transmission.

Manuscript received January 18, 2011.

Manuscript revised May 18, 2011.

[†]The author is with Electrical Engineering, Korea University, Korea.

^{††}The author is with the Faculty of Electrical Engineering, Korea University, Korea.

a) E-mail: suhaoru@dsys.korea.ac.kr

b) E-mail: sunshin@dsys.korea.ac.kr

DOI: 10.1587/transinf.E94.D.2280

problem, a simple situation can be considered. Given two readers i and j , the distance between them is d_{ij} . Tag t locates in the read range of reader i , which has a distance d_{it} from reader i . Reader i uses channel m . Reader j uses channel n . The spectral mask of channel m and channel n is SM_{mn} . In a backscatter communication system, SNR based on power must meet a required threshold $R_{required}$, which is decided by the tag encoding method and BER desired.

For reader i , the following must hold for successful tag detection if we ignore the thermal noise

$$\frac{P_{ri}}{I_{ji}} \geq R_{required} \quad (1)$$

where P_{ri} is the backscatter power from tag t , I_{ji} is the interference caused by reader j at reader i . P_{ri} can be calculated in terms of the reader transmission power P_{ti} , the path loss from reader to tag and back PL_{iti} , and the power ratio R_{act} to activate the tag as follows.

$$P_{ri} = P_{ti} \times PL_{iti} \times R_{act} \quad (2)$$

The path loss PL_{iti} can be evaluate by

$$PL_{iti} = K_1 / d_{it}^{4q} \quad (3)$$

where K_1 simplified presents the reader and tag antenna gains, modulation indexing and wavelength. The parameter q is the path loss exponent. Interference caused by reader j at reader i is given as

$$I_{ji} = P_{tj} \times PL_{ji} \times SM_{mn} \quad (4)$$

where P_{tj} is the transmission power of reader j , PL_{ji} is the path loss from reader j to reader i . PL_{ji} can be calculated by

$$PL_{ji} = K_2 / d_{ij}^{2q} \quad (5)$$

where K_2 presents the constant properties such as antenna gains of two readers, and wavelength.

From the above formulae, given the transmission power and the distance from reader i to tag t , we can get the minimum distance (d_{ij-min}) between reader i and reader j to avoid the reader collision, which is known as the interference distance.

$$d_{ij-min} = \left(\frac{K_2 \times P_{tj} \times R_{required} \times SM_{mn}}{P_{ti} \times PL_{iti} \times R_{act}} \right)^{1/2q} \quad (6)$$

From (6), we can see that when the distance of channels used by two readers is larger (spectral mask is smaller), the interference distance is shorter. Based on the calculation in [6], when the distance between the reader and tag is 1 m, the interference distance is 28.7 m for the same channel while 7.7 m for adjacent channels.

2.2 Multi-Dimensional Channel Management

We assume that omni-directional antennae are used in multi-channel mobile RFID system and collision is the only cause of failed reading. The basic concept of MCM is that we let

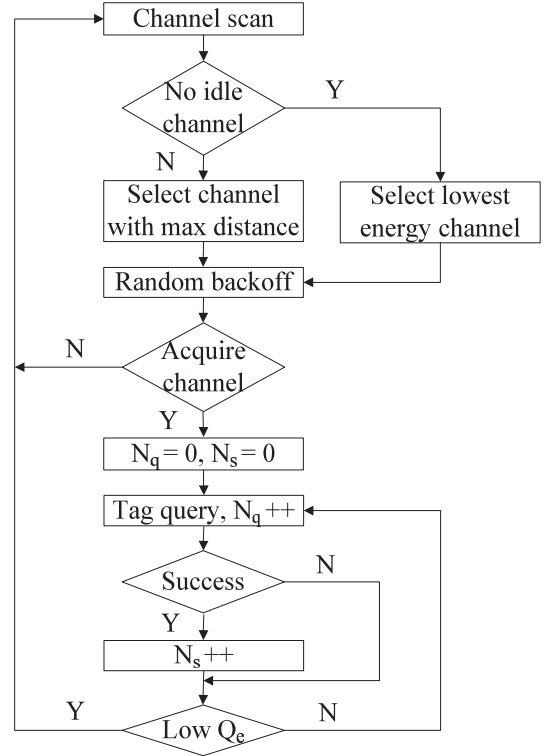


Fig. 2 Flow chart of MCM mechanism.

one channel be reserved as a control channel that all readers can share with. We also use one channel of separation between the control channel and data channels for protection. When a reader joins the network, it broadcasts a control message to ask which data channels are used. It selects one data channel with the maximum distance from the used channels. If there is no idle channel, it chooses the channel with lowest energy. Before channel acquisition, readers wait a random backoff time for avoiding the collision occurred by joining the same channel at the same time. After channel acquisition, readers begin to read tags. If the query efficiency is lower than a threshold value, the reader changes its data channel through executing the channel scan procedure again.

Figure 2 shows the flow chart of MCM mechanism. First, when a reader joins the network, it executes the channel scan procedure. It broadcasts a control message to recognize which channels are being used. If there is more than one idle channel, the new reader will select the clean channel which has the maximum distance with the used channels. If all the channels are used, it selects the channel with lowest energy since the probability of collision on this channel is much lower than other channels.

The proportion of used channels is defined as the channel utilization (U). It can be calculated by

$$U = N_u / N_t \quad (7)$$

where N_u presents the number of used channels, N_t is the total channel number. After one channel is selected, the reader performs a random backoff algorithm for protecting the col-

lision with other readers occurred by joining the same channel at the same time. However, if the backoff window size is unnecessarily large, it could be inefficient. It is calculated by using U as

$$BWS = \text{Round}(MAX_B - MIN_B) \cdot U + MIN_B \quad (8)$$

where BWS is the Backoff Windows Size. MAX_B and MIN_B represent the maximum and minimum value of BWS . BWS is defined as a cardinal number between MAX_B and MIN_B .

If the reader is successful when trying to acquire the selected channel, it begins to read tags. Otherwise, it scans the channel again. After a reader gets a data channel, it sets its number of queries (N_q) and number of successful queries (N_s) to zero. When the reader begins to read tags, it starts counting the N_q and N_s , and then calculates the query efficiency ($Q_e = N_s/N_q$). If the current query efficiency is lower a threshold value, the channel is considered to be causing interference with other readers frequently. In this case, the reader will scan the channels again and find another available data channel.

3. Performance Evaluation

We evaluate the performance of MCM through a series of simulations using NS2. We tested the protocols in a field of 10m×10m area, in which 400 tags were randomly distributed. The number of readers varied from 8 for sparse to 44 for dense case. The movement of a reader followed a random waypoint mobility model with the speed of 1 m/s, which reflects the movement of a person's walking. The application packets arrived with an exponential inter-arrival time t having an average value of 50ms throughout the simulation time of 60s. The aforementioned frequency (908.5 MHz–914 MHz) with 25 channels was used. The spectral mask was set according to the standard [1]. The sizes of control packets and data packets were set to 2 Bytes and 10 Bytes, respectively. The threshold value to find a new channel was set to 0.8. The simulation results are averaged with 50 experimental repetitions. Table 1 describes the values of power and time parameters for the simulation.

MCM was compared with ALOHA, Colorwave, Pulse, DiCa, and RAC-Multi in terms of three performance metrics: throughput, query efficiency, and energy efficiency. The throughput (Thp) is defined as the number of successfully sent queries per second as follows:

$$Thp = \frac{\sum_{i=1}^n Q_s(i)}{T} \quad (9)$$

where $Q_s(i)$ is the i th successful query, T is the total time. The query efficiency (Q_e) is denoted as the percentage of all queries that were successfully sent, as follows:

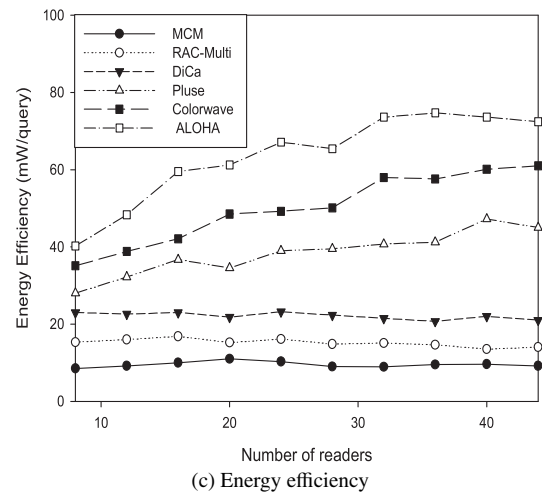
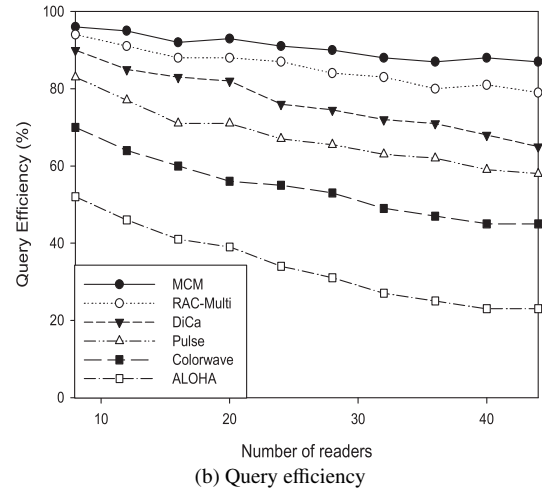
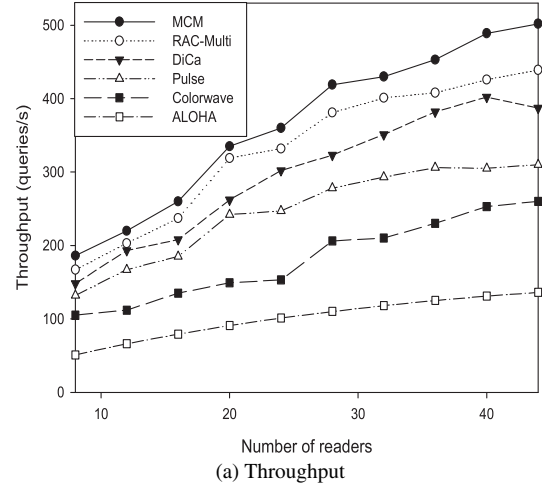


Fig. 3 Simulation results.

Table 1 Power and time parameters.

Parameter	Value
Power of transmission	52.2 mW
Power of receiving and listening	56.4 mW
Power of reading	1.5 W
Time to Tx/Rx a byte	32 μ s
Time from reader query to tag response	93.75 μ s
Time from tag response to reader query	93.75 μ s
Time between queries	75 μ s
Time to switch channel	0.2 ms

$$Q_e = \frac{\sum_{i=1}^n Q_s(i)}{\sum_{j=1}^m Q(j)} \quad (10)$$

where $Q(j)$ is the j th query. The energy efficiency (E_e) is defined as the energy required sending a query, which can be calculated by

$$E_e = \frac{E_t}{\sum_{i=1}^n Q_s(i)} \quad (11)$$

where E_t is the total energy consumption.

Figure 3(a) shows the throughput varying with the number of readers. ALOHA has the worst performance because it does not have any collision avoidance. Colorwave shows lower throughput since the time slots are underutilized in a distributed time slot mechanism. Pulse achieves better performance through control message exchange among readers. DiCa improves it by solving the hidden node problem. RAC-Multi advances the throughput because it considers the inter-channel interference. MCM has higher throughput since it lowers the probability of inter-channel interference by using a better channel selection method and random backoff before channel acquisition. Figure 3(b) illustrates the query efficiency. An improvement in query efficiency means a reduction in the number of collisions, which is related to the throughput. MCM shows better performance for the above reasons. The energy efficiency with respect to the number of readers is presented in Fig. 3(c). ALOHA shows low performance due to the large number of collisions and unnecessary transmissions. Pulse has better performance than Colorwave since it reduces the collisions. It consumes more energy than DiCa due to the exposed terminal problem and periodical beacon transmissions. DiCa shows worse energy efficiency than RAC-Multi since it transmits lots of contention messages. Periodical beacon transmissions incur that RAC-Multi needs more energy than MCM.

4. Conclusion and Future Work

In this letter, we proposed a Multi-dimensional Channel

Management (MCM) mechanism for multi-channel mobile RFID networks in order to solve the reader collision problem. In MCM, when joining the network, one reader scans the used channels and selects one channel with the maximum distance from the used channels or lowest energy. Random backoff before channel acquisition is used to avoid collisions. The performance of MCM is better than five other existing mechanisms according to the simulation results. However, when readers move frequently or move with high speed, frequent channel switching will decrease the performance. This problem should be solved in future works.

Acknowledgments

This research was supported by the MKE, Korea, under the ITRC (Information Technology Research Center) support program supervised by the NIPA (National IT Industry Promotion Agency) (NIPA-2011-c1090-1121-0001).

References

- [1] EPC Radio-Frequency Identity Protocols Class-1 Generation-2 UHF RFID Protocol for communication at 860 MHz-960 MHz Version 1.1.0, Dec. 2005.
- [2] N. Abramson, "The ALOHA system: Another alternative for computer communications," *Proc. Fall Joint Computer Conference*, pp.281–285, 1970.
- [3] J. Waldrop, D.W. Engels, and S.E. Sanna, "Colorwave: A MAC for RFID reader networks," *Proc. IEEE Wireless Communications and Networking Conference (WCNC)*, pp.1701–1704, New Orleans, USA, 2003.
- [4] S. Birari and S. Iyer, "PULSE: A MAC protocol for RFID networks," *Proc. EUC Workshops 2005*, LNCS 3823, pp.1036–1046, 2005.
- [5] K. Hwang, K. Kim, and D. Eom, "DiCa: Distributed tag access with collision-avoidance among mobile RFID readers," *Proc. EUC Workshops 2006*, LNCS 4097, pp.413–422, 2006.
- [6] K. Shin and W. Song, "Rac-multi: Reader anti-collision algorithm for multichannel mobile rfid networks," *Sensors*, vol.10, no.1, pp.84–96, 2009.