An Efficient MAC Protocol for Throughput Enhancement in Dense RFID System

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Abstract

In dense radio frequency identification (RFID) system, reader collision problem is bottleneck of overall system performance. In this paper we propose a distributed multi-channel reader anti-collision MAC (ACMAC) protocol to mitigate the reader collision problem. The proposed probability based channel selection approach helps selecting channel efficiently and reduces the waiting time and beaconing method solves the hidden and exposed node problem. Also, channel utilization probability based random backoff mitigates the collision possibility in the control channel. Simulation results show our protocol is energy efficient and gives higher network throughputs than the existing MAC layer protocol in RFID.

1. Introduction

Recently, there has been an increasing interest of several major supply chain, logistic, security and medical inventory companies in RFID system deployment. RFID provides a quick, flexible and reliable way to electronically detect, track and control a variety of items [1]. Fig. 1 shows an RFID system that consists of a RFID tag reader (commonly called RFID reader), a tag and backend system. The reader transmits a high power continuous wave (CW) to energize the passive tag that does not have an on board energy supply. The tag receives the energy and transmits the stored data by back-scattering communication with the reader. The data received from the tag is processed in the backend database system. Tags can be passive, semi-passive or active, depending on their functionality. Most commodities are equipped with low functionality passive tags. In conventional systems, a single reader is sufficient to read multiple tags within the interrogation zone. However, readers in the RFID system are becoming mobile and the stationary readers are becoming more functional. So, depending on the application and workload, we may need data from multiple readers simultaneously to provide a high tag read rate with higher accuracy of multiple tags streaming into the reader's interrogation zone. When a number of readers are deployed in a predetermined place they form a dense reader environment. These new advancements in RFID system came up with new challenges in RFID deployment.

Multiple readers in dense reader environment may try to access the same tag at the same time. The passive tags lack the frequency tuning circuitry, therefore in denser reader environment collision problem is highly prevalent. This causes degradation of performance of RFID system.

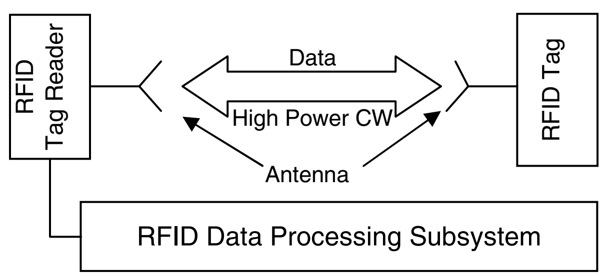

Fig. 1. Basic RFID operation.

When two or more mobile readers come into close proximity to each other, they may try to read the same tag at the same time and in the same frequency band and this may lead to collisions. This type of collision is called reader–to–reader collision. On the other hand, readers–to–tag collisions occur when a tag hears multiple readers' queries at the same time. In such a situation, the tag might not be able to respond to any reader at all. Both types of collisions, reader–to–reader and readers–to–tag, are called reader collision problem in RFID. In Fig. 2, the two readers, R_1 and R_2, are in the same workplace. When both readers R_1 and R_2 try to read tag T_1 at the same time, neither of them is able

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to do so. The reader collision problem is more serious in mobile dense RFID system.

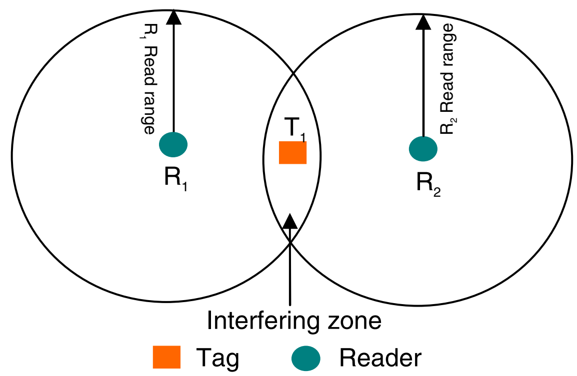

Fig. 2. Readers-to-tag collision.

The rest of this paper is organized as follows. Related previous works are surveyed in section 2. The proposed protocol is described in section 3. Simulation results and performance evaluations are discussed in section 4. Finally, conclusion and future works are given in section 5.

2. Related works

Listen-Before-Talk (LBT) is multiple access scheme based on CSMA scheme. This is standardized as ETSI EN 302 208 [2] and is developed for the RFID. In this standard, readers must listen ongoing transmission before accessing the channel. If the channel is idle, reader starts reading tags, otherwise it waits for certain time. However, only by carrier sensing, reader collision problem cannot be solved completely.

The Colorwave reader anti-collision algorithm [3][4] is a distributed TDMA based RFID reader anti-collision algorithm. In Colorwave, each slot is allocated with a different color. The readers in the network randomly choose color ranges from [0, Maxcolors]. The reader with a queued request for transmission can transmit data in its color timeslot. Colorwave enables the RFID system to easily adapt to local disturbances based on local information, such as the installation of the new readers or the presences of the mobile readers. However, the Colorwave requires the firm time synchronization between the readers. In the wireless mobile reader environment, the overhead of time-slot reselection continuously increases that waste resources.

Pulse [5][6] is a notification mechanism based protocol that attempts to solve the reader collision problem using two separate channels for the data and control packets in the RFID system. It works similar to the CSMA mechanism. Pulse mitigates the reader collision problem by continuously transmitting the beacon in the control channel. In this protocol beacon can collide with another beacon form another reader. Additionally, other readers have to wait until the current reader finishes the communication with tags. Waiting time may increase exponentially if the number of readers want to communicate are large in dense RFID environment.

The Distributed Tag Access with Collision Avoidance (DiCa) [7] is similar to pulse protocol. It implies a distributed and energy efficient collision avoidance algorithm. As in pulse, DiCa also has data channel and control channel. Each reader contends through control channel and the contention winner reads tags through data channel and other wait until the channel is idle. DiCa requires sufficient time to exchange the contention message. It tries to prevent the collision after it takes place rather than acting actively at the first sight. So, it does not reduce the collision problem efficiently.

HiQ-learning [8] based on reinforcement learning [9][10] presents online learning algorithm in hierarchical network architecture. HiQ gives solution to the reader collision problem by learning collision patterns of readers and assigning frequencies to the readers over time. The main drawback of this approach is that it requires additional managements in overall hierarchy even with a slight change in lower layer. So, in the highly mobile environment management overhead increases exponentially. Further, time synchronization is another overhead in this protocol. It uses the timeslots and all the readers to be synchronized.

The multi-channel MAC protocol (MCMAC) [11] is a contention based MAC protocol for RFID systems. In MCMAC, there are N-1 number of non-overlapping data channels with the same bandwidth and a control channel. Similar to the Pulse protocol, the control channel is a sub-band of the RFID spectrum and is only used for reader-to-reader communication. Readers can communicate simultaneously with the data channel and control channel. MCMAC works in a similar manner to the conventional LBT. MCMAC broadcasts a control message after it wins contention in a control channel and gains access to the data channel. The control message informs other neighboring readers within the interrogation zone that this particular channel is occupied for a certain time. After receiving a control message from a neighboring reader, the other readers do not use that channel for a certain period of time and try to gain access to another channel.

3. Reader anti-collision algorithm

In this section we propose a distributed multi-channel reader anti-collision MAC (ACMAC) protocol. We assume that there are N = $\{c_1, c_2, \ldots, c_n\}$ number of data channels and a control channel. Data channels are for the readers-to-tag communication and control channel is for the reader-to-reader communication. Readers can transmit control signal through the control channel while communicating with tags through the data channel. We only consider the reader side because tags do not contribute any role in reader collision problem.

In ACMAC, each reader listens before talk as in conventional LBT. The reader want to start communication enters into the Listening Stage (LS) for T_L time to win contention in a particular data channel. In the LS, if the reader receives any beacon message (in the control channel) from any of neighboring readers, it determines that the data channel is not idle. Now, it selects a backoff counter within contention window (CW) and wait until it becomes zero.

On contrary, if reader in LS does not receive any beacon message within T_L time, it enters in the Waiting Stage (WS) and waits for T_w time. T_w time is similar to the DIFS in 802.11. In the WS, if reader receives beacon message, the reader has to decide whether to wait in the same channel until that channel gets free or hop to another idle channel based on probability based channel selection algorithm. We discuss probability based channel selection in the section 3.1.

If the reader does not receive any beacon message in WS, the reader broadcasts the beacon message to the neighbors in the control channel and occupies the data channel. After broadcasting beacon message, reader waits for T_w time and starts communication with tags in the data channel. Fig. 3. shows the flowchart of working principle of ACMAC.

To avoid the possible collisions due to accessing the control channel by multiple readers at the same time we use random backoff mechanism. This mechanism transmits data after waiting the random amount of slot within backoff windows slot. Each node that wants to communicate should contend the control channel with random backoff. They select a backoff counter within a contention window (CW). CW start from the minimum value (B_{min}) initially and the counter is decremented. If the control packets collide in control channel with the packets from neighbor nodes, both of the colliding nodes increase their CW size multiplying by two. The reader that with the lowest slot size can occupy the channel and other nodes freeze the counter until next contention period.

The backoff windows slot can be calculated as follows

$$B_t(i) = \frac{pkt\_size}{Tx} \times U_t(i) + B_{\min} \quad (1)$$

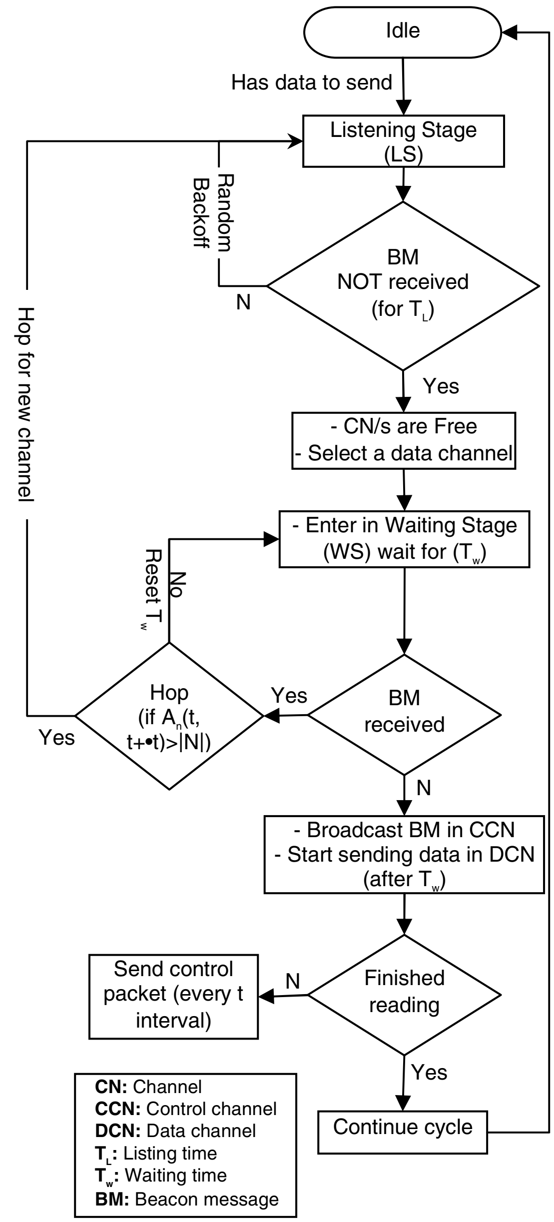

Fig.3. ACMAC working principle.

Where, B_{min} is a minimum backoff time, Tx is packet transmission rate and U_t denotes the channel utilization. ACMAC uses the linear historical prediction model to update the utilization of channel i for the next time slot t.

$$U_t = (1-\alpha)\, U_{t-\Delta t} + \alpha\, U_t \quad (2)$$

Where, $U_{t-\Delta t}$ is the channel utilization of last time slot t-Δt by channel i. U_t is the instantaneous utilization of channel. The average utilization of channel for t+Δt time can be calculated as

$$U_t(t, t+\Delta t) = \frac{1}{\Delta t}\int_t^{t+\Delta t} U_t dt \qquad (3)$$

3.1 Probability based channel selection

Let $A_n(t, t+\Delta t)$ be the available channels during the time interval (t, t+Δt) and it can be calculated as

$$A_n(t, t+\Delta t) = n[1 - U_n(t, t+\Delta t)] \qquad (4)$$

If a number of readers in the same interrogation area try to access the same channel at the same time collision occurs. The probability to win the channel access depends on the density of the readers in the reader's interrogation area. If the number of readers is greater than the channels available, the probability to gain access in the channel is less. In this case, waiting in the current channel is not efficient. If the number of channels are more than the number of readers at any time it may not be efficient to wait in the same channel. To make a decision on the basis of density of the readers is an estimable way to decide either to hop for new channel or just wait in the same channel, we calculate reader density by $d = |N|/c_i$. Where, |N| is number of readers residing in the same interrogation area, which can communicate with each other. c_i is the number of data channels available.

If $A_n(t, t+\Delta t) > |N|$, hopping is better than waiting in the same channel. If $A_n(t, t+\Delta t) < |N|$, the probability of getting ideal channel with hopping is relatively low. Thus, waiting in the same channel is better than hopping for new channel.

While reading data in data channel sometimes reader may not hear ongoing communication in control channel. It may cause collision whenever it tries to access in control channel. This problem is called multi-channel hidden terminal problem. To solve this problem in ACMAC, a reader does not communicate for at least T_h time in any other channel rather than it just used before.

4. Simulation results and performance evaluation

In this section we evaluate ACMAC and compare with the existing anti-collisions. In our simulation module readers are distributed by poison distribution. The T_L time is 15ms, channel switching time is 0.1ms, T_w time is 0.5ms and maximum period of continuous transmission is 4s. There are 4 channels and readers are chosen randomly. All the readers are homogeneous having radio range of 30 meters.

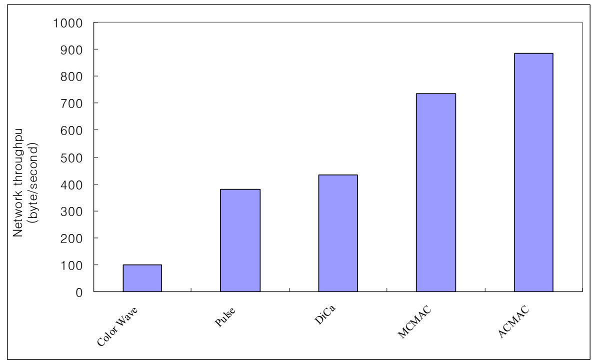

Fig. 4: Network throughput.

We selected Colorwave as a single channel protocol, Pulse and DiCa as a multi-channel (one data and one control channel) protocol, and MCMAC as a multi-channel (one control and multiple data channel) protocol for comparison. Fig. 4 shows the network throughput comparison. ACMAC has significantly higher throughput as compare to the existing single and multi-channel protocols. As it makes channel hopping decision on the basis of probability to get access in to the channel, it utilizes channels efficiently and fairly, thus gets higher throughput.

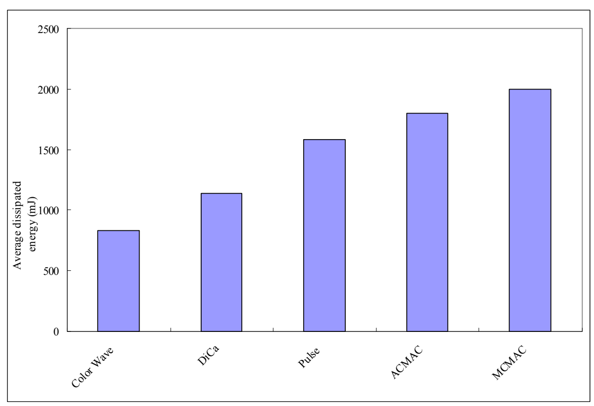

Fig. 5: Average dissipated energy.

In Fig. 5, we compare average dissipate energy of existing protocols including ACMAC. Energy consumption is slightly higher in ACMAC than other protocols except MCMAC because ACMAC use notification mechanism and is a multi-channel protocol. Pulse and DiCa have high energy consumption as compare to their throughput with ACMAC. However, ACMAC consumes higher energy than single data channel protocol but it consumes lower energy than multi-data channel protocol (i.e. MCMAC). MCMAC is a similar approach to ACMAC but it hops channels without considering probability to get channel, hence consumes more energy.

5. Conclusions and Future work

We presented a distributed MAC layer protocol for the dense RFID system to enhance throughput. This protocol not only mitigates the reader collision problem but also gives solution to the conventional hidden terminal problem and multi-channel hidden node problem. Simulation result shows, this protocol is more efficient than existing RFID reader anti-collision MAC protocols, hence is suitable for the wireless mobile RFID system. It would be applicable to a variety of RFID network configurations, under different traffic loads and characteristics. Real testbed evaluation for the mobile RFID system with sensor network is the future work.

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