A Multi-channel Based Reader Anti-collision Protocol for Dense RFID Environments

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Abstract. With the recent developments in Internet of things, RFID is getting more and more attention. In the dense RFID environment, reader collision occurs when some readers potentially interfere with the operation of others, and cannot correctly communicate with tags, which will limit the performance of RFID system. As we know, the tag collision has been widely discussed, but the reader collision has not received as much attention in the past few years. In this paper, we propose a novel multi-channel based reader anti-collision protocol (MRAP), which is suitable for dense RFID environments, to solve the reader collision problem. Based on the connected matrix and the distance between any two readers, we design the principle to confirm channel and communication timeslot for each reader. Using multi-channel, a new communication process is generated, in which the irrelevant readers can communicate with tags simultaneously, even in the same channel. The simulation and performance analysis results show that our protocol can achieve better performances than previous protocols in enhancing system throughput and system efficiency.

Keywords: Reader anti-collision protocol · Multi-channel · RFID · Pulse

1 Introduction

Radio frequency identification (RFID) is a perception processing technology in the Internet of things, which is widely used in several trades, such as traffic, logistics, security, etc. The routine RFID system is composed of many readers and tags. The tags are always passive, so they do not have an ability to distinguish the different frequency from the readers. The tag memories can be read in the read range of readers. A reader can choose the number of tags which it plans to communicate by adjusting its read range. In some applications, the dense RFID environment consists of many readers, in which some potentially reader interferences occur and the relevant readers cannot correctly communicate with tags. This is called the reader collision problem. As we know, the tag collision has been widely discussed, but the impact of reader collision has not been fully explored in the past few years. Each reader has the read range and interference range respectively. The reader collision problem can be divided into two cases: reader to reader collision and reader to tag collision. The two cases should be avoided in normal communication.

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(1) Reader to reader collision: Due to the power limit, the responses of tags are easy to be affected by the close readers at the same time and frequency, which means readers can affect the communications of other readers with tags in their interference range.
(2) Reader to tag collision: If a tag is located in the overlap reading region among more than one reader, it cannot respond the interrogations from several readers when they read it simultaneously. Because it is too simple not to distinguish the frequency from the different readers.

The Pulse [1, 2] has two channels, one of which is used to communicate with readers, another is used to read tags. Song et al. [3] propose a slot occupied probability (SOP) protocol based on Pluse, which can effectively decrease the number of collision timeslot by choosing unused timeslot. The above two protocols do not use multiple data channels, the performances of which need to be improved. In paper [4], the channels are divided into odd and even channels, in which the odd ones is used first. The system throughput is not optimal using this method to allocate channels. Meguerditchian et al. [5] use two control channels, from which distinguishes the same timeslot or the same frequency, but it does not consider the case that the two collisions occur simultaneously.

In this paper, we propose a novel reader anti-collision protocol (MRAP) based on the Pulse protocol, which has one control channel and several data channels and is very suitable for dense RFID environments. The number of the data channels is decided by the number of readers. To allot the multiple channels, we design a connected matrix of readers in which the unconnected readers should be arranged in the same channel. It is better for solving the reader to reader collision. By the distance of any two readers, we define a method to further confirm channels and communication timeslots for every reader, and give the relationship between the number of channels and backoff time delay [1]. Using the above method, we define the detail communication process to avoid the collision in dense reader model, in which the uncorrelated readers can share the same timeslot in the same channel, but the connected readers do not have the same timeslot to communicate with tags, even if they belong to the different channels. To prove it, we take a concrete application for example. The simulation and performance analysis results show that our protocol outperforms previous protocols in the system throughput and system efficiency even in a highly dense network.

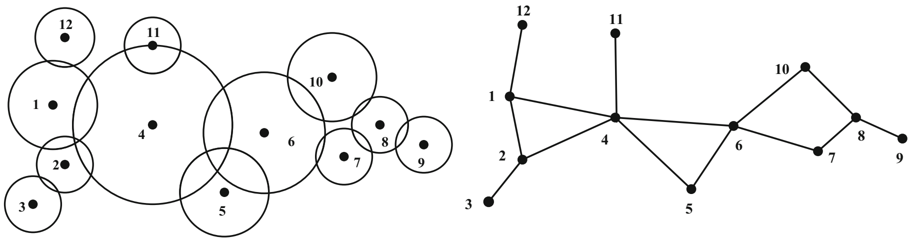
2 Assumption and Principle of Using Multiple Channels

2.1 Choosing Channel by the Connected Matrix of Readers

A graph $G = (V, E)$ is used to indicate the reader collision model, where the V expresses the vertices of the graph and the E expresses the connections between any two vertices called edges [7]. In reader collision model, $V = \{R_1, R_2, \ldots, R_n\}$ is the set of readers in which n is the number of readers, and $E = \{e(R_i, R_j)\}, i, j \in 1, 2, \ldots n$ is the set of edges connecting two readers R_i and R_j, if they have a communication overlapped region. If two readers are connected by a direct edge, they will possibly interfere with each other leading to either reader to reader collision or reader to tag collision.

The symmetric matrix $D = \{d_{ij}\}, i,j \in 1,2,\ldots n$ with size n × n is constructed to describe whether any two readers in RFID system will potentially interfere with each other. In the graph of reader collision model $G = (V,E)$, if $e(R_i, R_j) \in E$, then $d_{ij} = 1$, else $d_{ij} = 0$.

The situation of interference between any two readers is described in Fig. 1(a). Suppose the circle surrounding a reader is its read range, so the situation of connection among readers is showed in Fig. 1(b).



(a) situation of interference (b) situation of connection

Fig. 1. Reader collision in dense RFID reader environment

Suppose the interference range of reads is not considered, the unconnected readers should be arranged in the same channel or the same timeslot when the value of their corresponding edge is $d_{ij} = 0$, since that case can avoid interfering with each other.

If the reader has many choices for choosing its data channel, it will choose the channel with the biggest frequency distinctions among its connected reader channels, which can reduce the interference range between the two connected readers [4].

2.2 Further Confirming the Channel and Timeslot by the Distance Between Other Readers

Reader to reader collision occurs when a tag responds an interrogation interfered by another reader, which can be solved by using the different channels. Reader to tag collision occurs when one tag is located in the overlapping interrogation region of more than one reader, which can be solved by using the different timeslots. The different timeslots can be represented as the different backoff time delays [1], which prevent the relevant readers from communicating with tags simultaneously. However, the appearance of collisions is different from the variance of the distance between two readers, by which we will further confirm the channels and timeslots for the different readers. Suppose that the readers are expressed as $R_i, i \in 0,1,2,\ldots,n$, where r_i is the read range and I_i is the interference range of the reader R_i. Then we define $D(R_i, R_j)$ as the distance between the reader R_i and the reader R_j. Taking Fig. 2 for instance, the concrete conditions can be described as follows:

(a) If $D(R_i, R_j) < r_i + r_j$, the reader R_i and the reader R_j can be arranged in the different channels, then choose the different timeslots. There is a potential for reader to reader collision and reader to tag collision simultaneously.
(b) If $r_i + r_j < D(R_i, R_j) < max\{I_i, I_j\}$, the reader R_i and the reader R_j can be arranged in the different channels, then choose the different timeslots. There is a potential for reader to reader collision and reader to tag collision simultaneously.
(c) If $max\{I_i, I_j\} < D(R_i, R_j) < max\{r_i + I_j, r_j + I_i\}$, the reader R_i and the reader R_j can be arranged in the same channel, then choose the different timeslots. There is only potential for reader to tag collision.
(d) If $D(R_i, R_j) > max\{r_i + I_j, r_j + I_i\}$, the reader R_i and the reader R_j can be arranged in the same channel, then choose the same timeslot. There is no potential for reader collision.

The potential for reader to reader collision and reader to tag collision can also be solved by choosing the different timeslots, but the unconnected readers can use the same timeslot in the different channels or the same channel, which can effectively enhance the system throughput and improve the system performance.

Choosing the different channels can reduce the interference range between two readers. It is because that the interference signal strength of adjacent channels is reduced by spectral mask [5].

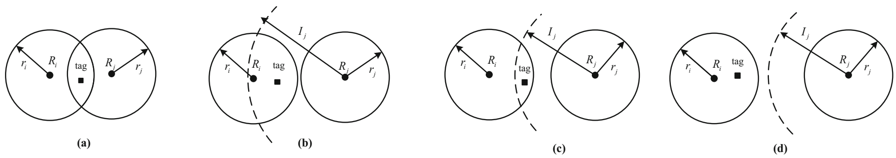


Fig. 2. The distance between two readers

3 MRAP Protocol

The proposed distributed protocol MRAP, is based on Pulse protocol [1, 2]. There are one control channel and several data channels. A reader will periodically broadcast a beacon signal on the control channel, when it is reading tags. The beacons which belong to the irrelevant readers can transmit on control channel. If a reader wants to communicate with tags, it will sense the control channel for the beacon of its relevant readers first. During a period of time, the reader does not sense any relevant beacon, which means it can start communicating with tags on its data channel.

The communication range of control channel is larger than that of data channels. We can suppose that the maximum of the control communication range is expressed as $max\{I_i + r_j\}$, $i, j \in 0, 1, \ldots, n$, which can be achieved by enhancing the transmit power. Perhaps two readers can communicate on the control, but they interfere with each other on their data channel. The control channel is special and independent of the RFID spectrum. Any communication on the control channel does not affect the normal communication on data channels.

Our protocol is present at the reader, which can transmit signal on both control channel and data channel simultaneously. The communication between readers is executed on the control channel and the communication between reader and tags is executed on the data channels.

We depict the method of how to confirm data channels and timeslots for readers, which can be used in the process of the MRAP protocol. It is assumed that the power of a beacon signal is boosted enough to be received by all of neighboring readers.

- On the basis of the connected matrix of readers, corresponding $d_{ij} = 0$, the irrelevant readers can be found. Using the principle of choosing channels (2.A), the reader can confirm which channels can be chosen.
- According to the distance information sent from other relevant readers and the principle (2.B), the reader can further confirm an optimal channel from the available channels and a timeslot which should be different among the relevant readers.

The process of MRAP protocol is described as follows:

- *Waiting* State: Every reader which wants to read tags must sense the control channel first. If a reader does not receive *beacon_i* signal from the relevant readers $R_i(i \in \textit{relevant readers})$, which means other relevant readers are not communicating with tags at that time, it will star its *Waiting State*. We define T_L as the length of timeslot. If a reader does not receive any beacon corresponding to its relevant readers during the thrice T_L time, it will star its *Contend State*. Otherwise it will continue to wait.
- *Contend State*: In this state, the reader must choose a delay of backoff time (*backoff_delay*) to prevent the readers from reading tags simultaneously. If the reader does not receive the information for *backoff_delay* from other relevant readers, and the previous *backoff_delay* is equal to zero, it will choose a random backoff time and broadcast it. Otherwise the reader will avoid choosing this backoff time received from others. When the previous *backoff_delay* is not equal to zero, the reader should resume previous *backoff_delay* and broadcast it. If a relevant beacon signal is received by the reader during the period of backoff time delay, it will return to the *Waiting State*. If the *backoff_delay* is over, the reader will enter the *Communicate State*.
- *Communicate State*: The reader can communicate with tags in this state, and it must periodically send a beacon on the control channel to keep the control of the data channel. If the communication between reader and tags is finished, it will return to the *Waiting State*. When the application queue is empty, it will enter the *Idle State*.
- *Idle State*: In this state, there is no message to transmit in either control channel or data channels, which means the system is idle.

Normally, the value of *backoff_delay* is decreased in the *Contend State*. When the relevant beacon is received, the value of *backoff_delay* will be stopped, and will be restarted as long as the control channel is idle again.

4 Simulation Experiments

4.1 Simulation Scenarios

To simulate the performance of the MRAP protocol, we assume the simulation scene as following. The data channel frequency is defined as the range from 860 MHz to 960 MHz, in which control channel frequency is 930 MHz. The transmission power of readers is −45 dBm. The read range and interference range on data channel is 1.62 m and 7.1 m respectively. The sensing range on control channel is 5.4 m. The data is sent between readers and tags by 2 Mbps. To better display the function of our protocol, it will remove some unnecessary effect, such as interference between two channels, path loss and fade, etc. The collision is the only reason leading to packet loss.

- The simulation field is a $10\,\text{m} \times 10\,\text{m}$ area, in which 400 tags is evenly distributed at an interval of 0.5 m.
- All the readers are fixed and randomly distributed in the simulation field. We will run the simulation 100 times in the different cases, then compute the average from them.

We assume the simulation time is 60 s and the interval of sending a packet is 0.5 ms. We use the same readers to take part in the experiment, and the number is 4, 9, 16, 25, 36, 49 and 64 respectively.

4.2 Results of Simulation and Analysis

We assume the number of channels should be varied with the different number of readers. When $n = 4$, the number of channels is 1. When $n = 9$ or 16, the number of channels is 2. When $n = 25$ or 36, the number of channels is 3. Finally, When $n = 49$ or 64, the number of channels is 4. We will compare our protocol with the previous protocols, such as CSMA [8], Colorwave, and Pulse.

The system throughput can be increased as a sign that the read rate is being enhanced. The increased system efficiency indicates that the ability of readers finding and eliminating the collisions is improved. We will show that the MRAP protocol is more effective in both dimensions than previous protocols by simulations.

(1) System Throughput

The system throughput comparing with the different protocols at $n = 25$ is shown in Fig. 3. Figure 4 shows the system throughput with varying number of readers.

In Fig. 3, even though the throughput of pulse is up to a saturation point of $n = 25$, it is still lower than our protocol. It shows the proposed protocol is not affected by the increasing number of readers, because it has more than one channel used to transmit. The number of channels will increase with an increase in the number of readers.

From Fig. 4, we can see that the system throughput of Colorwave is the lowest, because the timeslots randomly chosen to communicate are underutilized. We find the curve rising with an increase of the reader scale, which is due to the increase of utilization with more readers. CSMA suffers from the hidden terminal problem, so the system throughput is lower. As the number of readers increases, the throughput of it

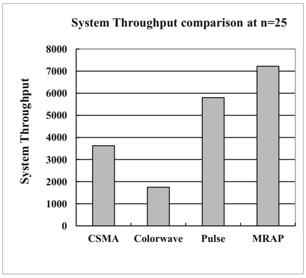


Fig. 3. Throughput comparing with the different protocols at n = 25

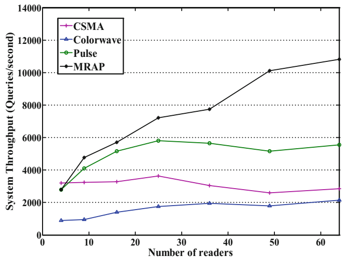


Fig. 4. Throughput comparison with varying number of readers

does not rise, so it is unable to fit for dense networks. In Pulse, the beacon signal is sent on the control channel when the data channel is being used, so the unnecessary collision can be avoided. It has the higher throughput compared with CSMA. Our Protocol has many data channels which can be used in transmitting signals to tags simultaneously. It avoids collisions by using the different timeslots between any relevant readers, so the system throughput is highest. With the increasing number of readers, the curve of our protocol keeps rising, the property above is more obvious. The proposed MRAP protocol is very fit to perform in dense reader environment.

(2) System Efficiency

The system efficiency comparing with the different protocols at $n = 25$ is shown in Fig. 5. Figure 6 shows the system efficiency with varying number of readers.

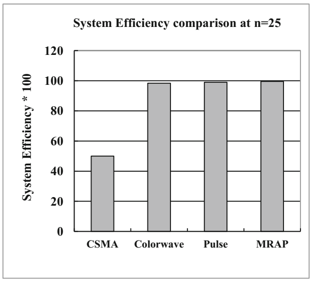


Fig. 5. Efficiency comparing with the different protocols at n = 25

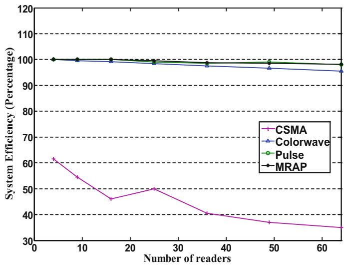


Fig. 6. Efficiency comparison with varying number of readers

In Fig. 5, the number of readers is 25, which is a saturation point for Pulse, but the efficiency of our protocol is still the highest one. It is because that the number of readers is less than the saturation point in a single channel, by which the process of the proposed protocol is more simple and effective. The collisions can be reduced by using the different channels to the relevant readers.

From Fig. 6, we can see that the system efficiency of CSMA is the lowest. When the number of readers increases, it continues decreasing. It is because the increasing number of hidden terminals. In spite of low throughput, the efficiency of Colorwave is higher than CSMA. In Pulse, the beacon is used to remove the effect of the hidden terminal, so its efficiency is in the middle. The successful transmission rate of all protocols decreases with the increasing number of readers. The proposed protocol is highest because it has many data channels which can be used in transmitting signals to tags. The number of readers in a single channel is less than Pulse which takes all readers in one channel, so its efficiency is higher than that of Pulse. With the number of readers increased, the characteristic is more obvious.

5 Conclusion

We describe a novel reader anti-collision protocol MRAP based on pulse by using multiple channels, which is suitable for large scale RFID systems. We propose the principle to confirm the channel and communication timeslot for each reader, which can increase the utilization of channels. During the novel process of communication to avoid collisions, we solve the problem of how to use the different channels and timeslots between the relevant readers, in which the irrelevant readers can enjoy a same timeslot in the same channel, but the relevant readers do not have a same timeslot to communicate with tags, even if they belong to the different channels. It can reduce the reader collision effectively and increase the efficiency of data transmission. The simulation and performance analysis results show that our protocol can achieve better performance than the existing protocols in terms of increasing system throughput and system efficiency. Based on the comprehensive analysis and comparison, our protocol can be used in applications requiring dense RFID environments.

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