Hindawi
Security and Communication Networks
Volume 2023, Article ID 9857028, 1 page
https://doi.org/10.1155/2023/9857028

Retraction

Retracted: An Improved Approach for Reader Anti-Collision in Industrial Internet of Things

Security and Communication Networks

Received 26 December 2023; Accepted 26 December 2023; Published 29 December 2023

This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] H. Qian, "An Improved Approach for Reader Anti-Collision in Industrial Internet of Things," *Security and Communication Networks*, vol. 2022, Article ID 1268577, 6 pages, 2022.

Hindawi
Security and Communication Networks
Volume 2022, Article ID 1268577, 6 pages
https://doi.org/10.1155/2022/1268577

Research Article

An Improved Approach for Reader Anti-Collision in Industrial Internet of Things

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Received 17 November 2021; Revised 10 March 2022; Accepted 12 May 2022; Published 27 May 2022

Academic Editor: Jian Su

Radio-frequency identification (RFID) technology has been used in numerous applications, e.g., supply chain management and inventory control. This paper focuses on the practically important problem of reader-to-reader collision in large-scale RFID systems. There are many technical challenges during the existing work such as high computational complexity and low identification efficiency. To tackle the above challenges, this paper proposes a novel reader anti-collision protocol optimized by minimal reverse weight (NRA-MRW), which includes two phases. Extensive simulation results show that our proposed NRA-MRW can improve the identification efficiency and system throughput over the existing protocols by 25.2% and 12.3%, respectively.

1. Introduction

Radio-frequency identification (RFID) technology has been widely deployed to monitor objects in the supply chain. Due to a decrease in the price of tags, RFID is increasingly used in many applications, such as real-time inventory control [1–5] and product tracking [6–9]. A simple RFID system consists of a reader, antennas, and a number of tags. The reader sends the continuous waves to tags, which include operation codes and specifying PHY/MAC parameters. When the tag is activated, it will backscatter a message or keep silent according to the reader's command. However, in these large-scale scenarios, tags are densely deployed in the RFID systems, and the single reader is unable to cover the coverage of such large-scale system. Therefore, multi-reader identification mode (MRIM) is introduced. MRIM refers to the deployment of multiple readers in a large-scale scenario to cover all tags and launches the identification process simultaneously for the purpose of improving the identification efficiency [10]. In MRIM, to avoid tag missing problem, the coverage ranges of readers overlap each other, which will introduce a new challenge—reader-to-reader collision (R2Rc). In this case, due to the strong transmit power of a reader, its interference signal will reach the identification field of other readers, so that the tags in the identification field of the reader cannot communicate with the reader normally. With the increase in the distribution density of readers deployed in the RFID system, the collision of readers will be more obvious. The R2Rc underestimates the tag populations due to the missing reading caused by communication failure, while a multi-coverage tag may be counted multiple times with distinctive readers. Such reader-to-reader collision leads to the degradation of system throughput and increase of identification delay. Although many RFID industry standards allow readers to operate at different operating frequencies in an attempt to mitigate the reader collision problem, in some RFID reader dense environments, there may not be enough frequency channels to avoid all potential reader collisions. Therefore, many researchers proposed corresponding anti-collision methods for readers to solve this problem. It is worth noting that there is another kind of collision in large-scale RFID systems, which is called multi-tag collision. Multi-tag collision, also called tag-reader collision, occurs when multiple tags are excited by the reader and send data to the reader at the same time. This problem is often seen when the reader needs to identify multiple tags in a short period of time. There are also some researchers who specialize in this problem [6, 7, 9]. However, this kind of collision problem is beyond the scope of this paper.

The mainstream approaches to cope with the R2Rc issue can be divided into three categories, namely, power regulation-based reader anti-collision protocol, scheduling-based reader anti-collision protocol, and shared information-based reader anti-collision protocol [11]. In power regulation-based reader anti-collision protocol [12], the reader adjusts the transmitting power to change its coverage range in order to avoid the collisions. However, in the scenario that a large number of tags are widely distributed in the system, the coverage ranges of readers may overlap with each other. If the reader adjusts its own transmitted power to avoid R2Rc, the direct consequence is that many tags will be missed. The scheduling-based reader anti-collision protocol can be further divided into time-domain scheduling and frequency-domain scheduling [13]. The working principle of the time-domain scheduling method is to divide the time into slots to avoid collisions. On the contrary, in the frequency-domain scheduling method, the reader transmissions are allowed to transmit into different subchannels with different frequency domains. When the R2Rc is severe, the scheduling-based method will run multiple rounds of scheduling, which will consume a lot of time slots and cause overall performance degradation. The information sharing-based reader anti-collision protocol assigns the corresponding control channel for the reader, and each reader exchanges information on this channel. Similarly, the R2Rc becomes more serious in large-scale scenarios, and the reader will consume many slots. With the vigorous development of the Internet of Things technology, RFID is installed in almost any occasion, such as large supermarkets, warehouse, and so on, in which R2Rc is one of the critical issues affecting the system efficiency. Therefore, it is necessary to design an efficient reader anti-collision protocol in large-scale RFID systems.

Therefore, we propose a novel reader anti-collision protocol optimized by minimal reverse weight (NRA-MRW), which combines the advantages of power regulation-based reader anti-collision protocol and scheduling-based reader anti-collision protocol. Firstly, the transmitted power is adjusted based on minimal reverse weight to minimize the collisions between the readers. Secondly, the time-domain scheduling strategy between readers is carried out. The contribution of this paper is summarized as follows.

(1) We combine the power regulation and time-domain scheduling strategies and simplify the system collision model.

(2) In the reader power regulation phase, the minimal reverse weight is used to determine the optimal transmitted power combination.

(3) The concept of collision threshold is introduced to further simplify the system collision model and allow more than one readers to work simultaneously.

2. Related Works

Many researchers presented the corresponding work to cope with the R2Rc issue. The authors in [14] proposed a probability-based query tree (PBQT) protocol. In PBQT protocol, the conflict identification and useless identification can be avoided via the shared information between the readers. A collision arbitration protocol for multi-channel readers was presented in [15], which uses different control channels and data channels to alleviate R2Rc. However, the reader needs to constantly broadcast the identification messages to neighboring readers during data communication process. The authors in [16] presented a reader collision arbitration protocol, namely, PQT. In PQT, all tags are divided into many subsets before they are identified. The PQT optimizes the number of total slots to achieve the highest identification efficiency. A multi-channel R2Rc arbitration protocol is presented for sparse RFID environment. In [17], a distributed method was adopted to avoid the extra hardware costs for centralized control. The authors in [18] proposed an improved reader anti-collision solution, namely, DPCCPSO. An efficient collision avoidance protocol called EMRCA protocol was proposed in [19]. The reader distance and collision type were analyzed, and the selection principle of data channel was put forward. There are some reader-scheduling schemes [20, 21] which were proposed to resolve the issues of R2Rc and multi-coverage tags, and their time efficiency is far from optimal because none of them makes use of the tag category distribution characteristics. In [22], the authors proposed a maximum-weight-independent-set-based algorithm (NWISBA) to tackle the reader-coverage collision avoidance arrangement problem. The NWISBA can allow the reader to adjust its coverage.

In summary, the above methods can improve the performance over the traditional reader-to-reader collision arbitration protocols. However, in reality, the R2Rc is more complicated. The current reader collision protocols consider all collision situations when designing, so they will consume a lot of resources and take up a longer identification time. In this paper, we present a solution based on minimal reverse weight. The concepts of reverse weight and collision threshold are introduced to simplify the collision situation between the readers.

3. The Proposed NRA-MRW Protocol

Considering the complicated collision phenomena in multi-reader scenario, a novel reader anti-collision protocol optimized by minimal reverse weight (NRA-MRW) is proposed in this section. The proposed NRA-MRW includes two important phases: collision simplifying and parallel working. In collision simplifying phase, first, when the tag set is completely covered by multiple readers, the power combination of all distributed readers can be derived through the tree search method. Second, we compute the reverse weight of each reader combination. Specifically, if the collision probability of a reader combination is the least, the weight of the combination is named as the minimal reverse weight. Third, we set a predefined value as a collision threshold, and collisions below the threshold are ignored. In parallel working phase, first, we calculate the number of collisions between each reader and other readers. According to the calculation result, the priority of each reader is calculated. Second, the reader with highest priority can be

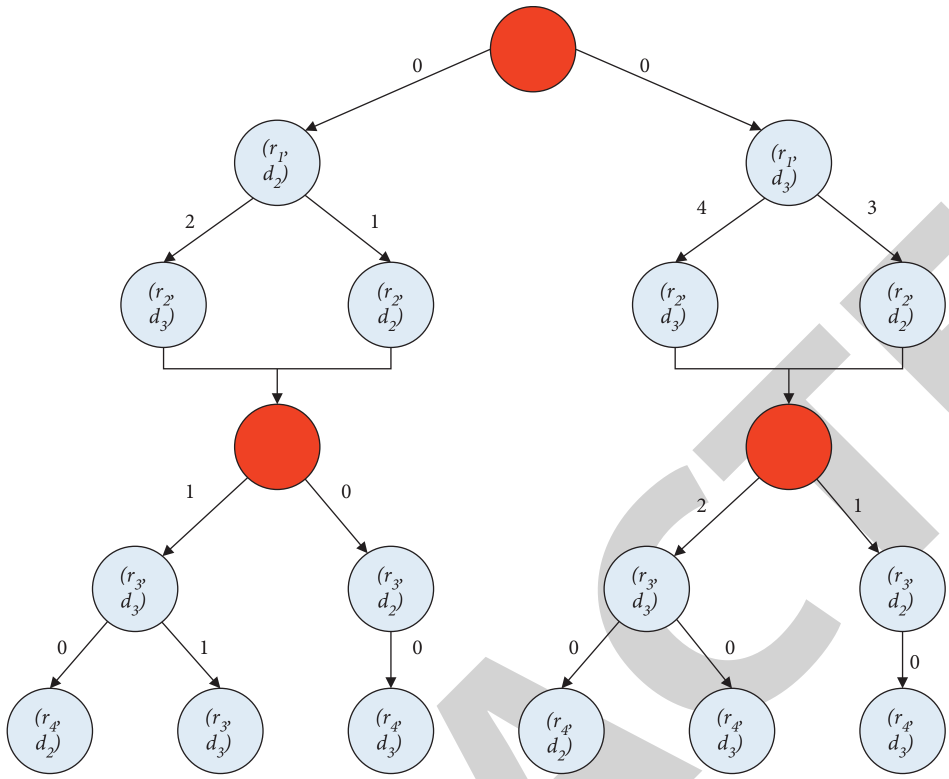

Figure 1: Traversal tree of reader combination.

viewed as a first node in a traversal tree. The proposed protocol can traversal the whole tree and reduce the collisions during the traversal process. When all readers are identified, the protocol is terminated.

3.1. Minimal Reverse Weight Calculation. Generally, in a large-scale RFID system, there are several readers and a large number of tags. Assume that each reader has m recognition ranges. At any time, the reader can only select one of the radii (corresponding to recognition range) for communication, which depends on its own transmitting power setting. Suppose there are N readers and M tags in the RFID system, and the coverage range of each reader has m outcomes. The reader combination can be viewed as a traversal tree structure as illustrated in Figure 1. As can be seen from Figure 1, each solid line from root node to the leaf node denotes an available reader combination, and the number in each line represents the number of collided tags involved in two readers. It is noted that the tree structure can be generalized to a M-ary tree. In Figure 1, the transmitting power of r_3 reader will be affected by r_1 and r_4, and has nothing to do with the r_2. In other words, no matter how the transmitting power of the reader r_2 is set, the subsequent combination is the same. The white node is used to represent a child node. Assume M, L, and G denote the number of combination methods, leaf nodes, and gray nodes, respectively. In the proposed combination method, M can be written as

$$M = L \times (G - 1). \quad (1)$$

We define the weight value of collisions between readers as inverse weights, which is expressed as

$$\psi = \alpha \sum S + \beta \sum X, \quad (2)$$

in which S represents the overlap area between different readers' coverage and α represents the weight proportion value of S. When considering all collision possibilities, β denotes the weight proportion value of X. When $\beta = 2\alpha$, the collision probability of readers can be the lowest.

To calculate the overlap area S, we need to determine the reader's receiving power. First, we set a control channel for r_i, and then r_i sends a fixed prefix on the control channel in turn before launching tag identification process. If other readers successfully receive the message transmitted by r_i, it means that the coverage between the readers overlaps. The overlapping area can be determined by receiving power at the reader side. The receiving power at the tag side can be calculated as

$$P_R = P_T \frac{G_T G_R \lambda^2}{(4\pi l)^2}, \quad (3)$$

where P_T is the transmitting power of a reader, G_T is the antenna gain, G_R is the path loss at free space, and λ is the wavelength. The message exchange between the readers is the same.

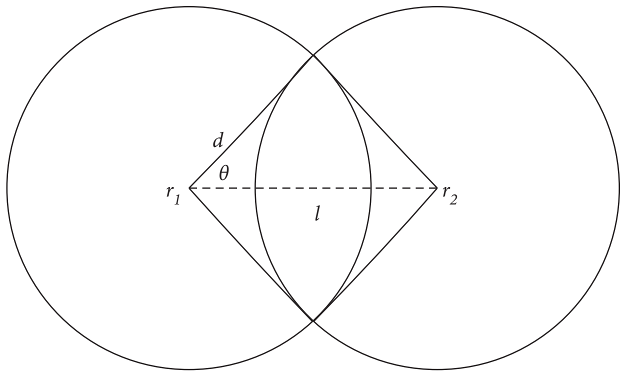

Figure 2: The overlapping area of readers' coverage.

$$l = \frac{\sqrt{P_T G_T G_R \times \lambda}}{4\pi \sqrt{P_R}}. \quad (4)$$

The overlapping area of readers' coverage is illustrated in Figure 2. As can be seen, d is the coverage radius of r_1 reader, l is the distance between two readers, and θ represents half of the center angle of the circle, which is written as

$$\theta = \arccos \frac{l}{2d}. \quad (5)$$

The area of the left sector is

$$S_{ls} = \frac{\theta \pi d^2}{180}. \quad (6)$$

The overlapping area of reader's coverage is expressed as follows.

$$S = 2\left(S_{ls} - \frac{l}{2} \sin\, \theta \times d\right) = 2S_{ls} - \sin\, \theta \times d. \quad (7)$$

Then, the reverse weight of individual power combination is determined by formula (7), and the combination with the smallest reverse weight is the optimal strategy.

3.2. The NRA-MRW Algorithm. The flowchart of our proposed NR-MRW algorithm is described in Figure 3. First, the system computes the inverse weights, and the power of each reader is set by the minimal reverse weight. It is assumed that when the power setting is finished, the readers' distribution can be determined. The time-domain scheduling is launched based on the priority of the reader. Firstly, the reader whose priority is the highest will be randomly selected as the first node, tracing the readers in the system, and the collision-free readers are identified as a group. It is noted that our proposed algorithm ignores many collision cases with small collision area. The benefit is that the complexity of whole system can be reduced and the implementation of our algorithm can be further simplified.

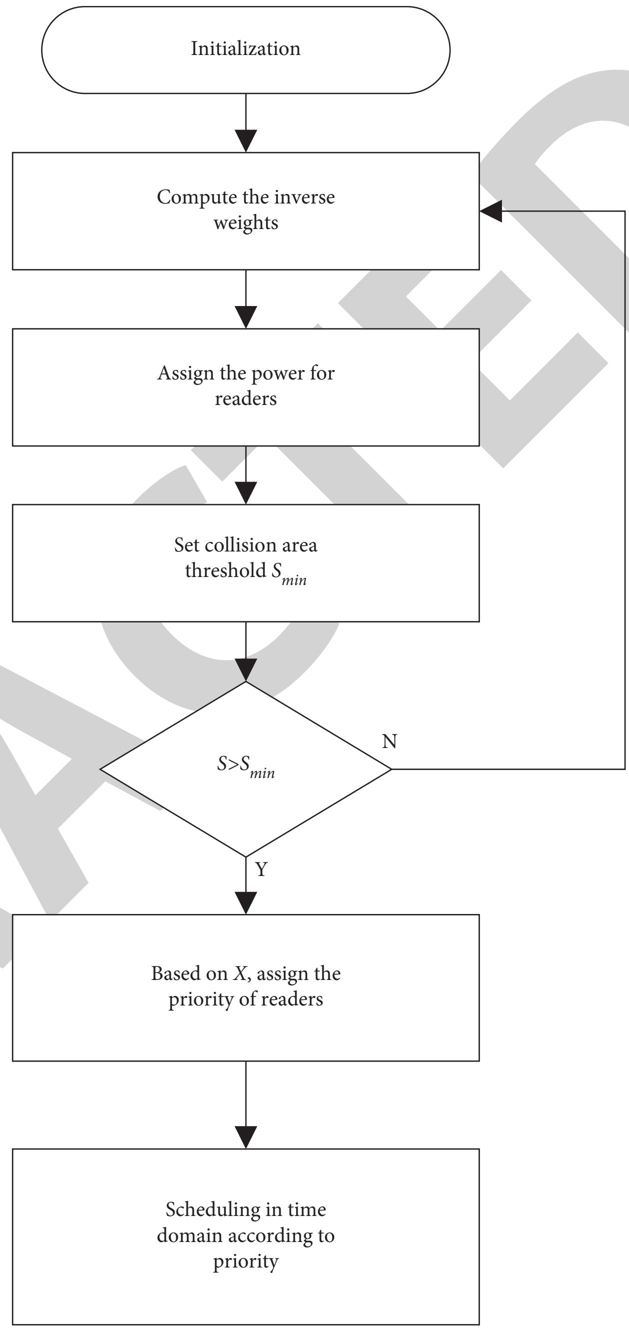

Figure 3: The flowchart of the proposed NR-MRW algorithm.

4. Performance Evaluation

In this section, we perform Monte Carlo simulations with MATLAB to verify the effectiveness of our proposed NRA-MRW. In our simulations, the number of readers is from 0 to 500 and the number of tags varies from 200 to 10000. We consider that the readers and tags are evenly distributed in 200×200 square area. In the system, a centralized server is mainly used for time synchronization and to broadcast commands to the reader. The radius of the server is set as $R = 100$ m, and the maximal identification radius of the reader is $r = 6$ m. We compare the performance of our proposed NRA-MRW to other algorithms including PQT, MWISBA, and multi-channel algorithm in two situations: small-scale scenario and large-scale scenario. To achieve the fair comparison and obtain the convergence results, simulations are averaged by 1000 times referring to the previous work [23, 24].

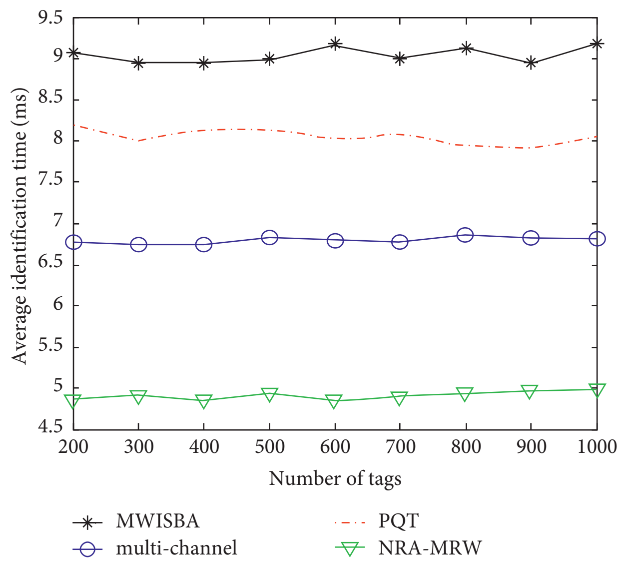

Figure 4: Simulation result comparison: average identification time in small-scale RFID system.

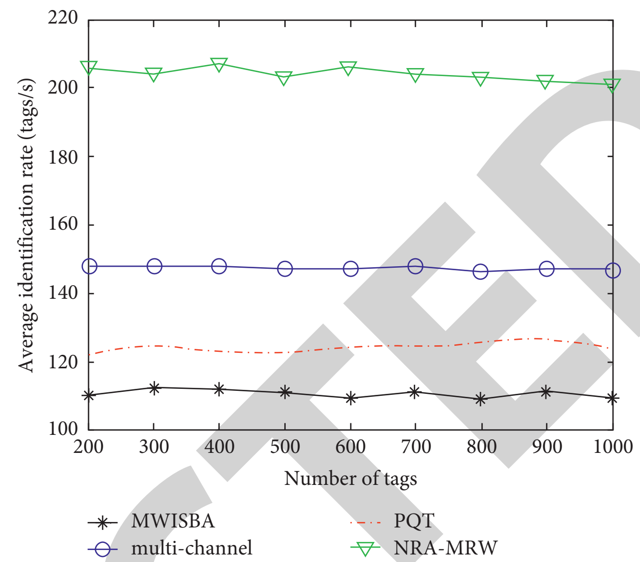

Figure 5: Simulation result comparison: average identification rate in small-scale RFID system.

In small-scale scenario, the number of readers is from 0 to 20 and the number of tags is from 200 to 1000. Both the reader and tags are densely distributed in a 50×50 square area. It is assumed that all readers activate maximal identification range to cover the whole system. We evaluate the performance in two metrics: average identification time and average identification rate (number of tags can be identified per second). Figure 4 compares the total identification of various algorithms under small-scale scenario. Specifically, our proposed NRA-MRW achieves the best performance in terms of total identification time. As can be observed from Figure 4, it consumes averagely 4.85 ms to identify one tag. The performance ranking from the highest to the least is NRA-MRW, PQT, multi-channel, and MWISBA. The reasons are as follows. The reference methods need to be prepared in advance and the tags are evenly distributed in the system. The number of tags covered by a single reader is limited.

Figure 5 plots the average identification rate when the number of tags is from 200 to 1000. Similar ranking can be observed. The best performance results are still from NRA-MRW, PQT, multi-channel, to MWISBA. Specifically, identifying the same number of tags, the average identification rate of our proposed NRA-MRW is 204 tags/s, which is 85.4%, 38.7%, and 64.5% higher than that of PQT, multi-channel, and MWISBA.

In large-scale scenario, the number of readers is from 100 to 500 and the number of tags is from 1000 to 10000. Both the reader and tags are densely distributed in a 200×200 square area. It is assumed that all readers activate maximal identification range to cover the whole system. We evaluate the performance in two different metrics: system efficiency and communication complexity. In the large-scale scenario, the tags' distribution is dense, the identification range of the reader overlaps each other, the complexity of various algorithms increases, and the performance fluctuates.

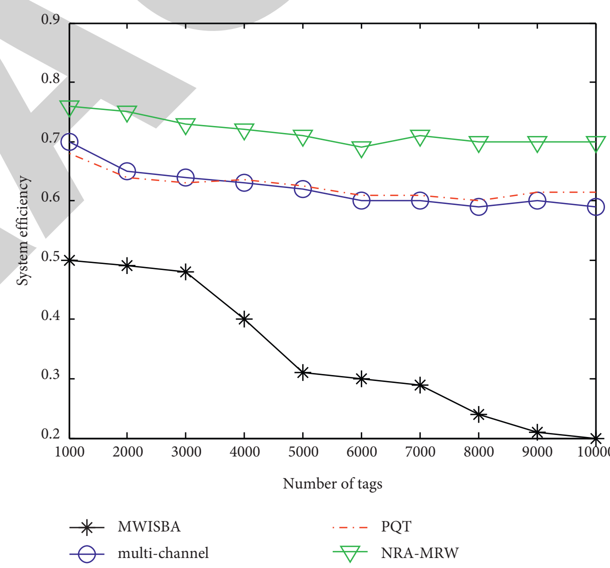

Figure 6: Simulation result comparison: system efficiency in large-scale RFID system.

Figure 6 compares the system efficiency when the number of tags varies from 1000 to 10000 in step of 1000. As can be seen from Figure 6, the performance ranking from the highest to the lowest is NRA-MRW, PQT, multi-channel, and MWISBA. Specifically, our proposed NRA-MRW can achieve the best system efficiency which peaks at 0.76 when the number of tags is 1000. In this paper, the system efficiency is defined as the ratio between the average identification time and the longest identification time to identify the same number of tags. As can be found from Figure 6, the average system efficiency of our proposed NRA-MRW algorithm is 0.717, which is 109.6%, 15.3%, and 14.5% higher than that of MWISBA, multi-channel, and PQT, respectively.

5. Conclusion

This paper proposed a reader-to-reader collision arbitration protocol (NRA-MRW) for both small-scale and large-scale RFID systems. NRA-MRW protocol utilizes minimal reverse weight to eliminate the invalid collisions and schedules the reader priority to improve the system efficiency. Also, the simulation results illustrate the superiority of NRA-MRW under various parameter settings compared with other scheduling protocols.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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