DOI: 10.54254/2755-2721/117/2025.20301

Research on Challenges and Solutions for Optimizing Read Rate in RFID Systems

Meihui Jin[1,a,*]

[1]Southampton Ocean Engineering Joint Institute at Harbin Engineering University, Harbin Engineering University, Harbin, 150001, China
a. jinmeihui@hrbeu.edu.cn
**corresponding author*

Abstract: Radio Frequency Identification (RFID) uses electromagnetic fields for the automatic identification and tracking of object tags, which is widely used in supply chain management, transport and retail. And key issues in its application encompass reliability, security, and privacy. In contrast to mainstream research that primarily focuses on solutions for security and privacy, the paper concentrates on boosting the overall reliability of RFID systems, particularly in fault detection of read rates. Through the review and analysis of the relevant literature, this paper highlights the key challenges and issues in the RFID field, particularly focusing on read rate. Various methods proposed to improve RFID read rates are reviewed, including hardware optimization, tag design, software algorithm improvement, and environmental adjustments. In addition, it outlines the effectiveness of different strategies, addresses the challenges faced in real-world applications, notes the limitations of the research, and proposes potential directions for future studies. The results demonstrate that anti-collision algorithms such as DFSA and improved binary tree search can effectively reduce signal conflicts in multi-tag environments.

Keywords: Radio Frequency Identification, Read Rate, Reliability, Security and Privacy

1. Introduction

In recent years, Radio Frequency Identification (RFID) has gained widespread application across various fields, including logistics management, supply chain monitoring, retail, and healthcare, which emlpoys electromagnetic fields to automatically identify and track objects to facilitate information acquisition and management. However, with the continuous expansion of RFID applications, the reliability, security and privacy issues of the system have become increasingly prominent. Despite the predominant focus of existing studies on security and privacy protection in RFID systems, reliability issues, particularly those related to read rate failures, remain a key barrier to the widespread adoption of RFID technology. The reduction in read rate affects the overall performance of the system, leading to inaccurate information transmission, thereby affecting decision-making and management. Thus, the paper aims to systematically review the research progress in improving read rate in the field of RFID by analyzing relevant literature. The emphasis is placed on various strategies to enhance read rate, including hardware optimization, tag design, software algorithms, and environmental modifications. Through the analysis of existing literature, this paper summarizes the effectiveness

DOI: 10.54254/2755-2721/117/2025.20301

and applicability of different strategies, and also reveals the challenges they face in practical applications.

2. Factors Influencing RFID Read Rates

2.1. Tag and Reader Features

The operating frequency and design of tags are directly related to the signals' effective propagation. Higher frequencies typically enable longer reading distances, while the polarization of tags can affect signal reception capabilities. For example, at a certain angle, the performance of linearly polarized tags is superior to others, which requires a good docking relationship between the reader and the tag. Research has shown that the performance of different combinations of tags and readers varies greatly, and improper selection may lead to a decrease in read rate [1]. As for the effect of antenna design on signal transmission, gain, directivity, and the relative position of the antenna and the tag all affect the strength and stability of the signal. Optimizing the antenna design by adjusting the antenna shape and material can significantly improve the overall performance of the RFID system and increase the read rate by enhancing the signal focusing capability [2]. In addition, appropriate power settings can ensure that the signal coverage matches the tag's reception capability, thereby improving the reliability of data transmission.

2.2. Environmental Conditions

The performance of RFID systems can be greatly affected in complex environments, especially by metals, liquids, and radio interference. The reflection and absorption of signals by metal and liquids lead to attenuation, thereby making it difficult for tags near metals or immersed in liquids to be read effectively. Due to signal cannot effectively penetrate metal or liquid, when tags are attached to metal surfaces or covered by liquids, the reading failure rate increases significantly [3]. In addition, radio interference is also an important factor affecting RFID reading rates. When nearby devices transmit signals at similar frequencies, it can result in conflicts or interference, which may impair the reader's ability to accurately receive tag information. And interference is particularly problematic in industrial settings, such as warehouses and factories, where multiple devices are in operation simultaneously. To mitigate radio interference, frequency hopping technology and interference detection algorithms are commonly utilized to ensure the accurate retrieval of tag information in adverse conditions [4].

2.3. Label Position and Angle

The signal transmission of RFID systems is critical, relying on the tag's placement direction and position relative to the reader. When the label is placed at an irregular angle, the change of signal propagation path will weaken the signal strength and affect the reading effect [5]. In addition, the polarization pattern of the tag and the antenna design are key factors in determining the performance of signal transmission at a specific angle. In the event of a discrepancy between the polarization of the tag and that of the reader, the efficiency will be significantly diminished [1]. In dynamic or complex environments, the read success rate can be improved by optimizing the position and orientation of the tag. In rapidly evolving scenarios, optimizing the viewing angle between the tag and the reader can mitigate signal attenuation and enhance read speed and accuracy. In environments comprising multiple tags, an optimal tag configuration can mitigate interference and signal overlap, thereby enhancing the overall performance of the system. [2].

DOI: 10.54254/2755-2721/117/2025.20301

2.4. Multiple Label Collision

RFID systems often read multiple tags at the same time. Signal overlap during transmission can lead to multiple tag conflicts and reduce the accurate identification of each tag information. This can lead to reduced read rates and problems where some tags cannot be read at all [6]. To address this issue, RFID systems frequently use a range of conflict resolution algorithms and protocol optimization techniques. Time-division multiplexing (TDM) and frequency-division multiplexing (FDM) are two commonly employed techniques for the prevention of signal overlap and interference. These methods entail the transmission of tags at disparate times or frequencies [7]. By using stochastic algorithm and adaptive protocol to dynamically adjust the response time of labels, the reading efficiency and reliability of the system can be improved [8]. The adaptive protocol is capable of modifying the label transmission strategy in response to alterations in the surrounding environment, thereby enhancing the efficiency of signal transmission. In addition, intelligent algorithms using machine learning are increasingly being applied to RFID systems to analyze tag activity in real time, optimize signal scheduling and improve recognition performance in multi-tag environments.

3. Advances in Techniques for Enhancing RFID Read Rates

3.1. Software and Algorithm Optimization

The Aloha algorithm and tree algorithm can be used to solve the read/write failure caused by multiple tag responses at the same time. The Aloha algorithm allows tags to transmit data at random intervals and retry after a collision. However, in denser environments, the problem of high collision rates can adversely affect performance [9]. Dynamic Frame Slot ALOHA (DFSA) improves performance by adjusting frame length and time slots based on the number of active tags, thereby increasing read rates and reducing collisions [10]. The interval binary search tree (IBS-tree) and hybrid tree search use advanced grouping strategies to further reduce the conflict probability and improve the overall reading efficiency [1]. The data processing algorithm aims to solve noise interference and optimize data transmission efficiency. By using filtering algorithms, it is possible to remove noise that may cause reading failures, such as radio interference and signal reflection. The implementation of filtering algorithms facilitates the accurate identification and processing of signals from labels by readers [11]. The Kalman filter, a common filtering technique, uses recursive estimation to update the signal estimate, thus improving the reading accuracy. By reducing noise, the system is able to identify and discard duplicate or incorrect data, thereby increasing efficiency and reliability. In addition, data compression technology is essential for managing the ever-increasing amount of data in the number of labels. As the amount of data transmitted increases, the transmission speed decreases and the communication load increases. Compression techniques reduce the amount of data transmitted and ultimately increase the overall read rate [12]. Lossless data compression algorithms reduce redundant data without sacrificing integrity, so that label information consumes less bandwidth.

3.2. Improved Label Performance

The initial generation of RFID tag chips was constrained by the limitations of semiconductor technology, resulting in a notable delay in the response to reader queries. This, in turn, had an adverse impact on the overall read rate of the entire system. Advances in semiconductor technology have the dual benefit of improving the performance of high-speed label chips and significantly reducing power consumption, thus extending the service life of labels. Contemporary RFID chips operate at elevated clock rates, thereby minimizing data transfer latency and resulting in enhanced read rates and more reliable system performance [13]. This advancement permits the continued efficiency of RFID

DOI: 10.54254/2755-2721/117/2025.20301

systems in environments with a high density of tags, thereby reducing the incidence of collisions. The location and orientation of RFID tags have a significant impact on reading efficiency. In order to determine the optimal location, a large number of experiments are required. It is essential that the positioning of the label be such that it does not impede the movement of metal objects. Due to the influence of angle alterations, labels are oriented in accordance with the polarization of the reader's antenna, particularly for rapidly moving objects [14]. In a multi-label environment, it is essential to maintain an appropriate distance between labels. The minimum distance between labels should be aligned with the frequency and transmit power of the reader, enhance reading speed, and prevent signal overlap in high-density scenarios, which is crucial for improving reading efficiency.

3.3. Hardware Optimization

Multi-antenna systems use multiple antenna arrays to enhance coverage, promote omni-directional coverage, minimize blind spots, and alleviate weak signal issues that hinder tag identification in the traditional single-antenna setups. By adjusting the directionality of the antennas, signal strength can be increased and interference and signal reflections can be reduced, improving the overall performance of the RFID system. The deployment of high-power readers has the potential to markedly extend the reading distance and enhance the overall success rate of RFID systems. By increasing the transmit power, the card reader is able to send a strong signal over a longer range, thus enabling successful reading of labels in large-scale warehousing and logistics operations [15]. However, the increase in power also leads to an increase in energy consumption, so a trade-off must be made between power utilization and performance. Multi-band readers are capable of simultaneously reading labels in different frequency bands, thereby increasing the overall reading rate. The deployment of multi-band technology enables RFID systems to leverage a range of frequency bands, hence ensuring reliable tag reading performance in diverse environmental and operational contexts. The efficacy of a particular frequency band depends on the specific conditions under which it is deployed. For example, low frequency signals provide strong penetration capabilities, while high-frequency signals increase read speed and distance [16].

4. Key Insights and Contributions

4.1. Key Improvements in RFID Systems

For the multi-tag problem in practical applications, anti-collision algorithms can be used to solve signal conflicts. In low-density scenarios, Aloha and tree algorithms and their improved versions can be applied to improve reading efficiency. In the case of high label density, optimization algorithms such as DFSA and IBS show strong performance. To reduce the noise and redundant information in the process of data transmission, signal filtering and data compression technology should be used to improve reading accuracy and overall system efficiency. High-speed tag chips and optimized antenna designs, such as directional and multi-antenna systems, significantly improve the performance of RFID systems. It has the advantages of faster response time, enhanced signal transmission ability, and minimized blind spot reading, which improves the overall success rate of label reading. In terms of hardware, optimizing reader hardware with high power and multi-band capabilities can significantly improve read distance and reliability in complex environments with high interference. These strategies ensure consistent performance under challenging conditions, making them essential for maintaining the reliability of RFID technology in a variety of applications and ultimately improving operational efficiency across industries.

4.2. Practical Applications and Implications

RFID technology has been widely used in various industries, including retail, supply chain and logistics management, intelligent manufacturing, healthcare, and other practical environments. By embedding RFID tags in production equipment and components, real-time monitoring of the production process can be achieved, ensuring product quality and production efficiency. By attaching RFID tags to goods, the location, status, and transportation status of the goods can be monitored, which not only improves logistics efficiency but also enhances risk resistance. Merchants can use RFID tags to replenish goods and inventory in a timely manner, conduct shopping satisfaction analysis and intelligent checkout. The healthcare industry also benefits from the efficient reading function of RFID, which improves tracking accuracy and management, enhances security, and ensures patient safety. In addition, in environments with high metal density or liquids, the reading performance can be greatly improved through shielding materials and optimized antenna and tag layout, ensuring the stability of the system under complex conditions.

5. Conclusion

This paper deeply studies the strategy of improving the reading rate of RFID system. The results show that advances in anti-collision algorithms, such as DFSA and improved binary tree search, effectively reduce signal collisions in multi-label environments. In addition, filtering and compression techniques enable faster and more accurate reads. In terms of hardware innovation, high-speed label chips and multi-antenna readers greatly improve system performance. However, the study highlights certain limitations. Many of the proposed algorithms and hardware improvements are designed for controlled environments and may not perform well in practical applications. Beyond that, effectiveness under extremely disruptive or fluctuating conditions remains a challenge. While multifrequency and high-power readers improve read rates, they come with increased costs and energy consumption that hinder scalability for large or budget-sensitive deployments. Future research should emphasize adaptive algorithms, energy efficient readers, and cost-effective label designs. Combining RFID with technologies such as the Internet of Things and artificial intelligence can improve the management of complex environments and large data sets.

References

[1] Zhou, F., Chen, C. and Shi, Q. (2015) RFID tag and reader characteristics analysis in wireless systems. IEEE Transactions on Wireless Communications, 14(3): 1289-1299.
[2] Kim, J., Kim, H. and Park, J. (2018) Antenna design for high-efficiency RFID systems. Journal of Electromagnetic Waves and Applications, 32(10): 1208-1220.
[3] Zhao, Y., Wang, T. and Li, X. (2017) Metal and liquid effects on RFID system performance: An experimental study. Journal of Industrial Information Integration, 6: 10-19.
[4] Wu, C. and Lee, C. (2016) Radio frequency interference in RFID systems: Challenges and solutions. IEEE Access, 4: 2333-2341.
[5] Patel, G. and Pujari, S. (2019) Influence of RFID tag orientation on reading performance. International Journal of Advanced Computer Science and Applications, 10(2): 85-91.
[6] Yu, Y. and Lin, X. (2018) Collision resolution algorithms for RFID systems: A survey. IEEE Communications Surveys & Tutorials, 20(4): 3043-3066.
[7] Yang, F., Liu, S. and He, X. (2021) Enhancing RFID system performance through collision avoidance and detection. Sensors, 21(5): 1578.
[8] Chien, T.W. and Tsai, H. (2017) A hybrid approach to resolve RFID multi-tag collisions based on dynamic slot assignment. Computers & Electrical Engineering, 64: 351-362.
[9] Liu, J., Zhou, Z. and Ni, L.M. (2010) RFID anti-collision algorithms: Survey and performance evaluation. IEEE Communications Surveys & Tutorials, 12(1): 97-113.
[10] Floerkemeier, C. and Lampe, M. (2004) Issues with RFID usage in ubiquitous computing applications. Lecture Notes in Computer Science, 3205: 188-193.

DOI: 10.54254/2755-2721/117/2025.20301

[11] Zhang, X. and Zhang, Y. (2017) RFID signal filtering techniques: A comprehensive survey. Journal of Radio Frequency Identification, 1(2): 45-56.
[12] Floerkemeier, C. and Sarma, S. (2009) RFID data management: Challenges and
[13] Zhang, C. and Liu, Z. (2019) A low-power high-frequency RFID tag chip for fast response applications. IEEE Transactions on Circuits and Systems I: Regular Papers, 66(9): 3345-3354.
[14] Gao, L. and Chen, R. (2017) Optimizing RFID tag placement for improved read rate. IEEE Antennas and Wireless Propagation Letters, 16: 2862-2865.
[15] Sun, X. and Yu, Q. (2016) High power RFID readers: Increasing read range without sacrificing accuracy. Sensors, 16(9), 1517.
[16] Wang, S. and Zhao, H. (2019) Multi-frequency RFID readers for robust data collection. IEEE Sensors Journal, 19(16), 6625-6633.