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# The Performance Analysis of RFID Anti-collision in ISO/IEC 14443 Type B Protocol

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**Abstract—**For multiple random accesses, a significant limitation lies in low throughput attributed to channel contention. The primary source of latency manifests during the contention phase, underscoring the imperative task of reducing delay times. Real network access collisions arise when two or more packets are concurrently transmitted, necessitating the resolution of contention when implementing a protocol in wireless data networks. In this paper, we leverage the concepts of elimination and dynamic tree expansion within RFID anti-collision protocols of ISO/IEC 14443 Type B. The objective is to diminish delay times and bolster throughput. Analytical results indicate that the application of the tree elimination algorithm notably enhances performance, particularly when the number of tags substantially exceeds the available slots from the RFID reader.

***Index Terms—***RFID, anti-collision, throughput, mean delay time, tree elimination algorithm

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## I. INTRODUCTION

The scheduling problem under consideration revolves around a cost criterion, specifically the sum of flow time or completion times within a system where all packets receive service. The system involves a single server, akin to the RFID reader in an RFID network, processing packets with associated processing times. These packets are generated by tags in the RFID network [1-3], with an active tag defined as one having packets to transmit.In the context of a queuing network, a stochastic or dynamic process can be viewed as a scheduling problem. Flow time, representing the average time difference between a packet entering and departing the system, is a crucial performance metric. When dealing with bandwidth sharing in random access network communication, the system's performance, encompassing throughput and mean delay time, and system stability become critical. The network infrastructure must be developed with limited bandwidth to optimize throughput, minimize mean delay time, and ensure stability, especially concerning time-constrained sources.

In a scheduling system, the system probabilistically generates an ordered sequence of packets, subsequently processed by the RFID reader after accumulating and scheduling information from all packets. Scheduling problems are typically specified in terms of access environments (protocol), packet characteristics, and optimality criteria. The schedule allocates or shares a pre-existing resource to process these packets, particularly in a random access network where independent, geographically distributed tags use a common channel to communicate with the reader.

For operating a multiple access network, active tags share a common access channel to transmit packets. Collisions occur when two or more active tags attempt simultaneous transmission. To meet quality of service and time constraint requirements, the RFID reader must organize the retransmission of colliding packets, ensuring every packet is eventually transmitted successfully with finite delay. The collision resolution algorithm not only determines the transmission process's behavior but also influences the packet's delay time until successful transmission, while maintaining multiple access scheme efficiency for maximum traffic rate.

ISO/IEC 14443 consists of four parts [4-7], defining two card types, A and B, operating under the 13.56MHz radio frequency. The main differences lie in modulation schemes, coding schemes [5], and protocol initialization procedures [6]. Regardless of type A or B, the transmission protocol defined in [7] is employed. The transport protocol specifies data block exchange and related mechanisms, including data block chaining, waiting time extension, and multi-activation. Proximity Coupling Device (PCD) and Proximity Integrated Circuit Card (PICC) are integral to ISO/IEC 14443.

Non-preemptive scheduling, as applied to RFID anti-collision of ISO/IEC 14443 Type B, entails a task that cannot be interrupted before determining the transmitted packet's successful reception or failure by the RFID reader once execution begins. The scheduling, in this case, is list scheduling, where the sequence of served tasks is ordered through repeated scans.

In the pursuit of minimizing the system's flow time, equilibrium is achieved by minimizing average starting times, waiting times, or service time. The primary objective is to develop an algorithm optimizing desired performance measures, such as scheduled length or mean time spent in the system for a packet. The completion of a packet at a specific time is considered the packet's cost function. In summary, the scheduling problem aims to identify a feasible schedule minimizing the total cost function.

The remainder of this paper is organized as follows: Section 2 describes the operation of RFID anti-collision of ISO/IEC 14443 Type B. Section 3 illustrates the relationship among delay-throughput characteristics for RFID anti-collision of ISO/IEC 14443 Type B. Numerical results are presented in Section 4, and concluding remarks are made in Section 5.

## II. ANTI-COLLISION MECHANISM OF ISO14443 TYPE B

ISO/IEC 14443 outlines the physical characteristics of Proximity Integrated Circuit Cards (PICCs), specifying the fields to be energized and the bidirectional communication between Proximity Coupling Devices (PCDs) and PICCs. When PICCs enter the communication coverage range of a PCD polling any PICC within its field, character format, frame structure, and timing information are initialized in the communication initialization phase. The Contactless Semi-Duplex Block Transmission Protocol defines procedures to activate and stop the protocol, applying to both TYPEA and TYPEB cards. The primary distinction between TYPEA and TYPEB cards lies in carrier modulation depth, binary number encoding method, and anti-collision mechanisms.

Under normal circumstances, a reader can only perform read and write functions on one radio frequency card in the magnetic field of a specified PCD at a given time. Collisions occur when multiple cards enter the RF field simultaneously, requiring the reader to select only one card for operations—a process known as anti-collision. This issue is unique to contactless smart cards, as contact smart cards have dedicated card holders, allowing only one card per holder.

The anti-collision mechanism in ISO14443 Type B utilizes a slot-oriented approach. Time slots act as sequence numbers, with the PCD specifying the number of slots. When multiple PICCs enter the RF field simultaneously, the PCD sends a PICC polling command, specifying the time slot range. Each PICC randomly selects a number within the specified range as its temporary identification number. The PCD then starts polling from the first time slot, and if only one PICC chooses the identified slot, it successfully gains the right to use the channel. If multiple PICCs answer the polling in the same time slot, a collision occurs, and the next slot is polled. This process continues until a PICC wins the right to use the channel. The PCD can then select and communicate with the chosen PICC using a SELECT command, avoiding further collisions.

Type B proximity cards employ a dynamic slotted ALOHA procedure for selection, with the number of slots determined by the PCD. PICCs randomly select a time slot, and collisions are resolved using slotted markers and ATQB transmissions. After calling all slots, the PCD checks the ATQBs of successfully completed PICCs. The procedure involves determining the purpose of the PICC card through the AFI in the ATQB's first byte, sending an ATTRIB command, and transitioning to the Active state if the card recognizes a valid ATTRIB command. In the Active state, the card responds to higher protocol layer commands with the proper CID and correct CRC B checksum. The card can be put into the Idle or Halt state by special commands in the higher protocol layer, and in the Halt state, it can only be reset to the Idle state by a valid WUPB command with the proper PUPI. The anti-collision mechanism of Type B is illustrated in Figure 1.

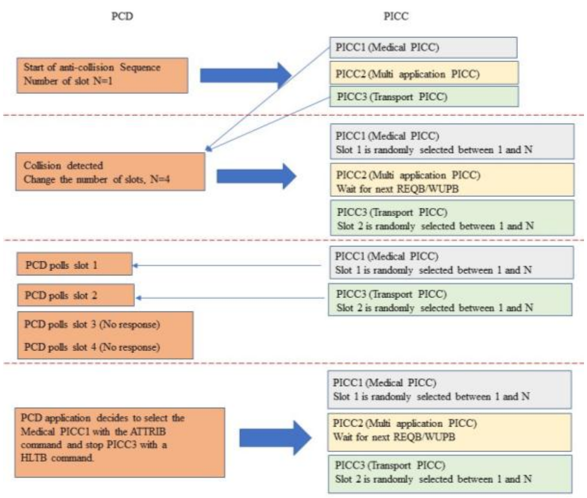


**Fig. 1.** The illustrated procedure of anti-collision mechanism of type B

## III. THE SYSTEM PERFORMANCE OF TYPE B

For multiple random accesses, the major limitation lies in the low throughput resulting from channel contention. The primary source of latency occurs during the contention phase, making the reduction of delay time a pertinent task. An efficient method to address colliding packets in communication networks is through the utilization of a tree algorithm [8-10], employing binary splitting search steps.

The inherent characteristics of the anti-collision protocol in the ISO 15693-3 standard allow the RFID reader to discern the number of collided packet slots and the creation of collision resolution cycles. This occurrence implies that the RFID reader is aware of the actual branches in a tree node. Utilizing these collided packet slots, no time is wasted as the collided packets are promptly split into subgroups based on their new transmitted contentions immediately after collision.

In this section, we primarily focus on the infrastructure of wireless networks. The RFID reader design functions as a controller overseeing the operation of the RFID anti-collision protocol. Given the fixed number of released slots, the interval of an anti-collision phase remains constant. Additionally, a dynamically-sized data interval, referred to as group transmission periods, is maintained to transmit packets among stations after contention. A polling cycle, defined as the time duration between two successive intervals once the PCD allows all PICCs to rejoin the channel contention, comprises a contention interval and a group of transmission periods.

When prepared to collect up-link packets, the PCD initiates an inventory request to all PICCs within its coverage. This message encompasses all relevant information and marks the commencement of a polling cycle. Assuming the total number of available slots is denoted as 'p,' PICCs randomly select one slot each upon receiving an inventory request from the PCD. Independently, PICCs generate and transmit their packets simultaneously from the available slots 'p.' Due to the selected slots, group transmission periods occur. The PCD polls the PICCs based on the ordered sequence of slot numbers. Active PICCs with the specified slot then simultaneously transmit their packets to the base station during the group transmission periods, eliminating any delay.

The tag transmits its response in the designated polling slot, being the sole transmitter, thereby preventing collisions. The UID is received and registered by the PCD. If the PCD successfully receives a packet from any PICCs, an EOF is sent, signaling a switch to the next slot. In case of a collision in a designated polling slot due to two or more active PICCs in the group transmission period, the PCD detects it and records the collision in the slot. If unsuccessful in receiving a packet from any PICCs, an EOF is sent, directing a switch to the next slot. If a slot is not selected among the PICCs, and no PICC transmits a response during polling, the PCD does not detect a PICC and decides to switch to the next slot. The PCD may continue to send EOFs until slot 'p-1.' Subsequently, the PCD sends an addressed request to tags whose UID has been correctly received and registered. If PICCs detect a faulty response, they exit the anti-collision sequence. These PICCs process the request and transmit their response according to the PCD's polling. The PCD creates a collision resolution cycle using the slotted Marker mechanism to resolve collided packets. After scheduled transmissions, the PCD initiates a new renewal (polling cycle), and PICCs that collided in the same slot are ready to receive another request. In the case of an inventory command, the slot numbering sequence restarts from 0.

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*A. Throughput*

In this section, we establish a system model to assess the performance of the system. All PICCs are considered independent and identical sources, with each PICC having precisely one packet of fixed length to transmit at any given time. We assume that there is no buffering for each PICC. Additionally, we assume perfect physical transmission, wherein the PCD receives generated packets (response packets) from these tags without any issues. For analytical simplicity, we assume that if the PCD detects collision packet periods in the previous collision resolution cycle, no new tags are allowed in any subsequent collision resolution cycle. This implies that the RFID protocol operates in a gated exhaustive manner.

Here, a collision packet period is defined as the time interval during which the PCD serves packets with a specifically transmitted slot. Similarly, a non-collision packet is defined as the time interval during which the PCD serves a PICC that exists only in a specially transmitted slot.

In general, the robustness of a protocol is often justified by throughput and average packet delay time. To derive the system performance, let's assume a total of $N$ tags within the coverage of the PCD. Since the arrival process follows a Poisson distribution with a mean of $\lambda$ for each PICC, and all PICCs are independent and identical sources, each PICC takes an exponentially distributed time to generate a new packet only if a previous packet has completed service.

The throughput is defined as the ratio of the expected successful transmission duration to the total time taken to completely serve all PICCs with responses during multiple access contention processes. Under steady state conditions, the average time ratio of non-collision packet periods in a mean polling cycle is referred to as throughput.

The random available epoch $T(n)$ is defined as the mean interval between the instant the PCD initiates a new polling cycle, during which n active PICCs contend for slots, and the ending instant at which all collided packets are resolved in this polling cycle. Let $U(n)$ be a random time variable for successfully transmitting these active PICCs in the polling cycle.
According to the definition of throughput, we have:

$$throughput[n] = \frac{U(n)}{T(n)} \quad (1)$$

Consider the following notation within the context of a system where $U(n)=n \cdot t_s$:

Let $t_{over}$ represent the packet duration of the inventory, including Start of Frame (SOF) and End of Frame (EOF) segments. $t_r$ denotes the response size, measured in time units, from each Passive Integrated Circuit Cards (PICCs) to contend for a special slot. $t_{EOF}$ signifies the size of the EOF packet in time units. $t_c$ corresponds to the packet collision period, and $t_p$ is the propagation time.

After contention, $t_s$ represents the packet transmission time to respond to the request from the Radio-Frequency Identification (RFID) reader for each tag that successfully contended for the channel.

For randomly selected slots, if there are $n_d$ successfully transmitted packets, $n_c$ collision packet periods, and $n_e$ slots not chosen by PICCs after contention, the mean time to completely serve these $n$ tags at the onset of the inventory request from the RFID reader is denoted as $T(n_d,n_c,n_e|n)$ and is expressed as given in reference [11].

$$T(n_d, n_c, n_e|n) = \left[t_{over} + n_d\left(t_{poll} + t_s + \tau\right) + n_c\left(t_{poll} + t_c + \tau\right) + n_e\left(t_{poll} + t_e + \tau\right) + \sum_{i=1}^{n_c} T\left(\tilde{n}_{c|i}, p'\right)\right] \quad (2)$$

In (1), the additional time, denoted as $\sum_{i=1}^{n_c} T\left(\tilde{n}_{c|i}, p'\right)$, accounts for the duration required to resolve unsuccessfully transmitted packets by halving the original p-value.

$$p' = \begin{cases} (int)p/2 & ,if\ p \geq 4 \\ 2 & ,if\ p \leq 2 \end{cases} \quad (3)$$

. This time parameter $T(n)$ also encompasses scenarios in which the final received packet exits the system within the specified maximum delay time. It holds paramount significance as it ensures the fulfillment of bounded time requirements for all sources, guaranteeing complete service within their respective maximum delay bounds. And

$$T(n) = \sum_{\forall\ n_d,n_c,n_e} P_r(n_d, n_c, n_e) T(n_d, n_c, n_e|n) \quad (4)$$

*B. Delay Time Performance*

A perfect channel is defined as a transmitted packet that is accurately received by the PCD when only one packet is transmitted in the channel. This definition implies that a tag can successfully transmit its packet if no collision occurs with another packet in the same channel. Under this condition, we have $n_d$ slots with successfully transmitted packets that are correctly received by the PCD. Consequently, the residual $n$ - $n_d$ PICCs must rejoin the next collision resolution cycle to transmit their packets.

If $X(n_d,n_c,n_e|n)$ is denoted as the delay time given $n_d$successfully transmitted packets and $n_c$ collision packet periods that have been detected by the PCD among these active tags, we have [11].

$$X(n_d, n_c, n_e|n) = pt_{over} + \left\{n_d\left(\frac{n_d - 1}{2}\right)\left(t_{poll} + t_s + \tau\right) + n_d\frac{n_c}{2}\left(t_{poll} + t_c + \tau\right) + n_e\left(t_{poll} + t_e + \tau\right) + (n - n_d)\left[n_d\left(t_{poll} + t_s + \tau\right) + n_c\left(t_{poll} + t_c + \tau\right) + n_d n_e\left(t_{poll} + t_e + \tau\right)\right]\right\} + \sum_{i=1}^{n_c} X\left(\tilde{n}_{c|i}, p'\right) \quad (5)$$

And

$$X(n) = \sum_{\forall\ n_d,n_{c,}n_e} P_r(n_d, n_c, n_e) X(n_d, n_c, n_e|n) \quad (6)$$

*C. Probability distribution*

Let$a_k$ be the number of active tags of address $k$ ($k$=0~$p$-1) selected among $p$ addresses, $\mathbf{1}_{\{\}}$ is called indicator function and

$$\mathbf{1}_{\{x\}} = \begin{cases} 0, if\ x\ is\ false \\ 1, if\ x\ is\ true \end{cases} \quad (7)$$

Let $P_r\{a_0,a_1,\ldots,a_{p-1}\}$ denote the probability mass function representing the selection of a set of $p$ addresses among $n$ active tags. Assuming that each address is chosen with equal probability, the expression for $P_r\{a_0,a_1,\ldots,a_{p-1}\}$ is given by:

$$P_r\{a_0, a_1, \cdots, a_{p-1}\} = \frac{n!}{[(a_0!a_1!\cdots,a_{p-1}!)(p^n)]} \quad (8)$$

And $a_0 + a_1 + \cdots + a_{p-1} = n$ , $a_k$!represents the factorial of$a_k$.Denoted

$$n_d = \sum_{k=0}^{p-1} \mathbf{1}_{\{a_k = 1\}} \quad (9)$$

$$n_c = \sum_{k=0}^{p-1} \mathbf{1}_{\{a_k \geq 2\}} \quad (10)$$

And

$$n_e = \sum_{k=0}^{p-1} \mathbf{1}_{\{a_k = 0\}} \quad (11)$$

then, the condition probability distribution function, in which there are $i$non-collision packet periods (only one packet is transmitted during this period) and *j*collision packet periods (two or more packets are simultaneously transmitted during this period) given *n*active tags, can be expressed as

$$P_r(n_d, n_c, n_e) = P_r\left(\sum_{k=0}^{p-1}\mathbf{1}_{\{|a_k|=1\}}, \sum_{k=0}^{p-1}\mathbf{1}_{\{|a_k|\geq 2\}}, \sum_{k=0}^{p-1}\mathbf{1}_{\{a_k=0\}}\right).$$
(12)

## IV. RESULTS

From Figure 2 and Figure 3, it can be observed that the performance of ISO 14443 Type B outperforms the strategy of maintaining a constant value of *p*. However, for *p*=4, there isn't a significant difference in delay performance, whereas the increase in throughput performance is more pronounced.In typical tree elimination methods, it's found that throughput decreases as the value of p increases; conversely, delay time increases as the value of p increases. However, in ISO 14443 Type B, when n is less than or equal to 6, lower values of p result in better throughput. This is because higher values of p only increase the chances of collisions, leading to time wastage. However, after n is greater than or equal to 7, throughput improves with increasing values of p. This is because with more tags, the probability of collisions increases, but higher values of p reduce the number of collision tags selected in the same slot, reducing the probability of tags' collisions and consequently decreasing the time taken to resolve collisions, leading to an increase in throughput.

We now shift our focus back to the operational mechanism of ISO 14443 Type B, specifically addressing the situation where collisions occur among tags. To resolve the current address collision issue, the count of released addresses (denoted as *p*) at this juncture undergoes modification to half of its original value. It is crucial to note that if there is only one released address, collisions persist among contending tags, rendering the collision problem unsolvable. Consequently, when *p* equals 2 or 3, the new *p* value for addressing collisions remains 2. However, when p is greater than or equal to 4, the revised *p* value used to resolve collision issues becomes half of the original p value.

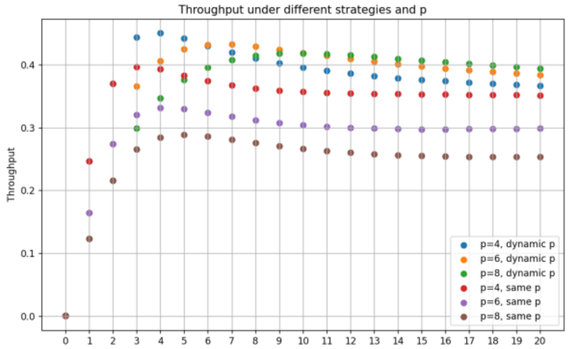


Fig. 2. The throughputperformance of ISO14443 Type B collision resolution mechanism vs. general tree mechanism underdifferent *p* value.

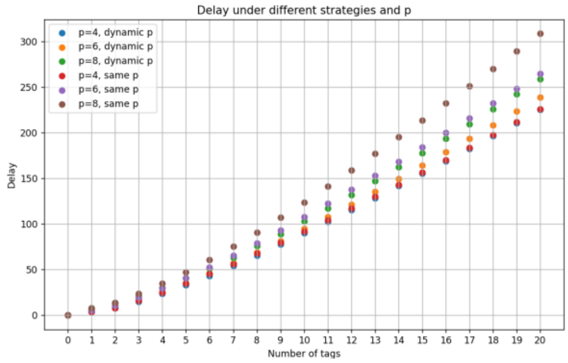


Fig. 3. The delay time performance of ISO14443 Type B collision resolution mechanism vs. general tree mechanism underdifferent *p* value.

Maintaining the stipulated *p*-value unchanged amidst collisions, the relationship between various *n*-values and performance is elucidated in the ensuing figures. If the collision detection time ($t_c$) is reduced to 0.1 seconds, the relationship between various *n* values and performance is depicted in Fig. 4 toFig. 9.Observing Fig. 4to Fig. 9, it becomes apparent from the graphs that the performance of *p* (address number) = 4 surpasses others. However, as the tag number increases, the performance diminishes with higher *p*-values.

In Figures 4 to 9, it is observed that the reduction in$t_c$ leads to an improvement in performance. Additionally, it is noted that a larger *p* value does not necessarily result in better performance with an increase in the number of tags. There seems to be a certain trade-off point. This trade-off point can be observed from Figure 2. Regarding throughput, in Figure 2, it can be seen that when *p* equals the number of tags in the system, it appears to result in the best throughput.

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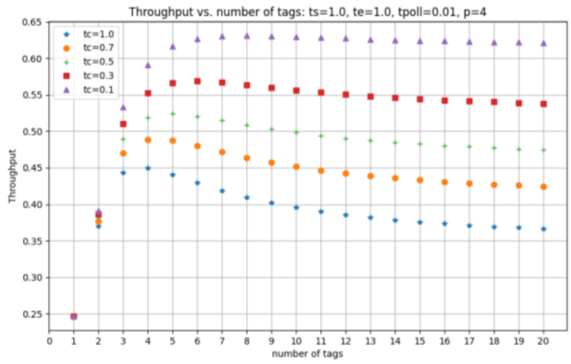


Fig. 4. The throughputperformance of ISO14443 Type B collision resolution mechanism with *p*=4 under various$t_c$.

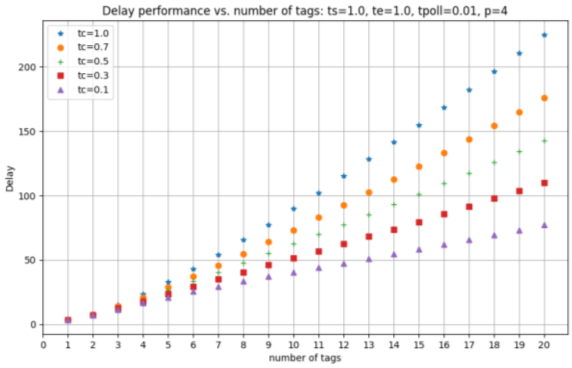


Fig. 5. Th delay time performance of ISO14443 Type B collision resolution mechanism with*p*=4 under various$t_c$.

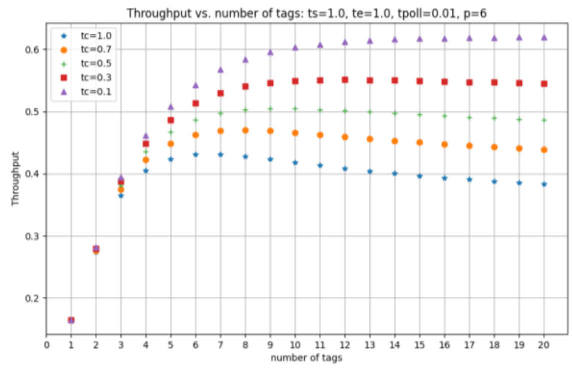


Fig. 6. The throughputperformance of ISO14443 Type B collision resolution mechanism with *p*=6 under various$t_c$.

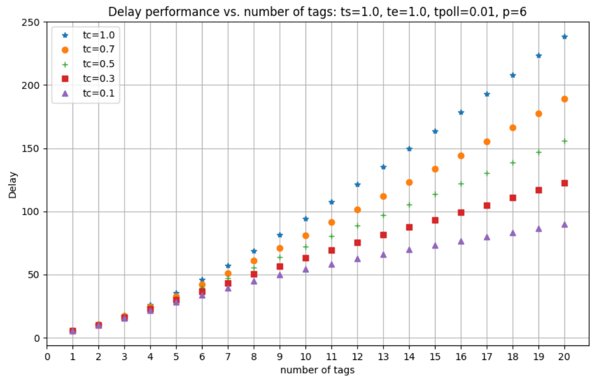


Fig. 7. The delay time performance of ISO14443 Type B collision resolution mechanism with *p*=6 under various$t_c$.

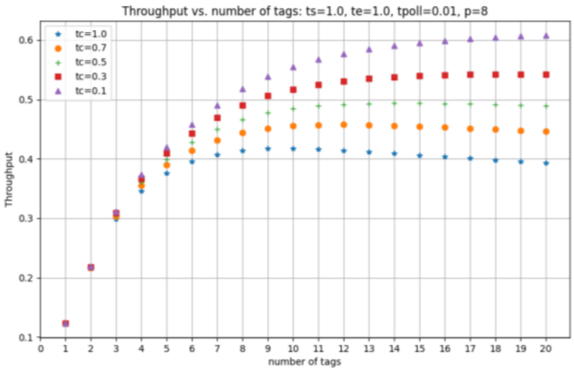


Fig. 8The throughputperformance of ISO14443 Type B collision resolution mechanism with *p*=8 under various$t_c$.

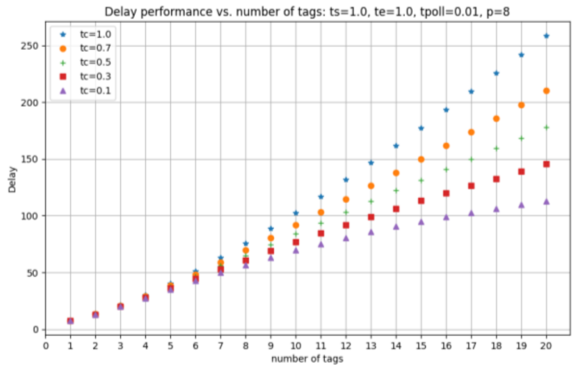


Fig. 9. The throughputperformance of ISO14443 Type B collision resolution mechanism with *p*=8 under various$t_c$.

From Figure 10, it can be observed that when the number of tags is less than 6, the throughput is optimal when *p* equals the number of tags. However, when the number of tags exceeds *p*, the throughput increases with the increase of *p*. Yet, when *p*exceeds 6, the increment in throughput is not very significant. Figure 11 illustrates that the delay time increases as the value of *p* increases.

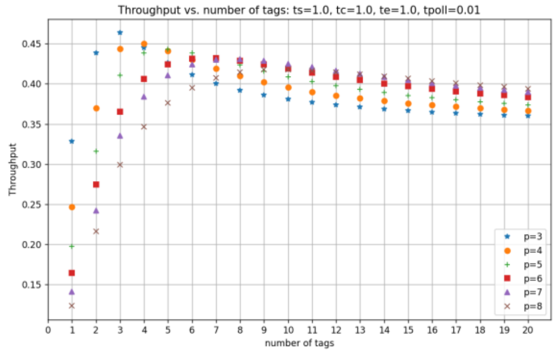


Fig. 10. The throughput performance of ISO14443 Type B collision resolution mechanism with various initial values of *p*

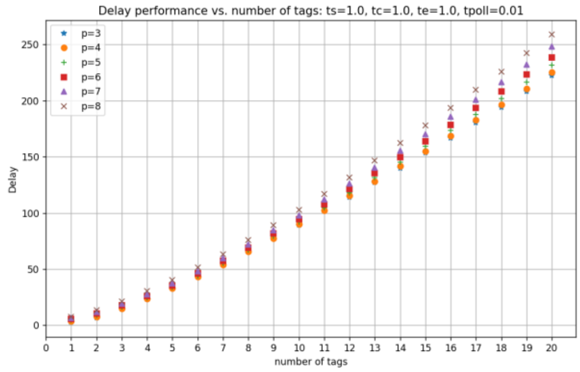


Fig. 10. The delay performance of ISO14443 Type B collision resolution mechanism with various initial values of *p*

## V. CONCLUSION

Our analysis suggests that the optimal choice for the *p* value in ISO 14443 Type B would be 6.Furthermore, if *p* is chosen as 4, then ISO 14443 Type B doesn't seem to offer any significant advantages. In other words, there's no need to adopt the strategy of halving *p* during tag collisions.

In this comprehensive analysis of ISO 14443 Type B RFID systems, we have delved deep into the intricate relationship between system parameters and performance metrics. Through a combination of experimental investigations and theoretical discussions, we have uncovered valuable insights into optimizing system efficiency, particularly in terms of throughput and delay time.

One of the key findings of our study is the nuanced impact of the address number (p) on system performance. While conventional wisdom suggests that maintaining a constant value of p is optimal, our analysis reveals that this is not always the case. In scenarios where the number of tags (n) is relatively low ($n \leq 6$), lower values of p lead to better throughput by minimizing collision-induced delays. However, as the number of tags increases, higher values of p become beneficial in reducing collision probabilities and enhancing throughput. This dynamic relationship underscores the importance of adaptability in RFID system design, where parameter optimization must be tailored to specific operational conditions.

Furthermore, our examination of collision resolution strategies has provided valuable insights into addressing address collision issues. By proposing a modification to the released address count (p) – halving the original value – we offer a practical solution to mitigate collisions effectively while striking a balance between collision resolution efficiency and system performance. This adaptive approach ensures that RFID systems can effectively manage address collisions without sacrificing overall system efficiency.

Moreover, our study highlights the critical trade-off point where the benefits of increasing p diminish as the number of tags exceeds a certain threshold. Beyond this point, the marginal gains in throughput from increasing p are outweighed by the associated increase in collision probabilities. This observation underscores the importance of understanding system dynamics and optimizing parameter values within the context of specific application requirements.

In conclusion, our research contributes to the ongoing discourse on optimizing RFID system performance, particularly in the context of ISO 14443 Type B systems. By providing a comprehensive analysis of system parameters, collision resolution strategies, and performance metrics, we offer valuable insights for practitioners and researchers alike. Moving forward, further research may explore advanced collision resolution algorithms, real-world deployment scenarios, and novel optimization techniques to continue enhancing the efficiency and effectiveness of RFID systems in diverse application domains.

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Chiang Ling Feng was born in 1974 and joined Bachelor Degree Program of IOT Engineering and Applications Department at Yu Da University of Science and Technology in 2023. He received a Ph.D. in electrical engineering in 2009. His main research areas are in the fields of communication networks, algorithms, intelligent networks and machine learning. He is currently an assistant professor at Yu Da University of Science and Technology.