

Conceptual Selective RFID Anti-Collision Technique Management

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Abstract

Radio Frequency Identification (RFID) uses wireless radio frequency technology to automatically identify tagged objects. Despite the extensive development of RFID technology, tag collisions still remains a major drawback. The collision issue can be solved by using *anti-collision* techniques. While existing research has focused on improving *anti-collision* methods alone, it is essential that the suitable type of *anti-collision* algorithm is selected for the specific circumstance. In this work, we evaluate *anti-collision* techniques and perform a comparative analysis in order to find the advantages and disadvantages of each approach. To identify the best *anti-collision* method selection in specific scenarios, we have proposed two strategies for selective *anti-collision* technique management: a “Novel Decision Tree Strategy” and a “Six Thinking Hats Strategy”. We have shown that the selection of the correct technique for specific scenarios improve the quality of the data collection which, in turn, will increase the integrity of the data after being transformed, aggregated, and used for event processing.

Keywords:

Radio Frequency Identification (RFID), Anti-Collision, Probabilistic, Deterministic

1. Introduction

RFID technology is an automated wireless technology that uses radio frequency to track items. It has the potential to improve the efficiency of business processes by providing automatic identification and data capture. Currently, there are various applications where RFID technology has been integrated such as warehouse and supply chain monitoring. There are several methods of identification, but the most common is to store a serial number that uniquely identifies a person or object, known as the “Electronic Product Code” (EPC) [1]. In those applications where numerous RFID tags are presented in the interrogation zone simultaneously, the RFID reader is required to have an ability to read the data from individual tags. If more than one tag tries to communicate with the reader at the same time, a collision will occur and the tag’s data will need to be re-transmitted. A technical approach that handles *tag collision* without any interference is called an *anti-collision* scheme.

Several methodologies have been proposed to minimise collision issues in RFID system. Two widely used types of tag *anti-collision* methods fall into the category of *Deterministic* and the *Probabilistic* approaches. In this study, we assess these two *anti-collision* techniques and carry out a comparative analysis in order to find the advantages and disadvantage of each method. We then propose two strategies for selective *anti-collision* technique management: a *Novel Decision Tree Strategy* and a *Six Thinking Hats Strategy*, in order to identify the best selection of *anti-collision*

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method. From this investigation, we have discovered that different *anti-collision* methods have advantages over others in certain cases. Thus, it is important that the correct type of *anti-collision* algorithm is applied to different scenarios.

The remainder of this paper is organised as follows: in Section 2 we provide general background information related to tag collisions and the importance of choosing the correct type of *anti-collision* technique. In Section 3, we perform a comparative analysis between two *anti-collision* approaches and determine the advantages and disadvantages of each approach. We propose two novel strategies for selective RFID anti-collision technique management in Section 4 and finally we conclude the paper in Section 5.

2. RFID Tag Anti-Collision Approaches

A chain reaction is a sequence of events where a reactive product or by-product causes additional actions to take place [2]. In a chain reaction, positive feedback leads to a self-amplifying chain of events. As for chain reactions within RFID data management, the most important step which will have the largest impact toward data is the RFID data collection process. If any error occurs at the data collection level [3], the impact will be increased towards all following steps, such as: data integration and aggregation; data query model and event processing; and data mining. While there have been previously proposed approaches based on identifying and rectifying the missing observational data after it has been stored within the database [4], [5], [6], it is crucial to select and employ the correct *anti-collision* technique in order to enhance the integrity of captured data before being stored into the databases.

The various types of tag *anti-collision* approaches for *tag collisions* can be classified into two types: *deterministic* and *probabilistic* approaches [7]. *Deterministic* methods operate by asking for the first EPC string of the tag until it gets matches for the tags, it will then continues to ask for additional characters until all tags within the region are found. There have been several methods proposed in literature in order to improve the quality of captured data such as: the Query Tree; the Adaptive Splitting Tree [8]; the Hybrid Query Tree [9]; and the Joined Q-ary Tree [10], [11].

In *probabilistic* methods, tags respond at randomly generated times. If a collision occurs, colliding tags will have to identify themselves again after waiting for a random period time frame. From past research, there have been several methods proposed such as: Basic Framed-Slotted ALOHA [12]; Dynamic Framed-Slotted ALOHA [13]; Enhanced Dynamic Framed-slotted ALOHA [14]; and Probabilistic Cluster-Based Technique [15], to enhance the performance efficiency of the data capturing process. In addition, several *Frame Estimation* approaches have been suggested to improve the accuracy of *frame-size* prediction for probabilistic *anti-collision* including the Schoute method [16], the Lowerbound method, the Chen1 and Chen2 methods [17], the Vogt method [18], the Bayesian method [19], and the Precise Tag Estimation Scheme (PTES) [20].

3. Comparative Analysis of Anti-Collision Techniques

For the *deterministic* approach, we consider our previously proposed Joined Q-ary Tree for comparative analysis as it has been shown that it outperforms existing techniques [11]. The Joined Q-ary Tree employs the right combination of Q-ary trees for each specific scenario. This will depend on the specific number of tags within an interrogation zone and the bulky movement of tags based on *EPC pattern*. The Joined Q-ary Tree adaptively adjusts its tree branches to suit the *EPC pattern*; this procedure will reduce the accumulative bits from the reader's queries and improve the robustness of the overall identification process.

Similarly, for the *probabilistic* approach, we have considered our previously proposed Probabilistic Cluster-Based Technique (PCT) for the comparative analysis purpose as it performs better than other existing methods [15]. The PCT method employed a dynamic *probabilistic* algorithm concept and uses a group splitting rule to split *Backlog* (estimated remaining tags) into group if the number of unread tags is higher than the maximum *frame-size*.

3.1. Joined Q-ary Tree Approach

The Joined approach is a combined Q-ary trees, specifically 2-ary and 4-ary trees, which have been identified to be the best Q-ary trees in previous researches [10]. The Joined Q-ary Tree employs the right combination of Q-ary trees for each specific scenario. Assuming that most items from the warehouse have massive movements, the first few bits of EPC will be identical and the remaining bits will be very similar. In order to optimise the performance of Joined Q-ary Tree, the right Separating Point (SP) between the two Q-ary trees needs to be configured. This procedure

will further reduce accumulative bits from the reader’s queries and improve the robustness of the overall identification process.

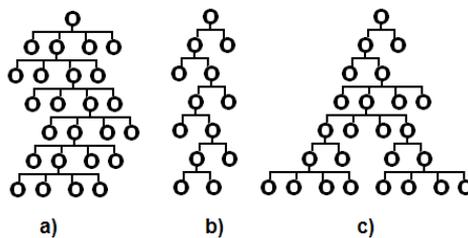


Figure 1: A sample of: a) a Naive 4-ary Tree, b) a Naive 2-ary Tree, and c) a Joined Q-ary Tree.

Figure 1 shows the example of a) Naive 2-ary, b) Naive 4-ary, and c) Joined Q-ary Tree. Joined Q-ary Tree bonded both the 2-ary and 4-ary trees together and applied to specific bits of the EPC depending on how Identical or Unique they are.

3.2. Probabilistic Cluster-Based Technique (PCT)

The PCT approach first estimates the number of *Backlog*, or the remaining tags, within the interrogation zone. If the number of *Backlog* is larger than the specific *frame-size*, it splits the number of *Backlog* into a number of groups and allows only one group of tags to respond. The reader then issues a “Query”, which contains a ‘Q’ parameter to specify the *frame-size* ($\text{frame-size } F(\min) = 0; F(\max) = 2^Q - 1$). Each selected tag in the group will pick a random number between 0 to $2^Q - 1$ and put it into its slot counter. Only the tag which picks zero as its slot counter responds to the request. When the number of estimated *Backlog* is below the threshold, the reader adjusts the *frame-size* without grouping the unread tags. After each read cycle, the reader estimates the number of *Backlog* using the PTES algorithm [20] and adjusts its *frame-size*.

Table 1 shows the PCT rule. For instance, if the number of *Backlog* equals to 900 tags, the PCT algorithm will split the unread tags into 3 groups of Q8 ($2^8 - 1 = 256$).

Table 1: PCT256 Rule - The number of unread tags, optimal frame-size (A and B), and number of group (A and B)

PCT256 Rule				
Backlogs	FS A	Group A	FS B	Group B
....
1233 to 1408	256	4	-	-
1057 to 1232	256	3	128	1
881 to 1056	256	3	-	-
705 to 880	256	2	128	1
529 to 704	256	2	-	-
353 to 528	256	1	128	1
177 to 352	256	1	-	-
89 to 176	128	1	-	-
45 to 88	64	1	-	-
23 to 44	32	1	-	-
12 to 22	16	1	-	-
6 to 11	8	1	-	-
....

3.3. Empirical Evaluation

In this study, we have empirically compared the performance of the Joined Q-ary Tree against the PCT *anti-collision* approaches because our *deterministic* and *probabilistic* methods have outperformed existing techniques in their own grounds [11], [15]. We believe that the comparative analysis is necessary to identify the best overall method for specific circumstances. There are two major test cases involved in our empirical evaluation, these test cases have been generated separately. The first test case considered specific *EPC pattern* (same product) with 50 and 100 tags per pallet. The second test case, which has been used for *probabilistic* approaches, had no specific *EPC pattern*

(different products) nor specific number of tag per pallet. These two cases represent a typical situation in a warehouse environment.

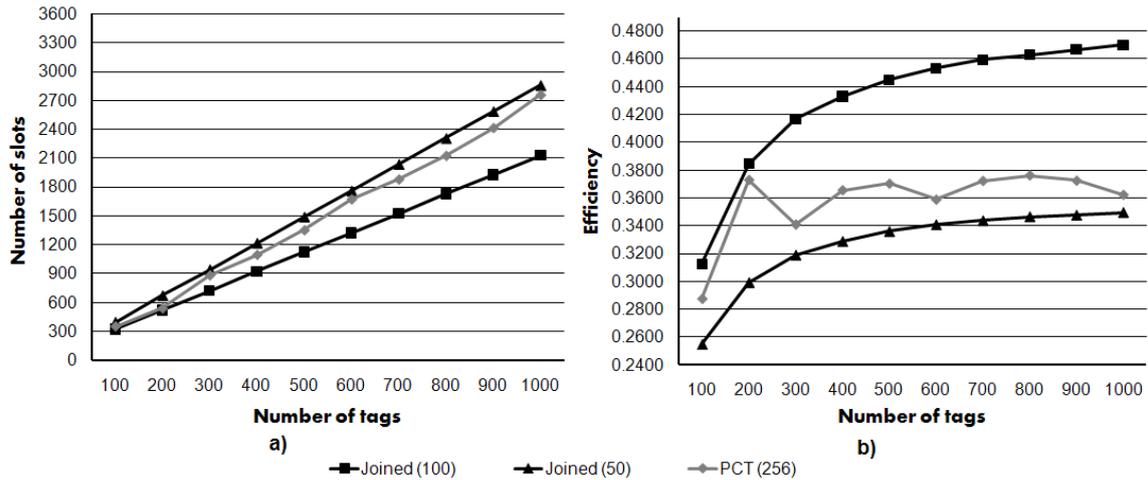


Figure 2: Comparative analysis of Joined Q-ary Tree versus PCT: a) Number of slots comparison and b) Performance efficiency

From the empirical study, we have investigated the performance of our proposed Joined Q-ary Tree and PCT. Figure 2a) illustrates that the gap between each method increased when the number of tags increased, this particularly become the most visible when reaches 1000 tags. The overall number of slots result have shown that the Joined Q-ary Tree with 100 tags per pallet (Joined(100)) obtained the minimal number of slots throughout the whole experiment, which leads to the minimal identification time required. In contrast, the Joined Q-ary Tree with 50 tags per pallet (Joined(50)) performed poorly compared with the Joined(100) and PCT. This results has proven that the selection of *EPC pattern* has a large impact on the performance of Joined Q-ary Tree. When the chosen *EPC pattern* involved has a very small group of tags (such as 50 tags per pallet), the performance of Joined Q-ary Tree cannot be optimised.

Figure 2b) show the performance efficiency of all methods. It can be seen that the Joined(100) achieved close to 47 percent efficiency once the number of tags reach 1000. Additionally, we can see than the performance efficiency of both Joined(100) and Joined(50) methods keep increasing in accordance to the number of tags. In contrast, the PCT cannot achieve a performance efficiency higher than 38 percent. By examining Figure 2b), it can be assumed that the efficiency of Joined Q-ary Tree will increase slower once the number of tags within the interrogation zone becomes very high. For Joined(50), if the number of tags keeps increasing, it is possible that the performance efficiency will achieve the same level as PCT.

From the comparative analysis, we have identified certain properties of importance for *anti-collision* methods in general. For *deterministic* methods, we have discovered that there are impacts from similar *EPC patterns*, the number of tags within one group of the *EPC pattern*, and the overall number of tags within the interrogation zone. For *probabilistic* methods, we have determined that the performance of the *anti-collision* technique depends on the Initial *frame-size* (or the Q value) specification, the accuracy of *Backlog* prediction techniques, and the overall number of tags within the interrogation zone.

4. Strategies for Choosing Suitable Anti-Collision Techniques

It is crucial that the RFID systems must employ *anti-collision* protocols in readers in order to enhance the integrity of the captured data. However, the step of choosing the right *anti-collision* protocol is also very important, since we cannot depend solely on the capability of *anti-collision* protocol itself, but also on the suitability of each selected technique for the specific scenario. The user may employ decision making techniques such as Decision Trees [21] and Six Thinking Hats Strategies [22] for complex selective technique management to determine the optimal *anti-collision* protocol. The novelty of using selective technique management is that we will be able to make a more

effective decision and correctly identify the most suitable *anti-collision* method for any scenario. This will then improve the quality of data collection and reduce the risk in changing the protocol later. It will also help over a long period of use when the captured data is needed for transformation, aggregation and event processing.

4.1. Decision Tree for Anti-Collision Methods Selection

A Decision Tree [21] can be used to clarify an answer to a complex problem. The structure allows users to take a problem with multiple solutions and display it in a simple format that shows the relationship between different events or decisions. In the scenario where not many RFID locations and constraints are involved, it is wise to apply the Decision Tree to decide between the use of either *deterministic* or *probabilistic anti-collision* protocols. In this study, we introduce the Novel Decision Tree Strategy for selective *anti-collision* technique management where either Joined Q-ary Tree, PCT no group or PCT group is applied. PCT no group does not split tags into groups as the number of tags may not be high enough to require the splitting. Certain properties of importance for *anti-collision* methods discovered from comparative analysis are also integrated with the decision making process.

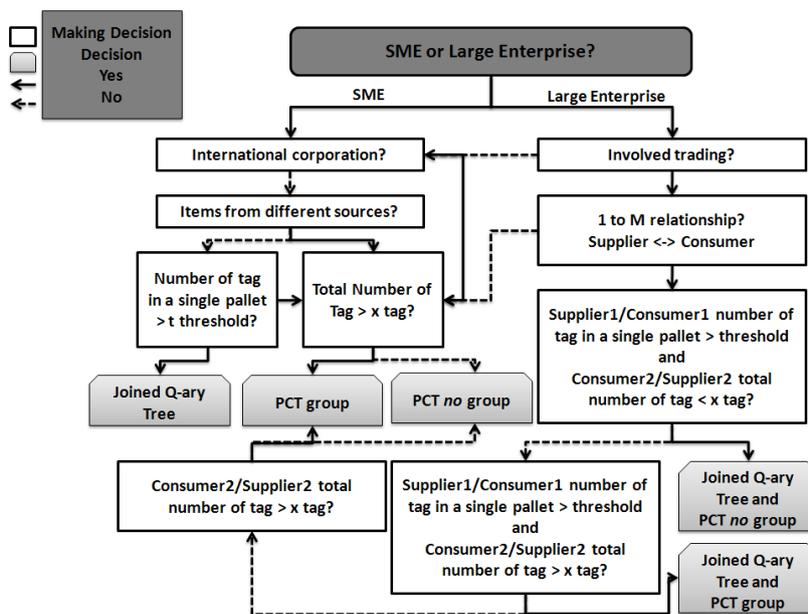


Figure 3: Novel Decision Tree Architecture for Anti-Collision Methods Selection. SME = Small and Medium Enterprise, 1-to-M = 1 to Many

Figure 3 illustrates the steps of the decision making process of the proposed Novel Decision Tree. By taking certain properties found from our empirical study into consideration, we have constructed a decision tree reflected on the size of the company, the number of tags per pallet, the total number of tags, the *EPC pattern* and the relationship between suppliers and consumers.

4.2. Complex Anti-Collision Methods Selection

This section introduces an alternative solution to be used instead of the Novel Decision Tree. It is possible that the Novel Decision Tree may not be the best approach for some complex cases and the complex decision making process. This involves more than facts and numbers as it will be required in order to obtain the best *anti-collision* selection. There are several everyday decision making techniques currently available. However, we must select the best technique, which will allow the selective decision to be precise and provide the best solution based on information, feeling and experiences. We propose the integration of the Six Thinking Hats Strategy [22] for the more complex *anti-collision* methods selection.

In this concept, there are six metaphorical hats and the thinker can put on or take off one of these hats to indicate the type of thinking used. The hats must never be used to categorise individuals, even though their behavior may seem to invite this. Figure 4 illustrates the Six Thinking Hats framework.

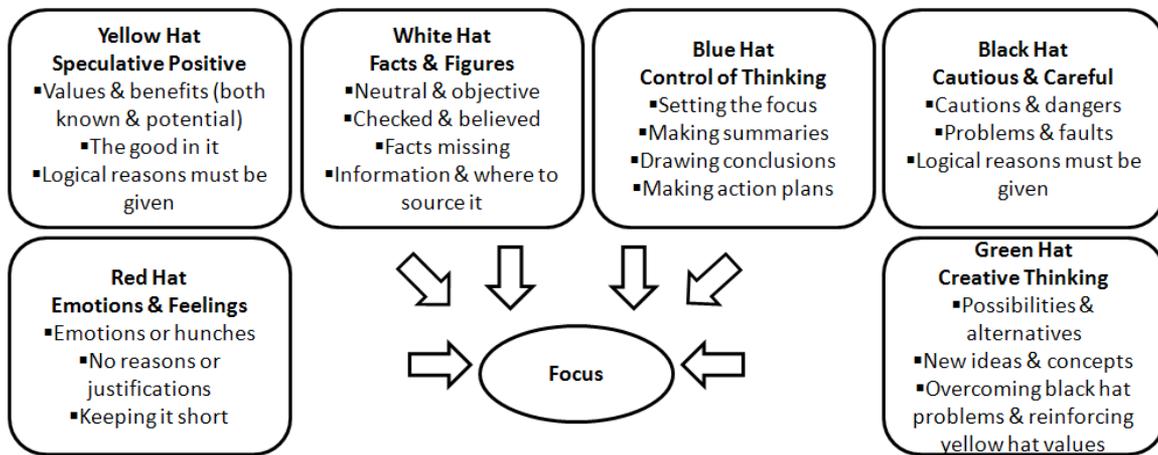


Figure 4: Six Thinking Hats Framework

4.3. Global Trading Enterprise (GTE) Scenario

In this work, we will use the Global Trading Enterprise (GTE) as a case study for our experimental evaluation. GTE is a large international business, with a Many to Many (M-to-M) relationship between suppliers and consumers. The company imports products from different countries, repackages them, and exports them internationally and locally to different companies. It also involves large amount of inventories, which are stocked into special warehouses with four different zones as shown in Figure 5.

ZONE ONE:	ZONE TWO:	ZONE THREE:	ZONE FOUR
Truck Unloading	Temporary Storage	Re-Tagging Area	Company Storage
Item unloaded from supplier's truck, RFID reader captured all items and stored data into company inventory databases	RFID reader obtained data and kept track of all inventories in the temporary storage (inventory monitoring)	Each item moved along conveyer belt toward re-tagging area, RFID reader monitored these items every t second	After re-tagging process, all items are stocked-up into warehouse storage, RFID reader acquired data and stored into stock databases

Figure 5: Six Thinking Hats: Global Alcohol Trading Enterprise (GTE) Scenario

After analysing the information given from Figure 5, Table 2 displayed the preferred algorithm for each location that will provide the optimal quality of collected data from GTE scenario.

Table 2: Preferred Anti-Collision Method for Each Location (Zone 1 - 4) in GTE scenario

Location	Joined Q-ary Tree	PCT Group	PCT no Group
Zone One	✓	X	X
Zone Two	X	✓	X
Zone Three	X	X	✓
Zone Four	X	✓	X

4.3.1. Decision Making Phase

When applying the Novel Decision Tree and Six Thinking Hats Strategies for the GTE scenario, different conclusions for *anti-collision* methods deployment were acquired. The steps of decision making processes are as follows:

Decision Tree.

- **Question:** Is this a SME or a large Enterprise? **Answer:** Large Enterprise.
- **Question:** Does the corporation involve trading? **Answer:** Yes, GTE is a global trading company.
- **Question:** Is the Supplier to Consumer, or Consumer to Supplier, relationship a 1-to-M relationship? **Answer:** No, GTE have more than one supplier and one consumer all over the world.
- **Question:** Does the total number of tags in an interrogation zone exceed x tags? **Answer:** Yes, GTE's warehouse stored numerous number of goods in storages and used RFID system to monitor and control inventories.
- **Outcome:** The suitable *anti-collision* method is a "Probabilistic Cluster-Based Technique".

According to the decision tree outcome, GTE should employed a PCT group as its *anti-collision* method for all locations.

Six Thinking Hats.

- **White Hat:** For GTE scenario, the thinker who wears the White hat goes for realistic data and stays with the Novel Decision Tree assessment, which is to select the PCT deployment for all four zones.
- **Red Hat:** The Red hat is put on by local warehouse staff who knows the environment better than the board of directors. Thus, the Red hat wearer decided that different *anti-collision* techniques should be deployed for the different zones.
- **Yellow Hat:** In this scenario, the thinker who wears the Yellow hat points out the advantage of the selected *anti-collision* technique and why it is necessary to keep the current decision. The thinker decided on deploying only PCT, since it is simple to order one lot of hardware and software from the same supplier, and to avoid unnecessary procedures and time frames for implementation.
- **Black Hat:** Logically, at the unloading zone (zone one), trucks usually arrive from the same company/supplier. In addition, at zone three where tagged items are moved along the conveyer belt, realistically it is impossible to have more than one hundred cases of alcohol sitting on the belt. Thus, the Black hat thinker decided that different *anti-collision* algorithm must be deployed at both zones one and three.
- **Green Hat:** The Green hat wearer agrees with the Black and Red hat wearers since the Green hat takes care of the old ideas and presents alternatives. However, because the options are strictly limited to either *deterministic* or *probabilistic* for each zone, Green hat decides on applying Joined Q-ary Tree to zone one instead of PCT, and also suggests PCT no group for zone three as not many tags will be present on the conveyer belt.
- **Blue Hat:** The thinker of the Blue hat will be thinking about thinking and set objectives for each section. For the *anti-collision* selective process, the thinker of the Blue hat is to decide who to put on each hat and what is the main scope of the overall selective process. From the overall analysis, the Blue hat has decided to employ both types of *anti-collisions* and apply them to different zones.

According to the Six Thinking Hats Strategy, GTE should employ a PCT group at *zone two* and *zone four* only, since these two zones are involved with arbitrary goods. The Six Thinking Hats strategy has recommended that the Joined Q-ary Tree is deployed instead of the PCT group at *zone one* since arriving items from supplier are usually delivered from the same supplier. At *zone three*, it is recommended that the PCT no group is implemented since this location is involved with arbitrary goods, but does not involve a numerous number of tags.

4.3.2. Solution Phase

For a complex scenario such as GTE, complex kinds of thinking is needed in order to obtain the optimal result from each *anti-collision* algorithm. The Six Thinking Hats can correctly identify the best algorithms for all four zones, as shown in Table 3. The Novel Decision Tree however, can only obtain correct algorithms for *zone two* and *zone four*. This is because the Novel Decision Tree only takes into consideration facts and figures without concern for any special circumstances unforeseen nor specific environmental requirements. Thus, for *zone one* and *zone three* where the information provided is ambiguous, the Novel Decision Tree cannot correctly identify the suitable algorithm.

Table 3: Selected Anti-Collision Methods. Joined Q-ary Tree = JQT; PCT Group = PCT-G; PCT no Group = PCT-NG

Location	Novel Decision Tree			Six Thinking Hats		
	JQT	PCT-G	PCT-NG	JQT	PCT-G	PCT-NG
Zone One	X	✓	X	✓	X	X
Zone Two	X	✓	X	X	✓	X
Zone Three	X	✓	X	X	X	✓
Zone Four	X	✓	X	X	✓	X

5. Conclusion

In this study, we have assessed two *anti-collision* approaches and have conducted a comparative analysis in order to find the advantages and disadvantages of each method when applied for particular cases. We presented two strategies for selective *anti-collision* technique management in order to obtain the optimal outcome of *anti-collision* method selection. By applying these two strategies, we have determined that the different *anti-collision* methods have advantages over others in specific cases, and we have made appropriate recommendations. We have shown that by correctly identifying the most suitable *anti-collision* technique using proposed *Novel Decision Tree Strategy* and *Six Thinking Hats Strategy*, the data collection process can be improved.

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