

Comparative Analysis of Traditional RFID Tag Anti-Collision Techniques for IoT Applications

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Abstract

Radio Frequency Identification (RFID) is seen as inevitable especially within the sensing layer of IoT architecture. RFID is important because it communicates wirelessly and numerous tags can be identified at same time. Besides, low cost of passive RFID tags makes the tagging and connectivity of things around us realizable. The tag collision problem (TCP) of RFID systems have received much research attention for small-scale tag deployments. However, the overcrowded nature of RFID tags in IoT puts a strong doubt, the ability of existing RFID tag anti-collision methods to effectively tackle TCP. This paper examines traditional methods (the probabilistic and deterministic methods) used in developing the existing RFID tag anti-collision protocol. Their pros and cons were explored. Both methods were implemented as M-files in MATLAB while simulation analysis were performed with varying tag density. RFID tags' unique RN16 were simulated using 16-bit random numbers generated in MATLAB and under overcrowded environment of minimum 100 tags and maximum 1000 tags. The 1000 tags represents IoT scenario. Results of a Monte-Carlo simulation show a tag identification rate (TIR) of 0.98 in IoT for ALOHA-based (probabilistic) method and a tag identification rate of 0.90 in IoT for Tree-based (deterministic) method. Simulation result also shows ALOHA-based method uses less number of time slots (identification time) of 3200 than 4400 of Tree-based method. Since access to the communication channel is represented in times slots, the simulation results imply that ALOHA method takes less time to identify tags.

KEYWORDS: IoT; RFID; Tag anti-collision protocol; Probabilistic method; Deterministic method; Time slot; Tag identification rate

1. INTRODUCTION

Internet of things (IoT) is a paradigm shift of the internet. IoT promises to make all objects (things) identifiable and data exchangeable [1]–[3]. Hence, in IoT, things around us will contribute to internet traffic more than computers. The migration from internet protocol version 4 (IPV4) to internet protocol version 6 (IPV6) has made IoT very much practicable as IPV6 has 2^{128} or 340,282,366,920,938,463,374,607,431,768,211,456 or 340 trillion trillion trillion IP available for addressing. IoT has diverse enabling technologies of which Radio frequency identification (RFID) is vital [4], [5]. Radio frequency identification (RFID) is a wireless technology used in identifying objects with little or no human intervention. RFID is key in the attainment of IoT especially within IoT sensing layer [6]–[8]. Figure 1 shows RFID playing an important role within IoT ecosystem. In figure 1, RFID tags are used in tagging objects or things while the RFID reader wirelessly reads tags' unique RN16. With the aid of 5G cellular network, this RFID set up in Figure 1 can be used to constitute a network of things (objects) that contributes to IoT data traffic and IoT ecosystem.

In RFID systems, one RFID reader can be used to identify (read) hundreds of RFID tags. Since tags share same communication channel in replying to reader queries, signal collision becomes inevitable [9]. Hence, RFID suffer tag collision problem (TCP). A TCP occurs when two or more tags try to reply to a RFID Reader query at the time and their signal collide causing no communication. This TCP is addressed using RFID tag anti-collision protocol. The existing protocol EPC C1G2 [10] cannot support overcrowded deployment of tags like in IoT [1]. Hence, the need for enhancement. This existing solution (algorithm) to RFID tag collision problem has two approaches in literature – ALOHA based (probabilistic) method and Tree based (Deterministic) method. To the best of our knowledge, most authors in literature focus on one of the methods in developing their solutions. None have tried to explore the strengths of the two methods so as find a possible hybrid solution that can support IoT application of RFID. This paper exposes the pros and cons of the two approaches and performs simulation experiment in MATLAB to analyze the performance of both methods. MATLAB is very versatile in implementing and analyzing both complex and the simplest of algorithms [11].

Therefore, random 16-bit numbers were used to simulate RFID tags' RN16 in MATLAB while Monte-carlo simulation was used performed for both algorithm of ALOHA and the Tree methods under varying tag population of 100 tags rising to 1000 tags. The 1000 tags represents IoT scenario. Results show the ALOHA-based method edges the Tree or deterministic method when the tag population is overcrowded (IoT scenario).

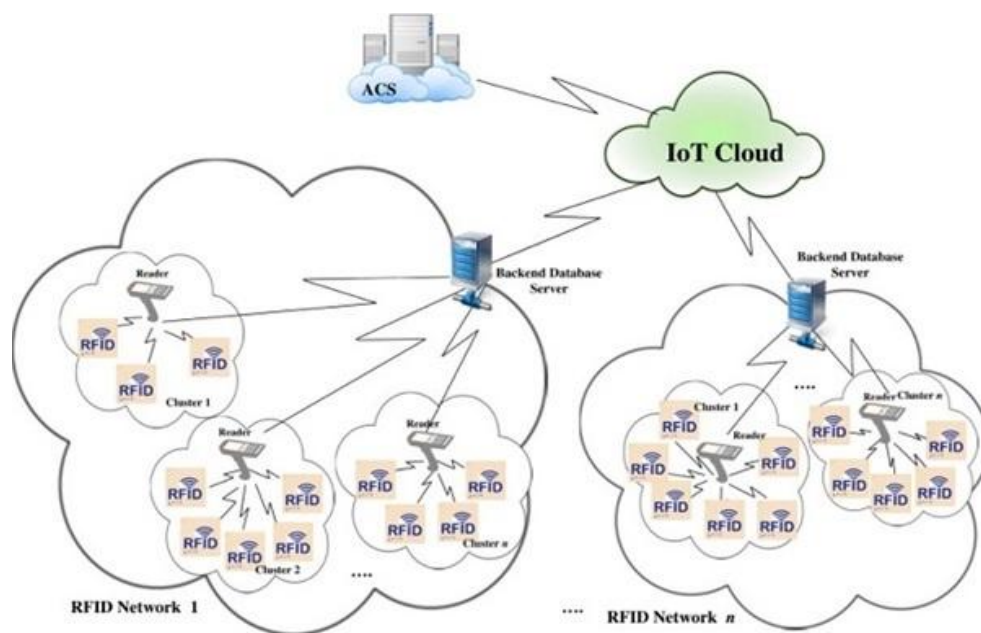


Figure 1: RFID playing key enabling role within IoT ecosystem

2. EXISTING METHODS FOR RFID TAG ANTI-COLLISION

In Literature, there are basically two approaches to RFID tag anti-collision algorithm development. The Deterministic or Tree-based method varies into Query Tree (QT) and Binary Tree (BT) algorithms while the probabilistic or ALOHA-based method evolved from Pure ALOHA to slotted ALOHA (SA) to frame slotted ALOHA (FSA) and finally to dynamic frame slotted ALOHA (DFSA). The media access control (MAC) component of EPC C1G2 which is the existing standardized RFID tag anti-collision protocol is DFSA based. This section elucidates the Pure ALOHA and Query Tree approaches.

2.1. Probabilistic or ALOHA-based Method

In pure ALOHA, when the reader is on, it sends a query requesting for the ID number (EPC code) of tags within its interrogation area using electromagnetic wave. Then the tags respond by randomly selecting time slots to make their IDs available to the reader. There is successful tag reading only when one tag responds to the reader query at time. However, there exists a probability that two or more tags transmit their IDs at the same time causing collision [12]. In the basic or pure Aloha protocol, tags can respond to readers' queries at any time [13], [14]. In 2012, [15] did a comparative study of pure ALOHA, slotted ALOHA, Frame slotted ALOHA and Dynamic Frame slotted ALOHA. They show that ALOHA can only work for a very few tags RFID application as it lacks the mechanism to detect or recover tag data in denser tag environment. Figure 2 demonstrates how collision happens in RFID systems using pure

ALOHA algorithm. In Figure 2, because there are no restrictions on how the communication channel should be accessed, all tags tried to respond to reader query at the same time causing both partial and full collision. The reader is unable to successfully identify any of both partial and full collision even when the number of tags are just five.

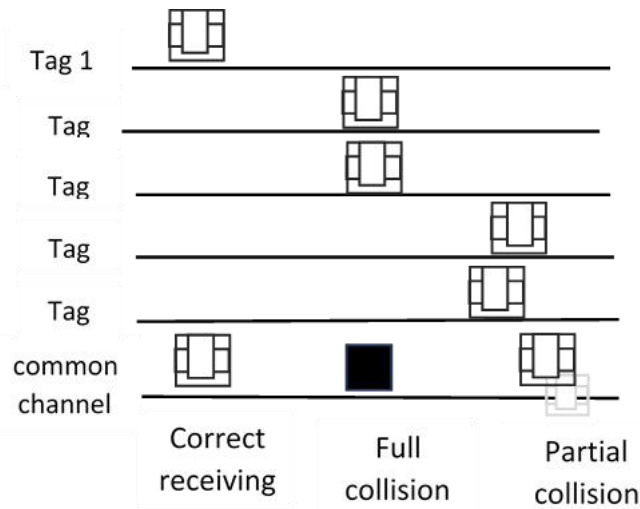


Figure 2: RFID tag collision using pure ALOHA method

According to [15] Collision occurs when the starting time for another frame satisfies the formula below:

$$(t_o - T_o) \leq t_1 \leq (t_o + T_o) \tag{1}$$

Where:

t_o is the initial time the RFID tag randomly selected a time slot

T_o is the duration the tag spent on the channel so as to be identified

t_1 is the time the tag accessed the shared channel

With throughput rate S , Input Load (data rate) G , [15] showed that:

$$S = G * P_1 \tag{2}$$

Where: P_1 is the probability of tags received or read correctly, and using Poisson distribution they showed that:

$$S = Ge^{-2G} \tag{3}$$

Reference [15] proved that the maximum throughput rate S of pure ALOHA algorithm is equal to 0.184 when the value of G is 0.5. Moreover, when the value of G is greater than 0.5, the throughput rate decreases rapidly and since increase in number means increase in the value of G , ALOHA can do little or nothing to preventing collision in large scale deployment of RFID tags which is IoT’s vision. ALOHA based algorithms have developed into Slotted ALOHA, Frame Slotted ALOHA, Dynamic Frame Slotted ALOHA and current research is targeted at Enhanced Dynamic Frame Slotted ALOHA [16], [17]

2.2. The Deterministic (Tree-based) Method

Deterministic or Tree-based RFID anti-collision protocols involves building Tree-like cycles from the root to the leaf using RFID tags EPC. During each identification cycle, a value is initiated from the previous cycle making it impossible for collision to occur in the next cycle. The Tree or Deterministic based algorithms are classified into the binary tree protocol (BT) and query tree protocol (QT) [16], [18]. In BT, the reader separates collided tags by randomly assigning a binary number to the tags and for QT, the collided tags are resolved by the reader’s query. In QT the RFID reader uses the RFID tags’ ID prefixes to avoid collision. The QT algorithm is achieved through rounds of queries (by readers) and responses (by tags) [19]. In each round, the reader queries the tags for prefixes in their IDs. If more than one tag responds, then the reader assumes there are more than one tag having that prefix.

As shown in Figure 3, the reader uses a frame L of 8 slots to successfully detect 5 tags in slots 3, 4, 5, 9 and 10 respectively. Initially, there was collision in slot 1, the reader then appends symbol “0” or “1” to the prefix and continues to query for longer prefixes to a pattern of 0’s and 1’s. When a given prefix matches a tag uniquely, that tag



is read by the reader. Hence, the prefix becomes longer and the number of ID's that match the new prefix decreases[19]. Therefore, by extending the prefixes until only one tag's ID matches, the algorithm can discover all the tags. From literature, different authors use different updating schemes for the prefix in their algorithms. For instance [20] used hash function in mapping tags to frame slots in their algorithm called STT protocol.

Where:

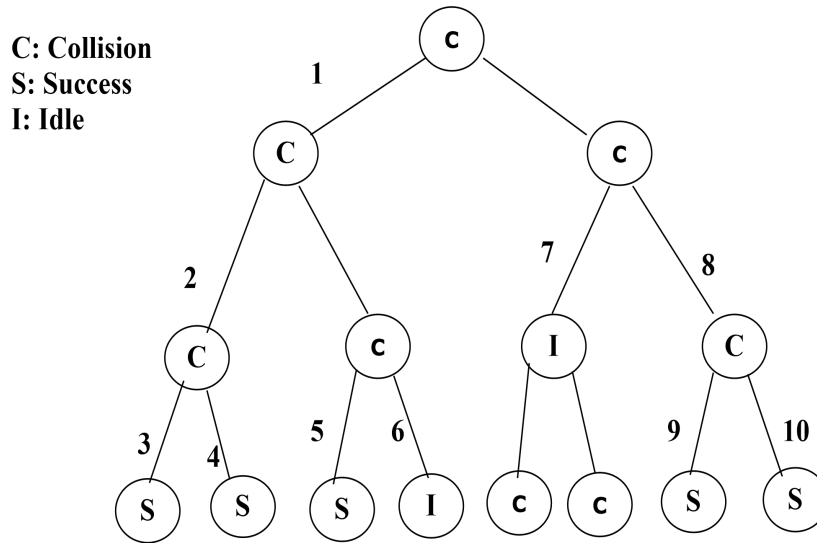


Figure 3: Tree-like structure of Query Tree (QT) method of RFID anti-collision Protocol

Deterministic approach generally are known to be recursive [21], [22]. However, they ensure no tag is left out in the identification effort [16], [23], [24] and that all tags will eventually be identified. That is to say Tree-based RFID anti-collision protocol conquer the tag starvation problem (TSP) [25]. However, because of its repetitive nature, this approach are always time, energy and space consuming. However, further sections of this paper which would focus on the simulation evaluation would further prove this assertions right or wrong.

3. PERFORMANCE ANALYSIS OF EXISTING METHODS TO RFID TAG ANTI-COLLISION

This section presents the nature of experiment carried out to implement and evaluate the two approaches. It presents the simulation environment, performance metrics and discusses the results of the evaluation.

3.1. Simulation Environment, Parameters and Performance Metric

The basic assumption made during the simulation is that the channel is error free and it's for a one reader scenario. The basic parameters used in the simulation are shown in Table 1. For the simulation environment, MATLAB was used to randomly generate 16-bit number that modelled each tag while different number of tags were constituted from 100 all the way to 1000 (representing dense or overcrowded IoT scenario). For the algorithm implementation, QT (see in figure 3) algorithm of the Tree (deterministic method) was used for the simulation study in MATLAB because according to the works of [26], among Tree based techniques, the QT is flexible and has less computational complexity. On the other hand, pure ALOHA was selected for baseline comparison over other variations of probabilistic or ALOHA method due to its simplicity [27], [28]. In the study, ALOHA was used in its pure form for fairness and to avoid any computational complexities that are inherent in the other variations of ALOHA (SA, FSA and DFSA) [29]. Furthermore, the communication channel is modeled with time slot as each slot represents unit access to the share channel. The time units for both reader-to-tag and tag-to-reader communication are shown in Table 1 as well as the values of the other simulation parameters.

Table 1: Simulation Parameters

Parameter	Value	Parameter	Value
Reader-to-tag Data 0	1 Tari	RTcal	37.5 μ s
Reader-to-tag Data 1	2 Tari	TRcal	50 μ s
Reader-to-tag rate	80kpbs	T1	62.5 μ s
Tag-to-reader rate	160kpbs	T2	62.5 μ s
Tpri	6.25 μ s	T3	100 μ s
Tari	12.5 μ s	Probe	4 bits
Feedback	3 bits	RN16	16 bits
Query	22 bits	ID	96 bits
Query Adj	9 bits	Ack	18 bits
R-T Preamble	112.5 μ s	QueryRep	4 bits
T-R Preamble	37.5 μ s	FrameSync	62.5 μ s

The performance metrics used in the study are tag identification rate (TIR) and total identification time slot. According to [30], TIR is the total number of tags identified per time unit in one query cycle. It is calculated as the total number of success slot divided by time

$$TIR = \frac{S_s}{S_T} \quad (4)$$

Where: S_s is number of success slot and

S_T is the total number of slots

On the other hand, the total time slot

$$T = S_s + S_c + S_i \quad (5)$$

Where: S_c = total number of collision slot and

S_i = total number of idle slot

4. RESULTS AND DISCUSSION

Firstly, it is seen from the tag identification rate (TIR) results of figure 4 that ALOHA based method performed excellently when tag population (tag density) was 500 and less while the Tree-based method (QT) could not guarantee the perfect identification of tags beyond 200 tag population. However, as the tag population increased (overcrowded) from 500 towards 1000 tags, ALOHA based method witnessed a fall in TIR to 0.985 while the Tree-based method TIR crashed to 0.90. The crash in TIR of QT can be attributed to the deterministic nature of tree-based methods. Tree-based method resolves tag collision after it has happened but probabilistic or ALOHA-based methods assumes collision and use probability in accessing the shared channel. This implies that the tree-based method does not support large scale deployment of tags per one reader, hence, might not be well suited RFID applications were tagged objects are overcrowded like in IoT. Besides, in most IoT applications of RFID, tag anti-collision protocols of less than 100% TIR is a serious issue [30]. Hence this paper recommends that for IoT applications of RFID, a threshold of one (1) reader to 500 tags should be used for RFID tag anti-collision design that suits IoT applications



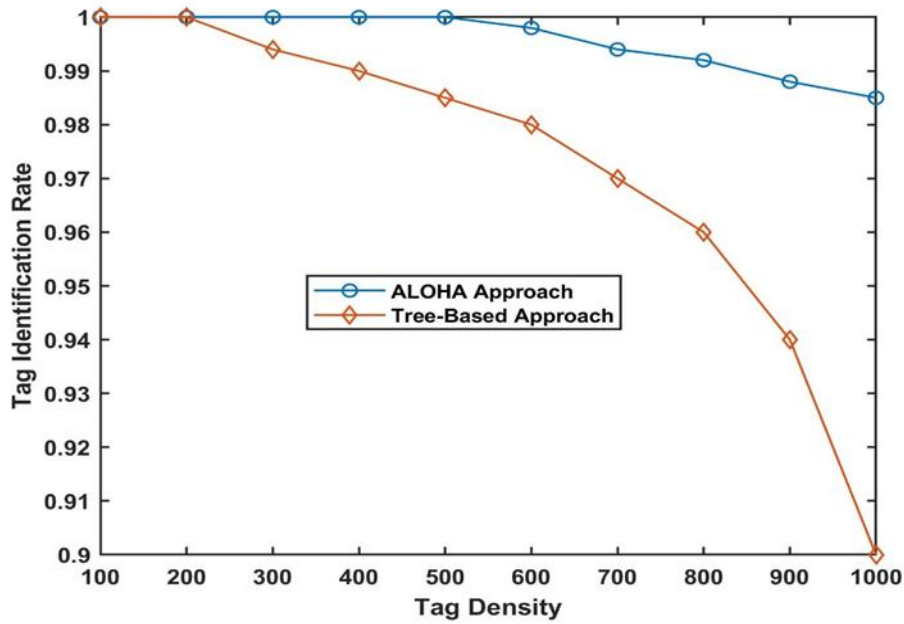


Figure 4: Simulation results of Tag Identification Rate (TIR) for the two Methods

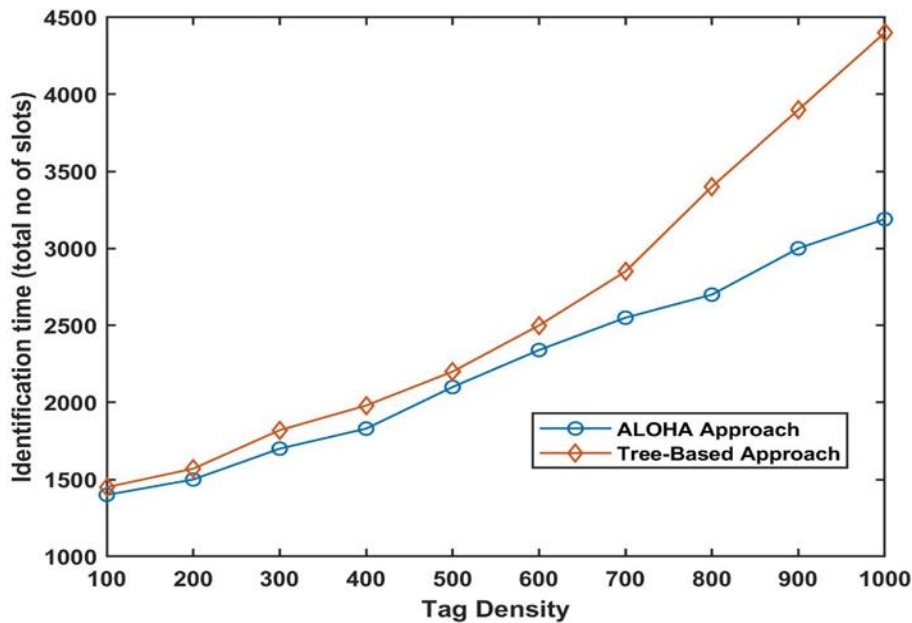


Figure 5: Simulation results of Total Identification Time (No of time slots) for the two Methods

In RFID research and as shown in equation (5), identification time as a performance metric is expressed as the total number of time slots a RFID reader utilizes in identifying all RFID tags within its read range [1], [7]. This is because the communication channel is shared into slots of time. Hence, all tags can only respond to reader queries using a given slot. Therefore, an efficient RFID tag anti-collision protocol is one that uses the least time slot in identifying given number of tags. From the simulation result of identification time of figure 5, there was no significant difference in time used by the two methods (ALOHA and Tree-based) when the number of tags (tag density) per reader were less than 100. This is because the Tree-based method used 1480 slots while the ALOHA-based method utilized 1460 slots when tags were 100. However, as the number tags increased to 600 and towards 1000, the tree-based method (QT) utilized almost 4500 slots (for 1000 tags) while the ALOHA-based or probabilistic method utilized just above 3000 slots. The large number of time slots utilized by QT (Tree-based) method can be attributed to the fact that QT is recursive in performing repeated prefix during collision resolution [21], [22]. Hence, QT uses additional time slots in identifying tags both when there is collision and where there is no collision. This implies that the probabilistic method takes significant lesser time in identifying RFID tags when tags are overcrowded (up to 1000 tags).

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Internet of things promises to enable objects and things around our environment and offices with internet connectivity and data exchangeability. RFID plays a major enabling role in sensing and identification. This paper addresses one important challenge with deploying RFID on an IoT scale – tag collision problem. The contributions made in this paper enhances existing RFID tag anti-collision by performing a simulation analysis of existing methods used in developing existing RFID tag anti-collision protocol in view of IoT scale. Results of tag identification rate (TIR) and identification time show the probabilistic method is promising in developing an RFID tag anti-collision protocol that would be robust enough to support the overcrowded nature of RFID tags in IoT applications. Finally, from the results of the simulation analysis, optimal performance is observed when the number of tags per reader is approximately 500.

5.2 Recommendations

Hence, it is recommended that future enhancement or updates to RFID tag anti-collision protocol design should consider five hundred (500) tags per reader threshold for efficient and effective tag identification and sensing in IoT applications

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