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Research Paper

Hybrid Dynamic-Binary ALOHA Anti-Collision Protocol in RFID Systems

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Abstract

The main techniques for identifying objects in an Internet of things environment are based on radio frequency identification, in which a specific object is identified by the reader through the tag mounted on the object. When there are multiple tags in the reader's interrogation zone, they respond simultaneously to the reader's request, thus causing a collision between the signals sent simultaneously to the reader from those tags. Such collisions reduce the data accuracy and prolong the identification time, thus making it difficult to provide a rapid service. This paper explores a hybrid anti-collision protocol, namely, the hybrid dynamic-binary ALOHA anti-collision protocol, which is designed to prevent tag collision and to enable more stable information transmission by improving the existing tag anti-collision protocols. The proposed protocol has achieved performance enhancement by shortening the tag identification process when tag collision occurs by combining the ALOHA and binary search protocols. In contrast to the existing protocols, whereby the reader's request is repeated after detecting a collision, the proposed protocol shortens the tag identification time by requesting only the collision bits. This contributes to a substantial reduction in the object identification time in an IoT environment.

Keywords: *RFID; Tag collision; Reader collision; ALOHA; Binary search tree; IoT.*

1. Introduction

Object recognition technology is essential for applications in ubiquitous computing and Internet of Things (IoT). Radio frequency identification (RFID), a technology used to identify specific objects and manage them in a ubiquitous sensor network environment, is a widely used core technology of IoT.
A typical RFID system comprises two components: a tag and reader. A tag mounted on an object contains identification data and sends out that information in response to the request message sent from the reader. The reader reads the information sent from the tag, identifies the corresponding object, and transfers the object information to the server. Currently, the tag works in a passive manner.
As the operation principle of an RFID system is the use of radio frequencies (RFs), the reader generates an AC magnetic field in the radio frequency range. If a tag that comprises the resonance circuit moves near the AC magnetic field, the energy of the magnetic field is induced into the resonance circuit of a tag through the receiver coil of the antenna, and the tag presses back the external AC magnetic field to a reader with data such as ID and bit strings for identification. This reaction is detected through a small change in the voltage drop across the oscillator coil of the transmitter, and the data is recognized.
A tag and reader are not in one-to-one correspondence, and a reader can face with multiple tags. This leads to collisions within an RFID system in the tag identification process, thus slowing down the data identification rate. The collision problem is divided into the reader and tag collisions.
A reader collision occurs in a multi-reader environment wherein two or more readers using the same frequency attempt to recognize a tag in the same interrogation zone, thus causing frequency interferences that prevents them from identifying the tag (Figure 1). Tag collision occurs in a multi-tag environment wherein two or more tags within a reader's interrogation zone respond simultaneously to the reader's request, thus preventing the reader from correctly identifying the data sent from the intended tag, as illustrated in Figure 2. Generally, collisions lead to erroneous information transmission or recognition failure, thus stagnating the information transmission and causing wastage of power and resources by prolonging the tag identification time.
The reader collision problem can be addressed by changing the frequency or data reading time slot and is thus less prone to data loss as compared with tag collision. Therefore, this study is aimed at increasing the tag identification rate by controlling the tag collision, which is prone to direct data loss.
RFID standards propose the use of the ALOHA, binary search (BS), and query tree (QT) protocols as tag anti-collision protocols. The existing protocols are configured to resend the request on detecting a collision during the tag identification process, thus causing the process to be repeated and prolonging the identification time. This is not suitable for applications in IoT and wireless-sensor-network (WSN) environments wherein real-time object identification is essential.
In this paper, conventional tag anti-collision protocols, such as the slotted ALOHA, dynamic framed slotted ALOHA (dynamic FSA), BS, and QT protocols, are analysed and a new anti-collision protocol is developed. The proposed hybrid ALOHA anti-collision protocol enables more stable information transmission by preventing tag collisions and reducing carrier power. The proposed protocol combines the dynamic FSA and BS protocols, and is the first attempt in this field for anti-collision. There is a need of attempting of state-of-the-art anti-collision protocols to inspire new research

efforts in the study. The proposed hybrid anti-collision protocol aims to serve for this purpose.

The achievements of this paper can be summarized as follows:
- This is a new protocol with enhanced tag anti-collision performance in RFID systems.
- Users are provided with rapid services in IoT and WSN environments by minimizing the tag collisions.
- The tag recognition time is reduced as compared with that of the existing protocols that repeat the identification process when a collision occurs.
- The probability of a tag collision is minimized by merging the dynamic FSA and BS protocols.

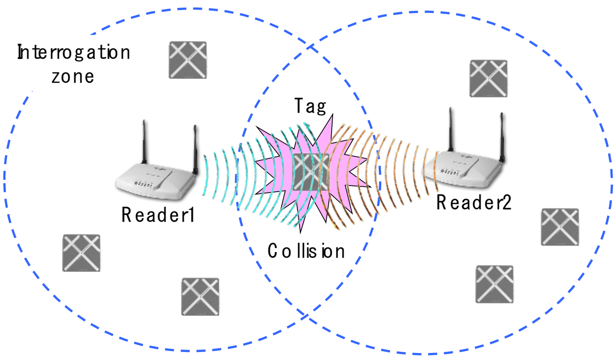

Fig. 1: Reader collision: when multiple readers attempt to read a tag at the same time, no readers take data from a tag.

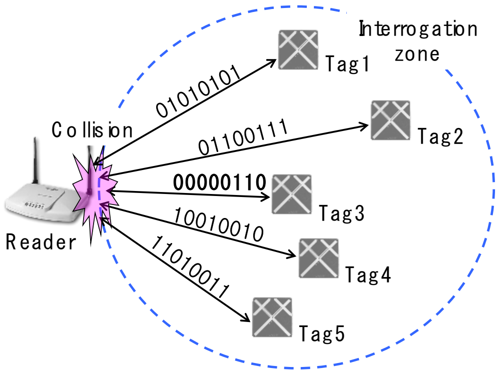

Fig. 2: Tag collision: when multiple tags respond to the reader at the same time, no tags' data reach a reader.

2. Related works

The research trends for tag anti-collision protocols can be referred to in the EPCglobal and ISO Standards. EPCglobal is a main enterprise in RFID companies. Table 1 presents the major protocols proposed by the standards. The protocols are divided into two types, tree type and ALOHA type, respectively [1].

Table 1: Standards of tag anti-collision protocols

Protocols	Standards	Summary
Binary Search (BS)	EPCglobal Class-0 (bit-based) ISO 18000-6B	Request collided bits from tags and identify tags.
Query Tree (QT)	EPCglobal Class-0 Gen 1	Identify tags by transmitting a prefix.
Slotted ALOHA	EPCglobal Class-1 Gen 2	Identify tags in time slots in a frame.
Dynamic Framed slotted ALOHA (FSA)	ISO 18000-6A	Identify tags by changing the size of the frames according to the tag collisions.

2.1. Binary search (BS)

BS uses the collided bits in tag data [2][3]. BS sends unique serial numbers to all tags at a fixed time in sync with the reader. This enables the location identification of the collision bits when a collision occurs. For example, if a collision occurs at bits 0, 4, and 6 of a received serial number with the values of other bits overlapping, there are two or more tags in the reader's interrogation zone. According to the BS protocol, this means that there are up to eight detectable tags related to the three collision bits ($2^{3\text{-}bits}$).
The BS protocol starts from the most significant bit (MSB) in order to detect the collision and moves on to the next request after converting 1 to 0 and 0 to 1 according to the rule of narrowing down the search range by excluding the MSB until it reaches the least significant bit. For example, a collision occurring at the bit [1X1X001X] points to the existence of at least one tag between [≥11000000] and [≤10111111]. Figure 3 illustrates the tag identification process whereby a tag is identified as a result of the request repetition, and Figure 4 presents the logical tree structure representing the data comparison process.

Down Link	REQUEST <11111111	Loop1	REQUEST <10111111	Loop2	REQUEST <10101111
Up Link		1x1x001x		101x001x	
Tag1	→	10110010	→	10110010	
Tag2	→	10100011	→	10100011	
Tag3	→	10110011	→	10110011	
Tag4	→	11100011		-	

Down Link	REQUEST <10101111	Loop3	SELECT 10100011	Read, Write	-
Up Link		10100011		↕	
Tag1					
Tag2	→	10100011		10100011	
Tag3					
Tag4					

Fig. 3: Tag identification of binary search.

2.2. Query Tree (QT)

In contrast to ALOHA-based protocols, tree-based protocols do not have the tag starvation problem [4], i.e., a state in which some tags remain unidentified for a long time owing to continuous collisions. In particular, the tags are identified by responding to any of the 1 to (n-1) prefixes transmitted by the reader in QT protocols. The QT-based approach is also called the memoryless tag anti-collision protocol because there is no need to remember the current ID bits [5]. The QT receives the unique numbers of all the tags in the reader's interrogation zone, as shown in Figure 5 [6], and locates the collision bits. In this method, one value is randomly selected from the collided MSB and only the tags having a higher or lower unique number than that value are allowed to respond. [5] shows an improved QT obtained by analysing the characteristics of the IDs of the tags. The key feature of the improved QT is the collision bit check from the first bit of the ID for solving the collision problem of a collided set of tags, drawing on the fact that tags usually have similar IDs with only a few last bits varying from one another.

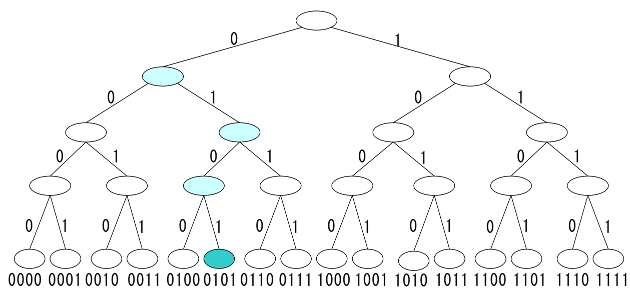

Fig. 4: Binary search and identification of bit collision.

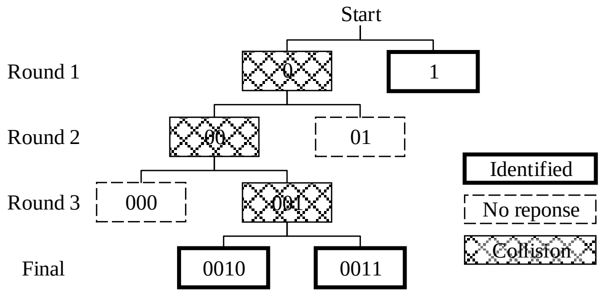

Fig. 5: Query tree and collision detection.

2.3. Slotted ALOHA

In the slotted ALOHA protocol, the number of slots is fixed in each frame, and the number of frames is predetermined. If the reader broadcasts information regarding the frame size and selected slot to the tags, each tag selects its own slot. A collision occurs when two or more tags enter the same slot, and the reader broadcasts new information for the tags to select their slots, as shown in Figure 6 [7]. For example, a downlink is a frame allocated from the reader to tags, and an uplink is a link transmitted from tags to the reader. If the protocol provides only three slots per frame, the data transmitted from the tags in response to the reader's request collide in Slots 1 and 2, and the collision-free tag is identified in Slot 3. The identified information is then transmitted to the server. Subsequently, the reader resends the request to the collided tags, data received from the tags are allocated to Slots 1–3, and the collision-free data in Slots 2 and 3 are transmitted to the server immediately. In this manner, the slotted ALOHA protocol can be used to solve the tag collision problem by repeating the retransmission requests.
This protocol is simple and easy to implement and understand, however, there is high identification cost to identify all tags in an interrogation zone of a reader.

2.4. Dynamic framed slotted ALOHA

In contrast to the slotted ALOHA protocol, in which the frame size is predetermined and same-size frames are sent with the same slots allocated whenever a collision occurs, the dynamic slotted ALOHA dynamically varies the frame size according to the data collision rate [8]. A frame has one or more slots and the number of slots is changeable. If the number of collided slots exceeds the threshold (*e*), the frame size is increased, and if the number of empty slots increases, the frame size is reduced (in detail, be increased or decreased slots).
The dynamic FSA has a higher collision avoidance rate than the slotted ALOHA because it estimates the number of required frames using a random variable for the number of tags and adjusts the frame size according to the collision rate.
This protocol is smarter than the slotted ALOHA in terms of collision avoidance. However, it also repeats the same process until all tags are identified, whereby the bits of the collision-free tag data are repeatedly identified, resulting in a prolonged tag identification time.

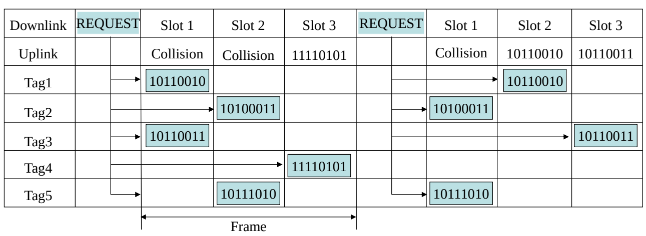

Fig. 6: Slotted ALOHA with fixed slots in a frame.

3. Hybrid dynamic-binary ALOHA anti-collision protocol

This section describes the distinctive features of the hybrid anti-collision protocol that is used for improving the tag identification performance of the existing ALOHA-based anti-collision protocols.

3.1. Dynamic frame-based threshold: improvement of the conventional ALOHA

The basic tag identification process of ALOHA comprises the following steps: broadcasting the time slots allocated to the tags, recognizing the tag arriving at a slot without collision, and reallocating slots to the collided tags to induce them into different slots. This process is repeatedly performed until the last single tag in a slot has been identified without collision. The total tag identification process time can be calculated as follows. In Equation (1), the number of bits means the size of tag data and it determines the identification time.

Number of tags × Number of bits + {Number of collided tags × Number of bits},({…}: gradually decrease) (1)

The existing ALOHA-based studies have attempted to realize tag identification performance enhancement by adjusting the time slot and frame size for reallocation. However, given the request repetitions for the collided tags, further improvement is necessary.
In this paper, a method for reducing the tag identification time is proposed through the shortening of the process of request repetition and slot reallocation, thus reducing the drawbacks of the dynamic FSA. For example, in the tag identification process, the size of the frame required for the next round is determined as follows. The number of slots is calculated by taking into consideration the uplink transmission from each frame slot and collision rate. This method appears to be similar to the existing one. However, in this study, the frame size is limited by the threshold *e* that is set relative to the bit length of a tag identified by locating the collision bit. Moreover, the retransmission request is limited to the collision bit, which reduces the processing time as compared with the retransmission of the entire data.
Figure 7 illustrates a case wherein the length of a frame is increased to four slots and all tags are allocated to each time slot according to the result of the dynamic frame number calculation. If a collision occurs when there are two slots, the number of slots is increased to three, and the collision-free data in Slot 2 are transmitted to the server. Subsequently, new data are allocated to Slot 2, and if collisions continue to occur, the number of slots is increased to four. As the remaining four data are allocated to the four slots, no collision occurs, and all four data are transmitted to the server, and the tag identification process is terminated. In the last frame, the number of data reading times is 32 (4 slots × 8 bits), although four data are allocated to four separate slots.

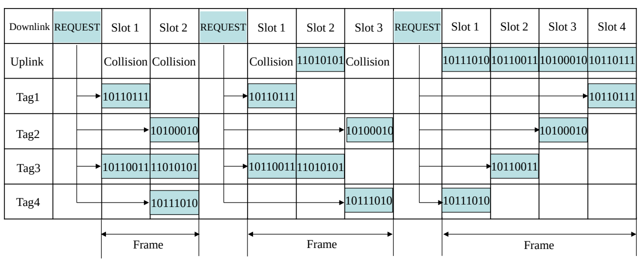

Fig. 7: Dynamic framed slotted allocation of proposed scheme.

The process of the frame size calculation based on the collision probability of each slot is employed from [10]. The details of the calculation steps are in [10], and brief steps are as follows. First, the delay time *D* required for the tag to send its ID to the reader is the number of retransmissions multiplied by the frame size. The frame size can be determined after the running of a round. The probability P for a tag to successfully transmit its ID per slot can be obtained from Equation (2). Here, L_{frame} is the frame size. Equation (3) represents the transmission probability per frame.

$$P_{success} = \frac{1}{L_{frame}} \times (1 - \frac{1}{L_{frame}})^{n-1} \quad (2)$$

$$P_{success} = \frac{1}{L_{frame}} \times (1 - \frac{1}{L_{frame}})^{n-1} \times L_{frame} = (1 - \frac{1}{L_{frame}})^{n-1} \quad (3)$$

The optimal frame size that reflects the collision rate can be derived from Equation (2) and (3), and is given by Equation (4). The optimal frame size L_{frame} is determined as the value when the delay time D is a minimum.

$$\frac{d}{dn}D = \frac{d}{dn} \cdot \frac{L_{frame}}{\left(1 - \frac{1}{L_{frame}}\right)^{n-1}} = 0 \quad (4)$$

The tag collision continues to occur because the optimal frame size is determined by a probability-based calculation. If the collision rate exceeds the threshold e, the number of frames should no longer be adjusted, and the collision bit must be calculated instead. The threshold is calculated as the ratio of the total number of bits transmitted to one slot and the number of collision bits as given by Equation (5).

$$number\ of\ collided\ bits\ /\ total\ bits \leq e \quad (5)$$

3.2. Application of the ALOHA-based BS

In the proposed protocol, the frame size is adjusted whenever a collision occurs in a slot during tag identification. If the frame size exceeds the predetermined threshold e, the request for the tag data is not repeated by the frame unit to improve the identification performance. Instead, the collision bit location is saved in the memory of the slot by marking it with an X in the same manner as in BS. The tag data transmission time can be reduced by sending the retransmission request to the bit corresponding to the location of the collision.
Figure 8 illustrates the dynamic FSA, where the frame size is varied dynamically according to the collision trend. In the exemplified case, the number of frame slots is adjusted dynamically while taking into account the collision rate until the frame size reaches the threshold e at frame n, and the collision bit is identified as 101X0X1X when a collision occurs in Slot 3.

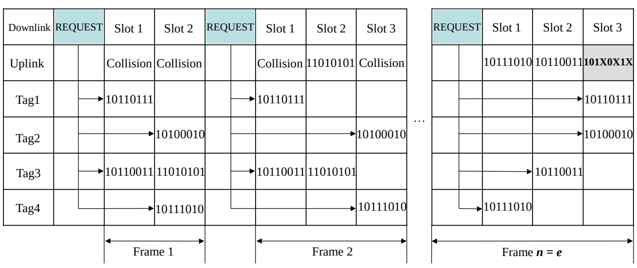

Fig. 8: Identifying tag collision in a dynamic environment.

The reader then saves the collision bit location in the memory and sends the data retransmission request to the first collision bit from the MSB of the data. The remaining collision bit locations marked with an X are also resolved by request repetition. This reduces the collision resolution time as compared with the method of retransmitting the entire data containing the collision bit. Figure 9 presents the algorithm of the proposed protocol. First, the frame number is adjusted according to the collision rate and the retransmission message is broadcast to the tags.
The tags check the time slots allocated to them and respond to the retransmission message. If the recalculated frame size reaches the threshold value, the reader marks the collision bit with an X and saves it in the memory. The reader broadcasts the instruction to ignore the bits up to (MSB - 1) among the collision bits of the tags. That is, the reader requests only the *K-th* collision bit information, and the corresponding tags transmit only the collision bit.

4. Performance evaluation

4.1. Simulation Environments

Owing to the difficulties associated with the simulation of the real environment in the construction of a large number of tag data and the reader, experiments were performed using virtual tag data. In order to compare the tag collision data, the virtual data were configured to contain 50% of the collision data. In the tag data collision experiments, the protocols proposed by the RFID standards, namely, the slotted ALOHA, dynamic FSA, and hybrid dynamic-binary ALOHA (D-B ALOHA) were compared by measuring the tag identification time and the cost for collision-associated data retransmission time.

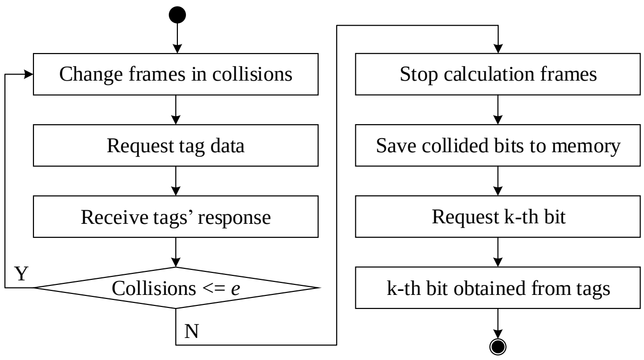

Fig. 9: Algorithm for detecting collisions by identifying collided bits in each frame.

A simulation was performed using the network simulator OMNeT++ [10], and the virtual tag data were obtained using the data generator DaVisual Code [11]. The data distributions are plotted as uniform and skewed distributions in Figures 10 and 11, respectively. Both sets of data contained collision data.
The skewed distribution data were generated to examine the collision avoidance efficiency when the tags are densely distributed. The conditions for the skewed distribution data generation are presented in Table 2.

Table 2: Configuration of skewed dataset generation

World Settings:
Dimensions [1..3]: 2
Size [1..100000, 1..100000]: 50000, 50000
Generator Settings:
Boxes created [1..100000]: 30000
Variable size of boxes: No
Non-zero size of boxes: Yes
Distribution: Skewed (p: 0)
Seed [1..65535]: 9445

The structure of the tag data generated is a C++ class, comprising <x, y, id, 8-bits data>; x and y are the tag location information and the 8-bit data stands for a product information briefly. All data is transmitted to the reader, and it is prone to collision at a reader's interrogation zone with multiple tags. Table 3 outlines the simulation environments.

Table 3: Simulation environments

Category	Summary
Dataset	Virtual data using generator
Tags	30,000 tags
Ratio of collision data	50% of tags
Distribution	Uniform, Skewed
Programming Language	C++
System	Linux(Fedora), RAM 8 GB, Intel Xeon 3.2 GHz

4.2. Analysis of Performance

The set of data used in the experiments totalled 30K and were divided into six subsets of 5K units. The performance was expressed as the mean value of 10 runs per data set.
In the experiment, the tag identification speed, i.e., the time taken for the reader to identify the given tag, was measured. If a collision occurred, the time taken to identify the tag after resolving the collision problem was measured because obtaining an accurate identification of the collided data was not possible.

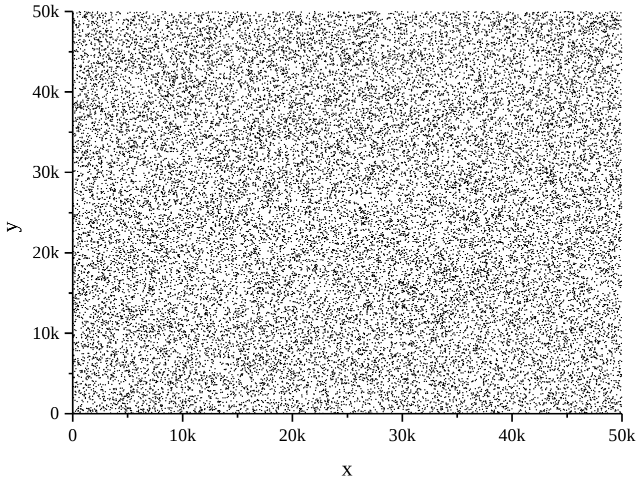

Fig. 10: Synthetic tag dataset in uniform distribution.

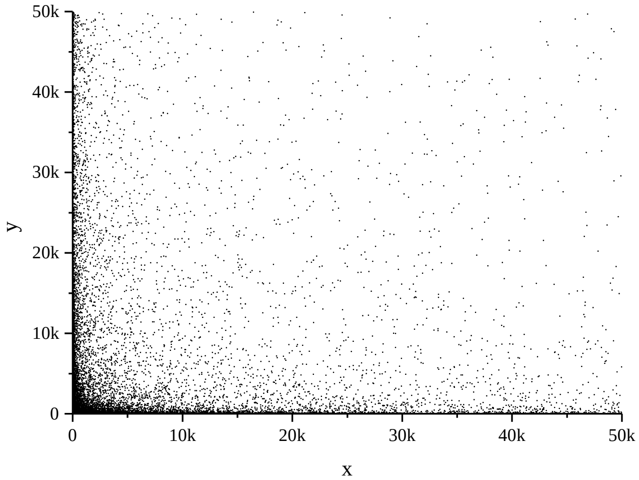

Fig. 11: Synthetic tag dataset in skewed distribution.

The performance for the reader to identify each tag is displayed as uniform and skewed distributions in Figures 12 and 13, respectively.

As shown in Figure 12, if the tags distributed in a certain space displayed a standard distribution, the dynamic FSA was found to be advantageous over the slotted ALOHA in identification speed, because the number of slots per frame was increased to facilitate the tag data identification in the presence of a collision. In addition, the greater the number of tags, the greater the difference between the two protocols. The hybrid D-B ALOHA protocol uses a method of bit-by-bit collision detection in the BS, which is faster than the dynamic FSA. The overall tag identification speed was comparatively high, although it slowed down slightly for the 20K dataset.
The results of the tag identification time measurements with a skewed tag distribution are plotted in Figure 13. The skewed data showed dense distributions along the x- and y-axes. Based on the experimental results, it can be observed that the slotted AHLOA, dynamic FSA, and hybrid D-B ALOHA protocols show similar performances for a dataset size of 5K.
In the skewed distribution, the existing protocols identify the tags more rapidly than in the standard distribution, presumably because low-density regions are contained in the skewed distribution subset. However, the tag identification time increased as the dataset size increased because of the increased density of the skewed data, increasing the data collision risk. In contrast, the proposed protocol shows a gradual increase in the tag identification time even when the number of skewed data increases and finally displayed the highest data identification speed.

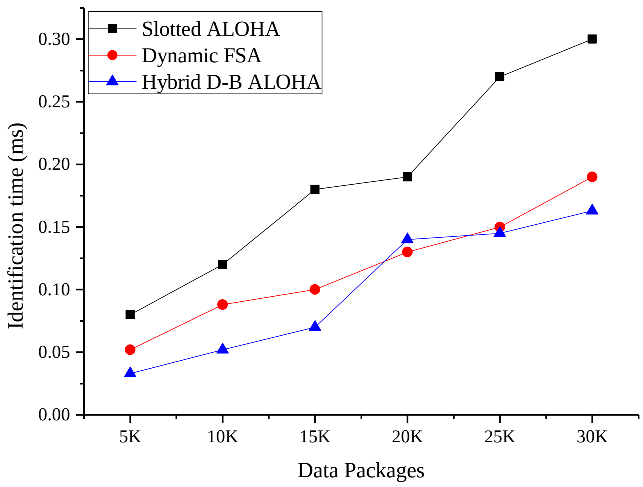

Fig. 12: Identification speed in uniform dataset.

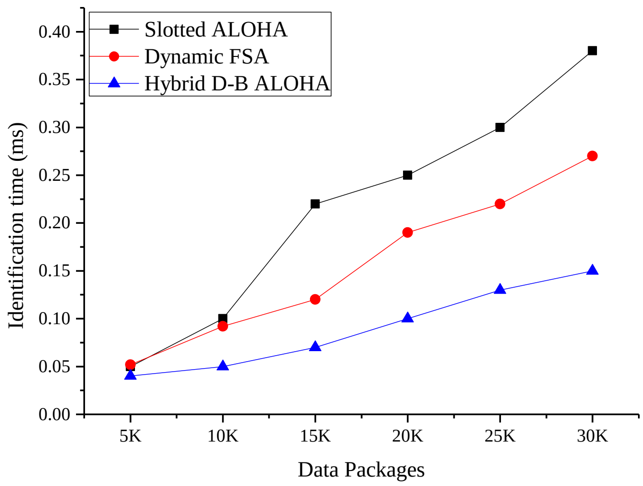

Fig. 13: Identification speed in skewed dataset.

5. Conclusion

The RFID tag anti-collision protocol, hybrid D-B ALOHA, proposed in this paper was designed to improve the tag anti-collision efficiency and shorten the tag identification time by resolving tag collisions. These attributes are essential for identifying objects in the IoT environment and a rapid data identification will contribute to enhancing the quality of service provision in the computing environment.

The proposed protocol uses a hybrid protocol combining the dynamic FSA and binary search protocols in an effort to overcome the drawback of the slotted ALOHA protocol, which is based on time slots.

The rapid tag identification speed of the proposed protocol, as demonstrated in the experimental results, is attributable to the reader's request to retransmit only the collision bits when rebroadcasting the instruction after detecting the collision. This is in contrast to existing protocols in which the reader requests to retransmit the entire data of the collided tag, thus causing a delay in the tag identification. Rapid data transmission is essential for rapidly identifying objects and reducing the service provision speed.

Acknowledgement

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