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Integrated reader and tag anti-collision protocol in RFID systems based on similar topology trees

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Abstract: This paper describes a new fast anti-collision algorithm for Radio Frequency Identification (RFID) system. In this paper, an efficient protocol is introduced for anti-collision of tags and readers in multi-tag multi-reader environment. The proposed anti-collision protocol is based on constructing Similar Binary Trees Topology (STT) for all readers in the collision domain. The novelty of our protocol is the Parallel Binary Splitting (PBS) identification path that will be used in the tag identification process. All readers are synchronised to reply similar information and build similar binary trees topology. The identification time is divided among the tags and the readers. One bit reply will be sent sequentially (one-to-one bit dialog) in the identification process. The tags in the overlapped reader-region will be identified one time only. The integrated treatment of the collision problem provides minimum bit transmission with minimum overhead, higher throughput, and simple logic operation. Performed computer simulations have shown that the proposed collision recovery scheme is very fast and simple.

Keywords: RFID; radio frequency identification; anti-collision protocol; tag collision problem; reader collision problem; binary tree protocol; parallel binary splitting; similar topology trees.

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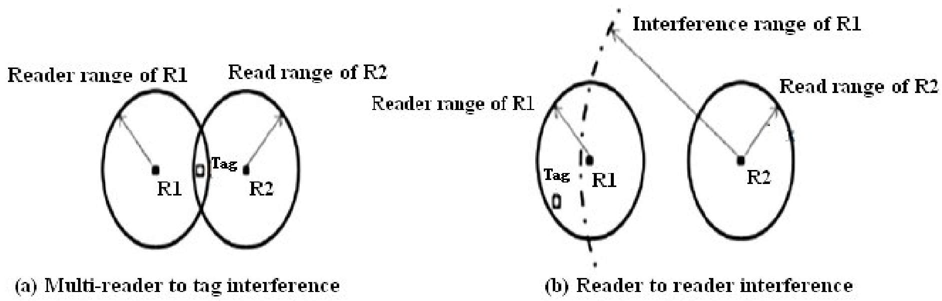
1 Introduction

The Radio Frequency Identification (RFID) system consists of electromagnetic readers and tags network, where the readers try to identify the tags as quickly as possible via wireless communications (Bonuccelli et al., 2006). However, since the readers or the tags are communicating over the same shared wireless channel, the collision problem in signal transmission occurs, which leads to slow in the identification process. Thus, it is a key issue to develop an efficient anti-collision protocol, reducing collisions, so as to identify all tags in the interrogation zone. It is important to note that the RFID tags can be active or passive, according to their technology. Active tags are continually powered by internal batteries, while passive tags have no internal power. To meet advancements in protocols and circuits design, cost, size and lifetime requirements, passive tags seem to be the best solution for RFID systems, and we focus on them in this paper. A passive tag has no internal power source; it is energised by harvesting energy from the electromagnetic radio waves transmitted by the reader and received by the tag antenna. Passive tag has very limited resources of power and computational logic. It is unreasonable to assume that the tags can directly communicate with each other or can detect the collisions. Passive tags use load modulation by reflecting the reader energy to set up a communication with the reader. There is asymmetric channel strength between the forward (tag-to-reader) and the backward (reader-to-tag) channel. Hence, each reader has a limited reading range. Collisions in RFID system are divided into reader collisions and tag collisions. The tag collision occurs when several tags try to answer the reader query at the same time. Messages would collide on the communication channel and thus cannot be interrupted by the reader. The other collision problem is the reader collision. Reader collision problems arise when multiple readers are simultaneously used in intersected interrogation zones. Reader collisions prevent the colliding readers from communicating with all the tags in their respective reading zones. In some applications, for improving reading rate and ensuring the coverage the whole existing tags in the environment, several readers are put together to form a dense RFID reader environment with intersected interrogation zones. Besides the existence of mobile RFID, readers can be installed in a cellular phone and services are provided over telecommunication network. The two collision problems reduce the reading throughput (number of reading tags per time unit). Resolving collisions has been a consistent research subject in wireless communication, included RFID systems. When the collision problem is solved, RFID system works effectively. Although both collisions modes (tags and readers collisions) increase the identification delay in RFID system, all previous research work discussed the tag and the reader collision problem separately. There are two sources of reader collision problem as shown in Figure 1. Multiple readers-to-tag interference occurs if the position of the tag is in the overlapped-reading ranges of several readers. In this case, more than one reader attempts to communicate with the same tag at the same time. The tag cannot communicate correctly because it cannot distinguish the reader. The tag receives multiple queries at the same time as shown in Figure 1(a). Reader-to-reader collision occurs when there is unwanted signal from nearby readers interfering with tags. This interfacing process produces masking of the low level tag transmission mission from being recognised by the nearby reader. It can occur even without intersection of the reading zones as shown in Figure 1(b).

Figure 1 Sources of reader collision problem



2 Background and literature review

2.1 Tag anti-collision protocols

In RFID system, there are two approaches of tag collision resolution scheme: (1) probabilistic algorithm which is based on ALOHA. In general, ALOHA-based protocols cannot perfectly prevent tag collisions because of the probabilistic procedure that allows random medium access in the identification process (Bonuccelli et al., 2006). (2) Deterministic algorithm (tree-based protocols) which detects collided bits and splits disjoint subsets of tags. The reader in Query Tree (QT) protocols sends a query containing a prefix having length of 1 to n bits. The tags whose prefixes match with the bits sent by the reader replies back with their tag ID. The reader asks the tags to answer if their ID matches the given prefix (Sahoo et al., 2006). There are different schemes of the basic query tree protocols as in Choi et al. (2007), Guo and Hu (2007), Li and Feng (2008), Cho et al. (2008), Liu and Chan (2009) and Bang et al. (2009) for reducing the exchanged overhead information between the reader and tags, and to have shorter identification time. For example, Bang et al. (2009) proposed Bi-Slotted Query Tree Algorithm (BSQTA) and Bi-Slotted Collision Tracking Tree Algorithm (BSCTTA) are presented. For fast tag identification, BSQTA and BSCTTA use time divided responses depending on whether the collided bit is ‘0’ or ‘1’ at each tag ID. The reader sends n–1 length inquiring bits (prefix) once to tags instead of sending the same prefix twice with different last bit. It reduces both prefix overhead and iteration overhead. There are different schemes of counter-based protocols as in Jihoon Myung et al. (2006), Guo and Ding (2006), Myung et al. (2007), Kim and Park (2007), Chen et al. (2007) and Chen et al. (2010) In Guo and Ding (2006), the tag uses its internal counter to determine when it changes the state from Quiet state to active state. The reader must send query bit of the last collision bit position to inform the tags with the last stop bit position. In Kim and

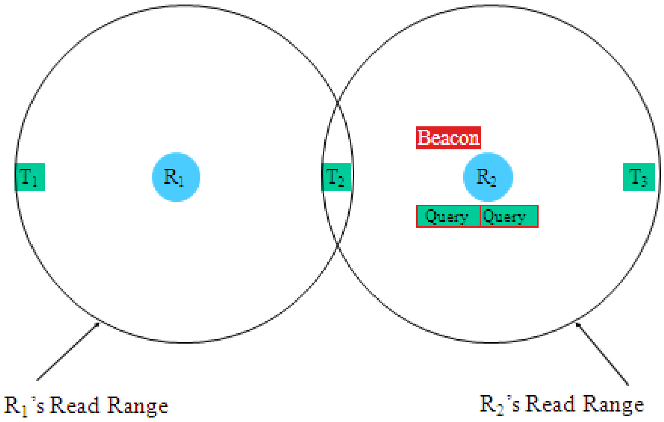
Park (2007), the basic search criterion is the Depth-First Search (DFS) algorithm. But, the reader command frame is long and it must contain the bit position of the most recently occurred collision. In Myung et al. (2006, 2007), Adaptive Binary Splitting (ABS) uses counter to reach the goal of anti-collision, but the splitting of sets depends on the generation of random binary number {0, 1}. So, it cannot achieve the best splitting result. The probability of occurrence of 1 or 0 is not 50%. At any moment, there won't be any splitting result, and may cause the next timeslot to be idle timeslot or collided timeslot. Consumption of timeslots and longer timeslot are the main drawback of the ABS protocol. A new idea in Chen et al. (2010) is introduced to reduce the probability of collision efficiently and to make fast identification. It reduces the length of the time slot by truncating unnecessary data bits to minimise the receiving time. The reader does not need to receive any data after receiving the first collided bit. A feedback message is sent by the reader to inform the tags about the type of a timeslot (collision, idle, readable or multiple-readable). Feedbacks are just like instructions and include operating code and some other information. The operating code in three bits is used. But in the other side, it has long reader instructions and the reader must inform the tag the position of collided bit in the collision code, for example, Opcode||Query String = 000||0010.

2.2 Reader anti-collision protocols

Because of the low functionality of the passive tag, the tag-reader interference can be avoided by involving the neighbouring readers processing at different times (Engels and sarma, 2003). Hence, most of the proposed protocols utilise the TDMA scheduling to prevent the simultaneous signal transmission of the readers. In Colorwave algorithm (Engels and sarma, 2003), a distributed TDMA-based protocol, the time is divided into frames and each frame is divided into a number of slots. Each reader selects randomly (colour) any time slot and reads the tags in its own time slot. If there is a collision, the reader selects a new time slot and sends a kick (small control packet) to its neighbours. The frame size can be increased or decreased according to percentage of collisions. Colorwave can reduce reader collisions by adjusting the frame size according to the collision probability. However, randomly selecting the time slot in the next frame interrupts the tag reading from another reader in the same time slot and produces collision. In the channel monitoring algorithm (Lee and Lee, 2006), each reader chooses the time slot with minimum occupied probability. Thus, collisions caused by randomly choosing a time slot are reduced. In Dong Wang et al. (2006), there is a central operating device – Central Cooperator (CC) technique. It converts the present 'Multiple Points to Multiple Points' (MP2MP) collision problem into two 'Multiple Points to One Point' (MP2P) classical collision problems. The reading queries from several readers are multiplexed by CC and the same tag information could be stored and shared among adjacent readers. Central server is used to receive the reader request and its position information in Eom and Lee (2008). The server decides whether a reader is safe to operate without collisions relative to the currently operating neighbours or not. If the server concludes that several readers may be interfered, it does not respond to the request. It defines the efficiency as the number of simultaneously operating readers per millisecond in an area.

In literatures (Birari and Iyer, 2005; Song et al., 2008; Liu et al., 2008; Yu and Lee, 2008, Hwang et al., 2006), there are modified versions of the PULSE protocol. The main idea of the Pulse protocol can be shown through Figure. 2. The communication channel is divided into two parts: data channel and control channel. The communication between the reader and tags will be via the data channel, and the control channel is used to send a beacon signal. The beacon signal notifies other readers to avoid collisions. If the reader receives a beacon signal, it will wait for a certain time, and then rechecks the control channel. The control channel scope is larger than the data channel in order to avoid all types of reader collision including tag hidden terminal problem (Birari and Iyer, 2005). In the conventional pulse protocol, when a reader generates a new random back-off delay, there is a probability that the back-off time delay is the same delay of another reader. It is important to note that the beacon signal can collide with another one, form another reader, in the control channel. In Song et al. (2008), the percentage of the number of readers that select the same time slot, from all active readers, is called Slot Occupied Probability (SOP). By communicating with other readers via the control channel, reader can easily find the back-off time delay of the other readers. Hence, reducing the probability of reader's collision in control channel can be achieved. To reduce the reader energy consumption, the beacon signal is not sent periodically (Liu et al., 2008). In Yu and Lee (2008), all readers share one control channel. In this protocol, it is not necessary to send beacon messages in all cases, further than the scope of interference range of readers to avoid hidden terminal problem. The beacon message is restricted to be sent only within a certain scope, i.e., only up to the distance that multiple reader to-tag collision might occur. In Hwang et al. (2006), DiCa protocol is similar to pulse protocol. It implies a distributed and energy efficient collision avoidance algorithm. As in the pulse protocol, DiCa also utilises data channel and control channel. Each reader contends through control channel and the contention winner reads tags through data channel. The other reader waits until the channel becomes idle. However, DiCa has some shortcoming. It requires sufficient time to exchange the contention message. It tries to prevent the collision after it takes place rather than acting actively at the first sight. So, it does not reduce the collision problem efficiently. In Dai et al. (2007), Joshi et al. (2009) and Joshi and Kim (2009), the modification of the pulse protocol is done by adding multiple data channels and the channel hopping technique. The channel hopping algorithm helps to decide whether to hop for new channel or wait in the same channel. In Dai et al. (2007), Multi-Channel MAC (MCMAC) broadcasts control message after it wins contention in a control channel and gains access to the data channel. The control message informs other neighbouring readers within the interrogation zone that the particular channel is occupied for a certain time. After receiving a control message from neighbouring reader, the other readers do not use that channel for a certain period of time and access to another channel. However, the channel hopping is performed in random fashion, which is not an efficient way because reader might perform continuous channel hopping for a long time. However, the channel hopping decision in the RAMP algorithm (Joshi et al., 2009) and the ACMAC algorithm (Joshi and Kim., 2009) is based on the basis of density of readers to decide either to hop for new channel or just wait in the same channel. It achieves efficient channel utilisation. Comparison of reader anti-collision protocols in RFID system is introduced in (Joshi and Kim, 2008). Even though many anti-collision protocols for tags collision and reader's collision has been proposed as reviewed before, we feel that the integration protocol for both collision types have not been exploited in reducing the identification time while maintaining a reasonable transmitting bits. Our goal is to develop a fast and simple protocol for resolving both collision types to reduce the overall identification time.

Figure 2 Example of pulse protocol (note: R2 active, R1 silent) (see online version for colours)



3 Parallel Binary Splitting (PBS) tag identification process

The main idea of the proposed algorithm is based on the idea of our previous work of the Parallel Binary Splitting (PBS) searching path (Mohammed and Salah, 2009) to identify completely all the tags in the interrogation zone with the minimum number of exchanged bits. The PBS protocol is mainly based on exchanging one bit sequentially between the tags and the reader. The reader provides the tags one bit comment about the collision state of the tags (collision or no collision). Each tag will modify its order based on the collision state. In the parallel splitting identification process, the identification will be done in each layer in the ID-tree instead of the traditional Depth First Search (DFS) technique. Figure 3 shows the difference between the new parallel splitting technique and the DFS technique. In the PBS technique, the tag can determine its future replying order and setting up a self-transmission control. The example in Figure 3(b) is a 4-level tree structure. The PBS searching path will finish these levels from up-to-down sequentially. By knowing the state of the last tags reply from the reader report, each tag continually changes its relative position in virtual replying queue and then send the next ID-bit. To do this operation, tags will use simple logic operation based on two counters and two registers. The registers and the counters are defined as follows:

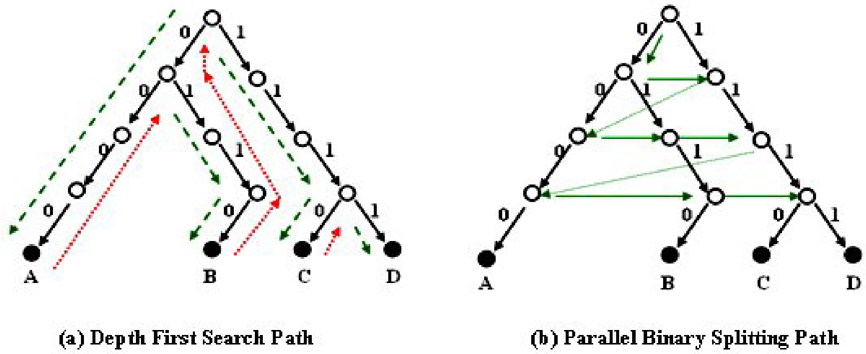
1 Current Path Register (CPR) is used to store the current number of paths (binary branches) in the current bit level. It contains the number of checked node in that binary level.

2 Next Paths Counter (NPC) is used to store the total number of continually discovered paths. It will be incremented when the reader reports a collision state. Any collision means an increasing in the binary braches by one. CPR will be loaded by NPC contents at the end of each bit level splitting.

3 Current Order Register (COR) is used to store the tag replying order with respect to the current number of paths in CPR.

4 Next Order Counter (NOC) is used to track the changing in the tag replying order. It will increment when a new branch of lower order appears in the binary tree. COR will be loaded by NOC contents at the end of each bit level splitting.

Figure 3 The difference between parallel splitting identification and the depth first search path (see online version for colours)



The tag operation can be described as follows:

1 Receiving the reader starting command.

2 Initially, each tag starts by thinking that it is the only tag in the reader range and resets the counters and the registers.

3 One-bit tag response in its replying order, one-bit reader report will follow that.

4 Scanning the discovered path (node) in the past splitting level.

5 Each subgroup sends the current marked bit in the current bit level.

6 Tags know the collision state from the reader report at each node.

7 Tags modify its control counters as follow:

   a IF ‘No Collision’: THEN no change in its order and the total number of paths.

   b IF ‘Collision’ : THEN

   *increment the total number paths (increment NPC).

   *“IF {‘the tag is not scanned in the current bit level (i.e. it is in the waiting state)’ OR ‘it is in the replying state and participating in the current tag collision by sending its marked bit which is one’} THEN:

   *incrementing its replying order in the next splitting level (increment NOC).

8 Registers COR and CPR are updated by the contents of the corresponding counters NOC and NPC respectively. The changing in the paths and the orders will not be considered until the start of the next splitting binary level.

9 Scanning the next splitting level and repeat the process starting from step 4 until completing '*n*' level of the ID length.

The upper limit (worst case) of the exchanged bits between the reader and tags:

Worst case (W): is the maxim maximum number of exchanged bits among tags and its interrogator.

W < 2 * number of existing tags tags * number of ID-bit of the tag

For example if you have at random 500 tag (with the tag ID length = 96 bit) then,

Number of exchanged bits will be less than 2*500*96 = 96,000 bit. Under bit rate of 100 kb/s we need, as maximum, 1 second to complete identification.

For one reader multi-tag identification process, reader operation can be summarised as follows:

1 Continually updating the reconstructed binary tree of existing tags according to tags reply.

2 Exploring the future nodes from each already discovered node (path) of the previous splitting level, by examining (scanning) the previously discovered paths in the past binary splitting level.

3 Receiving the marked bit of each subgroup in the predetermined order. Each tag replies to the reader interrogation in its previously replying order by sending its marked bit.

4 Detecting the state of the last tag reply, in the scanned subgroup, such that:

*Detecting Collision: send '1' as collision report.

*Detecting No Collision : send '0' as collision free report.

Each tag knows its current replying order, and remains in the queue until detecting a tag collision. The tags will classify themselves in a new subgroup according to the reader one bit signal only.

3.1 PBS demonstration example

The following example demonstrates the performance of one reader multi-tag system with PBS protocol. Figures 4 and 5 show the diagram of four tags binary tree, as an example,{A, B, C, D} = {0000,0110,1110,1111} to be identified, and the bit stream between reader and tags (with each node contains its order of reply). The reader constructs the binary tree by scanning the tree nodes in the shown order, and receiving tag responses. Table 1 describes in detail the process of node exploration with the modification order and the contents of the tag counters and registers.

In this example, the number of tree nodes (except the leaves node) equals 9 nodes. It consumes one bit for each tag response and one bit for reader to report the type of each node (collision or no collision). Then, number of transmitted bits by tags equals number of transmitted bits by reader equals 9 bit.

Figure 4 The transmitted-bit stream between reader and tags in the system (see online version for colours)

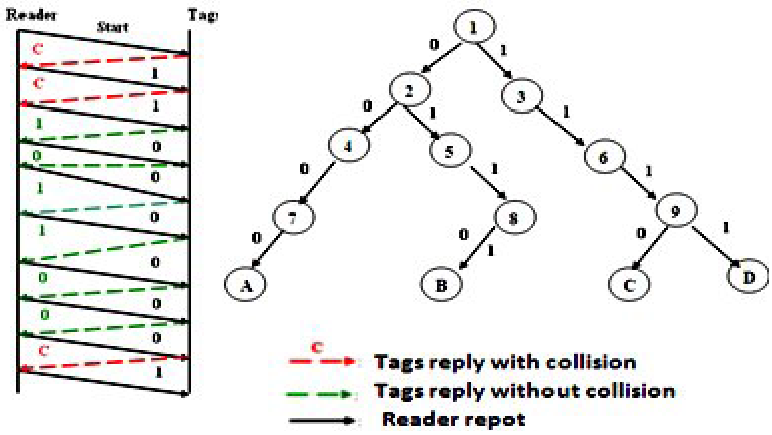


Figure 5 Parallel splitting scan for path exploration (see online version for colours)

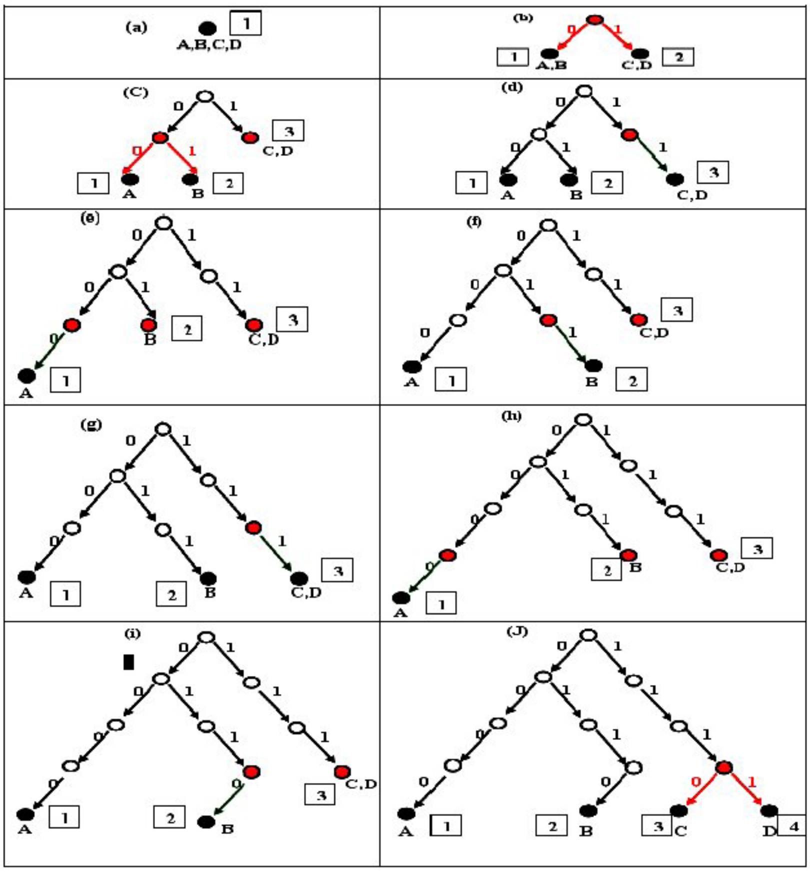


Table 1 The anti-collision process of the proposed algorithm (–: silent)

step	Reader Reply	Reply of TAG (After Reader Response)				Tags Registers & Counters									
						COR				NOC				CPR (for all tags)	NPC (for all tags)
		A (0000)	B (0110)	C (1110)	D (1111)	A	B	C	D	A	B	C	D		
a	Start	0	0	1	1	1	1	1	1	1	1	1	1	1	1
b	1	0	1	—	—	1	1	2	2	1	1	2	2	2	2
c	1	—	—	1	1	1	1	2	2	1	2	3	3	2	3
d	0	0	—	—	—	1	2	3	3	1	2	3	3	3	3
e	0	—	1	—	—	1	2	3	3	1	2	3	3	3	3
f	0	—	—	1	1	1	2	3	3	1	2	3	3	3	3
g	0	0	—	—	—	1	2	3	3	1	2	3	3	3	3
h	0	—	0	—	—	1	2	3	3	1	2	3	3	3	3
i	0	—	—	0	1	1	2	3	3	1	2	3	3	3	3
j	1	—	—	—	—	1	2	3	4	1	2	3	4	4	4

The overall transferred bit equals 9 bit tag response plus 9 bit reader reply equals 18 bit. The performance of the proposed mechanism is compared with the algorithm in (Lee and Lee, 2006) where it uses 30 bits to identify the same number of tree nodes. However, in the proposed algorithm, the relative order of each tag will be saved; and less number of transmitted bits to make another identification session will be achieved.

4 The proposed Similar Topology Trees (STT) protocol

This technique provides an integrated and fast solution for solving both readers and tags collision simultaneously in multi-reader environment. The proposed protocol does not require smart tags to detect collision. In solving both collision problems, the PBS technique is used to build similar binary trees. In Similar Topology Trees (STT) virtual (silent) paths are added to preserve the similar tree configuration for all readers. The proposed STT anti-collision protocol was built to solve the data collision problem even with all the following sources: (1) simultaneous tags' transmissions, (2) simultaneous readers' transmissions, (3) simultaneous tags and readers' transmissions. The proposed multi-reader multi-tag anti-collision protocol is described next with some inherent assumptions.

4.1 Practical assumptions of the proposed STT protocol

In the proposed anti-collision algorithm, the assumptions are considered as follows. (1) All readers and the tags are considered in one collision domain. (2) All active tags send their marked bit simultaneously. The role of the reader operation is to detect the collision and providing tags with collision report to dynamically update their replying orders (in the next bit level). (3) According to the PBS technique, the time is divided between tags and reader; each side will send one bit reply sequentially. This solves the third problem of simultaneous tags and reader's transmissions. (4) To solve the second collision problem (collision due to simultaneous readers' transmissions), all readers are synchronised (via control channel among the readers) to send a similar reply simultaneously. (5) Similar binary trees topology for all readers are constructed with one collision bit step. This means that all readers will send the same reply (1 or 0) to represent the collision state of last transmitting bit from the tags. Forcing all readers to send the same reply will provide some silent paths in some reader's tree to keep similar configuration of all readers. (6) The reader communicates with each other to report a collision state if any reader detects a collision. Readers share its one bit collision state (collision or no collision) through a separate control channel. (7) The tags can automatically change the contents of their internal counters and registers to represent the new relative replying order in the next bit level.

4.2 Reader and tag operation based on STT protocol

Our protocol is based on remapping the discovered binary tree configuration after each one bit dialog between tag and reader. For the tags, as mentioned before, the remapping process will be controlled by the contents of two counters and two registers. Relative to the reader report, each tag continually changes its relative position in the virtual replying queue as described in Section 3. However for the readers, virtual PBS path will be generated when the reader receives collision report from another reader outside its detecting range. Figure 6 provides a flow chart for the proposed STT protocol. In multi-reader multi-tag system, the reader and the tag and reader operation can be summarised as follows:

(1) All readers will be synchronised to start interrogation session.

(2) Initially, each tag starts by thinking that it is the only tag in the reader range and resets the two counters and the two registers. Then, the first bit of tags' ID is transmitted.

(3) All readers are listening to the transmitted tags ID-bit. Then, it is continually updating the pretended binary tree of existing tags, in its reading range.

(4) All readers share the collision state (collision or no collision) in its ranges in the collision domain, through the control channel as follows:

   (a) If the reader (R1 for example) detects a tag collision, i.e. receiving one and zero at the same time, then informing all other readers (Ri) to send one bit collision report and build similar topology tree (PBS tree). For R1, the inserted path is true path; however, for the other readers the inserted path is virtual path.

   (b) If the reader doesn't detect tag collision in its interrogation range, it will listen to the other readers. *If any reader detects collision through the collision acknowledgment in the control channel, all reader will follow it by sending collision report in its reading range in the data channel. In this case, for the current reader, the inserted path will be virtual path (silent path) to keep similar tree topology for all readers. Note that, the inserted silent paths are due to the tags' collisions outside the reader range.

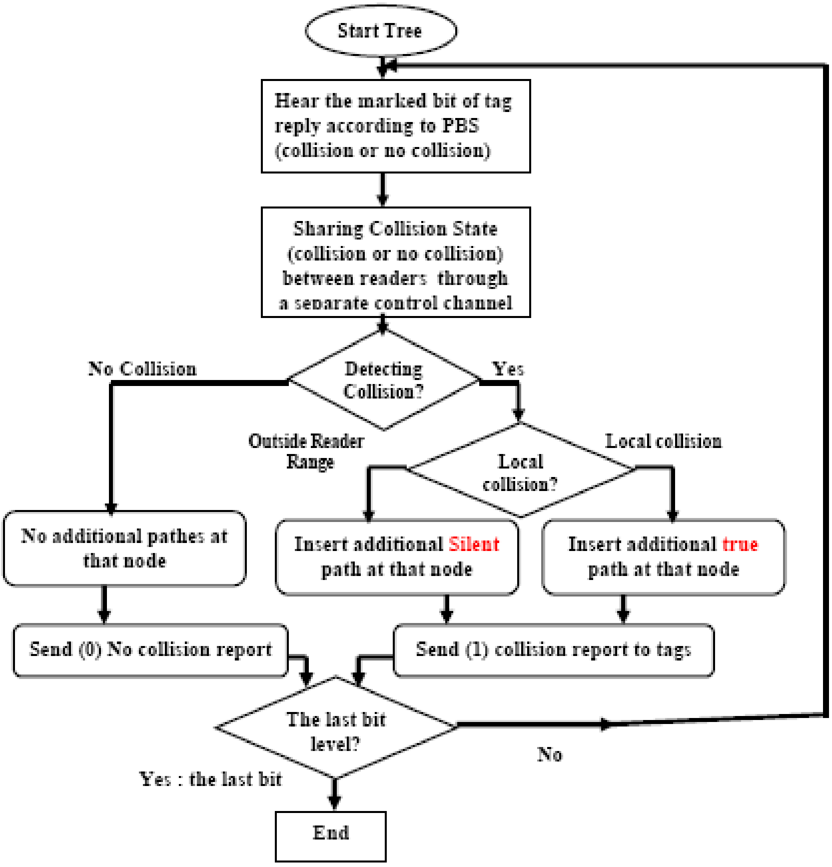
   *Else, all readers send no collision report.

(5) Tags update its replying order, of the next marked bit, according to the received reader's common report.

(6) The readers listen to the next ID-bits.

(7) If it is not the last bit, then go to step 4(a), Else, End.

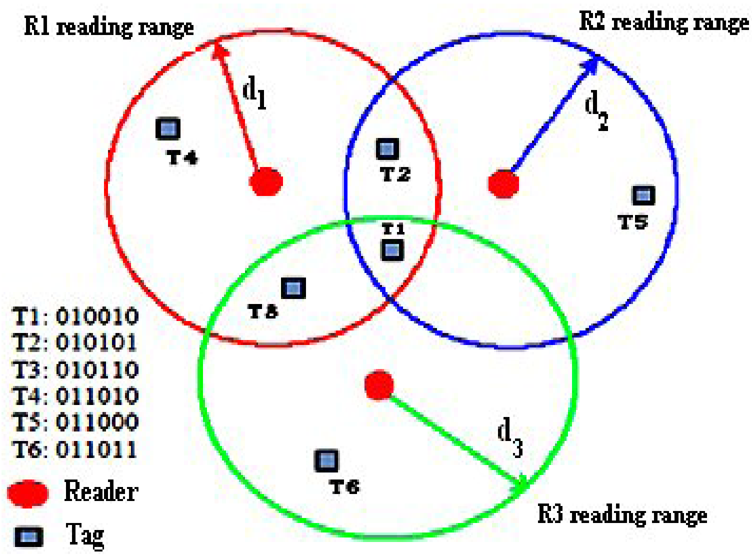
Figure 6 Similar Topology Trees (STT) protocol flowchart



5 Performance analysis

The performance of STT protocol will be discussed in multi-reader multi-tag system. The idea of similar topology trees will be clarified through the next example. Figure 7 shows a distribution of six tags and three overlapped reader's ranges, as an example, {T1, T2, T3, T4, T5, T6} = {010010, 010101, 010110, 011010, 011000, 011011} to be identified.

Figure 7 Three overlapped readers (see online version for colours)



We have three overlapped reader's region (R1, R2, R3). Each reader will build its binary tree under the proposed protocol. Figure 8 shows the complete identified binary tree of the six tags relative to one reader (if all tags exist in one reader range). However, Figure 9 shows the similar topology trees of the readers and the existing six tags. All readers will share its collision state through a control channel. When the six tags send its first ID-bit ('0') the readers will report no collision state to all tags and the identification paths is not changed. This case will be repeated with the second ID-bit of the tags. There is a collision state when the tags send its third and fourth bits in all reader's ranges. The splitting will be identical for the three readers. However, there are collisions in some reader's ranges at the fifth bit. In this case, a collision report will be sent to all tags and new virtual (silent) path will be generated with the readers that detecting no collision. Virtual nodes (paths) in the reader's binary tree are corresponding to the tags outside the reader range. As shown in Figure 9, virtual (silent) paths are added to preserve the similar tree configuration for all readers. For example, the position of T6 is in the reading range of R3. Then, there is a true path with respect to reader R3, while the there is a virtual path with respect to R1 and R2. Moreover, as shown in Figure 9, Reader R1 has two silent paths due to the transmitting bits of tags T5 and T6. The worst case of the identification time can be considered as the time of the PBS protocol for identifying of all tags by one reader. For the proposed protocol, the identification time is independent of the number of existing readers. Tags in overlapped reader's ranges will be identified, one time, by all readers simultaneously. For example, although tag T1 is in the reading ranges of the three readers, it will be identified by all readers once at the same time.

Figure 8 The complete binary tree of existing tags (see online version for colours)

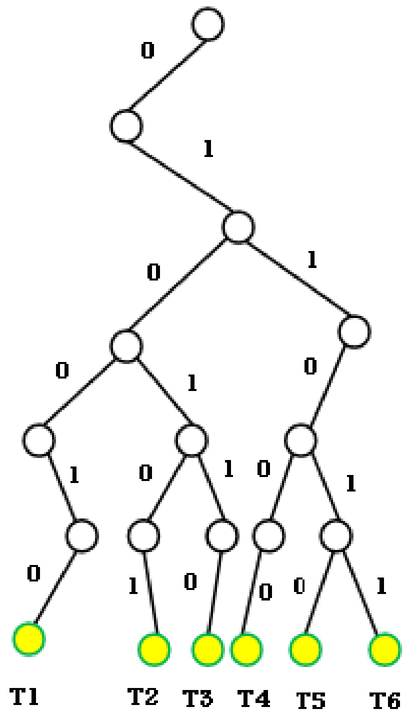
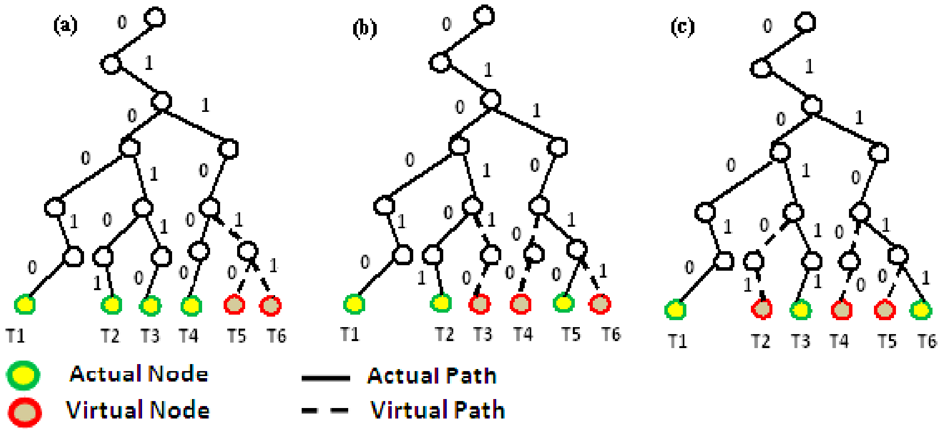


Figure 9 The three readers are building similar trees (see online version for colours)



6 Simulation results

The simulation results willbe carried out by Matlap to study the performance of the proposed protocol in a comparison form with some of recent protocols. Tags IDs will be generated and distributed randomly. First, the simulation is done for the main PBS protocol for the one-reader and multi-tag system. Then, the analysis of the integrated STT protocol for multi-reader multi-tag system will be introduced.

6.1 PBS protocol (one reader multi-tag system)

The analysis of the proposed protocol is based on the number of queries send by the reader and the tag (the number of sent bits by reader and tags). We will use the same simulation parameters (Tag ID length, bit rate and the number of tags). Figure 10 shows a comparison between the PBS algorithm and the Dynamic Bit Arbitration (DBA) in Ziming Guo and Binjie Hu, 2007. Note that, PBS provides better performance, with both random and sequential ID's, even with large number of tags. Figure 11 shows the identification time of the proposed PBS algorithm with 40 kb/s bit rate and ID length equals 16 bits. In this figure, the identification time of the proposed algorithm is compared with the algorithms of DBA and BIBD. In the BIBD technique (Shiyu Li and Quanyuan Feng, 2008), at list 450 ms is required to identify 300 tags, however, 2550 ms is required by the traditional query tree algorithm to identify the same number of tags. However, the proposed protocol can identify the same number of tags within 120 ms for random ID's and 19 ms for sequential ID's.

Figure 10 Total transferred bits vs. the number of the tags (ID length =32 bits) (see online version for colours)

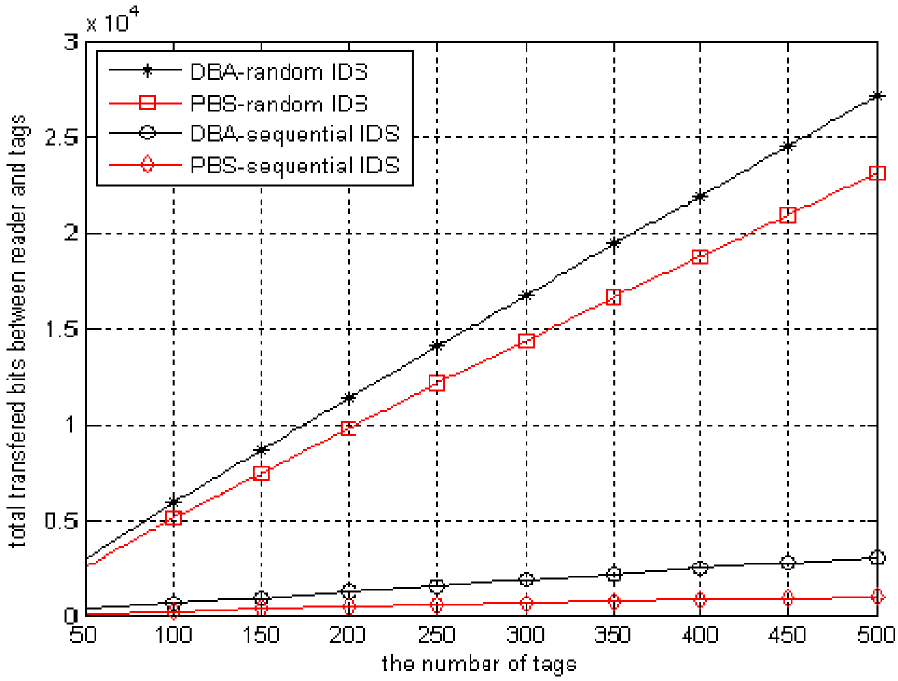
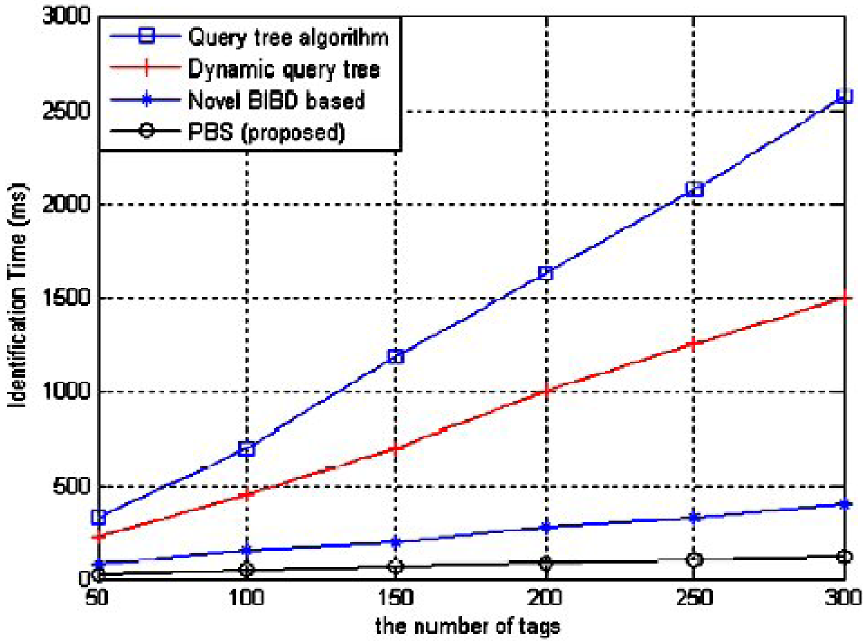


Figure 11 Identification time of different quantity of tags under 40 kb/s bit rate (ID length = 16 bits) (see online version for colours)



6.2 *STT protocol (multi-reader multi-tag system)*

In this section, the identification time and the system throughput of the proposed protocol will be studied. A case of identifying 500 tags with ID-bit 96 per tag (generated randomly by Matlap), and with different number of readers (from 1 to 12) is tested, irrespective of the tag distribution among readers. The tags are distributed randomly in the reader ranges without changing the simulation results.

- STT protocol is estimated under its worst case, i.e. with the maximum number of exchanged bits. The maximum number of exchanged bits is considered twice the number of existing tags multiplied by the number of ID-bit per tag.
- Max. exchanged bits < 2*500*96 bits = 96,000 bits = 12,000 byte.
- With bit rate of 100 Kb/s: The 96,000 bits are transmitted within one second. This provides a network throughput of 12,000 bytes/second.
- With bit rate of 50Kb/s: The 96,000 bits are transmitted within two seconds. This provides a network throughput of 6,000 bytes/second.

Figure 12 shows the results of the network throughput when the proposed STT algorithm and five of recent algorithms are used to identify the current 500 tags. It confirms one of the advantages of the proposed STT protocol. For the same number of tags, the proposed protocol provides constant identification time independent of the number of readers, and irrespective of tag distribution among readers, as shown in Figure 13.

Figure 12 The network throughput comparison (byte/second) at 50 kb/s bit rate (see online version for colours)

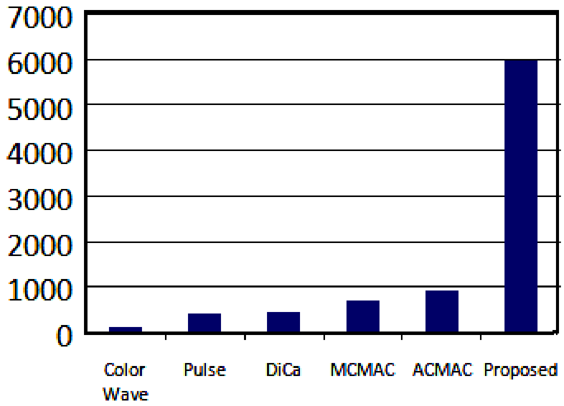
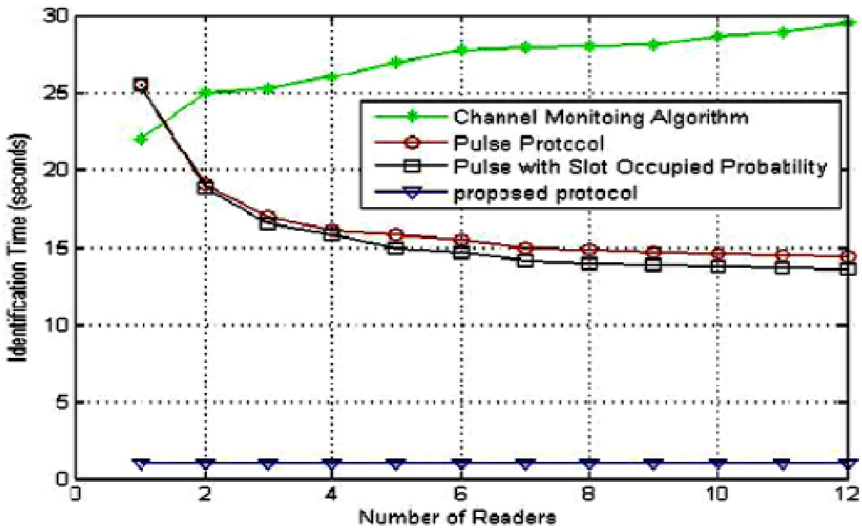


Figure 13 Comparison results of the identification time (see online version for colours)



This performance is achieved due to the synchronisation of all readers to build the same complete binary tree. Although the proposed protocol works under one collision domain, it work with one collision bit resolving, low bit overhead and simple dialog between reader and tags. It utilises simple one-to-one bit dialog, without retransmitting any information in the collision state. The main advantage of the proposed protocol arises from the integrated treatment of the two collision problem of the readers and the tags. Most of the previous protocols utilise the TDMA scheduling. So, the main drawback of these protocols is the long waiting time and the large overhead information. Moreover, the tags in the overlap reading ranges will be identified several times. However, in the proposed STT protocol, the tags in the overlapping reading ranges will be identified one time only.

7 Concluding remarks

This paper presents a new integrated tag and reader approach for anti-collision in RFID systems. The proposed protocol is based on constructing similar topology binary trees for all readers in one collision domain. It is based on a Parallel Binary Tree-Scan (PBS) with the self-modified relative order of tags. All readers are synchronising to send the same reply and to build Similar Topology Trees (STT). The proposed protocol provides constant identification time independent of the number of existing readers and irrespective of tag distribution among readers. The major advantages of the proposed scheme are low implementation complexity, the integrated solution of collision problem, and lower number of transferred bits between the readers and the tags in the identification process. Moreover, due to the simple dialog between readers and tags, the proposed protocol provides the best system throughput relative to the recent anti-collision protocols. Moreover, the PBS protocol can be used to solve the tag collision problem in one-reader multi-tag system.

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