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Full Length Research Paper

The research of quadtree search algorithms for anti-collision in radio frequency identification systems

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Nowadays, Radio Frequency Identification (RFID) systems are widely used in commercial applications such as warehouse management, artificial intelligence, intelligent robot and automation control to identify the tagged goods or materials. When there is the existence of multiple tags in the interrogation field of a transponder, the arbitration algorithm for RFID system is used to arbitrate all the tags to avoid the collision problem. A splitting algorithm which is called Binary Search Tree (BST) is well-known for multi-tags arbitration. In this paper, a quadtree search algorithm is developed to avoid collision. Then, its performance is compared with binary search tree and binary search tree with cut-through according to cost, mean number of stages for successfully arbitrating an RFID device, during the arbitration process. Comparing with the traditional DFSA algorithm, the simulation results show that our model reaches better performance with respect to reducing the cost and tag reading time.

Key words: Radio frequency identification (RFID), arbitration problem, anti-collision, binary search tree, quadtree.

INTRODUCTION

Radio Frequency Identification (RFID) has been developed and used in many applications in the real world. A RFID system consists of a reader and tags which each tag contains a unique Tag ID. The reader can identify a tag according to its Tag ID and communicate with tags via radio frequency. In RFID system, the most important issues that affect the data integrity is the collision resolution between the tags while these tags transmit their data to the reader. In majority of tag anti-collision algorithm, Dynamic Framed Slotted Aloha (DFSA) has been employed as a popular collision resolution algorithm to share the medium when multiple tags respond to the reader's signal command. According to power supply, tags are categorized into two types: active and passive tags. An active tag is a tag with power supply, it can emit RF signal to communicate with the reader actively, usually with longer access distance and better access time. A passive tag must have to listen to the signal emit from the reader and then respond to it. Both of these two types of tags are in widespread use in commercial applications.

When there is the existence of more than one tag in the interrogation field of a reader, the reader would send signals to each tag and all the tags would reflex signal with its Tag ID back to the reader at the same time. This may cause a collision problem and result in data loss, because the reader couldn't receive all the reflex signals simultaneously. However, the environment of multi-tags is very general in commercial applications and many researchers are dedicating in resolving this problem. Nowadays, several methods were developed for RFID anti-collision, including Time Division Multiple Access (TDMA), Space Devision Multiple Access (SDMA), Frequency Domain Multiple Access (FDMA) and Binary

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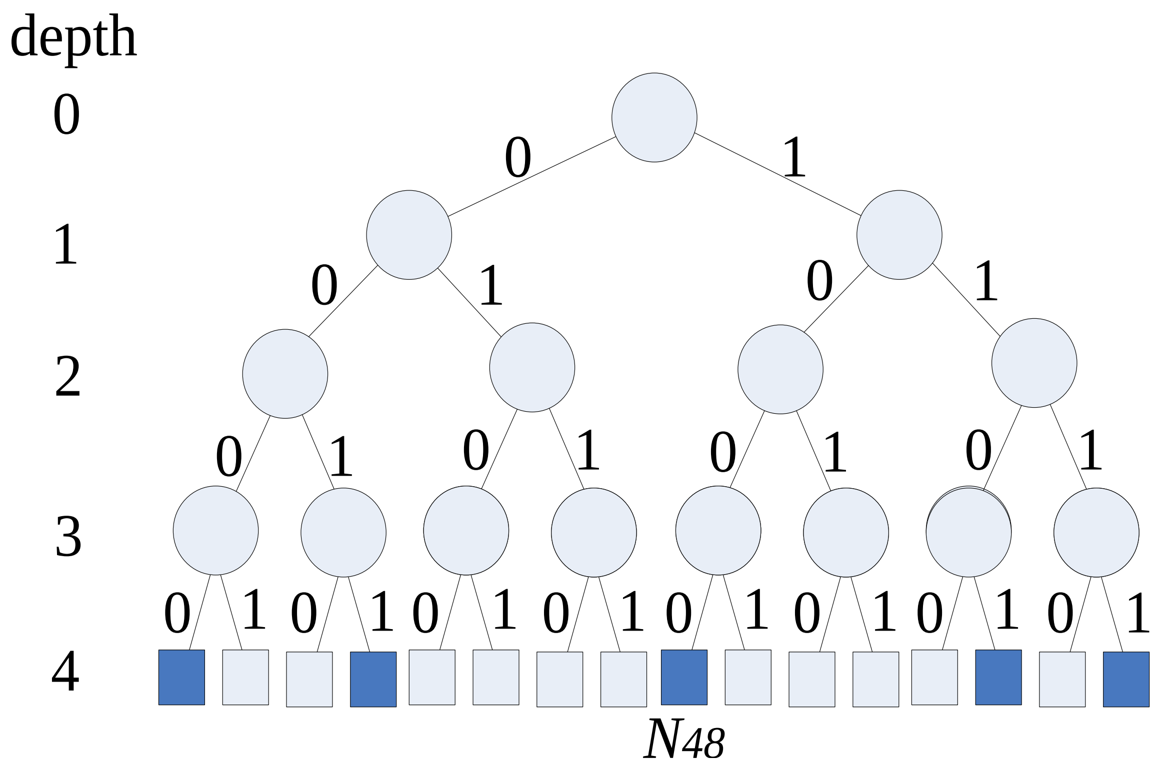

Figure 1. The Binary Search Tree (m = 5, k = 4).

Search Tree (BST) algorithm. In this paper, a splitting-based algorithm called Quadtree search algorithm is developed to simplify the tree structure. The proposed model successfully reduces the searching cost to arbitrate the tags in RFID system.

Binary search tree algorithm

Owing to the shared wireless channel between tags and the reader in the process of communication, the tag collision arbitration is one of the significant issues for reducing the communication overhead. Binary search tree (BST) is the famous approach for RFID anti-collision, and it takes the advantage of easy implementation and low power consumed during the process (Hush and Wood, 1998). BST is developed from tree algorithm for packet broadcast channels by (Capetanakis, 1979). Figure 1 shows an example of binary tree whose depth is 4. Each tag corresponds to a leaf node in a BST. If there are 5 tags with Tag ID of 4 bits length in the system, the ID of tag N48 is 1000. The searching procedure of BST is stated as follows:

1. Begin with the root node N_{00}, and ask if there is zero, one or more than one tags in the subtree too.
2. If there is more than one tag in T_{00}, it means that a collision happened at N_{00}. Then ask two succeeding nodes, N_{10} and N_{11} to check whether there is zero, one or more than one tags in subtrees. If any collision happens in N_{11}, N_{10} waits and asks the same question to succeeding nodes of N_{11}. The process follows “first in, last out” rule.
3. Recursively, if there is any collision; repeat the same question to its succeeding nodes until there is no collision.

If only one node is waiting, repeat step 3. If more than one node is waiting, follow the “first in, last out” rule to resolve them. At the end of the process, each leaf will contain at most one tag. In the example of Figure 1, the order of tags is: 1111, 1101, 1000, 0011, 0000, which needs to search four stages to find a tag. Recently, several researches were conducted to improve tree algorithm. One of the many famous algorithms is BST with Cut-Through Operation, which simplifies the structure of BST first and then searches it (Wang, 2006). Wang (2006) showed that BST with Cut-Through operation can improve the efficiency by simplifying the tree structure.

Quadtree algorithm

Quadtree is a finite elements method used to divide a region which contains multi-objects into many small

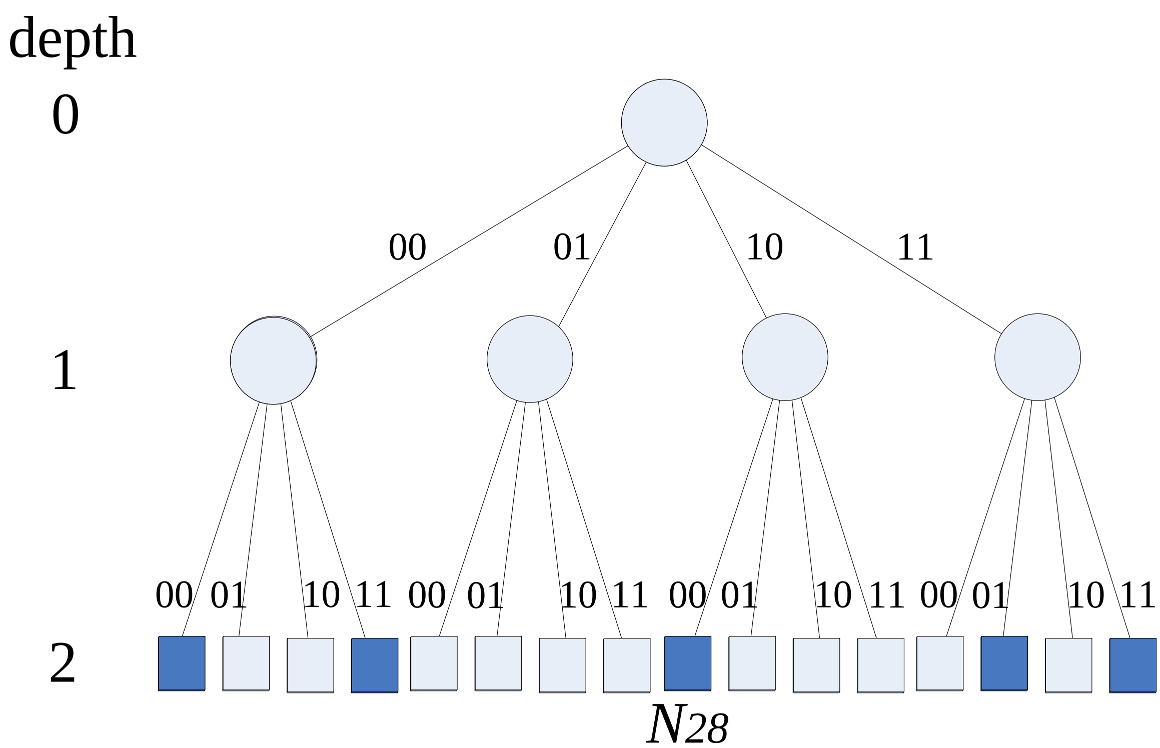

Figure 2. The Quadtree (m=5).

regions to identify each object (Mark et al., 2000). Moreover, RFID techniques in soft computing and artificial intelligence have been successfully applied to various fields, such as robot manipulation (Hsiao et al., 2005a, b, c, d, e; Chen et al., 2011a, b; Chen and Huang, 2011; Shih et al., 2011a, b; Lee et al., 2011a, b, c), engineering application (Lu, 2003; Amini and Vahdani, 2008; Chang et al., 2008; Chen, 2006; Chen et al., 2008d, e; Trabia et al., 2008; Tu et al., 2008; Yang et al., 2008a; Shih et al., 2010b; Yeh and Chen, 2010; Cakiroglu et al., 2010; Kucuksille et al., 2010; Shamshirb et al., 2010; Uddin et al., 2010), architectural engineering (Chen et al., 2004; Chen et al., 2010i; Hsieh et al., 2006; Chen, 2010a, b, c; Hsu et al., 2010; Chen, 2011c, d, e; Chen et al., 2011c, d; Liu et al., 2011; Tang et al., 2011), satellite observations (Lin et al., 2009a, b; Lin and Chen, 2010b; Lin and Chen, 2011; Yeh et al., 2011), marine research (Chen et al., 2005a, 2005b; Chen et al., 2006a, b, c; Chen et al., 2007a, b, c, d, e, f, g, h; Chen et al., 2008a, b, c; Tseng et al., 2009; Chen, 2009b, c; Chen et al., 2009c; Chen, 2010d; Chen, 2011a, b, c), network optimization (Chen et al., 2009g; Chen and Chen, 2010b; Shih et al., 2010a, c; Kuo et al., 2010; Kuo et al., 2011; Kuo and Chen, 2011a, b), system development (Chen, 2009a; Chen et al., 2009a, b, d, e, f; Chen, 2010c; Chen et al., 2010a, c, d, f; Lin and Chen, 2010a; Shih et al., 2011d; Tseng et al., 2011), educational improvement (Chen et al., 2010b; Shih et al., 2010d; Shen et al., 2011; Shih et al., 2011c; Chen, 2011f; Chen, 2012) and managements on leisure industries (Yildirim et al., 2009; Zhao et al., 2009; Tsai et al., 2008; Yang et al., 2008b; Yeh et al., 2008; Chen and Chen, 2010a; Chen et al., 2010e, g, h; Lee et al., 2010a, b; Chiang et al., 2010; Tsai and Chen, 2010; Tsai and Chen, 2011; Yu et al., 2011; Chen et al., 2011e, and (Chen et al., 2011d, 2011e, 2011f, 2011g, 2011h; Lee, 2010; Cheng et al., 2011; Chu et al., 2011; Chiou et al., 2011; Chen, 2011g, 2011h, 2011i; Kuo et al., 2011; Kuo and Chen, 2011; Lin and Chen, 2011; Liu et al., 2011a, 2011b; Lin et al., 2011b; Shen et al., 2011; Tang et al., 2011; Tsai and Chen, 2011a, 2011b; Chen, 2012a, 2012b, 2012c; Chen et al., 2012a, 2012b, 2012c, 2012d; Kuo and Chen, 2012a, 2012b; Lee and Chen, 2012; Lin et al., 2012a, 2012b; Lin and Chen, 2012; Liu et al., 2012a, 2012b; Su et al., 2012; Tseng and Chen, 2012; Tseng et al., 2012a, 2012b, 2012c; Yeh et al., 2012).

It is similar to BST which splits a set of objects into small subsets. A Quadtree is a rooted tree whose internal nodes have four children. The four branches of an internal node are labeled as 00, 01, 10 and 11 from left to right. Figure 2 shows an example of a BST. Each of the leaves corresponds to a tag whose tag ID is the bit stream consisting of the labels of branches from root to the leaf itself. For example, N28 is equal to N48 in Figure 1 which represent the tag with ID 1000. The Psuedo Code of constructing a BST and quadtree are

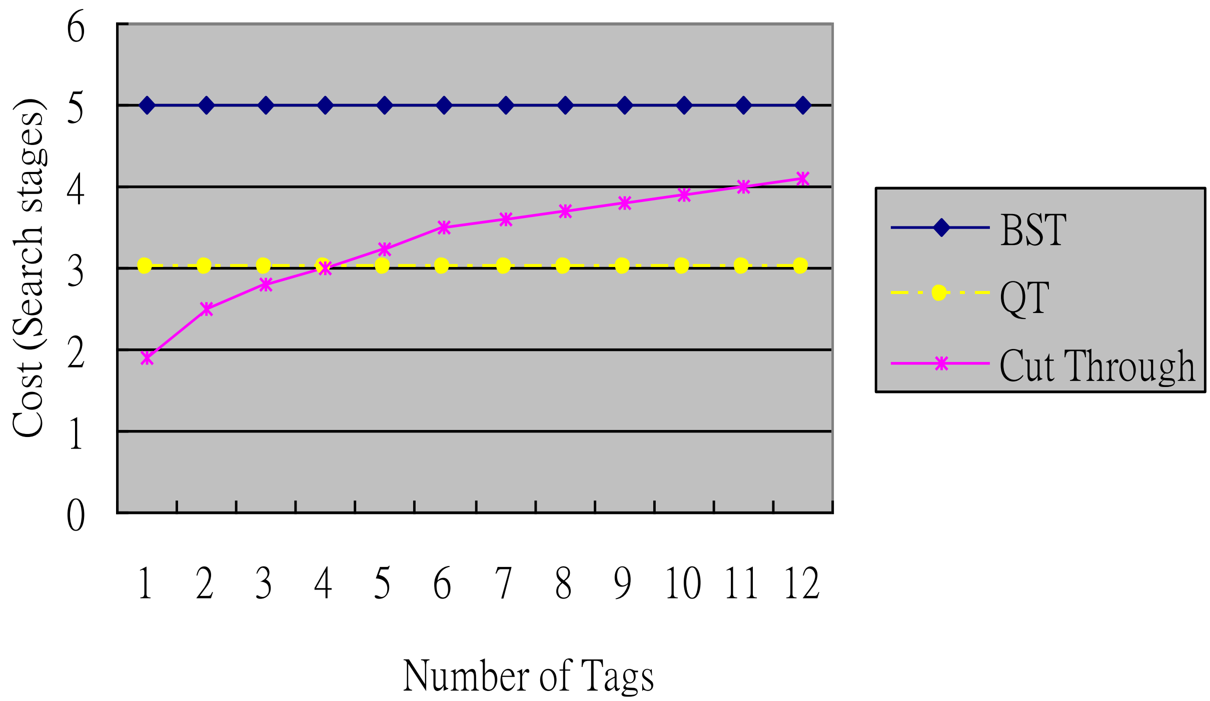

Figure 3. The cost with different m (n = 32).

respectively shown in Appendix 1 and 3. QT is a quadtree and DaDa+1 is the bit stream consists of ath and a+1th bits. The algorithm will insert each node to the appropriate position according to the DaDa+1. The four subtrees from left to right is defined as 1st ,2nd ,3rd and 4th subtree of quadtree. The searching process is the same as that in BST. Quadtree needs $\log_4 n$ stages to represent all tags which the number of stages is half of the depth of BST. Eventually, it is helpful for reducing cost and searching time during arbitration process.

Performance analysis

The performance is evaluated based on the cost consuming during the arbitration process. The cost is defined as average stages needed to find a tag successfully which is directly proportional to the depth of the search tree (3rd). Here, the average stages needed of BST, Quadtree and BST with Cut-Through are defined as:

L_{BST} , L_{QT} and $L_{Cut-Through}$

Assume that there are at most n possible tags and m tags exist in the field of reader. Then the 3rd, L_{BST} = $\log_2 n$=k, $L_{QT} = \log_4 n$ =k/2 and $L_{Cut-Through}$= $\sum_{j=1}^{k} j \times \frac{\sum_{i=1}^{2^{k-j}} C(2^{k-j}, j) \times C(2^k - 2^{k-j+1}, m-i-1)}{C(n-1, m-1)}$. Since L_{QT} = L_{BST}/2, the cost of Quadtree is obviously fewer than BST. The numerical result will show that the computational load of Quadtree is better than k stages of BST and $L_{Cut-Through}$ stages of BST with Cut-Through.

Numerical result of cost with different depth of tree is shown in Figure 3. The quadtree is better than BST and BST with Cut-Through. When the depth of tree is greater than 5, the quadtree would be obviously better than both of them. Numerical result of cost with different number of tags (m) is shown in Figure 4. BST has the worst performance in this evaluation. Obviously, quadtree outperforms significantly the BST and BST with Cut-through when m$\geq$4.

CONCLUSIONS

The anti-collision mechanism is an important part of the Radio-Frequency Identification (RFID) technology. An improved splitting-based algorithm, called Quadtree search algorithm, is successfully developed to simplify the structure of tree. The novelty of the proposed approach reveals that the Quadtree reduces half the number of stages of BST. Therefore, it is useful for

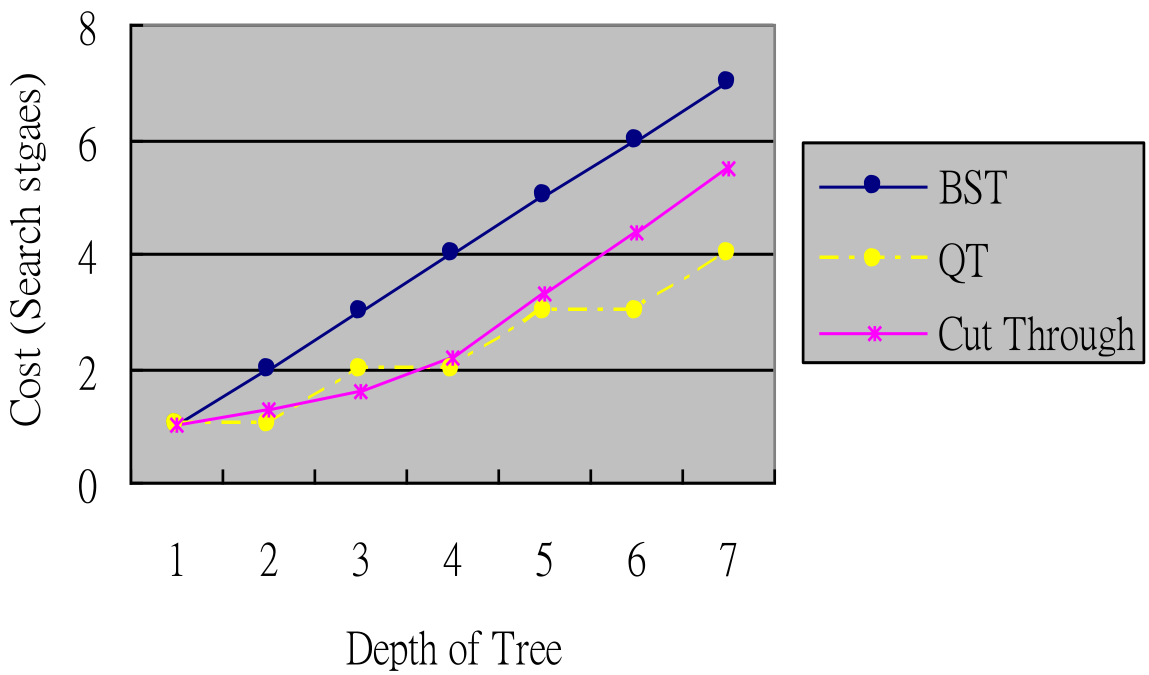

Figure 4. The cost with different tree.

improving the cost of searching tags. The performances are defined as cost evaluated by the searched stages. Especially, quadtree search algorithm is excellent for large number of tree stages.

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