A New Tree-based Tag Anti-collision Protocol for RFID Systems

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Abstract— *This paper proposes a tree-based anti-collision protocol for tags in the UHF (ultra high frequency, 300MHz–3GHz) band. To reduce the step for searching all tags in the interrogation zone, the depth-first search (DFS) is used as a basic search criterion like in query tree protocols. To prevent the redundant increase of the transmission bit length in process of implementing the DFS, the binary tree protocol is taken to restart the DFS at the height of binary tree, rather than the root, that was most recently marked when the tag collision happened. To substantiate theoretically that the proposed protocol achieves better performance than the previous protocols, the performance index in [8] consisting of both energy consumption and time delay is employed.*

Keywords: RFID Systems, anti-collision, passive Tag.

1. Introduction

Radio frequency identification (RFID) systems have received much attention in many industries, manufacturing companies, material flow systems, etc. The RFID systems consist of networked electromagnetic readers and tags, where the readers try to identify the tags as quickly as possible via wireless communications. However, since the readers or the tags communicate over the shared wireless channel, the collision problem occurs in signal transmission of the readers or the tags, which hardly leads to fast identification. Thus, it is a key issue to develop an efficient anti-collision protocol reducing collisions so as to search all the tags in the interrogation zone.

Collisions are divided into reader collisions and tag collisions [3], only the latter of which is considered in this paper. The tag collisions occur in the case where more than one tag reflect back a signal at the same time, called "multi-access", confusing the reader. Since low-functional passive tags cannot figure out neighboring tags or detect collisions, it is of great significance to develop a tag anti-collision protocol improving the identification ability of RFID systems. Tag anti-collision protocols can be classified into aloha-based protocols and tree-based protocols [5]. The aloha-based protocols cannot perfectly prevent tag collisions because of the probabilistic procedure. Moreover, they have the serious problem, called "tag starvation", that a tag may not be identified [10]. Meanwhile, the tree-based protocols such as the binary tree protocol [1] [2] [6] [5] [8] [11] and the query tree protocol [2] [6] [8] [11] do not cause tag starvation occurring in the aloha-based protocols although they require relatively long time to identify all of tags. In this paper, we shall develop a tree-based protocol to identify completely all the tags in the interrogation zone.

The design goals of this paper are described as follows: 1) the minimization of the total time to identification of all tags in the interrogation zone, and 2) the minimization of the power consumption of tags, which results in a larger interrogation zone. To achieve these goals, we shall take each advantage of binary-tree and query-tree protocols. Specifically, to reduce the step for searching all tags in the interrogation zone, the depth-first search (DFS) is used as a basic search criterion like in query tree protocols. To prevent the redundant increase of the transmission bit length in process of implementing the DFS, the binary tree protocol is taken to restart the DFS at the height of binary tree, rather than the root, that was most recently marked when the tag collision happened. To substantiate theoretically that the proposed protocol achieves better performance than previous protocols, we shall employ the performance index in [8] consisting of both energy consumption and time delay.

The paper is organized as follows: Section 2 states the physical principles of RFID systems. Section 3 proposes an improved protocol and calculates the performance for the protocol. Section 4 compares between the proposed protocol and the existing tree-based protocols through an example. Finally, in Section 5, we make some concluding remarks.

2. Preliminaries

Consider the equivalent circuit diagram of passive tags used in the UHF (ultra high frequency, 300MHz–3GHz) band (Fig.1), where the left-side of the "impedance matching" block denotes the equivalent circuit of the tag's antenna (X_a: complex resistance, R_r: radiation resistance, l_0: effective length, G_r: antenna gain) and its right-side denotes that of the rectifying and processing units (R_L: load resistance) of the tag. The electromagnetic wave transports energy in the surrounding

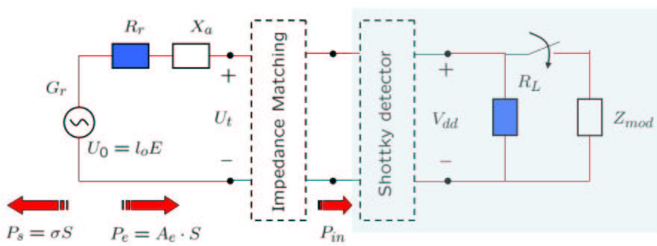

Fig. 1. Equivalent Circuit Diagram of Tag.

space and the energy is attenuated as increasing sphere surface area. Based on this fact, one define the radiation power per unit area, also called radiation density S.

$$S = \frac{\mathcal{P}_{EIRP}}{4\pi r^2} \tag{1}$$

where $\mathcal{P}_{EIRP}$ and r denote effective isotropic radiated power and distance, respectively. The tag's antenna absorbs some of the transmitted power, P_e, and reflects the remaining power, P_s:

$$P_e = A_e S, \quad P_s = \sigma S \tag{2}$$

where σ and A_e are called radar cross-section and effective aperture, respectively. It is well known that, in the case of power matching, the following equalities are satisfied:

$$\sigma = A_e = \frac{\lambda^2 G_r}{4\pi}, \quad P_e = \frac{\lambda^2 P G_s G_r}{(4\pi r)^2} \tag{3}$$

where G_s and λ denote the reader's antenna gain and the wavelength, respectively. In [8], the authors considered the equivalent circuit of the rectifying unit, called Shottky detector, to find energy charging elements (Fig.2), and then propose a

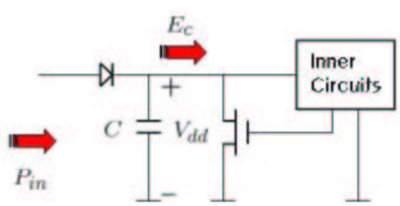

Fig. 2. Equivalent Circuit of Shottky detector.

performance index capable of handling both energy consumption and time complexity as follows:

$$P(k_2, k_1) = \frac{Cyc \cdot V_{dd}^2 \cdot C_{load}}{(k_2 - k_1) T_{INQ}} \left\{ \frac{1}{2} \sum_{i=k_1}^{k_2} A_i - \frac{V_{drop}}{V_{dd}} \frac{C}{C_{load}} \right\} \tag{4}$$

where the most critical factors are $k_2 - k_1$, Cyc and A_i which denote total cycle required to identify a tag, total cycle required to identify all tags in the interrogation zone and the circuit's total number of 0-to-1 transitions occurring at clock cycle i, respectively. The deriving procedure of the performance index is omitted in this paper. For the sake of simplification, we apply the following performance index $\mathcal{J}$ to develop an anti-collision protocol:

$$\mathcal{J} = \frac{Cyc}{k_2 - k_1} \left\{ \sum_{i=k_1}^{k_2} A_i - \eta_{mod} \right\} \tag{5}$$

where η_{mod} is a constant ratio of $(CV_{drop})/(C_{load} V_{dd})$. The cost of protocols proposed in [8] can be summarized as

- Binary-Tree Protocol (BP):

$$\mathcal{J}_b = (2k(n-1)+3)\left(10 - \frac{1}{2n-1}\eta_{mod}\right) \tag{6}$$

- Query-Tree Protocol (QP):

$$\mathcal{J}_q = (k(2n+8) - (n+3)) \times \left(8 - \frac{m^2 - 9m + 4}{2(n+4)(m+1)+4} - \frac{\eta_{mod}}{(n+4)(m+1)+2}\right) \tag{7}$$

- Improved Query-Tree Protocol (IQP):

$$\mathcal{J}_{iq} = (k(n+m+8) - 3) \times \left(8 - \frac{m^2 - 33m - 26}{2n + m^2 + 11m + 12} - \frac{2\eta_{mod}}{2n + m^2 + 11m + 12}\right) \tag{8}$$

where n denotes the length of tag IDs, k denotes the number of tags simultaneously appearing in the interrogation zone. and $m = \log_2 k$ denotes the depth.

3. Main Result

We are interested in developing an improved anti-collision protocol based on tree-based scheme for tags in the UHF band. To reduce not only the transmission bit length but also the step for searching all tags in the interrogation zone of a single reader, we take advantages of binary-tree and query-tree protocols. We first assume that the reader has an intelligent processing function of constructing a binary-tree map during searching tag IDs, and that each tag has a pointer, where the pointer moves toward a lower bit with the ongoing of inquiring. As shown in Fig.3, the reader sends sequentially one inquiring bit, inquiring position data and Null bit to tags during inquiring, where the Null bit is used to inform the termination of the data package. According to the existence

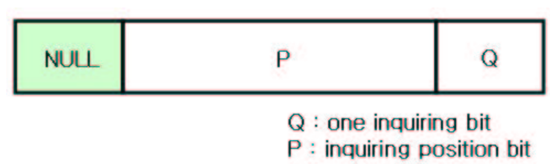

Fig. 3. Data package generated by the reader.

of the inquiring position data P, the tags operate differently. If there exists the inquiring position data P in the data package, transmitted serially (a bit at a time), the tags whose pointed bit and position data are identical to the inquiring bit Q and the inquiring position data P, respectively, send back their next bits to the reader, while the rest convert to the "stand-by" state S_1 and do not answer the remaining inquiries until one tag has been killed. In the case where there exists no position data P in the data package, the bit indicated by the pointer is only checked. If the reader detects one non-collision response bit, it is used as a next inquiring bit Q. Otherwise, the reader stores '1' and the position, called "height" in binary trees, and uses '0' as the next inquiring bit. After searching completely one tag, the reader sends the stored data in the form of Fig.3 and a new round of inquiring begins. An example of identifying 4 tags, whose IDs are 0001, 0011, 1000 and 1100, is shown Fig.4. Fig.4–(a) shows the bit stream between a reader and tags in the interrogation zone, where "c" denotes a collision detected by the reader and "n" denotes Null bit. Fig.4–(b) shows the flow diagram of searching tags. Fig.5

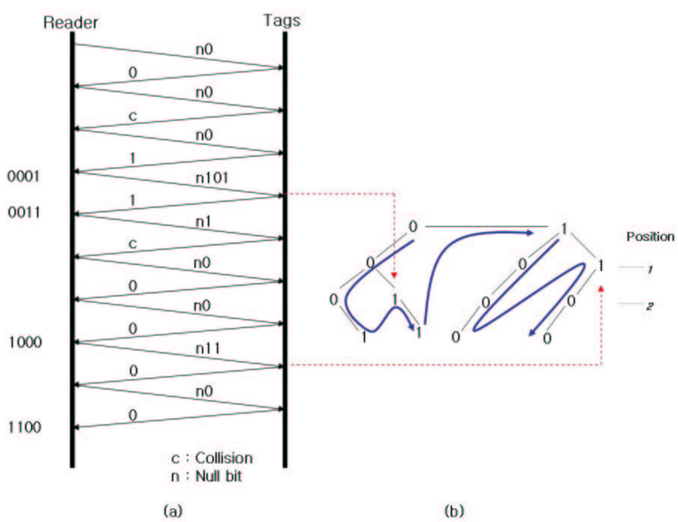

Fig. 4. (a) Bit stream between a reader and tags in the interrogation zone, (b) the flow diagram of searching tags.

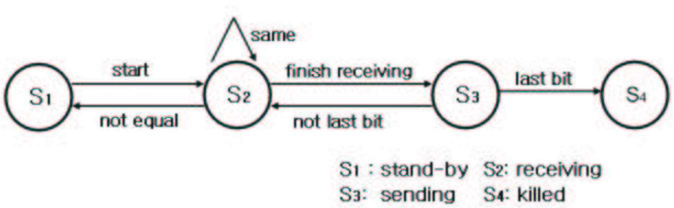

Fig. 5. State diagram for the proposed protocol.

shows the state diagram for the proposed protocol. To identify one tag, the numbers of clock cycles required for inquiring and answering are given as N_q and N_a, respectively.

$$N_q = \begin{cases} 2(n-1) & \text{in the absence of P} \\ 2+[\log_2 h+1]+2(n-h-2) & \\ & \text{in the case of position } h \end{cases} \tag{9}$$

$$N_a = \begin{cases} (n-1) & \text{in the absence of P} \\ (n-h-1) & \text{in the case of position } h \end{cases} \tag{10}$$

where $[\,\cdot\,]$ denotes an integer round-off operator.

Remark 1: In the case where the collision occurs in the last bit of tag IDs, the reader can simultaneously identify two tags.

The total clock cycle N_t required for identifying all tags is given as, for $n \geq 3$,

$$N_t = \underbrace{2 \times \left(2+\sum_{h=1}^{n-2}(2+2+[\log_2 h+1])\right)}_{for\ inquiring} + \underbrace{2 \times \sum_{m=2}^{n} 2^{n-m}}_{for\ answering} \tag{11}$$

Thus, the average clock cycle Cyc for searching k tags is given as $(kN_t)/2^n$, for $n \geq 3$. Beside, we can know that the shortest clock cycle for $k_2 - k_1$ is $2+[\log_2(n-2)+1]+1$ and the longest is $3(n-1)$, for $n \geq 3$. Using the result of [8], we can obtain

$$7.5(2+[\log_2(n-2)+1])+12.5 \leq \sum_{i=k_1}^{k_2} A_i \leq 7.5(2(n-1))+12.5(n-1) \tag{12}$$

Hence, we can obtain the upper bound of the performance index $\mathcal{J}$ as follows:

$$\mathcal{J} \leq \mathcal{J}_{up} = \max\left\{\max_{1\leq h\leq n-2}\mathcal{J}(h),\ \frac{k}{2^n}\frac{N_t}{3(n-1)}\{27.5(n-1)-\eta_{mod}\}\right\} \tag{13}$$

where

$$\mathcal{J}(h) = \frac{k}{2^n}\frac{N_t}{3(n-h-1)+[\log_2 h+1]} \times \{7.5[\log_2 h+1]+27.5(n-h-1)-\eta_{mod}\} \tag{14}$$

4. Comparison of the anti-collision protocols

In [8], it is known that the binary-tree protocol (BP) is better than two query-tree protocols (QP & IQP). Thus, by comparing only between the performance index of BP, $\mathcal{J}_b$, and that of the proposed protocol, $\mathcal{J}_{up}$, we substantiate that the proposed protocol achieves better performance than the existing protocols (see Fig.6–(b), (c)). Fig.6-(a) shows that the greater the length of tag IDs, the better the performance of the proposed protocol.

5. Concluding Remarks

This paper introduced a tree-based tag anti-collision protocol for passive RFID tags. To reduce the step for searching all tags in the interrogation zone, we used the depth-first search (DFS) as basic search criterion like in query tree protocols. To prevent the redundant increase of the transmission bit length in process of implementing the DFS, the binary tree protocol was taken to restart the DFS at the height of binary tree, rather than the root, that was most recently marked when the tag collision happened.

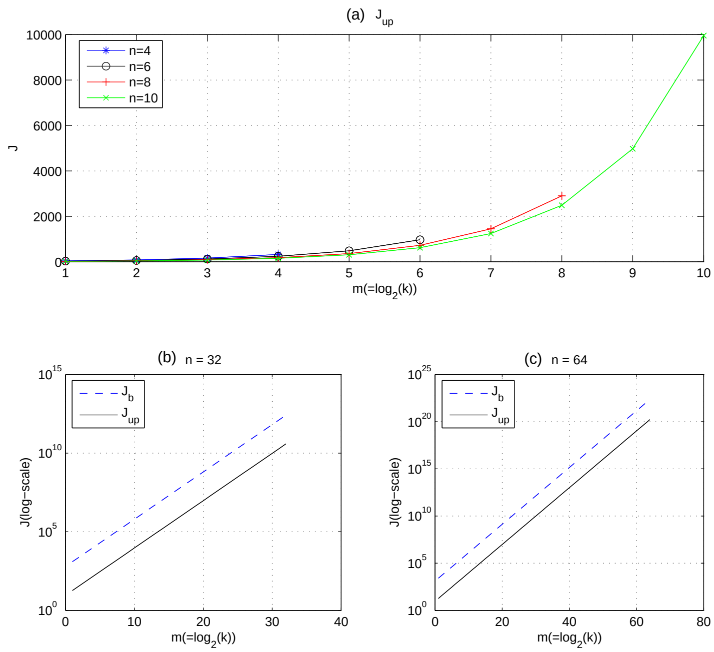

Fig. 6. (a) Performances of the proposed protocol for $n = 4, 6, 8, 10$, (b) Comparison of $\mathcal{J}_b$ and $\mathcal{J}_{up}$ for $n = 32$, (c) Comparison of $\mathcal{J}_b$ and $\mathcal{J}_{up}$ for $n = 64$.

6. References

[1] D. R. Hush and C. Wood, "Analysis for Tree Algorithms for RFID Arbitration," *ISIT*, Cambridge, MA, USA, pp. 107, 1998.

[2] C. Law, K. Lee, K. Y. Siu, "Efficient Memory-less Protocol for Tag Identification," *In Proceedings of the 4th International Workshop on Discrete Algotirhms and Methods for Mobile Computing and Communications*, Boston, Massachusetts, ISA, pp. 75–84, 2000.

[3] S. Sarma, D. Brock, and D. Engels, "Radio Frequency Identification and the Electronic Product Code," *IEEE Micro*, vol. 21, no. 6, pp. 50–54, 2001.

[4] C. Abraham, V. Ahuja, A. K. Ghosh, P. Pakanati, "Inventory Management using Passive FRID Tags: A Survey", Department of Computer Science, The University of Texas at Dallas, Richardson, Texas, pp. 1–16, 2002.

[5] K. Finkenzeller, RFID Handbook: Radio-Frequncy Indetification Fundamentals and Applications in Contactless Smart Cards and Identification, Second Edition, Jhon Wiley, New York, 2003.

[6] F. Zhou, D. Jing, C. Juang and H. Min, "Opimizing the Power Consumption of Passive Electronic Tags For Anti-collision Schemes," *In Proceedings of the 5th ASICON*, Beijing, China, pp. 1213–1217, 2003.

[7] EPCglobal Hardware Action Group, EPC Radio-Frequency Identity Protocols Generation 2 UHF RFID (Class 1): Protocol for Communications at 860 MHz - 960 MHz, 2003.

[8] F. Zhou, C. Chen, D. Jin, C. Huang and H. Min, "Evaluating and Optimizing Power Consumption of Anti-collision Protocols for Applications in RFID Systems," *ISLPED'04*, Newport Beach, California, USA, pp. 357–362, 2004.

[9] ISO/IEC 18000-6: Parameters for Air Interface Communications at 860MHz to 960MHz, International Standard, 2004.

[10] J. Myung and W. Lee, "An Adaptive Memoryless Tag Anti-Collision Protocol for RFID Networks," *The* 23^{rd} *Conference of the IEEE Communications Society*, 2005.

[11] D. Shih, P. -L. Sun, D. C. Yen and S. -M. Huang, "Taxonomy and Survey of RFID Anti-collision protocols," *Computer and communicatios*, 2006.