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A distributed multi-channel reader anti-collision algorithm for RFID environments

Haidar Safa *, Wassim El-Hajj, Christine Meguerditchian

American University of Beirut, Department of Computer Science, P.O. Box: 11-0236, Riad El-solh, Beirut 1107 2020, Lebanon

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ABSTRACT

In Radio Frequency Identification environments, several readers might be placed in the same area to scan a large number of tags covering a wide distance range. The placement of the RFID elements may result in several types of collisions. This paper proposes a multi-channel algorithm to solve the reader collision problems in a sense or sparse RFID environment. We adapt a distributed approach that avoids the need of costly extra hardware for centralized control. In addition, the proposed approach does not require global synchronization in the RFID network. It introduces a multi-channel notification protocol to make RFID readers aware of the network resources utilization. We have evaluated the performance of the proposed approach using NS3 and compared it to several anti-collision solutions such as NFRA, Dica and McMac. Results show that the proposed algorithm reduces the time needed for tags' identification, thus increasing the rate of successful interrogations while minimizing the network overhead.

1. Introduction

Radio Frequency Identification (RFID) started in 1973, as part of the "Automatic Identification and Data Capture" group, to replace the traditional use of bar codes. RFID enables wireless interaction over certain frequencies of RFID readers with a network system, to uniquely identify, track and capture the status of tagged objects within packages, animals or people at varying distances without the need of human intervention. As shown in Fig. 1, an RFID network is composed of four main elements: (1) RFID tags, (2) RFID readers, (3) the air interface, and (4) edge servers. Typically, RFID readers emit radio-frequency signals that RFID tags would detect if present in the reader's transmission range. RFID tags respond to the reader's queries by emitting radio waves back with the data stored in the chip [11]. In recent years, several major supply chain companies, such as Wal-Mart and Tesco, mandated the use of RFID systems in their warehouses. In this RFID environment (Fig. 1), hundreds of readers might be placed in the same area (i.e. in a building) to scan a large number of tags for a desired coverage range. Such a dense network exhibits high number of collisions that lead to reduction in data collection throughput, increase in identification delay, and degradation in network efficiency and reliability.

Three types of RFID collisions exist: (1) tag to tag collisions, (2) reader to reader interference (RRI), and 3) reader to tag interference (RTI). A tag to tag collision occurs when a reader broadcasts a message to tags, which, as a result of the message, transmit their IDs simultaneously to the reader [9]. Several tags anti-collision protocols exist and can be used to resolve tag collisions [16,30,31]. These protocols are generally ALOHA-based or tree-based protocols but they commonly focus on reducing the required time until a single reader completely recognizes the tags in the reader's identifying range.

As for the 2 reader collision problems (RRI and RTI), it is essential to differentiate between the transmission range of a reader and its interference range as shown in Fig. 2. This figure contains two readers, R1 and R2, and two tags, T1 and T2. The transmission/read range is the coverage area of the reader, which may reach 10 m when the reader is operating with an output power of 2 W [10], while the interference range is the area that the reader causes interference on, which may reach 1000 m [18]. RRI occurs when many readers are working at the same frequency within an interference range. In Fig. 2a, RRI occurs when R1 attempts to read data from T1 using a channel with frequency f_1 while R2 is trying to read data from tags in its transmission range (example T2) using the same channel with frequency f_1. The signal sent from R2 to read T2 will interfere with the reply signal sent from T1 to R1 as shown in Fig. 2b. RRI can be avoided by having the readers operate at different frequencies or different time slots [16].

* Corresponding author.
E-mail addresses: haidar.safa@aub.edu.lb (H. Safa), wassim.el-hajj@aub.edu.lb (W. El-Hajj), ckm03@aub.edu.lb (C. Meguerditchian).

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On the other hand, two types of RTI exist. The first type occurs when multiple readers, independently of the working frequency, try to simultaneously read the same tag located in their common reading range as shown in Fig. 3a. In this figure, RTI occurs when R1 and R2 attempt to read T1 simultaneously as shown in Fig. 3b. The tag T1 will not be able to decode the commands of both readers and consequently will not be able to reply. This type of collision can be avoided by having the readers operate at different time slots [16].

The second type of RTI occurs when two readers are operating at the same frequency, where a tag is located in the read range of one reader, and in the interference range of another. In Fig. 4a for example, RTI will occur when R1 and R2 attempt simultaneously to read T1 and T2 respectively using frequency f_1. Since T1 is in the interference range of R2 and the read range of R1, both signals will reach T1 and collision will occur at the tag (Fig. 4b). This type of collision can be avoided by having the readers operate at different frequencies or at different time slots.

In this paper, which is an extension to our work in [21], we propose a new distributed multi-channel anti-collision algorithm, referred to as DiMCA, for RFID networks. The proposed DiMCA aims to solve all types of reader collisions: RRI, and two types of RTI. It is distributed and introduces a multi-channel notification protocol to distribute network resources among readers. When compared to the state-of-the-art collision avoidance protocols (NFRA, Dica and McMac), our proposed DiMCA reduced the total time needed for tag identification and increased the rate of successful interrogations in the network. The remainder of this paper is organized as follows. In Section 2, we survey the related work. In Section 3, we present our new approach. In Section 4, we evaluate the performance of the proposed approach and compare it with other well-known algorithms. Conclusion is presented in Section 5.

2. Related work

Many approaches were recently proposed to reduce the impact of RFID collisions, minimize interference, and maximize the read range [1,4,6–10,12,14,15,17,19,20,22,24–29]. ETSI 302 208 [10] is a standard that presents a regulation to govern the operation of RFID readers. It applies "Listen before talk" (LBT) or Carrier Sense Multiple Access (CSMA). It states that prior to transmission, the interrogator must listen for the presence of another signal within its intended sub-band of transmission. The listening time comprises a fixed period of 5 ms plus a random time chosen from 0 ms to 5 ms in 11 steps. If the sub-band is free, the random time shall be set to 0 ms. The sub-band is then used for 4 s by a reader after selection and then freed for at least 100 ms. The frequency band of 865–868 MHz (UHF) is allocated for RFID deployment. The band is divided into 15 sub-bands, each spanning 200 kHz. The main disadvantage of this standard is that readers might be placed in a way where they cannot see each other according to their located angle positions, hence resulting in unsolved collisions.

EPC Class 1 Gen 2 [9] is a standardization effort, based on frame slotted aloha [24], proposed by EPC Global. It is applied to UHF and used for supply chain. It uses techniques like frequency hopping or frequency agile systems. The allocated frequency band is divided into 10 sub-bands. A reader uses only one channel, not the entire band. Readers randomly change bands every 0.4 s according to the Frequency Hopping Spread Spectrum (FHSS) technique which aims to minimize collision probabilities. Readers operate in even numbered channels whereas tag backscatter using odd-numbered channels, so the readers are left with only 5 channels available. This standard suffers from the reservation of a single channel by a certain reader in a large area, preventing others from using it. In addition, the study conducted in [22] has shown that the current EPC Class 1 Gen 2 standard, under ideal conditions, theoretically adds 10% overhead in terms of delay to the basic frame slotted aloha protocol.

An approach was proposed in [19] for synchronization among readers through a central control unit. It uses fine tuning methods, dynamic channel assignment and optimized spectrum management. All readers start listening at the same time, and then synchronously talk at the same time. The same channel is assigned for readers that are very far from each other. It also suggests reducing radiating power, which allows reducing the minimum distance between two antennas using the same channel. Some ideas have been mentioned but not applied like: reducing talking time, using sensors to turn readers on and off, using RF opaque and absorbing materials which are very expensive solutions.

Colorwave [27,28] is a distributed TDMA based algorithm, where each reader chooses one of the time slotted colors in [0,

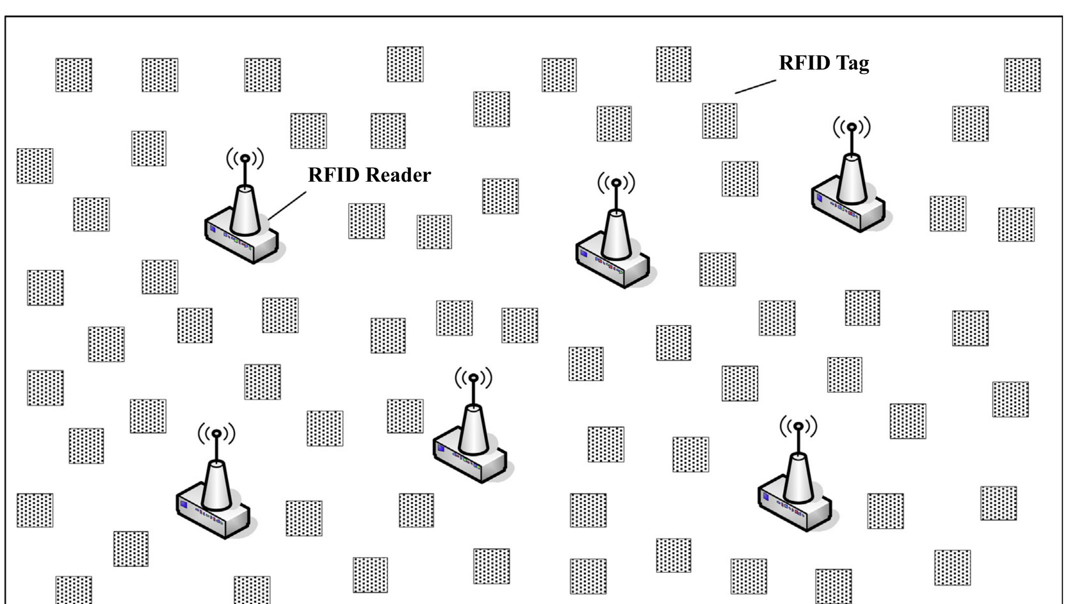

Fig. 1. An example of a dense RFID environment.