Poster Abstract: Analysis of RFID Anti-Collision Algorithms using Smart Antennas [*]

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ABSTRACT

Recently, the radio frequency identification (RFID) technology has gained significant attention. One of the important performance issues in RFID systems is to resolve the collision among responses from RFID tags from the viewpoint of wireless media access control. We consider two kinds of smart antenna systems to enhance the RFID tag reading rate, namely the adaptive array antenna and the multiple-input multiple-output (MIMO) antenna. We consider passive tags that are operating without battery. We evaluate how much performance can be improved by employing smart antennas in the cases of the binary tree splitting algorithm and the Slotted-Aloha algorithm.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Wireless communication*

General Terms

Algorithms, Design, Performance

Keywords

Anti-collision, RFID, Smart antennas

1. INTRODUCTION

The Radio Frequency Identification (RFID) system is a flagship technology to identify and trace objects by attaching a small RFID tag to the objects. Recently, RFID technology is becoming a real-world application of wireless sensor networks and will be used in many areas such as supply chain management, asset management and security. An important question is whether we need a battery to operate the RFID tags. An *active tag* uses a battery to power the circuitry and transmits/receives a signal. On the other hand, a *passive tag* draws power entirely from the electromagnetic waves sent by an RFID reader, hence only respond after receiving a radio frequency (RF) signal from the reader.

Due to the order of magnitude difference in cost, passive tags are expected to be used much more widely. However, they can respond only once for each RFID reader's signal, which limits the design of a wireless communication protocol. This limitation has become a crucial issue for environments where a large number of tags should be identified almost simultaneously, thus leading to what is called an *anti-collision* problem. To tackle this problem, we focus on the slotted Aloha (S-Aloha) algorithm [1] and the binary tree splitting algorithm [2].

Since smart antennas have been shown to increase the throughput in wireless communications, we propose to incorporate them into RFID readers in order to enhance the RFID tag reading rate. We will consider two kinds of smart antenna systems, which have different functionality in terms of the number of RFID identification at a time.

2. SMART ANTENNA MODELS

In the receiver side of wireless communications, smart array antennas mainly fall into two categories [3]: (i) adaptive array antennas and (ii) multiple-input multiple-output (MIMO) antennas. In general, a smart antenna system with K element antennas is said to possess K *degrees of freedom* (DOFs). In the first category of antennas, a K element array adaptively nullify $K-1$ interferers. In other words, one element receives the desired signal while the other elements are used to remove interference to increase the signal-tonoise ratio. In MIMO systems, however, each antenna element receives a superposition of the multiple transmitted streams with different spatial signatures. These differences are used to separate the multiple streams with signal processing at the receiver. In short, a MIMO antenna with K DOFs can receive K streams simultaneously. In either case, collision occurs (no signal can be decoded) when the number of simultaneous replies from RFID tags is greater than K.

3. ANTI-COLLISION ALGORITHMS

A typical communication procedure between an RFID reader and RFID tags is a series of messages (Request, Select, Read Data), which is repeated for individual RFID tags. For simplicity, we will describe the following two al-

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gorithms on a slot basis assuming each series of the above messages is completed in one slot and same length for collided, idle and successful slots. The number of tags in our problem is fixed during the run of the algorithm, whereas the general multiple access problem usually models network traffic as a stochastic process. Our concern here is to reduce the number of slots are required to identify all the tags in the reading volume by using smart antennas.

3.1 Binary tree splitting

This algorithm is the most viable solution in RFID systems with passive tags to date. Each tag has a globally unique identifier (ID) represented by a string of bits. The reader is able to specify the range of tag IDs in the request message to which the tags coming under that range must respond. In the first slot, the reader requests all relevant tags in the reading volume to respond.

When a collision occurs (the number of responding tags is greater than K), say in the ith slot, all tags involved in the collision are split into two subsets. The reader uses the successive bits of the original ID field to make narrowed-down choice of the ID range. For example, the range [0000,1111] will be split into two parts, one for each subset 0xxx and 1xxx where x can be either 0 or 1. The reader requests the first subset to respond in slot $i+1$, and if that slot is idle (no response) or successful (K or less responses), the second subset is requested to respond in slot $i+2$ with the MIMO antenna and in slot $i+L+1$ with the adaptive array antenna where $L(\leq K)$ is the number of tags allotted to the first subset. In the case of the adaptive array antenna, when the slot $i+1$ is successful with responses from L tags, the reader read all L tags one by one. Thus, the second subset is asked to transmit in slot $i+L+1$. On the other hand, if another collision occurs in slot $i+1$, the first of the two subsets splits again, while the second subset waits for the resolution of that collision. This splitting mechanism is recursively repeated until no further collision occurs.

3.2 Slotted Aloha (S-Aloha)

When the reader requests tags to respond, each tag holds the transmission of its data until expiration of a counter whose value is generated randomly and independently of other tags. The reader announces the beginning of each slot e.g., by putting a gap pulse (no RF field for some designated time) at which the random number counter of each tag decrement. When a collision occurs (i.e., more than K tags respond in the same slot), each tag discovers the collision in the absence of a feedback message (selecting itself) from the reader, and becomes backlogged. Each backlogged tag again waits for some random number of slots before retransmitting.

4. PERFORMANCE EVALUATION

First, we evaluate the throughput (measured as successfully recognized tags per slot) of the binary tree splitting algorithm with the assumption of the uniform distribution of tag IDs in the bit range interested. Let us first analyze the MIMO antenna case. The expected number of slots in the jth split, $s(j)$, is expressed recursively as $s(j) = 1 + 2 * s(j+1) * P_{col}(j)$ $(0 \leq j < R-k)$ with a boundary condition $s(R-k) = 1$, where R is the number of bits indicating the initial ID range interested, k is the number of bits mapped to the DOFs ($K = 2^k$), and $P_{col}(j)$ is the probability of collision in the jth split. One slot is required by default regardless of the possible outcomes: *Idle, Success or Collision.* In the case of the adaptive array antenna, one or more slots are required to read all tags. Therefore, the expected number of slots in the jth split is $s(j) = 1+1*\sum_{i=2}^{K} P_i(j)+2*s(j+1)*P_{col}(j)$ $(0 \leq j < R-k)$ with a boundary condition $s(R-k) = 1+1*\sum_{i=2}^{K} P_i(R-k)$, where $P_i(j)$ is the probability of i number of responding tags in the jth split.

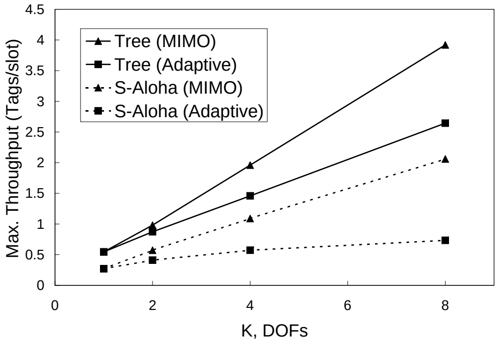

Figure 1: Maximum Throughput vs. DOFs

Next, we analyze the S-Aloha algorithm as follows. Let $p(n, s)$ be the probability of having n tags $(0 \leq n \leq N)$ read successfully until the mth slot, where N is the total number of tags to be read. For analysis, we employ the two-dimensional Markov chain where each of n and m corresponds to a dimension. If the initial transmissions (responses) from the tags and the retransmissions from backlogged tags are sufficiently randomized, it is plausible to approximate the total number of retransmissions and initial transmissions in a given slot as a Poisson random variable with a parameter $\frac{N-n}{T}$ where T is the time window size for randomization [4]. Then, $p(n, m)$ can be calculated iteratively from the initial state $(0, 0)$ such that $p(0, 0) = 1$, and the expected number of slots to read all N tags is calculated by $\sum_{i=0}^{\infty} i * p(N, i)$.

Fig. 1 shows the maximum throughput by smart antenna based RFID systems. We observe that the throughput increases with K. The S-Aloha with the adaptive array antenna shows little enhancement because the nullified tags have to participate in collision resolution again.

5. REFERENCES

[1] L. G. Roberts, *Aloha Packet System with and without Slots and Capture*, ASS Note 8, Stanford Research Institute, Advanced Research Projects Agency, Network Information Center, 1972.

[2] J. I. Capetanakis, "Tree algorithms for packet broadcast channels," *IEEE Trans. on Information Theory,* vol. IT-25, pp. 505-515, September, 1979.

[3] K. Sundaresan and R. Sivakumar, "A unified MAC layer framework for ad-hoc networks with smart antennas," in *Proc. of ACM MOBIHOC*, May, 2004.

[4] D. Bertsekas and R. Gallager, *Data Networks.* Section 4.2. Prentice-Hall, New Jersey, 1992.