A Communication Model for Stateless Networked Tags

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Abstract—Traditional radio frequency identification (RFID) technologies allow tags to communicate with a reader but not among themselves. By enabling peer-to-peer communications among nearby tags, the emerging networked tags make a fundamental enhancement to today’s RFID systems. This new capability supports a series of system-level functions in previously infeasible scenarios where the readers cannot cover all tags due to cost or physical limitations. This paper makes the first attempt to design a new communication model that is specifically tailored to efficient implementation of system-level functions in networked tag systems. Instead of exploiting complex mechanisms for collision detection and resolution, we propose a collision-resistant communication model (CCM) that embraces the collision in tag communications and utilizes it to merge the data from different sources in a benign way. Two fundamental applications: RFID estimation and missing-tag detection, are presented to illustrate how CCM assists efficient system-level operations in networked tag systems. Simulation results show that system-level applications through CCM outperform those through ID collection.

I. INTRODUCTION

RFID (radio frequency identification) is becoming ubiquitously available in asset management, automatic payment, access control, fast checkout, theft prevention, etc. An RFID system typically consists of three components: tags, readers, and application software. In today’s prevalent application model, tags are treated individually as ID carriers embedded in library books, passports, driver licenses, car plates, medical products or other objects, allowing an RFID reader to quickly identify or access the properties of each individual object. Recently, new research has made a paradigm shift from this individual view of tag identification to a collective view of system-level functions [1], such as estimating the number of tags [2] and detecting the missing tags [3].

Networked Tags: Traditionally, tags can only communicate with readers but not between themselves. An emerging research branch of networked tags proposes a fundamental change: peer-to-peer communications are enabled amongst the tags. The new capability of forming a network provides great flexibility in various applications, where the readers cannot cover all tags due to cost or physical limitations. There can be two types of networked tags. The stateful networked tags maintain state information such as their current neighbors and correct routing tables. These tags are similar to the nodes in a typical sensor network. However, they have to frequently exchange messages to keep state information up-to-date, which costs energy. The state-free tags do not maintain any network state prior to operation, which makes them different from the nodes in traditional networks, including sensor networks. Similar to [4], we consider state-free networked tags in this paper. There are two reasons for this. First, establishing neighborhood and then routing tables across the network is expensive and may incur much more overhead than tag operations themselves. Second, maintaining the neighbor relationship and updating the routing tables (as tags may move between operations) require frequent network-wide communications, a cost not worthwhile for infrequent operations by tags that sleep most of the time to save energy.

Collision-resistant Communication Model: The goal of this paper is to design a new communication model that is specifically designed for efficient implementation of system-level functions for state-free networked tags. Our observation is that, unlike traditional wireless systems (such as WiFi networks and sensor networks), the amount of information to be delivered from tags to a reader is very small, often just one bit per tag. It is not worthwhile to implement complex mechanisms for collision detection and resolution, which carry high overhead in multi-hop networks, where collision happens hop by hop. Hence, we propose a collision-resistant communication model (CCM) that embraces collision in tag communications and utilizes it to merge the data from different sources in a benign way. To meet the low hardware requirement of tags, our model is much less demanding: It does not require tags to record signal waveforms and separate aggregate symbols into individual ones. It only requires a tag to be able to tell whether the channel is busy or idle in each time slot.

We select two important applications, RFID estimation [2] and missing-tag detection [3], as examples to demonstrate how to apply our new model to implement system-level functions efficiently. Simulation results show that CCM-based RFID estimation and missing-tag detection are far superior to the ID-collection-based approach [4].

II. DESIGN OF CCM

A. Sessions, Frames and Slots

The communications between the reader and tags are performed in sessions. Each session allows the reader to broadcast one request to all tags and collect an information bitmap that combines the input from all tags. A session consists of time frames, each carrying either the reader’s request or the information bitmap. Every frame is logically divided into
slots, each carrying one bit. Consider the simple on-off keying modulation at the physical layer: If a bit is ‘1’, a signal is transmitted in the corresponding slot; if a bit is ‘0’, nothing is transmitted.

B. Reader Request Broadcast

When the reader transmits its request, all tags in its neighborhood receive the request. These tags are called tier-1 tags. The request carries a tier-number field, which is initialized to 1. In the next frame, all tier-1 tags increase the tier-number field by 1 and re-transmit the reader’s request, which reaches their neighbors that have not received the request yet; these tags are referred to as tier-2 tags. This process repeats and the request fans out tier by tier until the outermost tags, as shown in Fig. 1. Note that all tier-1 tags are transmitting the same bit sequence and collision happens in a positive way: Signals for ‘1’ strengthen each other in the same slot; nothing for ‘0’ remains nothing.

C. 3-Frame Cycle

Each tag follows a 3-frame cycle for communications. After a tag receives the request in a certain frame, it knows its tier number i. After it re-transmits the request in the next frame, it will repeat a 3-frame cycle: (1) listening to the transmission from tier-(i + 1) tags, (2) listening to the transmission from tier-(i − 1) tags, and (3) transmitting its own data. These three frames are referred to as $L_{i+1}$, $L_{i-1}$ and $T_i$, respectively.

D. Two Waves of Information

The communication model of 3-frame cycle allows two waves of information to flow in the network without interfering each other. One wave is to deliver the request to all tags, which begins from the reader and fans out tier by tier towards the outermost tags in the network. The other wave is to deliver the data from all tags, tier by tier, converging towards the reader. Each tag will merge the data received in $L_{i+1}$ frames from its tier-(i + 1) neighbors, transmit the merged data in $T_i$ frames to its tier-(i − 1) neighbors. An example of two-wave transmission is given in Fig. 2.

III. PERFORMANCE COMPARISON

We evaluate the time efficiency of SICP [4], GMLE-based RFID estimation [2] through CCM (GMLE-CCM), and TRP-based missing tag detection [3] through CCM (TRP-CCM), in networked tag systems. In each simulation, we consider N=10,000 tags. For RFID estimation, the confidence level $\alpha$ is set to 95%, and the relative error $\beta$ is set to 5%, the optimal sampling probability is $p = \frac{\delta^2}{1.506} = 1.506 \times 10^{-4}$, and the frame size $f$ is set to 1671 in order to meet the accuracy requirement. For the missing tag detection, the detection probability $\delta$ is set to 95%, and the missing tolerance $m$ is set to 0.005. $N = 50$. Based on the parameter configuration specified in [3], we derive the smallest frame size $f = 3228$ that meets the detection accuracy $\delta$. Table I shows the execution time measured by the number of time slots under different inter-tag communication ranges $r$. GMLE-CCM and TRP-CCM take much fewer slots than SICP, meaning that CCM makes the system-level functions work more efficiently in a networked tag system. Specifically, GMLE-CCM and TRP-CCM cuts the time by an order of magnitude when comparing with SICP. For example, when $r = 6$, the number of slots in SICP is 512,466, whereas those numbers in GMLE-CCM and TRP-CCM are just 23394 and 46592 — 95.4% and 90.9% reduction, respectively. This great performance boost well indicates that the high time-efficiency of CCM.

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TABLE I: EXECUTION TIME WITH RESPECT TO $r$.

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REFERENCES