Poster: Anonymous Category-level Joint Tag Estimation

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ABSTRACT

Radio-frequency identification (RFID) technologies have been widely used in many applications. Tag estimation, which is to estimate the cardinality of a single tag set, is an important research topic. This paper expands the estimation research as follows: It performs joint estimation between two tag sets, and more importantly the estimation is fine-grained in an effort to accommodate common practical scenarios, where each tag set consists of tags belonging to different categories. For any two given tag sets, we want to know the detailed information about the joint property of each category, instead of just the aggregate information of the whole sets. Furthermore, due to the open nature of RFID communications, it is often desirable that category-level joint estimation can be performed in an anonymous way without revealing the tags' IDs. To support these requirements, we develop a new technique called mask bitmap that can encode a tag set without requiring the tags to report their IDs or category IDs. Any two mask bitmaps that encode different tag sets can be combined to perform category-level joint estimation. Simulation results confirm that the proposed solution can yield accurate category-level estimates and preserve tags' anonymity.

Categories and Subject Descriptors

C.2.4 [**Computer-Communication Networks**]: [Distributed Systems]

Keywords

RFID; Category level; Anonymity; Joint estimation

1. INTRODUCTION

Radio Frequency Identification (RFID) technologies integrate simple communication, storage, and computation components into attachable tags that can communicate with RFID readers wirelessly over a distance. Due to this significant advantage over traditional bar code systems, RFID systems have been widely used in many applications. Each tag not only identifies its associated object, but also indicates its category information through a subfield of tag ID called *category ID*.

One important RFID research topic is *tag estimation* [1], which is to estimate the *cardinality* of a tag set (i.e., the number of tags in the set) at a certain location. Prior work on tag estimation has some limitations. First, most approaches only consider a single tag set. There is limited work on joint estimation of two tag sets[2], which is however based on a questionable relative error model. This paper is based on an absolute error model. Second, most prior work only estimates the aggregate information of the whole tag set(s), but ignores the fact that tagged objects belong to different categories.

To our best knowledge, this is the first work that studies anonymous category-level joint estimation in RFID systems with new contributions summarized as follows:

First, we expand the research on tag estimation into new domains of category-level estimation. The category-level joint estimation is capable of depicting the dynamics between two arbitrary tag sets at the category level.

Second, we propose a formal anonymous model to numerically evaluate the anonymity of different tag estimation protocols for the first time.

Third, we develop a new technique called *mask bitmap* to achieve anonymous category-level joint estimation. A mask bitmap can tactfully encode all tags without knowing their IDs or category IDs, while the information of each category can be retrieved later for joint estimation.

2. PROBLEM STATEMENT

Suppose all objects in an RFID system can be classified into m different categories, denoted by a set M of category IDs $\{cid_1, \ldots, cid_m\}$. Consider two arbitrary tag sets N_p^* and N_q^* in a large distributed RFID system, where they may refer to two sets at different locations, p and q, respectively, or two sets at the same location but different times, in which case p and q refer to time. The wildcard superscript $*$ means that the notation covers tags of all categories. Consider an arbitrary category $cid \in M$. Let $N_p(cid)$ be the subset of tags in N_p^* that

MobiHoc'16 July 04-08, 2016, Paderborn, Germany

DOI: http://dx.doi.org/10.1145/2942358.2942400

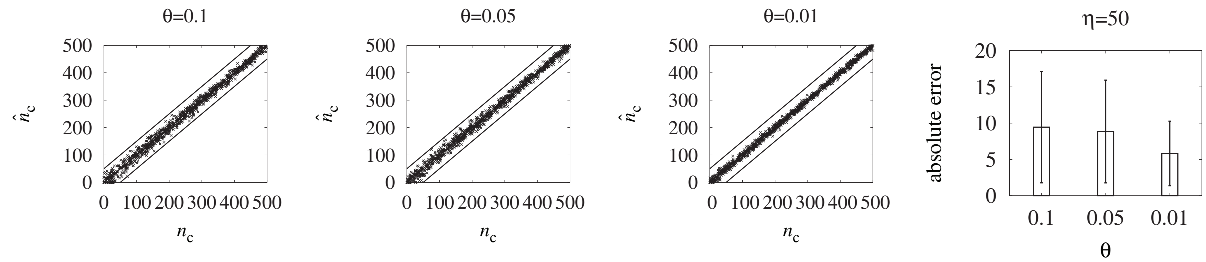

Figure 1: Estimation results when n_p and n_q follow normal distribution $Norm(750, 100^2)$, and n_c of each category follows a uniform distribution over $[0, 500]$.

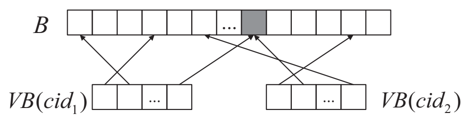

Figure 2: Two virtual bitmaps $VB(cid_1)$ and $VB(cid_2)$ are built on top the mask bitmap B for categories cid_1 and cid_2, respectively.

belong to category cid, and similarly $N_q(cid)$ be the subset of tags in N_q^* that belong to category cid. Let $N_c(cid) = N_p(cid) \cap N_q(cid)$, and $n_c(cid) = |N_c(cid)|$. We will abbreviate $N_p(cid)$ simply as N_p when the context does not raise confusion. Similarly, we will use N_q, N_c, and n_c without explicitly including (cid) in order to simplify these notations. The problem is to estimate n_c for each category under an accuracy requirement and an anonymity requirement, which are defined as follows.

Accuracy requirement: Our goal is to give an accurate estimate $\hat{n_c}$ for n_c, such that

$$Prob\{|\hat{n_c} - n_c| \le \eta\} \ge 1 - \theta, \qquad (1)$$

where η is an absolute error bound and θ is a probability.

Anonymity requirement: The estimation should be performed in an anonymous way. We use two two metrics to evaluate how much anonymity is preserved after executing a tag estimation protocol: (1) *ID anonymity* is the probability p_{id} that the adversary cannot infer a tag's ID from the transmissions; (2) *Category anonymity* is the probability p_{cid} that the adversary cannot crack a tag's category ID based on the transmissions.

3. PROTOCOL DESIGN

To preserve the anonymity of tags, we design a new data structure called *mask bitmap*, a variant of traditional bitmap. The idea is, instead of allocating a separate bitmap for each category, we use a single large bitmap B to accommodate all categories. For each category, we build a *virtual bitmap* (VB) by randomly choosing some bits from B. As a result, any bit in B can be shared by multiple categories. Fig. 2 illustrates two virtual bitmaps $VB(cid_1)$ and $VB(cid_2)$ randomly chosen from the mask bitmap B for categories cid_1 and cid_2, respectively, where the bit in grey is shared by both virtual bitmaps. A significant advantage of such bit-level sharing is that all categories use a common bitmap, so there is no need for transmissions of category IDs any more. More importantly, since each bit in the mask bitmap is shared by multiple categories, it helps mask the tag ID and the category ID of a tag that sets this bit. Our anonymous category-level joint estimation protocol (ACJEP) consists of two components: an encoding component for encoding a tag set to a mask bitmap, and an offline data analysis component to combine two arbitrary mask bitmaps, retrieve information of each category, and estimate n_c for any interested categories.

4. SIMULATION RESULTS

In simulations, we use 1000 different categories, namely, $m = 1000$. n_p and n_q of each category independently follow a normal distribution $Norm(750, 100^2)$, and n_c of each category follows a uniform distribution over $[0, 500]$. In addition, we vary θ from 0.1, 0.05, to 0.01, and set the absolute error bound $\eta = 50$. Fig. 1 shows the estimation results. The first three plots in the figure show the results with different values of θ. In each plot, the x coordinate represents the true value of n_c for a category of tags, and the y coordinate represents its estimated value $\hat{n_c}$. Each point gives a $(n_c, \hat{n_c})$ pair of a particular category. The fourth plot gives the mean and standard variance for the absolute error $|\hat{n_c} - n_c|$ under different settings of θ.

5. CONCLUSION

This paper studies a new problem of anonymous category-level joint estimation in RFID systems: Given a particular category, we want to estimate its cardinality in the intersection of two arbitrary tag sets anonymously. We propose a protocol called ACJEP based on a novel data structure called mask bitmap. We perform simulations to evaluate the effectiveness of our protocol.

6. ACKNOWLEDGMENTS

This work was supported in part by Natural Science Foundation of United States under grant CNS-1409797.

7. REFERENCES

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