Efficient Group Labeling for Multi-Group RFID Systems

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***Abstract*—Ever-increasing research effort has been dedicated to multi-group radio frequency identification (RFID) systems where all tags are partitioned into multiple groups, such as group-level queries, and multi-group missing tag detection. However, it is assumed in the existing work that all tags know their individual group IDs, which thus leaves group labeling problem unaddressed. To tackle the under-investigated problem, this paper is devoted to devising an efficient group labeling protocol to inform each tag of its corresponding group ID fast and accurately. To this end, we employ multiple seeds to build a composite indicator vector (CIV) indicating the assigned seed in each slot, which reduces transmissions of useless information and thus improves time efficiency. Specifically, we first theoretically show that the seed assignment problem (SAP) arising in establishing the CIV is NP-hard and then develop a myopic approximation algorithm. Finally, the simulation results confirm the superiority of the proposed protocol over the state-of-the-art solution in terms of time efficiency.**

I. Introduction

Recent years have witnessed an unprecedented development of the radio frequency identification (RFID) technology. As a promising low-cost technology, RFID is widely used in various applications ranging from inventory control and supply chain management to object tracking and location, where RFID tags are usually attached to objects with different attributes, for instance, diverse manufacturers, different categories (e.g., adult or infant food), or production/expiry dates. In these scenarios, managers of an RFID system may partition tags into multiple groups on request. For example, managers would like to group the objects (tags) with the same expiry date and frequently check the status of the expiry-date-sensitive objects. If tags with the same expiry date share the same group ID, the reader is able to transmit the same data once to all group members, which not only significantly reduces the communication overhead in comparison with the traditional unicast transmission, but also enables diverse queries, such as top-k query [2] and missing tag detection [3]. As a consequence, the group labeling problem is of practical importance and is the fundament for many RFID-enabled applications.

In this paper, we study the RFID group labeling problem which is to efficiently inform all tags of their associated group IDs. Despite its importance, the group labeling problem is emerging and under-investigated. The state-of-the-art solution to this problem, referred to as CCG, is proposed in [1] where the authors attribute CCG's improvement over the other methods to its concurrent transmissions of multiple group IDs in one frame. Nevertheless, CCG wastes time on the transmissions of useless slots and operates inefficiently due to low probability of useful slot in a single indicator vector.

To improve efficiency, multiple seeds can be used to map tags, respectively, and the reader compounds from useful slots of multiple mappings one indicator vector. The rationale behind this is two-fold: On the one hand, a useless slot under one seed may become to a useful one under another seed, and a k-useful slot where k tags of the same group are mapped may become to a k^+-useful one with $k^+ > k$ on the other hand.

Motivated by the observations above, we develop an efficient group labeling protocol in multi-group RFID systems, informing each tag of their individual group IDs fast and accurately. Our contributions can be summarized as follows:

Firstly, we introduce a multi-seed method to address group labeling problem which seeks k^+-useful slots instead of k-useful ones, differentiating it from the existing work.

Secondly, we prove the seed assignment problem (SAP) arising in the proposed multi-seed method is NP-hard. We would like to emphasize that, to the best of our knowledge, this is the first work to show the NP-hard nature of the multiple seeds-based methods.

Thirdly, due to the NP-hardness, we give a myopic approximation algorithm and then consolidate it with detailed communication protocols for the reader and tags.

Fourthly, we conduct a series of simulations to evaluate the performance of the proposed protocol in comparison with the start-of-the-art solution.

II. Problem Statement And Proposed Solution

Problem Statement. Consider a set $X = \{x_1, x_2, \cdots, x_N\}$ of N tags divided into G disjointed groups. Suppose the size of group g ($1 \leq g \leq G$) is N_g and we have $\sum_{g=1}^{G} N_g = N$. For presentation conciseness, we set the ID of group g ($1 \leq g \leq G$) to its index g. Note that a slot is useful if and only if there are one or multiple tags from the same group mapped to it, and useless otherwise. We are interested in addressing the problem of informing each tag of their individual group IDs quickly and correctly, which is formally defined as follows: The optimum group labeling problem is to devise an algorithm

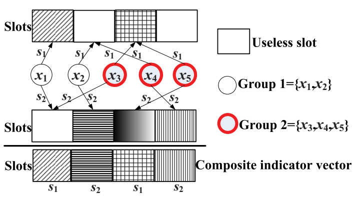

Fig. 1. Exemplifying the basic idea

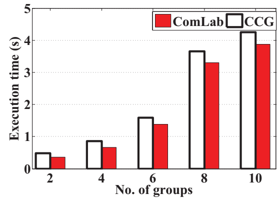

Fig. 2. Time v.s. No. of groups

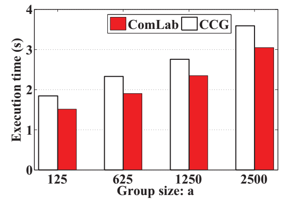

Fig. 3. Time v.s. size of 2 groups

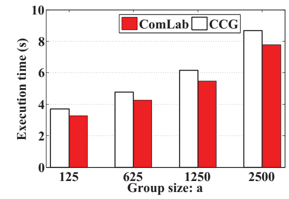

Fig. 4. Time v.s. size of 6 groups

of minimum execution time which can broadcast each group's ID to all its members accurately.

Basic Idea. As a single indicator vector constructed from one mapping generates a limited useful slots and much time is wasted on transmitting useless slots, we use multiple seeds to generate multiple mappings and pick the most informative slots from them to build a composite indicator vector (CIV), reducing the number of useless slot.

Take an example with seeds s_1, s_2 and frame size four as shown in Fig. 1 where shaded rectangles stand for useful slots. From Fig. 1, we find just partial slots useful in both mappings, but a CIV with all slots being useful can be built by selecting the most informative slots. Specifically, picking the first and third slots under s_1, and the second and fourth slots under s_2, we can build a CIV indicating which slot is assigned to which slot so that all slots to be executed become from useless ones to useful ones and from 1-useful one (e.g., the 3rd slot under s_2) to 2-useful one (e.g., the 3rd slot under s_1).

Challenge. The key of the multi-seed approach lies in the seed assignment in constructing the CIV. Specifically, given l seeds s_i ($1 \leq i \leq l$) and frame size f, the reader needs to designate one seed for each slot and then tags mapped to this slot are deterministic. Since each tag will be mapped to l slots, slots from multiple mappings may share the same tags. Thus, we should carefully select such seeds that the union of tags mapped to the slots under the picked seeds is maximum, which is referred to as seed assignment problem (SAP) in this paper.

The main challenge here is that SAP is NP-hard, which can be proven by making SAP polynomially reducible from a classic NP-hard problem-Maximum coverage problem. The formal proof is omitted due to limited space. To solve SAP, we develop a myopic approximation algorithm.

Approximation Algorithm. The core of our algorithm is summarized as follows: For each slot the reader 1) picks one seed that covers the most uninformed tags from the same group; 2) marks the tags mapped under the chosen seed as covered and removes them from the remaining useful slots; 3) repeats the operations for the next slot. The algorithm outputs seed allocation for each slot and a collection of tags to be informed. The reader, consequently, is able to build a CIV to be sent to tags in the current frame.

III. Group Labeling Protocol Design

The designed protocol, referred to as ComLab, will run for multiple rounds, with each round consisting of three phases which are detailed as follows:

1) Initialization Phase: In the first phase of the ComLab, before sending out a query, the reader first builds a CIV following the approximation algorithm.

2) Marking Phase: The reader broadcasts a request message containing the CIV, the frame size f and l seeds s_i. Upon receiving the request, each tag can extract two pieces of information from the CIV: One is whether the tag is scheduled to receive group ID in this frame. The other is in which slot the tag should wait for its group ID.

3) Labeling Phase: After the marking phase, only eligible tags partake in this phase. As the reader has information on all tags' IDs and the CIV, it knows the slots selected by the eligible tags. The reader then sends a group ID at each slot to the eligible tag(s) that selects the slot. Since the tag(s) in each slot comes from the same group, the reader can label them simultaneously. On the other hand, each tag learns from the indicator vector at which slot the reader transmits its group ID and consequently is able to receive its group ID successfully from the slot.

After the current round, the reader moves to the next round, which is identical except that the labeled tags will keep silent. That is, only the unlabeled tags attend the next round. The above process repeats round after round until all tags receive their corresponding group IDs.

IV. Simulation Results and Discussion

Simulation Results. In simulations, we evaluate the impact of group size and group population on the performance of our protocol. Firstly, we let each group size follow a uniform distribution $U[100, 2000]$ and vary the number of groups from 2 to 10. We observe improvements by up to 24.3% in the results in Fig. 2. Secondly, we set the group population to 2 and 6 with the group size chosen from $U[a, 5000]$ randomly and uniformly where a varies from 125 to 2500. The results in these scenarios are shown in Fig. 3 and Fig. 4, with the performance gain up to 18.3% and 12%, respectively.

Discussion. This paper studies group labeling problem arising from Multi-group RFID systems, which is NP-hard. In the future, we will give the formal proof of the NP-hardness and develop more advanced approximation algorithms with constant approximation ratio. Moreover, we also plan to study the problem under the more realistic wireless environment with error-prone channels and explore code-based approaches to overcome the performance degradation.

References

[1] J. Liu, B. Xiao, S. Chen, and et. al. Fast RFID grouping protocols. In *IEEE INFOCOM'15*, pages 1948–1956. IEEE, 2015.

[2] X. Liu, K. Li, J. Wu, and et. al. Top-k queries for multi-category RFID systems. In *IEEE INFOCOM'16*, pages 1–9, 2016.

[3] J. Yu, L. Chen, R. Zhang, and et. al. On missing tag detection in multiple-group multiple-region RFID systems. *IEEE TMC*, 2016.