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A Novel Anti-Collision Scheduling Protocol for RFID-based Wireless Localization

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***Abstract*— In an active RFID based wireless localization system, usually a number of RFID readers are required to generate localization beacon broadcasts from which a RFID tag can collect multiple RSSI measurements and forward them to a localization server for calculating the location of the tag. Such operations should be done from time to time when the tag is moving. Collisions may happen at the tag if the readers send the beacon broadcasts at the same time or at the server if the tags forward the measurements at the same time. In this paper, we present a novel hybrid slotted anti-collision scheduling protocol for such RFID-based wireless localization of mobile tags by considering tag mobility and treating the existing tags and newly entered tags differently. In the proposed protocol, a time frame consists of a reader beaconing phase, a sequential polling phase for existing tags, and a tree-splitting anti-collision measurement forwarding phase for newly entered tags. Because the existing tags do not participate in the third phase for competition, we are able to improve the time efficiency and the QoI (Quality of Information) of the localization. Analysis and simulation results verify the performance of the proposed protocols.**

***Keywords*—RFID; wireless localization; collision avoidance; tree-splitting algorithm; quality of information**

I. INTRODUCTION

Wireless localization has been studied extensively, and can often be deployed by active RFID technique. A typical active RFID localization system consists of a number of RFID readers and tags to be localized. The readers are used to generate localization beacon broadcasts from which a RFID tag can collect multiple RSSI measurements and forward them to a localization server for calculating the location of the tag.

Different from the normal RFID identification system where the tag only need to be identified by one reader, in a RFID localization system, every RFID tag should at least collect RSSI measurements from at least 3 different RFID readers, in order to be localized using some algorithms such as tri-lateration algorithm and the fingerprinting algorithm [1, 2]. Also, the localization system needs to keep track of the tag locations from time to time when the tags are moving in the field. When sharing the same wireless channel, various collisions may happen, for example, at a tag when 2 readers broadcast the beacons at the same time, at the localization server (assume it has a receiver to collect the packets from the tags) when 2 tags transmit their RSSI measurements at the same time. Anti-collision scheduling protocol must be used to resolve these collisions, such that the length of localization cycle can be minimized and the localization accuracy can be improved.

In the RFID systems, anti-collision scheduling algorithms have been studied under the passive RFID mechanism [3-8]. Typical anti-collision protocols in RFID system include the tree-splitting algorithms [3-6], I-code protocol [3, 7], and the contact-less protocol [3, 8]. Their working mechanisms are similar, which are all to split a big group of tags into smaller and smaller groups using certain criterion like random numbers. Finally, every tag must be allocated to a unique time slot, so that the data sent by tags can be successfully received without collision. Some variations of the tree-splitting method are proposed [3]. Shortcutting and aggressive advancement are used to skip the query attempts which have very high probability to end up with a collision. There are also some CSMA-based protocols, which uses random back offs for collision resolution. Sift [9] is such an algorithm that uses a fix-size contention window and non-uniform probability distribution on transmitting in each slot of the window. Accelerated Frame Slotted ALOHA [10] is also proposed to avoid the wastage in bit times due to collisions and idle slots. Such anti-collision schemes can not be directly used for the wireless localization system due to the existing of localization beacon broadcasts of multiple readers and the multiple localization requirements for any mobile tag.

To our knowledge, there are few work can be found in the literature to address the anti-collision scheduling algorithms and protocols for RFID based wireless localization of multiple mobile tags. In this paper, we will present a novel solution for this problem by considering tag mobility and treating the existing tags and newly entered tags differently based on the observation that under most cases, the moving distance of a tag within a localization cycle is supposed to be relatively small compared to the communication range of a RFID reader. In the proposed protocol, after an initial reader beaconing phase, the collisions of existing tags are resolved using polling method, and the collisions of newly entered tags are solved using tree-splitting algorithm. Because the existing tags do not go through the binary splitting process, the number of collisions can be greatly reduced.

The paper is organized as follows: The proposed anti-collision scheduling protocol is described in Section II. Analysis and simulation results are reported in Section III to show the performance of the proposed protocol. Finally conclusions and future work are given in Section IV.

II. PROPOSED HYBRID ANTI-COLLISION SCHEDULING PROTOCOL

In this paper, we consider a simplified model for an active RFID localization network, which comprises several readers, a number of tags that are mobile to enter, leave, or move inside the network, and a localization server who has a transceiver and has control over the whole system. We assume that:

- The readers, the tags, and the localization server are in one-hop neighborhood with each other.
- The whole network is synchronized.
- The server knows the location of each reader.

A typical network is shown in Fig. 1 which consists of 1 localization server, 4 RFID readers, 4 existing tags, 2 new tags joining the network, and 2 tags left the network.

In the protocol, the localization server maintains a tag recording list (TLST) of the existing tags to keep their IDs and locations. This list will be adjusted from time to time with the joining and leaving the network of a tag.

The proposed protocol is slotted and runs cycle by cycle. As shown in Fig. 2, each cycle is divided into three phases, i.e., an initial reader beaconing phase, a sequential polling phase for existing tags, and a tree-splitting anti-collision measurement forwarding phase for newly entered tags.

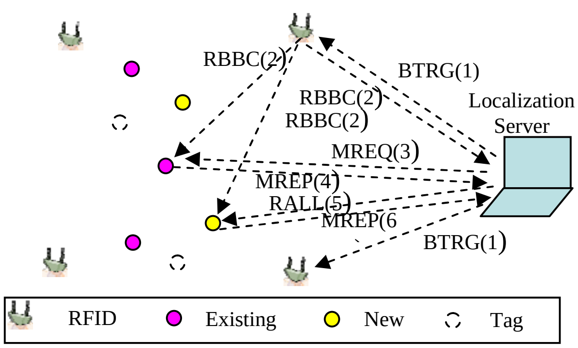


Figure 1 An example network and message exchanges

In the reader beaconing phase, the localization server sends a Beacon Triggering (BTRG) message to initiate the localization cycle. Upon receiving the BTRG message, the readers sequentially broadcast to all tags in their allocated time slots using the Reader Beacon Broadcast (RBBC) message which contains the reader's ID. Upon receiving this RBBC message, each tag will collect the RSSI value of this message. Therefore after this phase, each tag in the network will have the RSSI measurements corresponding to all readers.

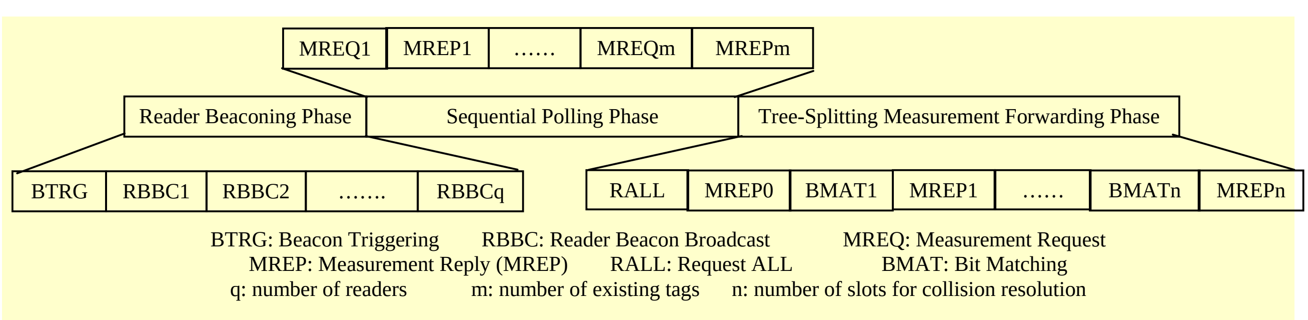
In the sequential polling phase, the localization server polls the existing tags one by one by sending the Measurement Request (MREQ) message. Here two cases may happen:

- If the tag being queried is still present in the system, it replies to the server with the RSSI data stored in its memory using a Measurement Reply (MREP) message.
- If the tag being queried has left the system, there will be no reply at all. The reader will remove the record for this tag from the TLST.

In the final tree-splitting anti-collision measurement forwarding phase, the reader resolves the collision of newly entered tags using the binary tree-splitting method [4], and the successfully identified tag will send the stored RSSI measurement data to the reader using the MREP message.

In this phase, the location server queries the tags using the node ID as a prefix. It first queries all new tags using a Request ALL (RALL) message. Each new tag just joining the network will reply with a MREP message. If collision occurs at the location server, it queries the tags with first bit of the tag ID being 0 or 1 separately using the Bit Matching (BMAT) message, which belong to the node 0 and 1 respectively as shown in Fig. 3. If collision occurs again at node 0, it further query tags with first two bits being 00 or 01. This process is repeated using the binary approach until all tags are identified and replies with MREP message. In detail, three cases can happen when querying tags for a specific node in the binary tree:

- If more than one tag belongs to this node, a collision will occur. The localization server will query for the next node in the binary tree.
- If only one tag belongs to this node, this tag will be identified and its RSSI measurement data will be successfully received by the localization server, and identification at this node and all its sub nodes is finished.
- If no tag belongs to this node, the reader will receive no reply. The identification at this node and all its sub nodes is finished.



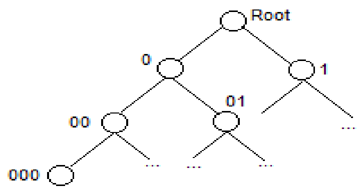


Figure 3 Binary tree used for collision avoidance

In the above protocol, the collision between the reader beaconing readers is resolved by assigning different broadcasting time slots to them in the first phase, which also naturally avoid the collision between any reading beaconing broadcast and any RSSI measurement reporting message. The RSSI measurement reporting of an existing tag will also be sent to the localization server without collision because only the polled tag will reply. Collisions can only be happen among the new tags in phase 3. However because normally the number of new tags are small, therefore the required slots for tree-splitting collision resolution are much smaller compared to query all the tags together.

III. Analysis and Simulation of the Proposed Protocol

When analyzing the performance of the proposed protocol with mobile tags, we assume that the total number of tags inside the system keeps unchanged, and the rates of tags coming in and going out the system are the same. Here, we define the Mobility of Tags as the total number of tags coming into the system within one cycle.

In the RSSI reporting phase, a reader query corresponds to a reply from the tag, so the number of time slots needed in this phase is twice of the number of reader queries.

For the RSSI reporting phase for the existing tags, the number of queries needed for polling all m tags is simply m, so the total number of time slots needed is

$$N1(m) = 2m.$$

In [5], it shows that the worst case time complexity for queries sent by the reader following the binary tree-splitting algorithm is $n(k + 2 - \log_2 n)$, so the total number of time slots needed is:

$$N2(n)=2n(k + 2 - \log_2 n).$$

In the above formula, n is the number of tags to be identified using binary tree-splitting method, and k refers to the maximum number of ancestors for a specific tag located in the binary tree, which is 8 for the tags with 8-bit ID.

The formula can be simplified as

$$N2(n)=2n(10- \log_2 n).$$

Using the proposed algorithm, we assume there are m existing tags and n new tags in the present cycle, this also means that n tags has left the system after last localization cycle to keep the total number of tags unchanged. However, the leaving tags will still be queried as existing tags, because their records are still present in the tag recording list (TLST).

Under the worst case, the total number of queries needed for a system with m existing tags and n new tags is:

$$N_{new}=N1(m+n)+N2(n)=2(m+n + n(10- \log_2 n)).$$

Whereas using the old tree-splitting algorithm, the total number of queries needed for the same system under the worst case is

$$N_{old}=N2(m+n)=2(m+n)(10- \log_2(m+n)).$$

Practically for m>>n, we can do some approximation for the above equations:

$$N_{new} \approx 2m, \text{ and } N_{old} \approx 2m*(10-\log_2(m)).$$

For tags with 8-bit ID, m< 2^8=256, which leads to $\log_2(m)$ <8, so we can know that:

$$N_{old} > 2m*(10-8)=4m>N_{new}.$$

We also perform simulations to examine the performance of the proposed scheme. We assume the number of readers in the simulations is 4. In the reader beaconing phase for the 4-reader system shown in last part, 5 time slots are needed. With 10% Mobility of Tags, we can find the relationship between number of tags and the number of time slots needed for a complete localization cycle through random simulations. The values obtained for the reporting phase are based on the average values from 100 repetitive simulations using random 8-bit tag IDs. The simulation results are shown in Figure 4. As we can see, the total time slots needed within a single cycle is greatly reduced. This is because the size of the binary tree is greatly reduced by avoiding the existing tags being involved in the collision resolution process.

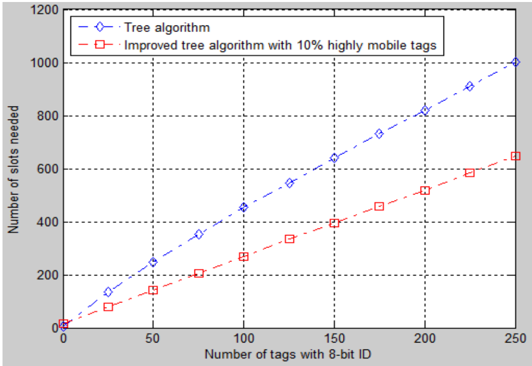


Figure 4 Comparison of time efficiency between tree -splitting algorithm and extended tree-splitting algorithm

Using the data obtained above, we can also evaluate the QoI (Quality of Information) of the new algorithm [11].

Here, QoI can be used to describe the uncertainty of the tag's location after the interval between two RSSI reporting slots of the same tag. By assuming a constant speed for the tag motion, we can treat QoI as the circle, whose radius is determined by the time difference between the tags' two reporting time slots. It can be expressed as follows:

$$q(t) = r(t)$$

Here r(t) is the maximum distance a tag is expected to move within the time between its two RSSI reports, which is also the duration of a complete localization cycle.

Assuming a constant displacement of a tag within a single time slot, which is v, r(t) can be expressed as:

$$r(t) = v * N_{slot},$$

where N_{slot} refers to the number of slots used in a whole localization cycle.

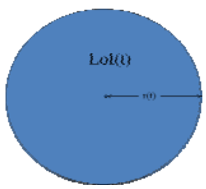


Figure 5 Quality of Information and Loss of Information for a certain tag

Through the QoI, we are able to define the Loss of Information (LoI), which is the area of the circle with the radius r(t):

$$LoI(t) = \pi r^2(t)$$

Based on the above formulae, we can plot the uncertainty of tag positions in Figure 5. Based on the number of time slots shown in Figure 5, we are able to compare the LoI, which expresses the uncertainty of tag's position after the duration of one localization cycle. The comparison is shown in Fig. 6. As we can see, the LoI is greatly reduced in the proposed scheme.

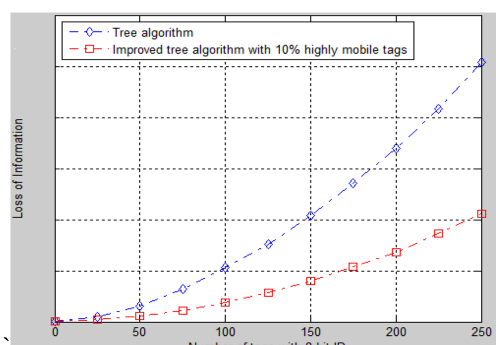


Figure 6 Comparison of LoI between tree-splitting algorithm and extended tree-splitting algorithm

IV. Conclusion

In this paper, we have proposed an approach for collision avoidance scheduling protocol in a RFID-based wireless localization system for moving tags. The proposed protocol consists of three phases, including a reader beaconing phase, a sequential polling phase for existing tags, and a tree-splitting anti-collision measurement forwarding phase for newly entered tags. Because only the new tags will be involved in the tree-splitting collision resolution process whereas the reader localization beacons and the RSSI reporting packets of existing tags can be scheduled without collisions, the proposed scheme can significantly reduce the slots needed totally and improve the localization accuracy.

Future research issues include the development of anti-collision scheduling and routing protocols for wireless localization in a multi-hop wireless mesh network, tag handover between different areas covered by different readers, more advanced QoI-driven scheduling protocols based on Kalman filtering or particle filtering algorithms, as well as real test-bed development.

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