

The Tag Duplication Problem in an Integrated WSN for RFID-Based Item-Level Inventory Monitoring

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Abstract—Radio Frequency Identification (RFID) technology has been adopted in various supply chain management applications because of its fast and low-cost ability to identify items uniquely. In this paper, we consider the integration of a Wireless Sensor Network (WSN) with RFID to provide item-level inventory monitoring in retail stores. First, we present a basic formulation for RFID-based item-level inventory monitoring applications. With the formulation, we illustrate that tag duplication problems can exist in the network layer due to tags' mobility and overlaps of RFID readers' interrogation zones. In order to prevent the tag duplication, we propose a tag-filtering scheme by utilizing multihop routing capability of an integrated WSN with RFID. Our proposed filtering scheme is implemented in the nesC programming language and is executed in the TOSSIM simulator to demonstrate its efficiency. Our preliminary results indicate that our filtering scheme improves network latency and tag check-out rate.

Index Terms—RFID systems, Wireless Sensor Network, Ad Hoc Network

I. INTRODUCTION

Item-level deployment of RFID technology for real-time inventory tracking is a vision for many retailers such as Wal-Mart, Mark and Spencer and Tesco [1]. These retailers foresee that real-time inventory tracking of item-level units can eliminate long queues and reduce check-out times [1]. In addition, WSN is considered to be integrated with RFID technology to provide real-time, item-level, inventory tracking with environmental monitoring such as temperature and humidity for perishable goods [2]. In this paper, we consider a WSN integrated with RFID technology for real-time item-level inventory monitoring.

For item-level inventory monitoring applications in retail stores, RFID readers should be densely deployed with overlapped interrogation zones to cover all RFID tags. Therefore, tags located in the overlapped interrogation zones can be identified multiple times. If an RFID tag had the intelligence to distinguish which RFID reader it belonged to, overlapped interrogation zones would not produce any duplicated tags. However, tags having such capability are too costly [3]. In this paper, we consider low-cost passive RFID tags for item-level inventory monitoring applications.

Due to the overlapped interrogation zones of RFID readers, identified tags can appear multiple times in an item level inventory monitoring system. Previous researches [4] [5] identified

the tag duplication problem in the overlapped interrogation zones and provided solutions in the physical layer. They assigned different frequencies to adjacent RFID readers and synchronized RFID readers to eliminate duplicated tags in the overlapped interrogation zones between adjacent RFID readers. However, duplicated tags can still appear in non-overlapped RFID readers' interrogation zones because items attached to tags can be moved across RFID readers' interrogation zones. Thus, RFID readers need to communicate with one another to identify and eliminate duplicated tags.

To solve the tag duplication problem, we propose a network layer solution that filters duplicated tags. Some researches [6] [7] already pointed out the need for filtering redundant data in RFID based inventory monitoring system. However, they did not describe any specific method nor evaluate the efficiency of filtering. In this paper, we introduce a *tag check-out rate* as a metric to measure the efficiency of our proposed filtering scheme. For communication between RFID readers, we used wireless micro sensor nodes manufactured by Crossbow Technologies, Inc., called Motes [8]. The Motes have sensors for detecting environmental changes and are equipped with a wireless multihop routing protocol for sensor nodes' communication. Thus, the Motes can be used in an integrated WSN for RFID based item-level inventory monitoring with environmental sensing such as temperature and humidity for perishable goods. However, we caution that the Motes' transmitters only support low-rate communication (i.e. 38.4kbps for Mica2 and 250kbps for Micaz). Thus, the filtering scheme implemented in the Motes can only be applied for RFID based retail stores with a *small* business transaction rate. If a *high* business transaction rate is expected, the sensor nodes' transmitters should be replaced by faster one such as WiFi. On the other hand, since our proposed filtering scheme is implemented in the network layer, it can be applied regardless of the sensor nodes' transmission capabilities.

This paper is organized as follows: In Section II, we formulate the tag duplication problem based on a basic model for RFID item-level inventory monitoring applications. Section III proposes a solution for tag duplication based on a potential application of an integrated WSN for RFID item-level inventory monitoring. Section IV measures the efficiency of our proposed filtering scheme and Section V summarizes

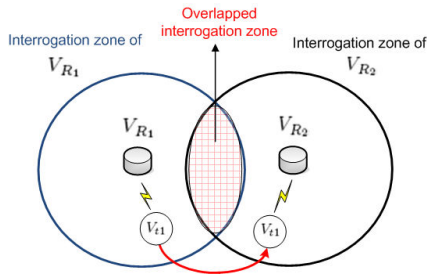


Fig. 1. Tag duplication by tags' mobility

our findings.

II. BASIC FORMULATION

RFID based item-level inventory monitoring system can be expressed as a graph $G = (V, E)$ where $V = V_t \cup V_R$ (V_t : RFID tags, V_R : RFID readers) and $E = E_t \cup E_R$ ($E_t = (V_t, V_R)$: Channels for interrogating V_t nodes, E_R : Channels between V_R nodes).

In G , tags are identified as

$$Ident : V_t \times V_R \rightarrow V_t \quad (1)$$

where $Ident$ is the function that identifies tags. Therefore, $Ident[(V_t, V_R)]$ is the set of identified tags in G .

Since the RFID based item-level inventory monitoring application is required to track *uniquely* identified RFID tags, it must satisfy the following equation:

$$\sum_{k=1}^{|V_R|} |Ident[(V_t, V_{R_k})]| = |V_t| \quad (2)$$

where $|Ident[(V_t, V_{R_k})]|$ = number of identified V_t nodes by V_{R_k} nodes, $|V_R|$ = number of V_R nodes in G and $|V_t|$ = number of V_t nodes in G . That is, the number of *all identified tags* should be the same as the number of *all deployed tags*.

Since V_R nodes should be densely deployed to cover all V_t nodes in G , interrogation zones of V_R nodes can be overlapped and V_t nodes can be identified more than once. Therefore, the sum of identified tags in all interrogation zones, $\sum_{k=1}^{|V_R|} |Ident[(V_t, V_{R_k})]|$ can be larger than the actual number of tags, $|V_t|$. Furthermore, even though there is no overlapped interrogation zone, tag duplication can happen due to tags' mobility. For the case where V_t nodes move around G , V_t nodes can be identified more than once. Fig. 1 shows that V_{t1} is identified by both V_{R1} and V_{R2} when V_{t1} moves from non-overlapped interrogation zone of V_{R1} to non-overlapped interrogation zone of V_{R2} .

In Fig. 2, we illustrate our basic model for RFID based item-level inventory monitoring. Interrogation zones of V_R nodes are somewhat overlapped to cover all deployed V_t nodes. The root node monitors V_t nodes identified by V_R nodes. All identified V_t nodes are delivered via pre-assigned channels, E_R . For example, $Ident[(V_t, V_{R3})]$ can reach root node via (V_{R3}, V_{R1}) and $(V_{R1}, Root)$. When a WSN is integrated with RFID readers, E_R can be mapped to routes between sensor nodes.

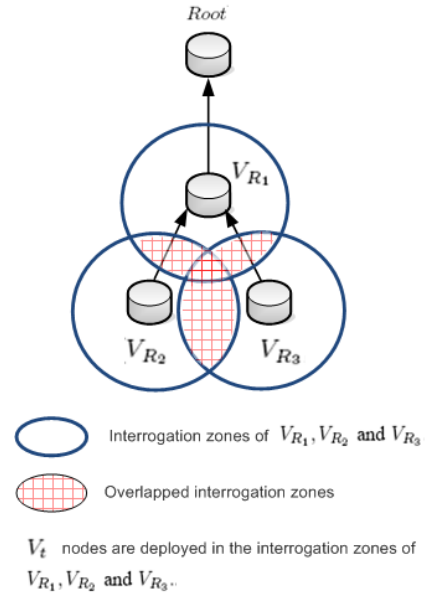
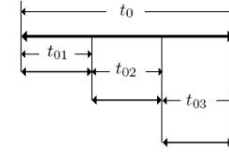


Fig. 2. Basic model for RFID based item-level inventory monitoring



t_0 : a cycle for all V_R nodes to interrogate V_t nodes
 t_{01} : a time assigned to V_{R1} for interrogating V_t nodes
 t_{02} : a time assigned to V_{R2} for interrogating V_t nodes
 t_{03} : a time assigned to V_{R3} for interrogating V_t nodes

Fig. 3. Time Division Interrogation is applied to Fig. 2

To show that tag duplication problems can happen in the network layer regardless of the interrogation method E_t , we consider two interrogation methods: Frequency Division Interrogation [4] and Time Division Interrogation [4].

Frequency Division Interrogation is the case where $|E_t| = |V_R|$. Adjacent V_R nodes use different frequencies (i.e. different E_t) to interrogate V_t nodes. So, V_t nodes can be identified multiple times through different frequency channels. For example, some V_t nodes located in overlapped interrogation zones in Fig. 2 or moving between non-overlapped interrogation zones as shown in Fig. 1 can be identified by both V_{R1} and V_{R2} through $E_{t1} = (V_t, V_{R1})$ and $E_{t2} = (V_t, V_{R2})$.

Time Division Interrogation is the case where $|E_t| = 1$. Adjacent V_R nodes are synchronized to interrogate V_t nodes in their overlapped interrogation zones at different times. Fig. 3 shows a synchronization of three V_R nodes in Fig. 2. In Fig. 3, t_0 is the cycle for interrogating all V_t nodes at a time and is divided into k time slots ($k = |V_R|$). Each V_R node only interrogates V_t nodes in its assigned time slot. That is, t_{01} is a time slot assigned to V_{R1} , t_{02} is assigned to V_{R2} and t_{03} is assigned to V_{R3} . However, when either V_t nodes are located in the overlapped interrogation zones or V_t nodes move between

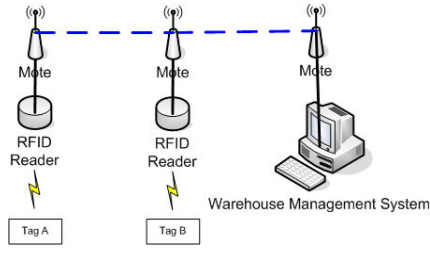


Fig. 4. Checking out tags through multihop routing

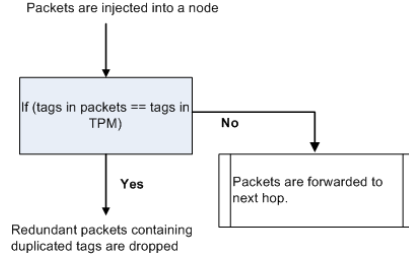


Fig. 5. TPM filtering scheme

time slots (i.e. t_{01} , t_{02} and t_{03}), V_t nodes can be identified multiple times. For example, some V_t nodes identified by V_{R_1} in t_{01} can also be identified by V_{R_2} in t_{02} .

When either Frequency Division Interrogation or Time Division Interrogation is applied to the basic model in Fig. 2, $\sum_{k=1}^3 |Ident[(V_t, V_{R_k})]|$ can be larger than $|V_t|$. That is, regardless of the interrogation method, there will be duplicated tags in RFID-based item-level inventory monitoring applications.

In Section III, we provide a solution for the tag duplication problem based on a potential application of a WSN integrated RFID for item-level inventory monitoring.

III. PROPOSED SOLUTION FOR TAG DUPLICATION

Our application network consists of wireless sensor nodes (Crossbow Technology Inc's Mote) integrated with RFID readers. The Mote integrated with an RFID reader supports multihop routing to forward packets to other Motes. The tag information identified by RFID readers in the wireless sensor nodes are sent back via the Motes' multihop routing to the warehouse management system (WMS) which is a real-time inventory tracking database as illustrated in Fig. 4.

To reduce the amount of duplicated traffic by overlapped interrogation zones and tagged items' mobility as illustrated in Section II, we propose that each intermediate node forwarding traffic to WMS filters out duplicated information. The filtering mechanism is achieved by recording and comparing the sent and forwarded tags' information in the local cache, called the temporary path marker, TPM [9]. A TPM is a table that records payloads of packets carrying tags' information. The TPM is updated whenever packets containing new tags' information are sent or forwarded in a sensor node. Fig. 5 shows the proposed filtering scheme with a TPM.

Basically, the size of a TPM depends on the number of tagged items in the interrogation zones of the RFID readers.

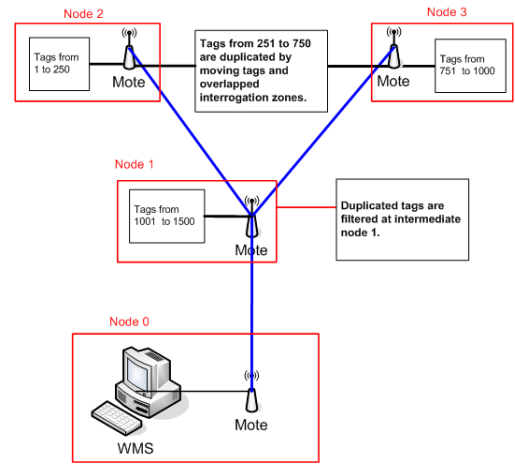


Fig. 6. Test application

Since commercial RFID readers for inventory monitoring have a large amount of memory rather than Motes' (64Mbytes for RFID readers, 128Kbytes for Motes) [10], the TPM of each node can be located in the memory of its RFID reader. If one intermediate node receives the same (duplicated) tags' information with previously forwarded tags' information, the node does not forward the tags' information and just drops them according to the TPM.

IV. IMPLEMENTATION AND EFFICIENCY MEASUREMENT

To measure the efficiency of our proposed filtering scheme described in Section III, we implemented our test application in the nesC programming language [11] and executed it in the TOSSIM [12] simulator. Our test application consists of 3 combined nodes (RFID reader + Mote) and 1 WMS node. Since TOSSIM has no model for RFID readers and tags, we simplified the identification of tags by generating a small amount of traffic containing tags in TOSSIM simulator. Each combined node has the list of identified tags in its interrogation zone. Tags used for our test application are 96-bit long as defined by the EPCglobal [13] standard. Since the payload size of TinyOS is 29bytes, two 96-bit tags' information can be encapsulated in one TinyOS message.

Fig. 6 shows our test application. Since node 2 and node 3 have 500 duplicated tags, node 2 can identify tags from 1 to 750 and node 3 can identify tags from 251 to 1000. Therefore, tags from 251 to 750 are identified by both RFID Readers of node 2 and node 3. Table 1 shows parameters' mapping between our basic model in Fig. 2 and our test application in Fig. 6.

An item is checked out from the database of the WMS when its tag information is received by the WMS. The WMS has the list of all 1,500 tags at the beginning of the test application. As soon as items are checked out, they are removed from the list of WMS. When all tags are removed from the tag list of WMS, all products are sold out and our test application is completed. To model the purchasing rate within a node, we use the timer interrupt interval of a Mote. Each Mote in

TABLE I
PARAMETERS' MAPPING BETWEEN BASIC MODEL AND TEST APPLICATION

Basic model in Fig. 2	Test application in Fig. 6
Root	Node 0
V_{R1}	Node 1
V_{R2}	Node 2
V_{R3}	Node 3
$ V_t $	1500
$ Ident[(V_t, V_{R1})] $	500
$ Ident[(V_t, V_{R2})] $	750
$ Ident[(V_t, V_{R3})] $	750
$ Ident[(V_t, V_{R1})] \cap Ident[(V_t, V_{R2})] $	0
$ Ident[(V_t, V_{R2})] \cap Ident[(V_t, V_{R3})] $	500
$ Ident[(V_t, V_{R1})] \cap Ident[(V_t, V_{R3})] $	0

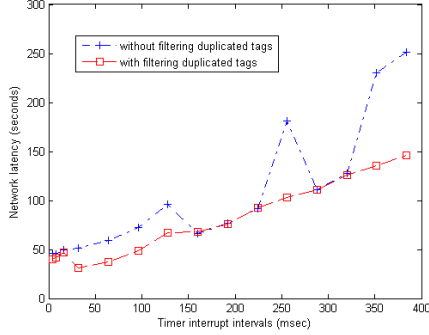


Fig. 7. Network latency

a node of our test application sends a packet whenever the timer interrupt is fired. Fig. 7 shows our simulation result for network latency. When our proposed filtering scheme is used, network latency is improved by 13% .

We introduce the *tag check-out rate* as a metric to measure the efficiency of a retail store that integrates RFID and WSN for item-level inventory monitoring.

$$\text{Tag check-out rate} = \frac{\text{total number of tags}}{\text{total time to check out all tags}} \quad (3)$$

The tag check-out rate can be used as a design guideline in an integrated RFID with WSN infrastructure for retail stores.

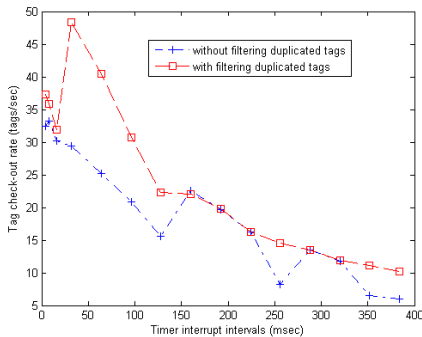


Fig. 8. Tag check-out rate

For instance, if the average customer generally purchases 30 items and the goal is to complete the customer's check out process in one second, the tag check-out rate should be equal to or larger than 30 tags/sec in Fig. 8.

V. CONCLUSION

In this paper, we discussed the tag duplication problem in an integrated WSN with RFID technology for real-time, item-level inventory monitoring. First, we described a basic formulation of RFID based item-level inventory monitoring. From the formulation, the tag duplication problem was identified in the network layer. We also explained that tags can be duplicated due to tags' mobility even if there is no overlapped interrogation. To eliminate tag duplication by both interrogation zones' overlaps and moving tags, we proposed a filtering scheme in the network layer. Our proposed filtering scheme was implemented in the nesC programming language and executed in the TOSSIM simulator to demonstrate its efficiency. Our results indicate that our filtering scheme improves network latency and tag check-out rate.

ACKNOWLEDGMENT

This research was partially supported by the National Science Foundation under Grant No. EEC-0332605. Any opinions, findings and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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