A Data-Filtering Approach for Large-Scale Integrated RFID and Sensor Networks

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Abstract. Radio-Frequency identification, referred as RFID, is a technology for storing and retrieving data remotely using radio-labeled tags. Tags are small objects, and can be pasted or incorporated into objects and products or even implanted in living organisms. In the last years, several researches have focused on how to take benefit from this technology to build performing rechargeable sensor networks. The fusion of both technologies can extend widely the network's lifetime and improve it performances since radio communications are only performed between readers and not between sensor tags. However, the RFID sensor networks present some drawbacks due to the random deployment especially for large scale systems, which can disturb the system's performances and cause issues such as data duplication, and medium access control (MAC) collisions. In this paper, we deal especially with the redundancy problem by proposing an algorithm that avoids a priori the transmission of duplicated data before sending it into the network. Our approach can be considered as proactive since it predicts duplication by planning a first network discovery phase. Our scheme showed good performances in terms of latency, packet delivery, and computational cost.

Keywords: RFID · Sensors · Reader/tag · Collision · Filtering

1 Introduction

Nowadays, Wireless Sensor Networks (WSNs) are increasingly used in many applications [1–3], and gaining more scientific interest to improve the features of such networks [4,5]. These networks are deployed to monitor the physical environment such temperature and humidity. As nodes are small components that suffer from very limited energy resources, several research works have focused on the problem of network's lifetime prolongation [6–8]. However, the contributions proposed in the literature, which tend to optimize the network's lifetime by proposing new routing protocols for example, have recently showed their limits.

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The trend is now for searching new solutions taking benefit from many energy harvesting technologies [9]. Among these technologies, we can find techniques of recovering energy from ambient environment as Radio Frequency waves [10,11]. In this area, the Radio Frequency Identifications (RFID) has emerged as an alternative solution of typical battery-limited sensors [12,13]. This technology is used since 1970 in order to track objects and animals [14]. It uses electromagnetic fields to automatically identify and track labels attached to objects. The tags contain information stored electronically [15]. There are two types of tags: Passive and Active [16]. Passive tags collect energy from reader that interrogates it using radio waves. Active tags have a local power source such as a battery and can operate hundreds of meters from the RFID reader. The integration of RFID technology with the sensor networks is a fairly recent idea. Indeed, conventional RFID systems that only harvest simple data such as an identification as a single numerical value. The idea here is to combine RFID systems with sensors embedded on tags. Such integration takes benefit from the synergy between the two technologies by converging the sensing capability of WSNs with the RFID identification capabilities for an integration into the internet of things (IoT) context [17]. This conducts to several applications which require a strong synergy between the detection and the marking, in particular in the industrial and agricultural fields.

However, in RFID systems, several issues are reported and many challenges need to be addressed. Among these issues, we mention the problems of medium access control (MAC) layer collisions [18] and data redundancy [19] and also security. In fact, the deployment of RFID systems, that include tags and readers, is usually not optimal. The tags can be located in the reading area of two or more readers. These two problems may decrease significantly the performances of the system [20].

This work is motivated by a concern of reducing of the impact of RFID system issues over the integrated network. We propose in this paper a solution based on a proactive approach that deals with the data duplication problem. The pro activity of our approach is very important since it allows the elimination of redundant data before it transmission into the network.

The remain of the paper is organized as follow; we start with presenting the problematic faced by the RFID systems related to the random deployment, in Sect. 3 we present our solution of the data duplication problem to the problem. In Sect. 4 we present simulation results where we validate our solution. Finally, Sect. 5 gives a conclusion and presents some perspectives to future works.

2 Problem Presentation

In this section, we introduce some issues related essentially to the random deployment of RFID tags.

2.1 Deployment Problem

One of the most relevant problems in any RFID system is the deployment problem [21]. This problem can be defined as a problem of energy supply. The solutions for this problem tend to optimize the network in order that all sensor tags receive a minimum of energy to transmit data to the readers. However this solution has to take into consideration the overlap between the reading fields of readers as illustrated in Fig. 1.

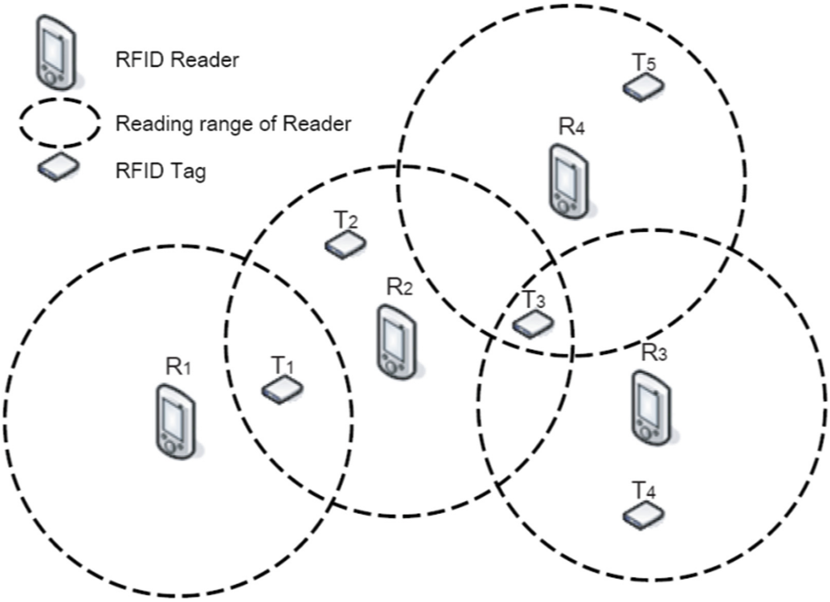

Fig. 1. Reading range overlap in RFID system.

Definition 1. *A RFId tag i is powered by reader if the average recharge power it receives* P_r *is higher than a minimum power* P_s *necessary to perform send data. We also say that the entire network is powered if all the tags are powered.*

This problem is similar to the coverage problem in traditional WSNs, where sensors are deployed to sufficiently monitor a region of interest. However, an essential difference between the two problems is the direction of signal transmission: Tags are charged from the RF signals transmitted by the deployed readers while the sensor nodes are deployed to detect the signal transmitted by the targets in a typical coverage problem. Since the wireless recharge model of tags is fundamentally different from the sensor detection model, existing solutions to the coverage problem in traditional WSNs can't be applied to the energy powered problem.

For this purpose, we refer to the point provisioning solution presented in [22] to define the conditions where it is considered that a tag is energy provisioned by a reader. So we consider the situation where a minimal number of readers are deployed over the area. Figure 2 shows the adopted model based on triangle deployment.

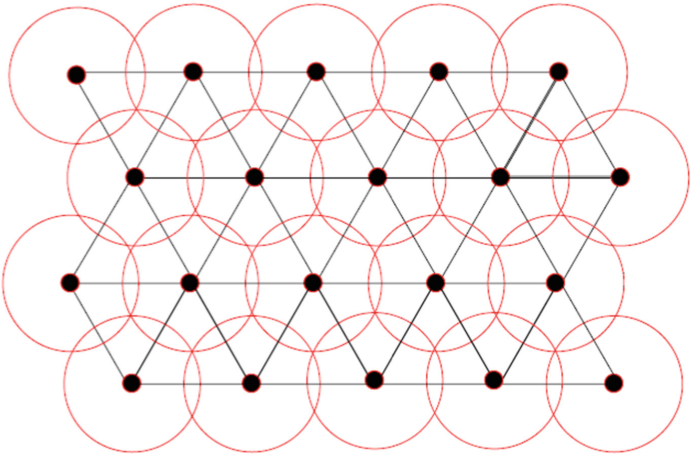

Fig. 2. Reading ranges overlap in RFID system.

As we can note, despite the optimization of the deployment, some areas still suffer from the problem of reader's overlap. This situation causes the occurrence of two main problems: The reader's communication collision and the data redundancy [18,19]. In the following, we give details of these two issues.

2.2 Reader's Communication Collision

In a multi-channel network, readers could use different channels to read tags, but that does not prevent collisions. To better illustrate this problem, we consider Fig. 3 where the dashed lines represent the communication links between readers, the small circles show the reader's radius of action, the dashed circles show the interference radius of the adjacent channels, and the large circles illustrate the radius of the reader interference. The readers R1 and R2 can communicate in a wireless manner and they are in the communication range of each other. In a multi-channel RFID network, if two readers use the same frequency to read labels, regardless of the distance between them, the tags in the overlapping area of their fields will not be read. But if two players use different playback channels, even if they are active at the same time, the tags in the overlay area of their fields will be read successfully if and only the distance between the readers is greater than 3.3 dRT [23].

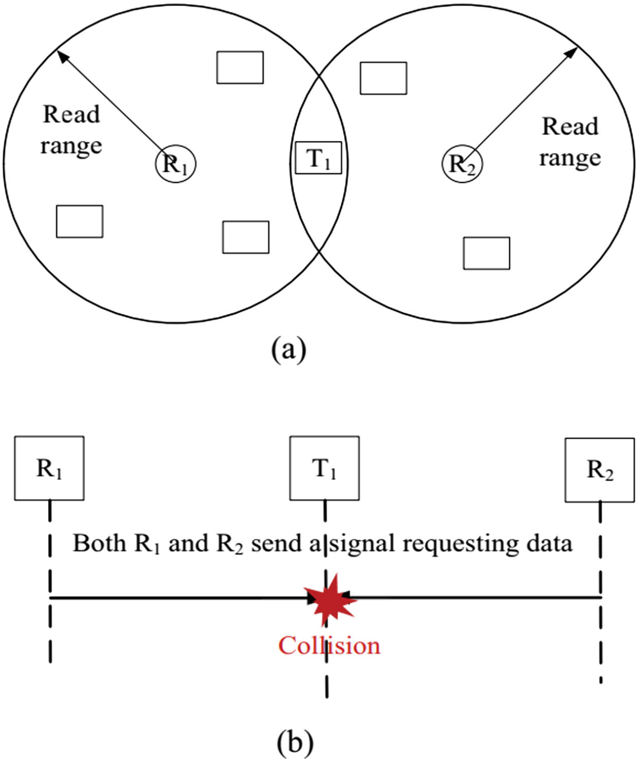

Fig. 3. Reading ranges overlap in RFID system.

2.3 Data Redundancy Problem

As previously explained, the majority of architectures proposed for the integration of RFID with sensor networks consider the tags as semi-active. In this situation, tags are equipped with small and low-capacity batteries in order to perform local tasks, such as capturing and processing data. So the most energy consuming task related to sending and receiving data, is not supported by the sensor's battery. This explains the passivity of the tags during data transmission. However, this passivity has lead to a situation where tags ignore the topology of network, so the transmission of data is performed blindly.

So when a reader is located on the reading area of two tags, there is no way the tag can detect that the generated data will go to two or more readers since it's passive at this moment. This is the cause why data duplication is triggered without being detected by the tags.

In this paper, we first consider that only readers form the topology, and tags are considered passives. We also consider that the topology formed is a mesh, where readers exchange routing tables. To better control the problem, and following a policy of divide and rule, we partition the problem of data redundancy

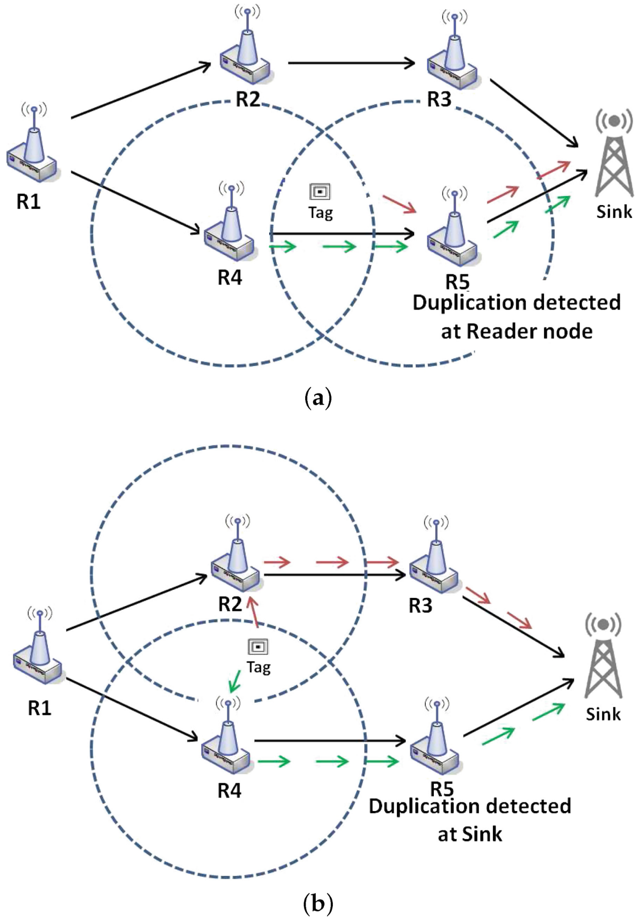

Fig. 4. Data duplication problem (a) intra-path data duplication between Reader 4 and Reader 5; (b) extra-path data duplication between Reader 2 and Reader 4.

as two sub-problems: intra and extra path problems. For this purpose, we consider that mesh topology is adopted to organize the communication between readers also considered as routers.

As we can notice in Fig. 4a, the intra-path duplication of data can be easily detected and removed at one hop. Meanwhile, extra path duplication shown in Fig. 4b is difficult to detect before reaching the sink. That explains why the main effort of this paper is to try to resolve the extra path duplication problem by prediction.

3 Proposed Solution

In this section, we present a solution for the extra path problem caused by the overlapping readers. Our solution is based on three phases to prepare the network: Preliminary phase (PP), network discovery phase (NDP).

3.1 The Preliminary Phase

In this first phase, the network has to choose which readers will start the NDP phase. For this purpose, the sink will send a message to all readers including the number of hops (incremented at each hop) and a sequence number. The main goal is to identify for each potential route, the node with maximum number of hops to reach the sink. If a reader considers itself as the node with maximum hops to sink, it will be elect to start the second phase. In Fig. 5, we can see an example of the message broadcast over the network.

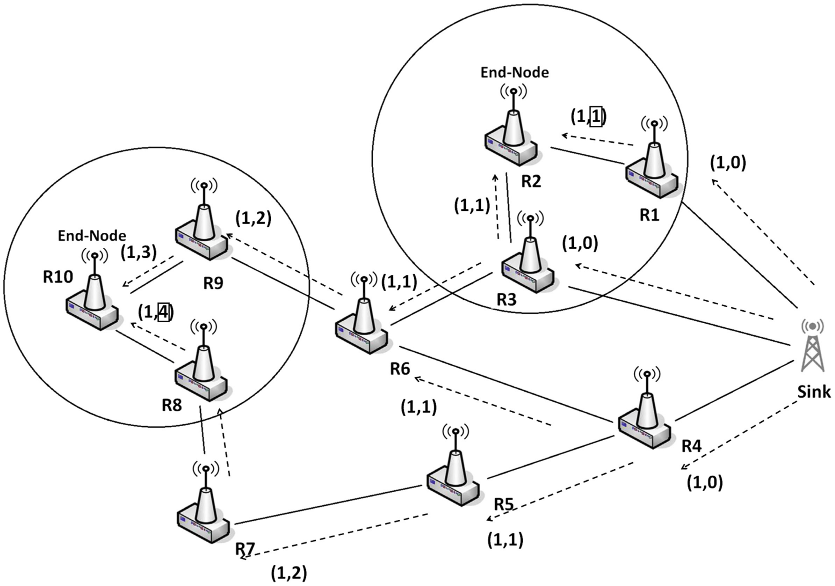

Fig. 5. Message broadcast over the network.

3.2 Network Discovery Phase

In this phase, the goal is to detect which reader nodes generate duplicated data. To do that, the nodes elected at the previous phase will send a message (Discovery Message) including a list of the tags located in their reading area. The final goal at end will be to obtain a list of all tags associated to readers. However, in order to deal only with extra path duplication, the detected intra-path duplication, detected at this phase will be removed. At the end we will only obtain redundancy caused by the extra path problem.

The Discovery Message (DM) includes the list of tag for reach reader. This list will be updated at each hop. Also for each tag, we include the number of hops and a filtered status. The structure of the DM is shown in Fig. 6.

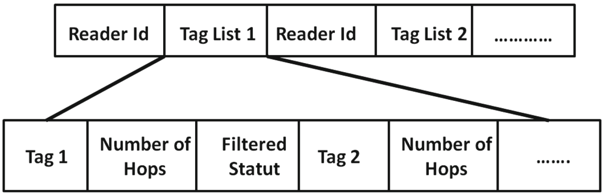

Fig. 6. Structure of discovery message.

During this phase, two algorithms must be implemented. The first one is executed by the all the reader nodes and the second is executed by the sink when it receives all the DM from all routes.

In the first algorithm, the reader starts by checking and deleting the intra-path duplication. The process is simple, if a tag coming from the neighbor is detected in the PM, and the reader has the same tag in it list, it delete it before sending the message forward. Each reader that receives the PM will perform this step, add it tag list, and forward the PM to the sink via the next reader. The process is explained in Algorithm 1.

Algorithm 1. Filtering Algorithm at Reader During NDP

Require: Discovery Message (DM) received
Ensure: Send Filtered DM to next hop
1: On receiving DM
2: **if** $\exists$ $Owntag \in DM$ **then**
3: Filter Duplication
4: **end if**
5: $DM \leftarrow DM \oplus t_i$
6: Increment number of hops
7: Send DM to next reader

When all the DMs arrive to the sink, the second algorithm can be executed. It has first to detect the duplication. Since all intra-path duplication has been removed, the redundancy detected must necessarily be an extra path. When duplication is detected for the same tag, knowing that each tag is associated with it reader, the algorithm will check which tag id has the minimum number of tags. The tag with minimum number of hops will be stored in a message called request message, which will be later sent to each reader. Finally the main goal is to predict which generate the duplication, filter the duplication with maximum number of hops, and ask for the readers with minimum number of hops to send the list of tags and eventually the related data. At the end of this phase, a request message (RM) is sent to each reader with a list of tags that he can send into the network. The rest will be filtered locally. This process is explained in Algorithm 2.

Algorithm 2. Filtering Algorithm at Sink during NDP

Require: All Discovery Messages Received
Ensure: Send Request Messages

```
if DM_i received then
    S ← S ⊕ DM_i {Add the i^th Discovery message (DM) to sink list (S).}
end if
for all Tag Ids in S do
    if ∃ S_i duplicated with S_j then
        Filter tag with minimum number of hops
    end if
end for
Send Request Message RM_{id_reader} from S to each Reader.
```

4 Simulation and Results

In this section, we evaluate the performances of our approach by calculating the amount of transmitted data into the network. The main goal was to improve the capacities of the RFID systems by reducing the number of packets transmitted, which conduct to the reduction of delay and computational cost. The simulations were performed using the Network Simulator 2 (NS-2). In the performed simulations, we consider a case of a random deployment of tags over a restricted area of 200×200 m. We consider that tags are semi-actives. Thus, the communications will only be performed between readers. Table 1 show more simulations details.

In order to evaluate the performances of the system, we focus on three main metrics that will reflect the capacity of predicting the data duplication. These parameters are cited below:

- Number of packets transmitted
- Number of filtered packets into the network
- Average delay

To obtain significant result, we compare our approach with to other methods in literature based in tree topology [24] called In-network phased filtering mechanism -INPFM and the second one based on clustering called clustering called In-network RFID data filtering IRFD [25]. Note that in the figures, we call our method: Proactive Data-Filtering-Scheme PDFS.

Table 1. Simulation parameters

Simulation parameters	Values
Deployment area	200 m × 200 m
Maximum number of tags	300
Minimum number of readers	40
Reading range	10 m
Transmission range	30 m
Reading period	15 s
Duplication rates	10%; 40%

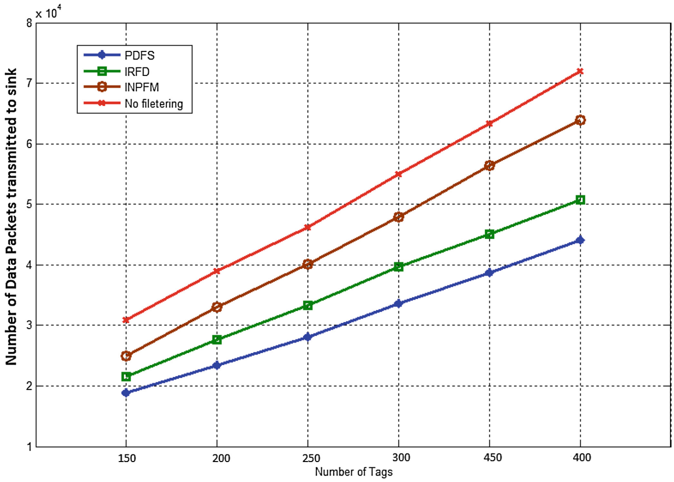

Fig. 7. Number of transmitted packets.

Let's start with the first result. As we can see in Fig. 7, the number of transmitted packets is considerably reduced when using our approach, in comparison with IRFD and INPFM.

The second result concerns the number of filtered packets filtered into the network shown in Fig. 8. As we can see, this number is reduced by our approach. This is not because our method filters less packets than other approaches, but it's due by the fact that in our scheme, data is filtered before being sent into the network. This reduce considerably the computational cost and delay in the system.

Thus, the final result concerns the delay. The fact that computational cost is reduced, and less data is sent into the network, reduce considerably the average delay into the network as we can notice in Fig. 9.

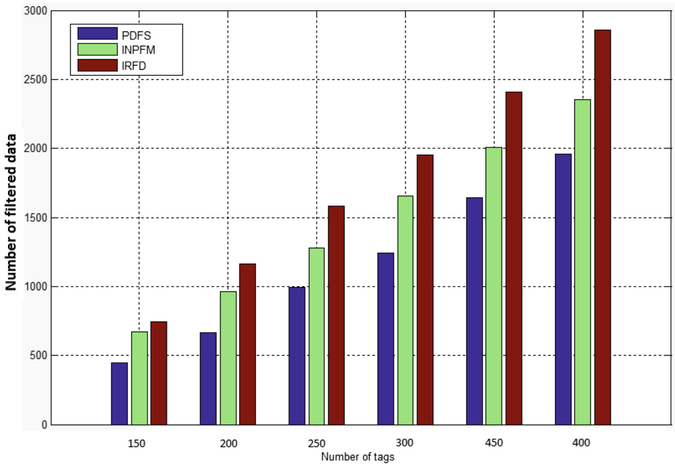

Fig. 8. Number of filtered packets into the network.

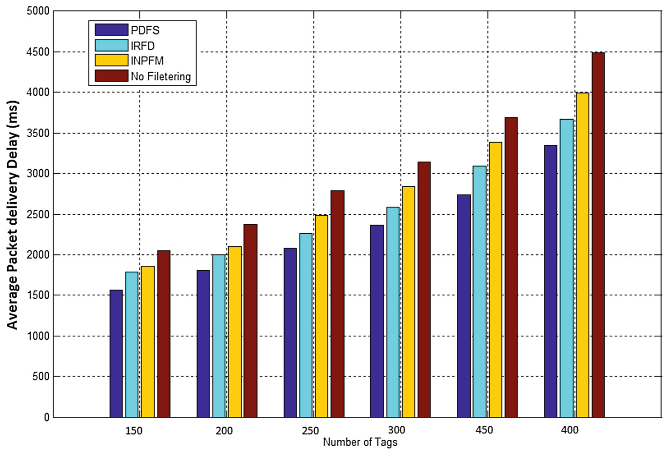

Fig. 9. Number of filtered packets into the network.

5 Conclusion and Perspectives

In conclusion, the integration of RFID system with wireless sensor networks technology has a major advantage in terms of reducing the transmission costs that the sensors must support. In these systems, readers are responsible for the transmission of data, when sensors (integrated to tags) simply read the data and stores.

However, such type of sensor networks has to deal with problems related to RFID systems. In this paper we presented the major problems for these systems: MAC layer collisions and data duplication. In this context, we detailed our solution for the second problem. Our scheme was based on a predictive approach that detects readers that will generate duplication, and delete affected data before sending it into the network.

In future work, we will focus on an hybrid solution that deals with both RFID problems, in order to improve more the performances of the system. Our future approach will also take into consideration the energy consumption of the RFID readers.

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