New IoT proximity service based heterogeneous RFID readers collision control

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Abstract

Purpose – Internet of Things' (IoT's) first wave started with tracking services for better inventory management mainly using radio frequency identification (RFID) technology. Later on, monitoring services became one of the major interests, including sensing technologies, and then more actuation for remote control-type of IoT applications such as smart homes, smart cities and Industry 4.0. In this paper, the authors focus on the RFID technology impairment. They propose to take advantage of the mature IoT technologies that offer native service discovery such as blutooth or LTE D2D ProSe or Wifi Direct. Using the automatic service discovery in the new framework will make heterogeneous readers aware of the presence of other readers and this will be used by the proposed distributed algorithm to better control the multiple RFID reader interference problem. The author clearly considers emerging Industry 4.0 use case, where RFID technology is of major interest for both identification and tracking. To enhance the RFID tag reading performance, collisions in the RFID frequency should be minimized with reader-to-reader coordination protocols. In this paper, the author proposes a simple distributed reader anti-collision protocol named DiSim that makes use of proximity services of IoT network and is compliant with the current RFID standards. The author evaluates the efficiency of the proposal via simulation.

Design/methodology/approach – In this paper, the author proposes a simple distributed reader anti-collision protocol named DiSim that makes use of proximity services of IoT network and is compliant with the current RFID standards. The author evaluates the efficiency of the proposal via simulation to study its behavior in very dense and heterogeneous RFID environments. Specifically, the author explores the coexistence of powerful static readers and small mobile readers, comparing the proposal with a standard ETSI CSMA method. The proposal reduces significantly the number of access attempts, which are resource-expensive for the readers. The results show that the objectives of DiSim are met, producing low reader collision probability and, however, having lower average readings per reader per time.

Findings – DiSim is evaluated with the ETSI standard LBT protocol for multi-reader environments in several environments with varied levels of reader and tag densities, having both static powerful RFID readers and heterogeneous randomly moving mobile RFID readers. It effectively reduces the number of backoffs or contentions for the RFID channel. This has high reading success rate due to the avoided collisions; however, the readers are put to wait, and DiSim has less average readings per reader per time. As an additional side evaluation, the ETSI standard LBT mechanism was found to present a good performance for low-density mid-coverage scenarios, however, with high variability on the evaluation results.

Research limitations/implications – To show more results, the author needs to do real experimentation in a warehouse, such as Amazon warehouse, where he expects to have more and more robots, start shelves, automatic item finding on the shelve, etc.

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Practical implications – Future work considers experimentation in a real warehouse equipped with heterogeneous RFID readers and real-time analysis of RFID reading efficiency also combined with indoor localization and navigation for warehouse mobile robots.

Social implications – More automatization is expected in the future; this work makes the use of RFID technology more efficient and opens more possibilities for services deployment in different domains such as the industry which was considered not only in this paper but also in smart cites and smart homes.

Originality/value – Compared to the literature, the proposal offers the advantage to not be dependent on a centralized server controlling the RFID readers. It also offers the possibility for an existing RFID architecture to add new readers from a different manufacturer, as the readers using the approach will have the possibility to discover the capabilities of the new interaction other RFID readers. This solution takes advantage of the available proximity service that will be more and more offered by the IoT technologies.

Keywords Internet of Things, RFID technology, Device to device, Proximity service, RFID reader-to-reader collision, Supply chain efficiency

Paper type Research paper

1. Introduction

Radio frequency identification (RFID) was one of the first technologies to be used in Internet of Things (IoT) first applications with the Auto-ID project in 1999. RFID is a widespread radio technology that allows for contact-less identification and tracking of electronic tags. This identification is similar to the bar-code system and would allow for individual item identification and tracking on industry processes such as transportation, supply-chain and storage management. A recent Xerfi report shows a high interest of industry in stock management and tracking by RFID and Big Data (Xerfi, 2014). Several patents are being constantly filed for RFID technology; Google Patent shows more than 600,000 results for this keyword[1]. Also note the initiative of Amazon announced in 2015 which aims to integrate RFID into the online retailer's existing high-tech fulfillment system to further improve supply chain efficiencies.

RFID is nowadays a mature technology that is used and exploited by the industry. Industry 4.0 is an effort to bring advanced technology into the factories and production processes. This is related to IoT technologies, ubiquitous networks, robotics and automation. This interest in advanced technologies can be easily seen in Amazon robotics and high-technology warehouses[2,3]. RFID identification is made part of many Industry 4.0 efforts, as shown by the research and development in RFID venture by the French company Decathlon that has started its own RFID business as Embisphere[4]. While the RFID tags are simple and inexpensive, the RFID readers and systems for Industry 4.0 would likely be high-end IoT devices, generally provided with more than one radio connectivity option and powerful computing capacities. Moreover, modern RFID readers like Zebra RFD8500[5] support themselves on smart-phones and mobile-OS to perform the required calculations and communications. Therefore, it is not strange to assume that IoT RFID readers will have an available back-end radio network, independent of the RFID band, over which some distributed communication can be achieved, eliminating the need for additional centralized optimization services.

In IoT Industry 4.0, heterogeneity of devices and the presence of standards would be the norm, having several vendors and RFID readers of different sizes and capabilities. To cope with this heterogeneity, we propose simple distributed intelligence to be in place at the RFID readers and the midlware, respecting the existing standards and regulations. Taking benefit of the IoT capabilities of RFID readers, I propose a distributed simple anti-collision algorithm for heterogeneous RFID scenarios.

In the scope of smart IoT-enabled warehouses, factories and stores, the location, identification and tracking of assets and products can be made by RFID technology, supported by the Electronic Product Code EPC Class1 Gen2 standard. An average warehouse could be expected to work on the principle of smart-shelves, where the goods are deposited following a logical disposition tracked by an information system instead of statically assigned sections. Smart-shelves allow for better utilization of the warehouse space. The goods would be placed densely, without any pre-assignment of space, and this density and location would change significantly fast.

The use of passive EPC Class1 Gen2 tags would be expected due to their low cost, high capabilities and global unique identification.

On the other hand, powerful IoT-enabled RFID reader would be used to perform fast and reliable tag identification. High-power static readers[6] would be placed to cover the total area, at least in a basic manner, similar to the IEEE 802.11 Access Points deployment strategy or at the entry and exit points to do inventory-like scanning. Operators, workers or even robots would wander around with mobile RFID readers[7]. Both types of readers would be products of different manufacturers, different power capabilities but compliant with the EPC Gen2 standard.

We considered this scenario as a realistic use case for IoT-enabled RFID readers, and we propose the simulation and evaluation under this scenario, where in fact an RFID architecture design in a warehouse or smart factory might have heterogeneous RFID readers and need to rely on an effective heterogeneous RFID reader signaling for collision control, and this is precisely the scope of this work.

The rest of this paper is organized as follows: Section 2 explains the RFID mechanisms and collisions problems, Section 3 does a brief survey of the state of the art of RFID distributed anti-collision protocols and the IoT wireless technologies that offer device-to-device (D2D) proximity services, Section 4 gives a brief introduction of proximity services, Section 5 details the contribution of this work, Section 6 details the simulation experiments for the proposed algorithm, Section 7 discusses the results, and Section 8 concludes the paper and proposes further work that need to be conducted in the future.

2. Radio frequency identification reader collisions problem

A passive RFID system is composed by a large number of passive tags and at least one reader. UHF Passive tags are simple RF devices with no power-source attached, and the circuit is powered from the electromagnetic emitted by the reader. The tags transmit their information back to the reader using back-scattered signals, reflecting a modulated signal back to the reader. The UHF RFID architecture and protocols are standardized by EPCGlobal in their standard (EPCglobal, 2015) and by ISO/IEC in their standard 18000-6C (ISO/IEC, 2013). UHF RFID systems operate in the frequency band of 866-868 MHz or 902-928 MHz, having different regulations according to the country rules and laws, however, following the regulations of FCC and ETSI. In the European context, ETSI has issued the UHF RFID standard EN 302 208 (ETSI, 2016) that specifies the frequencies and power limitations available.

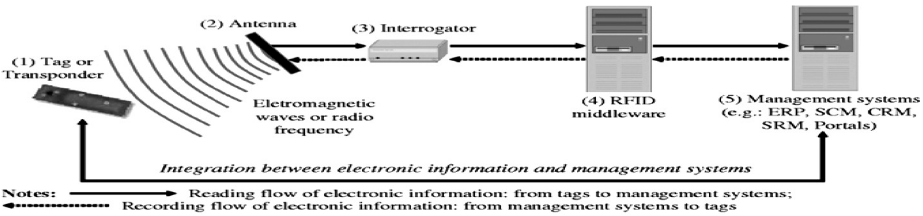
The tags, being passive, can be read only after the reader emits a signal to power them. Some tags will be in the *reading* area of the reader (where the reader can energize the tags and read the signals returned), which can be modeled as a circular area of radius R_{rt}. However, the signals from the readers can go beyond this area and interfere with other tags or readers in a modeled circular area of radius R_{rr}. Due to the reduced power of the signals returned from the tags, it is assumed that $R_{rt} < R_{rr}$. Depending on the RFID reader antenna and power capacities, the R_{rt} distance can be in the range of 10 m, whereas the R_{rr} would have a greater value. Bueno-Delgado *et al.* (2013) state that the R_{rr} could be as much as

1,000 m, under their signal propagation model and the specific RFID reader specifications that are considered in their work.

The multiplicity, heterogeneity and mobility of devices make the scenario subject to collisions in the RFID frequency. Because of the characteristics of the tags, collisions are to be resolved by the readers only. Tag-to-tag collision, when more than one tag replies at the same instant to a reader, is treated by the EPC Class1 Gen2 anti-collision mechanism specified in the standard, the dynamic framed slotted ALOHA (DFSA) (EPCglobal, 2015).

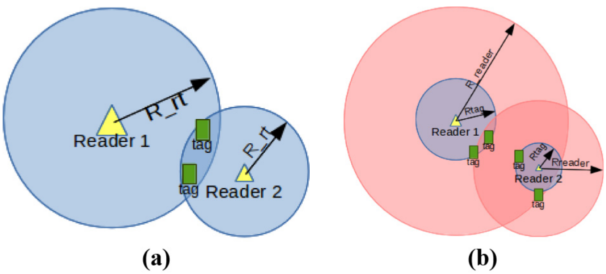
On the other hand, reader-to-tag and reader-to-reader collisions are also likely to occur and, hence, need to be managed. Reader-to-tag collisions occur when a tag is under the coverage zone of two readers that might transmit at the same time, and the tag is not able to decode any useful signal. Reader-to-reader collisions occur when a tag is in the reading zone of one reader (rt radius), but another reader transmits at the same time and causes interference that masks the tag's backscattered signal (rr radius). These two collisions are illustrated in Figure 2; both degrade the system performance by decreasing the number of identified tags per time unit. This problem is of a major negative impact in RFID-based inventory service, where 100 per cent of the tags has to be identified.

To mitigate this problem, the ETSI EN 302 208 standard proposes a basic mechanism to make use of the four available channels in the RFID UHF frequency by using a Listen-Before-Talk (LBT or CSMA) strategy controlled by minimal and maximal permanence periods (Figures 1 and 2). All readers select a random channel and listen to it for at least 5



Source: http://tracktio.com/learn-about-rfid/

Figure 1.
RFID tag reading elements



Notes: (a) Reader-to-tag collision; (b) reader-to-reader collision

Figure 2.
RFID reader collisions

min; if the channel is free, it is occupied for up to 4 s by that reader. After this time, the channel must be free for, at least, 100 min.

However, because of the amount of readers that can be operating in the area of our use case, even with four different frequencies, there would be always a group of devices operating on the same frequency and competing for the medium. More sophisticated mechanisms have been proposed in the literature and are reviewed in Section 3. Many proposed solutions tend to introduce changes to the IT infrastructure like adding a purpose-specific device or process, but an autonomous distributed algorithm would be more appropriate and more likely to be adopted by the industry.

The standard ETSI EN 302 208, applicable in the EU, defines a four-channel plan for the RFID UHF band, limiting also the irradiated power to 3.2 W EIRP. For dense reader scenarios, a simple mechanism is proposed to reduce the collisions by using the available channels. A reader randomly selects a channel and listens for 5 min; if no signal is detected, it takes the channel and starts the identification process, remaining in the channel for up to 4 s. If there is no reply from tags in 100 min, the channel is left. After an identification round, the reader waits 100 min before taking another channel (ETSI, 2014).

One of the possible drawbacks of the ETSI EN 302 208 standard in high reader density scenarios is that it could cause some readers to starve, meaning that they can lose the contention for the medium several times in a row and, therefore, not have a fair chance to access the RFID channel. To the best of our knowledge, no indication is given about the time period to backoff or the frequency of retries.

3. Related work

Research efforts on RFID technology have been present in literature for several years. Some other protocols different from the adopted in the Electronic Product Code EPC standard have been proposed and evaluated mainly to tackle the collision problems:

- Regarding the tag-to-tag collisions, where several tags might enter into collision when responding to one same reader, Klair *et al.* (2010) present an extensive survey of the different problems and mechanisms to resolve them. The Dynamic Framed-Slotted Aloha-aka DFSA algorithm of the standard is also treated in this work.
- *Control vs no-control-based RFID reading*: Regarding the multi-reader collision problem and its associated reader-to-tag and reader-to-reader collision problems, Li *et al.* (2011) propose an interesting classification of the different reader anti-collisions protocols into three categories: schedule-based, coverage-based and control-based mechanisms. This proposed method is in this last category, as it makes use of an additional control channel for the coordination of the RFID reading by several readers in the same area.
- *Centralized vs distributed approach*: Another more recent study of the RFID reader anti-collision in dense environments (Nawaz *et al.*, 2013) bases the classification in centralized and distributed approaches. This proposed method belongs to the latter, as it does not require any central device or knowledge which is more convenient and flexible; schedule-based anti-collision mechanisms are based on properly multiplexing the common RFID channel, usually making use of graph coloring techniques, and have centralized and distributed versions. In Konstantinou (2012), a distributed algorithm based on graph coloring is proposed called Expowave. The readers in an area have a random color among the number of colors available, the color meaning a time slot to read; between an iteration of colors, there is a kick slot when the readers communicate among themselves via broadcast messages. When

the readers detect a collision, the number of colors is increased, and new colors are randomly chosen by the readers. When there is a successful color iteration, the number of colors decreases. Expowave uses a backoff mechanism, like the one used in slotted ALOHA, and an upper bound for the number of colors. Even if the algorithm is distributed and does not need location information, it supposes that the readers are synchronized, not an easy task in a fully distributed system, and would require to define the additional messages for the kick communication among readers. In a more recent paper, Sen *et al.* (2016) present another scheduling-based anti-collision algorithm based on Colorwave, both in the centralized and distributed versions. It is based on the localization information of the readers. With this information, a graph is built and colored, where each color is a time slot for the readers to operate. In Tang *et al.* (2011), a distributed scheduling algorithm is presented that does not require pre-calibrated location information of the readers. It is based on the assumption that the readers can measure the interference caused by nearby readers and build an interference graph. Once the graph is build, a number of tags can be simultaneously identified by activating a subset of the readers. The algorithm maximizes the tags to be identified by optimally scheduling the activation of a set of readers;

- *Extra channel for RFID reader coordination*: As a reference protocol that uses a control-mechanism, DiCa is proposed in Hwang *et al.* (2009), using a wireless sensor network as the control channel, where a broadcast mechanism is available. This protocol is based on a previous work on control-mechanism protocols called PULSE (Birari and Iyer, 2005). The control operation is based on three messages that the readers broadcast only when reading tags, which reduces energy consumption. The readers contend for the right to use the RFID data channel; only one reader wins and takes the channel until the reading is finished. When contending, the readers backoff a randomly selected time, and the first to have its timer expired wins. To deal with the exposed and hidden-node problems, the readers are expected to have control over the power of the control channel radio and adjust it such that $R_{control} \geq R_{data}$. These assumptions would mean the need of additional investment on a wireless sensor network and a very specific radio-power control hardware feature perhaps not available in all RFID readers. This protocol also has a possible deadlock when a reader is waiting for the channel to be free but never receives the notification and could remain waiting for long periods.
- *Central server RFID reading coordination*: In the European scenario, Bueno-Delgado *et al.* (2013) propose a centralized control-based mechanism based on the Neighbor Friendly Reader Anti-collision (NFRA) protocol (Eom *et al.*, 2009). This proposal assumes that the readers can reach a central server (CS) via an Ethernet or 802.11 wireless link, and this CS will execute the operations of the NFRA algorithm, which is a contention resolution mechanism for nearby readers. This approach, called GDRA, makes use of the four channels available in the European standard ETSI EN 302 208, and the contention is used only for readers in the same channel. Instead of using a uniformly distributed random slot number in the contention phase, a sift probability distribution is used, which is a truncated geometric distribution. When an identification round starts, it is signaled by the CS, and the contention phase starts divided in time slots. The readers select a random number according to the sift probability function; the ones selecting one will broadcast a beacon. If there

is a collision of beacons, the affected readers leave the contention and wait for the next round started by the CS. In the simulation results, their algorithm has higher throughput than NFRA.

4. Proximity services

Proximity services are arising in recent wireless standards such as WiFi Direct, 3gpp LTE release 12 and 5G. Note that Bluetooth was the first technology to include automatic service discovery at the link layer where the service profile was defined, and different Bluetooth devices could discover the capabilities of over connected devices over the Bluetooth channel. Other wireless and mobile technologies later introduced the proximity service concept. In this work, I am interested in a secondary communication channel to be available on the RFID readers to exchange their service capabilities to feed the DiSim algorithm proposal that will avoid reading collisions. The main idea of proximity services – a.k.a ProSe in wireless and mobile technologies – is to allow devices to discover and communicate directly with other devices located in their vicinity (so called D2D communication). The vicinity is technology-dependent, being related to the distance the wireless signal can reach. One important motivation behind ProSe is the possible application in mobile social networks[8], advertisements and other cases.

4.1 Proximity services in WiFi direct

In WiFi (IEEE 802.11x), clients are usually mobile devices which connect to a WLAN announced by a static access point (AP). In this model, the two functionalities are attributed to two different types of devices: mobile and AP. In WiFi direct, these roles are *dynamic* and can be played by the same device at the same time or at different time instants. These functions become rather logical, and the AP role is incorporated as a piece of software (also called Soft AP) into the mobile devices.

To communicate directly without passing through a "traditional" AP, the devices form P2P groups. When associating to each other, they negotiate the roles and the device that is chosen to play the AP role called as P2P group owner (P2P GO). After the group is established, other devices can join it in a similar way to traditional WiFi. Legacy devices that do not support WiFi Direct can still join a group[9] because the soft AP provides the full functionality of a hardware AP.

Figure 3 shows possible use cases or scenarios of WiFi direct networks.

The figure also shows that a device can play simultaneously both client and P2P GO roles by communicating over two different channels.

An interesting feature of WiFi direct is the ability to discover services at the link layer (Layer 2), before establishing any connection with the peer device. This is implemented using the *Generic Advertisement Protocol (GAS)* of 802.11u that transforms advertisement message of upper layers at the link layer.

An overview of the architecture, message exchange, performance evaluation and other aspects are detailed in Camps-Mur *et al.* (2013).

In 2015, WiFi alliance released a new standard for proximity services called *Neighbor Awareness Network (NAN)* a.k.a Wifi-Aware[10]. Their goal was to enable devices to discover other nearby devices while not draining the device's battery at the same time. WiFi-Aware runs in the background of a smartphone or tablet, and the user can use a specifically designed application to publish presence of service or to subscribe to interesting services. This allows devices to discover each other – based on the match

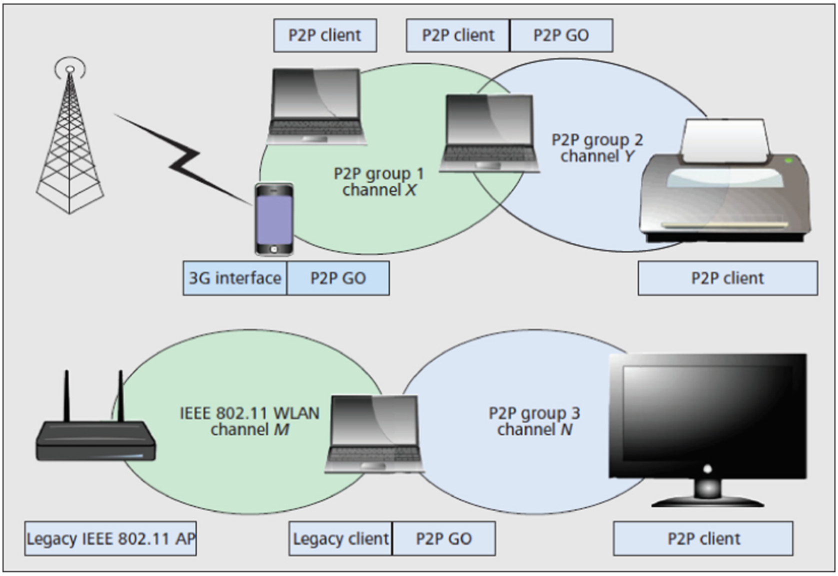


Figure 3.
Example of WiFi direct network

Source: Camps-Mur *et al.* (2013)

of interest – even before establishing a communication channel or exchanging application's data. Camps-Mur *et al.* (2015) provides an overview of NAN architecture, discovery process, messages and other details. According to Saloni and Hegde (2016), there are three categories or classes for Wifi-Aware use cases:

(1) Mobile-to-Mobile, where two mobile devices can discover each other.

(2) Mobile-to-fixed location services, where a mobile device can discover a service announced by a service in a fixed location, for example, coffee shop, museum, etc.

(3) Fixed location services-to-mobile, where a fixed location service can discover a mobile device passing in the vicinity.

This kind of technology can be leveraged in smart cities, IoT and many other scenarios.

4.2 Proximity services in LTE

Proximity services were introduced in LTE in release 12. There are two basic functions that are essential to proximity services in LTE: D2D Discovery and D2D Communication (Athul *et al.*, 2014; Salam *et al.*, 2017; Lin *et al.*, 2014). D2D Discovery allows the user equipment (UE) to use the air interface to discover other devices, and D2D Communication allows them to use the air interface to setup a direct communication link to exchange messages without passing through the eNB. The communication can have three different scenarios described in Figure 4.

In-coverage communication when both UE are covered by an eNB, i.e. the network controls the resources assigned for the terminals to communicate. *Out-coverage* is when they are not covered on the frequency used for D2D, but they may be covered on terminal to eNB frequency for normal cellular communication. *Partial coverage* is when one of the device is in-coverage but not both of them.

The communication can be *inband* when it is controlled by the cellular network or *outband* when the devices communicate over other wireless technology. I*nband* has two modes *underlay* and *overlay*. The former is more spectrum efficient and can achieve a data rate of around 1 Gbps up to a distance of 1 km. *Outband* can be *controlled* by the cellular network or *autonomous* where the second wireless interface is not under the cellular control. Distance and data rate of outband communication is much lower than inband.

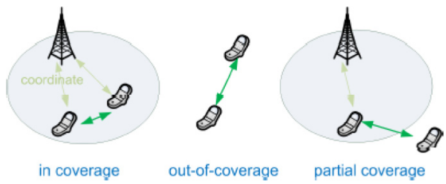
According to Lin *et al.* (2014), there are two ways of device discovery: *direct discovery* or *evolved packet core-level discovery*. In the first mode, the devices must continuously transmit and receive to detect each other, and there are two possible mechanisms: push where the device announces its presence, and pull where it asks the other devices to send information if they are discoverable. In the other case, the EPC determines the proximity of the devices and the UE does not start the device discovery until it receives its target from the network.

5. The author's contribution

In this paper, we developed a distributed control-mechanism-based RFID reader anti-collision protocol for IoT-enabled readers, which makes use of IoT proximity services available in the back-end radio (i.e. Blutooth, 802.11 WiFi-Direct or LTE ProSe or any available IoT-based low level service discovery technology). I present this protocol as DiSim. The back-end radio, called the *control-channel*, is assumed to have a larger coverage area than the RFID channel, approximately twice the size of the *RFID-channel*, as indicated by Hwang *et al.* (2009). The proposed algorithm and its validation take as basis the use case described in the "Introduction" section, where the RFID readers are heterogeneous in their characteristics, which is a different consideration from other research work. The tag-to-tag collisions within the reading area of a RFID reader are assumed to be solved by the RFID EPC Class1 Gen2 standard.

The proposed distributed simple RFID reader anti-collision protocol, DiSim, is briefly described in Figure 5 with a finite state machine model. This proposal deals with the coexistence of RFID readers with different capacities and power, some static and some mobile. It does not require any centralized software service, neither additional hardware from the already exiting in commercial RFID readers. It also does not need to track the location of the readers in the area. A priority mechanism is embedded in DiSim to ensure reading fairness and absence of starvation. Additionally, as DiSim is based on status notifications over the IoT channel, it avoids constantly probing the RFID frequency periodically to contend for the medium with the neighbor readers.

The basic idea is that whenever an RFID reader (called the INCOMING reader) wants to read tags, first it determines if there is a nearby reader already reading (called the ACTIVE reader) or waiting to read tags (called the WAITING readers). This identification process happens over the IoT channel, using proximity services. The IoT-enabled readers would



Notes: Device-to-Device Communication Whitepaper, Rohde & Schwarz: www.rohde-schwarz.com/appnote/1MA264

Figure 4.
D2D scenarios classification according to coverage

make use of the publisher/subscriber facilities of the IoT technology to easily discover other readers in the area and exchange notifications that would help coordinate the use of the RFID channel. Additionally, this approach takes into consideration the limitations imposed by the European ETSI EN 302 208 standard regarding the shared use of the RFID frequencies and timing constrains for actions in the frequency (ETSI, 2016).

DiSim faces the problem of reader starvation and fairness by a FIFO queuing strategy, where the more a reader is kept waiting, the more likely it is to take the RFID medium. If there is an ACTIVE reader or one or more WAITING readers, the INCOMING reader will ask the neighboring readers for an *order ticket*, which is the last place in the FIFO waiting queue to use the RFID channel and move to the WAITING state. All the RFID readers in a neighborhood area coordinate themselves autonomously by taking *order tickets* and increasing its value every time, a nearby ACTIVE reader leaves the RFID frequency (i.e. finishes reading and pops out of the queue).

The INCOMING reader that is about to take the RFID channel, after determining that there are no ACTIVE or WAITING readers nearby, checks for any signal on the RFID channel to avoid the case where two or more INCOMING readers were sensing the RFID channel simultaneously. There is a quick random silence time before probing the RFID channel from 5 to 10 ms, to comply with the ETSI minimal listening time. If at this point the INCOMING reader does not detect activity on the RFID channel, it becomes an ACTIVE reader and starts reading tags in the area.

The readers in WAITING state will retry to take the RFID channel after a notification from the ACTIVE reader when its reading is terminated or after an internal timeout is triggered in case the ACTIVE reader leaves the neighborhood area silently. This timer is set to 8 s, twice the ETSI maximum time for any reader to occupy the RFID channel. This value is chosen to prevent triggering the timer event just before a valid long reading has finished.

The ACTIVE reader will notify its neighbors at the end of the reading process. For a short time after reading the tags, the ACTIVE reader will pass by a FINISHED state to prevent it from re-taking the RFID channel before any of its neighbors do. This time is set to be 100 ms, as stated in the ETSI standard.

The WAITING readers, when notified by the outgoing ACTIVE reader or its internal timer, will check the highest *order ticket* in the neighborhood to determine who is to access the RFID channel next. In a similar way, the RFID frequency is checked just before to avoid any possible unexpected collision. All the WAITING readers that remain waiting increase their *order ticket* by 1. This mechanism of increasing ticket orders is established to assure fairness on the WAITING readers, as the higher the

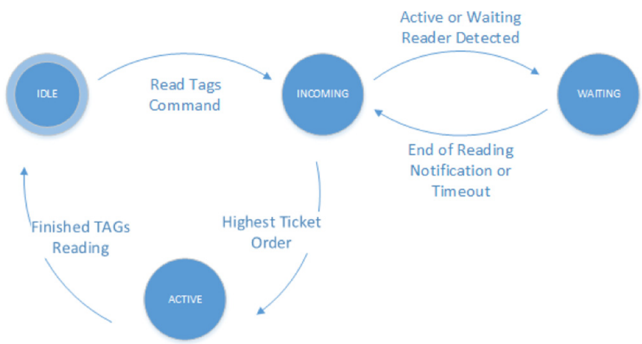


Figure 5.
FSM model of the proposed anti-collision algorithm

ticket value, the higher class in the waiting queue. The next reader to take the RFID channel is the one in the highest class. If there are more than one in this class, the first to respond will take the medium and the others will remain waiting with a higher *order ticket*.

5.1 Residual collision areas

In an heterogeneous RFID readers scenario, avoiding reader-to-reader collision areas will cause the reader-to-tag problem to be also minimized, as $RFID_{rr}$ is greater than the $RFID_{rt}$. Considering that $RFID_{rr} \geq 2 * RFID_{rt}$ if a reader listens to the RFID frequency before attempting to use it, it will be able to detect nearby readers and prevent some reader-to-reader collisions and all reader-to-tag collisions. However, even if the reader listens to the air before trying to transmit, there will be reader-to-reader collisions when their distance is not large enough as to ensure there is no overlapping of the $RFID_{rt}$ with the $RFID_{rr}$ radius. Figure 6 shows these residual collisions on the reader R_x area when the distance to another reader R_a is in the range $(Ra_{rr}; Rx_{rr} + Ra_{rt})$. Due to the distributed nature of DiSim and its independence from location and positioning, these collisions cannot be detected in advance but are minimized by the inter-reader coordination over the IoT channel, which has greater distance reach than the RFID channel.

5.2 Use of Internet of Things back-end radio proximity services

This protocol is intended to be agnostic to the specific IoT technology used, as long as some basic features are supported. The IoT proximity services, either WiFi-Direct, LTE or any other service, must provide the following features to be used in this proposal:

- Detection of nearby RFID readers via broadcast messages or Beacons. The detection message must allow to identify the device as an RFID reader.
- Message exchange with discovered devices, in a Broadcast manner, without association or pairing needed before. The messages must allow any-to-any communication, generally by using Publish/Subscribe techniques.

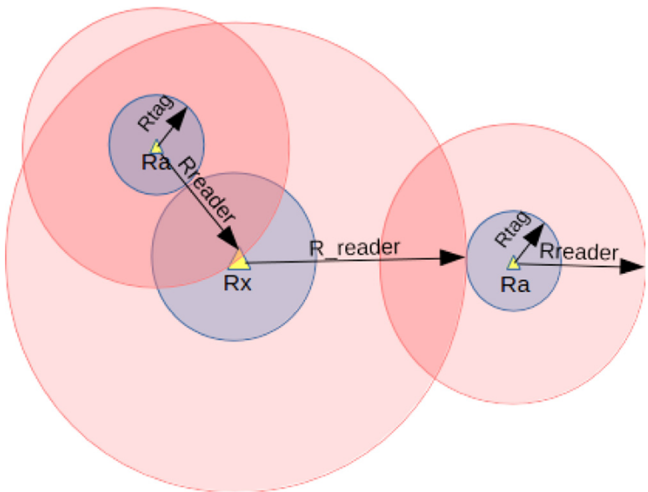


Figure 6. Reader-to-reader collision zones for heterogeneous RFID readers

5.3 Blocking probability option

As an additional feature to prevent excessive waiting times for the readers in very dense environments, DiSim has a blocked channel option. Before an INCOMING reader starts its process if there are more WAITING readers in the area than a defined threshold, it will declare the RFID medium as blocked and abort the reading operation. This operation would happen on extremely dense scenarios and is used to prevent an RFID reader from having a very low efficient reading, meaning that it will remain waiting for a very long time, causing other INCOMING readers to wait as well and have a very long queue of readers waiting for the medium to be free. For this work, the blocking value was set to 75 per cent of the total neighboring readers, so that when there are 75 per cent of neighbors WAITING, it is considered blocked, and the tag reading is aborted.

Contrary to the ETSI standard LBT method, we consider the fact that the RFID medium is shared and has to be orderly coordinated between the readers, similar to the way a single resource is shared in a queuing mechanism. The queue is thought as a G/G/1/N model, where the N capacity determines the blocking stage of the queue.

6. Experimentation

6.1 Simulation

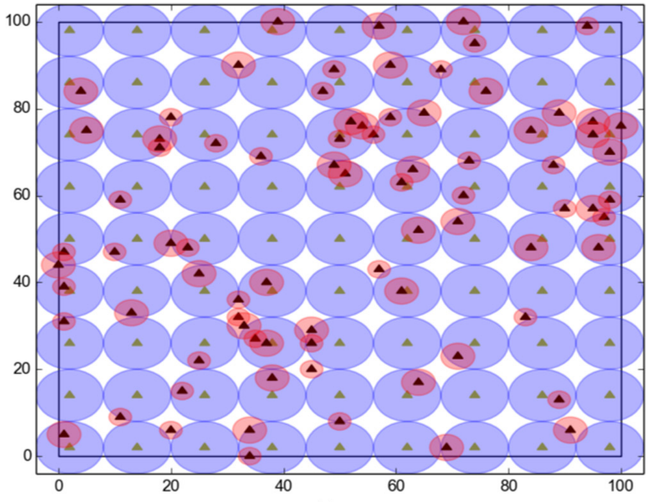
I evaluate the simple protocol in a homemade *Python* model simulation using discrete-event framework *Simpy*[11]. I simulate a mixed reader scenario as described in Section 1. The simulation parameters are summarized in Table I. To understand the real value of the DiSim proposal Both both DiSim and RFID standard ETSI anti-collisions protocols are simulated.

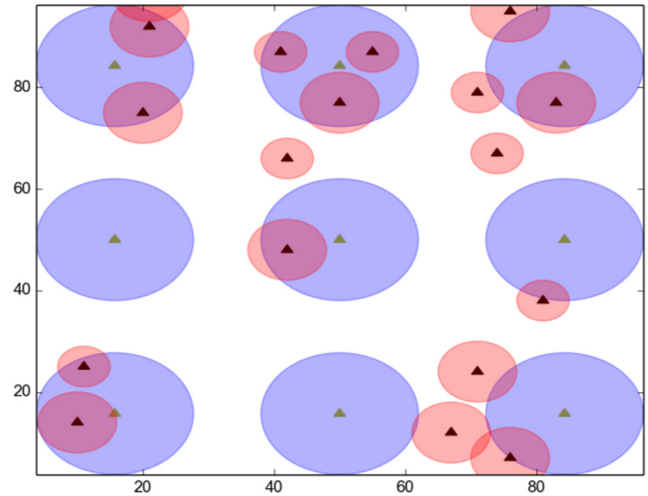
The area considered for the simulation is a square of $100 \times 100\ m^2$, which is an average size for an industrial warehouse area. It has a number of powerful static homogeneous and small mobile heterogeneous readers. The average tag density of the area, expressed in $tags/meter^2$, is the main parameter that determines the properties of the readers deployed in the area, following the logic that the RFID engineer would choose the appropriate readers to effectively read all the tags in its area in a short manageable time. For the simulation, it is considered that no reader would take more than 4 s to read the tags deployed in its area, which is the standard ETSI EN 302 208 maximum stay time in the RFID channel. A subset of the static readers population performs a tag-read operation every 5 s, with 0.5 random probability.

The number of static readers is determined based on two parameters: the tags density and the coverage level. The tags density implies the adjustment of the reader characteristics (coverage range, reading time, etc.), whereas the coverage level represents the user requirements of whether the area must be completely covered or if it is sufficient to cover a certain percentage of the total area. Figure 7 shows the deployment of static readers with a high-coverage ratio, where the static readers are deployed regularly, and no reader-to-tag collision areas exist between the static readers and a mid-coverage ratio, where the static

Table I. Simulation parameters

Parameter	Values	Description
Static coverage ratio	0.5 or 1	Determines how well covered is the simulation area by homogeneous static readers
Mobile readers ratio	0.5, 1, 2	Determines how many mobile readers there are, compared to the number of static readers
Average tag density	1, 10, 50 $tags/m^2$	Average tag density in the simulation area





Notes: (a) High-coverage deployment, with high tag density; (b) mid-coverage deployment, with low tag density

Figure 7.
Static readers deployed according to the desired coverage ratio

readers are deployed regularly leaving some uncovered zones, representing corridors or not interesting areas. These two scenarios are considered with the objective of evaluating also the ETSI protocol in conditions which are generally said to be favorable to this protocol and compare it to the performance of DiSim in the same conditions, where perhaps the benefits of the inter-reader coordination are not noticeable.

The base RFID reader model used in the experiments has a reader-to-tag radius of 10 m, reader-to-reader radius of 30 m and IoT network radius (e.g. WiFi, LTE, BLE) of 60 m. Note that IoT network here is the extra communication technology of the RFID readers. This consideration is similar to the one taken in Amadou and Mitton (2015).
Assuming that there is a maximum capacity of tags that a reader can read within the reading time of the ETSI standard, the simulator scales the two RFID radius based on the tag density so that a reader is able to read all the tags in its range within the allowed time. In a real scenario, the tags population of all static readers would not be not uniform; hence, the readers are not assumed to have all the same reading time, so it is uniformly randomized up to the maximal value; however, the other characteristics remain uniform for all the static readers.

The number of mobile readers can be altered with a parameter to simulate low, medium and high population of mobile readers and study their effect on the static readers and on each other. The heterogeneity of the mobile RFID readers is intended to simulate a realistic environment with different RFID models, ranges and capacities. The mobile readers are assigned randomly a scale value of 2 or 3, meaning that all the RFID parameters area half or a third of the reference RFID reader, respectively. The mobility of the readers is simulated by random moves, happening with an inter-move time randomly chosen between 10 and 15 s. After each move, a subset of the mobile readers population perform a tag-read operation with a random probability of 0.5.

The simulation starts with a setup phase as follows:

- Initialization of the area.
- Initialization of a static reader model according to the protocol being simulated (DiSim or ETSI), adjusted to the average tag density of the area.
- Deployment of static readers, in a regular manner, according to the area coverage parameter.
- Randomization of the reading time of the static readers.
- Deployment of mobile readers, in an irregular manner, according to the mobile reader density parameter. The mobile readers are given randomly a scale value of half or third of the static reader model. Their reading time is also randomized.
- Activating the static readers, performing a tag-reading operation with a probability p, every 5 s.
- Activating the mobile readers, performing a tag-reading operation with a probability p and moving randomly to another position with an inter-movement time randomly chosen between 10 and 15 s.

The simulation parameters are summarized in Table I. There are nine scenarios proposed, altering the average tag density and the mobile readers ratio. The scenarios increase in reader density, and all of them are evaluated in high and mid static reader coverage areas. This complex evaluation is performed to match several realistic combinations of parameters where the amount of readers varies and the effects on the mobile and static readers could be identified. The scenarios are described in Table II for the areas with mid and high-coverage of static readers.

6.2 Evaluation

I compare the proposal with a simple random-time backoff mechanism, as described in the standard ETSI EN 302 208 (ETSI, 2016). DiSim and the ETSI standard are distributed protocols, and DiSim considers the ETSI RFID times to comply with the European regulation environment.

Every simulation scenario is repeated 20 times, and the results are averaged. In the worst case of all the metrics, the 95 per cent confidence interval corresponds to around 15 per cent of the average value.

For both anti-collision protocols, ETSI and DiSim, after a tag-reading operation, the existence of a reader-to-reader collision zone invalidates the reading, therefore, declaring it unsuccessful and not taken into consideration for evaluation.

The main objective of DiSim is to reduce the number of collisions. Hence, the first effective parameter to evaluate is the average *number of successful tag-reading operations* per reader. In the same interval of time, both protocols will achieve a certain number of successful readings per reader, which are readings that did not have any reader-to-reader collision and, thereby, no reader-to-tag collision either. The metric that evaluates how many successful tag-readings happened over the total reading performed is the *success rate*. The higher the rate, the more successful the reader has been in reading tags, the less collisions have interfered with the tag-reading.

The *efficiency* metric is defined as the ratio between the time used to effectively read the tags, *RFID reading time*, over the total time used for the tag-reading operation, *RFID reading time + waiting time*. This efficiency is evaluated only for successful tag-readings and set to 0 for collided or failed tag-readings. We evaluate the average and the minimum efficiency for the static and mobile reading population separately.

Another useful metric is the number of backoffs, as this is resource intensive and energy consuming. The more contention the more backoffs will be noticed. The average and maximum *number of backoffs* occurrences per reader is evaluated. The maximum number of backoffs is taken into account because this represents the worst case for a reader. While DiSim reduces the number of backoffs, it achieves this by communicating through the IoT channel. The use of the IoT channel by DiSim is evaluated also by the average and maximum number of communications (called *packets*) over it. The maximum value is similarly considered as the worst-case scenario.

7. Results

All the results figures are shown in Appendix.

The first metric to evaluate is the average successful tag-readings performed by the static readers, which are reading more tags and more frequently. In the high-coverage scenario, where there are more static readers and they are closer to each other, the ETSI protocol achieved more successful readings per readers that DiSim in all scenarios. This is because of the waiting and queuing behavior or DiSim; under very dense environments, it

Scenario	Tag density ($tags/m^2$)	Mid-coverage area (static/mobile)	High-coverage area (static/mobile)
Scenario 1	1	4/2	9/4
Scenario 2	1	4/4	9/9
Scenario 3	1	4/8	9/18
Scenario 4	10	25/12	81/40
Scenario 5	10	25/25	81/81
Scenario 6	10	25/50	81/162
Scenario 7	50	81/40	289/144
Scenario 8	50	81/81	289/289
Scenario 9	50	81/162	289/578

Table II. Evaluation scenarios for mid and high static reader coverage deployment causes less readings attempts because many readers are kept participating in the protocol and less are IDLE to be called to read tags again. However, it is to notice that the variation of the average number or readings per reader is less in DiSim due to the fairness characteristic that ensures that eventually all readings have a chance to read when they enter the queue and the blocking control that avoids readers to participate if their neighborhood has an already large waiting queue. This can be seen in Figure A2. In the case of this evaluation for mobile readers, as they are smaller and read less frequently, both protocols have similar results, having the same decreasing behavior for high density scenarios under high-coverage areas. In the mid-coverage scenario, as the number of readers are minor and the need for collisions and coordination are less frequent, both ETSI and DiSim have similar behavior with high variability.

The aggressive nature of the ETSI LBT approach would cause a higher number of reading attempts that will fail in the end because of collisions. This is measured by the *Success Rate*, shown in Figure A5. For mobile readers in the mid-coverage scenario, the average success rate does have an important variation, and it is not possible to identify any trend. However, for mobile readers in the high-coverage scenario, it is clear that DiSim has higher ratio even for high-density scenarios, whereas ETSI lower its values. This is understood as the aggressive behavior of ETSI causes more collisions that can be avoided and renders a low success rate. On the other hand, DiSim has lower number of successful readings for high-density scenarios with a high success rate, meaning that the readers that effectively take the RFID frequency to read tags are less likely to find a collision that invalidates its reading; nevertheless they are obliged to read more slowly because of DiSim organization of concurrent readers.

The *Efficiency* metric reflects the good use of the total tag reading time, shown in Figure A3. ETSI protocol has higher efficiency values for both mid and high-coverage areas, because some readers might just win the random time backoff competition and skip the order of arrival, leading to shorter waiting time. However, DiSim does respect such order, so in very dense environments, readers will wait a considerable time until all the neighbors have finished reading in their turns, with the benefit of better fairness. This might seem contra productive, but remember that DiSim has a higher success rate in those dense scenarios, which could be understood as "waiting is worth it". Also, the variation of the efficiency value, between average and minimum values, is higher for ETSI protocol and less for DiSim due to this fairness characteristic. It can be seen that DiSim has a saturation effect in the most dense scenarios [Figure A3(b)] due to the blocking probability, which appears in such scenarios, not allowing more than 75 per cent neighboring readers to participate in the waiting queue with extremely high waiting times.

Regarding the less number of the CPU and energy expensive backoffs, Figure A4 shows that DiSim causes less average backoffs in all scenarios for the high-coverage area. Moreover, this is true also for the maximum number of backoffs, representing the worst case for a reader, where the backoffs are around four times more than the average. ETSI protocol is based on LBT approach and in dense environments backoffs are very likely to happen for both static and mobile readers. It is noticed that the more dense the scenario, the more backoffs happen, which is consistent with the considerations for ETSI protocol. However, because of the organization of the readers, DiSim does not need to probe the RFID frequency and backoff. In the mid-coverage area, where there are less static readers and some uncovered areas, it can be seen that ETSI protocol penalizes heavily the mobile readers while almost not disturbing the static ones. This would cause an important number of collisions because the static readers cannot not hear the smaller mobile readers, do not backoff and cause reader-to-reader collisions. However, DiSim causes both mobile and static readers to wait to prevent these collisions. For the ETSI protocol, the maximum backoffs is around five times the average case, whereas for DiSim it is at most 2.5 times more than the average case; this is explained by the fairness property of DiSim.

Lower number of backoffs means that DiSim effectively saves on resources and energy compared to the ETSI mechanism. However, the use of the IoT back-end channel has to be considered also. In Figure A6, an estimation of the average IoT communication overhead is presented, where the more dense the scenario becomes, the more use of the IoT channel is needed for DiSim to operate. This behavior is consistent for both static and mobile readers that have very similar values for both mid and high coverage areas. Moreover, the difference between the average case and the worst case (maximum number to packets) is small, at most 20 per cent difference for the most dense scenario. This gives an idea of the predictability of the traffic pattern of DiSim on the IoT channel, which could be used to evaluate its impact in the use of the IoT bandwidth.

8. Conclusion

In the context of emerging IoT Industry 4.0, I have proposed an effective distributed RFID reader anti-collision protocol, DiSim. It uses the IoT capabilities of commercial RFID readers, together with proximity services available in other wireless technologies, to coordinate the neighboring RFID readers in a queuing mechanism to have access to the RFID frequency. DiSim takes into consideration the timing values defined in the European standard ETSI EN 302 208 (ETSI, 2016). DiSim is evaluated with the ETSI standard LBT protocol for multi-reader environments, in several environments with varied levels of reader and tag densities, having both static powerful RFID readers and heterogeneous randomly moving mobile RFID readers.

It effectively reduces the number of backoffs or contentions for the RFID channel. It has high reading success rate due to the avoided collisions; however, the readers are made to wait, and DiSim has less average readings per reader per time.

As an additional side evaluation, the ETSI standard LBT mechanism was found to present a good performance for low density mid-coverage scenarios, however, with high variability on the evaluation results.

Although this work tries to explore many different concepts and evaluate the proposed RFID reader anti-collision, there is still further work to be conducted in different aspects.

The blocking condition found in DiSim is proposed to be a very simple static percentage value, but an optimal limit could be studied in relation with some variable parameters such as the reading probability and reader density. This feature could be analyzed from the point of view of queuing theory, perhaps using multi-dimensional Markov chains to represent the different concurrent groups formed by the readers waiting to take the RFID frequency.

In the simulations, the mobility of the readers is represented with a random movement without any defined pattern. A particular feature of the mobile readers is their mobility pattern and parameters, a mobility model. This model is to be detailed and studied, mainly its impact on the evaluations of the mobile readers and perhaps some correlation with effects on the static ones.

While DiSim prevents the readers from sensing and contending for the RFID frequency, which is resource and energy expensive, it does make use of the IoT frequency. The energy gain trade-off could be analyzed to balance the energy saved on the RFID channel but needed on the IoT channel for the operation.

Finally, from a security point of view, the effect of RFID jammers that try to keep the air busy and cause a denial of service of the RFID tags can be examined. This kind of disturbance affects the overall performance of the system and may be taken into consideration to define a countermeasure for this kind of attacks.

Future work considers experimentation in a real warehouse equipped with heterogeneous RFID readers and real time analysis of RFID reading efficiency also combined with indoor localization and navigation for warehouse mobile robots.

Notes

1. Google Patents search on RFID. https://patents.google.com/?q=rfid
2. Amazon Robots in TechRepublic.com, www.techrepublic.com/article/amazon-robots-and-the-near-future-rise-of-the-automated-warehouse/
3. Amazon Wharehouse in CNet.com, www.cnet.com/news/inside-amazon-warehouse-360-degrees/
4. RFID Journal on Decathlon RFID, www.rfidjournal.com/articles/view?13815
5. Zebra handheld Readers, www.zebra.com/us/en/products/rfid/rfid-handhelds/rfd8500.html
6. www.intermec.com/products/rfidif2a/index.aspx
7. www.barcodesinc.com/janam/part-xm20w-fnrlck1.htm
8. https://en.wikipedia.org/wiki/Mobile_social_network
9. It is under the condition that they not only are 802.11b but also have the security-required mechanism.
10. Wifi Alliance Video Presenting Wifi-Aware. www.youtube.com/watch?v=xwSYPqqhTsQ&feature=youtu.be
11. Simpy Python library: As we are concerned by controlling the reader collision problem, in particular the heterogeneous readers installed in same area, we selected a set of parameters to compare between the standard ETSI approach and our DiSim approach. The first parameter is the number of mobile readers and static readers in a zone. In fact, installed static readers might enter in collision with mobile reader in this same zone if no coordination is set up. Second, we are interested in the tag density, as it affects directly the reading time of a reader. So we will consider average and high density, and we will test the reading success using our proposed DiSim compared to ETSI standard collision problem management of RFID readers. https://simpy.readthedocs.io/en/latest/

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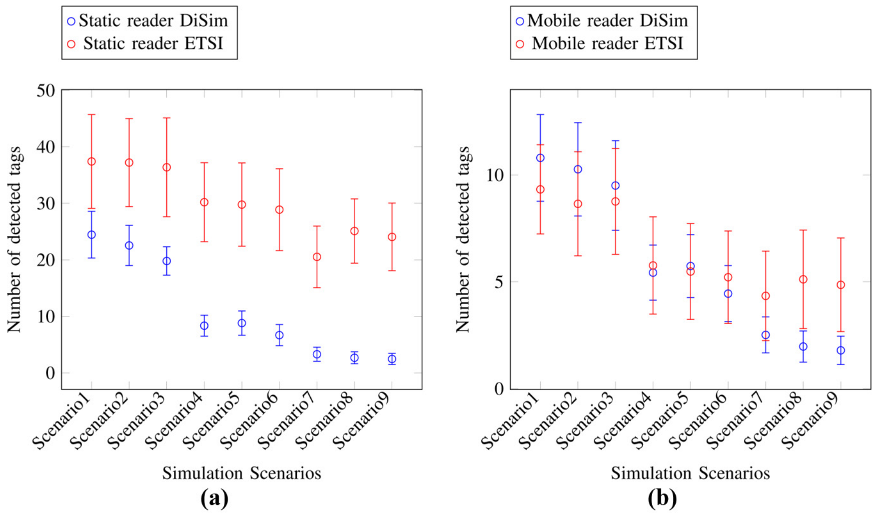
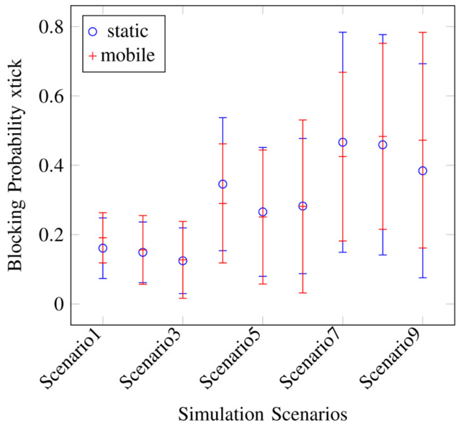
Appendix. Result figures



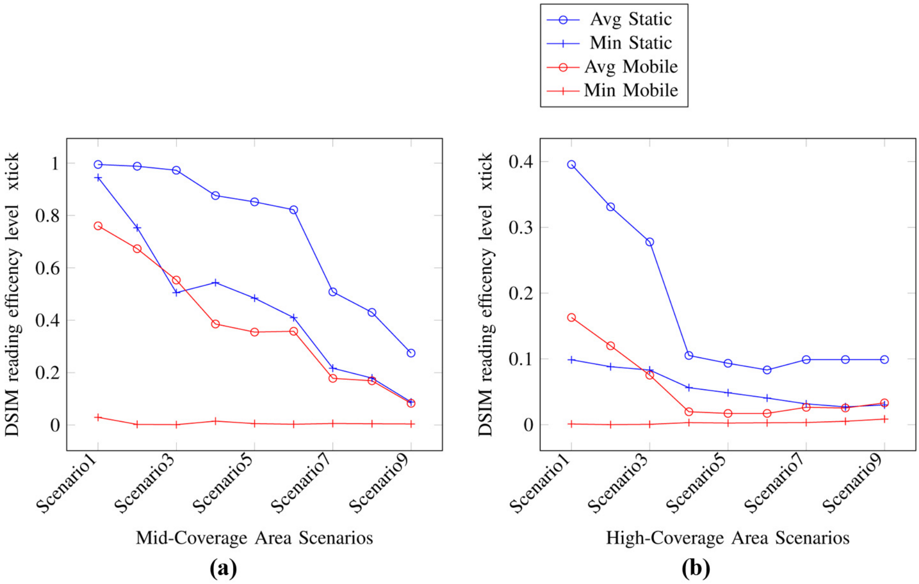
Notes: The bars show the standard deviation of the value among the many readers; (a) average number of successful tag-readings per static reader, in high-coverage area; (b) average number of successful tag-readings per mobile reader, in high-coverage area

Figure A1. Maximum and average number of successful tag-reading operations for static and mobile readers, for both mid- and high-coverage areas



Note: Static readers high-covered area

Figure A2. Average blocking probability for DiSim algorithm



Notes: (a) Average and minimum efficiency for DiSim readers, for mid-coverage area; (b) average and minimum efficiency of DiSim readers for high-coverage area; (c) average and minimum efficiency of ETSI readers, for mid-coverage area; (d) average and minimum efficiency for ETSI readers, for high-coverage area

Figure A3.
Average and minimum tag-reading efficiency for static and mobile readers, for both mid and high-coverage areas

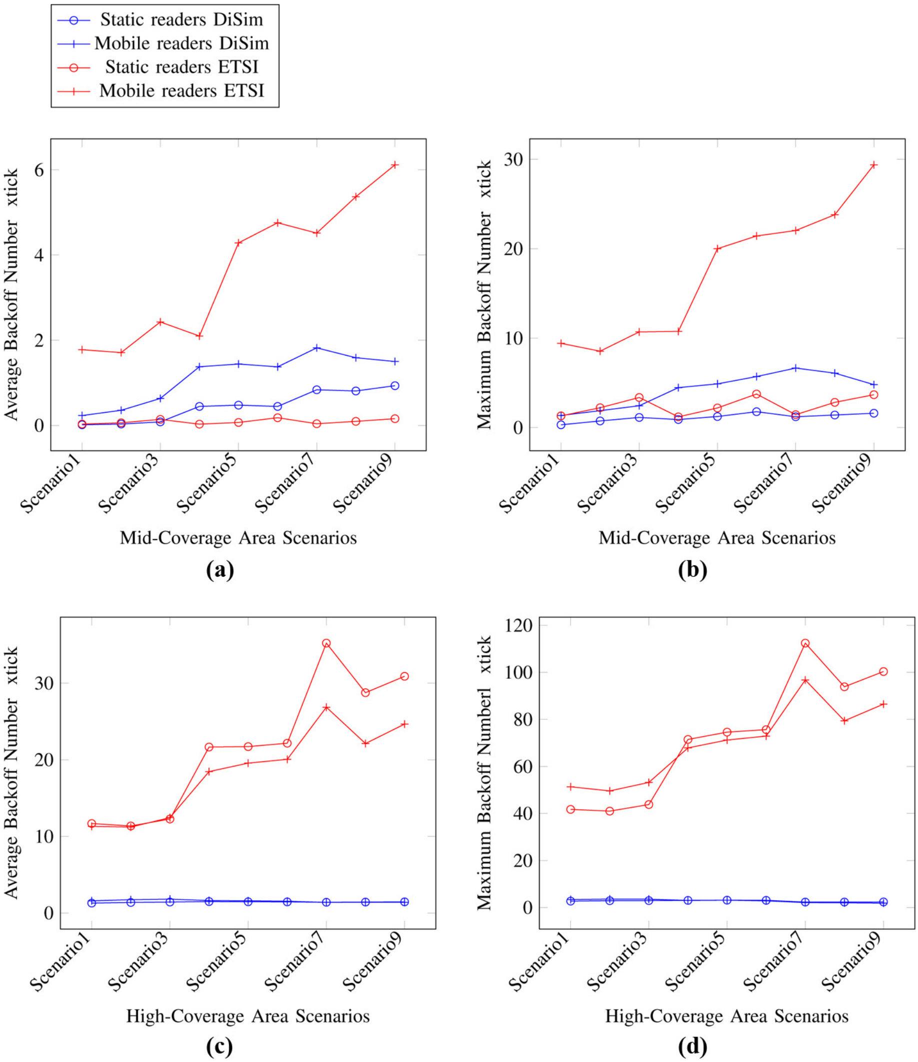
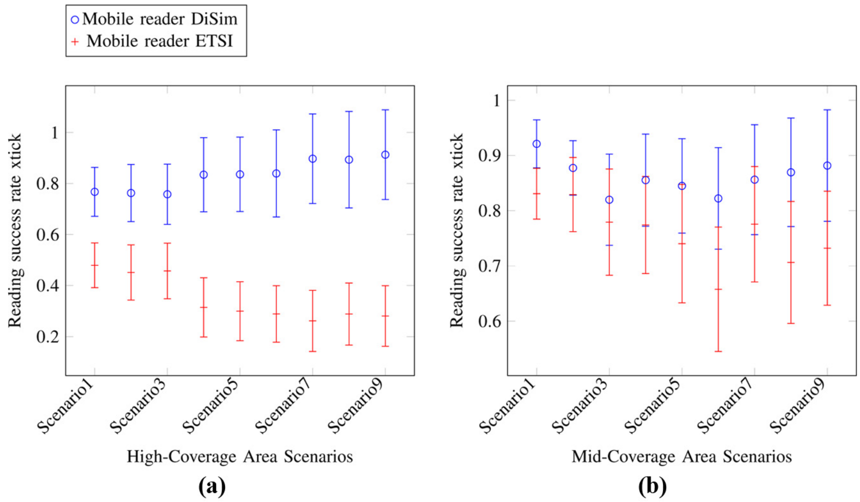


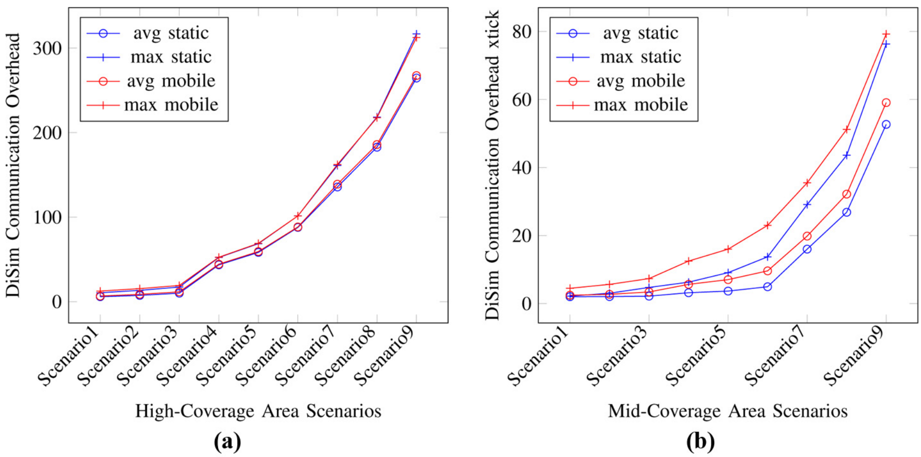
Figure A4. Average and maximum number of backoffs/contentions per reader, for both mid- and high-coverage areas

Notes: (a) Average number of backoffs per readers, for mid-covered area; (b) maximum number of backoffs per readers, for mid-covered area; (c) average backoff number per reader, for high-coverage area; (d) maximum number backoffs per reader, for high-coverage area



Notes: (a) Average reading success rate for high-coverage area; (b) average reading success rate for mid-coverage area

Figure A5. Average success rate of tag-reading operations for static and mobile readers, for both mid and high-coverage areas



Notes: The bars show the standard deviation of the value among the many readers; (a) IoT packets for DiSim readers in high-coverage area; (b) IoT packets for DiSim readers in mid-covered area

Figure A6. Average and maximum IoT communications/ packets per reader using DiSim algorithm, for both mid and high-coverage areas

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