# Overcoming EPC Class 1 Gen 2 RFID limitations with *p*-persistent CSMA

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Abstract-Nowadays, Radio Frequency IDentification (RFID) is a widely spread technology used in a diverse set of applications. One of the main problems faced by RFID networks is tag collision. This occurs when two or more tags respond simultaneously to the RFID reader, causing errors and bringing retransmissions in the wireless channel, increasing the delay required to identify the whole set of tags in the coverage range of the reader. There are two standards for RFID tag identification: ISO 18000-7 and EPC Class 1 Gen 2. We propose in this paper a *p*-persistent CSMA mechanism for RFID tag identification; we also compare our mechanism with the EPC Class 1 Gen 2 as well as with a non-persistent CSMA approach that has been proposed in the literature. We show that the mechanism we propose provides a lower identification delay than the two other mechanisms. Furthermore, our mechanism uses less identification cycles than its non-persistent CSMA counterpart.

Keywords - RFID, EPC Class 1 Gen 2, p-persistent CSMA.

## I. INTRODUCTION

Nowadays, Radio Frequency IDentification (RFID) is a technology used on a wide set of applications. According to [1], 1.3 billion of RFID tags have been built in 2005, and by the end of the last year the amount of tags grew up to 33 billion [1]. Some examples of RFID applications are: public transportation, access control, asset tracking, item identification, counting tasks and automated inventory management.

One of the main advantages of RFID compared to barcodes is its ability of identifying objects in a wireless fashion with no contact or a direct sight line among the communicating devices. Since RFID is now widely used, the identification process must be done in a faster and efficient way. To that end, it is crucial to find better collision resolution mechanisms for RFID networks. This way, the identification process as well as power consumption are improved.

There are two standards for RFID tag identification: ISO 18000-7 and EPC Class 1 Gen 2. We propose in this paper a p-persistent CSMA mechanism for RFID tag identification; we also compare our mechanism with the EPC Class 1 Gen 2 (EPC-Gen 2 from now on) as well as with a non-persistent CSMA approach that has been proposed in the literature. In Section II, we present a review of the state of the art in RFID as well as the problem of tag collisions. In Section III, we depict the related work about collision resolution of RFID tags. We propose finally in Section IV our p-persistent CSMA protocol

for RFID; we also compare numerically our mechanism with the EPC-Gen 2 standard as well as with a non-persistent CSMA approach that has been proposed in [2]. The results described in Section V show that our protocol overperforms the other two proposals in terms of identification delay as well as in the average number of identification cycles. We execute simulations for a wide number of tags in the coverage range of the reader. We finally conclude our paper in Section VI and describe our future work.

## II. RFID AND TAG COLLISIONS

An RFID network is composed of two sets of devices that communicate through radio-frequency (RF) waves: a set of *tags* joined to objects that need to be identified, and one or more *readers*. A reader has storage and processing abilities, it sends read commands within a given coverage range in order to identify the whole set of tags inside such range. Tags are devices having a unique identifier; they store information about the object they are attached to. RFID tags may be classified as:

- *Active tags*: They account with high processing and storage abilities. They include a power source for data transmission and are also responsible of sensing the channel and detect collisions.
- *Passive tags*: They have limited processing, storage and data transmission characteristics. They have no power source; instead they get power through the energy induced by electromagnetic waves sent by the reader. Besides, they have no sensing capabilities **nor-or** sensing functions.
- *Semi-passive tags*: They use internal batteries to power their circuits and rely on the reader to supply its power for broadcasting.

Based on the type of application, a given type of RFID tag is chosen. Passive tags are frequently used due to their low cost. However, semi-passive and active tags are rapidly gaining an important place in the RFID market.

## A. The tag identification problem

A tag identification process consists of a broadcast message sent by the reader to request tags their IDs and/or their stored data. By receiving such broadcast message, the tags send their response to the reader. If just one tag responds, the



Fig. 1. RFID collision resolution protocols' taxonomy

reader will receive only one message. If several tags respond simultaneously, there will be collisions in the RF channel. Such problem is known as *tag collision* and is one of the main research problems on RFID networks. The time taken to identify the whole set of tags within the range of the reader is known as the *identification delay*; this is one of the most important performance measures in this kind of networks.

Besides tag collisions, there are also reader-reader collisions and reader-tag collisions. The former occurs when there is interference between the signals of two or more readers. The latter occurs when two or more readers want to communicate with the same tag [3].

Currently, the tag collision problem is solved by implementing a collision resolution protocol specified either by the EPC-Gen 2 standard or by the ISO 18000-7 standard. The former being used for passive as well as for active RFID environments, and the latter for active RFID environments. In a recent work [4], we have presented a comparison between our *p*-persistent CSMA protocol and the ISO 18000-7 standard. In this paper, we restrict ourselves to comparing our work with the EPC-Gen 2 standard and the non-persistent CSMA approach we cited before.

### III. RELATED WORK

The wireless nature of RFID networks implies the use of a collision resolution protocol at the MAC level of the network stack. Thus, the aim of a collision resolution protocol for an RFID network is to coordinate the access to the transmission medium. We present in Fig. 1 a taxonomy of collision resolution protocols on the basis of medium access and then on the type of protocol used.

#### A. ALOHA-based protocols

ALOHA-based protocols are probabilistic protocols exhibiting low values on the identification delay. However, such protocols have the problem of *tag starvation* due to their aleatority; such problem happens when a tag has not been identified in a long period of time.

The most widely used protocols in this class are Pure ALOHA (PA), Slotted ALOHA (SA), and Framed-Slotted ALOHA (FSA). These protocols impact directly the performance of RFID networks. The two standards used for RFID networks are based on a modified version of Framed-Slotted ALOHA.

1) Framed Slotted Aloha (FSA): The FSA protocol is based on the SA protocol which assumes that time is slotted and grouped into frames. A slot is a time interval where tags are allowed to transmit their ID [5]. FSA executes several identification cycles (IC) in order to identify the whole set of tags within the coverage range of the reader. Every identification cycle consists of one frame. A frame is a time interval elapsed between reader requests; it is formed of a given number of slots [5]. FSA improves PA and SA by limiting tags to transmit once per frame in order to avoid frequent tag-to-tag collisions.

FSA starts with the reader broadcasting the frame size, N. Once tags know N, every tag generates a random number uniformly distributed between  $[0 \dots N-1]$ . The generated number corresponds to the slot of time where tags transmit their ID. When two or more tags transmit in the same slot, there is a collision; this event generates a new identification cycle. Such identification cycle is particularly intended for the tags that generated such collision. Furthermore, if there is only one transmission during a slot, the corresponding tag is correctly identified by sending an ACK message; this avoids including the same tag in the next identification cycle.

2) The EPC-Gen 2 standard: The EPCGlobal organization has proposed the EPC-Gen 2 standard for RFID networks. In [6], the "Gen 2" collision resolution protocol is independent of the type of RFID device in which it is implemented, being either passive or active.

Similar to the ISO 18000-7 standard, the EPC-Gen 2 standard proposes to use FSA as a collision resolution protocol for RFID networks. However, EPC-Gen 2 suggests a specific algorithm for adapting the frame size. EPC-Gen 2 works on an environment of 1 reader and N tags. The identification process starts when the reader sends a startup command; then every tag responds to such command causing a collision. When the reader detects the collision, it starts a new identification cycle. An identification cycle starts with the broadcast of a Query packet by the reader including the value of  $Q \in [0, \ldots, 15]$ , this is useful to indicate that the size of the current frame is  $2^Q$  slots. From this point, the tags choose a time slot r in the interval  $[0, 2^Q - 1]$ ; this selection process is randomly done according to a uniform distribution. The value of r represents the frame slot in which every tag transmits its ID. The start of every slot into a frame is controlled by the reader with the transmission of a QueryRep packet, with the exception of the first slot which starts after the Query command. Thus, the tags use r as a counter which decrements its value after receiving every QueryRep packet. When the r value of a tag reaches zero, the tag sends its ID; such event generates three possible cases:

- If two or more slots choose the same time slot, there will be a collision. On one side, the reader detects the collision and sends a QueryRep packet. On the other side, the involved tags update r according to r = 2<sup>Q</sup> 1.
- If there is only one reply in a given slot, there will be a successful identification. Thus, the reader responds with an ACK packet. Even if all the tags receive such packet,



Micro-slot Successful identification Collection Command Micro-slot Micro-slot

Fig. 3. Non-persistent CSMA with Sift distribution for active RFID environments.

selecting the last micro-slots turns to be high. So,  $p_r$  is given by:

$$p_r = \frac{\alpha^r (1-\alpha)^k}{1-\alpha^k} \tag{1}$$

only the "winner" tag will respond with a Data packet. Afterwards, once the reader receives the Data packet it responds with a QueryRep packet.

• If there is no response before the reader finishes reading the time slot, the reader assumes an empty slot and starts a new one by sending a QueryRep command.

Fig. 2. Frame adapting mechanism for Q.

This process continues slot after slot until the end of the identification cycle, i.e., until the end of the frame. At the end of each frame, the reader adjusts Q based on the number of empty slots, the number of slots with only one response, the number of slots with multiple responses, and consequently the size of the subsequent frame. The identification process finishes when the whole set of tags has been identified, i.e., when all the slots of the frame have been flushed.

Fig. 2 depicts the EPC-Gen 2's frame adapting mechanism. As we can see, such mechanism increments Q for every slot in which there was a collision, and decrements it for every empty slot in the current frame. The standard proposes the use of  $C \in [0.1, \ldots, 0.5]$  to control the frame adapting mechanism in a slot-by-slot fashion. However, it does not specify how to choose C, it only recommends using high values of C for low values of Q and vice-versa.

## B. Non-persistent CSMA

In [2], the authors propose the use of non-persistent CSMA for RFID. They extend such protocol to work on an environment of one reader with several tags. The work presented by the authors is based on a contention window for the identification process; this is equivalent to an FSA frame in the context of ALOHA-based protocols. They implement a distribution function that is used also in [7] so as every tag randomly chooses a micro-slot in a contention window to transmit its ID.

The *Sift* distribution (1) associates the probability  $p_r$  to the micro-slot r as a function of its location in the contention window and the maximum number of tags. In this way, the probability of choosing the first micro-slots is low while

with  $r \in [1, ..., K]$  and  $\alpha = M^{-1/(K-1)}$ . K is the size of the contention window, and M represents the maximum number of contenders.

We now describe how this protocol works: the reader broadcasts an ID-request including the size of the contention window and the maximum number of contenders, which is a priori unknown. After receiving this message, the tags choose a micro-slot in the contention window according to (1) so as to transmit their ID in the chosen micro-slot. Afterwards, every tag sense the channel until the value of the micro-slot chosen and then they transmit if and only if the medium remained free. In other case, a tag leaves until the transmission of the next command by the reader. If there is no collision, the reader sends an ACK-Collection command which indicates that the tag has been already identified, and thus requesting more IDs. The same process is repeated for the tags that remain unidentified. Fig. 3 depicts the non-persistent CSMA protocol with Sift distribution.

Under this mechanism, the contention window size remains constant during all the identification process and only one tag is identified per identification cycle. The results shown in [2] show that non-persistent CSMA with Sift distribution overperforms the EPC-Gen 2 standard with respect to the identification delay.

## IV. *p*-persistent CSMA for active RFID Environments

*p*-persistent CSMA is a slotted scheme where a station that wishes to transmit senses firstly the channel. If the channel is idle, the station transmits with probability p and delays its transmission until the next slot with probability q = 1 - p. If the next slot is free, a transmission occurs or it is delayed with probabilities p and q, respectively. This process is repeated until the end of the contention window, or until the beginning of a new transmission by another station. In this last case, the protocol behaves as if a collision had occurred. If at the beginning of a transmission a station detects a busy channel,

it waits until the next time slot and then follows the algorithm just described.

In order to extend the behavior of *p*-persistent CSMA for RFID, we have that there are N tags in the coverage range of a reader which we need to identify in an ordered fashion by using a congestion window of a fixed size. The reader broadcasts a command of data collection along with the size of the contention window. Following the reception of this command, every tag chooses a time slot in the contention window according to a Sift distribution. Then, every tag computes the transmission probability corresponding to the selected time slot. If it decides to transmit, then it senses the channel during a time equal to a given number of micro-slots according to a Sift distribution, and transmits if and only if the channel remains idle after such period of time. Otherwise, it withdraws until the next collection command; i.e., until a new identification cycle. If there is no collision, the reader sends an ACK to tell a tag that it has already been identified and asks for more IDs. In this way, the transmission probability not only reduces the number of participants within a contention micro-slot, but it also allows for tag save energy. This is the key difference between the non-persistent CSMA protocol and our *p*-persistent approach.

By observing the results reported in [2], we observe that an increase in the number of tags is proportional to the number of collisions, even if the probability of choosing the first microslots is very low. In that sense, we see that we require that the transmission probability of each tag is a function of the time micro-slot chosen. Thus, by following the Sift distribution, once a tag has selected one of the first micro-slots to transmit, the probability that this tag does not transmit is close to zero.

In order to assign different transmission probabilities to time micro-slots in a contention window, we use in our proposal (2) so that every tag computes the transmission probability,  $p_t$ , based on the contention window size and the time micro-slot chosen in the contention window as well. Once  $p_t$  is computed, every tag decides its transmission based on this probability and a random number.

$$p_t = \frac{K - r}{K},\tag{2}$$

where K is the total number of time micro-slots in the contention window and  $r \in [1 \dots K]$  is the time micro-slot chosen for transmission.

The Sift distribution in our scheme offers the advantage that when a tag chooses one of the first time micro-slots, the probability of a decision change is practically zero.

One difficulty faced by our scheme is to decide when there are no more tags to identify, since using the transmission probability does not allow us to be sure of this fact. In order to solve this problem, when the first identification cycle is empty, we make the transmission probability equal to one. This way, we are sure that all the tags in the coverage range of a reader are actually identified.

We can see in Fig. 4 the building blocks of our p-persistent CSMA mechanism with Sift distribution.



Fig. 4. *p*-persistent CSMA with Sift distribution for active RFID environments

#### A. Performance parameters

We focus on the identification delay as a performance parameter for comparing our proposal with the non-persistent CSMA protocol as well as with the EPC-Gen 2 standard. The identification delay is the time needed to identify the whole set of tags in the coverage range of the reader. Since the time taken by an identification cycle is a function of the number of slots and the number of messages between the reader and the tags, we transform the identification cycles to absolute time. The parameters we consider are the same as in [2].

When working with EPC-Gen 2, the empty slots and the slots with collision are shorter than the slots that have a correct ID. So, if for example the channel capacity is 40 kbps, a slot with a correct ID lasts for 2.505 ms and the empty slots as well as slots with collision last for 0.575 ms.

For non-persistent CSMA and *p*-persistent CSMA, we consider that one identification cycle lasts the sum of the following times:

- The time taken by a data recollection command (0.55 ms).
- The time taken by an ID packet (1.4 ms).
- A micro-slot time (0.1 ms), and
- The time duration of an ACK packet, in case of a successful identification (1.4 ms).

We assume that tags have a coherent CCA (Clear Channel Assessment), i.e., that the channel is busy when a packet's preamble is detected. We also consider that the network is free of the *capture effect*. The capture effect on RFID refers to the event when two or more tags try to transmit simultaneously to a reader, and one of the tags achieves its transmission because it is under better physical conditions like a higher transmission power or because it is closer to the reader.

We implement EPC-Gen 2 with the mechanism specified in [6], non-persistent CSMA and our *p*-persistent CSMA with a contention window size equal to 8 micro-slots and M equal to 64. We execute 300,000 simulations for each protocol and we obtain confidence intervals of 95% with a precision less to 1 ms. We also vary the number of tags from 10 to 100. Furthermore, since we are simulating a widely used standard



Fig. 5. Identification delay of EPC-Gen 2, non-persistent CSMA and *p*-persistent CSMA.

for RFID systems, our results are valid for any type of active RFID tag.

## V. RESULTS

We present in Fig. 5 the performance comparison between the three protocols we are evaluating. At the beginning of the plot, our protocol exhibits a small degradation on performance compared to the non-persistent CSMA approach, but as the number of tags increases our protocol clearly improves its performance.

In general, the results we get show that our proposal improves the performance of non-persistent CSMA and the EPC-Gen 2 standard. This is because our proposal uses less identification cycles than the non-persistent CSMA approach since the identification delay is directly proportional to the number of identification cycles, even if our proposal uses a bit more micro-slots than non-persistent CSMA. Due to the timescale in Fig. 5, it might seem that the improvement obtained with *p*-persistent CSMA is little; however, if the time taken by an identification cycle is increased then the improvement is clearer.

Fig. 6 shows a plot that compares the number of identification cycles between non-persistent and *p*-persistent CSMA.

## VI. CONCLUSIONS

We have presented in this work a proposal of *p*-persistent CSMA with Sift distribution for its use on active RFID environments. We compared our protocol with a non-persistent CSMA approach previously proposed in the literature as well as with the widely known EPC-Gen 2 standard. Our results show an improvement of up to 2% in terms of identification time compared to non-persistent CSMA.

We observed that the time taken by an identification cycle directly impacts the performance of every protocol, because a bigger amount of messages is exchanged between the reader



Fig. 6. Identification cycles used by non-persistent and p-persistent CSMA.

and the tags. So, by reducing the number of identification cycles the performance is improved. Finally, the improvement we got with p-persistent CSMA is clearer when the time spent during the identification cycles increases.

Our future work will focus on finding the value of p that optimizes the identification process; i.e., jointly maximizing the throughput while minimizing the loss rate. Furthermore, even if additional performance parameters (e.g., bandwidth, loss rate) are directly related with the identification delay, we will also explore the behavior of our approach with respect those parameters as well. We believe that future versions of RFID standards (i.e., ISO 18000-7 and EPCGen-2) for collision resolution may consider CSMA variants in their proposals.

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