Tag Loss Probability Evaluation for a Continuous Flow of Tags in the EPC-Global Standard

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Abstract. This paper addresses the evaluation of a passive RFID system under a continuous flow of tag arrivals and departures, for instance, in a conveyor belt installation. In such configuration, the main operational variable is the *Tag Loss Probability* (TLP). Since tags stay in the coverage area of the reader for a finite amount of time, it is possible that some tags leave the area unidentified if many tags compete for being simultaneously identified. A suitable configuration of the system (flow speed, tags per block, time between blocks, etc.) must be selected to assure that TLP remains under a given operative threshold. In this paper we focus on the EPCglobal Class-1 Gen-2 standard, which specifies an anti-collision protocol based on Framed Slotted Aloha. Our work is aimed at evaluating the TLP for the different configurations of such protocol, and selecting the right scenario configuration to guarantee a TLP below a given limit. This issue has not been studied yet, despite of its relevance in real-world scenarios based on assembly lines or other dynamic environments. Simulation results show that both anti-collision protocol operation mode and flow configuration heavily impacts in the performance. Additionally, real test have been conducted which confirm simulation results.

1 Introduction

Radio Frequency IDentification (RFID) technologies are designed as an affordable solution to remotely identify items by means of wireless communications. A RFID system consists of one or more readers or interrogators placed in strategic zones and a potentially large population of cheap and small devices called tags or transponders. Tags automate the identification of the items to which they are attached. A tag contains an antenna, a simple electronic circuitry and a minimum amount of memory where it stores some information about the object (e.g. standard codes, history of transactions, temperatures monitored by a sensor, etc.). When the tags are in the coverage range of the reader system, executes an identification protocol to send their stored information to it. This paper focuses on RFID systems based on passive tags. Passive tags have no battery. They are simple and low-cost devices. The energy to operate is obtained from the RF electromagnetic excitation induced when they are

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under coverage of the reader system. The identification range varies from some centimeters to a couple of meters. Passive tag technology is inevitably chosen in systems with a large number of identification objects, where the cost of the tag is a dominant factor in the system. In passive RFID systems, the communication between the reader and the tags share the RF spectrum. When several tags are simultaneously in the coverage area, a Medium Access Control (MAC) protocol is needed to handle/avoid collisions caused by simultaneous transmissions. The extreme simplicity of the tag is a hard constraint for the design of suitable anti-collision protocols. Complex or sophisticated behavior can only exist in the reader system [1-3].

Fig. 1. Industrial environment with a passive RFID system (dynamic scenario).

The number of anti-collision algorithms for passive tags has increased considerably. They can be classified into two types: deterministic and probabilistic protocols. The former protocols assume *a priori* knowledge of the tags which must be identified, for instance an access control door where the reader check each new identification tag (tag card) with its list of permitted tags [1-10]. Nevertheless, in many practical scenarios the reader system does not have such knowledge, e. g. the unload area of a warehouse. Therefore, protocols based on probabilistic algorithms are needed, in which the tags should contend for the shared medium. Pure-Aloha is the most simple, [11] anti-collision scheme has been implemented in passive tags with read-only-memory. Slotted-Aloha outperforms Pure-Aloha [12], at a cost of requiring a reading system that manages a slotted time synchronization. Frame-Slotted-Aloha (FSA) [5] is a variation of Slotted-Aloha. In FSA, the reader maintains a frame structure composed of a fixed or variable (Dynamic FSA) number of slots. One tag must choose a slot within the frame, where to send its information to the reader. When a frame finishes, an identification cycle concludes. Then, the reader, following some rules, makes a decision about to increase/decrease/maintain the number of time-slots in the next identification cycle [13,14]. FSA has been implemented in many commercial products: I-Code [5,15], Philips and selected by standard such as ISO/IEC-18000-6C [16] and EPCglobal under the EPCglobal Class-1 Gen-2 standard [17]. EPCglobal is an institution focused on the development of industry-driven standards for the Electronic Product Code (EPC) to support the use of Radio Frequency Identification (RFID). This paper focuses on the EPCglobal standard for passive RFID systems

Class-1 Gen-2 [17], in the UHF band (860MHz-930MHz). This standard includes a set of specifications for the hardware of the passive tag (which is assumed to be very simple), and the hardware and software in the reader systems (which carry the true system complexity). After its publication in year 2005, it has been widely adopted by RFID systems manufacturers. Many commercial RFID systems like [18, 19] has been implemented following this standard.

A relevant set of performance studies has been conducted in the last years for EPC-Global standards and other protocols for passive RFID systems [13, 20-22]. Commonly, these studies consider a block of a given number of tags that enter into the coverage area of a reader system, and never leaves it [4, 5, 13, 23]. We denote this as static tags flow scenario. Three related performance measures are commonly considered on static scenarios: collision probability, packet loss probability and elapsed time for identification. However, in many real RFID applications (e.g. a conveyor belt installation), the tags enter the coverage area, stay there a given time, and then leave the coverage area. We denote this as continuous tags flow scenario. For this type of systems, a new performance measure should be evaluated: the probability of a tag leaving the coverage range without a successful identification by the reader. We denote this as the Tag Loss Probability (TLP). Note that depending on the application, even a TLP = 10^{-3} may be disastrous and cause thousand of lost items per day. Let us think, for instance, of tracking individual letters in a post company.

This paper is an attempt to conduct a performance study in a realistic continuous flow RFID system, like the one shown in Fig. 1. We focus on a commercial RFID system where the EPCglobal Class-1-Gen-2 is implemented [19]. The physical layer parameters of the tag and reader have been brought from this commercial hardware. A relevant objective of our study is to fairly evaluate if, for the same average rate of tags to identify, systems that distribute the tag arrivals in more frequent smaller blocks outperform in terms of TLP to those systems in which tags are brought together in larger batches. This issue is studied under the two configuration alternatives implemented in EPCglobal Class-1 Gen-2. As far as the authors know, the TLP performance of EPCglobal anti-collision protocols under continuous flow scenarios has not been studied yet, despite of its relevance in real-world scenarios based on assembly lines or other dynamic environments.

The rest of the paper is organized as follows: in section 2 the EPCglobal Class-1 Gen-2 standard communication protocol is described as well as its frame adaptation algorithm. In section 3 different scenarios are introduced together with the parameters used to evaluate the protocols. Besides, the simulation and experimental results are shown. Finally, section 4 concludes the paper and suggests future work.

2 EPCglobal Class-1 Gen-2

This section describes the identification procedures defined in the EPCglobal Class-1 Gen-2 standard, which are evaluated in this paper. At a first stage the reader system is continuously monitoring the environment to detect the presence of tags by means of *Broadcast* packets. Tags in the coverage area are excited by the electromagnetic waves of the reader and send a reply immediately, producing a multiple collision. The reader detects the collision and starts the identification cycle. During each identification cycle, the time is structured as one frame, which is itself divided into slots, following a FSA scheme (see Fig. 2). An identification cycle starts when the reader transmits a *Query* packet, including a field of four bits with the value $Q \in 0,...,15$, stating that the length of the frame will be of 2^Q slots. Tags in coverage receive this packet and generate a random number r in the interval $[0, 2^Q-1]$. The r value represents the slot within the frame where the tag has randomly decided to send its identification number ***ID*=*r***. Inside each frame, the beginning of a slot is governed by the reader by transmitting the *QueryRep* packet, excepting the slot 0, which is automatically initiated by the *Query* packet. The tags in coverage use an internal counter to track the number of transmitted *QueryRep* packets since the last *Query* packet, and then recognize the slot when they should transmit. When the moment arrives, the tag transmits its identification number ID, which corresponds to the random value r calculated for contention, which is also equal to the slot number in the frame. After transmitting its ID, three actions can follow:

(i) If more than one tag has chosen the same slot, a collision occurs which is detected by the reader. Then, the reader reacts initiating a new slot with a *QueryRep* packet (see slot 0 in Fig. 2). The tags which transmitted their ID assume that a collision occurred, and must update their counter value to *counter*=2^Q-1. That means that they will not compete again in this identification cycle.

(ii) If the reader receives the ID correctly, and this coincides with the slot number within the frame, then it responds with an *Ack* packet. All tags in coverage receive the packet but only the identified tag answers with a *Data* packet, e.g. an EPC code. If the reader receives the *Data* packet, it answers sending a *QueryRep* packet, starting a new slot. The tag identified will finish its identification process (see slot 1 in Fig. 2). If the reader does not receive a correct *Data* packet within a given time, it considers the time-slot has expired, and sends a *Nack* packet. Again, all tags in coverage receive it, but only the tag in the identification reacts by updating its counter value to *counter*=2^Q-1. Thus, this tag will not contend again in this identification cycle (see slot 3 in Fig. 2). After this, the reader will send a new *Query* or *QueryRep* packet to start a new frame or slot respectively.

Finally, when a cycle finishes, a *Query* packet is sent again by the reader to start a new identification cycle. Tags unidentified in the previous cycle will compete again, choosing a new random r value.

The anti-collision mechanism described in the EPCglobal Class-1 Gen-2 standard provides a high degree of flexibility. The reader system governs the frame structure in two interesting ways: (i) it controls the initial number of slots of the frame through the Q value, (ii) it can decide to reset the identification cycle at any time, by sending a new *Query* packet with the same, or a new Q value. Controlling the Q value strongly affects the identification time performance. If the Q value is high and the number of tags in coverage is low, many empty slots appear in the frame. On the contrary, if the Q value is low and the number of tags is high, many collisions appear. Both situations should be avoided. In this paper, two configuration alternatives are tested, all of them based on the standard:

1) *Q-static configuration*. All identification cycles (frames) have the value Q=4 (defining frames of 16 slots). This value is brought from the default Q value in the standard. It is common to find commercial systems with this configuration.
2) *Q-dynamic configuration* (denoted as frame-by-frame adaptation). The Q value is adapted cycle-by-cycle following the algorithm depicted in Fig. 3. The reader starts with a value Q=4. Then, in each frame it counts the number of empty slots, and occupied slots (summing busy slots with one tag identified, and collision slots). If all slots are empty, an internal Q_{fp} (*Q floating point*) value is decreased by user defined variation parameter $C \in [0.1,0.5]$. If just one slot is occupied, the Q_{fp} value is maintained. If more than one slot is occupied, the Q_{fp} value incremented by C. Actually, the new Q value employed in the subsequent frame is calculated from rounding Q_{fp} to an integer value, and limiting it to a minimum value of 1 and a maximum value of 15. Note that higher values of parameter C imply faster modifications of the Q value.

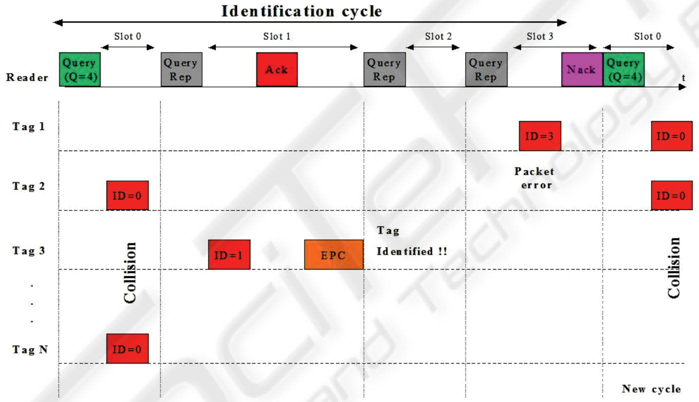

Fig. 2. EPC Class-1 Gen-2 procedure.

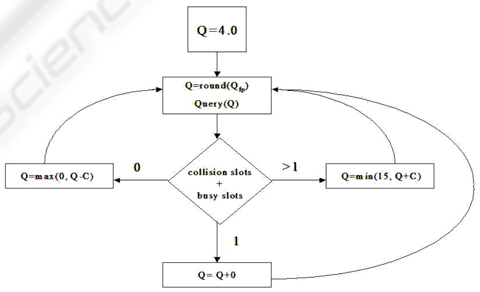

Fig. 3. Adaptative Q algorithm.

3 Tag Loss Probability Evaluation

3.1 Scenario Description

Our testing scenario corresponds with that of a warehouse in which pallets full of items to be identified while enter the facility. Each pallet transports a deterministic number *N* of tags. Pallets pass below a reader system situated at the input door of the facility. The duration *T* of the coverage time (the time in which a block of tags is under coverage of the reader system) depends on the speed of the pallet, and the coverage distance. Let us suppose that in our scenario, the pallets move at a deterministic speed of 1 m/s. The reader is located in a position so that all the tags in a pallet are in coverage during 3 meters. That means that a pallet is in coverage for a deterministic time of *T*=3 s (see Fig.4).

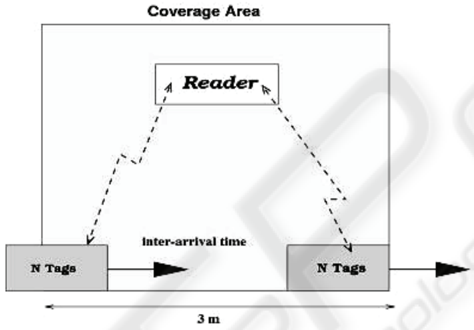

Fig. 4. Scenario Description.

Two parameters tune this system. First, the number of tags transported in each pallet *N*. Second, the time elapsed between the arrivals of two consecutive pallets, which we denote as inter-arrival time, T_{IA}. When $T_{IA}<T$, more than one pallet is in coverage at the same time: some of them have just entered the coverage area, while others are close to be out-of-range. When $T_{IA} \geq T$ at most one pallet is in range at a time. This last case corresponds to that named as static scenario. For any configuration, we denote as λ the average rate in tags per second that enter the coverage area. Note that this equals the average rate of tags that leaves the coverage range. Also note that the *average* tag rate λ, the *average* number of tags in range (*K*), and the *average* time that a tag is in range (*T* in our example) are related by the equation: $K = \lambda T$. This can be easily obtained by applying the Little's law to the coverage area, seen as a black box where tags enter and leave. This relation holds for any traffic pattern of tags.

Our interest lays on studying how it affects to the system performance, the burstiness of the arrivals of tags. That is, for a given rate of tags per second that should be identified:

- what is the EPC protocol which guarantees a successful identification of a rate of tags per second?
- is it better to distribute them in smaller blocks that arrive more frequently, so that more than one block is in range at a time?

In order to obtain valuable results that may help to clarify these questions, special care has been taken to design tests that are related to real-world scenarios. We have employed physical layer parameters which correspond to commercial hardware. Transmission error probability which depend on the environment where the RFID system is installed and parameters associated with the physical configuration of the tags and the reader: transmission/reception rate, modulation type, packet length, etc. To take into account these parameters, the characteristics that a lot of commercial passive tags, readers an antennas [19, 20] carry out nowadays are assumed:

Table 1. Parameters of the commercial devices assumed to get the simulation results.

Paremeters	**Passive tags**	**Reader/antenna**
Work frequency	UHF 868MHz-928MHz	UHF 868MHz-928MHz
Communication range	10cm-3m	Up to 10m
Memory Available	96-256 bits	--
Modulation	ASK	ASK/PSK
Transmission /Reception rate	40 Kbps	80Kbps
Maximum Power of the antenna	--	10 W
Maximum RF Power of the Reader	--	4W

3.2 Simulation Results

The evaluation results have been obtained by means of simulation. We have developed our simulation tool within the freeware network simulation environment OMNeT++ (*Objetive Modular Network Testbed in C++*) [24]. OMNeT++ is a discrete even-driven and object oriented framework, used in many research fields like multi-processors systems, hardware architectures validation, performance of software systems. The simulator collects statistic results for some performance measures of interest like tag loss probability, identification delay, average number of identification cycles. The two different anticollision protocols explained in section 3 have been implemented. The Fig. 5 shows the simulation results in terms of TLP to the Q static standard protocol. Although $Q \in 0,...,15$, it has been established to $Q=4$, which is the value recommended by the standard and established in a lot of commercial readers. EPCglobal implemented in the scenario described above: a continuous tags flow scenario with a deterministic traffic pattern and a flow of tags arrivals per second defined in the x axes. The influence of the inter-block arrival time of λ has been studied to different inter-blocks-arrivals times, $T_{IA}=0.5, 1, 2, 3s$. The results of the EPCglobal Class-1 Gen-2 standard with static frame show worst results, obtaining a high TLP value with a low λ. This result is because of the fact that the Q value is low(Q = 4) and doesn't change. If Q takes a high value, the results obtained will be displaced to the right of the graphics. In fact, the results will be better than other anticollision procedures in terms of TLP but the identification delay will be higher, even more when the number of tags in coverage is low because of the frame length will depend on the Q value. The results of the Fig. 5 also confirm that if $T_{IA}=3s$, it means $T_{IA}=T$, the continuous flow of tags doesn't affect to the TLP obtained. Fig 6, shows the simulation results in terms of TLP but, in this case, with the Q dynamic standard protocol

EPCglobal. The results show that this alternative configuration has a better response in terms of TLP to a higher λ than *Q* static protocol. For all $T_{IA,}$ results are better using the *Q*-dynamic protocol.

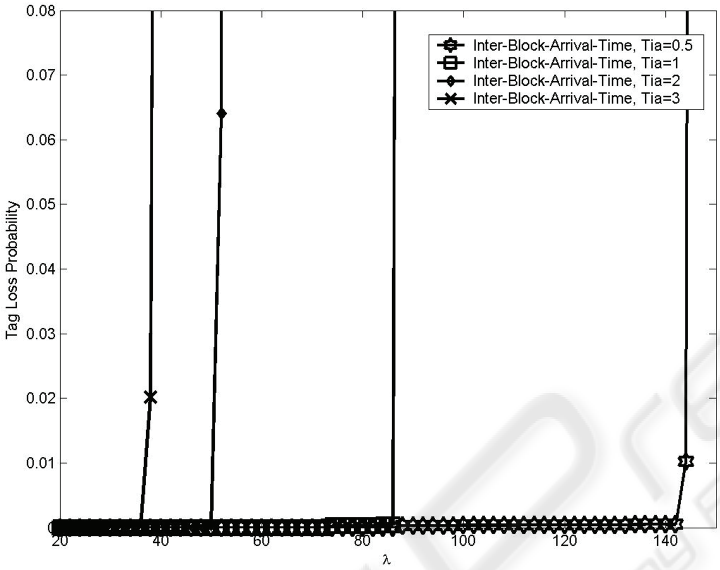

Fig. 5. Tag Loss Probability with Q-static protocol.

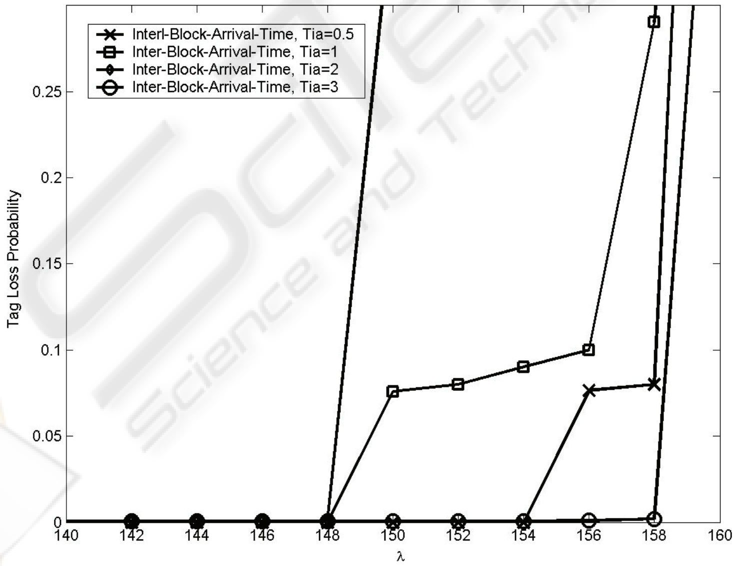

Fig. 6. Tag Loss Probability with Q-dynamic protocol.

TLP is clearly degraded for both protocols if λ > 160. Thus, it is necessary to reduce the tag flow to get a given TLP limit. This threshold will depend on the requirements of each installation.

To get an accurate vision about how to apply the results to the design of a RFID system some criteria has to be selected. First, two different thresholds have been assumed: TLP=10^{-3}, 10^{-6}. Then, taking into account all parameters explained in the previous section (velocity of the pallet, read range of the reader, anticollision protocol, etc.) both alternatives of EPCglobal Class-1 Gen-2 standard has been evaluated. Results are shown as the maximum number of tags per pallet for different traffic loads and for the deterministic traffic pattern.

The results of the two configuration proposed in this paper are shown in the figure 7. The X axe represents the inter-arrival time of two consecutive pallets. The Y axe represent the number of tags in each block. Simulations show that the *Q*-adaptative algorithm exhibits the best results in terms of TLP. The results of Fig.7 helps us to answer the questions introduced in section 3.1. On the one hand, the *Q*-dynamic protocol is better than *Q*-static protocol in terms of get the maximum λ value with the lowest TLP value. On the other hand it tags arrivals are distributed in more frequent smaller blocks outperform in terms of TLP to those systems in which tags are brought together in larger batches. Indeed Fig 7 help us to get select a suitable configuration to our real RFID system. If we have a RFID system installed in a coveyor belt, we can fix an objective TLP (e. g. TLP = 10^{-6}), it means, the percentage of items that we can permit to not identify. With the TLP fixed and taking to account the results of Fig.7, we can design our RFID system: the reader's anticollision protocol, the interblock arrival time (the velocity of the coveyor belt) the number of tags in each block (the number of items per pallet), etc…

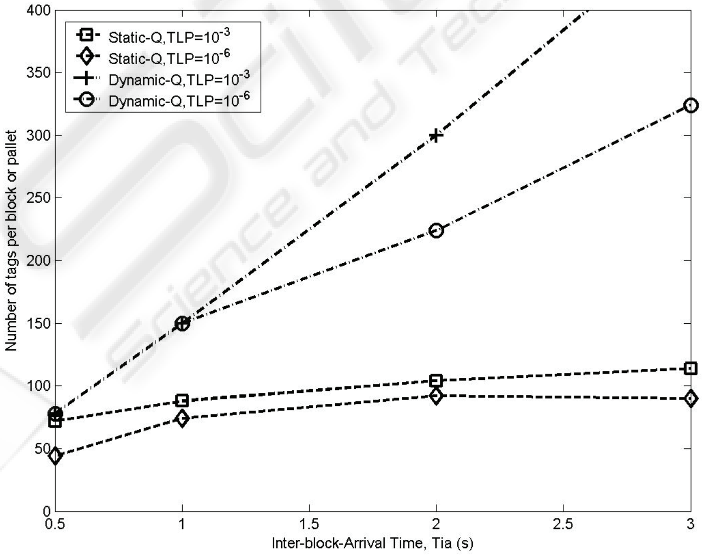

Fig. 7. Number of Tags per pallet with a TLP threshold.

3.3 Experimental Results

Finally, an experimental set-up has been studied to compute the TLP under continuous flows. In this set-up we used an “Alien 8800” reader, working in the UHF band of 868 MHz, with two circular polarized antennas (gain 6dBi), one acting as transmitter and the other as receiver, installed one in front each other (2 meters away). The tags used are compatible with EPC Class 1 Gen 2. The anti-collision protocol used by the reader is the *Q*-static procedure, with Q=4. In our test we aim at simulating a traffic flow and measuring the actual TLP associated. Two configurations where tested:

- Coverage time of blocks, 3 s. TLP objective 10^{-3}. Thus, according to Fig. 7, the number of tags per block is slightly over 100. We use 100 tags for this configuration.
- Coverage time of blocks, 0.5 s. TLP objective 0.1. For this configuration our simulations suggests a maximum number of 70 tags in each block.

To simulate the actual traffic of tags we put a static block with the selected number of tags in the coverage area. Then, we issue a reader order to the Alien reader. This reader returns a list of each tag present, and indicates the time (with millisecond accuracy) at which tag is detected. Thus we compute the TLP counting the number of tags detected after the selected coverage time. This experiment was repeated 100 times and the average values obtained are a TLP of 0.003954 and 0.196 for the first and second configuration, respectively. As a conclusion, the actual TLP is in both cases slightly worst (but in the same order) than the TLP expected for such configurations. Although tag loss in real installations (like in our test) suffers from additional issues, such as signal propagation, which can affect the performance, our study provides a good starting point to select a suitable system configuration.

4 Conclusions and Future Works

Most of works related to identification and anticollision procedure in the RFID systems have been studied to minimize the identification delay assuming static scenarios with a fixed number of tags in the read range of a reader. However, several practical RFID systems are installed in environments with a continuous flow of tags entering and leaving the coverage area of the reader. In this case, the critical parameter is the TLP. In this work this probability has been computed for different scenarios under different traffic loads. All scenarios have been evaluated with the identification/anticollision defined in the standard protocol EPCglobal Class-1 Gen2, configured both with static frame and with dynamic frame cycle-by-cycle. Results show that the standard protocol with the adaptative *Q* cycle-by-cycle mechanism exhibits the best results in terms of TLP in all scenarios studied. Additionally, the results help us to select a suitable system configuration (selecting a objective TLP and a coverage time).

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