A Communication Protocol and Physical Characteristics Simulator for an RFID Sensor Environment

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Abstract—**Radio Frequency Identification (RFID) systems have been widely used for asset identification in supply chain as well as in many Wireless Sensor Network (WSN) projects, where both identification and location of objects are mandatory activities among other RFID features. This work describes an RFID environment (RFID-Env) simulation software that considers the influence of several environment variables and also both the physical characteristics and the type of electronic identification tags. The main objectives of RFID-Env are: (i) to evaluate the characteristics of a given physical environment, such as both the tag reading and writing speed and also the distance between the interrogator and the tags; (ii) to allow the performance comparison among anti-collision communication protocols, which are ISO standardized used in both UHF RFID 18000-6 and EPCGlobal Gen2 devices - currently being the most used types of RFID tags; (iii) to make the development of new anti-collision algorithms easier.**

Keywords: Radio frequency identification (RFID); RFID physical simulation environment; anti-collision simulation algorithms

I. Introduction

Radio Frequency Identification systems present some functioning difficulties which are very discussed by the developers, such as the collisions of simultaneous tags communication, electro-magnetic interferences, ideal positioning of the tags regarding to the interrogator antennas and the amount of interrogator antennas [1, 2, 3].

RFID technology has been employed in many WSD systems throughout the years. As, for instance, in [4] RFID tags were utilized as a type of network node position. In [5] was presented an RFID and WSN-based implementation of workflow optimization in warehouses, aiming to solve the problem of fulfilling an order that involves the retrieval of items that are stored among a large number of shelves scattered through out a warehouse in an optimal manner. Finally, in [6] three forms of a new system architecture that combines both the RFID and WSN technologies is proposed and its feasibility and technical challenges are discussed thoroughly.

All these presented works may struggle through RFID difficulties. Our proposed system reduces these problems's occurrence through the complete RFID environment simulation where the developer can improve the configuration of certain parameters and also enable fast and optimized designs. The simulation takes account of (i) the anti-collision protocol used by the tags; (ii) the amount of tags to be read in a given time window; (iii) the environment temperature; (iv) the distance between the tags and the interrogator antennas; (v) the tags' exposition speed to the interrogator reader or writer. It is possible for the user to enter physical and technical characteristics of the RFID environment and then, the simulator reports the RFID tags functioning regarding this configuration. Thus, with the supplied information, the prediction of different physical tag's reading situations is possible, and, therefore, we can tell whether it is a feasible scenario or not. This feature helps with the most important concern of every RFID developer: to know if the tags will be read in a determined environment or not.

The RFID-Env framework is based on high-level abstraction models and can be completely parameterized, allowing the designer to set up different scenarios to represent the real environment in a better manner. The framework contains an Anti-Collision Protocol Library (ACPL) that describes the four ISO 18000-6 (A, B, C) standards: ALOHA LST, ALOHA FST, Btree and Random Slotted (Q Algorithm). Besides that, the library contains the Calculated Q anti-collision algorithm which is an improved version of the Q algorithm proposed by ISO 18000-6C (EPC Gen 2). The ACPL was described in Java language and can be easily extended by the designer with any new anti-collision protocols. RFID-Env was validated through several test scenarios with the different anti-collision protocols proposed by ISO 18000-6 and the results were compared with the ISO standards.

To the best of our knowledge, none of previous works proposes a complete and flexible fast performance evaluation environment. Indeed, the majority of these others environments make the performance evaluation at low abstraction levels, i.e., need the physical or the RTL (register-transfer level) implementations of the test environment. At these levels, performance evaluation has prohibitive costs and demands lots of simulation time.

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Most of the efforts in RFID area are currently directed to passive UHF tags (ISO 18000-6 standard), due to small tag sizes, reading range close to 5 meters (m) and reading zone control through direction of the antennas and reader configurations [2, 7, 8, 9]. Therefore, this paper is focused on the physical characteristics and anti-collision algorithms used by these tags.

This paper is organized as follows. Chapter II describes the RFID-Env technical characteristics and a simulation example. Chapter III describes how the simulator deals with physical parameters. The environment types that can be simulated, such as *conveyor belt* mode or *gate* mode are presented in Chapter IV. Finally, conclusions and future work are presented in Chapter V.

II. RFID-ENV: ENVIRONMENT DESCRIPTION OF THE DEVELOPED SOFTWARE

The simulation performed by RFID-Env, regarding the tag reading, considers A, B and C tag types of the ISO 18000-6 standard and their anti-collision communication protocols. In this environment the anti-collision implementation details are respected: there are both interrogator and tags procedures. Some few extra processes have been specifically implemented to the simulation, for instance, the one that generates the information of each tag (the Unique IDentification code - UID). In a real system, the tags have a previously recorded UID value which is used at the moment that the protocols are executed. However, in the RFID-Env, a *UID generator* initial process is executed and allocates the corresponding UID for each tag of the simulation, varying from 16 bits (in the ISO 18000-6 C) to 64 bits (in the ISO 18000-6 B).

In fact, during the tags' identification process, the protocol may use only a part of the total tag memory. In the ISO 18000-6 A, a SUID (Sub Identifier) of 40 bits is sent. In the ISO 18000-6 B, the whole 64 bits UID is sent, and in the ISO 18000-6 C, the RN16, an exclusive 16 bits random value for anti-collision process use, is sent.

Three interfaces compose RFID-Env: Simulator, Single Mode and Portal Mode. Fig. 1 depicts the Simulator screen, where the user specifies: (i) the anti-collision protocol he wishes to verify; (ii) the amount of tags in the environment; (iii) according to the selected protocol, some specific parameters, such as the initial frame size in the ALOHA protocols, utilized by the ISO 18000-6 A and C standards. The user may also select the total number of executions (in order to make the generation of statistics results easier) and the output report format.

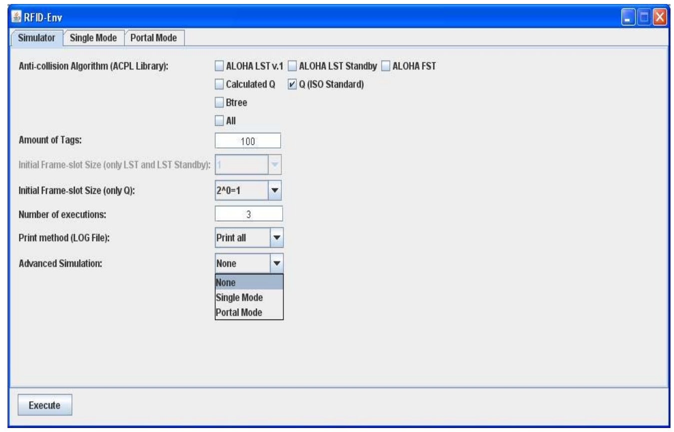

Figure 1. Initial window of RFID-Env and selection of the environment type

The simulation screen contains a selection box (optional), named Advanced Simulation, where the user can select the operation mode of the simulating system (*single mode* or *portal mode*). When material characteristics of tags, such as the substrate material, and environment variables, such as the amount of interrogators and antennas, the tag exposition speed, temperature, and others, must be considered, the user must select the Single or the Portal mode. However, if the user wishes to test only the functionality of the algorithm, without any physical interference, the option mode may be dismissed, as well as the related tabs. Fig. 2 depicts the screen when the *portal mode* is selected after the *advanced simulation* selection.

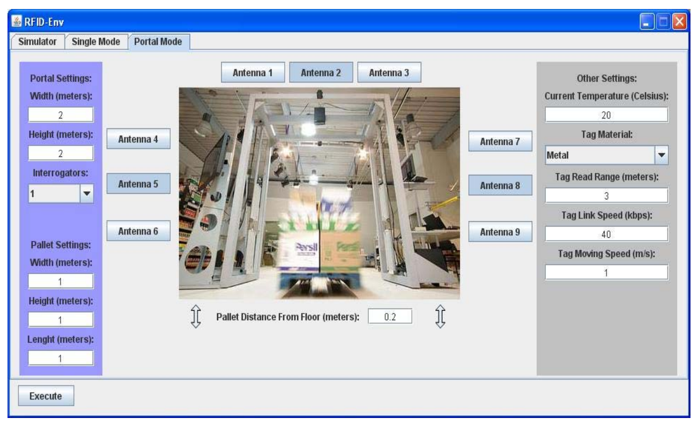

Figure 2. Portal mode screen of *RFID-Env*

When the user informs the amount of tags present in the environment, the UID generation process is executed and then, for each virtual simulation tag, a unique code is attributed. Fig. 3 shows the virtual environment and initial simulation steps.

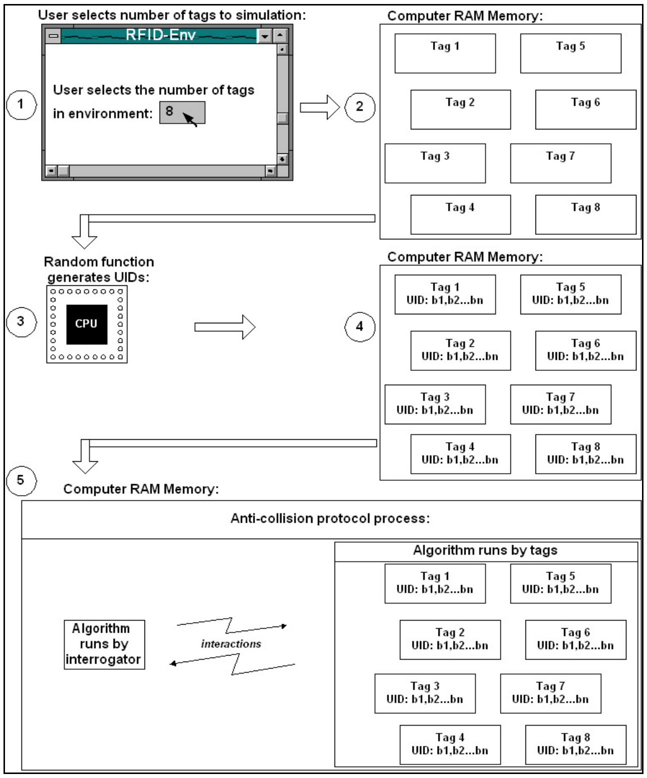

Figure 3. Simulation environment and initial steps of *RFID-Env* functioning

```
-----------------|BTREE|----------------
--Iteration #1, Tags that replied:
E0E069FEC02185EC20 | E0B4909015F4627A76
E08C1013BF9FCB2BAE | E059592730460AF424
E0BB6B2EA85B402E70 | E0D49AC0DD20AEE2E7
E041E50008FC2F6965 | E096E4892AAEA7DCF9
E03783A6E0D9449A7D | E0A77048EDBEF83434
--Iteration #2, Tags that replied:
E059592730460AF424 | E0BB6B2EA85B402E70
E0D49AC0DD20AEE2E7 | E041E50008FC2F6965
E096E4892AAEA7DCF9 | E03783A6E0D9449A7D
E0A77048EDBEF83434
--Iteration #3, Tags that replied:
E041E50008FC2F6965 | E03783A6E0D9449A7D
E0A77048EDBEF83434
--Iteration #4, Tags that replied:
E0A77048EDBEF83434
--Iteration #5, Tags that replied:
E041E50008FC2F6965 | E03783A6E0D9449A7D
                  ...
--Iteration #11, Tags that replied:
No tag replied
                  ...
--Iteration #27, Tags that replied:
E08C1013BF9FCB2BAE
---------- Performance Report ---------
Tags: 10
Iterations: 27
Iterations with tag collision: 13
Iterations with no tag reply: 4
```

Figure 4. Btree execution report, with 13 collisions, 4 empty slots and 27 total slots

Fig. 3 depicts five of the main simulation steps of *RFID-Env*. When simulation starts, the number of tags that will be considered into the environment (Fig. 3, step 1) is required to the user. Afterwards, the software generates a memory space to the UID values of each tag (step 2) and then the system starts the tags UID generation process, by associating an ID to each tag (steps 3 and 4). In Step 5 the process, which runs the specific algorithm of the simulated protocol, is started and interacts with the tags, that is, the interrogator process interacts with the tags processes.

A. Execution Example: Btree Protocol

Given tags's type and quantity, the system can perform a simple tag reading simulation, i.e., the anti-collision protocols. As an example, it is shown a report simulation of 10 tags reading, which are using ISO 18000-6 B (Btree Anti-Collision Protocol) standard. The Btree protocol algorithm has a substantial difference in comparison to ALOHA based ones: it does not have the round size concept [10]. While the other three ISO anti-collision protocols need to determinate an initial round size, Btree uses an approach that ignores this concept. Therefore, while ISO 18000-6 A LST and FST algorithms have extremely low performances for reading an amount above 256 tags, Btree does not have this limitation [10, 11, 12]. On the other hand, Btree employs a boarding where the first slots will always generate many collisions, as shown in Fig. 4.

When the number of simulation tags is given, RFID-Env executes the simulation and generates a summary report with iterations and performance. Fig. 4 shows that during the first iteration, all 10 tags try to transmit their information, generating many signal collision. After the first frustrated transmission, all tags randomly select either *zero* or *one* value. Tags that generated *one* increment their slot counter and they will only retransmit when their slot counter reaches *zero*. Tags that generated *zero* do not need to increment their slot counter and keep having the opportunity to retransmit on the next iteration.

If more than one tag randomly select *zero* (which happens in the second iteration of the Fig. 4), again these tags randomly select either *zero* or *one* value, while the ones that already had *one* in their slot counter (the other three tags in the environment) increment it once again. These steps are repeated, until only one tag has randomly selected *zero* and all the others had randomly selected *one*, which happened in the Iteration #4.

This characteristic of many collisions on the first Btree iterations is proper of this protocol.

The final report of Fig. 4 shows that the algorithm execution needs 27 iterations for 10 tags reading, considering that 13 slots had tags collision and 4 slots without any tag transmission.

III. PHYSICAL PARAMETERS CONSIDERED BY THE RFID-ENV

This section presents the physical parameters considered by the RFID-Env, how they are analyzed and their influence in the final results of the simulation.

A. *Maximum Reading Distances and Total Exposition Time*

The maximum reading distance depends mainly on: RF frequency, substrate material of the tag's antenna and magnetic and physic environment interferences. [3, 13, 14] report that the UHF tags have a maximum possible value for the distance between the interrogator and the tags of 5m in average, which can vary from 3.65 m to 10.66 m due to both frequency and material of the tag.

RFID-Env considers these values in the following way: given the average reading distance of the tags and the movement speed of the tagged products, the total exposition time of each tag to the magnetic field provided by the interrogator is calculated through the Equation 1. This formula is based on the reading speed values of the tags found in [10, 11, 13, 15] and the amount of transmission bits.

total exposition time >= [time to read (y bits * *n* tags*)]* (1)

Where:
total exposition time = total exposition time of the group of tags to the reach the interrogator reading distance
y bits = amount of bits of each tag
n tags = amount of tags to be read

The calculation of each tag's total exposition time needs both right and left maximum reading distance and is shown in Fig. 5 where the points T1 and T2 are highlighted and used throughout this paragraph. Thus, considering the situation of an environment based in conveyor belt, with an antenna directed to the tags, there is a point T1 where the tags reach the interrogator reading range, imagining a left to right movement. The T2 point would be the exact frontal position to the interrogator and the half-total distance covered by the tag inside the interrogator reading range. In the analogous form, there is a point T3 (not explicit in the figure), at the T2's right, that would be the maximum interrogator reading range, where the tag would be leaving this reading range. Dividing this value by the speed (m/s) of the tags, the total exposition time is then determined. This is the total exposition time in the formula (1), in which the interrogator should be able to read all bits of the tags of each package in movement.

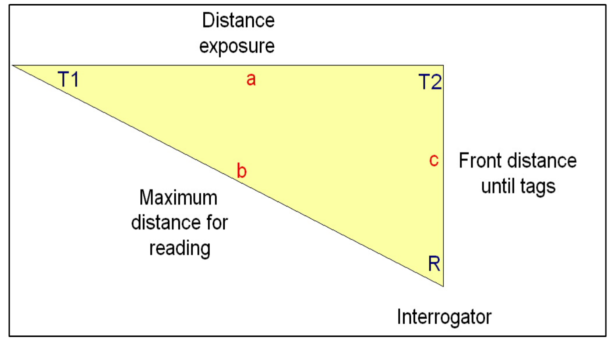

Figure 5: Computation of exposition time and distance

Fig. 6 depicts the *single mode* data entry screen, where the following information is required: temperature, tag material, maximum read range, tag link speed, tag movement speed and frontal tag to interrogator distance, in other words, the distance (c), or "smaller leg" of a rectangle triangle, shown in Fig. 5.

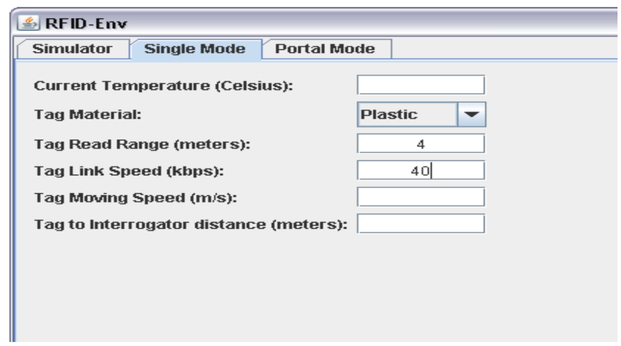

Figure 6: *Single mode* environment analysis data

It is important to point out that the total needed reading time calculus of a tags' group is performed after its complete reading simulation with the selected anti-collision protocol. Then, with the total number of slots needed to the full reading of the tags' group, the simulator will calculate:

$$t\_total = total\_number\_of\_slots \ X \ each\_slot\_reading\_time \quad (2)$$

Where:
total_number_of_slots: number of slots generated in the simulation
each_slot_reading_time: amount of bits to be read in each tag divided by reading speed value of the tags

With the requested information in the *single mode* interface, RFID-Env may calculate the distance of the leg (a), considering that the maximum tag reading distance is the hypotenuse distance (b). The frontal distance between the interrogator's antenna and the tags refers to the leg distance (c). This environment configuration forms a geometric situation just as a rectangle triangle form, where the measures may be calculated through the Pythagorean Theorem. In the Fig. 5, the formula utilized by the RFID-Env to the leg distance (a) calculus is the following:

$$a^2 = b^2+c^2 \quad (3)$$

Fig. 6 shows an interface containing a material type selected (Plastic) and the typical maximum distance to this material (4 m) [14]. According to the material selected by the user, the material reading distance reference value is shown in the *tag read range* field. However, since this value may vary between manufacturers and other physical issues, RFID-Env only suggests the distance value, allowing the user to change it, according to technical information provided by a tag supplier. This is also applicable to the tag link speed parameter, which RFID-Env suggests to use the typical 40 Kbps, which also can vary among manufacturers.

Then, with the supplied information, it is possible to predict impossible physical reading situations of a determined number of tags. An example is shown in the report of Fig. 7, where the given information by the user were the following: 4 m to the maximum reading distance, 40 Kbps to tag link speed, 5 m/s to tag movement speed and 2 m for frontal distance. These information refers to a group of 1000 tags (a box with 1000 products for example, moving on a conveyor belt) using the ISO 18000-6 C protocol. With this configuration, RFID-Env infers that there is a non-functioning possibility of the system.

```
------|ISO 18000-6 C Protocol |------
      - Performance Report -
Tags: 1000
Slots needed to all tags reply: 2822
Slots with tag collision: 727
Empty Slots (with no tag reply): 1095
Total required time to read all tags:
           28.22 seconds (worst case)
Calculated Total Exposition Time:
            1.38 seconds
-------------------------------------
With this configuration the group of
tags couldn't be fully read
```

Figure 7: RFID-Env warning to the reading impossibility due to physical features

The simulator points the following solutions to solve the problem: (i) communication protocol switching, aiming to reduce the amount of slots needed by the entire reading; (ii) reduction of the amount of simultaneous tag reading (the amount of tags contained in the same package); (iii) reduction of tags movement speed; (iv) reduction of the distances between the tags and the interrogator, or even (v) a junction of all these solutions.

IV. RFID-Env: Environment Type Configuration

Considering some of the typical RFID installation environments, RFID-Env user may simulate the reading of a tag group in three different modes: (i) *simulator*, that is, without environment variables; (ii) *single,* that is, conveyor belt mode with one antenna; (iii) *portal*, that is, gate mode for pallets.

The initial simulation process takes place in the main window, previously shown in Fig. 1. If the user wishes to simulate only the functioning of one or more anti-collision protocols, without the physical environment variables, only this interface is needed. Yet, in the main window, the environment type selection field may be visualized: *none* (simulations without environment variables), *single mode* or *portal mode*. According to the selection, relative tabs will be either enabled or disabled.

When the user wishes to test a conveyor belt environment, he must select the *single mode*, which enables interfaces with specific information about the environment, for instance: temperature, type of material used in tag assemblage, movement speed of the tagged products in the conveyor belt and the frontal distance from the interrogator's antenna to the conveyor belt. Therefore, by the time the user selects the tag material, the simulator enables a field with the default value for the typical average distance reading (between the interrogator's antenna and the tag). For example, when the user selects glass as the tag's material, the value 2 m will appear in this field. When plastic is selected, it will appear the value 4 m. These values, typical among many RFID manufacturers, were obtained in the references [3, 13, 14]. Once again, these values are only suggested by the RFID-Env as references, and thus, the user can change them as the RFID-Env aims to reproduce faithfully the tags' technical specification.

A. Portal mode: amount of antennas versus portal and pallets measures

According to Fig. 2, the RFID-Env *portal mode* simulates environments with tunnel shaped gates, where the pallets or other transport means shall pass. Besides the same information that is requested in the *single mode*, in relation to the distances, temperature and link speed, the gate measure and the pallet that carries the tagged products are also required. The user needs also to provide the amount of interrogators and antennas in the gate. Typically, an interrogator has a limit of four antennas.

According to the antennas position the simulator may estimate the approximated tag direction in relation to the total of tags that are going to be read. Supposing a uniform distribution of all tagged packages, if the user selects one antenna in each part of the gate (left side, right side and upper side), the simulator will consider that *n* tags are distributed with their faces directed in these three directions in an equal form, that is *n/3*.

With portal and pallet size measures, the simulator can determine the lateral and superior distances between the pallet and the interrogator's antenna, which were selected as active by the user. In the current RFID-Env version, the *portal mode* works in a similar way that *single mode*, except by the number of active interrogators, which is divided according to the amount of tags in the *portal mode*. The lateral antennas work exactly like in the *single mode*, while the upper antennas also work in the *rectangle triangle* manner, but seeing this geometric structure in a different angle from that saw by the lateral antennas. The advantage having more antennas is evident - it increases the sphere of action in various directions and reduces the number of tags to be read by each interrogator.

This would radically diminish the challenge of a simultaneous system reading.

Future RFID-Env versions will enhance the parameters analysis in the *portal mode*, such as more detailed physical consideration of directing and positioning of antennas and also the antenna type. There are antennas that have characteristics for reading in longer straight-line distances, while others work better with a large reading angle. It will be also taken into consideration the physical characteristics of the tagged products and the interferences of these materials in the RF signal reflection. It is well known that readings of tagged products in the center of the pallets are the ones that present larger difficulties, due to the interference around of the product layers.

V. Conclusions and Future Work

This work shows features and details of RFID-Env software, which allows the functional simulation of the four ISO 18000-6 RFID standard protocols, the types A LST and FST, the type B, and the type C. The tests show that software like the one we proposed may help many RFID systems users to determine which protocol may better fulfill the characteristics of the system that will be implemented.

The ability of describing physical characteristics of the environment, such as tag speed in relation to the interrogators, distances, amount of antennas and amount of tags that are going to be read simultaneously, increases the RFID-Env simulation range. As a result, RFID-Env can demonstrate, for instance, that a determined environment pattern or configuration does not fulfill the application requirements in some situations, as those WSN projects where RFID features are used.

Future work involves the improvement of the tool concerning physical environment issues, such as the tagged material interferences in the RF signal reflection and the antennas types and direction. The current version does not allow the adjustment of the antennas direction, for example. It is also important that the user can indicate the information characteristics of the tags (UID or SUID) of the target system, therefore the simulator knows the exactly amount of bits that are going to be read and then indicates which protocol is the best option to fulfill the RFID project needs.

According to [15], the temperature has a great influence especially on the time that the registers need to hold their logical values. The registers can rise the persistent storage time of the values when the temperature is below 25º and when the temperature overpasses this value the registers start losing the storage capacity for more than 8 seconds. Besides, there is a temperature limit for the proper functioning of the tag, which is also considered by RFID-Env. Therefore, the user is warned whether the selected temperature overpasses those supported by typical circuits or not.

Next RFID-Env version will consider the registers maintenance time, regarding to the temperature. This information has significant influence in the simulation results, when analyzed in addition to reading speed, exposition time, amount of tags and physical interferences that cause the tags to run out of energy for a few seconds.

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