# CSMA Multi-Stage Anti-collision Protocol for Active RFID Systems

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**Abstract.** Current anti-collision protocols for active RFID systems stem from the ISO-18000-7 standard, which selects Frame Slotted Aloha as the underlying Medium Access Control protocol. However, these approaches neglect the possibility of using the Listen-Before-Talk mechanism already available in active RFID tags. In this work, a Carrier Sense Multiple Access mechanism with Multi-Stage, (CSMA/MS), derived from the quasi-optimal Sift distribution, is developed in order to substitute the anti-collision procedure in active tags. The key of CSMA/MS is to concatenate various contention windows, where only winners contend in the next contention windows. We demonstrate that this approach nearly achieves a 100% of identification probability per slot, improving Sift results and outperforming standard procedure.

## 1 Introduction

Radio Frequency Identification (RFID) systems are one of the enabling technologies for the ubiquitous computing paradigm [1]. Its foreseen applications cover from replacement of bar-code systems to location of containers in large cargo vehicles. All of them share a common architecture: a basic RFID cell consists of a *reader* device and a (potentially large) set of RFID tags, which reply to the queries or enforce the commands from the interrogator. RFID devices are classified according to the source of energy of the tags: **passive** ones do not have a power source and obtain the energy from the reader signal (via induction), whereas **active** ones incorporate their own battery. On the one hand, passive tags are targeted to be inexpensive and, thus, very simple, usually read-only, devices. Their coverage typically ranges from centimeters to a couple of meters. On the other hand, active tags are more complex devices, with more sophisticated capabilities (usually integrating a microprocessor and memory) and they can be read and written from distances in excess of 100 meters [1]. Whereas passive RFID systems are the most deployed and have been studied for years [2–4], active RFID systems have recently been standardized [5] using Frame Slotted Aloha (FSA) as the underlying medium access control mechanism.

In both cases, the *tag collision* problem arises: in a RFID cell, if multiple tags are to be identified simultaneously, reply messages from tags can collide and cancel each other. Thus, an anti-collision mechanism is needed. Since, in a typical application, items (with attached tags) enter and leave the reader coverage area, the goal of this mechanism is to communicate with the tags as quickly and reliably as possible, ensuring that all tags have been identified. An additional goal for active tags is to save energy in order to maximize the battery lifetime. Therefore, the tag identification problem deals with identifying multiple objects with minimal delay and power consumption, reliability, line-of-sight independence and scalability. Unlike classical medium access protocols, channel utilization and fairness are not usually issues in RFID systems.

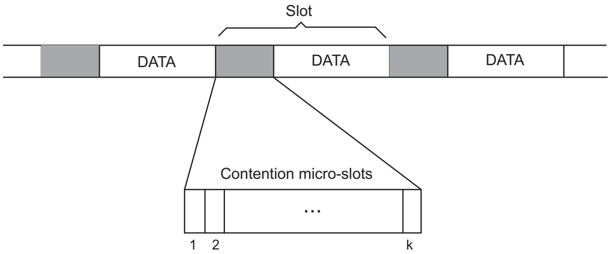


**Fig. 1.** General identification procedure in CSMA

In a previous paper [6], we proposed the use of non-persistent Carrier Sense Multiple Access (CSMA) as anti-collision mechanism for active RFID tags. This protocol can be seamlessly integrated with current active tags, since they already include the Listen-Before-Talk capability. In this case, time is divided in slots (see Figure 1) which include contention periods. During the contention period tags select a contention micro-slot, and transmit their identities only if medium is empty. Contention winners (note that if there is more than one winner a collision takes place and that tags are not aware of simultaneous transmissions) continue transmitting their identifications in the data period.

Our performance evaluation shown that using a classical uniform distribution for contention micro-slots do not necessarily improves the identification process. However, performance is greatly improve if the micro-slot selection is based on the optimal distribution $CSMA/p^*$ proposed by Tay *et. al* in [7]. In this work authors determines the best probability distribution assignment if the number of contenders is known. Nevertheless, in a general situation, this parameter is unknown. Therefore, in [7] is already proposed a distribution named Sift which nearly approximates the optimal one, and which depend only on a maximum boundary for the number of competitors. Both distributions outperform the FSA mechanism used in active RFID systems in performance and scalability.

The new proposal is called CSMA/Multi-Stage (henceforth, CSMA/MS) and it is based on the concatenation of several micro-contention windows before data transmissions, where only contention winners transmits in the successive windows. In this work we show that, for an equal overall number of contention micro-slots, even though the optimal distribution and its approximation are able to achieve almost 96% of transmission success in each slot, CSMA/MS improves further the identification process, achieving 99% of success and, more importantly, providing linear identification time with the number of tags. That is, our proposal scales well to large sets of tags. Let us remark that the optimal distribution itself cannot be improved obviously, but, combined with the efficient splitting procedure proposed the overall identification process improves. The key difference is the following: the goal of the optimal distribution $p^*$ is to minimize the latency of the first few successful transmissions in an event-based traffic pattern, whereas in an RFID system the goal is to minimize the collision probability of *all the transmissions*. The optimal distribution achieves 96% percent of success of any transmission. This is an outstanding result but, as we say, it may be insufficient in some scenarios: we consider a scenario where a very large number of tags must be identified as fast as possible. The optimal result that can be achieved is to identify a tag every identification cycle, which implies 100% of transmission success which would render a linear identification time.

The rest of this work is organized as follows: Section 2 describes the ISO-18000-7 standard for active RFID solutions. Section 3 discusses related works, with an emphasis on solutions for active RFID anti-collision protocols. Section 4 introduces the CSMA/Multi-Stage mechanism, and describes how it can be adapted with minor modifications to the ISO 18000-7 standard. Section 5 shows the performance evaluations of CSMA/MS in comparison with CSMA/$p^*$, Sift and conventional FSA. Finally, Section 6 concludes this work.

## 2 ISO 18000-7

ISO 18000-7 [5] is the *de facto* global standard for active UHF RFID solutions. It defines the Physical and the MAC layer requirements and the communication protocol for active RFID systems communicating at 433 MHz. ISO 18000-7 was ratified in 2004, and has undergone modifications in 2008 and 2009.

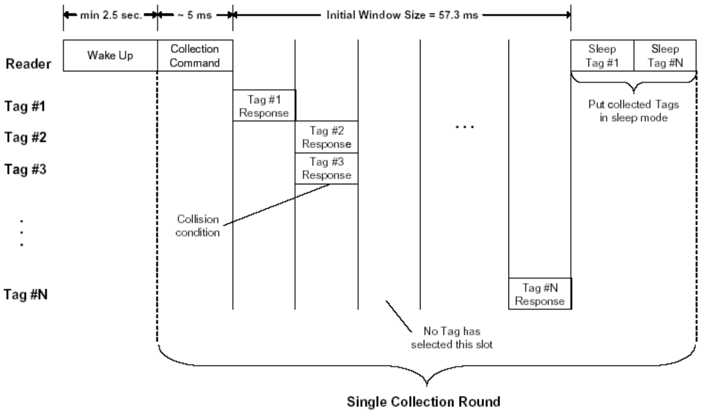


**Fig. 2.** Anti-collision procedure of ISO/IEC 18000-7 (from [5])

### 2.1 Anti-collision procedure

The anti-collision algorithm defined in ISO 18000-7 is based on a FSA procedure. Figure 2 illustrates the identification sequence. The reader initiates the identification procedure sending a *Wake-Up* signal, which wakes up the $N$ tags within its coverage range. Tags move to *idle* mode, listening to the channel. Then, the reader initiates a collection round by sending a *Collection* command, with two parameters:

- The time the reader will be listening to the channel, waiting for tag responses. The standard denotes this parameter as *Window Size* ($W_S$).
- The length of the tag responses ($T_{tag}$), determined by the field *type* in the *Collection* command. Note that this parameter determines the type of tag response (*e.g* tag identifier $ID$ or specific data).

After transmitting the *Collection* command, the reader senses carrier signals during *Windows Size* time, waiting for tag responses. Every time the reader detects a tag response, it processes the corresponding tag identifier and inserted it into a buffer, called *sleep queue*. After the collection round, the reader extracts the identifiers from the sleep queue one by one and, for each identifier, the reader transmits an unicast *Sleep* command (see Figure 2). When tags receive the *Sleep* command, they change to sleep mode (saving energy mode) and do not participate in the next collections rounds. Afterwards, the reader starts a new collection round, resuming the identification process, which eventually finishes after three consecutive collection rounds without reply.

In the identification procedure, tags operate as follows: When they receive a *Collection* command, extract the value of *Windows Size* parameter (in seconds) and calculate the number of slots ($K$) and the slot size ($T_{slot}$). The latter is calculated as follows:

$$T_{slot} = T_{tag} + T_{proc} \tag{1}$$

being $T_{proc}$ the time the reader needs to process the data received from a tag and the time to be ready to listening to the following tag response. By default, the standard sets $T_{proc}$=2 ms. Once $T_{slot}$ is calculated, the tag uses it to calculate $K$ as follows,

$$K = \left\lceil \frac{W_S}{T_{slot}} \right\rceil \tag{2}$$

$K$ is rounded up to the nearest integer.

The process continues with tags selecting a random slot (with uniform distribution) to send their *Response* packet. Each tag controls when the slot selected starts by means of an internal clock. Let us remark that carrier sensing is not performed in this procedure although active tags implement this capability. When a slot selected by a determined tag starts, this tag changes to transmit mode and sends its identifier. After that, the tag changes to receive mode and listens to the channel. If the tag is successfully identified, it will receive a *Sleep* command to change to the sleep mode. Otherwise, tag will receive a new *Collection* command, indicating a new slot starts.

The most extended operational mode in ISO-18000-7 is *Fixed Windows Size* procedure,where the reader uses the same $W_S$ in every collection round $i$. The general formula to calculate $W_S$ is as follows:

$$W_{S_{i+1}} = W_{F_i} \cdot 57.3 \tag{3}$$

for $i$= 0,1,2,. . . , $C$. Note that $C$ is the total number of collection rounds in a identification procedure. $W_{F_i}$ is defined by the standard as the *Windows Factor* to adjust $W_{S_i}$ in every cycle. In *Fixed Windows Size procedure*, $W_{F_i}$ takes the same value for every collision round $i$. The standard recommends to set $W_{F_{i \in C}}$=1.

| **Command Code** | **Windows size** | **Reserved** |
|---|---|---|
| ‘10’ | 2 bytes | 1 bytes |

**Fig. 3.** Collection command format (from [5])

## 3 Related Work

There is a lack of scientific literature that specifically addresses the collision problem for active tags. The ISO 18000-7 standard [5] deals with it and proposes FSA as an anti-collision protocol, suggesting a frame length adaption mechanism but without specifying a particular one and leaving it open to the vendors. Some works suggest improvements of ISO 18000-7 identification procedure, such as in [10][11], where the authors suggest new tags and readers designed to save energy, and compatible with the standard. However, they do not propose any mechanism to improve the identification performance. In [12] the authors focus their proposal on the sleep round (see Figure 2), suggesting a mechanism to reduce the number of *Sleep* commands to exchange between reader and tags. However, this procedure does not reduce the collisions. In [13] it is proposed to modify the content of the *Collection* commands to improve the performance. The reader, instead of sending the windows size value in the collection command, sends the values of $T_{slot}$ and $K$, previously calculated by it. Hence, tags only have to calculate the guard time $T_{proc}$. This solution has some drawbacks: the maximum $K$ value is limited to 256 slots. Therefore, if the number of tags in coverage ($N$) is higher than the maximum $K$ (a likely condition due to the large communication range of active devices), collisions will raise up and the number of collection rounds will increase. Besides, the proposal forces tags to calculate $T_{proc}$, though they do not suggest any procedure to do it. Finally, [13] also suggests to use the variable window size mechanism proposed in [14]. However, as we demonstrate in [15], it is not efficient.

On the other hand, a typical active tag has the capabilities of an on-board microprocessor and a sophisticated transceiver and may use Bluetooth or IEEE 802.11 protocols or Wireless Sensor Networks (WSN) MAC protocols [9]. It is clear that these protocols are designed with different requirements in mind and, at the moment, the cost of these devices is still possibly too high. Therefore, it seems that the possible choices are: very simple approaches also suitable for passive tags or very sophisticated proposals designed for different purposes.

In [6] we propose the use of CSMA with the optimal probability distribution ($p^*$) for the selection of CSMA contention micro-slots derived in [7].This distribution maximizes the probability of success when $N$ stations become simultaneously backlogged, but depends on the number of slots in use ($K$) and the number of nodes ($N$) contending. Since the latter is usually unknown (also in RFID), an approximation is also provided, the Sift distribution, which not only keeps close to the optimal for a wide range of its configuration parameters but it is also scalable. The authors of reference [7] discuss different applications in wireless sensor networks, but RFID is not mentioned. In this paper we show that RFID is a major field of application of this optimized distribution.

CSMA/p* and Sift [7] are probability distributions that optimize the probability of success in a CSMA contention compared with the uniform distribution. In this paper we discuss the key aspects of these distributions and make a new proposal: the **CSMA/Multi-stage protocol**.

The key idea of CSMA/p* and Sift distributions is to unbalance the probability of selecting a contention micro-slot, increasing the probability of selecting one of the last ones available. Thus, transmission is successful when the the first micro-slots are selected by very few nodes with a higher probability. CSMA/p* is optimal, in the sense that given $K$ contention micro-slots, there is no other distribution that provides a higher probability of success. However, it requires knowledge of the number of contenders. Since usually this information is not available, it is not practical. Fortunately, the Sift distribution approximates CSMA/p* without knowing number of contenders. It only needs a parameter, $M$, that is the maximum number of contenders, and is the analog of 802.11 maximum window size. Sift works very well, compared to the uniform distribution, and also has the desirable property it scales linearly as the maximum number of contenders raises. That is, an exponential increase of the number of contenders only need a linear increase of $K$, keeping the probability of success around 99%. In this paper we propose the slotted multi-stage CSMA protocol, based on the Sift distribution, but with an additional procedure that approximates the probability of success to 100%.

## 4 Slotted Multi-Stage Proposal

In this section we describe CSMA/MS algorithm. Before, the operation of CSMA-Sift based is also introduced in depth since CSMA/MS uses also this distribution.

### 4.1 Sift operation

The operation of the identification protocol when using CSMA would be as follows: after receiving a collection command from the reader all $N$ tags listen to the channel for a number of *micro-slots* chosen randomly from a set of $K$. If the channel remains idle after the number of selected micro-slots, a node sends its ID. Otherwise, it withdraws until the next collection command. If there is no collision, the reader sends an ACK-Collection command, which indicates the node already identified and asks for more IDs. The remaining nodes start the process again.

The probability of success $\pi_p(N)$ when $N$ nodes select a contention micro-slot using probability distribution $p$, where $p_r$ is the probability each contender independently picks slot $r$, is [7]:

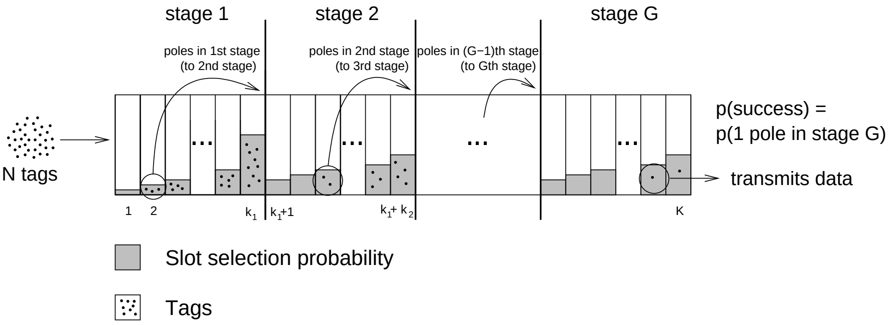


**Fig. 4.** Slotted Multi Stage procedure

$$\pi_p(N) = N \sum_{s=1}^{K-1} p_s(1 - \sum_{r=1}^{s} p_r) \tag{4}$$

Let us assume first that the slots are chosen uniformly. In this case $p_r = \frac{1}{K}$. Like FSA, this procedure does not scale well either. In fact, its performance is worse and together with the additional device complexity it may be one of the reasons why it has never been proposed as an anti-collision procedure for RFID systems.

Besides, let us assume now the Sift distribution is used, which is an approximation to the optimized distribution derived in reference [7]. In this case, $p_r = \frac{\alpha^{-r}(1-\alpha)\alpha^K}{1-\alpha^K}$ for $r = 1 \ldots K$ and $\alpha = M^{\frac{-1}{K-1}}$. $M$ is a parameter of the Sift distribution, pre-configured before deployment and representing the maximum number of contenders (as expected by the designer). The results reveal [6] that the number of cycles increases almost linearly with the number of tags, unlike the exponential increment of FSA. Therefore, this procedure scales well. In addition, by increasing the number of micro-slots the number of cycles tends to the minimum necessary ($N$ cycles), but it implies increasing the duration of a cycle and may be even counterproductive.

These results show that after choosing carefully the distribution for the contention window CSMA becomes an scalable technique for the identification of RFID tags. In Section 5, the different proposals for active tags are compared and discussed.

### 4.2 CSMA/MS

CSMA Multi-Stage proposal is based on the idea of splitting the original contention micro-slots ($K$) into $G$ stages of respective lengths $k_1, k_2, \ldots$, where $k_1 + k_2 + ... + k_G$=$K$, where tags are dropping from the contention process from one stage to the following. The operation is as follows (see Figure 4):

- In the first stage (of length $k_1$), all tags select randomly (using an arbitrary distribution $p$) a micro-slot $i$, being $i$= 1,2,$\cdots$,$k_1$. Note that one or more tags ‘win’ in this stage selecting the same initial slot. Let us denote these tags as the *poles* of stage

#1. Remainder tags detects the medium busy and withdraw from contention. Note that if the number of poles is greater than 1, a collision has taken place. Hopefully, this collision is solved in next stage.
- In the second stage (of length $k_2$) the poles of the first stage contends again. Each one select again a random micro-slot $i$, being $i$= $k_1 + 1, k_1 + 2, \cdots, k_1 + k_2$, and the same procedure of the first stage takes place.
- This process continues until to stage $G$, where only the *poles* from stage $M - 1$ contend. In this case, if there is only one pole, or there is a single winner in this stage, one tag can successfully transmits its identification. Otherwise, a collision takes place.

Let us remark that more than one tag may compete in consecutive slots since several tags may select the same lowest slot (a collision event). Moreover, the overall collision probability depends on the number of stages and its relative length, henceforth let us denote CSMA/MS($k_1 + \cdots + k_M$) to the specific configuration selected for the MS protocol. Also note that at each stage, a micro-slot can be chosen with any arbitrary distribution. We propose to use the Sift distribution since it is quasi-optimal for a single-stage scenario. Therefore, in each stage, the Sift distribution is configured using two parameters, the number of $k_i$ micro-slots in this stage, and the parameter $M$. In the first stage, $M$ is the maximum number of contenders, as shown in [7], but in the following ones the number of contenders that reach a stage $i$ is a random variable $N_{i-1}$, which depends on the number of contenders that have reached the previous stage, and the number of micro-slots of that stage. Usually, as we will be discuss in section 5, the highest probability corresponds to a single tag reaching to the next stage. So in stages $2, \cdots$ the Sift parameter $M$ is set at 2 (note that Sift does not allow $M$=1).

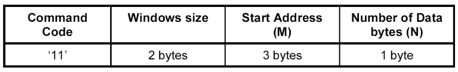
### 4.3 Modified anti-collision algorithm

The adaptation of the mechanism proposed in the previous section the ISO 18000-7 involves minor modifications in the anti-collision algorithm of the current standard, without adding extra hardware in readers or tags. The operational mode is as follows:

The reader transmits the *Collection* command indicating, not only the *Windows Size*, but also the number of stage ($s \in 1, 2, \ldots, S$). The latter is sent to the tags in the reserved byte field of *Collection* command (see Figure 3).

If $s$=1, tags in coverage which were not identified previously calculate the number of contention micro-slots of that stage using the same procedure defined by the standard and select one of them randomly using the Sift distribution. Each tag listens to the channel (Carrier Sense) until the number of micro-slot chosen starts. If the channel remains idle after the number of selected micro-slot, the tag sends its $ID$. If there is no collision, the reader sends an command, which confirms the tag has won the contention and it can send its Data. After that, the reader asks for more $IDs$ using a new *Collection* command setting $s$=1 (see Figure 4). The tag identified changes to sleep mode (saving energy mode) and the remaining tags start the process again. Otherwise, if two or more tags select the same micro-slot, a collision occurs. Then, the procedure works as follows:

- Colliding tags do not detect the collision because they were in transmitting mode. Hence, they keep waiting for a reader response.
- Those tags listening the channel while the collision was happening, do not participate in the identification process until they receive a new *Collection* command with $s$=1.
- Reader, that has also detected the collision, send a new *Collection* command, indicating a new *Windows size* and a new stage, $s$=2. Colliding tags receive the command and compete again.



| Command Code | Windows size | Start Address (M) | Number of Data bytes (N) |
|---|---|---|---|
| '11' | 2 bytes | 3 bytes | 1 byte |

**Fig. 5.** Collection command with Data format (from [5])

The contention procedure continues until the maximum $s$ value configured in the reader. If, after $S$ stages no new tags are identified, the reader starts a new *Collection command*, setting $s$=1, and provoking all tags in coverage not identified previously compete again.

Note that the duration of each micro-slot (denoted as $T_{m-slot}$) depends on the duration and accuracy of carrier sensing *Clear Channel Assessment* (CCA), which depends on the technology, device and implementation [18]. There are many possibilities, but we assume that devices use coherent CCA, that is, the channel is busy when the packet preamble is detected. Thus, we set the micro-slot time as follows:

$$T_{m-slot} = T_{tt} + T_{preamble} \tag{5}$$

being ($T_{preamble}$) the duration of the preamble and $T_{tt}$ the time a tag needs to start transmitting its identifier. ISO 18000-7 fixes $T_{preamble}$=1 ms and $T_{tt}$=1 ms [5]. Hence, $T_{m-slot}$=2 ms can be considered a conservative value, since current devices can perform this task in less time [18].

Tags calculate the number of contention micro-slots $K_{m-slot}$ in every stage as follows,

$$K_{m-slot} = \left\lceil \frac{W_S - T_{tag} - T_{proc}}{T_{m-slot}} \right\rceil \tag{6}$$

As in the standard, $W_S$ and $T_{tag}$ values are extracted from *Collection* command. $K$ is rounded up to the nearest integer.

In summary, our proposal only involves the use of the reserved field of the typical *Collection* command (see Figure 3) and a slight modification of the *Collection with data format* command defined by the standard (see Figure 5) to be used as *ACK-Collection* command. Figure 6 shows how the *Start Address* and *Number of Data bytes* fields of *Collection with data format* command are replaced by *Tag ID* field.

| Command Code | Windows size | Tag ID |
|---|---|---|
| ‘11’ | 2 bytes | 4 bytes |

**Fig. 6.** ACK-Collection command

## 5 Simulation results

As stated in the previous section, CSMA/MS performance depends on the number of stages and on their size. We evaluated the performance of different configurations by means of Montecarlo methods using Matlab. For each point (configuration) evaluated 100000 samples has been averaged. In addition, CSMA/MS has been compared with CSMA/$p^*$, Sift and a uniform selection of slots in a single stage CSMA protocol. Let us remark that the total available micro-slots does not change among these options, only its distribution in different stages (for CSMA/MS) or the probability function used to select the micro-slot. Of the different configurations possibilities of CSMA/MS the configuration (7+7+7+7) has been selected for these tests. Besides, for CSMA/MS the parameter $M$ is adjusted as explained in section 4. In this case, for the first stage $M = 250$, and the following ones sets $M = 2$.

Figures 7 and 8 show the identification success probability for each one of these options (note that 8 provides a zoom view of 7). Clearly, configuration CSMA/MS(7+7+7+7) improves the success ratio, and sets it nearly optimal. Moreover, the uniform distribution is evidently disastrous.

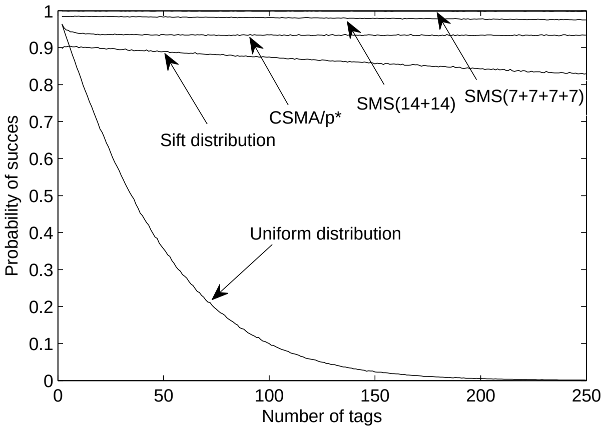


**Fig. 7.** Identification success probability

Besides, Figure 9 shows the overall identification delay (in time slots) as a function of the number of initial contenders. CMSA/MS(7+7+7+7) improves Sift by a $15\%$,

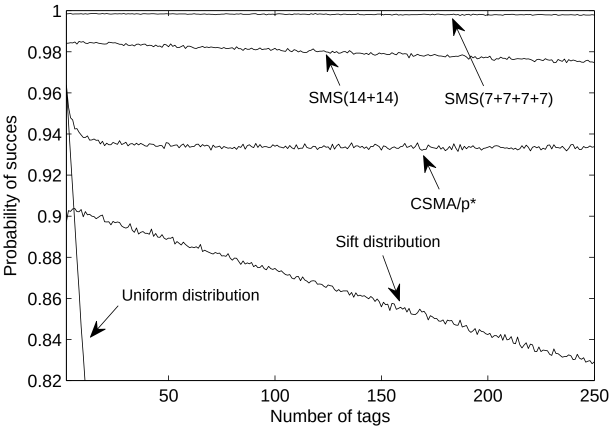


**Fig. 8.** Identification success probability (zoom view)

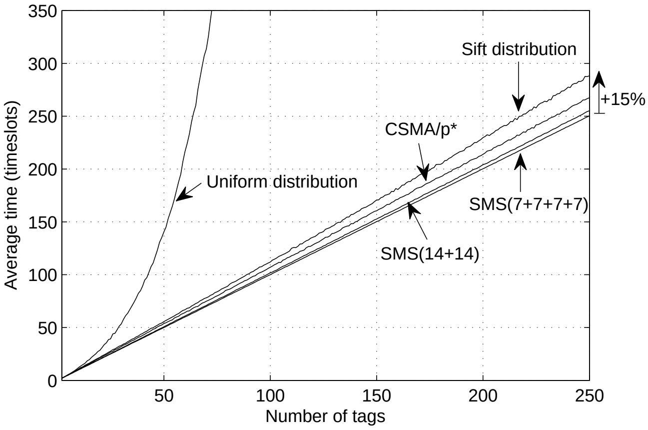


**Fig. 9.** Identification time

and it is slightly better than CSMA/$p^*$ (however let us remarks that CMSA/$p^*$ can be implemented in actual systems as discussed in the introduction).

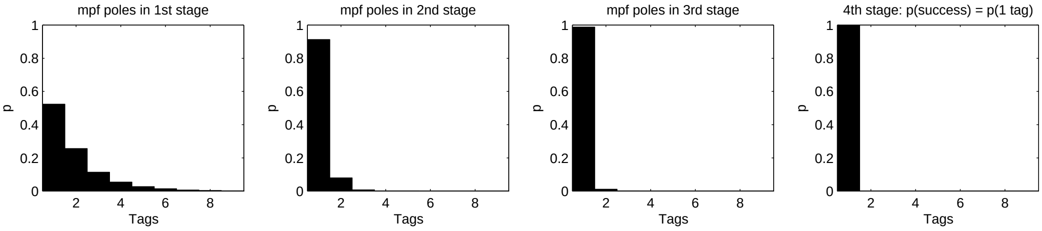


**Fig. 10.** Mass probability function for CSMA/MS(7+7+7+7)

Finally, Figure 10 shows the mass probability function of the random variable “number of contenders at stage $i$” for the different stages $i = 1, \cdots, 4$. Note how the system behaves as a filter, removing in each stage a significant ratio of the tags contending, increasing the probability of having a winner at the end.

## 6 Conclusions and further works

In this work we have demonstrated how a multi-stage strategy which uses CSMA-Sift distribution at different contention windows improves the identification delay of a population of tags. By means of simulation an evaluation was carried out for a 4-stage configuration with 7 micro-slots each, which outperforms FSA and uniformly selected micro-slots CSMA. This distribution also improves a Sift distribution of 28 micro-slots, yielding to a feasible MAC strategy. A discussion is also developed on how to seamlessly adapt our approach to ISO-18000-7 compliant systems.

Several question remain open: given a number of $K$ micro-slots which are the optimal number of stages, and which slot distribution is optimal? which is the analytical expression for the probability of success and for the identification delay of a population of N tags?.

## Acknowledgements

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## References

1. Stanford, V., “Pervasive Computing Goes the Last Hundred Feet with RFID Systems”, *IEEE Pervasive Computing*, vol. 2, no. 2, pp. 9–14, April–June 2004.
2. Shih, D., Sun, P., Yen, D., Huang, S., “Taxonomy and survey of RFID anti-collision protocols”, *Elsevier Computer Communications*, vol. 29, pp. 2150–2166, 2006.
3. Vogt, H., “Efficient Object Identification with Passive RFID Tags”, *Lecture Notes in Computer Science*, vol. 2414, pp. 98–113, 2002.
4. Zhou, F., Chen, C., Jin, D., Huang, C., Min, H., “Evaluating and Optimizing Power Consumption for Anti-Collision Protocols for Applications in RFID Systems”, in *Proc. Int. Symp. on Low Power Electronics and Design 2004*, pp. 357–362, 2004.
5. ISO/IEC 18000-7:2004 Information technology–Radio frequency identification for item management–Part 7: Parameters for active air interface at 433 MHz, 2004.
6. Egea-Lopez, E., Vales-Alonso, J., Martinez-Sala, A. S., Bueno-Delgado, M. V., Garcia-Haro, J. “Performance Evaluation of non-persistent CSMA as anti-collision procedure for active RFID tags”, *Lecture Notes in Computer Sciences*, vol. 4517, 2007.
7. Tay, Y., C., Jamieson, K., Balakrishnan, H., “Collision-Minimizing CSMA and its Applications to Wireless Sensor Networks”, *IEEE Journal on Selected Areas in Communications*, vol. 22(6), pp. 1048–1057, 2004.
8. Class 1 Generation 2 UHF Air Interface Protocol Standard Version 1.0.9: “Gen 2”. Available online at: http://www.epcglobalinc.org/standards
9. Zhao, F. y Guibas, L., Wireless Sensor Networks. An information processing approach. *Morgan Kaufmann*, 2004.
10. Jones, A.K., Hoare, R., Dontharaju, S., Tung, S., Sprang, R., Fazekas, J., Cain, J.T., Micke, M.H., “An Automated, FPGA-based reconfigurable low-power RFID tag”, *Journal of Microprocessors and Mircosystems*, vol. 31 (2), 2007, pp. 116-134.
11. Cho, H., Choi, H., Lee, W., Jung, Y., Baek, Y., “LITeTag: design and implementation of an RFID system for IT-based port logistics”, *Journal of Communications*, vol. 1 (4), 2006, pp. 48-57.
12. Jang, S.J., Chung, S.H., Yoon, W.J., Lee, S.J., “An effective design of an active RFID reader using a cache of tag memory data”, in *Proc. International Workshop on Service, Security and its Data management for Ubiquitous Computing*, vol. 4819, 2007, pp. 584-595.
13. Yoon, W.J., Chung, S.H., Lee, S.J., “Implementation and performance evaluation of an active RFID system for fast tag collection”, *Journal on Computer Communications*, vol 31, 2008, pp. 4107-4116.
14. Cha, J-R., Kim, J-H., “Novel Anti-collision Algorithms for Fast Object Identification RFID System”, in *Proc. 11th Conference on Parallel and Distributed Systems*, vol. 2, 2005, pp. 63-67.
15. Bueno Delgado, M.V., Vales Alonso, J., González Castao, F.J, “Analysis of DFSA Anti-collision Protocols in Passive RFID Environments”, in *Proc. 35tn International Conference of the IEEE Industrial Electronics Society*, Porto (Portugal), 2009, pp. 2630-2637.
16. Kleinrock, L., Tobagi, F., “Packet Switching in Radio Channels: Part I-Carrier Sense Multiple Access and their throughput-delay characteristics”, *IEEE Transactions on Communications*, vol. 23, pp. 1400–1416, 1975.
17. Wieselthier, J. E., Ephremides, A., Michaels, L. A., “An exact analysis and performance evaluation of framed ALOHA with capture”, *IEEE Transactions on Communications*, vol. 37(2), pp. 125–137, 1988.
18. Ramachandran, I., Das, A., Roy, S., “Clear Channel Assessment in Energy-constrained Wideband Wireless Networks”, *IEEE Wireless Communications Magazine*, forthcoming.