

On the optimal configuration of CSMA-MS algorithm

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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 a previous work, a CSMA (Carrier Sense Multiple Access) mechanism CSMA/MS (Multi-Stage) was proposed in order to substitute the anti-collision procedure in active tags. The key of this CSMA/MS is to concatenate various contention windows, where only winners contend in the next contention stage. With the same overall number of contention slots, the staging approach greatly improves performance if the window division is correctly selected. In this new work, this issue is investigated and suitable configurations, derived by means of numerical test, are provided.

I. 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.

In a previous paper [6], we proposed the use of non-persistent Carrier Sense Multiple Access (CSMA) as anti-collision mechanism for

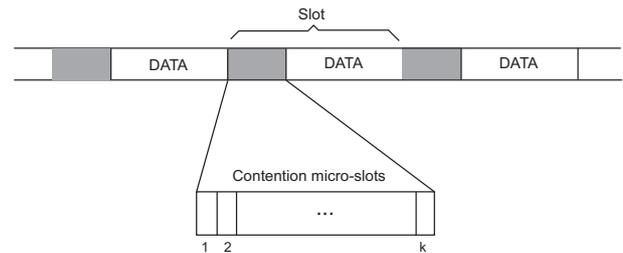


FIGURE 1 - GENERAL IDENTIFICATION PROCEDURE IN CSMA

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.

Lately, in [8] we proposed CSMA/Multi-Stage (henceforth, CSMA/MS) which is based on the concatenation of several micro-contention windows before data transmissions is actually performed. In CSMA/MS only contention winners transmits in the successive windows. In that work we shown that, for an equal overall number of contention micro-slots, even though the optimal distribution $CSMA/p^*$ and its approximation are able to achieve almost 96% of transmission success in each slot, CSMA/MS improves further the identification process, achieving for proper configurations nearly 100% 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 of $CSMA/p^*$ itself cannot be improved, but, combined with the efficient splitting procedure proposed over the overall identification process it may improve. The key difference is the following: the goal of the optimal distribution $CSMA/p^*$ is to minimize the latency of the first few successful transmissions in an event-based traffic pattern,

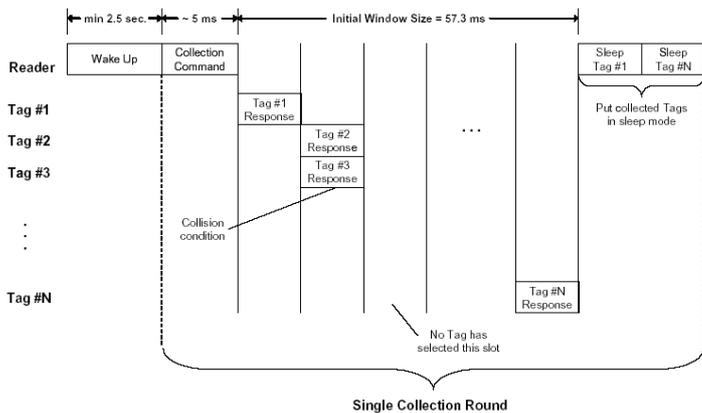


FIGURE 2 - ANTI-COLLISION PROCEDURE OF ISO/IEC 18000-7 (FROM [5])

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. CSMA/MS is a step in that direction, since in case of good choices partitions of the contention micro-slots it was demonstrated that identification ratio improves from $CSMA/p^*$. This new work is devoted to the selection of the best partition configuration. We also take into account current active RFID standards to propose suitable configurations.

The rest of this work is organized as follows: Section II. describes the ISO-18000-7 standard for active RFID solutions. Section III. discusses related works, with an emphasis on solutions for active RFID anti-collision protocols. Section IV. introduces the CSMA/Multi-Stage mechanism, and describes how it can be adapted with minor modifications to the ISO 18000-7 standard. Section V. shows the performance evaluations of CSMA/MS in comparison with $CSMA/p^*$, Sift and conventional FSA. Besides, section V. also describes the optimal partition configurations for different tag populations, as well as microslot numbers. Finally, Section VI. concludes this work.

II. 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.

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. Ev-

Command Code	Windows size	Reserved
'10'	2 bytes	1 bytes

FIGURE 3 - COLLECTION COMMAND FORMAT (FROM [5])

ery 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:

$$T_{slot} = T_{tag} + T_{proc} \quad (1)$$

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,

$$K = \left\lceil \frac{W_S}{T_{slot}} \right\rceil \quad (2)$$

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:

$$W_{S_{i+1}} = W_{F_i} \cdot 57.3 \quad (3)$$

for $i=0,1,2,\dots,C$. 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 $W_{F_i \in C}=1$.

III. 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 [11] [12], 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 [13] 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 [14] it is proposed to modify the content of the *Collection* commands to improve the performance. The reader, instead of sending the window 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, [14] also suggests to use the variable window size mechanism proposed in [15]. However, as we demonstrate in [16], 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 [10]. 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. 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. In this paper we discuss the key aspects of these distributions and study the optimal configuration of our CSMA/MS proposal.

IV. 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

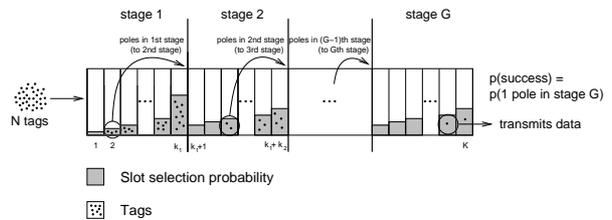


FIGURE 4 - SLOTTED MULTI-STAGE PROCEDURE

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]:

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

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 is:

$$p_r = \frac{\alpha^{-r}(1-\alpha)\alpha^K}{1-\alpha^K} \quad (5)$$

For $r = 1 \dots K$ 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 a scalable technique for the identification of RFID tags. In Section V., 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, \dots , where $k_1 + k_2 + \dots + k_G = K$, 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 $i = 1, 2, \dots, k_1$. 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 $i = k_1 + 1, k_1 + 2, \dots, k_1 + k_2$, 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($k_1 + \dots + k_G$) 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 V., the highest probability corresponds to a single tag reaching to the next stage. So in stages 2, \dots 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 in the reader and tag is as follows:

The reader transmits the *Collection* command indicating the *Windows Size* (or frame). Note that *Windows Size* is the time where several competing stages occur (with equal or different length) as well as a data transmission. For every *Windows Size* and a maximum tag population in coverage (N), there will be an optimal frame configuration (stages and their lengths). These configurations have been computed in Section X, and summarized in Table Y. We assume that both reader and tags work with data from Table Y. Once the reader sends *Collection* command, it keeps listening to the channel, waiting for tags data and two possibilities can arise:

- If channel is empty during the first stage, reader assumes there are no tags competing. Hence, check the *sleep queue* for sleep notifications and sends a new *Collection* command with the same or different *Windows Size*.
- If channel is busy during first stage, reader assumes there are tags competing, and keep waiting until the end of the last stage for receiving a tag data. Independently if data are received successfully or not, a new frame starts, and reader keeps waiting for tag responses. Note that when a new frame starts, reader does not send any *Collection* command. Hence, the frame configuration (number of stages and stages length) is the same as the previous one.

The reader process is summarized in Figure 5.

On the other hand, when tags receive *Collection* command, they extract the info, check Table Y and obtain the number of stages (G) for competing as well as the stages length ($K_i, \forall i = 1, \dots, G$).

After that, the first stage starts and tags select one of the micro-slots available in that stage, using the Sift distribution. Every tag listens to the channel (carrier sense) until the number of micro-slot selected and two possibilities can arise:

- If the channel remains idle after the number of selected micro-slot, the tag sends its *ID* until the stage finishes.
- If the channel is busy before the micro-slot selected (a collision occurred), the tag does not participate again until the slot for data transmission finishes or when it receives a new *Collection* command.

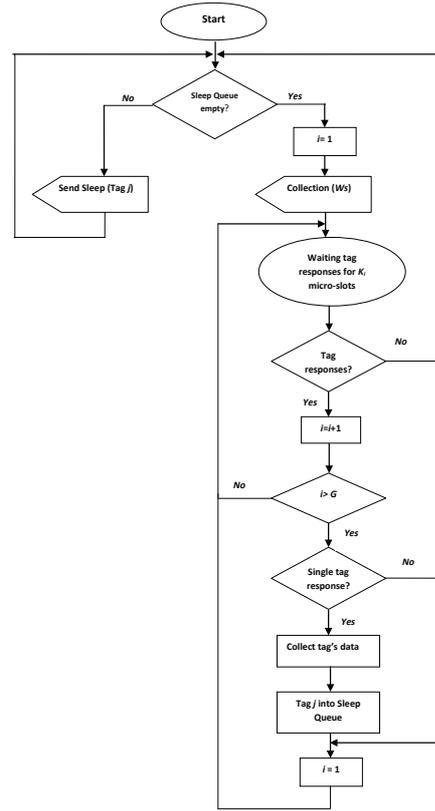


FIGURE 5 - READER PROCESS WITH SMS ALGORITHM

At the end of the last stage, only those tags that sent their *ID* in the previous stage, can transmit their data. After that, these tags keep waiting for a *ACK-Collection* command (see Figure 7), which involves they have sent their data successfully. The tags identified change to sleep mode (saving energy mode) and the remaining tags compete again in the new collection round. If tags only receive a new *Collection* command, it means data were not received correctly (e.g. due to collision) and tags must compete again in the new collection round.

The tag process, for an arbitrary tag j , is summarized in Figure 6 .

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 [19]. 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:

$$T_{m-slot} = T_{tt} + T_{preamble} \quad (6)$$

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 [19].

In summary, our proposal only involves a slight modification of the *Collection with data format* command defined by the standard (see

Command Code	Windows size	Tag ID
'11'	2 bytes	4 bytes

FIGURE 7 - ACK-COLLECTION COMMAND

Figure 3) to be used as *ACK-Collection* command. Figure 7 shows how the *Start Address* and *Number of Data bytes* fields of *Collection with data format* command are replaced by *Tag ID* field.

V. SIMULATION RESULTS

As stated in the previous section, CSMA/MS performance depends on the number of stages, on their size, and on the number of contenders. To reach the highest probability of success in transmission, and therefore the lower time to read all the notifications, configuration of CSMA/MS must be chosen optimally. By means of a sequence of simulations, sweeping all the possible configurations for a given number of K contention micro-slots, is possible to get the best configuration (highest probability of success) for a specific number of contenders. But this is possible only for a limited number of micro-slots, because the number of possible configurations grows rapidly, as shown in Table V..

Micro-slots	8	16	32	64	128
# configurations	12	609	1 346 268	$6.55 \cdot 10^{12}$	$1.55 \cdot 10^{26}$

TABLE 1 - NUMBER OF POSSIBLE CONFIGURATIONS FOR A GIVEN NUMBER OF K MICRO-SLOTS

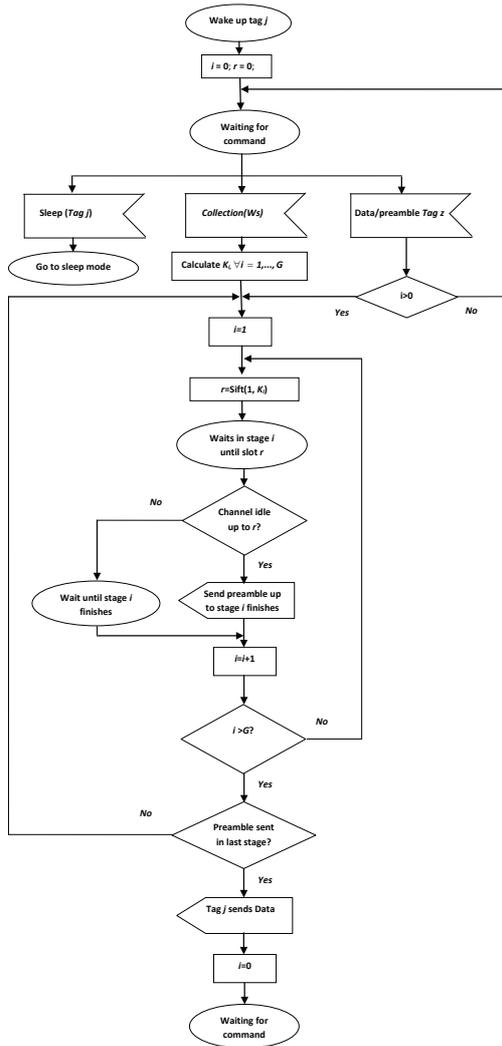


FIGURE 6 - TAG PROCESS WITH SMS ALGORITHM

Computational complexity to optimize a system with a large number of contending micro-slots, involves the use of a meta-heuristic method. In our simulations, *all* the possible configurations has been simulated, therefore no results for large K are provided. In Table V. the optimal configurations obtained for $K = 8$ and $K = 16$ are shown.

As the number of contenders increases, the optimal configuration suffers slightly changes. It is also remarkable the fact that not all the possible stages are used. For $K = 16$ a maximum of 8 stages of 2 micro-slots each one are allowed, but the maximum probability of success is achieved with only 5 stages. We evaluated the performance by means of Montecarlo methods using Matlab. For each point (a single tag) 100 000 samples has been evaluated and 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.

Performance has been evaluated for the optimal configuration for $K = 16$ and 250 contenders (4+3+3+3+3). Besides, for CSMA/MS the parameter M is adjusted as explained in section IV.. In this case, for the first stage $M = 250$, and the following ones sets $M = 2$.

Figures 8 and 9 show the identification success probability (note that 9 provides a zoom view of 8). Clearly, configuration CSMA/MS(4+3+3+3+3) improves the success ratio, and sets it nearly optimal. Moreover, the uniform distribution is evidently disastrous.

Besides, Figure 10 shows the overall identification delay (in time slots) as a function of the number of initial contenders. CMSA/MS(4+3+3+3+3) improves Sift by a 25%, and it is slightly better than CSMA/ p^* (however let us remark that CMSA/ p^* can not be implemented in actual systems as discussed in the introduction).

Finally, Figure 11 shows the mass probability function of the random variable "number of contenders at stage i " for the different stages $i = 1, \dots, 5$. 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.

Contenders	50	250	500	750	1.000	10.000
K=8	3 2 3	4 2 2	4 2 2	4 2 2	4 2 2	4 2 2
K=16	3 4 3 3 3	4 3 3 3 3	4 4 2 3 3	4 2 2 4 4	4 2 3 3 4	5 3 3 3 2

TABLE 2 - OPTIMAL CONFIGURATIONS FOR $K = 8$ AND $K = 16$

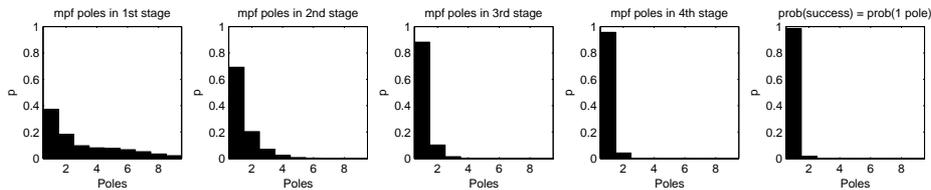


FIGURE 11 - MASS PROBABILITY FUNCTION OF POLES IN EACH STAGE FOR CSMA/MS(4+3+3+3+3)

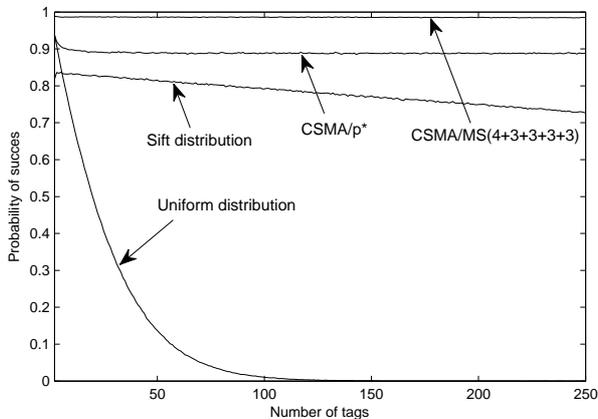


FIGURE 8 - IDENTIFICATION SUCCESS PROBABILITY FOR $K = 16$

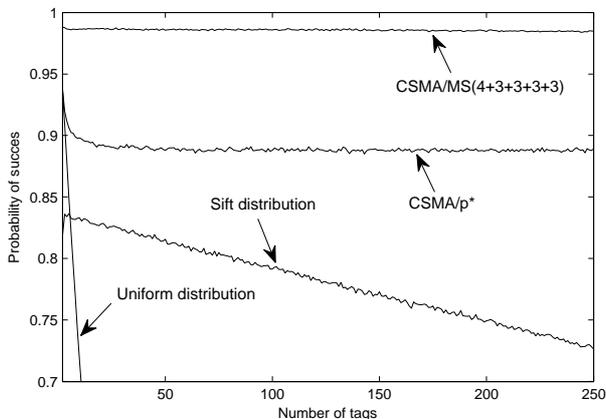


FIGURE 9 - IDENTIFICATION SUCCESS PROBABILITY FOR $K = 16$ (ZOOM VIEW)

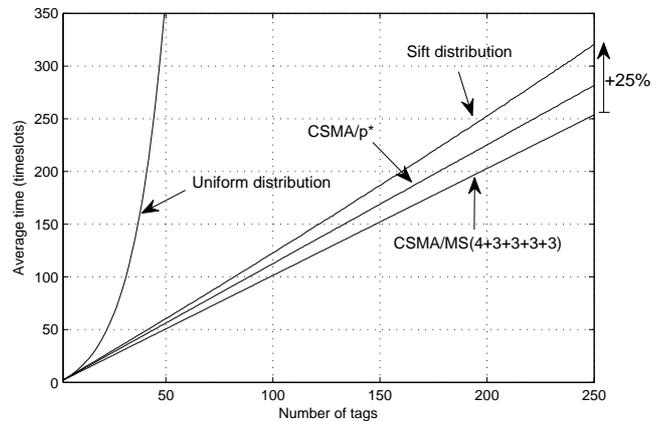


FIGURE 10 - IDENTIFICATION TIME

VI. 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 the optimal configuration of CSMA/MS for 16 micro-slots. This mechanism outperforms FSA and uniformly selected micro-slots CSMA, approaching to **100% probability of success**. This distribution also improves a Sift distribution, yielding to a feasible MAC strategy. A discussion is also developed on how to seamlessly adapt our approach to ISO-18000-7 compliant systems. With this mechanism, an exponential increase on the number of tags only requires a linear increase of the number of contention micro-slots, to get the same probability of success. It also implies **linear reading time** for tags populations as large as needed, allowing communications as quickly and reliable as possible. In addition to that, active tags save energy and maximize battery life.

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