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Deterministic Distribution of Replicas Positions for Multiuser Random Transmissions in Satcoms

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Abstract—**Random Access (RA) protocols have considerably evolved in satellite communications, especially after the introduction of Contention Resolution Diversity Slotted Aloha (CRDSA). However, CRDSA finds itself in a deadlock when the number of users is important. A complementary treatment Multireplica Decoding using Correlation based Localization (MARSALA) has hence been proposed to unlock CRDSA. This is fulfilled by localizing then combining replicas of the same undecoded packets using correlations. Based on a prior knowledge of the potential frame content by the receiver, a random Shared POsition Technique for Interfered random Transmissions (SPOTiT) is proposed to reduce MARSALA's localization complexity. As a matter of fact, random SPOTiT highlights a manner for the receiver to be aware of time slot positions and the preamble used by each subscriber. Then it uses this information to target a lower number of slots for localization correlations. In this paper we propose a hybrid solution that mixes both DAMA and Random Access in order to lower the Packet Loss Ratio (PLR) floor. In fact, a centralized computing can manage replicas positions and preambles to use, in a way that no loops are created. This also allows to keep a simple packet localization as in SPOTiT. Hereafter, we provide an optimal distribution of frame content using two replicas per packet which is evaluated through simulation.**

Index Terms—**Satellite communication, DAMA access, Time slot position, Multiuser detection, Random Access**

I. Introduction

The global coverage, the wide range, and the communication availability of satellites have made them interesting to many technologies and a target to several applications. Demand assigned Multiple Access (DAMA) has taken an important part of the satellite interactive communications. As a matter of fact, many aspects have been explored in literature regarding free resources utilization [1] and priority assignment [2]. The centralized management of DAMA offers a good organization of multiuser transmissions until it becomes questionable due to the insufficient resources facing large users communities. Random access based on spread spectrum or Aloha protocol [3] have then been proposed to overcome that obstacle. We focus in this paper on the various slotted ALOHA techniques. Slotted ALOHA [4] was the first step towards a synchronized packet transmission on

well-defined time slots within a frame. Then, a multi-replica scheme have been proposed in Diversity Slotted ALOHA [5] in order to increase the packet decoding probability. Contention Resolution Diversity Slotted Aloha (CRDSA) [6] [7], with multiple replicas, that apply Successive Interference Cancellation (SIC) at reception provides better performance in terms of throughput and Packet Loss Ratio (PLR). Other aspects of ALOHA RA protocols have been studied. On the one hand, Irregular Repetition Slotted Aloha (IRSA) [10] introduces an irregular number of replicas that varies from one transmitter to another. On the other hand, coding rates have been particularly explored in the literature: the coded slotted Aloha CSA [11] divides the packet into several fragments before encoding each with an erasure code; Multi-Slot Coded Aloha (MuSCA) [12], instead, encodes the packet before dividing it into several fragments. In both cases, signaling fields to locate the fragments are added. Nevertheless, RA schemes keep evolving towards effective and less complex solutions.

Later, a complementary treatment to CRDSA have been introduced: MultireplicA decoding using corRelation baSed locALisAtion (MARSALA) in [8] aims to resolve CRDSA's deadlock when no more packets can be retrieved. It is based on a computation of correlations between a reference time slot and the remaining signal on the rest of the frame. This makes it possible to locate, then to combine replicas of the same packet, in order to have a higher probability of decoding when CRDSA is blocked. Many enhancements regarding signal processing aspects of MARSALA have been proposed in [9]. However, it introduces an additive complexity related to the data localization correlation operations.

Considering MARSALA's efficiency and the complexity regarding its implementation, random SPOTiT [13] came out with a new solution aiming to reduce the localization correlations. It uses the pseudo-orthogonal characteristic of preambles, in addition to the shared information between the receiver and each of the transmitters to target a lower number of slots for localization correlations. As a matter of fact, it exploits the commonly known identification information by each user and the receiver as a seed for a pseudorandom number generator. This latter is used by the transmitter to

select replicas time slot positions and the preamble to be used, and at the same time allows the receiver to be aware of them. The localization correlations are hence made only on potential replicas time slot positions of packets with the same detected preamble that can be collided on the analyzed slot.

In this paper, we propose a new technique, called Smart SPOTiT, aiming to improve the Packet Loss Ratio (PLR). Indeed, PLR curves of MARSALA/SPOTiT have a floor corresponding to the probability that some users choose the same replicas positions. This improvement is mostly due to the centralized management of time slot positions and the preamble to use by each transmitter. The main idea is thus to allow the receiver to manage time slot positions and the preamble to be used for each subscriber in without having more than one user transmitting its replicas on the same time slot positions, which defines a loop. It can be viewed as a mix between DAMA and RA. The RA aspect lies in the fact that a resource is permanently allocated to a community of users and not to only one user. Each of them transmit data whenever it is needed. This allocation depends on an optimal distribution that eliminates data loops between users.

We organize this paper by introducing, first, in Section II the system overview. Section III describes our contribution to SPOTiT and introduces an optimal distribution of replicas positions. Simulation results are presented in Section IV and we eventually conclude and discuss future work in Section V.

II. SYSTEM OVERVIEW

The context of the proposed technique fits both environments, the terrestrial up link and the satellite return link. Let us give attention to multiuser transmission and reception through a random channel on the return link via satellite, which is standardized in DVB-RCS2. N_U subscribers associated to a gateway transmit synchronously, over the same frequency, N_R replicas, each on a time slot within a frame of N_S slots. Assuming that each user waits for the next frame to send another packet, the worst scenario in this case happens when all of the N_U users transmit their replicas on the same frame. Users are synchronized with each other and receive gradually synchronization tables. Packets have equal power, and are composed of a payload after coding and modulation of N_b information bits, a preamble, and a postamble. We consider N_P pseudo-orthogonal preamble codes (e.g. Gold sequences, Zadoff-Chu sequences). Guard intervals are used at the end of each slot to avoid interpacket interference due to potential synchronization errors. When a frame is received, CRDSA will first attempt to decode a maximum number of packets through SIC by browsing slots one by one until it can no longer retrieve information. A complementary treatment is triggered afterwards to resolve CRDSA's deadlock. It can be legacy MARSALA, or the proposed Smart SPOTiT. The difference between those methods is that the latter avoids loops and requires less complexity for packets localization compared to random SPOTiT. As a matter of fact, since the frame structure at the worst scenario is known to the receiver, it uses the pseudo-orthogonality of preambles to determine which among all users candidates have transmitted data on the analyzed frame. The whole proposed technique is described in the next section.

III. SMART SPOTiT

This section describes a method of assigning to each user time slot positions on the frame and the associated preamble in a way that no loops are created. Another goal is to make sure that each potentially transmitted packet has one of its replicas having a unique preamble on its time slot position. This will allow to determine which users have sent data on the analyzed frame without proceeding to data localization correlations as in MARSALA. Once replicas are localized, combination is performed before demodulation and decoding.

A. Smart SPOTiT Principle

In this smart operating mode two main characteristics are to be pointed out:

1) The receiver's role: the receiver manages the time slot positions of replicas on the frame and the associated preamble for each subscriber. It makes sure to differentiate from the others the potentially collided preamble on the same slot of one of the packet's replicas and eliminates data loops. These optimal time slot positions and preamble choice, must be communicated to the transmitters as signaling information. It is sent only once and can be added to the logon phase. On the one hand, the PLR is expected to be improved due to the disappearance of the error floor, in CRDSA and MARSALA, that can be created by loops when the number of transmitters is low. On the other hand, the intelligent layout regarding the choice of time slot positions and preambles reduces the level of complexity in terms of correlations. As a matter of fact, each preamble used by a packet will be unique on one of its replicas slots; this means that no data localization correlations are necessary when the preamble is detected.

2) Preambles role: the pseudo orthogonality of preambles is taken advantage of to restrain the localization correlations. Their detection probability relies mainly on having good auto and cross-correlation properties, in addition to their length. When a preamble is detected on a slot, the receiver can guess whether this preamble is unique or not. It will consequently confirm the presence of packets that have a unique preamble on one of their replicas positions, specifically when their other replicas exhibit a correlation peak. In other words, only preamble detection correlations are utilized to correctly locate replicas. As stated in [6], these preambles can also be used for an initial phase estimation.

B. An optimal distribution scheme

In this part, we present an optimal distribution scheme regarding loop free time slot positions and preambles to be used for a community of subscribers with packets of two replicas each. In order to have an optimal disposition of time

slot positions and preamble choice, several methods can be applied. One way is to create preamble groups that contain each, loop free time slot couples for a certain number of users, all having the same preamble. In addition, no slot is assigned to two different users; it is used only once within a preamble group. This will prevent localization correlations because a correctly detected preamble will indicate the presence of only one user. We can conclude that, with an even number of slots, there can be $\frac{N_S}{2}$ couples in N_P preamble groups. From this initial idea, we propose a scheme based on a cyclic shift applied to the position of the second replica at each preamble group. Transmitters, having each a couple of time slot positions, that belongs to a preamble group use the same pseudo-orthogonal sequence. They are characterized by an index j where $j \in [0; N_P - 1]$ is the preamble index, which is also the value of the cyclic shift applied to the second replicas positions. Each user u sends then his two replicas on the time slots $Pg_1(u)$ and $Pg_2(u)$. The structure of a preamble group j including all first and second slots (couples) is defined as follows:

$$G_j = \begin{cases} Pg_1 \in \left\{0,\ 1,\ ..\ \frac{N_S}{2} - 1\right\} \\[6pt] Pg_2 \in \{\ \frac{N_S}{2} + [\frac{N_S}{2} + j](\mathrm{mod}\,\frac{N_S}{2}), \\[4pt] \qquad \frac{N_S}{2} + [\frac{N_S}{2} + j + 1]\ (\mathrm{mod}\,\frac{N_S}{2})\ .., \\[4pt] \qquad \frac{N_S}{2} + [\frac{N_S}{2} + j + \frac{N_S}{2} - 1]\ (\mathrm{mod}\,\frac{N_S}{2})\ \} \end{cases}$$
(1)

Pg_1 and Pg_2 are the set of the first time slot positions of the first replicas and the set of the second time slot positions of the second replicas, respectively, for each subscriber in the group with the cyclic shift j. It is desired not to assign, more than once, one of the N_P preambles to a group of time slot couples in order to avoid a potential collision between users with the same preamble on a time slot. Consequently, there are N_P possible cyclic shifts, thus N_P groups, having each $\frac{N_S}{2}$ subscribers and a distinct preamble. This gives at the end a total number of $\frac{N_S}{2} \times N_P$ subscribers, over the same frequency, which are attached to a gateway. However, some of the possible time slot couples are not used because of the preamble uniqueness necessity on each slot for complexity matter.

In order to exploit all possible combinations, let us first, make the assumptions that the number of time slots is a power of two and that the number of preambles is equal to the number of slots divided by two: $N_P = \frac{N_S}{2}$. We can now create subsets with a dimension reduced by two from the basic level as explained and illustrated in the upcoming example. This will result in a certain number of levels $N_L = log_2(N_S)$. At each level, there is the same number of preamble groups. The difference lies in the fact that a preamble group of a level $i + 1$ constitutes a subset of the preamble group at level i that uses the same preamble, and with a reduced number of users. In fact, a preamble group, at a level i occupies a certain number of time slot positions and has a certain number of users. Its corresponding subset (preamble group) with the same preamble at level $i + 1$ occupies half of its

time slot positions with a half number of users. Independently, each preamble group at any level keeps the same properties regarding preamble uniqueness over the occupied slots and the loop free condition. In the end, the total number of users from all preamble groups of the different levels correspond to the binomial coefficient $\binom{N_S}{N_R} = \frac{N_S \times (N_S - 1)}{2}$, which represents the maximum number of loop-free time slot couples.

1) Preamble group structure for $N_S = 2^{N_L}$ and $N_P = \frac{N_S}{2}$: the composition of each preamble group at each level is formally described, below, in terms of time slot positions and preamble choice for each user.

Each level i includes $N_{E,i} = 2^{i-1}$ sets of slots $E_{i,s}$ with $s \in [1; N_{E,i}]$, each of which contains $\frac{N_P}{2^{i-1}}$ preamble groups of $\frac{N_S}{2^i}$ subscribers. Each set $E_{i,s}$ is associated to $N_{ss}^i = \frac{N_S}{2^{i-1}}$ slots defined as $E_{i,s} = \{(s-1) \times N_{ss}^i.......s \times N_{ss}^i - 1\}$. Otherwise expressed as $E_{i,s} = \{B_{\inf}(i,s).......B_{\sup}(i,s)\}$ with $B_{\inf}(i,s)$ the lower bound which is equal to $(s-1) \times N_{ss}^i$, and $B_{\sup}(i,s)$ the upper bound which is equal to $s \times N_{ss}^i - 1$. There are N_P groups for level 1, each having a separate preamble, of $\frac{N_S}{2}$ subscribers. The next level can simply be formed by redefining the bounds of the new sets of slots resulting from the division by two of the previous levels set. Therefore the number of subscribers in each preamble group belonging to these new slot sets will be reduced to half compared to the previous level. Each set of slots of the form $\{B_{\inf}(i,s)...M_{i,s}...B_{\sup}(i,s)\}$, with $M_{i,s}$ the central value of the set; $M_{i,s} = B_{\inf}(i,s) + \frac{B_{\sup}(i,s) - B_{\inf}(i,s) + 1}{2} - 1$, having $N_P(i) = \frac{N_P}{2^{i-1}}$ preambles at a given level i, will be divided into two slots sets at level $i + 1$ of the form $\{B_{\inf}(i,s)...m_{i+1}^s...M_{i,s}\}$, $\{M_{i,s} + 1...m_{i+1}^s...B_{\sup}(i,s)\}$ each having $\frac{N_P(i)}{2}$ preambles. At this level $i + 1$, m_{i+1}^s is calculated in the same way as $M_{i,s}$ at the previous level i. It should be noted that each set of slots has different preamble groups from those of the other sets. As stated before, in order to create the preamble groups, cyclic shifts are performed only on the position of the second replicas Pg_2, within the same set of slots $E_{i,s} = \{B_{\inf}(i,s)...M_{i,s}...B_{\sup}(i,s)\}$. The latter occupy, all, exactly the same slots, it means that for each group, the first replicas are on the slots $[B_{\inf}(i,s); M_{i,s}]$ and the second replicas are on slots $[M_{i,s} + 1; B_{\sup}(i,s)]$.

Example: Let us consider the case with the following values : $N_S = 8$, $N_P = 4$, $N_R = 2$, $N_L = 3$, $N_U = 28$. Fig. 1. shows the disposition of each potential packet on the frame. In other words, it illustrates the worst case when every user U_u, with $u \in [1; N_U]$, has sent a packet. Each preamble is represented by a color. The blue preamble for example includes one preamble group from each level. These are: first, the preamble group in level 1, to which belong the users U_1, U_2, U_3, U_4, second, the preamble group in level 2, to which belong the users U_{17}, U_{18}, and finally the preamble group in level 3, to which belongs the user U_{25}. Two properties can be noticeable. First, a set of slots of a level $i + 1$ is associated to a number of slots which are half of the slots of the previous level i. Thus, $E_{2,1}$, for instance,

has the packets of its preamble groups (blue and red) on the slots $[0; 3]$, which are half of the slots where the packets of the preamble groups of $E_{1,1}$ can be transmitted $[0; 7]$. Secondly, a set of slots of a level $i + 1$ regroups half of the preambles of the previous level i. As a matter of fact, $E_{2,1}$ is associated to two preambles (blue and red) which are half of the preambles of the previous level $E_{1,1}$ (blue, red, green, and brown). Considering these two properties, at each level, every preamble group has one of the replicas of its packet assigned to a unique preamble on their time slot positions, compared to the following levels. Indeed, at level 1 for example the blue preamble group has the second replicas of its packets U_1, U_2, U_3, U_4 having a unique preamble on their respective slots $[4; 7]$, compared to the following levels. This is valid for all preamble groups at any level. the latter is investigated and proved next through a lemma and a theorem. Therefore, we assume there is no restriction on the number of detectable preambles, and decodable packets over a time slot. The detection operation is attempted using preamble correlations over each slot, and is performed during CRDSA. Smart SPOTiT can potentially enhance preamble detection by taking into account the already known distance, in terms of number of slots, between both expected correlation peaks of replicas belonging to the same packet. This would decrease false alarm probability and can be used to create a synchronization framework for estimation matter.

Let us now prove the optimality of the proposed scheme.

Fig. 1. Eight slots frame disposition at the worst scenario

Lemma. *Each preamble group at any level has one of its two components Pg_1 or Pg_2 not interfered by any packet of the associated group that uses the same preamble at the higher level.*

Proof. Let's take any preamble group j of level i having packets on the slots set $\{B_{\inf}(i,s)..M_{i,s}...B_{\sup}(i,s)\}$ and the corresponding preamble group of level $i+1$. A preamble group of any level that has any set of slots has $\frac{N_S}{2^i}$ users. We consider a minimum distance between $B_{\inf}(i+1,s)$ and $B_{\sup}(i+1,s)$

bigger than 1, such as:

$$G_{i,j} = \begin{cases} Pg_1 \in \{B_{\inf}(i,s), B_{\inf}(i,s)+1, \ ... \ M_{i,s}\} \\ \\ Pg_2 \in \{(M_{i,s}+1) + [j\left(\mathrm{mod}\frac{N_P}{2^{i-1}}\right)](\mathrm{mod}\frac{N_P}{2^{i-1}}), \\ (M_{i,s}+1) + [j\left(\mathrm{mod}\frac{N_P}{2^{i-1}}\right)+1]\ (\mathrm{mod}\frac{N_P}{2^{i-1}}), ..., \\ (M_{i,s}+1) + [j\left(\mathrm{mod}\frac{N_P}{2^{i-1}}\right)+\frac{N_S}{2^i}-1]\ (\mathrm{mod}\frac{N_P}{2^{i-1}})\} \end{cases}$$
(2)

With $j \in [(s-1) \times \frac{N_S}{2^i}; s \times \frac{N_S}{2^i} - 1]$. At the higher level $i+1$, the group using the same preamble j as the one in level i will belong either to the set of slots $\{B_{\inf}(i,s)..m^s_{i+1}..M_{i,s}\}$ or to $\{M_{i,s} + 1..m^s_{i+1}...B_{\sup}(i,s)\}$. These are the sets of slots to which belongs one of the two components Pg_1 and Pg_2 of level i. Let's take the first slot set for instance:

$$G_{i+1,j} = \begin{cases} Pg_1 \in \{B_{\inf}(i,s), B_{\inf}(i,s)+1, \ ...m^1_{i+1,s}\} \\ \\ Pg_2 \in \{(m^1_{i+1}+1) + [j\left(\mathrm{mod}\frac{N_P}{2^i}\right)](\mathrm{mod}\frac{N_P}{2^i}), \\ (m^1_{i+1}+1) + [j\left(\mathrm{mod}\frac{N_P}{2^i}\right)+1](\mathrm{mod}\frac{N_P}{2^i}), ..., \\ (m^1_{i+1}+1) + [j\left(\mathrm{mod}\frac{N_P}{2^i}\right)+\frac{N_S}{2^i}-1](\mathrm{mod}\frac{N_P}{2^i})\} \end{cases}$$
(3)

We can notice that the slot sets $\{B_{\inf}(i,s)..m^s_{i+1}..M_{i,s}\}$ or $\{M_{i,s} + 1..m^s_{i+1}...B_{\sup}(i,s)\}$ at level $i + 1$ correspond exactly to Pg_1 or Pg_2 respectively, of the main slot set $\{B_{\inf}(i,s)..M_{i,s}...B_{\sup}(i,s)\}$ at level i. Therefore, a preamble group j of the level i has one of its the two components Pg_1 and Pg_2 not interfered with any packet of the preamble group that has the same preamble j at level $i + 1$. $\square$

Theorem. *A signal-frequency data loop free system, requiring only preamble detection to localize packets replicas, is built with a maximum number of users that is equal to the binomial coefficient $\binom{N_S}{N_R}$:*

$$N_U = \frac{N_S \times (N_S - 1)}{2}$$
(4)

Proof. We organize the proof in two parts. The first one concerns the number of users and the second one concerns the localization and decoding ability.

Part 1 : Number of users
At each level i, there are N_P preamble groups of $\frac{N_S}{2^i}$ subscribers each, i.e. a total of $N_U(i) = N_P \times \frac{N_S}{2^i} = \frac{N_P^2}{2^{i-1}}$ subscribers. Hence the total number of subscribers throughout the N_U system is:

$$N_U = \sum_{i=1}^{N_L} N_U(i) = N_P^2 \times \sum_{i=1}^{N_L} \frac{1}{2^{i-1}}$$

$$= 2N_P^2 \times \left(\sum_{i=0}^{N_L} \frac{1}{2^i} - 1\right) = 2N_P^2 \times \left(\frac{2^{N_L+1} - 1}{2^{N_L}} - 1\right)$$

$$= 2N_P^2 \times \left(\frac{2N_S - 1 - N_S}{N_S}\right) = \frac{N_S \times (N_S - 1)}{2} = \binom{N_S}{N_R}$$
(5)

We can observe that this number of users corresponds to the maximum number of position couples without loops on

a frame of N_S slots.

Part 2: Localization and decoding ability
Let's take a given preamble and the worst scenario where all groups of this preamble belonging to the different levels have transmitted on the same frame and see how the SIC can help us decode all the packets.

According to the Lemma above, each preamble group at a given level i has one of its two components Pg_1 and Pg_2 not interfered with any of the packets of the corresponding higher level group. On the one hand, localization can be performed for each preamble group packets on one of the replicas time slot position. Thus, no extra localization correlations are necessary. On the other hand, the entirety of the level $i + 1$ packets indeed occupies half of all the slots of the level i. By reasoning in the same way for the rest of the levels, level i will always have one of its components not interfered by any packet of any higher levels. Therefore, a preamble group of a given level is decodable using SIC if all lower levels packets have been decoded. In other words, an algorithm that starts the decoding operation from level 1 packets will unblock the higher levels one by one until no more packets are on the frame. □

2) Preamble group structure for $N_S = 2^{N_L}$ and $N_P \neq \frac{N_S}{2}$: each group uses the same preamble and each preamble is used by one group at each level. Therefore, if N_P isn't equal to $\frac{N_S}{2}$, fewer cyclic shifts will be applied, thus fewer preamble groups are created. Let us recall, when $N_P = \frac{N_S}{2} = 2^{N_L-1}$, the total number of users which is maximum according to (5) is $N_U = \sum_{i=1}^{N_L} \frac{N_P^2}{2^{i-1}}$. When N_P is no longer half of N_S, N_U becomes: $N_U = \sum_{i=1}^{N_L} \frac{N_P N_S}{2^i}$. We can then state that N_U depends on the number of preambles which corresponds, in turn, to the number of preamble groups applying each a different cyclic shifts.

Case 1 - N_P is a power of two lower than $\frac{N_S}{2}$: N_P can then be expressed as $N_P = 2^{N_L-1-d}$ with $d \in [1; N_L - 1]$.
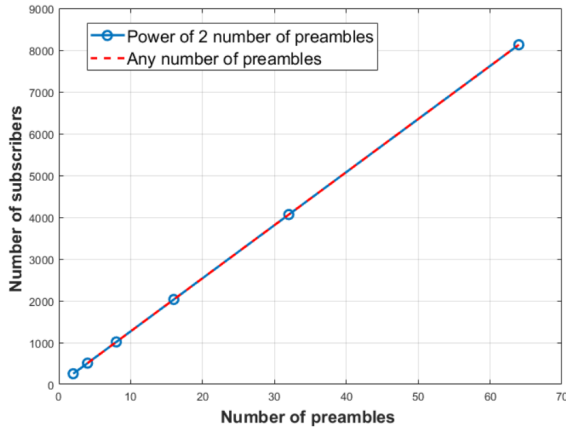

Fig. 2. Impact of N_P when it is not equal to $\frac{N_S}{2}$

This means that the total number of subscribers is reduced by 2^d:

$$N_U = \frac{N_S(N_S - 1)}{2^{d+1}} = \frac{\binom{N_S}{N_R}}{2^d} \quad (6)$$

Case 2 - N_P is lower than $\frac{N_S}{2}$ and is not a power of two: in this case, N_P can be expressed as $N_P = 2^{N_L-1} - k$ with $k \in [1; 2^{N_L-1} - 1]$. This means that the total number of users becomes:

$$N_U = (N_S - 1)\left(\frac{N_S}{2} - k\right) = \binom{N_S}{N_R} - k(N_S - 1) \quad (7)$$

Figure 2 displays the total number of subscribers according to the number of preambles for the example of 128 slots. When it is a smaller power of two, this number of users is divided by two at each value. Thus, it follows a linear evolution. When N_P is still smaller than $\frac{N_S}{2}$ but not a power of two, it also evolves according to a linear function superimposed to the smaller power of two one.

IV. SIMULATION AND RESULTS

A 2-replicas system has been chosen for complexity matter. However, what degrades the performance of a system with two replicas compared to a higher number of replicas system is that the probability of loops is more significant. As a result, a PLR floor formed in low network loads can be observed in CRDSA and MARSALA. With the parameters we took; QPSK modulation and Turbo coding of rate $1/3$ over an AWGN channel of an $E_s/N_0 = 10$ dB, one loop can be solvable by CRDSA. This can easily be observed using the Packet Error Rate (PER) of the ModCod. As a matter of fact, one interference is resolvable in CRDSA. Considering SIC operations, one of the replicas in a loop can be suppressed when interfered with only one other packet, thus breaking the loop. It is important to note, according to simulation in Fig. 4, that the probability of having two or more loops represents exactly the CRDSA error pattern in the low network loads until the number of collisions becomes large enough (0.6 bits/symbol), due to the number of transmitters, to prevent decoding. The loop occurrence probability and its impact on CRDSA's performance is investigated in appendix D of [14]. For MARSALA, it is perfectly matched up to a load of 1.5 bits / symbol (see Fig. 3). Beyond this load, the number of collisions becomes larger and the level of SNIR will no longer allow correct demodulation and decoding. Smart SPOTiT which is based on an optimal management, regarding replicas positions on the frame and the choice of preamble, prevents loops and makes sure to have a unique preamble on one of the packet's replicas position. The goal is to further simplify packets localization, and improve the PLR performance by removing the error floor created by loops. On the one hand, we have seen that this distribution can prevent data localization correlations and rely only on preamble detection for packets localization. Then, in order to be able to compare the PLR of MARSALA-2, we have chosen to use a no loop system with 100 slots and the first level of $i = 1$ of Smart SPOTiT with 50 preambles. As a result, Fig. 3 shows that the PLR floor
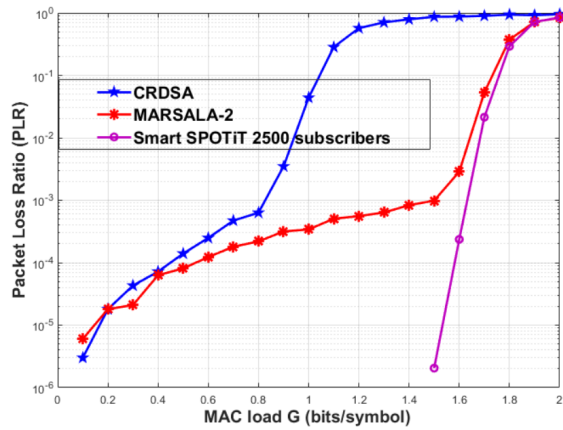
Fig. 3. PLR of smart SPOTiT, MARSALA-2 and CRDSA with QPSK modulation and turbo coding of rate $1/3$, 100 slots/ frame, 100 information bits, AWGN channel and $E_{\mathrm{s}}/N_0 = 10\ dB$
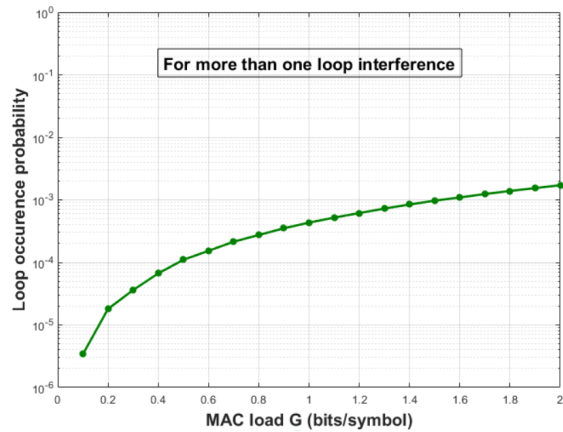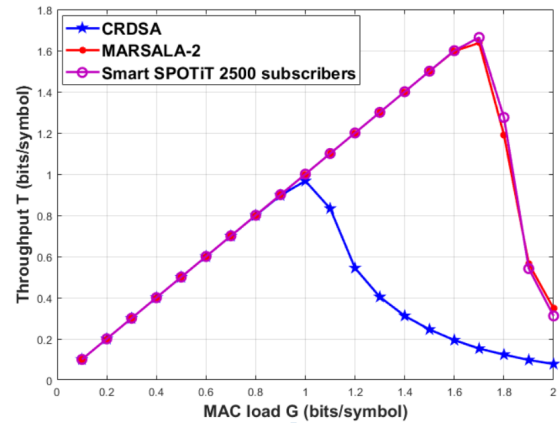

Fig. 5. Throughput of smart SPOTiT, MARSALA-2 and CRDSA with QPSK modulation and Turbo coding of rate $1/3$, 100 slots/ frame, 100 information bits, AWGN channel and $E_{\mathrm{s}}/N_0 = 10\ dB$

Fig. 4. Probability of more than one interference loop in a CRDSA-like frame of 100 time slots.

is no longer present. The throughput enhancement (Fig. 5) is insignificant because its collapse occurs at a load of 1.7 bits / symbol. At this level, the PLR is degraded in the same way for both MARSALA-2 and the Smart SPOTiT.

V. CONCLUSION AND FUTURE WORK

This paper summarizes a new synchronous random access technique over a multiuser channel which can be complementary to the legacy CRDSA. In particular when no more packets can be retrieved by the latter. It is mainly based on a centralized management, by the receiver, of time slot positions and the preamble to use for each transmitter. This optimal frame content distribution prevents loops between users and makes sure one of the replicas of the same packet has a unique preamble on its time slot position. Consequently, better PLR performance is resulted and only preamble detection is used to locate packets replicas. Future work should further extend the proposed technique to an asynchronous environment with a prior knowledge of replicas positions on virtual frames that are specific to each user independently from the others.

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