ME-SSA: an Advanced Random Access for the Satellite Return Channel

G. Gallinaro, N. Alagha, R. De Gaudenzi, K. Kansanen, R. Müller, P. Salvo Rossi

***Abstract*—The paper analyzes the performance of an advanced random access scheme for the return channel of a satellite communication link. The scheme is an evolution of the E-SSA scheme proposed in [1], [2] that couples an asynchronous Spread Spectrum Aloha access with Successive Interference Cancellation (SIC) at the central Gateway (GW) receiver to increase the channel throughput. Main feature of the proposed scheme is the exploitation of an approximate linear Minimum Mean Square Error (MMSE) detector in place of the conventional Single User Matched Filter (SUMF) detector used in E-SSA. A gain of 50% in terms of spectral efficiency is achieved over E-SSA in most typical scenarios.**

***Index Terms*—CDMA, Spread Spectrum, Satellite Communications, Up Link, Multiple Access, Random Access.**

I. INTRODUCTION

THIS paper investigates the performances of a new advanced random access scheme specifically designed for the return channel of a satellite communication link. The proposed scheme is an evolution of the Enhanced-Spread Spectrum Aloha (E-SSA) proposed in [1] and [2]. As the acronym suggests E-SSA improves the performance of the conventional Spread Spectrum Aloha ([4], [5]) random access through a process of Successive Interference Cancellation (SIC).

It is known that Spread Spectrum Aloha (SSA) (assuming a sufficiently high Processing Gain, PG) may significantly exceed the throughput provided by non-spread Aloha (slotted or unslotted) [5]. An issue with SSA is its sensitivity to signal power unbalance which can significantly reduce its spectral efficiency. The exploitation of interference cancellation in E-SSA actually turns signal power unbalance into an advantage as access efficiency is actually increased by the variation of power in incoming packets. It was actually found [7] that optimal performances of E-SSA are achieved for power distributions of incoming packets which are approximately uniform when power is measured in logarithmic scale (i.e. dB). The optimal range of packet powers, for a given peak E_b/N_0, is also addressed in [7].

The E-SSA access scheme is very well suited for supporting a large population of terminals with very bursty traffic (e.g. M2M applications, interactive TV, messaging). Demand Assignments Multiple Access (DAMA) strategies are, in fact, not very well suited to cope with such traffic scenario and large size networks due to the large signaling overhead which would result in such cases [5]. The E-SSA random access has been recently adopted in the S-MIM standard of ETSI for use in the return channel of S-band multimedia satellites ([8], [9]).

The E-SSA scheme is particularly attractive since it requires minimal processing on the user terminals as all cancellation processing is done at the GW receiver. Also, no network timing synchronization is required as terminal access to the RF channel is fully asynchronous. Furthermore, no user identification is required prior to user packet detection and decoding. In fact, all users reuse the same spreading codes. Code collision probability is, in fact, minimized by the use of long spreading codes (not repeating within the packet) and the truly asynchronous nature of user transmission.

A single spreading code for all users is typically used in E-SSA systems as this reduces the GW receiver complexity which has only to search for a single preamble to detect the presence of packets on air. Given the fact that packet acquisition is likely the most computational intensive part of the receiver, the advantage of searching for a single waveform signature is evident.

Current E-SSA random access adopts a conventional Single User Matched Filter (SUMF) receiver for despreading the received packet. It is well known, however, that a linear MMSE detector can boost the achievable performances in a CDMA access scheme [10]. Using the MMSE detector in place of the SUMF detector in an E-SSA like random access has thus the potential of further improving the spectral efficiency in particular when the packets' power unbalance is reduced. On the other hand the MMSE-SIC processing is able to reach the multiple access channel capacity, as shown in [11]. Given its use of the MMSE detector we call this new random access scheme ME-SSA (MMSE Enhanced Spread-Spectrum Aloha).

Incorporating the MMSE detector in an E-SSA like scheme is not straightforward. E-SSA is in fact a totally asynchronous system with packets being randomly transmitted. The active transmitters are changing continuously. This fact, together

This work was supported by ESA Contract No 4000108548/13/NL/JK.

G. Gallinaro is with Space Engineering S.p.A., Rome, Italy.

N. Alagha and R. De Gaudenzi are with the European Space Agency, Noordwijk, The Netherlands.

R. Müller is with Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany.

K. Kansanen and P. Salvo Rossi are with NTNU, Trondheim, Norway.

with the use of long spreading code sequences and relatively short packets, makes infeasible the use of an adaptive MMSE detector. Since the implementation of MMSE through a direct matrix inversion is too cumbersome, the adopted solution is the use of a multistage detector approximating the MMSE one ([12]-[15]).

The remainder of the paper is organized as follows. Section II provides some detail on the ME-SSA access design as well as some information on the signal design and the trade-offs considered in such design. Section III provides a short description of the considered GW receiver processing. Finally, simulation performances are addressed in Section IV where performances of E-SSA and ME-SSA in different conditions are shown and results discussed.

II. ME-SSA ACCESS DESIGN

A. *E-SSA signal design*

As mentioned in the introduction, the ME-SSA is an evolution of the E-SSA random access. Key design drivers for the E-SSA design were the asynchronous nature of user transmission, the lack for user identification (before actual packet decoding), the user terminals' low-cost and low-transmitting power requirements and the affordable GW receiver complexity.

The lack of user identification and the need to limit the GW receiver complexity calls for a signal design based on spread spectrum signal with a long spreading code shared by all the users in order to only search for one code in the receiver.

The E-SSA waveform specification was largely based on the 3GPP W-CDMA up-link waveform ([16]-[18]). The same FEC scheme (turbo code with rate 1/3) was also retained as well as the presence of a Physical layer Control Channel (PCCH), carrying reference symbols to aid the receiver demodulator and an optional signaling field informing on the actual carrier format. The actual traffic data are carried by a Physical Data CHannel (PDCH). Both channels are BPSK modulated in the up-link. Similarly to 3GPP W-CDMA, the two channels are code multiplexed (each channel using a different Walsh Hadamard orthogonal code as spreading code) and mapped to the I and Q axis of a complex signal which is in turn scrambled by a complex long scrambling code (Fig. 1). The above approach is justified on the fact that BPSK modulation is actually optimum when a SUMF detector is used at the receiver and ensure robustness to possible channel carrier phase estimation errors.

Differently from the 3GPP W-CDMA the long scrambling code has the same length as the packet. It never repeats within a packet. The long spreading code approach, in addition to minimizing the collision probability is also optimal when used in a FEC coded system as it randomizes the interference, forcing it to the equivalent of Gaussian noise.

B. *ME-SSA signal design*

BPSK modulation is not optimal when a linear MMSE detector (or one of its approximations) is used at the receiver. QPSK modulation appears preferable in such case [19]. In fact, the MMSE detector performances decrease for higher system loading [20]. With QPSK modulation the system loading is halved with respect to BPSK modulation (assuming the same FEC code rate for both options) thanks to the signal space dimensions doubling. The adoption of QPSK modulation requires a modification of the E-SSA waveform design. In particular, the code multiplexing between PCCH and PDCH is not any more appropriate. Time domain multiplexing between the two channels is now adopted as this allows a constant envelope signal (before filtering). A single binary Walsh Hadamard spreading code followed by a complex long scrambling code is thus adopted (Fig. 2) similarly to the approach chosen for the down-link of the 3GPP W-CDMA.

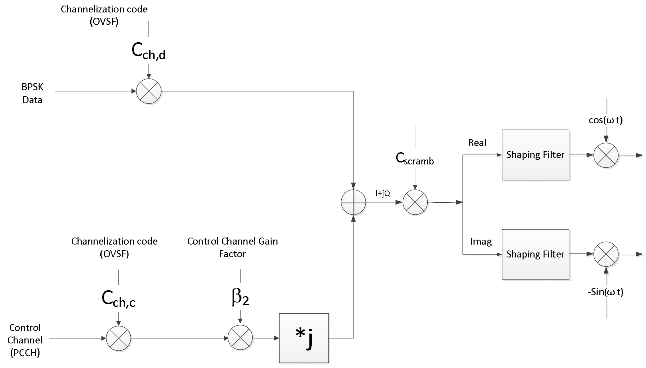

Figure 1

Figure 1. Spreading and Scrambling strategy in E-SSA

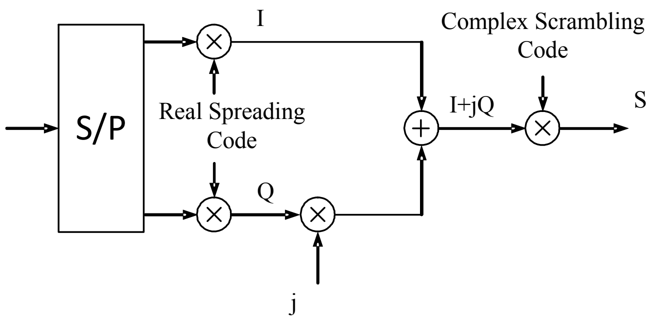

Figure 2. Spreading and Scrambling strategy in ME-SSA

III. RECEIVER DESIGN

Different receiver architectures at the GW can be considered for demodulating, decoding and cancelling the incoming packets. In the following we will consider a serial receiver approach as this was implemented in our software simulator to assess the performances of both E-SSA and ME-SSA schemes (Fig. 3). An alternative receiver architecture is the shared memory implementation which is briefly described in [21]. The two proposed receiver architectures are equivalent as far as performances are concerned. The serial receiver architecture is actually composed of a serial chain of all equal modules with each modules composed of a set of demodulators and decoders for the incoming packets and a set of re-modulators allowing the subsequent cancellation of the

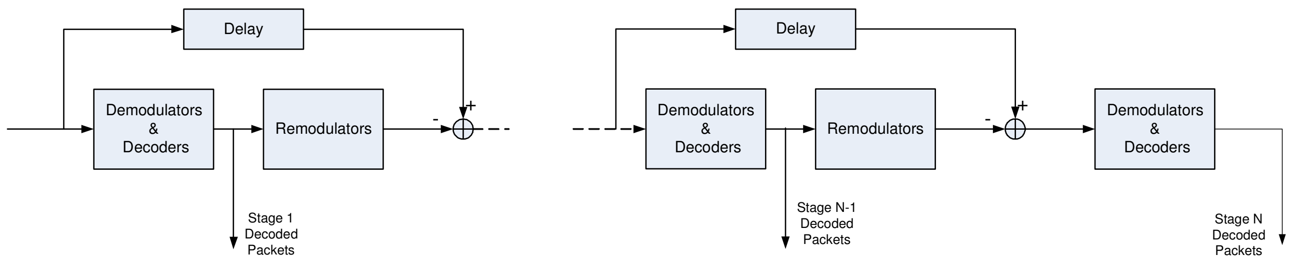

Figure 3. Serial Receiver Architecture

regenerated signal from a suitably delayed input signal replica. Such a delayed input signal replica, after cancellation of the decoded packets, is then provided to the next receiver stage for further processing. The number of stages in the receiver is thus equivalent to the number of SIC iterations in the cancellation process. The above discussed receiver architecture is quite general and applicable for both E-SSA and ME-SSA. Clearly given the different waveform formats the actual demodulators and re-modulators will differ. However, the main difference between the receiver for ME-SSA and E-SSA is the spread spectrum signal detector used in the demodulator. E-SSA uses a conventional SUMF detector and ME-SSA adopts a detector approximating MMSE detection.

As noted before, a direct MMSE solution computation is unfeasible for systems with a large number of active users. In fact, considering for simplicity of notation a chip synchronous system (for an asynchronous scheme the complexity would further grow for the need to process interval comprising multiple symbols) with spreading factor equal to N and with K users on air, the following signal model can be written:

$$\mathbf{y} = \mathbf{\Psi}\sqrt{\mathbf{P}}\mathbf{b} + \mathbf{w} \tag{1}$$

where $\mathbf{\Psi}$ represents the spreading matrix of size N by K and $\mathbf{P}$ is K by K a diagonal matrix containing the users' powers. The N by N covariance matrix of the thermal noise vector $\mathbf{w}$ is diagonal with all equal diagonal elements.

We recall that the MMSE matrix $\mathbf{M}$ is:

$$\mathbf{M} = \mathbf{R}^{-1}\mathbf{\Psi}^H \tag{2}$$

with $\mathbf{R}$ being the signal plus noise covariance matrix given by:

$$\mathbf{R} = \sigma_w^2\mathbf{I} + \mathbf{\Psi}^H\mathbf{P}\mathbf{\Psi}$$

Given the previously mentioned complexity of inverting $\mathbf{R}$, a practical solution is instead to approximate the MMSE detector through a multistage detector approach ([12]-[15]) whose complexity scales linearly with the number of users.

The multistage detector approximates the inverse of the covariance matrix, $\mathbf{R}^{-1}$, by a polynomial expansion in $\mathbf{R}$, i.e.:

$$\mathbf{R}^{-1} \approx \sum_{k=0}^{S} w_k \mathbf{R}^k \tag{3}$$

This expansion can be derived applying the Cayley-Hamilton theorem to the matrix $\mathbf{R}$. The theorem states that a square matrix of size K by K whose eigenvalues are $\Lambda=\{\lambda_1, \lambda_2, \dots \lambda_K\}$ is a zero of its characteristic polynomial, i.e.:

$$\prod_{k=1}^{K}\left(\mathbf{R} - \lambda_k\mathbf{I}\right) = \mathbf{0} \tag{4}$$

Expanding the above equation we have:

$$\sum_{k=0}^{S} c_k \mathbf{R}^k = \mathbf{0} \tag{5}$$

where the coefficients c_k are functions of the eigenvalues Λ. The above equation can be rewritten after multiplying both sides for $\mathbf{R}^{-1}$ and solving for $\mathbf{R}^{-1}$ as:

$$\mathbf{R}^{-1} = -\sum_{k=0}^{K} \frac{c_{k+1}}{c_0}\mathbf{R}^k \tag{6}$$

Hence K stages would be sufficient to invert the matrix $\mathbf{R}$. In practice a number of stages equal to 2 or 3 can already give a good approximation of $\mathbf{R}^{-1}$. Since the eigenvalues of a large random matrix only depend on its statistics, the eigenvalue can be computed off-line thus allowing to derive the coefficients w_k also by off-line computation.

For a multistage detector with S stages (with $S< K$), optimal weighting is discussed in [13]-[15]. It can be shown that the coefficients that minimize the MSE due to the discarded terms in (3), satisfy a set of Yule-Walker equations, i.e.:

$$\begin{bmatrix} m_1 \\ m_2 \\ \dots \\ \dots \\ m_{S+1} \end{bmatrix} = \begin{bmatrix} m_2 + \sigma^2 m_1 & \dots & m_{S+2} + \sigma^2 m_{S+1} \\ m_3 + \sigma^2 m_2 & \dots & m_{S+3} + \sigma^2 m_{S+2} \\ \dots & \dots & \dots \\ \dots & \dots & \dots \\ m_{S+2} + \sigma^2 m_{S+1} & \dots & m_{2S+2} + \sigma^2 m_{2S+1} \end{bmatrix} \begin{bmatrix} w_0 \\ w_1 \\ \dots \\ \dots \\ w_S \end{bmatrix}$$

where the m_k are the eigenvalue moments given by:

$$m_k = \frac{1}{K}\sum_{i=1}^{K}\lambda_i^k$$

The multistage detector actually builds an approximation to $\mathbf{R}^{-1}\mathbf{\Psi}^H$ by concatenating S stages with each stage performing despreading (with a SUMF detector) and then re-spreading of the input signal. These operations are respectively equivalent to multiply by matrix $\mathbf{\Psi}^H$ (despreading) and then by matrix $\mathbf{\Psi}$ (re-spreading) the input signal. The coefficients w_k can be chosen to approximate the MMSE detector or other detectors (e.g. the decorrelator).

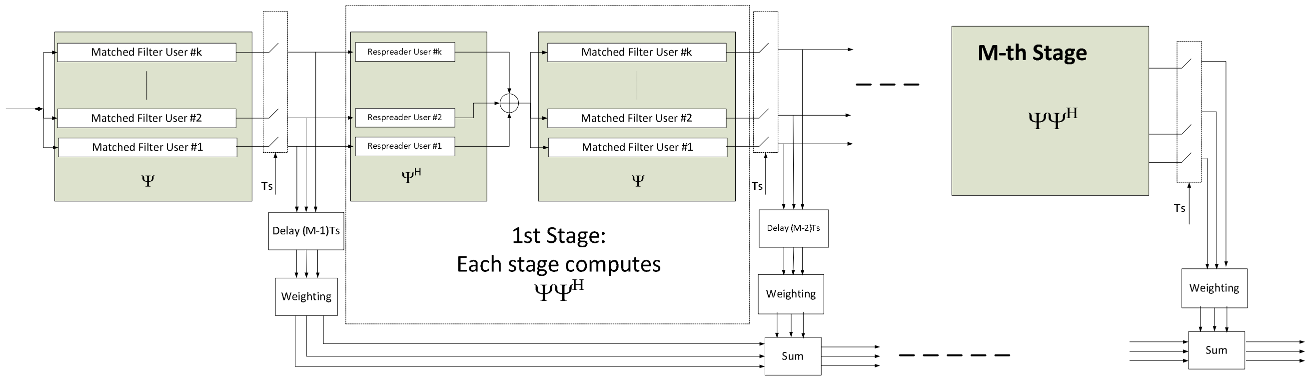

Figure 4. Principle scheme of a multistage detector.

However, the optimal weighting coefficients must be calculated. Although the Yule-Walker equations can be solved in quadratic time (through the Levinson-Durbin recursion) this approach still has excessive complexity if one considers that eigenvalues have to be estimated for the method to be applicable. In general, the computation of the eigenvalues of a matrix has cubic complexity. Hence, deriving such optimal coefficient can be a problem of similar complexity to matrix inversion. Luckily, for sufficiently large Spreading Factor (SF), asymptotic weight values can be computed off-line. This is because eigenvalue moments do not depend on the actual spreading code on air (at least for sufficiently high spreading factor) but only on system loading (i.e. number of users on air at a given time), user power distribution and waveform characteristics (e.g. roll-off).

The principle scheme of the multistage detector is summarized in Fig. 4 where it is evident the composition of each stage by a despread unit (composed by SUMF detectors) followed by a respreader unit. The output of the various SUMF detectors is then weighted to compute the final despread signals. The resulting multistage detector complexity is only marginally higher than that of a SUMF detector.

In practice, in an asynchronous random access environment, computation of the weights shall be done dynamically as new packets on air are detected or older packets terminate. Still, complexity of such operations is marginal. Furthermore, E-SSA typically requires a larger number of SIC iterations with respect to ME-SSA to achieve the optimal performances particularly in presence of large power unbalance between packets. Finally, we have to stress that the actual complexity of the receiver in both E-SSA (using SUMF) and ME-SSA (using the multistage detector) is dominated by the packet acquisition circuitry which is not addressed in this paper (see [21] for a discussion of packet acquisition).

IV. Performance Assessment

Performances of E-SSA and ME-SSA have been derived using a physical layer simulator also implementing the random access layer by asynchronously generating packets according to some arbitrary distribution. In this paper we present results where packet distribution is Poisson (exponentially distributed packet inter-arrival time). For simplicity, in each simulation run, a single packet type (i.e. packet length, spreading factor, and FEC code rate) is considered. Although acquisition has been considered ideal in the following simulation results, a preamble of 96 symbols (before spreading) was also included in the simulations and real channel estimation has been considered. A PCCH (control channel) @-10 dB relative power level was considered for E-SSA. The PCCH was used to carry only pilot symbols for channel estimation purposes. For ME-SSA the time multiplexed control channel was also carrying solely pilot symbols. In particular, one symbol out of 10 was associated to the control channel. The overhead for the control channel was thus identical in the performed simulations for both E-SSA and ME-SSA. However no optimization of the PCCH overhead was done.

If not stated otherwise, the number of receiver stages used in the simulations is 10 for both E-SSA and ME-SSA, allowing for 10 SIC iterations. For ME-SSA, a three-stage multistage detector was used instead of the SUMF detector of E-SSA.

Fig. 5 shows a performance comparison between E-SSA and ME-SSA in the case that all packets are received at the same power. The comparison is done in terms of spectral efficiency and Packet Loss Ratio (PLR). Increasing the system load results in higher spectral efficiency until a point where the PLR starts to grow very rapidly due to the excessive interference in the system. Further increase of the system load will ultimately produce a collapsing of the performances. As PLR=10^{-3} appears to be a reasonable operating requirement for several application scenarios, we consider as actual spectral efficiency of the system that one corresponding to such target PLR.

The simulations reported in Fig. 5 were done for the same Es/No after despreading. As ME-SSA uses QPSK modulation instead of the BPSK used in E-SSA whilst the FEC code rate was the same, the E_b/N_0 in ME-SSA was 3 dB lower than in E-SSA. Notwithstanding the lower E_b/N_0, from Fig. 5, it appears that in such uniform packet power case, ME-SSA provide about 50% higher spectral efficiency than E-SSA at the target PLR of 10^{-3}. Actually, advantage of ME-SSA can be even larger if comparison is done at higher E_s/N_0. In fact,

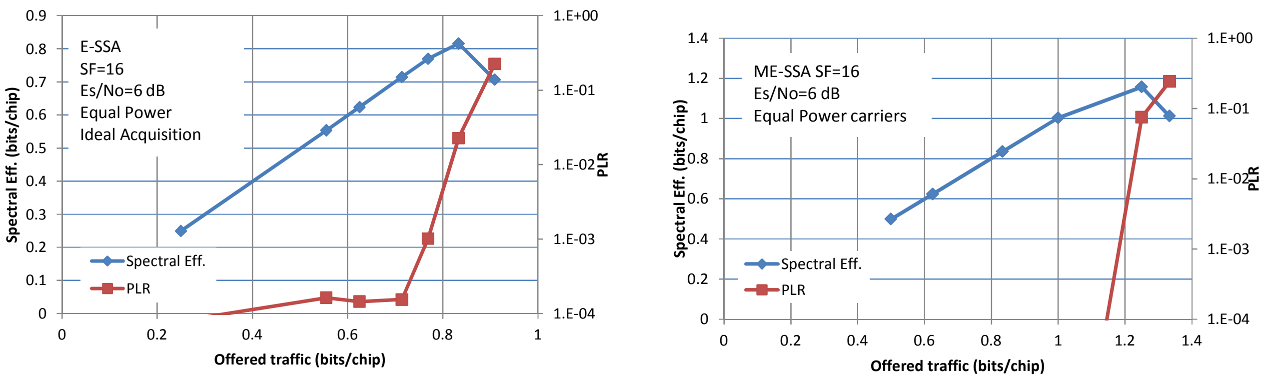

Figure 5. Comparison of performances between E-SSA and ME-SSA @Es/No=6 dB and equal carrier power (SF=16). Packet Length was 1200 info bit with 3GPP code rate 1/3FEC. 96 symbols preamble. Ideal acquisition considered. 10 SIC iterations performed

performance of ME-SSA improves with the SNR whilst those of E-SSA are almost insensitive (in such uniform packet power case) to the SNR.

All incoming packets having the same power will clearly not happen in practical systems (even on satellite links). Actually [7] has shown that E-SSA performances are maximized, for a given peak E_b/N_0, if the incoming packet are received at power levels (in dB) which are approximately uniformly distributed. The range of E_b/N_0 will thus range from the peak E_b/N_0 down to a minimum value that is larger than the minimum E_b/N_0 threshold required for correct packet decoding (for the target PLR). The margin over the threshold depends on the cancellation efficiency of the SIC process. With ideal cancellation efficiency the optimal power range bottoms out at the minimum E_b/N_0 required to achieve the target PLR. In the S-MIM specification of E-SSA [9] a signaling mechanism is foreseen to support an explicit transmit packet power randomization aiming at achieving the optimal power distribution. In practice, the packet power distribution will never be identical to the optimal one. Anyway, computing the performances with such optimal power distribution will give us an upper limit to the achievable performances. Fig. 6 shows a further comparison between E-SSA and ME-SSA performances in presence of packet power randomization (with uniformly distributed packet power). The performance comparison was done for the same E_b/N_0 (11.77 dB in both cases). The spreading factor (SF) of ME-SSA was double of that of E-SSA (32 against 16 in the specific case here) as the comparison was done for the same occupied bandwidth and information bit rate. The advantage of ME-SSA is even larger than 50% in such a case. It has to be observed that the required number of SIC iterations required to get optimal performances is generally larger in presence of a larger packet power dynamic range. This is particularly true for E-SSA. As stated before in Fig. 6 the continuous curves refer to the performance achievable with 10 SIC iterations. A single point from each performance curve (cross/triangle) has been also re-simulated with a larger number of iterations (20 for E-SSA and 18 for ME-SSA). Although, the multistage detector approximation to an MMSE detector is strictly valid only for very large SF, good performances are actually achieved with the multistage detector even for very small SFs. In this regard, Fig. 7 shows the performances of ME-SSA @SF=4 and E_b/N_o=11.77 dB.

For comparison the performances of E-SSA at the same E_b/N_o are also shown. As the comparison is done for the same bandwidth, a SF=2 is required for E-SSA. For such extremely small SF the performance of E-SSA are particularly degraded (particularly if we consider performances at a target PLR=10^{-3}). For ME-SSA there is instead only a very minor decrease of performance with respect to the case of Fig. 6.

Results showed so far assumed a-priori knowledge of packets on-air. In practice a preamble is used for packet detection. For E-SSA the packet preamble is sized in order to have a good detection probability at an $E_b/(N_0+I_0)$ such that the decoder can provide, with some non-negligible probability, a correct decoding. In the S-MIM specs, a 96 symbols preamble is defined for such purpose. In ME-SSA, there could be an advantage in also detecting the preamble of packets whose $E_b/(N_0+I_0)$ is below the threshold for correct decoding, as the multistage detector requires a good knowledge of the system load as well as the packet power distribution for optimal operation. As a matter of fact, simulation results shown in this paper for E-SSA will not change significantly if also the acquisition process is fully simulated. For ME-SSA, some impact is expected when real acquisition is simulated and a longer preamble might be preferable in some case.

V. CONCLUSIONS

An evolution of the E-SSA random access scheme exploiting a multistage detector approximating the linear MMSE detector has been presented. The new access scheme allows a significant improvement of the achievable throughput making this random access scheme much more appealing for a wide range of services beyond those typically considered as targets for random access. The new access scheme can also be employed in relatively narrow-band channels as good performances can be achieved even with very low spreading factor.

REFERENCES

[1] O. del Rio Herrero, R. De Gaudenzi, A high efficiency scheme for quasi-real-time satellite mobile messaging systems, in the Proc. of the

10th International Workshop on Signal Processing for Space Communications, SPSC 2008, 6-8 Oct. 2008, Rhodes Island, Greece.
[2] O. del Rio Herrero, R. De Gaudenzi, "High Efficiency Satellite Multiple Access Scheme for Machine-to-Machine Communications", IEEE Trans. on Aerospace Engineering, Oct. 2012.
[3] De Gaudenzi, O. Del Rio Herrero, "Advances in Random Access protocols for satellite networks", International Workshop on Satellite and Space Communications, 2009, IWSSC 2009, Siena, Italy Sept. 9-11, 2009, pp. 331-336.
[4] United States Patent No. 5,537,397, N. Abramson, July 16, 1996, Spread Aloha CDMA data communications.
[5] O. del Rio Herrero, G. Foti, and G. Gallinaro, "Spread-Spectrum Techniques for the Provision of Packet Access on the Reverse Link of Next-Generation Broadband Multimedia Satellite Systems", IEEE Journal on Sel. Areas in Comm., vol. 22, no. 3, pp. 574 - 583, Apr. 2004.
[6] N. Abramson, "The Throughput of Packet Broadcasting Channels", IEEE Trans. Communications, vol. COM-25, no. 1, pp. 117-128, Jan. 1977.
[7] F. Collard and R. De Gaudenzi, On the Optimum Packet Power Distribution for Spread Aloha Packet Detectors with Iterative Successive Interference Cancellation, Submitted to IEEE Trans. on Wireless Communications, November 2013.
[8] ETSI TS 102 721-1 V1.1.1 (2011-12), "Satellite Earth Stations and Systems; Air Interface for S-band Mobile Interactive Multimedia (S-MIM); Part 1: General System Architecture and Configurations".
[9] ETSI TS 102 721-3 V1.1.1 (2011-12), "Satellite Earth Stations and Systems; Air Interface for S-band Mobile Interactive Multimedia (S-MIM); Part 3: Physical Layer Specification, Return Link Asynchronous Access".
[10] S. Verdu, and S. Shamai, "Spectral Efficiency of CDMA with Random Spreading", IEEE Transactions On Information Theory, Vol. 45, No. 2, March 1999.
[11] M.K. Varanasi and T. Guess, Optimum Decision Feedback Multiuser Equalization with Successive Decoding Achieves the Total Capacity of the Gaussian Multiple Access Channel, IEEE Proceedings of the 31st Asilomar Conference on Signals, Systems and Computers, Vol. 2, pp. 1405-1409, 2-5 November 1997, Pacific Grove, USA.
[12] S. Moshavi, E. G. Kanterakis, and D. L. Schilling, "Multistage linear receivers for DS-CDMA systems," Int. J. Wireless Inform. Networks, vol. 3, no. 1, pp. 1–17, Jan. 1996.
[13] R.R. Müller and S. Verdù, "Design and Analysis of Low-Complexity Interference Mitigation on Vector Channels, IEEE Journal on Selected Areas in Communications", vol. 19, Issue 8, pp. 1429-1441, Aug. 2001.
[14] L. Cottatelluci, M. Debbah and R.R. Müller, "Asymptotic Design and Analysis of Multistage Detectors for Asynchronous CDMA Systems", IEEE International Symposium on Information Theory, 27 June - 2 July 2004, Chicago, USA.
[15] L. Cottatellucci and R.R. Müller, "A Systematic Approach to Multistage Detectors in Multipath Fading Channels", IEEE Transactions on Information Theory, Vol. 51, Issue 9, pp. 3146-3158, Sept. 2005.
[16] ETSI TS 125 211 V3.12.0 (2002-09): Universal Mobile Telecommunications System (UMTS). Physical channels and mapping of transport channels onto physical channels (FDD).
[17] ETSI TS 125 213 V3.11.0 (2002-09): Universal Mobile Telecommunications System (UMTS). Multiplexing and channel coding (FDD).
[18] ETSI TS 125 213 V3.9.0 (2003-12): Universal Mobile Telecommunications System (UMTS). Spreading and modulation (FDD).
[19] G. Caire, S. Guemghar, A. Roumy, and S. Verdú, "Maximizing the Spectral Efficiency of Coded CDMA Under Successive Decoding", IEEE Transactions on Information Theory, vol. 50, no. 1, January 2004.
[20] S. Verdù and S. Shamai (Shitz), "Spectral Efficiency of CDMA with Random Spreading", IEEE Transactions on Information Theory, Vol. 45, No. 2, March 1999ù
[21] R. De Gaudenzi, O. del Rio Herrero and G. Gallinaro, "Enhanced spread Aloha physical layer design and performance", Int. J. Satell. Commun. Network. (2014), Published online in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/sat.1078.

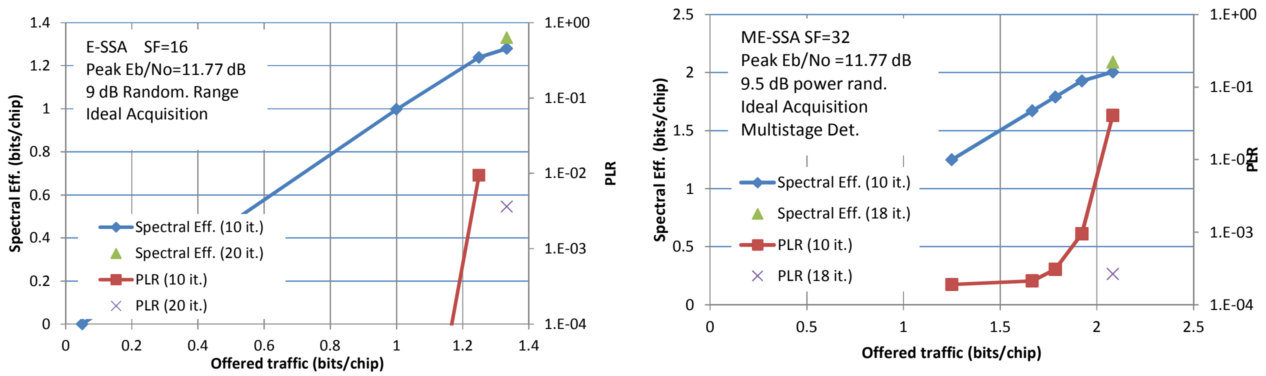

Figure 6. Comparison of performances between E-SSA and ME-SSA @ E_b/N_0=11.77 dB and power randomization. Packet Length:1200 info bit. FEC: 3GPP turbo-code rate 1/3. 96 symbols preamble. Ideal acquisition. 10 SIC iterations considered for both E-SSA and ME-SSA although some performance improvement can be obtained increasing the number of iterations (as shown from a single point also plotted for 20 iterations (left) or 18 iterations (right)

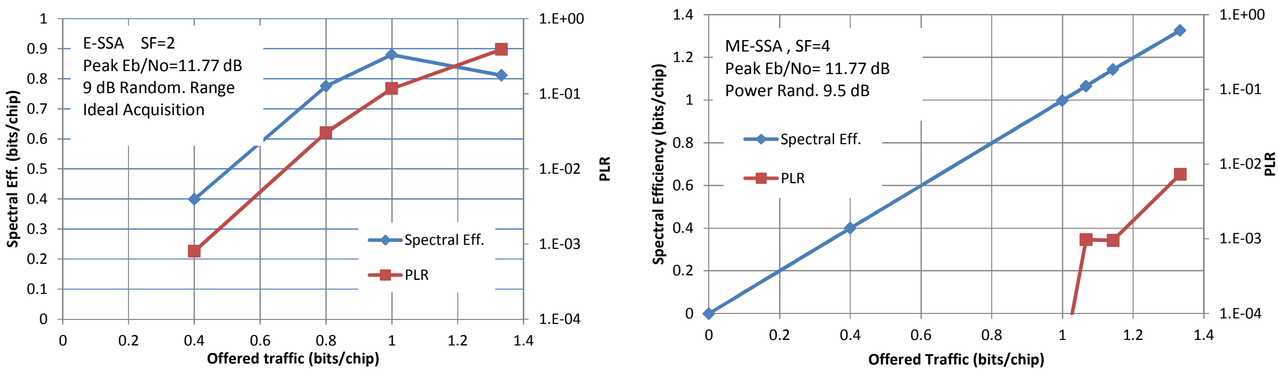

Figure 7 Comparison of performances at low SF between E-SSA and ME-SSA @E_b/N_0=11.77 dB and power randomization. Packet Length was 1200 info bit with 3GPP code rate 1/3FEC. 96 symbols preamble. Ideal acquisition considered. 20 SIC iterations were considered for both E-SSA and ME-SSA.