MC-CDMA and SCMA Performance and Complexity Comparison in Overloaded Scenarios

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***Abstract*—In 5G wireless networks, the perspective of very large number of simultaneous connections is challenging. In this sense, an overloaded system is a basic scenario of 5G multiple access techniques, that is, the number of active users is greater than the number of system subcarriers. Some schemes of non-orthogonal multiple access (NOMA) have been proposed in the literature and, two of them are compared in this paper. These NOMA techniques are the multi-carrier code division multiple access (MC-CDMA) and sparse code multiple access (SCMA). The performance, in terms of the mean bit error rate, and the decoding complexity, in terms of number of mathematical operations are evaluated. In MC-CDMA, the multi-user maximum likelihood detector (MU-MLD) implemented via sphere decoding (SD) algorithm is considered, which is the optimum receiver, but with polynomially complexity. In SCMA, a near optimal receiver is used, named as message passing algorithm (MPA), which is based on the sum-product algorithm, whose complexity does not depend, directly, on the number of users. Monte Carlo simulations and theoretical expressions are used to compare both multiple access techniques in the uplink of a cellular scenario. Results show that, for an equivalent spectral efficiencies, MC-CDMA performs better than SCMA and SD algorithm is less complex than MPA.**

***Index Terms*—5G, MC-CDMA, Message Passing Algorithm, Overload Scenarios, SCMA, Sphere Decoder.**

I. INTRODUCTION

Future 5G wireless networks are expected to support different requirements. The main technical objectives for these systems are extremely high data rates, massive number of connected devices, ultra low latency and ultra reliable support for various critical applications [1]. Over the last decades, the multiple access technologies used in commercial wireless networks are code division multiple access (CDMA) and orthogonal frequency division multiple access (OFDMA), in 3G and 4G networks, respectively [2]. CDMA is characterized by its high interference immunity and OFDMA by its easy implementation and also by the immunity against undesirable effects produced by multipath channels [3].

Some multiple access techniques have been proposed for 5G networks. They can be divided into orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA). According to [4], NOMA allows multiple users to simultaneously occupy the same time-and-frequency resources, and they can be divided into power-domain NOMA, code-domain NOMA and spatial-domain NOMA. On the other hand, OMA techniques do not allows users to share the same resources simultaneously. Based on 5G requirement of massive number of connected devices, NOMA techniques are much more promising than OMA. So, this work compares the performance and complexity of two NOMA techniques.

The first technique, named as multi-carrier code division multiple access (MC-CDMA), was proposed in [5] and it is an hybrid scheme combining CDMA and OFDM (Orthogonal Frequency Division Multiplexing). As this technique is based on CDMA, users share the same bandwidth simultaneously and they can be differentiated by employing spreading sequences. However, unlike CDMA, MC-CDMA maps the chips of the spreading symbols in the frequency domain. As this technique is also based on OFDM, instead of the symbols being transmitted in only one carrier, the same information is sent over some subcarriers, which makes the chip duration equal to the symbol duration. Hence, modulation and demodulation stages of MC-CDMA are implemented through OFDM principles. These combinations, makes the MC-CDMA signal tolerant against frequency selective channels, inter-symbol and inter-carrier interference (ISI, ICI) through the use of cyclic prefix and equalization [6]. Therefore, MC-CDMA is an interesting option for future communication standards, because it has an inherent frequency diversity [7].

The second technique was proposed in [8], and also combines CDMA with OFDM. It is named as sparse code multiple access (SCMA). Instead of traditional DS-CDMA random spreading, SCMA uses low density signatures (LDS) technique [9], in which the spreading sequences are designed with some nonzero elements (chips). The sequence sparsity allows the use of a near optimal maximum likelihood (ML) receiver, but less complex, named as message passing algorithm (MPA). Besides that, the SCMA main idea is to combine the symbol mapping and the spreading stage, and thus, the bits to multidimensional codewords of a codebook. The key of the SCMA system is the codebook design, which improves its systematic capacity and performance, in terms of the mean bit error rate (BER). The optimum codebook design is still an open problem, and some suboptimal methods are proposed [10] - [14]. This work is based on the codebook design presented in [10], where a multidimensional constellation is designed with a good Euclidean distance profile and then the original constellation is rotated to achieve a good product distance [15].

This paper presents a performance comparison in terms of mean bit error rate, between MC-CDMA and SCMA techniques. In addition, their complexities are evaluated in terms of the number of operations. Even though both techniques are based on CDMA and OFDM, the recommended multiuser detector, in order to obtain a near optimal detection, is different for each one of them. The multiuser maximum likelihood detector (MU-MLD) could be used in both cases, but as the detection complexity grows exponentially with the number of users ($\mathcal{O}^K$) [16], it becomes infeasible in overloaded scenarios[1]. Therefore, as mentioned before, MPA is used as the SCMA detector. For MC-CDMA, the MU-MLD is implemented using the sphere decoding (SD) technique [17], which transforms the decoding process into a tree search algorithm, reducing the detection complexity.

In what follows, lowercase letters (x), bold lowercase letters ($\mathbf{x}$) and bold uppercase letters ($\mathbf{X}$) denote scalar, vectors and matrices, respectively. In addition, $(\cdot)^T$ denotes transpose, $\|\cdot\|$ is Euclidean norm and $\mathrm{j} = \sqrt{-1}$.

II. System Model

The uplink of a multiple access system is considered. The spectral spacing between subcarriers is considered to be greater than the channel coherence bandwidth [18], which ensure independent fadings[2] in different subcarriers. On the transmission terminals and at the base station receiver only one antenna is considered. The channel is modeled by a $\mathcal{CN}(0,1)$, where the channel gain can be written as $h_{g,k} = \alpha_{g,k}\exp(\mathrm{j}\phi_{g,k})$, where $\alpha_{g,k}$ is the Rayleigh fading and $\phi_{g,k}$ is a phase uniformly distributed over $[0, 2\pi)$ in g-th subcarrier of the k-th user. Besides that, the received signal is corrupted by additive white Gaussian noise (AWGN), which can be modeled by a zero-mean Gaussian random variable whose components have variance $\sigma_n^2 = N_0/4T_s$, where N_0 is the unilateral noise power spectral density and T_s is the symbol duration.

If K user equipments transmit their signals at the same time, the received signal at the base station can be expressed as,

$$\mathbf{y} = \kappa\mathbf{H}\mathbf{s} + \mathbf{n} \tag{1}$$

where κ is a normalization factor for the transmitted power, $\mathbf{H}$ is the channel gain matrix, $\mathbf{s}$ is a K-dimensional column vector with the transmitted symbols and $\mathbf{n}$ is the complex additive white Gaussian noise vector.

III. MC-CDMA and SCMA Overview

As mentioned before, this work compares the performance and complexity of MC-CDMA and SCMA. Thus, based in (1), each multiple access technique processes the signals according to their respectively multiuser detector. An overview of these multiple access technologies is presented in the following.

A. MC-CDMA

For MC-CDMA, the information symbols are spread by a random spreading sequence of length G and, as a multicarrier technique, each chip is transmitted over G subcarriers. As a consequence, the chip period (T_c) is equal to the symbol duration (T_s), as occurs in OFDM systems, i.e., $T_c = T_s$. Thus, the same modulation and demodulation process of OFDMA can be applied for MC-CDMA.

Fig. 1 shows the k-th user transmitter block diagram, where the bits are mapped into symbols. These symbols are transmitted over different subcarriers according to the spreading sequence of length G. In order to obtain frequency diversity, a frequency domain interleaving is applied to ensure that the separation between adjacent subcarriers is greater than the channel coherence bandwidth. After the interleaving stage, each chip is modulated by one of the G orthogonal subcarriers [6].

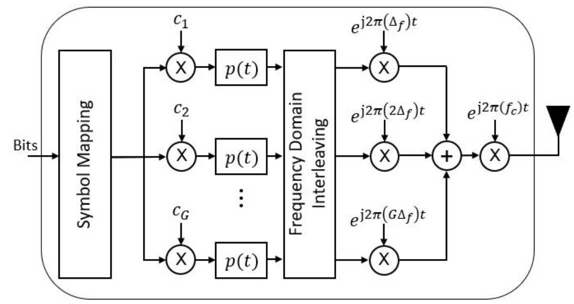


Fig. 1: Block diagram of MC-CDMA transmitter for k-th user.

Fig. 2 shows the block diagram of a MC-CDMA receiver, which is situated at the base station. It can be observed that, after the demodulation stage, a multiuser detector is employed to take decisions on the transmitted symbols. In this work, a MU-MLD detector is employed, which is implemented via SD algorithm.

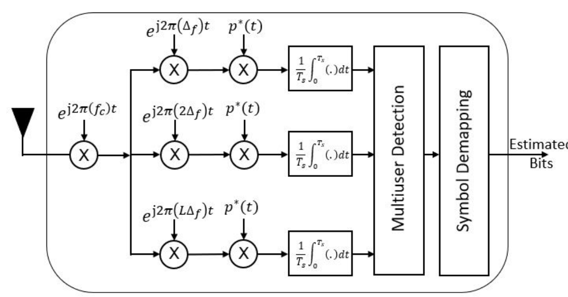


Fig. 2: Block diagram of MC-CDMA receiver at the base station.

The SD detector [17], allows the MU-MLD implementation with reduced complexity. The MU-MLD chooses the vector $\hat{\mathbf{s}}$ via the minimum distance criterion [16]:

$$\hat{\mathbf{s}} = \arg\min_{\hat{s}} \left|\left|\mathbf{y} - \kappa\mathbf{H}\hat{\mathbf{s}}\right|\right|^2 \tag{2}$$

where $\kappa = A/(2\sqrt{G})$ is the normalized factor for MC-CDMA transmission, A is the signal amplitude of all users considering perfect power control and $1/2$ appears due to the modulation/demodulation process. $\mathbf{H}$ is a $G\times K$ matrix, whose (g,k)-th element is given by the product of $\alpha_{g,k}$ and $c_{g,k}$, where $c_{g,k}$ is the g-th chip of the spreading factor of the k-th user.

The SD algorithm performs a search of all symbol vectors, $\hat{\mathbf{s}}$, within a hypersphere of radius $\mathcal{R}$, centered at the received vector $\mathbf{y}$, which is given by (1). Thus, the MU-MLD problem is

[1]An overloaded scenario refers to a system where the number of active users is greater than the number of system subcarriers.

[2]In wireless systems, fading refers to a specific kind of attenuation which is highly frequency and time dependent.

transformed into a tree search algorithm, where the symbols associated with the path leading to the final node with the smallest metric results in the algorithm decision. Different pruning techniques can be employed to eliminate sub-trees and to arrive to the final solution with lower complexity. In this work, the depth-first pruning technique is used [19]. Moreover, in order to employ SD algorithm, matrix $\mathbf{H}$ must be factorized. Thus, in order to support detection in overloaded scenarios, $K > G$, MMSE sorted QR factorization is considered [20], that also contribute to complexity reduction [21].

In [22], theoretical expressions of the MC-CDMA minimum complexity, in terms of the number of complex operations performed by the SD detector, are obtained. This minimum number of operations considers MMSE sorted QR factorization and the aforementioned pruning technique. These expressions are obtained for high signal-to-noise ratio, where there is a high probability that the first final node reached in the tree is the one with the smallest metric. These expressions show the minimum number of additions/subtractions and multiplications/divisions operations performed by the SD detector and they are respectively given by,

$$N_{AS}^{SD} = K^3 + \left(G + \frac{M}{2}\right)K^2 + \left(G + \frac{3M}{2} - 2\right)K + M, \quad (3)$$

$$N_{MD}^{SD} = K^3 + \left(G + \frac{3}{2} + M\right)K^2 + \left(G + \frac{1}{4} + M\right)2K + 3M. \quad (4)$$

where M is the modulation order. From (3) and (4), we can conclude that SD minimum complexity is cubic, that is $\mathcal{O}(K^3)$.

In [22], it has been presented a theoretical analysis of an uplink MC-CDMA scenario with MU-MLD detection implemented via SD algorithm, which results in mean BER asymptotes expressions. For 4-QAM modulation, the mean BER asymptote is given by

$$\overline{P_b} \approx \frac{1}{2}\binom{2G-1}{G}\left(\frac{1}{2\overline{\gamma_b}}\right)^G \left[\sum_{l=0}^{1}\frac{\binom{2K}{l}}{(2^{K-l})^G} + \sum_{l=2}^{2K-1}\frac{\binom{2K}{l} - \binom{2K-2}{l-2}}{(2^K - l)^G}\right] \quad (5)$$

where $\overline{\gamma_b}$ is the mean signal to noise ratio (SNR), which is given by $\overline{\gamma_b} = (E_b/N_0 \log_2 M)/G$. From (5), the MC-CDMA diversity order is G. For 16-QAM and 64-QAM modulations, the mean BER asymptote is given by

$$\overline{P_b} \approx \mu(G, M)\binom{2G-1}{G}\left(\frac{\omega}{4\overline{\gamma_b}}\right)^G \quad (6)$$

where $\mu(G, M)$ and ω are functions of the modulation order M. They are given, respectively, by [22, eq.(3.32)] and [22, eq.(3.25)] .

B. SCMA

The SCMA technique assembles the QAM mapping, signal space diversity (SSD) and CDMA LDS spreading in a unique stage, where $\log_2 M$ bits are directly mapped to a multidimensional complex codeword. After the codebook mapping, the sparse codeword is modulated in OFDM subcarriers. Fig. 3 shows the basic SCMA transmitter block diagram for k-th user. Each SCMA encoder is composed by a codebook set, where each codebook has M complex codewords. These codewords are L-dimensional, and similar to MC-CDMA, L is the number of subcarriers, $L = G$. Based on LDS spreading, and in order to reduce the detector complexity, each SCMA user is allowed to spread its symbols in only N resource elements ($1 \leq N \leq L$). Hence, from L codeword elements, only N of them are nonzero. In order to enable the receiver distinction of users, any two users cannot occupy the same set of N subcarriers. As a consequence, the SCMA system can support up to J users, $J = \binom{L}{N}$. When $J > L$, an overloaded scenario is created and the overload factor is given by $\beta = J/L$. Without loss of generality, the codebook set has J codebooks.

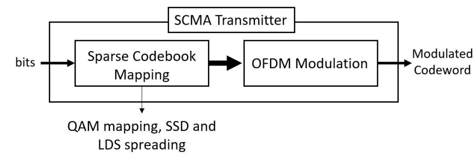


Fig. 3: Basic SCMA transmitter block diagram for k-th user.

Based on the variables described above, a mapping matrix, $\mathbf{F}_{L,J}$, can be constructed to represent the users resource allocation. The rows of the mapping matrix represent the subcarriers and the columns represent users. $F_{l,j} = 1$ means that the j-th user transmits information on l-th subcarrier. The $\mathbf{F}_{4,6}$ mapping matrix, is used in this work, that is given by

$$\mathbf{F}_{4,6} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}, \quad (7)$$

where the overload factor is $\beta = 150\%$.

A factor graph is a graphical representation of the user allocation on subcarriers. This graphical model can be built based on matrix $\mathbf{F}_{4,6}$ and is presented in Fig. 4. The variable node (μ_j) and function node (c_l) represents, respectively, the j-th user and l-th subcarrier. If an edge connects a variable node to a function node, it represents the user allocation at a specific subcarrier. As an example, the user 1, denoted by the variable node μ_1, transmits its information over subcarriers 1 and 2, denoted by variable nodes c_1 and c_2, respectively.

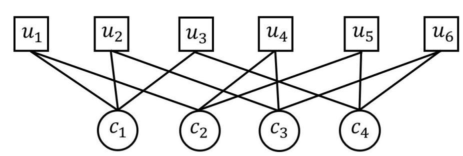


Fig. 4: Factor graph representation of a SCMA with $L = 4$, $J = 6$ and $N = 2$.

The factor graph shown in Fig. 4 can be classified as regular, once the number of edges connected to each function node (d_f) are equal and the number of edges connected to each variable node ($d_v = N$) are also equal. As the codebook design is not the scope of this work, the codebooks from [10] are used in the analysis.

The MPA detector is based on the sum-product algorithm [23] used on LDPC [24] decoders. This detector exchange extrinsic information, iteratively, among the nodes of the factor graph. The information from a function node (c_n) to a variable node (u_k) is denoted by $I^t_{c_n \to u_k}$ and $I^t_{c_n \leftarrow u_k}$ denotes the information from a variable node (u_k) to a function node (c_n), where I^t is the extrinsic information changed at the t-th iteration.

Given the sparse structure of the mapping matrix or, the factor graph, MPA detection could be used as a joint multiuser detector with reduced complexity. The sparser the codewords, less complex is the MPA detection [10]. MPA detector is based on three stages, e.g., 1) initialization, 2) iterative step and 3) symbols estimation. As an iterative algorithm, I_T iterations are executed.

The initialization stage, $t = 0$, considers that all variable nodes have the same probability [9]

$$I^0_{c_n \leftarrow u_k}(s_k) = \frac{1}{J}. \tag{8}$$

At the iterative stage, each iteration is composed by the variable node update and by the function node update. The variable node update is given by,

$$I^t_{c_n \to u_k}(s_k) = \sum_n \left[P\big(y_n|\mathbf{s}^{[n]}\big) \prod_{m \in \zeta_n \backslash k} I^{t-1}_{c_n \leftarrow u_m}(s_m) \right], \tag{9}$$

where $m \in \zeta_n \backslash k$ means the set of all variable nodes connected to the n-th function node, except the k-th. In (9), $P\big(y_n|\mathbf{s}^{[n]}\big)$ is the function node probability, given by,

$$P\big(y_n|\mathbf{s}^{[n]}\big) = \frac{1}{\sqrt{2\pi}\sigma} \exp\Big(-\frac{1}{2\sigma^2} \big|\big|y_n - \mathbf{h}^{[n]T}\mathbf{s}^{[n]}\big|\big|^2 \Big), \tag{10}$$

where σ^2_n is the AWGN variance, $\mathbf{h}^{[n]}$ is the channel gain of the n-th chip and $\mathbf{s}^{[n]}$ represents the symbol vector transmitted by all users that transmit on the n-th chip.

In order to complete an iteration, the function node updating is given by,

$$I^t_{c_n \leftarrow u_k}(s_k) = \lambda_k \left[\prod_{l \in \xi_k \backslash n} I^t_{c_l \to u_k}(s_k) \right], \tag{11}$$

where $l \in \xi_k \backslash n$ means the set of all function nodes connected to the k-th variable node, except the n-th. In (11), λ_k is chosen for that $\sum_k P(s_k) = 1$.

Finally, after I_T iterations, MPA goes to the final stage in order to estimate the symbol vector,

$$\hat{\mathbf{s}}_k = \arg\max_{s_k} \Big[\prod_{n \in \zeta_k} I^{I_T}_{c_n \to u_k}(s_k) \Big]. \tag{12}$$

The computational complexity of MPA detector is presented in [25], where it is assumed that the factor graph is regular. The computational complexity is measured by the number of mathematical operations performed by the function node set and by the variable node set. This complexity can be obtained as

$$\begin{aligned} N^{FN}_{AS} &= I_T G d_f (M^{d_f} - M), \\ N^{FN}_{MD} &= I_T G d_f M^{d_f - 1}(M + d_f - 2). \end{aligned} \tag{13}$$

where N^{FN}_{AS} and N^{FN}_{MD} are, respectively, the number of additions/subtractions and multiplications/divisions, performed by the function nodes. The variable nodes complexity can be expressed as

$$\begin{aligned} N^{VN}_{AS} &= I_T J d_v (M - 1), \\ N^{VN}_{MD} &= I_T J M d_v \min(3, d_v). \end{aligned} \tag{14}$$

where N^{VN}_{AS} and N^{VN}_{MD} are, respectively, the number of additions/subtractions and multiplications/divisions performed by variable nodes. Its important to report that the MPA detector also performs M^{d_f} exponential operations.

IV. Numerical Results and Discussions

In order to compare MC-CDMA and SCMA techniques, both systems are evaluated considering the same spectral efficiency. Without loss of generality, it is assumed that each SCMA codebook is attributed to only one user. So, the number of SCMA codebooks is equal to the number of MC-CDMA users, $J = K$. Finally, the number of subcarriers ($L = G$) and the modulation order (M) of both systems are the same in each scenario, in order to ensure the same spectral efficiency.

Monte Carlo simulations are made in order to compare both techniques performance, in terms of the mean BER as a function of signal to noise ratio per bit, $\overline{\gamma_b}$, and in terms of the detection complexity based on the number of calculations, of SD and MPA detectors.

The SCMA technique is set with the same parameters given by the factor graph of Fig. 4. These parameters are $J = 6$ users and $G = 4$ subcarriers, where each user is allowed to spread its information only in $N = 2$ subcarriers, according to the respective codebook. On the other hand, MC-CDMA is set with $K = 6$ users and the same spreading factor of $G = 4$ subcarriers. Based on these parameters, the performance and complexity are analyzed considering 4-QAM and 16-QAM.

Fig. 5 shows the mean BER as a function of $\overline{\gamma_b}$ for 4-QAM. The SCMA curve is simulated considering 6 iterations of the MPA detector. In this scenario, using less than 6 iterations can compromise the mean BER. On the other hand, using more than 6 iterations, the performance gain is insignificant and, does not justify the complexity growing. The MU-MLD asymptote, given by (5), is also included as a theoretical reference, once MC-CDMA simulation curve converges to its asymptote. Despite that both systems have the same spectral efficiency, MC-CDMA performance is much better than SCMA. It can be observed that MC-CDMA diversity[3] order is greater than the SCMA one. In this case, MC-CDMA diversity order is $G = 4$ and SCMA diversity order is 2. As $\overline{\gamma_b}$ grows, the performance difference between SCMA and MC-CDMA becomes greater.

The 16-QAM performance evaluation is shown in Fig. 6, where the number of iterations of the MPA detector is adjusted to 9, as higher values do not contribute significantly with the mean BER. Notice that MC-CDMA diversity order ($G = 4$) is maintained. However, the SCMA performance is improved and now achieves a diversity order 4. This growing on SCMA diversity order occurs because 4-QAM is based on a rotated BPSK constellation, which has dimension one. So, as $N = 2$, the diversity order of 4-QAM is 2, as observed in Fig.

[3]The diversity is related with the slope of the BER curve.

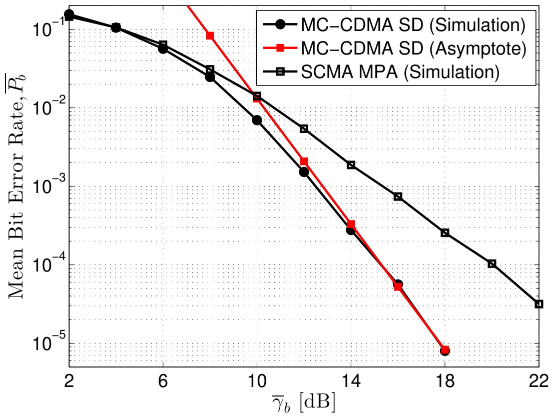


Fig. 5: Mean BER as a function of $\overline{\gamma_b}$ considering MC-CDMA and SCMA for 4-QAM, $K = 6$ users and $G = 4$ subcarriers.

5. For 16-QAM, the symbols have in phase and quadrature components, reaching the diversity order of 2. So, as $N = 2$, the 16-QAM diversity order is 4.

In addition, the mean BER difference between both techniques is constant. MC-CDMA maintains an advantage close to 1.6 dB over SCMA. Another point to observe is the accuracy between MC-CDMA simulation results and the BER asymptote. This difference is explained by the self-noise introduced by the MMSE QR factorization used in the SD algorithm.

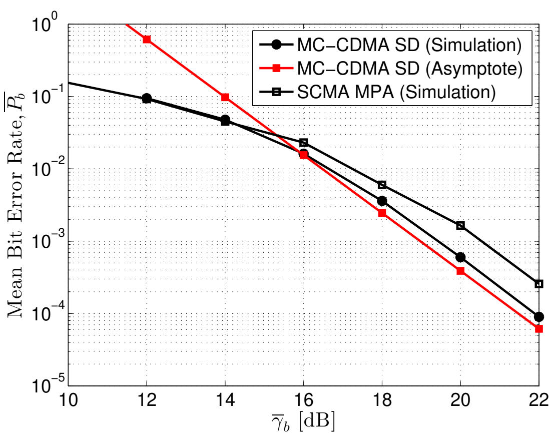
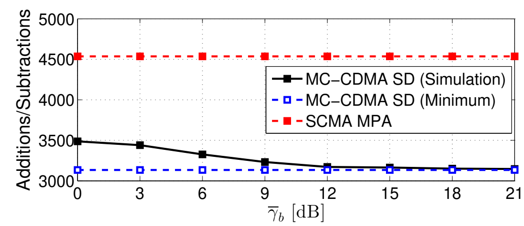


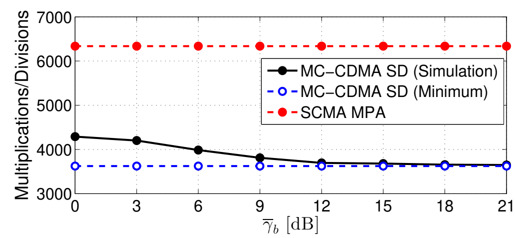
Fig. 6: Mean BER as a function of $\overline{\gamma_b}$ considering MC-CDMA and SCMA for 16-QAM, $K = 6$ users and $G = 4$ subcarriers.

From the above, MC-CDMA technique obtains better performance than SCMA. However, the detection complexity needs to be investigated in order to conclude this study. Thus, for SCMA technique, (13) and (14) are used to calculate the number of complex additions/subtractions and multiplications/divisions operations performed by MPA detector. For SD algorithm, these parameters will be obtained by simulation, because the number of operations required to calculate the metric associated to each branch of the decoding tree are random and depend on the stage at which that branch is into the tree. In [26], it was determined that the mean complexity of SD algorithm is of polynomial type. However, (3) and (4) are the minimal number of complex operations performed by the SD algorithm. Thus, considering the parameters from previous scenarios, the computational complexity in terms of the number of mathematical operations is determined for 4-QAM and 16-QAM in the following.

Fig. 7 shows the computational complexity as a function of $\overline{\gamma_b}$ for 4-QAM modulation. Notice that MPA computational complexity for both operation types, additions/subtractions and multiplications/divisions, considering 6 iterations, does not depend on the SNR. On the other hand, the SD computational complexity varies according to $\overline{\gamma_b}$, but tends to stabilize as $\overline{\gamma_b}$ grows, converging to the minimum number of operations, described by (3) and (4). Comparing both decoding methods, notice that SD detector is less complex than MPA. For example, at 21 dB, SD performs 30% and 42% less additions/subtractions and multiplications/divisions operations than MPA, respectively.



(a) Additions/Subtractions

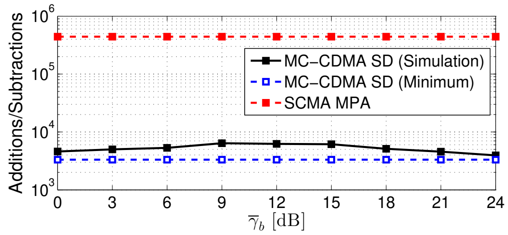


(b) Multiplications/Divisions

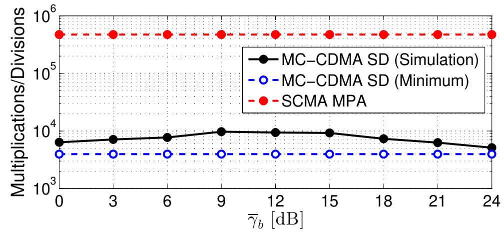
Fig. 7: Computational complexity as a function of $\overline{\gamma_b}$ for MC-CDMA and SCMA considering 4-QAM, $K = 6$ users and $G = 4$ subcarriers.

Fig. 8 shows the complexity comparison for 16-QAM. As defined before, this modulation order requires 9 iterations of the MPA detector and its complexity does not vary as a function of $\overline{\gamma_b}$. MC-CDMA detection complexity presents a slight variation, but as $\overline{\gamma_b}$ increases, it simulation curves converge to (3) and (4). As occurred for 4-QAM, the MU-MLD implementation via SD detector present less complexity comparing to MPA. In this case, the complexity difference between both detectors is high. For example, at 24 dB, e.g. SD performs less than 99 % of the MPA additions/subtractions and multiplications/divisions. These surprisingly results can be justified by (13), where SCMA complexity is exponential and depends on $\mathcal{O}(M^{d_f})$.

As described in the literature, the MU-MLD implemented via SD algorithm require look-up tables (LUT) to perform the detection process. However, the MPA detector, based on sum-product algorithm, also require LUT in the detection [27]. Thus, from the additions/subtractions and multiplications/divisions complexity analysis, for SD, as $\overline{\gamma_b}$ increases, the number of LUTs access reduces. In MPA, the number of LUTs is proportional to the number of iterations. For one MPA iteration, the number of LUT accesses is similar to SD. But, as more MPA iterations are required to achieve a given



(a) Additions/Subtractions



(b) Multiplications/Divisions

Fig. 8: Computational complexity as a function of $\overline{\gamma_b}$ for MC-CDMA and SCMA considering 16-QAM, $K = 6$ users and $G = 4$ subcarriers.

performance, the number of LUT accesses for MPA become greater than for SD.

V. Conclusion

MC-CDMA and SCMA performance were compared in terms of mean BER and computational complexity, which is given by the number of mathematical operations. Monte Carlo simulations were used to compare both performance measures for overloaded scenarios ($\beta = 150\%$). The MC-CDMA mean BER asymptote was also employed in this analysis. For SCMA, the codebooks designed presented in [10] were considered. MC-CDMA has presented superior performance in all evaluated scenarios. Specially for 4-QAM, where the diversity order of MC-CDMA is two times better than for SCMA. MPA is defended as a lower complexity detector to be employed in 5G networks, but its computational complexity grows exponentially with d_f, $\mathcal{O}(M^{d_f})$. On the other hand, MU-MLD implemented via SD algorithm with depth-first pruning technique and MMSE sorted QR factorization presents a complexity that grows polynomially with K, $\mathcal{O}(K^3)$ for high SNR. Theoretical and simulation results have showed that MC-CDMA implemented with SD algorithm performs lower calculations than SCMA, achieving a reduction of more than 130 times, for 16-QAM scenario. It has also been verified that MU-MLD implemented via SD requires lower look-up table access than via MPA detector. As a future work, this analysis will be performed for encoded scenarios.

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