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Improved IDMA for Multiple Access of 5G

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Abstract: Due to its good performance and low complexity, IDMA is believed to be an important technique for future radio access (FRA). However, its performances are highly affected by the interleaver design. In this paper we propose two contributions to improve the performance of the IDMA. First, we propose a new interleaver design, called "NLM interleaver", which improves the computational complexity, reduces the bandwidth consumption and the memory requirements of the system. It also provides infinite sets and quasi-orthogonal spreading codes and interleavers based on only one parameter. Second, we propose a new user grouping algorithm based on the correlation function to improve the resources (codes and interleavers). In fact, all users are divided into several equal-size groups where each group's data are transmitted at the same time, with the same frequencies and the same interleaver. The simulation results indicate that the proposed scheme achieves better performances compared to the existing algorithms.

Keywords: IDMA, G-CDMA-IDMA, Interleaver Domain, New Logistic Map, User Grouping, FRA, 5G.

1. Introduction

The 3G technology has achieved a lot of success by using spread spectrum DS-CDMA techniques. In the last four years, the 4G mobile communication systems such as long-term evolution (LTE) [1] and LTE-Advanced [2, 3] standardized during the spring 2011 by the 3rd Generation Partnership Project (3GPP), have been widely deployed in most countries in the world. This technology provides important benefits to users, i.e., improves robustness against multipath interference and provides better affinity to MIMO technologies.

However, 4G wireless networks have not been able to cope with the increasing demand of mobile devices' users. This is why new telecommunication solutions, like future radio access (FRA) or more particularly 5th generation wireless system (5G), have been adopted. Some of the main promises of 5G wireless communication systems are achieving mobile broadband speeds up to 10Gb/s, multiply system capacity by 1000; multiply energy efficiency by 10, multiply average mobile cell throughput by 25, and add new services with less power consumption.

One of the hardest issues in all wireless networks (from 2G to 5G) is sharing the communication channel and the common resources between large set of active users in a cell. To deal with this issue, several approaches have been proposed, such as spread spectrum in CDMA (widely used in the 3rd generation mobile communication system). In fact, CDMA has been emerged as the main technique where users' data are multiplexed by distinct spreading sequences rather than orthogonal frequency band, as in FDMA, or orthogonal time slots, as in TDMA. It has been limited by the mutual interference (MAI) caused by the users' signal. For this reason, CDMA is not suitable for 4G technology despite the efforts made by several researches for cancellation of MAI, such as successive interference cancellation (SIC) [4-7] and parallel interference cancellation (PIC) [8-10]. 4G networks rely on orthogonal frequency division multiple access (OFDMA) in the downlink and on single carrier frequency division multiple access (SC-FDMA) in the uplink. However, considering the use of FRA, these approaches (CDMA, OFDMA and SC-FDMA) are not sufficient or need to be improved. Thus, to realize 5G promises (offer universal communications for all users regardless of the time, terminal, wireless device, or geographical position), advanced multiple access techniques need to be developed. Such techniques should share frequency and time resources by multiple users on the available bandwidth, and separate users' signals using another parameter.

In order to enhance the spectrum efficiency with new parameter, Higuchi et al. superposed multiple users in the power domain and have developed a new multiple access technique called Non Orthogonal Multiple Access (NOMA) [10]. In this technique the time and frequency resources are shared by all users and their different signals are separated by using the power domain. Its performance compared to the OFDMA increases when the difference in channel gains is large [10].

Based on the advantages of SIC receiver, Saito et al. have proposed a NOMA with SIC [11] in order to separate the desired and interfering signals. They argue that NOMA with SIC is a promising technique for FRA. The SIC schemes attempt to remove MAI from each user received signal before making data decisions.

Another multiple access technique, called Interleave-Division Multiple Access (IDMA) has been developed by Ping et al [12]. This technique explores the possibility to share time, frequency and spreading codes by all users, and use the interleavers to distinguish their signals. The adoption of the IDMA technique has been limited due to:

- The bandwidth resources requirements: the exchange of interleavers between transmitter and receiver requires a large bandwidth.
- The memory resources requirements: amount of memory is needed to store the interleavers at the transmitter and the receiver, which may cause serious concern when the number of users is large.
- Computational complexity: computation of user specific interleaver.

To overcome these limitations, some researchers have developed different designs of interleavers with the aim of reducing the bandwidth and memory resources, such as Orthogonal Interleaver (OI), Random Interleaver (RI), Nested Interleaver (NI) [13], Shifting Interleavers (SI) [14] and Deterministic Interleaver (DI) [15]. In most of these designs, the exchange of the spreading codes and interleavers' matrix between transmitter and receiver is needed. Thus, a large bandwidth will be consumed and the spectrum efficiency will be reduced.

In this paper, we firstly describe our motivation regarding user grouping CDMA-IDMA with the New Logistic Map Interleavers (NLM Interleavers). Secondly, we propose an algorithm to generate the required parameters (spreading codes and the interleavers' matrix) to distinguish users in G-CDMA-IDMA, using only one parajj v saaaaynhbbvbv cvvmeter (the initial state). This method is realistic, since it does not require a lot of memory to store v hggbbbbhgf gbetween the transmitter and the receiver is a single parameter. Thirdly, we propose a new user grouping algorithm based on a correlation function. We divide all users into several equal-size groups where each group's data are transmitted at the same time, with the same frequencies and the same interleaver. We exclusively allocate an interleaver to a group and we affect the orthogonal spreading codes to different users. These codes are reused in other groups.

Based on our simulation results, the chaotic system NLM, used to generate radio resources (codes and interleavers), is designed to be easily implemented. In addition, it has been conceived to be secure and generate infinite sets of codes and interleavers. This technique reduces bandwidth efficiency and memory consumption. Moreover, our user grouping algorithm is suitable when resource availability is a serious concern in the desired systems, as in the case of 5G.

The remainder of this paper is organized as follow. Section 2 describes our motivations. Section 3 defines the system model and G-CDMA-IDMA system structure. Section 4 develops our proposed algorithm to generate the spreading codes and NLM interleavers. In Section 5, we discuss the user grouping algorithm based on the orthogonality of spreading codes. Section 6 presents simulation results and discusses the performances of the proposed systems. Finally, Section 7 concludes the paper.

2. IDMA Motivations

Various multiple access techniques are proposed to satisfy 4G requirements. Among these techniques, we can find MC-CDMA (Multicarrier-CDMA), OFDMA (Orthogonal FDMA), SC-FDMA (Single Carrier FDMA), and IDMA (Interleave Division Multiple Access). They deliver high data rates transmission and reliable coverage for broadband wireless access with high efficiency.

In this section, OFDMA, NOMA, Sparse code multiple access (SCMA) and IDMA are investigated to highlight their fortes and weaknesses as candidates for FRA.

The performance of the OFDMA and SC-FDMA, OFDMA and NOMA, and OFDMA and SCMA have been widely compared respectively in [17, 18] and [19]. The OFDMA and SC-FDMA are adopted to achieve higher throughput performance for 4G. A number of existing works have found that the OFDMA are sensible to imperfect synchronization [23] and cross layer optimization (CLO) for heterogeneous users (becomes more complicated for device to device (D2D) communication) [21-25]. In this sense and to accommodate 5G services, NOMA [26, 28], [33-35] and SCMA [29] has been recently proposed as multiple access techniques for FRA. The NOMA scheme should be used with dirty paper coding (DPC) or a SIC receiver to improve its performances. In [26], NOMA is used with a SIC receiver to cancel inter-cell interference. This receiver requires demodulation and decoding for all sets of devices. This may increase the processing delay. Due to the use of a SIC receiver, that technique has a drawback in terms of receiver complexity. In addition, its feasibility will highly depend on the evolution of device processing capabilities expected toward 2020s [26]. The SCMA is a multi-dimensional codebook-based non-orthogonal spreading technique; it is a type of MC-CDMA with a particular choice of a sparse code book facilitating low-complexity maximum likelihood (ML) detection. Such as MC-CDMA, SCMA suffer from a high complexity in receiver and transmitter and multi-user interference which make it complicated at high number of users. For this reason b nnnnnnnnnnnn believe that the IDMA technique with NLM interleaver and user grouping is a promising candidate as multiple access technique for 5G networks.

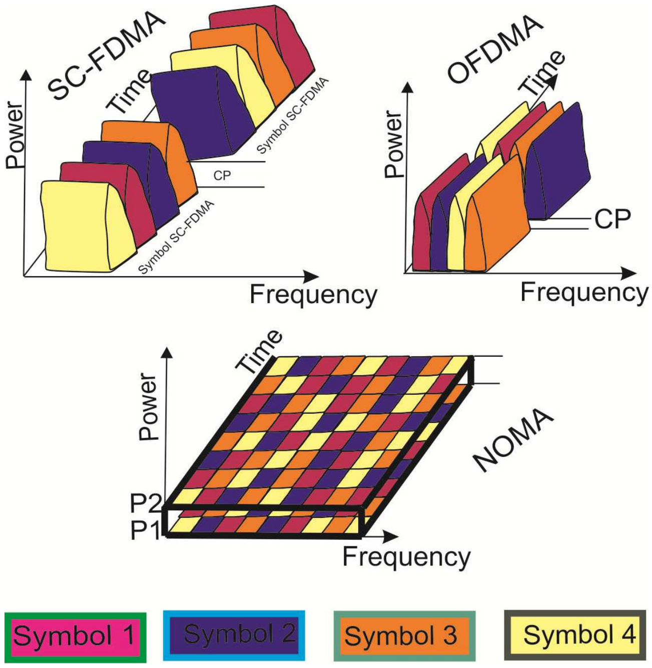

Figure 1. Four QPSK data symbols to be transmitted in NOMA, OFDMA and SC-FDMA.

2.1 Distinguishing users in single channel: required parameters

The MC-CDMA is based on the concatenation of spreading codes with multi-carrier modulation to distinguish user symbols. Consequently, the orthogonality of frequency spreading sequences is required and the spectral correlation should be null or small. On other hand, the system requires the exchange of the spreading codes at high rates, which makes it impractical at high traffic. In contrast to MC-CDMA, OFDMA based on OFDM techniques, formed by dividing the available subcarriers into several non-overlapping subsets. The available subsets of subcarriers are assigned to each user (flexible assignment of frequency resources to individual users). Using OFDMA allows more granular exploitation of multiuser diversity for higher spectral efficiency [27] with an ability to provide superior quality of service (QoS). Unfortunately, there are also some disadvantages to this technique, such as strong sensitivity to carrier frequency offset and strong sensitivity to nonlinear distortion in power amplifier. This is due to the high peak to average power ratio (PAPR). NOMA utilizes power domain such as new additional domain for user multiplexing. However, SIC and capacity- achieving channel codes (like Turbo code or LDPC) are used to achieve separation of users' signals.

In SCMA systems, data of different users are spread in frequency-domain using a sparse code book (SCB). The SCB produces low-complexity maximum likelihood (ML) detection.

In IDMA technique, users are distinguished by their unique user-specific interleavers. Each users' data spread using same spreading codes and transmitted at the same time and the same frequencies. With user grouping technique we succeeded to divide all users into several equal-size groups. Each groups' data are transmitted at the same time, with the same frequencies and the same interleaver. The orthogonal spreading codes are affected to different users in a group and reused in other groups.

2.2 Utilization of additional domain for user multiplexing

In the main multiple access technologies, the access coordination may be carried out in the frequency domain (FDMA, OFDM, OFDMA,...), in the time domain (TDM, TDMA,...), in the code domain (CDMA) or in a combination of these domains (MC-CDMA, SC-FDMA, ...). The NOMA [33, 35] utilizes an additional new domain, i.e., the power domain. Users in this domain share a common primary supply set, which is unusable when the number of users is very large. This is mainly due to the difficulty of power control. As a different technique, IDMA utilizes the interleaver domain (superposes multiple users in the interleaver domain).

3. IDMA System Model

In our G-CDMA-IDMA system, U simultaneous users are divided into G smaller and equal-size groups using a user grouping algorithm (which will be described in section 5). Each user u in a group g spreads its information bits $a^{u,g}$ by its spreading sequence C^u of length N_c, given in bits. The spreading operation generates $b^{u,g} = a^{u,g} \times C^u$. The chip streams of all users in the same group are interleaved by an interleaver Π^g with a length N (N belong to the set of natural numbers excluding zero) allocated to this group. The sequences $d^{u,g} = \Pi(b^{u,g})$, produced after interleaving, are modulated by using Binary Phase Shift Keying (BPSK).

At the receiver, the signal is perturbed by Additive White Gaussian Noise (AWGN) with zero mean and covariance σ_w^2.

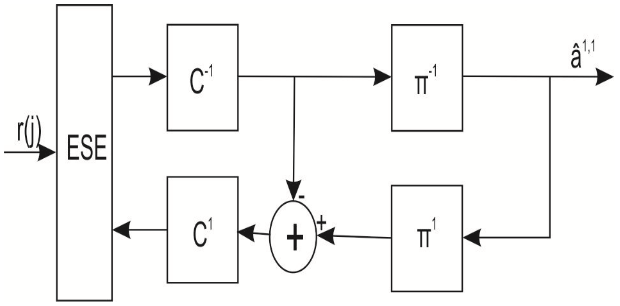

Figure 3. G-CDMA-IDMA receiver structure.

We assume that group the user belongs to and the interleaver of this group are perfectly known at the receiver.

The iterative detection process treats group-by-group, where the IUI in each group can be completely eliminated (the orthogonal spreading codes are employed in each group). It can implement an Elementary Signal Estimator (ESE) and U single user a posteriori probability decoders (APP-DEC). After knowing the group to which the user belongs, the receiver works in the same way as in IDMA systems [32]. A list of the symbols and their description used in this paper is given in Table 1.

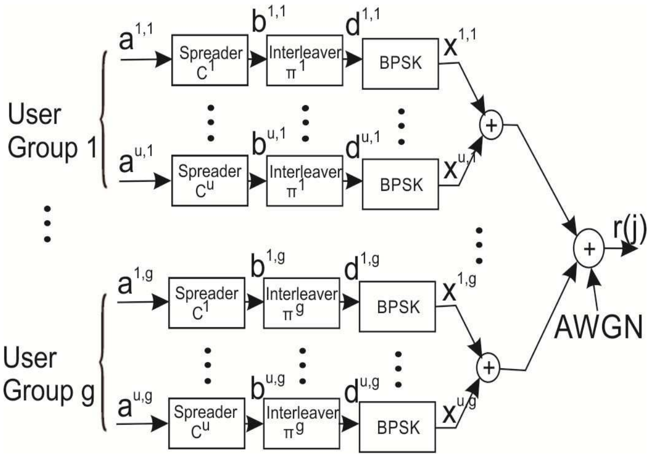

Figure 2. G-CDMA-IDMA transmitter structure.

4. Generating the Interleavers and spreading codes: Proposed algorithms

Here, we modified the logistic map [30] and developed, as explained in [16], a new one-dimensional chaotic map, named "New Logistic Map (NLM)". To generate the spreading codes and the interleavers' matrix of all users we use the NLM described by:

$$Z_{(n+1)} = \lambda Z_n \left(1 - \frac{Z_n}{N}\right) \quad (1)$$

Where $Z_n \epsilon [0\ N]$ and N represent the sequence (code or interleaver) length.

The results of NLM chaotic behavior (Lyapunov exponents and bifurcation diagram) and its stability points are presented in [16].

Table 1. Used parameters and their descriptions

Symbols	Description
U	Number of users
G	Number of groups
$a^{u,g}$	Information bits of user u in a group g
C^{u}	Spreading sequence
N_c	Length of spreading sequence
Π^{g}	Interleaver of group g
N	Length of Interleaver
χ_z, χ_y	Footsteps
U_{ss}	Number of desired spreading codes
$G_{\max}$	Maximum number of users in a group
$\Psi(.,.)$	Correlation function
U_g	Number of users in a group
N_g	Number of groups (according to the number of available orthogonal spreading codes and available number of interleavers)

The system (1) will be chaotic when the signs of Lyapunov exponents are all positive or when *λ>3.58*. Thus in the rest of this paper, we fixed *λ =4*.

To generate the first interleaver, the system (1) starts at an initial state

$$Z_0^1 \in \left]0 \quad \frac{N}{2}\left(1-\sqrt{\frac{N-1}{N}}\right)\right[\cup \left]\frac{N}{2}\left(1+\sqrt{\frac{N-1}{N}}\right) \quad N\right[.$$

We calculate the states $Z=\left\{Z_1^1, Z_2^1, \ldots\ldots, Z_N^1\right\}$ of the system. These states form a set of real sequences between *0* and *N*. The transition to integer sequences is realized by maximizing $\lceil z \rceil$ to remove the decimal numbers and keep only the main integers. Finally, to obtain the interleaver matrix, we eliminate redundant elements from the founded integer vector.

We construct the initial state to generate the second interleaver by adding a footstep χ_z to the Z_0^1 ($Z_0^2 = Z_0^1 + \chi_z$).

The initial state to generate g^{th} interleaver is given by $Z_0^g = Z_0^1 + (g-1)\times\chi_z$. This operation is repeated until obtaining desired interleavers.

Algorithm 1 Generating NLM Interleavers

```
Require $N$, $i=0$, $n=0$, $g=1$, $\Pi^g=\{\ \}$, $Z_i^{g-1}$, $\beta = Z_i^{g-1}(1-\frac{Z_i^{g-1}}{N})$ and $\chi_z$.
Ensure
$Z_i^{g-1} \in \left]0\ldots.\frac{N}{2}(1-\sqrt{\frac{N-1}{N}})\right[ \cup \left]\frac{N}{2}(1+\sqrt{\frac{N-1}{N}})\ldots..N\right[$
for $g=1$ to $G$ do
    $Z_i^g \Leftarrow Z_i^{g-1} + (g-1)\times\chi_z$
    $\Pi^g \Leftarrow \{\Pi^g, |Z_i^g|\}$
    While $n \le N$ do
        $Z_i^g \Leftarrow 4\times Z_i^g(1-\frac{Z_i^g}{N})$
        if $|Z_i^g| \notin \Pi^g$ then
            $\Pi^g \Leftarrow \{\Pi^g, |Z_i^g|\}$
            $n \Leftarrow n+1$
        else
            $i \Leftarrow i+1$
        end if
    end while
end for
```

We generate the first spreading code by the system (1) (with $N=1$). The initial state Y_0^1 is given by the solution of the following equation:

$$Y_0^1(1-Y_0^1) = Z_0^1(1-\frac{Z_0^1}{N}) \quad (2)$$

By solving this equation, we find two fixed points:

$$Y_0^1 = \frac{(1-\sqrt{(1-4\beta)})}{2} \text{ and } Y_0^1 = \frac{(1+\sqrt{(1-4\beta)})}{2}.$$

Where $\beta = Z_0^1(1-\frac{Z_0^1}{N})$.

Only one value of Y_0^1 will be chosen. To extract u^{th} spreading code C^u from the i^{th} real value of the sequence Y_i^u, we use the threshold function:

$$C^u = \begin{cases} 1 & \text{for} \quad Y_i^u > I_{th} \\ -1 & \text{for} \quad Y_i^u \le I_{th} \end{cases} \quad (3)$$

Where I_{th} is the threshold. It ensures that the number of ones and zeroes in the binary code is the same.

We construct the new initial state to generate the next spreading code by adding a footstep χ_y to the Y_0^1. We repeat this technique until U_{ss}, with U_{ss} is the desired number of spreading codes.

The interleavers generated will be assigned randomly to different groups and there are two scenarios to assign the spreading codes to different users after dividing it into groups. In fact, in the first scenario, we allocate the spreading codes to the users, one by one, of each group. When a group has reached its maximum spreading code capacity, the next spreading codes are allocated to the users of the next group. By this way, we allocate all generated codes to the users. In the second scenario, we select only orthogonal spreading codes among those generated and we apply our user grouping algorithm as detailed in Algorithm 3.

Algorithm 2 Generating NLM Spreading Codes

```
Require $N=1$, $i=0$, $n=0$, $u=1$, $U_{ss}$, $Z_0^1 \in \left]0 \quad 1\right[$, $Y_i^u$, $\chi_y$ and $I_{th}$.
Ensure $Y_i^u = \frac{(1 \pm \sqrt{(1-4\beta)})}{2}$
for $u = 1$ to $U_{ss}$ do
$Y_i^u \Leftarrow Y_i^u + (u-1) \times \chi_y$
While $n \le N_c$ do
$Y_i^u \Leftarrow 4 \times Y_i^u (1 - Y_i^u)$
if $Y_{i+1}^u \succ I_{th}$ then
        $C^u \Leftarrow +1$
        $i \Leftarrow i+1$
        else
        $C^u \Leftarrow -1$
        $i \Leftarrow i+1$
end if
    $n \Leftarrow n+1$
  end while
end for
```

5. User grouping algorithm

Here, we propose a straightforward strategy based on the orthogonality of spreading codes. We assign to each user of a group a spreading code weakly correlated with all others spreading codes assigned to other users. One of the advantages of this is that the number of desired spreading codes is not large (due to reusing codes). Thus, it is easier to find weakly correlated codes for all users (whatever the number of users).

Let G_{max} be the maximum number of users in a group and G be the total number of groups.

The proposed user grouping algorithm is described as follows:

Algorithm 3 User grouping algorithm

```
Require $U_{ss}$, $G$, $G_{\max}$, $g=1$, $U_g = 0$ and $C^g = \{\ \}$, $\forall g \in G$
  while $g \le G$ do
    repeat
      for $u_a = 1$ to $U_{ss}$ do
      Generate $C^{u_a}$ by Algorithm 2
      $C^g \Leftarrow \left\{ C^{u_a} \right\}$
      $U_g \Leftarrow length\ (C^g)$
      for $u_b = 1$ to $U_{ss}$ do
      Generate $C^{u_b}$ by Algorithm 2
      if $\Psi(C^{u_a}, C^{u_a}) \to 0$ and $U_g \le G_{\max}$ then
       $C^g \Leftarrow \left\{ C^g, C^{u_a} \right\}$
      $U_g \Leftarrow length\ (C^g)$
      else if $\Psi(C^{u_a}, C^{u_a}) \to 0$ and $U_g > G_{\max}$ then
        $g \Leftarrow g+1$
        $C^g \Leftarrow \left\{ C^g, C^{u_b} \right\}$
        $U_g \Leftarrow length\ (C^g)$
       end if
      end for
     end for
   until all the users are grouped
 end while
```

6. Simulations results

6.1. Computational complexity

The complexity of generating spreading codes and interleavers' matrix (at the transmitter and receiver side) is a major concern. Especially, when the number of users is high [31]. In this section, this complexity is calculated for our strategy then compared to the complexity of the other techniques. To estimate the complexity of generating the spreading codes (resp. the interleavers) we need to calculate the number of cycles in term of the number of users (resp. groups). The simulation results for the computational complexity to generate the interleavers are shown in Table 2.

As expected, table 2 shows that the computational complexity increases with the number of user U for Shifting interleaver (SI), whereas it is not the case for Orthogonal (OI) and Nested Interleaver (SI). The SI focuses on the correlation between the first interleavers and, consequently, need more cycles to generate the next interleaver (the number of reindexing is $O(\omega U)$). For orthogonal and Nested

Interleaver, the complexity is linear to the number of users (number of groups). For our method (described in section 3), the complexity is *O(1)*. In fact, it is independent from the number of users (number of groups).

Table 2. The number of cycles needed to generate the u^{th} interleaver.

U	Orthogonal	Shifting	Nested	NLM
1	1	1	1	1
2	2	$2\times\omega$	2	1
3	3	$3\times\omega$	3	1
4	4	$4\times\omega$	4	1
16	16	$16\times\omega$	16	1
50	50	$50\times\omega$	50	1
120	120	$120\times\omega$	120	1
200	200	$200\times\omega$	200	1

($\omega = \mathrm{int}(\frac{N}{U})$ is the greatest integer not larger than $\frac{N}{U}$.)

Hence, our proposed method helps significantly reduced the computational complexity compared to the most used schemes.

Moreover, this complexity decreases when the number of the users in each group increases.

6.2. Required bandwidth resource

Lack of bandwidth resource is one of the main issues in communication systems. This becomes worse especially when the number of users is large. In fact, there is still a need to increase the number of users while the bandwidth is limited. Another problem is that the transmitter and receiver must hold the same spreading code and the same interleaver matrix. In most of existing algorithms, the transmitter needs to transmit the code and the interleaver matrix, assigned respectively to the user in a group and to a group; such transmission requires a large bandwidth.

We note that many works in the literature have treated the consumption of bandwidth using spreading codes. For simplicity, we will study only the case of the interleavers. To estimate the bandwidth consumption, we evaluate the initialization parameters (required to generate interleavers' matrix), and the number of bits occupied by all users (in the different studied designs).

The process of generating Nested Interleaver starts by initializing the state of the linear feedback shift register (LFSR) with a primitive polynomial. A pseudo random interleaver, generated by using the bits, represents the coefficients of this primitive polynomial. It is necessary to store the "seed" of these interleavers in the mobile stations. According to the first interleaver, the next $(g+1)^{th}$ interleaver can be obtained by the permutation of $\Pi^{g} o \Pi^{1}$ with $g = 1,2,....G$.

In order to have a similar Nested Interleaver in the transmitter and the receiver, it is necessary to exchange the primitive polynomial, the initial state of the LFSR and the first pseudo random interleaver.

In the case of the Shifting Interleavers, the generating process is based on the circular shifting master interleaver. This last interleaver is generated by a specific pseudo noise (PN) sequence generator and LFSR. The transmitter and receiver need to exchange the primitive polynomial, the initial state of the LFSR and the master interleaver.

Contrary to the previous designs, in our design, we exchange only a unique parameter z_0^g (the initial state of the NLM function) between the transmitter and the receiver. The interleavers matrix are generated using the algorithm 1.

In table 3, we show an example of the number of bits transmitted in the frame. This enables the receiver to: generate a corresponding interleaver matrix. We assume that the length of an interleaver *N=64*. The results are shown in term of the number of simultaneous users *U* increases.

Table 3. The number of bits required as a function of *U* for different interleaver designs with *N=64*.

U	RI	OI	SI	NI	NLMI
1	*396*	*30*	*414*	*30*	*24*
4	*1548*	*30*	*414*	*30*	*24*
16	*6156*	*30*	*414*	*30*	*24*
64	*24588*	*30*	*414*	*30*	*24*
128	*49164*	——	*414*	*30*	*24*
256	*98316*	——	*414*	___	*24*

6.3 BER performance results

The next goal of this section is to evaluate the quality of transmission using bit error rate (BER) analysis of conventional IDMA system, without grouping, for proposed NLM interleaver along with Random Interleaver. For simplicity, we evaluate an IDMA system with BPSK modulation in AWGN channel. The block size of data bits for each user is *512* bits and the used spreading code for all users is *C=[1, -1, 1,. . .,1]* with the length *S=32*. The number of iterations is set to be *10* in each case.

Figure 4 shows the simulation results for *U=32*, *64* and *128*. One can observe that the NLM interleaver achieves similar BER performance compared to RI in case of similar simulation conditions when *U=32* and *U=64*, but much better than that of random interleaver when *U=128*. We find that the results are meaningful when the number of users is large and at high SNR. Therefore, we can conclude that our algorithm is more efficient with higher number of users.

Now, we evaluate the quality of transmission and viability of the proposed user grouping algorithm using bit error rate (BER) analysis at different SNR values. First, we assume that the IDMA system use BPSK modulation in single path AWGN channel. We evenly divide 128 users into N_g*=1, 2, 8, 32* and *128* groups with U_g*=128, 16, 4* and U_g*=1* users in each group, respectively.

Note that N_g*=1* corresponds to the Ci-CDMA system and N_g*=128* leads to an IDMA system. We make *10* iterations for each block size of *512* data bits. Figure 5 presents the results of the BER performances of the G-CDMA-IDMA system at different SNR values.

We observe that for $N_g=1, 2, 8, 32$ and 128, the value of the BER at high SNR is not the same even is the total number of users is the same. This implies that N_g has an important effect on the BER performances. Hence, increasing the number of users per group would increase the number of spreading codes and decreases the number of interleavers

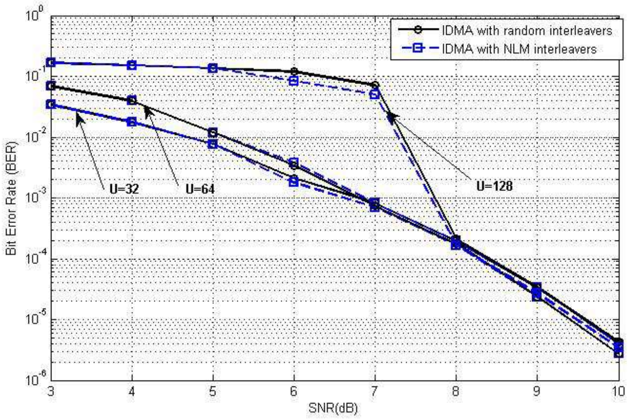

Figure 4. BER Performance comparison of NLM interleaver and Random Interleaver in IDMA system without grouping.

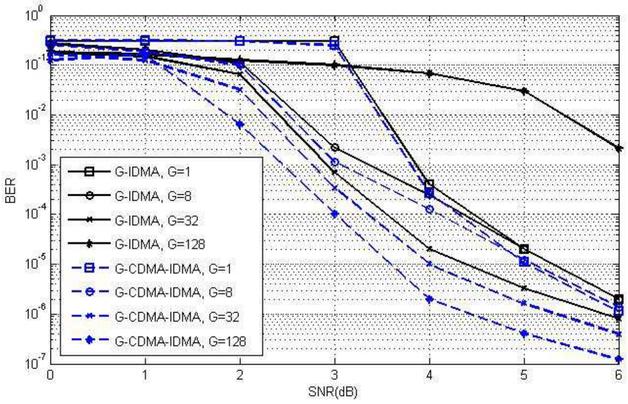

Figure 5. BER performance of G-CDMA-IDMA and G-IDMA with NLM interleaver for $N_g=1, 8, 32, 128$.

For Grouped-IDMA described in [36], $N_g=8$, 32 and 128 guarantee the performance of the system, and $N_g=1, 2$ deteriorate it. In fact, a lot number of orthogonal spreading codes will be used when the number of users in each group is large. However, it is not the case of G-CDMA-IDMA system with our user grouping algorithm. This can be intuitively explained as the available orthogonal spreading codes and interleavers are higher if our algorithm is applied. Thus, grouping the users with smaller groups is more suitable.

In general, the selection of N_g should be decided according to the number of available orthogonal spreading codes and available number of interleavers.

Figure 6 illustrates the BER performance comparison of G-CDMA-IDMA with SCMA, OFDMA and SC-FDMA techniques. We use 16-QAM modulation in single-input multiple-output AWGN channel (SIMO 1x2). As illustrated, the proposed scheme G-CDMA-IDMA outperforms SCMA, OFDMA, and SC-FDMA and the gain is over 3dB compared to SC-FDMA and OFDMA. The transmit power is assumed to be the same for all users as for all data symbols.

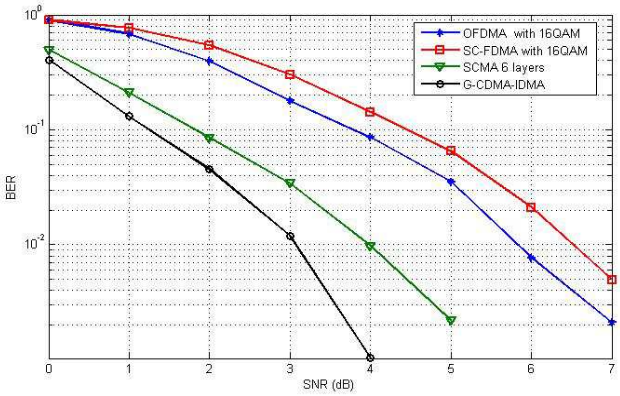

Figure 6. BER Performance comparison between G-CDMA-IDMA, SCMA, OFDMA, and SC-FDMA.

7. Conclusion

This paper presented a G-CDMA-IDMA concept to increase the spectral efficiency of FRA toward the 2020s. Different from the current techniques, G-CDMA-IDMA utilizes the chaotic interleaver domain and the user grouping algorithm. These features provide several advantages for G-CDMA-IDMA: i) simplicity to generate a considerable number of the parameters required to distinguish a large number of users; ii) reduce bandwidth consumption (exchanged information between the transmitter and the receiver is only the initial state rather than the spreading codes and interleavers' matrix.

Future work will focus mainly on extending the use of NLM Interleaver in the communication systems. Also, we plan to include an improvement of our user grouping algorithm to group users more efficiently.

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Abbreviations

Abbreviation	Full Name
IDMA	Interleave-Division Multiple Access
FRA	Future Radio Access
G-CDMA-IDMA	Grouped CDMA-IDMA
PAPR	Peak to Average Power Ratio
SIC	Successive Interference Cancellation
PIC	Parallel Interference Cancellation
HSPA	High Speed Packet Access
NOMA	Non Orthogonal Multiple Access
SI	Shifting Interleavers
NI	Nested Interleaver
DI	Deterministic Interleaver
NLM I	New Logistic Map Interleaver
SCMA	Sparse code multiple access
CLO	Cross Layer Optimization
D2D	Device-to-Device
DPC	Dirty Paper Coding
LDPC	Low-Density Parity Check
SCB	Sparse Code Book
ESE	Elementary Signal Estimator
APP-DEC	A Posteriori Probability DECoders