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Analysis and Evaluation of Pattern Division Multiple Access Scheme Jointed With 5G Waveforms

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ABSTRACT Nonorthogonal multiple access (NOMA) techniques represent a key feature for 5G systems in order to increase multiple users' systems' capacity. In particular, we propose, for study, a pattern division multiple access (PDMA) technique, which defines a pattern matrix used for mapping the users to a group of resource elements that might be shared by multiple users. The contribution of this paper is the analysis of the performances, in terms of bit error rate (BER), of 5G candidate waveforms, such as orthogonal frequency division multiplexing (OFDM), filter bank multi-carrier (FBMC), and generalized frequency division multiplexing (GFDM), in the PDMA scheme. Regarding the detection of different users' data, the successive interference cancellation algorithm is performed at the receiver side. The simulation results, consolidated by the analytic study, exhibit that OFDM and FBMC could be used in the NOMA context, while the BER related to GFDM is very high.

INDEX TERMS Fifth generation (5G), PDMA, SIC, OFDM, FBMC, GFDM, BER.

I. INTRODUCTION

The three 5G features are: enhanced Mobile Broadband (eMBB), which requires high data rate and mobility, massive Machine Type Communication (mMTC), supporting massive connection, and Ultra Reliable Low latency Communication (URLLC) [1]. Thus, 5G systems will have to support various services and emerging applications [2]. In order to achieve their requirements, new signal processing techniques at different levels are proposed and investigated.

On one hand, new candidate waveforms are proposed. OFDM is the most prominent multi-carrier technique in wireless standard and is adopted for 4G standards. However, it presents some drawbacks such as the use of the Cyclic Prefix (CP) which degrades the communication system performances especially the spectral efficiency. Additionally, OFDM requires a strict time and frequency synchronization in order to maintain the orthogonality. Finally, it exhibits large peak to power ratio (PAPR) which impacts the system energy efficiency. Thus, new alternative modulation techniques are proposed. In this paper, we investigate FBMC Offset Quadrature Amplitude Modulation (OQAM) waveform [3] where each sub-carrier is filtered by a time frequency

translated prototype filter. We also studied the GFDM [4] waveform which is based on the modulation of independent blocks, where each block consists in a number of sub-carriers and sub-symbols. The sub-carriers are filtered with a prototype filter that is circularly shifted in time and frequency domain.

On the other hand, new Multiple Access Schemes, which have been always considered as key features to define the different wireless systems, are studied. Most communication systems from the first to the fourth generation adopt the Orthogonal Multiple Access (OMA) schemes to reduce the complexity at the receiver side, since orthogonal resources are allocated to the different users. However, to deal with the new challenges for the fifth generation such as massive connectivity and system capacity, novel multiple access schemes are to be introduced. In this context the NOMA techniques [5] are proposed to satisfy these requirements. Particularly, NOMA schemes can increase the systems capacity and improve the spectral efficiency. Variant NOMA techniques are studied and could be classified in three category: Power domain based techniques, such as Super-Position Coding NOMA (SPC-NOMA) [6], Code domain based techniques,

for instance, Sparse Code Multiple Access (SCMA) [7] or PDMA [8] and Inter-leaver based techniques such as Interleave Division Multiple Access (IDMA) [9].

Among, the different NOMA schemes, we opted, in this paper, for studying in particular PDMA technique for its flexible adaptation to diverse 5G scenarios, high spectral efficiency and low power consumption. This technique allows multiplexing the users in different domain such as, code power, spectre... [8]. Up to now, this technique has, always, been evaluated using only OFDM modulation [8], [10], [11]. The main contribution of this work is to introduce new waveforms in a PDMA scenario. In this paper, we have studied and evaluated the performance of PDMA technique associated with 5G candidate waveforms. The paper is organized as follows. Section II introduces the presumed techniques in terms of candidate waveforms and NOMA technique. In section III, we present the system model including the assumed scenario and the receiver algorithm. The section IV is dedicated to present the analytic study related to our scenario, while the section V presents the simulations results compared to theoretical analysis. Finally, the main conclusions are presented in section VI.

II. PRESUMED TECHNIQUES

A. CANDIDATE WAVEFORMS

Multi-Carrier Modulation (MCM) use is still receiving high interest in wireless communication systems. It operates by dividing the data stream to be transmitted into parallel streams over separate narrowband sub-carriers. MCM aims to reduce the inter symbol interference in a frequency selective channel, to make easier the resources management and to offer high data rates. OFDM has been the choice for 4G/LTE systems. However, with 5G challenges, new waveforms such as FBMC and GFDM are to be considered. In this section, we analyze these waveforms using common mathematical notations.

Let us consider the data symbols x_q to be drawn from a Quadrature Amplitude Modulation (QAM) constellation. N denotes the total number of sub-carriers, while q and n refers to the sub-carrier and time indices respectively.

1) ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

At the transmitter side, in OFDM modulation, the data are filtered using a rectangular pulse response and are converted to the frequency sub-carriers [12]. Then, all sub-carriers are summed. The digital implementation is performed using an IFFT and then adds a cyclic prefix (CP). Thus, the transmitted signal is given by the equation 1:

$$s_{ofdm}[n] = \sum_{q=0}^{N-1} x_q e^{j\frac{2\pi qn}{N}} = \sum_{q=0}^{N-1} x_q g_q[n] \quad (1)$$

where $g_q[n] = g[n] e^{j\frac{2\pi qn}{N}}$ represents the sub-carriers with the rectangular pulse shaping filter $g[n]$.

At the receiver side, the CP is first discarded before applying FFT and recovering the data symbols. The use

of CP reduces the spectral efficiency of this waveform. Furthermore, the use of rectangular window in time domain, yielding to a sinc shaped sub-carriers, leads to very high Out of Band (OOB) radiation [13] which limits the fragmented spectrum applications and the multiple access schemes since sufficient guard bands should be predicted. To overcome this drawback, 5G waveforms rely on other pulse shaping functions.

2) FILTER BANK MULTI CARRIER

In order to address the loss of spectral efficiency introduced by adding CP in OFDM, FBMC relies on an additional filter that spans over multi-carrier symbols in time domain [14]. Each FFT output is filtered by a frequency shifted version of a prototype filter and the sub-carriers are individually pulse shaped to reduce the OOB radiation.

In the European project, Physical layer for dynamic access (PHYDYAS), the Mirabbasi-Martin Filter was adopted for its high efficiency on decaying, which results in very low out-of-band leakage. The adopted filtering, however, causes self-interference between sub-carriers and between multi-carrier symbols. The interference could be avoided by either using only odd or even sub-carriers which reduces the efficiency or establishing real orthogonality [15]. To address this drawback, FBMC restores orthogonality in real-plane by the mean of OQAM operation. The transmitted FBMC signal can be presented by the equation 2:

$$s_{fbmc}[n] = \sum_{q=0}^{N-1} (j^q \Re(x_q) g[n] + j^{(q+1)} \Im(x_q) g[n - \frac{N}{2}]) e^{j\frac{2\pi qn}{N}} \quad (2)$$

where $\Re(x_q)$ and $\Im(x_q)$ denote real and imaginary parts of x_q respectively.

As a result, FBMC systems do not need to add CP to combat the ISI introduced by the wireless channel. However, the symbol duration in this case should be larger than the channel impulse response [15].

3) GENERALIZED FREQUENCY DIVISION MULTIPLEXING

GFDM is a generalized multi-carrier modulation. It is a block filtered scheme where the block consists in multiple sub-symbols that are transmitted on the same sub-carrier. It applies circular pulse shaping of the individual sub-carrier [14]. Each of these sub-carriers transmits, not only one, but M data symbols. Thus M represents the number of sub-symbols or the block size.

The GFDM transmitted signal can then be expressed as:

$$\begin{aligned} s_{gfdm}[n] &= \sum_{q=0}^{N-1} \sum_{k=0}^{M-1} x_{q,k} g[(n - kN) \bmod (NM)] e^{j\frac{2\pi qn}{N}} \\ &= \sum_{q=0}^{N-1} \sum_{k=0}^{M-1} x_{q,k} g_{q,k}[n] \end{aligned} \quad (3)$$



FIGURE 1. PDMA pattern example.

$x_{q,k}$ is the data symbol transmitted at q^{th} sub-carrier and k^{th} sub-symbol and $g_{q,k}[n]$ is a time and frequency shifted version of a prototype filter $g[n]$. The circularity principle allows GFDM to explore CP. Unlike OFDM where the CP is used to face channel dispersion, in GFDM, the CP is used to combat time dispersion introduced by all the filters. Regarding the limitations of Out Of Band (OOB) emissions, it is obtained through the use of pulse shaping.

In GFDM different receiver might be used:

- Matched filter (MF) receiver: maximizes the SNR per sub-carrier but introduces self interference when non orthogonal pulse shapes are applied.
- Zero forcing (ZF) receiver: removes the self interference but enhances the noise factor which depends on GFDM parameters such the number of sub-symbols.
- Minimum mean squared error (MMSE) receiver: presents a good trade off between removing self interference and the noise enhancement however it presents higher complexity since it requires the knowledge of noise power.

B. NOMA TECHNIQUE: PDMA

The main idea behind PDMA technique is to recover the advantages of antenna diversity without loosing in terms of spectral efficiency [16]. In fact, multi users communication can be considered as a Multiple Input Multiple Output (MIMO) communication and the diversity order can be generalized to multi users non orthogonal transmission [10]. The transmission diversity is defined as the transmission of the data over independent resources in order to face deep fading on one resource, which can be time, frequency or spatial resource. The PDMA relies on mapping the users' data that are to be transmitted into a group of resource elements according to a defined pattern. A resource element might have a power, code, time or spectre dimension. In this case, the transmission order is defined as the number of mapped resources. Thus non orthogonal transmission is performed since multiple users are multiplexed over the same resource.

Figure 1 presents the case where 6 users are sharing 4 resource elements. For instance, the user 1 is multiplexed on 4 resource elements and sharing the Resource Element (RE)s 1 with user 2, user 3 and user 4. The transmission diversity of the 6 users is, respectively, 4,3,2,2,1,1.

Regarding the detection of the multiple users, various algorithms can be used to separate the users' data multiplexed on the same RE such as Successive Interference Cancellation (SIC) [8] which is a non linear detection algorithm or

Message Passing Algorithm (MPA) algorithms as the Belief Propagation (BP) [11]. In this work, we opted for the SIC receiver since it presents a good trade-off between complexity and performances in terms of multi users detection quality.

The users' patterns define the mapping of the users with the REs and can be collected in a $(N \times K)$ PDMA pattern matrix where N is the number of REs and K is the number of users. Each column defines a user pattern and the dimensions of the matrix define the overloading factor as $(\frac{K}{N})$. A given overloading factor can be associated with different configurations. The complexity and performance of the receiver depend on the properties of the pattern matrix such as the dimensions and sparsity. Originally, the matrix is binary and the value of the element informs if a user is mapped on a resource element. For example equation 4 presents the PDMA pattern matrix relative to the pattern in Figure 1 with an overloading factor of 150%.

$$\mathbf{G}_{PDMA}^{[4,6]} = \begin{bmatrix} 1 & 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

In practice, in non orthogonal transmission, multiplexing different users in one RE is transmitting a linear combination of different users modulation symbols. For instance if users 1 and 2 are sharing the j^{th} RE, then transmission signal v_j is defined as:

$$v_j = x_1 + x_2 \quad (5)$$

where x_1 and x_2 are the modulation symbols of users 1 and 2 respectively.

However, the linear combination of the users' symbols alters the signal characteristics and complicates the extraction of the data at the receiver side. By adding the modulation symbols, the combined constellation introduces an ambiguity [10] dependent on the modulation type and the receiver will not be able to separate the users' data. Thus, a power scaling and a phase shifting factors should be included in PDMA matrix in order to protect the users' data and to make the detection easier. The transmitted data on the j^{th} RE will be as follows:

$$v_j = \sqrt{\beta} x_1 e^{j\phi} + \sqrt{1-\beta} x_2 \quad (6)$$

By introducing the power scaling β and phase shifting ϕ factors, the combined constellation is changed and the ambiguity could be removed. The optimal scaling and shifting factors depend on the number of users and the shape of the input constellation.

III. SYSTEM MODEL

A. STUDIED SCENARIO

The studied scenario proposes a downlink case where the base station communicates with different users, in our case vehicles. The context of the work is the management of crisis and emergency situations which requires a maximization of the number of users communicating simultaneously with the base station. In these situations, we assume that the number

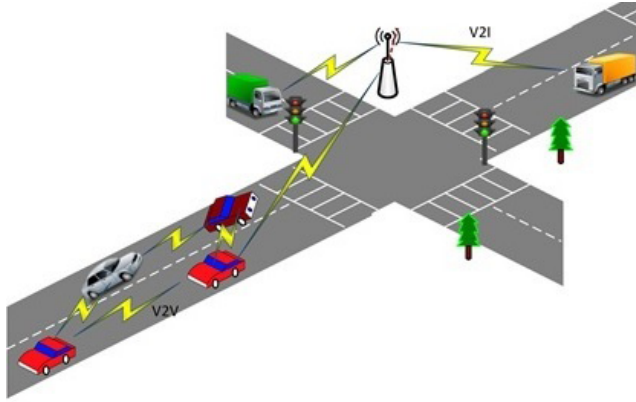


FIGURE 2. System scenario.

of available resource elements N is lower than the number of users K . Thus, sharing the resources between the users is necessary and NOMA techniques are suggested.

As presented in Figure 2, we assume, in a basic scenario, that the number of users communicating with BS is $K = 3$ and $N = 2$ is the number of available resource elements. The presented scenario is very common in vehicular context where, we usually have limited number of vehicles communicating with the base station and having access to restricted number of resources.

Multi-carrier multiple access techniques are used in our scenario where N_s is the number of sub-carriers and shared between the different users. We assume that a resource element corresponds to a block of $\frac{N_s}{2}$ sub-carriers. Each resource element is shared by different users by applying a power domain multiplexing. Various power factors and resources (according to PDMA matrix) are assigned to the users to have different users' orders. This should ease the detection of the users' data.

B. SIC RECEIVER

Different algorithms could be used in multiple users detection schemes to separate the users' data multiplexed on the same REs with considering a good trade-off between performance and complexity. SIC is recommended as a detection algorithm at the receiver for massive Machine Type Communication [11]. As the Figure 3 suggests, the main idea behind the SIC algorithm is to detect the users' data then reconstruct the signal and finally subtract it from the combined signal following an iterative way. However, SIC algorithm could suffer from error propagation and thus deteriorates the multiple users detection and, as a consequence, NOMA transmission performance. The problem of error propagation could be mitigated by arranging the users according to the diversity order of PDMA pattern and by this mean the users multiplexed on higher number of resources are detected first.

The SIC detection algorithm is as follows:

- Initialization: the combined signal $y_t^i = y_t$ and the matrix $\mathbf{G}^1 = \mathbf{G}$.

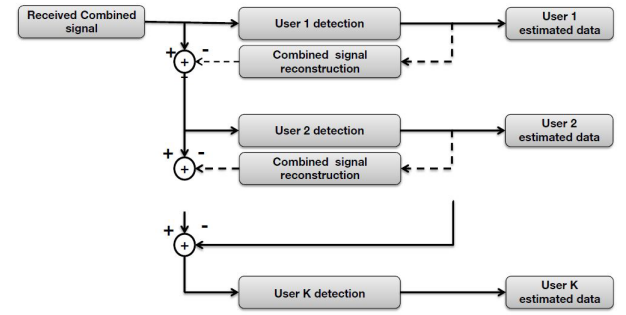


FIGURE 3. SIC Receiver.

- Nulling: at the i^{th} stage, the nulling matrix \mathbf{W}^i calculated as the pseudo inverse of \mathbf{G}^i

$$\mathbf{W}^i = (\mathbf{G}^i)^+ \quad (7)$$

The selected user's order is k_i and the detected user's symbols x_{k_i} are given by:

$$w_{k_i} = (\mathbf{w}^i)_{k_i} \quad (8)$$

$$x_{k_i} = w_{k_i} y_t^i \quad (9)$$

- Cancellation: the detected data are subtracted from the combined received signal:

$$y_t^{i+1} = y_t^i - g_{k_i} x_{k_i} \quad (10)$$

IV. ANALYTIC BER STUDY

The analytic Bit Error Rate expressions for the proposed scenario are studied in this section. This work is performed by analyzing the Signal to Interference and Noise Ratios SINR and by taking into account the SIC algorithm for users' data separation.

At the receiver side in a downlink scenario, as presented, and after multi carrier demodulation, the combined received signal is given by equation 11:

$$\mathbf{y} = \mathbf{G}\mathbf{x} + \mathbf{n} \quad (11)$$

where, \mathbf{y} is $(N \times 1)$ vector, \mathbf{G} is $(N \times K)$ PDMA matrix, \mathbf{x} is $(K \times 1)$ QAM modulated vector and \mathbf{n} is AWGN vector. N and K are, respectively, the number of resource elements and the number of users. As explained, the SIC receiver iterates over the users to separate their data and to do that in an optimal manner, it orders the users according to the diversity order which is, in our case, the number of the resource elements assigned to the user. Thus, we start the SINR analysis with the first SIC layer relative the first detected user data denoted here x_1 .

- **SIC layer 1:** Detection of x_1

At the first iteration, the nulling matrix \mathbf{H}_{sic} is computed from PDMA matrix \mathbf{G} . It can be $\mathbf{H}_{\text{sic}} = (\mathbf{G})^+$, the pseudo inverse of \mathbf{G} or $\mathbf{H}_{\text{sic}} = (\mathbf{G}^H \mathbf{G})^+ \mathbf{G}$, if zero forcing (ZF) detection is used which our case. The choice of ZF detection is motivated by the simplicity of the algorithm since Minimum Mean

Square Error (MMSE) detection assumes the knowledge of noise power. The estimated \hat{x}_1 is given below:

$$\hat{x}_1 = \underbrace{\mathbf{H}_{\text{sic}} \mathbf{G}(1, 1) x_1}_{\text{desired signal term}} + \underbrace{\sum_{k=2}^K \mathbf{H}_{\text{sic}} \mathbf{G}(1, k) x_k}_{\text{interference term}} + \underbrace{n_1}_{\text{noise term}} \quad (12)$$

As a result, according to SIC algorithm detection the resulting SINR relative to the first user is defined as the ratio of the power the desired signal to the other users interference added to the noise consecutive powers and is given by:

$$\text{SINR}_1 = \frac{|\mathbf{H}_{\text{sic}} \mathbf{G}(1, 1)|^2 p_1}{\sum_{k=2}^K |\mathbf{H}_{\text{sic}} \mathbf{G}(1, k)|^2 p_k + \sigma^2 \|\mathbf{H}_{\text{sic}}\|^2} \quad (13)$$

where p_k with $1 \leq k \leq K$ are the allocated powers to the different users and σ^2 represents the noise variance.

As proposed in [17] the average bit error rate of co-existence scenarios is presented as the average over the constellation weighted by the assigned powers to the different users. As the SINR expression exhibits, the BER would be distorted not only by the variance of the noise but also by the interference caused by the users sharing the same resource element. The proposed generalized bit error rate in this paper is composed of two parts. The first one is based on the manner how the SIC algorithm works. In fact, the SIC at each iteration considers one user data, assumed to be user 1 in layer 1 to be estimated and the other users data interference with AWGN noise as equivalent noise.

$$P_1^1 = Q\left(\sqrt{\frac{p_1}{I + N}}\right) \quad (14)$$

where p_1 is the power allocated to user 1, I is the PDMA users interference term power and N presents the noise power which are given by equation 13. The second part takes into account the modification of the original constellation introduced by the PDMA scheme and the summing of the users data. This part of BER is obtained by averaging over the constellation symbols as proposed in [17].

$$P_1^2 = \frac{1}{L_c^2} \sum_{i=1}^{L_c} \sum_{j=1}^{L_c} Q\left(\sqrt{\frac{|p_i c_i + p_j c_j|}{N}}\right) \quad (15)$$

where L_c is the length of the constellation and c_i are the constellation symbols. Thus the resulting BER of the user 1 is:

$$P_1 = \frac{1}{2} (P_1^1 + P_1^2) \quad (16)$$

• SIC layer 2: Detection of x_2

Regarding the second iteration, where the first user data are estimated \hat{x}_1 , the first performed is updating the $\mathbf{H}_{\text{sic}}^2$ by eliminating the column relative to the first user and thus we have new PDMA matrix also \mathbf{G}_2 .

The SINR is given below:

$$\text{SINR}_2 = \frac{|\mathbf{H}_{\text{sic}}^2 \mathbf{G}_2(1, 1)|^2 p_2}{\left(|\mathbf{H}_{\text{sic}}^2 \mathbf{G}_2(1, 1)|^2 p_1 e_1 + \sum_{k=2}^{K-1} |\mathbf{H}_{\text{sic}}^2 \mathbf{G}_2(1, k)|^2 p_k + \sigma^2 \|\mathbf{H}_{\text{sic}}^2\|^2 \right)} \quad (17)$$

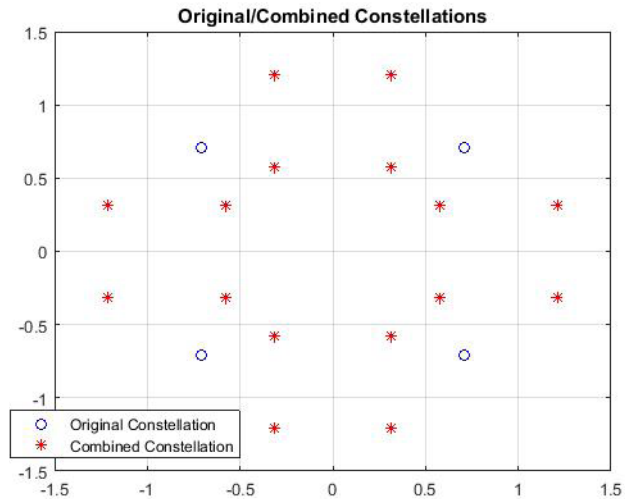


FIGURE 4. Original and combined constellations.

where $e_1 = E\{|x_1 - \hat{x}_1|^2\}$ is the detection error of the user 1. Based on SIC approach, the BER of the second user is inferred from P_1 and is given below:

$$P_2 = P_1 + (1 - P_1) Q\left(\sqrt{\frac{p_2}{N}}\right) \quad (18)$$

Concerning the higher layer, the detection and the BER analysis is performed as the second user estimation.

V. SIMULATIONS RESULTS

A. SIMULATION ASSUMPTIONS

The performance evaluation is obtained through simulation. FBMC, GFDM and OFDM, as 5G candidate waveform are compared in a PDMA context. The PDMA overloading factor is 150%. The configuration is (2×3) with the following PDMA pattern:

$$\mathbf{G}_{\text{PDMA}}^{[2,3]} = \begin{bmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \quad (19)$$

According to the PDMA pattern presented by the matrix 19, two users are multiplexed on each RE. In order to make the detection easier by protecting the combined constellation, a scaling power and a phase shifting are performed as presented in equation 6 where $\beta = 0.8$ and $\phi = \frac{\pi}{4}$. By applying these factors, we are able to remove the ambiguity in the combined constellation resulting from summing the modulated symbols, as is Figure 4 shows for 4-QAM case.

Waveforms simulation parameters are presented in table 1. The different systems are simulated in an additive white Gaussian noise. The implemented modulation is 4-QAM with number of sub-carriers $K = 64$. For FBMC system, the prototype filter is selected as presented in the PHYDYAS project [3] with an overlapping factor $K = 4$. Regarding, the GFDM systems the block size is $M = 15$ and Root-raised cosine filter with a roll off factor $\alpha = 0.3$ are used. Both MF and ZF receivers are implemented.

TABLE 1. Simulation parameters.

Common parameters	
Modulation scheme	4-QAM
FFT size	64
Channel	AWGN
OFDM	
Cyclic prefix	6
GFDM	
Number of sub-carriers N	64
Number of sub-symbols M	15
Filter type	RRC
Roll-off factor	0.3
Receiver type	MF and ZF
FBMC	
K (filter)	4

B. BIT ERROR RATE RESULTS

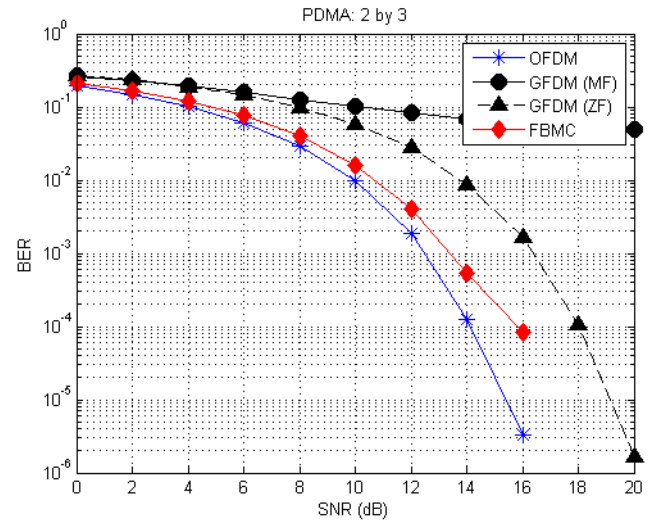
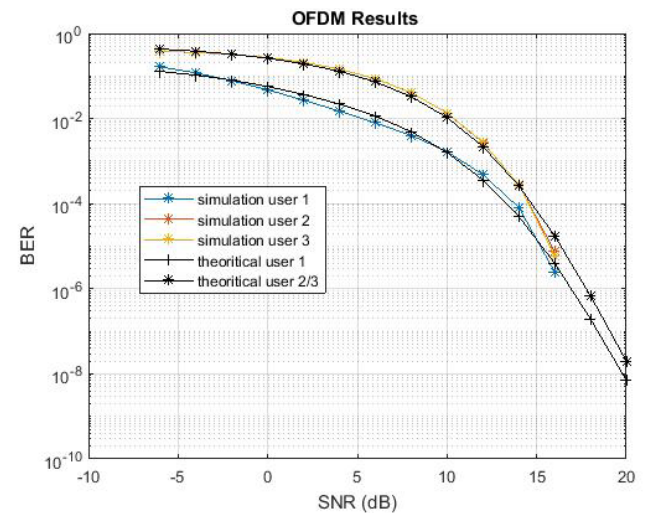
According to the simulation parameters presented in the previous subsection, we aim, on one hand, to evaluate the performance of FBMC and GFDM waveforms in a NOMA context and to compare the results with OFDM waveform. On the other hand, we look for validating the theoretical analysis performed in the previous section.

The first simulation results are presented by Figure 5 where the bit error rate relative to OFDM, FBMC and GFDM waveforms are compared. As shown in Figure 5 presenting the BER averaged over all users at different SNRs, the OFDM system presents the best BER results compared to FBMC and GFDM. However, the FBMC systems results remain satisfying when compared to GFDM results. Thus by combining a NOMA technique, namely PDMA, with FBMC, we are able to recover properly the multiple users data at reasonable SNR values using SIC receiver, especially, when we take into account the reduction of OOB emissions offered by FBMC system.

Regarding GFDM performances, the BER results are less encouraging than FBMC. The GFDM-ZF receiver might be equivalent for some configurations and GFDM parameters (the number of sub-symbols and sub-carriers) to OFDM system. For instance, the noise enhancement is not prominent, here, because of the choice of the block size and we notice that if we change the block size the results can be even more degraded. However, the GFDM-MF receiver results are degraded because the self interference problem and clearly PDMA scenario deepens further this problem even at high SNR. As a result, we focus on OFDM and FBMC waveforms, for the rest of the paper studying the analytic side. In fact, FBMC systems offer a gain in terms of spectral efficiency around 20% [18] and could present an interesting trade off between bit error rate and spectral efficiency.

In Figure 6, we present the BER results relative to OFDM case for different users.

The user 1, according to PDMA matrix presented by the equation 19, is multiplexed on both available resource elements which makes him a privileged user and gives him a


FIGURE 5. BER vs SNR (PDMA: 2 by 3).

FIGURE 6. BER vs SNR (PDMA: 2 by 3).

higher order. This explains the BER results which are better than the other two users BER results. Users 2 and 3 are assigned to one resource element shared with user 1. Besides, by opting for $\beta = 0.8$ higher power is assigned to the user 1. All these reasons explains the degraded results of users 2 and 3 (which are equivalent since both users have the same configuration) when compared to user 1.

The simulated results are compared with the theoretical results proposed by the analysis presented by equations 14, 15 and 16 for user 1 and equation 18 for users 2 and 3. The comparison shows by following the SIC algorithm steps and by taking into account the users interference term, we are able to recover the BER trend for user 1 in a first step. Then, in a second step, we can deduce the BER for users 2 and 3.

Regarding, FBMC waveform we have two major results extracted from Figure 7. The first one is of a general nature

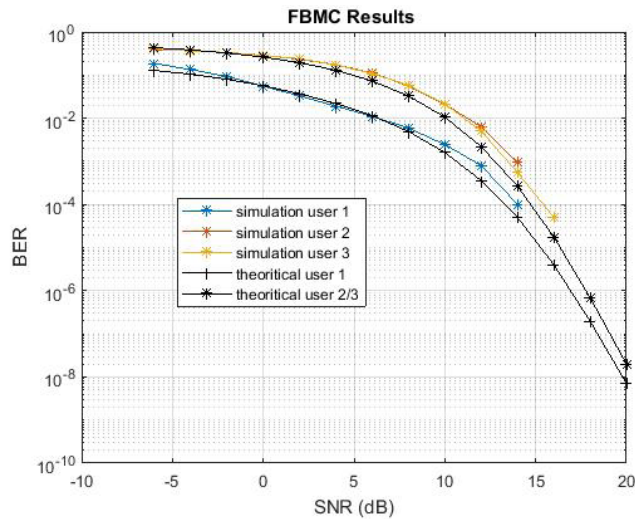


FIGURE 7. BER vs SNR (PDMA: 2 by 3).

when we compare the results to OFDM case. In fact, we can notice that the BER results for FBMC system are very close to OFDM case. Thus the association of PDMA with FBMC waveform do not degrade the performance in terms of BER and allows us to benefit from the better spectral efficiency offered by FBMC systems.

The second result is about the comparison with analytic study results. As presented in [19], in AWGN channel and equivalent system parameters OFDM and FBMC offer equivalent performances in terms of BER. Based on this results, we applied the same theoretical development for FBMC and OFDM systems. We observe a slight difference between the theoretical and simulation results which is due to the difference between the waveforms in OMA scenario and is slightly highlighted in NOMA context. Although this difference, the theoretical results compared to simulation remain very satisfying for the different users.

VI. CONCLUSIONS

With the aim of facing the explosive development of mobile communication systems and answering to the new emergent applications and their requirements, various signal processing techniques are studied for 5G communication. In this paper, we studied in particular a PDMA scheme, as NOMA technique, jointed with 5G candidate waveforms, namely, OFM, FBMC and GFDM. The detection of multiple users sharing the same resource elements is performed using SIC receiver. The performances are studied in terms of bit error rate and the simulations results are validated with an analytic study. The results show that GFDM systems are not suitable for NOMA scenarios while OFDM systems offer the best performance. However, OFDM systems are very restrictive in multi users access because of OOB radiation. Thus, when higher spectral efficiency is required, FBMC systems can be used since the BER performances remain quite fair

could present a better trade off between BER and spectral efficiency.

Future works concern two different levels. Firstly, the simulation of an other receiver algorithm such as Belief propagation algorithm and comparing the performances with SIC algorithm. Secondly, source and channel coding are to be implemented in order to study the improvement of the performances in NOMA context.

REFERENCES

- [1] X. Meng, J. Li, D. Zhou, and D. Yang, "5G technology requirements and related test environments for evaluation," *China Commun.*, vol. 13, no. 2, pp. 42–51, 2016.
- [2] S. Borkar and H. Pande, "Application of 5G next generation network to Internet of things," in *Proc. Int. Conf. Internet Things Appl. (IOTA)*, Jan. 2016, pp. 443–447.
- [3] PEF Project. (2010). [Online]. Available: <http://www.ict-phydyas.org>
- [4] N. Michailow *et al.*, "Generalized frequency division multiplexing for 5th generation cellular networks," *IEEE Trans. Commun.*, vol. 62, no. 9, pp. 3045–3061, Sep. 2014.
- [5] K. S. Ali, H. Elsayy, A. Chaaban, and M.-S. Alouini, "Non-orthogonal multiple access for large-scale 5G networks: Interference aware design," *IEEE Access*, vol. 5, pp. 21204–21216, 2017.
- [6] S. Qi, W. Sen, H. Shuangfeng, and C. L. I, "Unified framework towards flexible multiple access schemes for 5G," *ZTE Commun.*, vol. 14, no. 4, pp. 26–34, Oct. 2016.
- [7] A. Li, A. Benjebbour, and A. Harada, "Performance evaluation of non-orthogonal multiple access combined with opportunistic beamforming," in *Proc. IEEE 79th Veh. Technol. Conf. (VTC Spring)*, May 2014, pp. 1–5.
- [8] J. Zeng, B. Li, X. Su, L. Rong, and R. Xing, "Pattern division multiple access (PDMA) for cellular future radio access," in *Proc. Int. Conf. Wireless Commun. Signal Process. (WCSP)*, Oct. 2015, pp. 1–5.
- [9] L. Ping, L. Liu, K. Wu, and W. K. Leung, "Interleave division multiple-access," *IEEE Trans. Wireless Commun.*, vol. 5, no. 4, pp. 938–947, Apr. 2006.
- [10] S. Chen, B. Ren, Q. Gao, S. Kang, S. Sun, and K. Niu, "Pattern division multiple access—A novel nonorthogonal multiple access for fifth-generation radio networks," *IEEE Trans. Veh. Technol.*, vol. 66, no. 4, pp. 3185–3196, Apr. 2017.
- [11] B. Ren *et al.*, "Link performance estimation technique for PDMA uplink system," *IEEE Access*, vol. 5, pp. 15571–15581, 2017.
- [12] Z. Zhao, M. Schellmann, X. Gong, Q. Wang, R. Böhne, and Y. Guo, "Pulse shaping design for OFDM systems," *EURASIP J. Wireless Commun. Netw.*, vol. 2017, no. 1, p. 74, Dec. 2017.
- [13] M. Pauli and P. Kuchenbecker, "On the reduction of the out-of-band radiation of OFDM-signals," in *Proc. IEEE Int. Conf. Commun.*, vol. 3, Jun. 1998, pp. 1304–1308.
- [14] M. Van Eeckhaute, A. Bourdoux, P. De Doncker, and F. Horlin, "Performance of emerging multi-carrier waveforms for 5G asynchronous communications," *EURASIP J. Wireless Commun. Netw.*, vol. 2017, no. 1, p. 29, Dec. 2017.
- [15] M. Bellanger, "FBMC physical layer: A primer," Tech. Rep., 2010.
- [16] X. Dai *et al.*, "Successive interference cancellation amenable multiple access (SAMA) for future wireless communications," in *Proc. IEEE Int. Conf. Commun. Syst.*, Nov. 2014, pp. 222–226.
- [17] M. B. Çelebi and H. Arslan, "Theoretical analysis of the co-existence of LTE-a signals and design of an ML-SIC receiver," *IEEE Trans. Wireless Commun.*, vol. 14, no. 8, pp. 4626–4639, Aug. 2015.
- [18] F. Schaich, "Filterbank based multi carrier transmission (FBMC)—Evolving OFDM: FBMC in the context of WiMAX," in *Proc. Eur. Wireless Conf. (EW)*, Apr. 2010, pp. 1051–1058.
- [19] Q. He and A. Schmeink, "Comparison and evaluation between FBMC and OFDM systems," in *Proc. 19th Int. ITG Workshop Smart Antennas (WSA)*, Mar. 2015, pp. 1–7.



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