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Power Allocation scheme for GFDM with Adaptive Modulation in Rayleigh fading channels

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Abstract-This paper is to design and evaluate the resource management scheme for multi-user GFDM with adaptive modulation in frequency selective fading channels, where resources are assigned based on channel knowledge. Expected results of this paper is an iterative algorithm, which perform the multi-user sub carrier, sub-symbol and power allocation to meet Quality of Service (QoS) constraints. The performance should be compared with existing allocation schemes. The transmitter has a perfect knowledge of the instantaneous channel gains for all users, we propose a multi-user GFDM subcarrier, sub-symbol and power allocation algorithm to minimize the total transmit power. This work analyses the performance of using a specific set of parameters for aligning GFDM with long term evolution (LTE) grid and Bit Error Rate performance. The results show that the performance of the proposed algorithm using GFDM is closer to the performance of using OFDM and outperforms multiuser GFDM.
Index Terms- OFDM, GFDM, LTE, QoS, FDMA

1. INTRODUCTION

The fourth generation (4G – LTE) allows higher-speed data rates up to 100 Mbps and enables a better Quality of Experience (QoE) than any other previous generation. At the moment, Orthogonal Frequency Division Multiplexing (OFDM) is the main multiplexing scheme adopted because of its robustness against multipath channels and the easy implementation based on Fast Fourier Transform (FFT). Nevertheless, OFDM has some drawbacks that affect its application. New requirements for future networks are predicted to go beyond LTE networks capacities and data rates [1,2]. New application scenarios that will require much more network flexibility are foreseen and some of those will not be satisfied with current multiplexing schemes. In this work I contemplate a frequency selective fading channel which means that the channel is affected by multipath propagation during the wave transmission. To counter this effect, adaptive modulation is considered. Adaptive modulation takes into account the conditions of the radio link in order to improve the rate of transmission by choosing the order of the modulation according to the channel state information [3,4].

2. GFDM FOR 5TH GENERATION CELLULAR NETWORKS

When the fourth generation for mobile systems was developed, it was optimized to provide both higher data rates and reliable coverage to mobile users. However, cellular systems for the next generation network will need to challenge new demands with more diversity of application requirements such as, ultra-high data rate, ultra-low latency, battery-driven communication sensors which need ultra-low power consumption, and some control applications that require a very short round trip time (RTT). In table 1 there is a description for the main scenarios foreseen for 5G networks [12].

Table1. 5G Applications and requirements

Applications	Requirements
(WRAN)	Wireless networks have relatively small cell size and operate in licensed frequencies, which makes them economical unfeasible in low populated areas. When using OFDM as air interface, it is difficult to attend the emission mask imposed by spectrum regulations. So next generation network should cover large coverage areas using dynamic channel allocation based on CR with low OOB emissions and the multipath effects by reducing the impact of the cyclic prefix (CP) in the overall data rate.
Tactile Internet	Real-time control applications with at most 1 ms round-trip latency, i.e. tactile, haptic, visual and auditory interfaces. The ultra-low latency is going to be determined by the physical layer because the time budget for the physical layer (PHY) will be of less than hundreds μs.
Machine Type Communication	This is about enabling direct communications among devices and connect these devices to the Internet, also called Internet of Things (IoT). Normally a battery supports these devices and the power consumption is a very important factor to take into account. So for this scenario it

	is required to achieve reliable communication in exchange of a loose of synchronization
Bitpipe Communication	Low-out-of band is crucial to allow fragmented spectrum allocation with Cognitive Radio (CR) technology. The opportunistic utilization of white spaces, where radio terminals are able to detect white spaces in the spectrum and establish the communication in that space until they detect a primary user and do change to another channel. Especially for this particular case OFDM cannot be efficiently used because of its high out-of-band emission (OOB) and the high PAPR (Peak-to-Average-Power-Ratio)

A data block d, that consist of N elements decomposed into M sub symbols and K subcarriers each. The total number of symbols in that block follows as $N = KM$. The $d_{m.k}$ are the individual elements on data block corresponds to the m^{th}sub symbol and k^{th}subcarrier of the data block[5,6]. Therefore, a Data Matrix [A]is created with M rows and K columns as shown in figure 2. If the sub symbol spacing $M = 1$ then the total number of symbols in that block is $N = K$, the GFDM system follows back to OFDM system and also derived the single carrier frequency domain equalization (SC-FDE) by making $K = 1$ as shown figure 1.

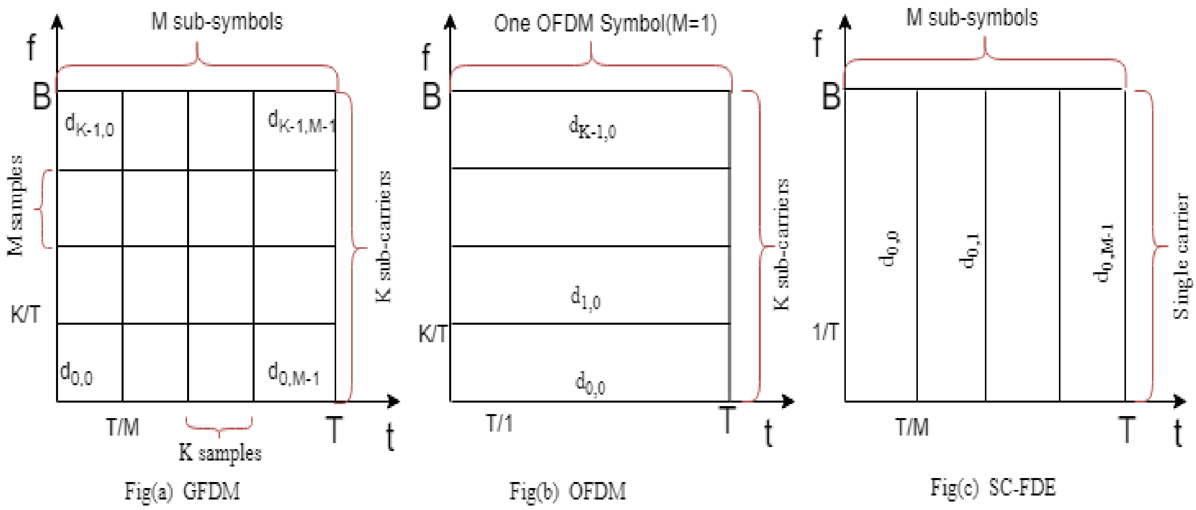

Figure1: Concept of GFDM by setting number of sub carriers and sub symbols

The block diagram of GFDM transceiver is as shown in the figure.1. At transmitter, the binary date is encoded, mapped as a QAM symbols from 2^M- valued complex constellation and then given to the GFDM modulator [7]. The CP is added to the modulated signal and then transmitted on wireless channel. At the receiver side CP will be removed then demodulated by GFDM demodulator into QAM symbols, which are de-mapped and decoded as a binary information as shown in figure 2.

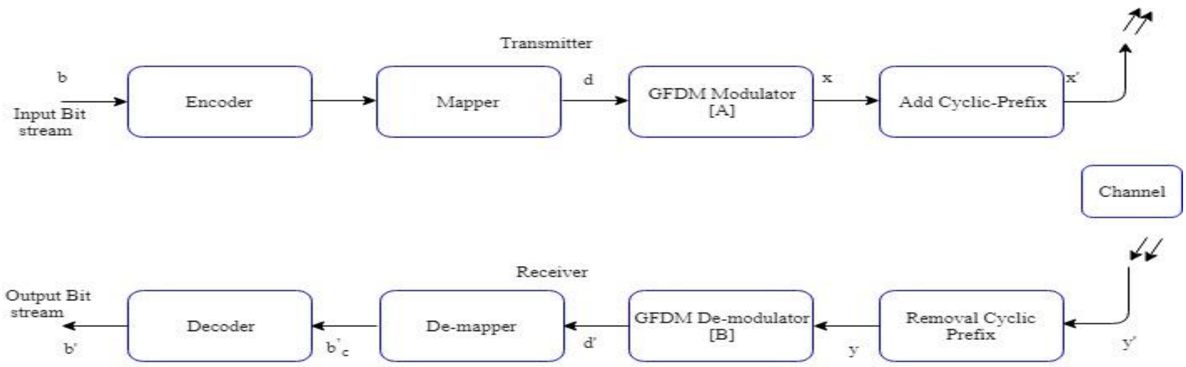

Figure2: Block diagram of GFDM

3. PROPOSED POWER ALLOCATION SCHEME

3.1. *System Modelling and Implementation*

The main goal of this work was to design a low complexity algorithm (resource management scheme) based on a MATLAB code and evaluate it.
In this proposed scheme, the main objectives are:
1. Minimize the total transmit power by using the best channel conditions for each user. For this reason, perfect channel knowledge at the transmitter side is required and assumed.

2. Guarantee that all users will obtain their desired data requested. With this constraint even a user with poor channel conditions will be able to transmit data but in exchange of increasing transmit power.

3. Reward with a higher modulation order (more bits per symbol) those subcarriers that have better conditions. That is by definition what adaptive modulation does in this system[8].
To make this possible some trade-offs between users that have very good channel conditions versus other ones that never have good channel conditions have to be made. Also, the combination of using higher or lower modulation order will have an impact to the necessity of using more or less subcarriers.

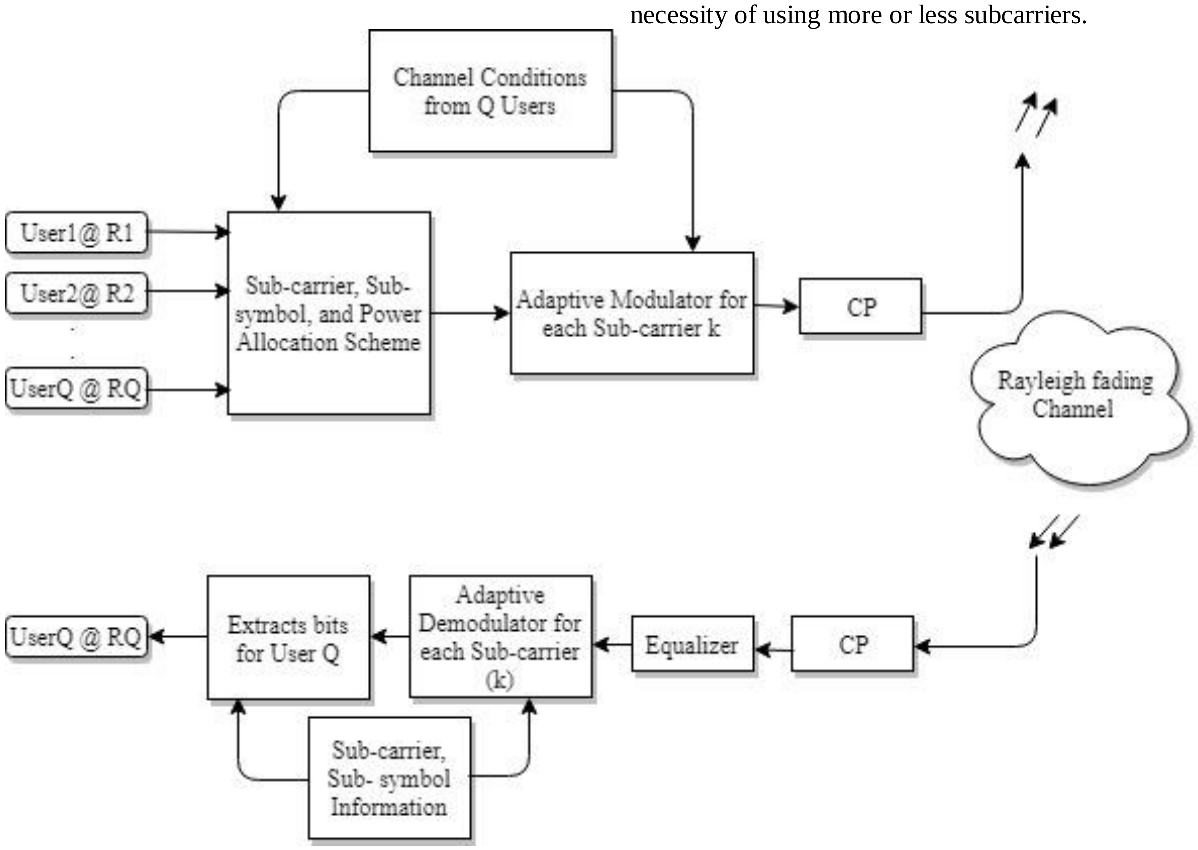

Figure3: Multi-user GFDM with adaptive allocation

3.2. Adaptive power allocation algorithm

In this section some of the already existing allocation schemes for OFDM are shown. Adaptive modulation is a very strong technique to achieve high spectral efficiency. This technique chooses the order of the modulation based on the channel conditions. Nevertheless, when OFDM with adaptive allocation is used in a frequency selective channel each user is given a predetermined frequency band or time slot.

Because of that, some of the subcarriers may not be used and these unused subcarriers are wasted and not used by other users. However, if one subcarrier is in deep fade for one user it does not mean to be in deep fade for all users as the fading parameters are mutually independent. The same happens with GFDM. For this reason, a resource management scheme is needed in combination with the adaptive modulation technique. The system consists of Q users and K subcarriers, and the bits transmitted for each OFDM symbol for the qth user is Rq. A perfect channel state information is assumed in both the transmitter and the receiver. For this system each subcarrier can only be used by one user, so allocating bits to one subcarrier prevents other users to transmit on that subcarrier.

In the transmitter, the data from these Q users are put into the subcarrier and bit allocation block.

Depending on the number of bits assigned to each subcarrier the adaptive modulator will use the corresponding modulation scheme. We define cq,k the number of bits assigned to the qth user on the kth subcarrier and $D = \{0,1,2\ldots,S\}$ where S is the maximum number of bits/OFDM symbol allowed for each subcarrier. The magnitude of the channel gain is defined as αq, (considering coherent reception) of the qth user seen by the kth subcarrier. Finally, the function $(c)(1)$:

$$f_c(c) = \frac{N_0}{3}\left[Q^{-1}\left(\frac{P_e}{4}\right)\right]^2 (2^c - 1) \tag{1}$$

Denoting the required received power (in energy per symbol) for a MQAM symbol in a subcarrier for reliable reception of c bits per symbol when channel gain is equal to unity. The noise power spectral density is denoted by $N0$ and the probability error by Pe. Hence, the optimization problem becomes

$$P_T = \min_{\substack{c_{q,k}\epsilon[0.S] \\ \rho_{q,k}\epsilon[0.1]}} \sum_{q=0}^{Q-1}\sum_{k=0}^{K-1} \frac{f_q(c_{q,k})}{\alpha_{q.k}^2}\rho_{q,k} \tag{2}$$

$$R_q = \sum_{k=0}^{K-1} \rho_{q,k}\, c_{q,k} \quad and \quad \sum_{q=0}^{Q-1} \rho_{q,k} = 1 \tag{3}$$

The $\rho_{q.k}$ is a time-sharing factor (in this system it will take values of 0 or 1 only). So the purpose of the system is to minimize the transmit power over all users and subcarriers, constrained to: i) Total rate of q[th] user is equal to the sum of the data over all subcarriers being used by that user ii) Ensures that only one user can use each subcarrier. For making the problem more tractable, variable $c_{q,k}$ has to be rewritten as $\frac{r_{q,k}}{\rho_{q,k}}$ otherwise the function$\rho_q(c_{q,k})$ is not convex shown equation (4) .

$$P_T = \min_{\substack{c_{q,k}\epsilon[0,S\rho_{q,k}] \\ \rho_{q,k}\epsilon[0.1]}} \sum_{q=0}^{Q-1}\sum_{k=0}^{K-1} \frac{\rho_{q,k}}{\alpha_{q.k}^2} f_q\left(\frac{r_{q,k}}{\rho_{q,k}}\right) \tag{4}$$

$$R_q = \sum_{k=0}^{K-1} r_{q,k} \quad for\ all\ q\epsilon\{0,1,2 \ldots\ldots\ldots.. Q-1\} \tag{5}$$

$$\sum_{q=0}^{Q-1} \rho_{q,k} = 1 \qquad foe\ all\ k\epsilon\{0,1,2,\ldots\ldots\ldots. K-1\} \tag{6}$$

Following the procedure using standard optimization techniques [7] we obtain the Lagrangian

$$\sum_{q=0}^{Q-1}\sum_{k=0}^{K-1} \frac{\rho_{q,k}}{\alpha_{q.k}^2} f_q\left(\frac{r_{q,k}}{\rho_{q,k}}\right) - \sum_{q=0}^{Q-1}\gamma_q\left(\sum_{k=0}^{K-1} r_{q,k} - R_q\right) - \sum_{k=0}^{K-1}\beta_k\left(\sum_{q=0}^{Q-1}\rho_{q,k} - 1\right) = L \tag{7}$$

Where γ_q and β_k are the Lagrange multipliers for the constrains I and ii after differentiating L with respective $r_{q,k}$ and $\rho_{q,k}$ we obtain proportionality:

$$r_{q,k}^* = \rho_{q,k}^* {f'}_q^{-1}(\gamma_{q,k}\alpha_{q,k}^2) \tag{8}$$

Where

$$\gamma_{q,k} = \begin{cases} \frac{{f'}_q^{-1}(0)}{\alpha_{q,k}^2} & if\ {f'}_q^{-1}(\gamma_{q,k}\alpha_{q,k}^2) < 0 \\ \gamma_q \ \ if\ \ 0 \le {f'}_q^{-1}(\gamma_{q,k}\alpha_{q,k}^2) \le S \\ \frac{{f'}_q^{-1}(M)}{\alpha_{q,k}^2} & if\ {f'}_q^{-1}(\gamma_{q,k}\alpha_{q,k}^2) > M \end{cases} \tag{9}$$

And

$$\rho_{q,k}^* = \begin{cases} 1 & if\ \beta_k > H_{q,k}(\gamma_{q,k}) \\ 0 & if\ \beta_k < H_{q,k}(\gamma_{q,k}) \end{cases} \tag{10}$$

$$H_{q,k}(\gamma) = \frac{1}{\alpha_{q,k}^2}[f_q({f'}_q^{-1}(\gamma_{q,k}\alpha_{q,k}^2) - \gamma_q\alpha_{q,k}^2{f'}_q^{-1}(\gamma_{q,k}\alpha_{q,k}^2)] \tag{11}$$

Equation (12) can be seen in another way. Since constraint (7.ii) must be satisfied, we deduce that for each subcarrier if $H_{q,k}(\gamma)$ for q=1,..,Q are all different, only the user with the smallest $H_{q,k}(\gamma)$ can use that subcarrier. This can be formulated as follows:

$$\rho_{q,k}^* = 1\ and\ \rho_{q,k}^* = 0\ for\ all\ q \ne q' \tag{12}$$

Where $q' = \text{argmin}_g\, H_{q,k}(\gamma_{q,k})$

The way this algorithm works is by iterative searching. It starts giving small values for all lambdas and then increases them individually until the individual rate constrain is reached. Then it switches to another user. This procedure is repeated until the total data rate constraint is satisfied. More detailed information and figures about this scheme are shown in (12).

4. SIMULATION RESULTS

In this section, the algorithm mechanics are explained step by step as and the parameters chosen in each simulation. First of all a structure with system parameters is initiated, which is common for all simulations. Parameters are the following:

TABLE 2: Simulation parameters

Parameter	**Number**
Number of users	5
Number of subcarriers	128
# Sub-symbols OFDM	1
# Sub-symbols GFDM	15
Total requested data rate (OFDM)(All users) $RTot$	512 bits/block
Total requested data rate (GFDM)(All users) $RTot$	7680 bits/block (512*15 sub-symbols)
Individual data rate Rq	#Subsymbols*[104,100,104,100,104] bits
Pulse OFDM	Raised cosine with roll-off 0 (time domain)
Pulse GFDM	Raised cosine with roll-off 0.3 (freq. domain)

Secondly, five random Rayleigh fading channels with 5-taps each are created and their channel gain information are saved into a channel gains matrix. Once all channel gains are saved in to matrix $\boldsymbol{H}$ (with dimensions 5x128) the bit and subcarrier allocation process starts assigning 2 bits (lowest modulation scheme 4-QAM) for each subcarrier to the user that has a higher channel gain. If all subcarriers are already assigned it sums up the total data rate from each user. Normally, in this step some users may not have any subcarrier ascribed to, i.e. a user, whose channel conditions are bad over all the available bands, so it could not transmit data. Afterwards, it has to be checked if each user can transmit his desired data rate with that allocation. In case one user can't reach the individual data rate, it means that he does not have enough subcarriers or that the subcarriers assigned to that user are already carrying the maximum bits permitted per subcarrier, so that user needs more subcarriers. Hence those users that needs more subcarriers are given another one (at this point subcarrier which should be changed from one user to another is not important).

This process is repeated until all users are able to transmit their desired data with that allocation. At the same time, for each extra subcarrier that is accessed to this user another one has to be taken away from another user. For this reason, all users are checked and the ones with more subcarriers associated with are marked with leftover subcarriers. The next step is to choose carefully which subcarrier can be taken from the user with leftover subcarriers. An iterative procedure will be done here, which searches for the subcarrier with minimum channel gain of the user with leftover subcarriers. Then we modify the parameter ρqthat indicates for which user q that subcarrier is activated. Also that subcarrier will be initialized with two bits. This procedure is repeated until all leftover subcarriers are assigned. Now it can be guaranteed that with that subcarrier allocation it is will be possible to satisfy all users. Following the same example as in figure 7 and in figure 8, it is shown that some subcarriers have changed from one user to another. In circles there is the equivalent channel. It just shows which user is using which each subcarrier. Furthermore, channel gain average at each subcarrier is shown by stars. Figure 9 shows a flow chart providing the detailed description of the multiuser subcarrier, sub-symbol and power allocation.

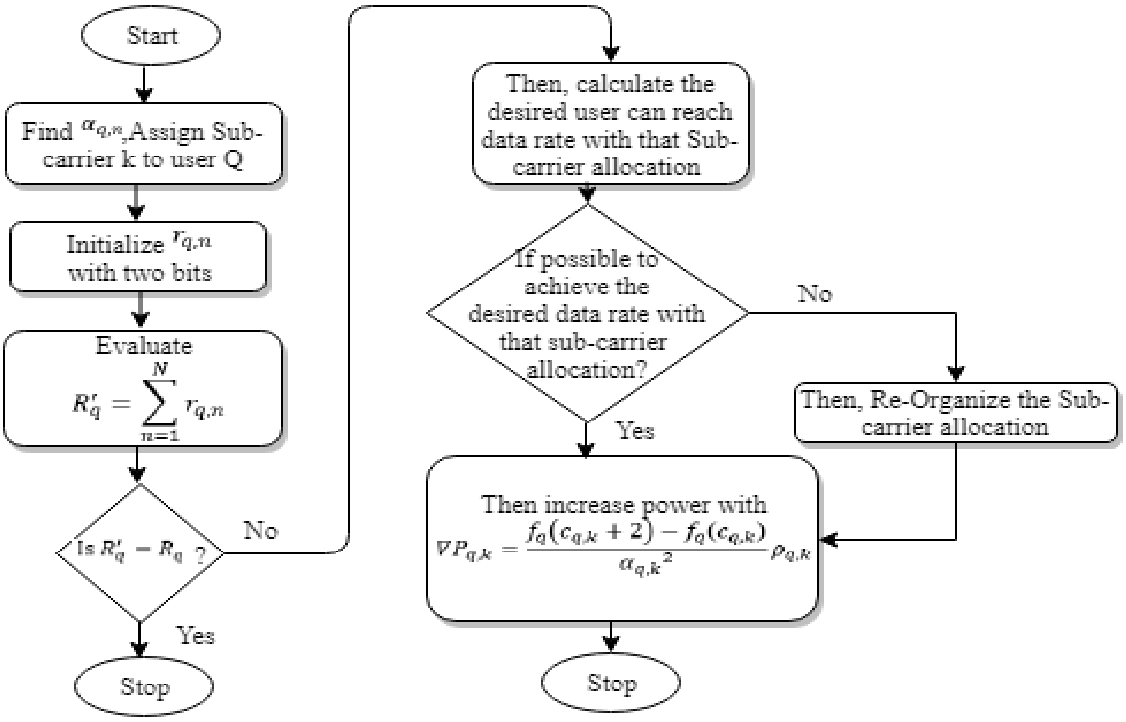

Figure4: Flow chart for Multi-user GFDM with adaptive allocation

Lastly, the adaptive bit allocation is applied. In this step those subcarriers with better channel gains will be given a higher modulation order to carry more bits. To do that, the increment of power which is needed to transmit 2 bits more in the subcarriers/sub-symbols with $\rho^*_{q,k} = 1$ has to be calculated:

$$\Delta P_{q,k} = \left(\frac{f_q(c_{q,k}+2) - f_q(c_{q,k})}{\alpha^2_{q,k}}\right) \quad (13)$$

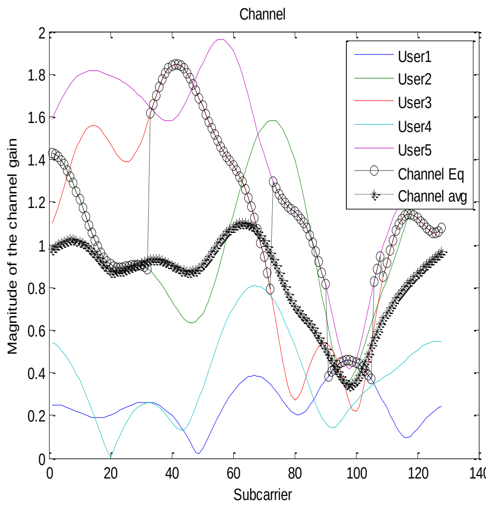

Figure 5: Magnitude of the channel gain varying with number of sub-carriers

Figure 6 compares the SER performance of OFDM and GFDM when a different roll-off factor is used for the transmitter pulse of the GFDM signal under a frequency Rayleigh fading channel. The figure shows that the pulse shape is an important factor to take into account in the GFDM performance. From the theory we know that when using a root cosine (RC) filter with roll-off=0 the OFDM and GFDM curves should match. For this reason, GFDM plots starts with a roll-off factor equal to 0.1 / 0.5 / 0.9. On the other side, it is shown that when roll-off is equal to 0.9 the performance is much worst and that's because of the noise

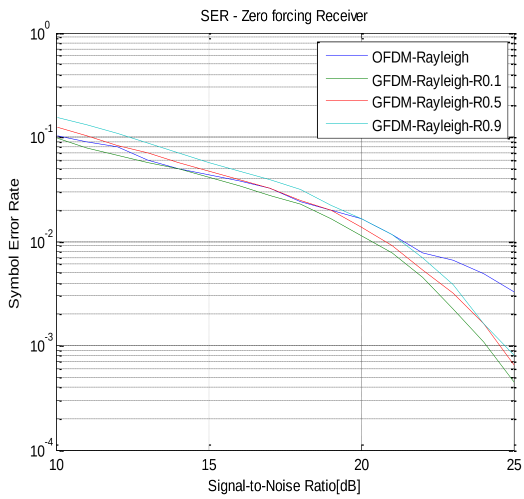

Figure 6: Signal to Noise ratio verses SER for different Roll off factors

Figure 7 shows the average SNR needed to achieve a certain SER when having five systems with different number of users. We see that when the number of users change (that means more channels, one for each user) the average SNR to achieve a certain SER is lower as more users the system has. The reason of this is that when the number of channels is bigger, the resource allocation algorithm has more chances to satisfy users with better channel conditions.

Notice that for this simulation the total requested data rate is the same for all systems, 512 bits, hence when the system has 7 users the individual average requested data is less than when the system has 3 users. On the other hand, when the system has 3 users the band is given to those 3, that means that if one user has poor channel conditions 1/3 of 512bits will be transmitted by this channel, whilst if the system has 7 users and one has bad conditions the proportion will be around 1/7.

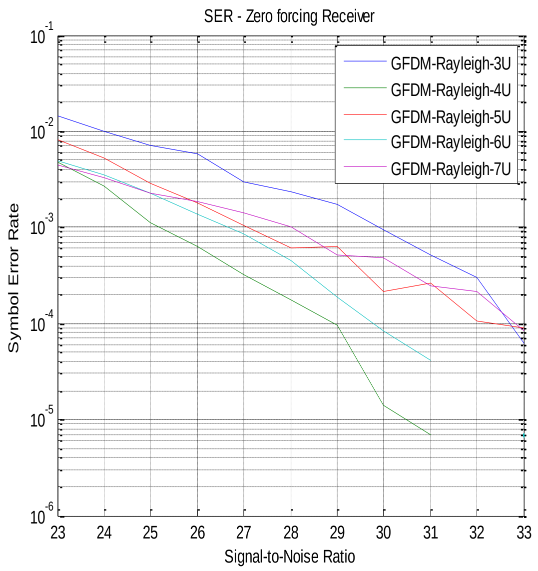

Figure 7: Signal to Noise ratio verses SER for different users

Figure 7 is just the illustration of the system when one iteration is done. It is shown within two figures to make it look clearer than showing it all together, but both are from the same iteration. Theoretical curve is obtained from equation (6) (notice that for this equation $N0$ is equal to 1 and the Pe is equal to $10{-}3$).

On the other hand, the power of the simulated signal is obtained from multiplying the received samples versus their conjugate and then divided by the channel gain. Another point that is worth mentioning, is that for plotting the power per subcarrier of the GFDM signal it only takes into account one sub-symbol for each GFDM symbol (first calculates the power including all sub-symbols then is divided by the number of sub-symbols to have an average).

Looking into the plot it is clear that the results obtained when using the theoretical formula versus the simulated results differs a bit from each other. I attribute this differences due to the noise power and the probability error. In the theoretical values $N0$is fixed to 1 and Pe to $10{-}4$, while in the simulated results the power is obtained directly from the received samples that have convoluted with the channel.

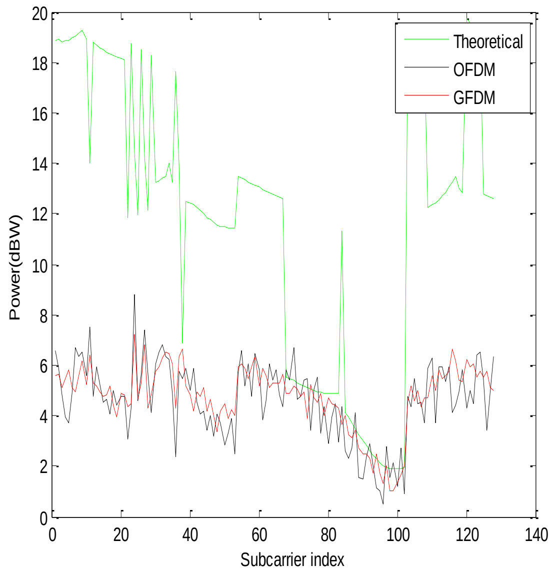

Figure 8: Power (dBW) verses different subcarriers using OFDM and GFDM

5. CONCLUSIONS

In this paper, the performance of using a multi-user GFDM system, aligned with LTE resource grid, with adaptive subcarrier, sub-symbol and power allocation is analyzed. After testing and simulating the performance of the proposed scheme, it is clear that knowing the channel gains helps to reduce the average transmitting power. To this end, it can be stated that when using the proposed scheme for GFDM it is possible to achieve a very close behaviour compared with OFDM in terms of SER and received power when the same amount of data is shown. Furthermore, if each GFDM symbol is demodulated independently we can achieve very low latency maintaining a more than acceptable SER with the average transmitting power being slightly above than it is in OFDM for high SNR, and a better performance than OFDM for low SNR, when the same amount of data is compared. Low latency is an important feature for future 5G networks and here we have seen that when GFDM is configured in this way it reduces the impact of the PHY layer overall system latency. This is possible because of the use of one CP for each M sub-symbols and the reduction of the GFDM symbol duration.

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