

MULTICARRIER TRANSMISSION WITH COORDINATION IN CELLULAR ENVIRONMENT

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ABSTRACT

The cellular environment continues being a very good support for the development of the new generation of mobile communication. Its main characteristic is the levels of interference as a result of intensive reuse of the spectrum. Inter-cell interference limits the capacity of wireless networks, so, it is important to know its statistic over the surface of the cell and to use new technologies with some levels of coordination to mitigate it. The objective of this study is to analyze the behavior of the interference over an active cell from the nearest one (first time in this case) and to provide a comparison between a partially coordinated OFDM in front of a fully uncoordinated frequency hopping OFDM network. We present the results of the total throughput in both cases.

1. GENERAL INFORMATION

The continuous growth in the demand for mobile communications has led the scientific community and the industry into intense research and development efforts towards a new generation of cellular systems. Currently there are several ongoing research projects regarding the design of a high flexible and scalable next generation mobile radio access concept (4G) with respect to high data rates and spectral efficiency. For this 4G systems there are several attractive candidates of transmission schemes based on multi-carrier systems.

Orthogonal Frequency Division Multiplexing (OFDM) is one of the promising techniques for achieving a high speed data rate, required in the new wireless data systems, with a relatively low complexity receiver (requiring only a fast Fourier transform processor followed by a single tap equalizer over the subcarriers) [8]. OFDM divides the entire channel into many narrow sub channels and transmitting data in parallel, therefore, it is used in wireless communications to combat the distortion due to multi-path propagation and to increase the spectral efficiency. Furthermore OFDM prevents intersymbol interference (ISI) and intercarrier interference (ICI) by inserting a guard interval between adjacent OFDM symbols.

Different publications [1] - [6] have presented the principal advantage of use OFDM in combination with other technologies like antenna arrays to enhance system capacity, based on the development of adaptive modulation and the introduction of coding [3, 5, 11]. The possibility to use OFDM as a physical layer in mobile communications, bring about the necessity to analyze the behavior of it in a more realistic scenarios, i.e., cellular structures with many interference signals from different sectors around the principal one.

The basic principle of the cellular communications is to split an area into cells and the coverage of each cell is then

ensured by one base station (BS) which communicates with its mobile terminals (MS). The BS can use an omnidirectional transmission system or a sectorial one, with the use of sectorial antennas. The problem to assign the spectral resources in order to perform a spectrally efficient coverage of an area has been treated and two main spectrum management strategies exist [9]. In the one hand, all BS and all associated mobile terminals share the entire available bandwidth and the spectrum is reused from one cell to another (single frequency network or universal frequency reuse) [7], so, it is necessary to use any spread-spectrum based multiple access technique, such as DS-CDMA or Frequency Hopping OFDM (FH-OFDM). The other possibility is to divide the complete transmission bandwidth and to assign different portions to adjacent cells and the reuse patterns are defined so as to minimize the multi-cell interference. These two solutions present their own advantage and disadvantage and the performance depends on the access technique which is used.

In general, the term *frequency assignment* has been used to describe different types of problems which often have different objectives [9, 10],

1. Planning models for permanent spectrum allocation (a fixed subset of subcarriers is assigned to each MS and BS or wireless station in general).
2. Planning models to establish different types of services within a given allocation.
3. Dynamic assigning frequencies to users within an established network, with special interest in land cellular mobile. No predefined subset of subcarriers is assigned. Based on the quality of each subcarrier from each BS to each MS an optimal set of subcarriers is used in a dynamic way.

Recently, the uses of dynamic subcarrier scheduling mechanism related with multicarrier technology [12, 13], have gained a lot of interest with the main motivation to exploit the possibility to analyze the interference levels and to assign sub carriers among terminals according to their quality. In this paper we have chosen to focus on a system using FH-OFDM with a random frequency assign, this access method appears as a promising candidate in future wireless standards for many reasons: flexibility in subcarrier attribution, no multiuser interference, simplicity of the receiver, etc [7] and OFDM system with a level of coordination at the moment to distribute the frequency in the adjacent sectors (*resource allocation*) based in the optimization of the total interference from the users in the different sectors. The growing interest in wireless communications has highlighted the fact that the usable radio spectrum is a finite resource. The rest of

the paper is outlined as follows. Section 2 presents the multi-cell environment and the model used to calculate the interferences with a precise formulation. In Section 3 the analysis of the interference over the area of the sector and we highlight the interference's difference by zones. Section 4 analyzes the total throughput in the main sector using FH-OFDM and partially coordinated OFDM. Section 5 contains the conclusions.

2. MULTI-CELL ENVIRONMENT

In the analysis, a typical hexagonal structure is assumed for the cellular network where all the cell sizes are equals. Each cell is served by a base station with omnidirectional antenna structure or a perfect sectorized antennas with unit gain in the angular interval of service and zero spill over. In figure 1 it is depicted the one-tire multi-cell environment, where only the nearest interfering cells around the desired cell is considered, it means that the effects of $N_c = 7$ cells will contribute to the interferences in the central cell and each cell has $N_s = 3$ sectors (dashed line in figure 1)

Interference power estimation is based in the use of log-distance path loss model and in the log-normal approximation. The propagation models indicate that average received signal power decreases by the logarithm of the distance between the transmitter and the receiver (outdoor or indoor). Such models have been used extensively in the literature [8]. The average large-scale path loss (PL) is expressed as a function of distance by using a path loss exponent, γ

$$\overline{PL} \propto \left(\frac{d}{d_o}\right)^\gamma. \quad (1)$$

where d_o is the close-in reference distance which is determined from measurements close to the transmitter and d is the separation distance between the transmitter and the receiver. Using this model, if an arbitrary base station is able to provide p_o watts to a certain user located at distance d_A , it will interfere with other user in other sector (or cell) at distance d_B with a power p_i given by,

$$p_i(d_B) = p_o(d_A) \cdot \left(\frac{d_A}{d_B}\right)^{-\gamma}. \quad (2)$$

The value of γ depends on the specific propagation environment, for example, in free space, γ is equal to 2 and when obstructions are present, γ will have a large value, typically between 2 and 6.

The model in (1) does not consider the fact that there are different conditions surrounding the locations having the same transmitter-receptor separation. In order to consider this situation, the log-normal approximation is used, where more measured signals are much different than the average value predicted by the equation (1). Mobile radio signals are composed of two fading components, fast fading caused by local multipath propagation and slow fading due to shadowing [14]. The envelope of the received signal can be expressed as $z(t) = s(t) \cdot f(t)$, where $s(t)$ is the slow fading component which is log-normally distributed, with standard deviation in the range 4-12dB, and $f(t)$ is the fast fading envelope which closely follows a Rayleigh distribution. The situation of the interferences will be better characterized by the distribution of the slow fading and the path loss, so it is possible to express the path loss as,

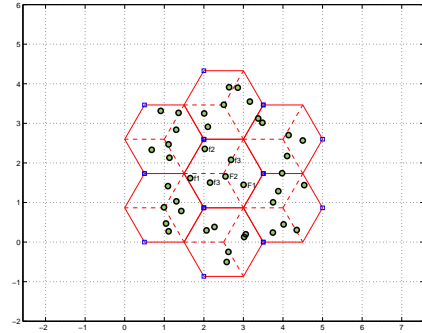


Figure 1: Scenario example with the first ring of interference cells, two users by sectors and three frequencies.

$$p_i(d_B) = p_o(d_A) \cdot \left(\frac{d_A}{d_B}\right)^{-\gamma} \cdot 10^{0.1X_\sigma}. \quad (3)$$

where X_σ is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (also in dB) [4]. In general, $p_i(d_B)$ is affected by shadowing and fast fading, so received power is in fact,

$$p_i(d_B) = p_o(d_A) \cdot \left(\frac{d_A}{d_B}\right)^{-\gamma} \cdot s_i \cdot f_i. \quad (4)$$

where s_i represents the slow fading with lognormal distribution and f_i is a unit power exponential distribution related to the Rayleigh fading.

2.1 The scenario

In the analyzes, it will be considered the effect of the first rings of cells, a total of $N_c=7$ cells each one with three sectors, that is, $N_s = 3$ (see figure 1). We dispose N_u users randomly per sector and it will be assigned them a total of N_f frequencies (f_1, f_2, \dots, f_{N_f}) with the condition, $N_f > N_u$, so it is possible to make different combinations in order to select the best one according to the interferences. Figure 1 shows an example where $N_u = 2$ users have been disposed in each cell and a total of $N_f = 3$ are used. The signs f_1, f_2, f_3, F_1, F_2 closed to the users in the centered cell under study mean the assigned frequency, where F_1, F_2 are the same frequencies like f_1, f_2 but they are assignment to the users in the main sector. Squares represent the base station locations and green circles the random user's positions.

3. ANALYSIS OF THE INTERFERENCE IN THE MAIN SECTOR

The main objective of this study is to provide some comparable results of the interference behavior when we use different strategies to assign the spectrum among users. These strategies are:

- A fully uncoordinated frequency hopping OFDM network. This is the simplest OFDM multicell scheme where null coordination is required, it supposes that every set of users are located over the available carriers randomly without any knowledge about the per carrier fading factor or the intercell interference that it is causing.

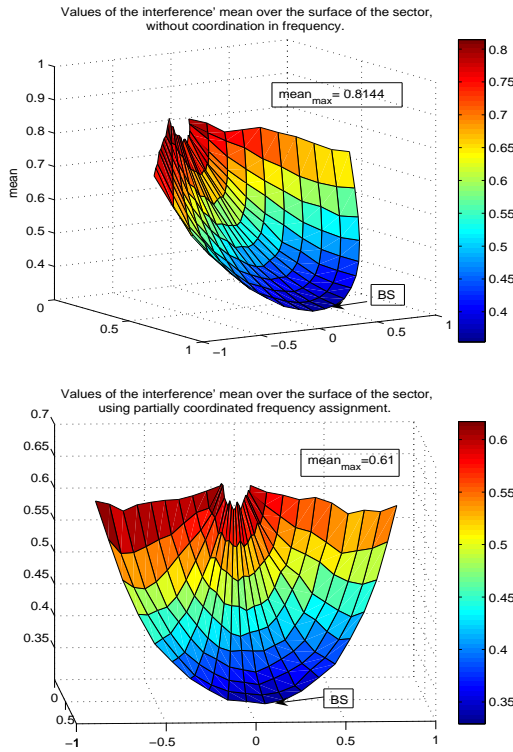


Figure 2: Surface of the mean values of the interference on the victim sector: (a) Using FH-OFDM, (b) Using a partial coordinated frequency assignment.

- Partially coordinated OFDM network. It means that the optimum search of the spectrum allocation will be based on the joint analysis of three sectors (in the central cell), while the interference of the neighbor cells is uncoordinated.

Once we know the user's disposition in each sector, we calculate the influence of the interference over the users in the main sector, knowing the position of each BS and frequency's distribution according to the two strategies. For the different positions of the users, we estimate the mean and the variance of the interference along the surface of the sector: we calculate extra distances from interference cells to the victim one and the attenuation according to (2). To optimize the network in order to reduce the interference, we analyze all of the possible combinations of frequency (*exhaustive search* over a large number of permutations). The number of permutations is:

$$\left(\frac{N_f!}{(N_f - N_u)!} \right)^{N_s} \quad (5)$$

approximation which is unfeasible for a number of users above 4. In this example the total number of combinations is 216. In order to get some results with reasonable computational time, we it is necessary to implement a simpler approach as a suboptimum process.

Figure 2 (a) y (b) represents the results of analyze the interference over the surface of the victim sector, in this case, a total of eleven sectors conform the interference. In the first case (Figure 2.a) we consider a frequency hopping OFDM with random frequency assignment (no coordination between

sectors) and in the second (Figure 2.b) it is represented a partially coordinated OFDM system, it means, the coordination in frequency assignment in the three main sectors (the victim sector and the two nearest). In both figures are represented the most significative value of the mean of the interference, where it is possible to appreciate the difference between the two cases:

$$\max(\text{mean})_{FH-OFDM} = 0,8144.$$

$$\max(\text{mean})_{OFDM\text{partial-coordination}} = 0,61.$$

In order to evaluate also the variance of the interference in both cases, it is better to represent the distribution of the interference over the surface of the sector. The distribution is depicted in figure 3

It is possible to see in figure 2 (a) y (b) that there are different zones around the BS with a clear differences in the mean value of the interference, depending on the distance from the position of the BS, so, it could be a good practice to analyze the interference from different zones inside the sector. So, we propose to divide the sector's area in three zones according to the value of the interference and classify them in high (*zone 1*), middle (*zone 2*) and low (*zone 3*) interference zones.

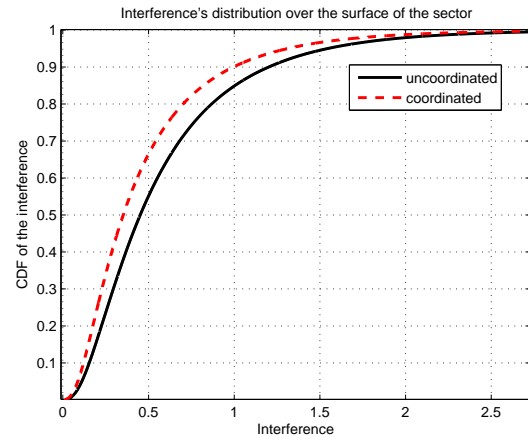


Figure 3: CDF of the mean value of the interference over the surface of the sector considering the two strategies of frequency assignment: FH-OFDM (*uncoordinated*) and partially coordinated OFDM (*coordinated*).

In figure 4 and table 1 is depicted the limits in azimuth and distance between different zones. We have considered the analysis of interference by zones, that is:

Interference Zones		
Zone	Azimuth (ϕ)	Distance
Zone 1	$[5\pi/3, 51\pi/30]; [9\pi/30, \pi/3]$	$0 \div 0.2$
Zone 2	$[51\pi/30, 53\pi/30]; [7\pi/30, 9\pi/3]$	$0.2 \div 0.4$
Zone 3	$[53\pi/30, 7\pi/30]$	$0.4 \div 1$

Cuadro 1: Position of the different zones according to the level of the interference.

where ϕ is the azimuth values of the first sector in the central cell (the values of ϕ in the first sector belong to $[5\pi/3, \pi/3]$).

Figure 5 shows for the zones nearest to the BS (interference zone 3), that the probability to obtain a value of interference less than a specific value in the abscissas is higher than in the rest of zones. It is a logical result considering the proximity of the BS. So, if we use these results, it is possible to develop an algorithm that, in coordination with a sub-optimum process, we can reduce the complexity in general, applying the frequency coordination only in the zones with higher values of the interference and to assign frequency in the rest of the sector randomly. The running time is reduced too.

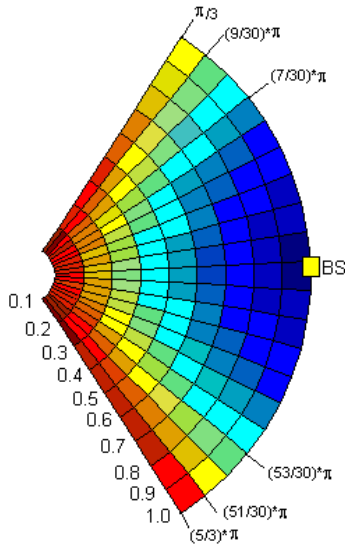


Figure 4: Surface of the mean values of the interference on the victim sector using a partial coordinated frequency assignment.

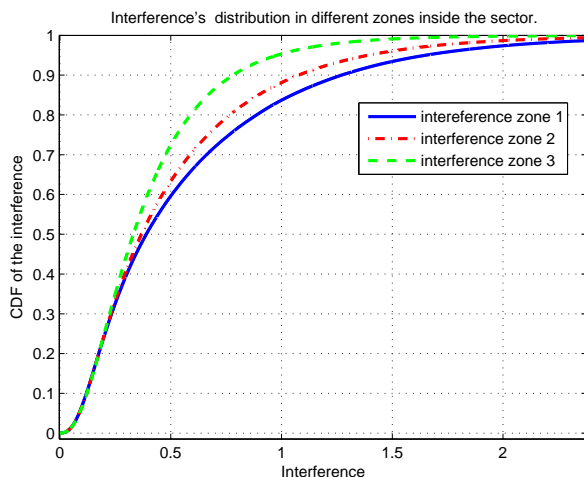


Figure 5: CDF of the mean value of the interference over the different zones of the sector, considering the partial coordinated OFDM (coordinated).

4. TOTAL THROUGHPUT IN THE MAIN SECTOR

An important criteria to choose optimum or sub-optimum allocation of frequencies is the sum throughput of all users in general or the users inside the principal sector. The throughput can be expressed like:

$$R = \sum_{k=1}^{N_u N_s} \log_2 \left(1 + \frac{P_k}{I_s(K) + I_c(K) + \sigma^2} \right) \text{ (bit/sec/user)} \quad (6)$$

where P_k is the received power from the BS, it is calculated from the expression, $P_k = A_t \cdot d^{-\gamma}$, where A_t represents the slow fading attenuation. $I_c(K)$ represents the interference power within the users in the three sectors that are being coordinated and $I_s(k)$ the interference from the rest of the sectors no coordinated and σ^2 is the noise power. In the same way, it is possible to analyze the behavior of the throughput using a frequency hopping pattern in all sectors and without limits of power in the BS and introducing the coordination in the principal sector.

The simulation considers 2 users by sectors, $N_u = 2$, and the use of three frequencies, $N_f = 3$. The result of the total throughput is depicted in figure 6. In spite of the coordination is made in the three principals sectors, it is possible to appreciate the possibility to get a higher throughput, in this case, the probability to have a total throughput less than any value, that is, $P(R < abcisa = 4)$ is 60 % for a partially coordination OFDM as strategy of frequency assignment and the 70 % for FH-OFDM without any coordination. The results will be better if it is possible to extend the coordination over the complete structure (the seven cells in figure 1) and to use a higher number of frequencies, it means, higher possibilities of combination in order to reduce the interference. The same result can be noticed in case of analysis the individual throughput.

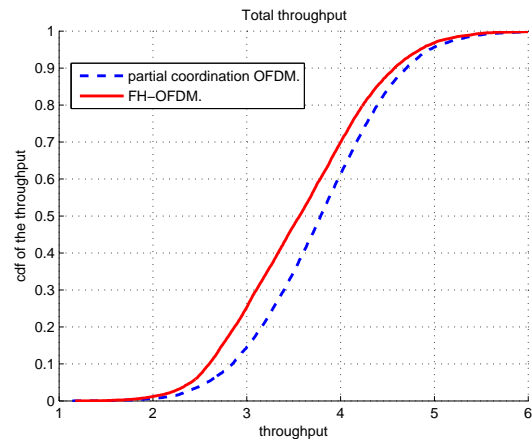


Figure 6: Total throughput of the users of the central cell considering FH-OFDM (uncoordinated) the partial coordinated OFDM (coordinated).

5. CONCLUSION

The use of dynamic subcarrier assignment in cellular environment offers high possibilities to increase the spectral efficiency by means of a algorithm with a proper criteria. It

is possible to analyze the level of the interferences at the moment to make the decision to use an specific subcarrier for different users. An important problem in this case is to identified a suboptimum algorithm that permits to extend the coordination in the complete cellular structure and reduce the running time, that can be implemented in practice. We remark the possibility to analyze the advantages we can obtain knowing the statistics of the interference on the surface of the sector, mainly to coordinate the zones with a higher probability of interference and in the rest of cellular system use FH-OFDM with its principals advantages, it permits to reduce the complexity of the coordination.

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