WCDMA and OFDMA coexistence with device-to-device communication overlaying cellular networks

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***Abstract*—The usage of Device-to-device (D2D) networks overlaying Cellular networks is a promising technique to increase the multimedia services capability of wireless networks based in a resource sharing environment. It offers the possibility of reusing the same wireless resource in multiple devices at the same time, improving the overall efficiency of the network. In this case, the assurance of the quality in both links depends on the interference conditions being below harmful levels. This concern involves mitigating the interference among the different devices in all directions, but since the D2D link will be established on resources firstly designated to cellular communication, it can be seen as a secondary layer of communication and cannot takes priority over the cellular links (primary layer). The network resource allocation policies must be developed in order to keep the interference in low levels while maximize the reuse probability. This paper proposes a new allocation scheme considering the coexistence between WCDMA and OFDMA in different layers and also a relocation algorithm for primary users on the OFDMA spectrum driven by the spread spectrum (WCDMA) characteristics of the secondary user, aiming an improvement in the the reuse probability through the mitigation of the interference between the two layers and regarding the quality assurance for the cellular users.**

***Index Terms*—Cellular Networks, WCDMA-OFDMA coexistence, Resource Sharing, D2D communication, Spectrum reuse.**

I. Introduction

THE usage of D2D communication overlaying cellular networks is a promising technique to increase the network throughput [1] [2] [3] [4]. However there are still technical difficulties on defining some aspects of this opportunistic communication, which includes the RAT and the mutual interference control [5] [6].

The coexistence of different links sharing the same resource is possible only if the mutual interference produced by them does not cause severe damages on the information reception on both sides. To achieve this requirement it is important to count on interference control strategies as power control algorithms and advanced receivers. In [1] multiuser diversity gain is obtained through a proper pairing of D2D and cellular links, aiming improvements on throughput exploiting the spatial reuse of the resources. Sum-rate optimizations are proposed in [7], where resource allocation policies are driven by the better channel conditions.

This paper exploits the characteristics of CDMA and OFDMA in a novel algorithm to mitigate the mutual interference observed by users that are sharing resources through different access techniques.

The OFDMA system splits a wideband channel into several narrowband subchannels distributed to its users, while the WCDMA spreads a single user data on a wideband transmission. Considering a WCDMA user overlaid to OFDMA users, the interference signal received for each of the OFDMA users will suffer different attenuation due to propagation effects. On the same way, each of them will contribute differently to the interference observed by the WCDMA user. This work uses the WCDMA spread spectrum shape to make a proper allocation of the OFDMA users into the narrowband channels, in order to reduce the mutual interference power in both receivers.

This paper is organized as follows: the system model description are described on Section II, while the WCDMA-OFDMA coexistence is detailed on Section III. The Resource relocation algorithm is proposed on Section IV, and the simulation results are presented on Section V. Section VI provides the conclusions.

II. System Model

The basis of the algorithm is a power control mechanism to D2D communication firstly proposed in [8]. However, at this paper we extended the results to the situation where the D2D pair and the cellular users are accessing the resources by different access technologies (WCDMA and OFDMA, respectively). Also, we proposed an optimization algorithm for the proposed scheme which aims gains in the resource sharing probability.

The ref-erence model considers a cellular user (CU) on uplink mode using an OFDM resource. This CU shares its resource with a D2D pair ($D2D_{TX}$, $D2D_{RX}$) causing mutual interference between the two links. The comprehension of this mutual interference is helpful in the design of allocation methods that tries to minimize its impact on both links.

This strategy considers the cellular users as primary users in the network, i.e., the presence of the D2D pair cannot cause harmful effects in the CU link. To achieve this, an interference margin is added to the primary user. Besides, it is considered from now on that the D2D pair is trying to obtain a link in a cellular network with all primary resources previously allocated to different CU.

The interference accross the links depends on the distances between different network elements, which are modeled by the letters C and D accompanied by two subletters, according to Fig 1. Where C describes distances measured from the CU, and D, the distances measured from $D2D_{Tx}$ and the two subletters represent the origin and the destination point of the signal, respectively. Hence, $C_{cu,bs}$ is the distance between the cellular user and the BS, while $C_{cu,dd}$ is measured between CU and $D2D_{Rx}$ and $D_{dd,dd}$ is the D2D pair distane. At last, $D_{dd,bs}$ is the distance between the $D2D_{Rx}$ and the BS. The BS represents a generic central node.

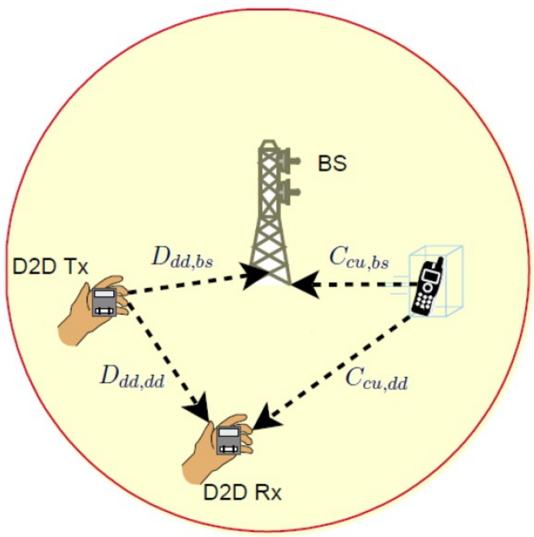

Fig. 1. Scenario example with the distances identification for the proposed model

Thus, the SINR of the received signal on BS side is

$$SINR_{CU} = \frac{P_{cu}C_{cu,bs}^{-\alpha}}{N + P_{dd}D_{dd,bs}^{-\alpha}}, \tag{1}$$

where P_x is the transmitted power of the element x, α is the path-loss coefficient and N is the AWGN power. And, following the same idea:

$$SINR_{D2D} = \frac{P_{D2D_{tx}}D_{dd,dd}^{-\alpha}}{N + P_{cu}D_{cu,dd}^{-\alpha}}. \tag{2}$$

One of the constraints of this resource sharing scheme is that the presence of the D2D link cannot cause a degradation higher than a certain margin, κ, on the CU SINR, which can be written as

$$SINR_{CU} = \frac{P_{cu}C_{cu,bs}^{-\alpha}}{N + P_{dd}D_{dd,bs}^{-\alpha}} \geq (1+\kappa)\beta_{cu} \tag{3}$$

where β_{cu} is the SINR of cellular link at the BS on the absence of the D2D signal. At the same time the D2D link must achieve at least a SINR target of β_{dd} according to

$$\frac{P_{dd}D_{dd,dd}^{-\alpha}}{N + P_{cu}C_{cu,dd}^{-\alpha}} \geq \beta_{dd} \tag{4}$$

Rearranging 3 and 4 one can find that the existence of the D2D link is conditioned to:

$$\begin{aligned} D_{dd,dd} &\leq D_{dd,bs}\left\{\frac{\kappa}{\beta_{dd}\left[1+(\kappa+1)\beta_{cu}\left(\frac{C_{cu,bs}}{C_{cu,dd}}\right)^{\alpha}\right]}\right\}^{1/\alpha} \\ &= d_{crit}, \end{aligned} \tag{5}$$

where d_{crit} is the maximum D2D pair distance which enables the D2D resource sharing.

III. OFDMA AND WCDMA COEXISTENCE

The harmful interference imposes a limitation on d_{crit} that may limits the existence probability of the D2D Link. Looking at eq. 5, since κ is only an interference margin it is reasonable to think its value to be lower than β_{dd}, hence

$$d_{crit} \leq D_{dd,bs}, \tag{6}$$

as the term in braces is not higher than 1.

In order to increase d_{crit} limitation and consequently the existence probability for the D2D link, it is proposed a novel sharing scheme where the network exploits different multiple access schemes aiming obtain the advantages offered by the different technologies. The new scheme enables the D2D link to use a WCDMA transmission sharing resources with several OFDMA CU users.

Since the WCDMA signal is a wideband signal occupying the same frequency of several OFDMA narrowband channels, only a portion of its power interferes on each OFDMA subchannel. On the other hand, the WCDMA signal receives interference of several CU. Thus the eq. 1 and 2 must be rewritten regarding the effective interference of the WCDMA signal on BS side and the sum of different interferers on $D2D_{Rx}$ side.

A. Interference in OFDMA signal

One WCDMA transmitted symbol can be modeled using

$$v(t) = A\sum_{n=0}^{G-1} C_n\psi(t-nT_c) \tag{7}$$

where C_n are the terms of the spreading sequence (assuming ±1 as possible values) modulated by the waveform $\psi(t)$ (time-limited on $[0, T_c)$) and with size G (spread factor). T_c represents the chip duration and A is the symbol to be transmitted. The power spectral density of this signal can be normalized as ([9]):

$$S_v(f) = A^2\frac{S_\psi(f)}{T_c}. \tag{8}$$

In eq. 8 $S_\psi(f)$ is the energy spectral density of $\psi(t)$.

At BS side the uplink reception is performed by an OFDM receiver which involves the FFT of the received signal. Then for the k-th subcarrier the signal of interference received due the WCDMA symbol on the receiver output is given by

$$i_k(t) = \frac{1}{T_{ofdm}} \int_0^{T_{ofdm}} \sum_{m=0}^{L-1} v(t - mGT_c) e^{j2\pi kt/T_{ofdm}} dt \quad (9)$$

where T_{ofdm} is the duration of the OFDM symbol and, also:

$$L = T_{ofdm}/GT_c. \quad (10)$$

The eq. 9 can be rewritten as

$$i_k(t) = \frac{1}{T_{ofdm}} \sum_{m=0}^{L-1} V(f) e^{j2\pi k \frac{mGT_c}{T_{ofdm}}} \quad (11)$$

where $V(f)$ is the Fourier transform of v(t).

Using the results of eqs. 7, 10 and 11 and using a proper variable change one can find that

$$i_k = \frac{\Psi(k/T_{ofdm})}{T_{ofdm}} \sum_{r=0}^{GL-1} Az_r e^{j2\pi kr/GL} \quad (12)$$

with $\Psi(f)$ being the fourier transform of $\psi(t)$, and $z_r = \pm 1$

Then, the interference power of the component i_k can be deduced by the signal variance $var(i_k)$ [10]:

$$\begin{aligned} I_k &= var(i_k) = \frac{|\Psi(k/T_{ofdm})|^2}{T_{ofdm}^2} var\left[\sum_{r=0}^{GL-1} Az_n e^{j2\pi kr/GL}\right] \\ &\leq \frac{A^2|\Psi(k/T_{ofdm})|^2}{T_{ofdm}T_C GL} GL \\ &= \frac{A^2|S(k/T_{ofdm}|}{T_{ofdm}} = \frac{P_{dd}|S(k/T_{ofdm}|}{T_{ofdm}} = \tilde{P_{dd}} \quad (13) \end{aligned}$$

Where $\frac{|S(k/T_{ofdm}|}{T_{ofdm}}$ is the portion of the transmitted power P_{dd} observed as interference on the k-th OFDM subcarrier. It is possible to see that the interference depends also on the waveform used for the WCDMA spreading signal and the subcarrier frequency position (k/T_{ofdm}).

B. Interference in WCDMA signal

On the WCDMA $D2D_{Rx}$ signal is multiplied by the despreading sequence and then filtered to produce the output of the receiver. As the interferer signal is an OFDM subcarrier it will be approximated by a frequency impulse with an offset, i.e. the k-th subcarrier can be modeled as an impulse on the frequency k/T_{ofdm}. Also, the fourier transform has the property for a given signal $x(t)$

$$\mathcal{F}(x(t)B_k e^{j2\pi f_0 t}) = X(f_0)B_k \quad (14)$$

where $X(f)$ is the fourier transform of $x(t)$.

Using this result, the power of the interference signal on the output of the WCDMA receiver, after low-pass filtering, can be approximated as [9]:

$$I = \frac{P_{cu}|S(\frac{k}{T_{ofdm}})|^2}{T_c G} = \tilde{P_{cu,k}} \quad (15)$$

meaning that the interference power of a single OFDMA carrier on the WCDMA signal also depends on the carrier frequency position, on the WCDMA chip waveform and on the CU transmitted power on subcarrier k, $P_{cu,k}$.

Now, considering that in a multisystem environment only part of the WCDMA power is observed as interference in a subcarrier and, also, for WCDMA receiver a portion of all different subcarriers must be summed it is possible, subsituting P_{dd} for $\tilde{P_{dd}}$ on eq. 1 and P_{cu} for $\sum \tilde{P_{cu,k}}$, rewrite the eq. 5

$$d_{crit} = D_{dd,bs} \left\{ \frac{\kappa T_c}{\beta_{dd} \max_n(|S_h(n/T_{ofdm})|)\,[1 + X]} \right\}^{1/\alpha} \quad (16)$$

where X corresponds to

$$X = \beta_{mu}(1+\kappa) \sum_{n=0}^{N_{sc}-1} \left(\frac{C_{uc_n,bs}}{C_{uc_n,dd}}\right)^\alpha |S_h(n/T_{ofdm})| \quad (17)$$

IV. Resource Relocation Algorithm

Based on the results of Sec. III a relocation algorithm has been developed in order to improve the d_{crit} value presented on eq. 16. As stated, the relation between the elements distance is an important parameter that directly affect the interference power. However the frequency position of the OFDM subcarrier also influences the amount of mutual interference. The same CU can affect more or less intensily according to the subchannels it is occuppying in an OFDM frame.

Considering, for example, a raised cosine waveform for the WCDMA chips, then the interference attenuation in eq. 15 is higher as the subcarrier moves away from center frequencies. It is possible to use this result relocating the subcarriers of the users that causes more severe interference on WCDMA users placing them far from the center frequency of the WCDMA carrier.

In other words it is possible to assign the sides frequencies to users which present high values of $\left(\frac{C_{uc,bs}}{C_{uc,dd}}\right)^\alpha$, in order to decrease the value of X on the denominator of eq. 16. The proposed algorithm rank all CU users accordingly to $\frac{C_{uc,bs}}{C_{uc,dd}}$ and allocate the highest value on the farthest located frequency available recursively until all the CU are rellocated.

V. Simulation and Results

The simulation scenarios consider a single cell system where all the CU users and the D2D pair are placed on the cell according to a uniform random distribution. Moreover each CU use one, and only one, resource block (RB) of contiguous subcarriers at the same time. Also the center frequency of the OFDMA and WCDMA frame are assumed to be the same. Other simulation parameters are given in details on Table I

For comparison, we also simulated an OFDM D2D link, according to the base model. In this case the D2D link is said to be possible if it can be established at least in one of the 25 resource blocks according to equation 5.

The first simulation considered a rectangular chip waveform time-limited for WCDMA signal on $[0, T_c)$, no resource relocation has been performed. The result is present on Fig. 2. In this picture the x-axis represents the normalized D2D link distance per cell radius and the y-axis is the link existence

TABLE I
SIMULATION - PARAMETERS

Parmetro	Valor
κ	1
β_{CU}	10 dB
β_{dd}	7 dB
α	3.5
T_{ofdm}	$0.1ms$
Chip rate	$2.3Mcps$
T_c	$1/T_c$
T_{ofdm}/T_c	230
Number of Subcarriers	450
Resource Blocks	25
System Bandwidth	4.5 Mhz

probability $Pr[LE]$. It is observerd in this picture that the processing gain influences strongly the $Pr[LE]$. As higher is the processing gain more efficient is the interference attenuation on WCDMA reception and the link is more robust, allowing higher values for d_{crit}. However, decrease the processing gain represents a decrease in the D2D bit rate.

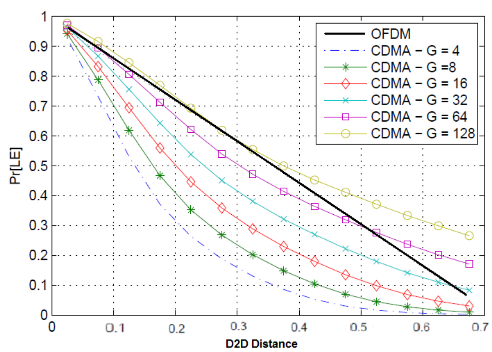

Fig. 2. $Pr[LE]$ comparison for OFDMA and WCDMA (different values of G) transmission

When compared to the OFDM D2D link, the performance of the WCDMA system showed worse performance for almost all the bit rates. In some long-distance cases the WCDMA showed better performance for low-rate transmission. On other hand, for short-distances, the WCDMA system decreases the $Pr[LE]$ in a general way, but when you have both options available sometimes can be better to establish the high rate WCDMA link.

On Fig. 3 we compare different $S(f)$ given different chip waveforms for WCDMA spreading sequence. The objective was improve the efficiency of the scheme exploiting the characteristics of different waveforms. We tested the rectangular waveform, a time-limited sinusoidal wavefor and a raised cosine waveform (rolloff factor = 0.9). While the sinusoidal waveform decreases the maximum value of $S(f)$ it shows a slow decay. The raised cosine filter shows a faster decays on the sides of $S(f)$. On Fig. 4 it is possible to see that, for G=8, the rectangular waveform had similar results of the sinusoidal chip, compensating the higher $S(f)$ peak with a faster decay. We can also observe the raised cosine filter improved a little the performance of the proposed scheme, however this improvement is not enough to be comparable to the performance of the OFDM D2D link.

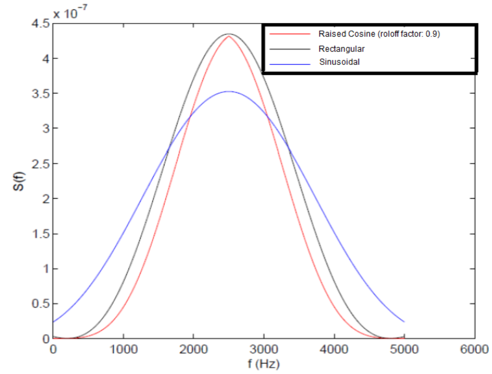

Fig. 3. Power Spectral Density for different chip waveforms

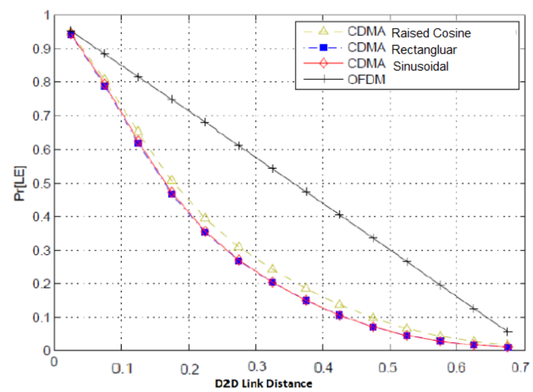

Fig. 4. Comparison of the proposed algorithm performance for different chip waveforms and $G = 8$

Although the faster decay presented by the raised cosine filter without resource relocation the system cannot exploit all the benefits offered by the proposed scheme, since in the central frequencies it has similar behavior $S(f)$ when compared with other waveforms. The system must use properly the faster side decay of raised cosine, to attenuante the most severe interferences sources. On Fig. 5 we used the raised cosine filter with the relocation algorithm proposed in this paper. There is a considerable improvement on the scheme performance when the relocation is performed. Even for high-rates WCDMA links the $Pr[LE]$ shows better perfomance when compared to OFDM link for almost all the cases.

Looking at eq. 16 it is possible to observe that, in some cases, it is possible to make the term in braces to be higher than 1, which allows the system to have

$$d_{crit} \geq D_{dd,bs}, \tag{18}$$

improving the link existence probability even for $D2D_{Tx}$ placed near the BS.

In order to show it the $D2D_{Tx}$ is placed randomly in a circle of $0.2R$, fixing $D_{dd,bs}$ in $0.2R$. The results are on Fig. 6 where one can see that the OFDM system cannot offer,for the given parameters, a D2D links with distance above $0.15R$ which has been outperformed by WCDMA results, in special for $G \geq 8$.

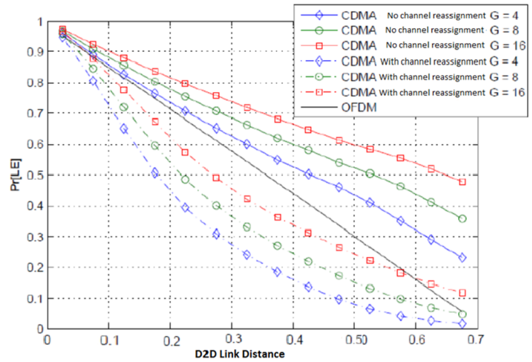

Fig. 5. $Pr[LE]$ comparison between the proposed scheme with channel reassignment and without channel reassignment

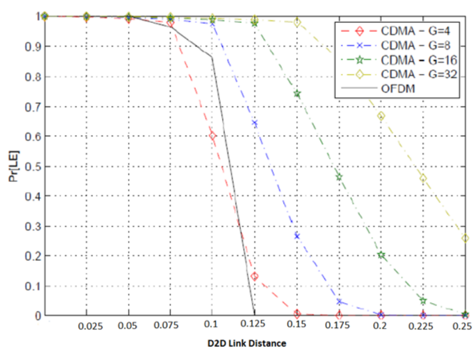

Fig. 6. $Pr[LE]$ comparison for $D_{dd,bs}$ fixed

VI. Conclusion

In this paper we proposed a novel resource sharing scheme, which aims an increase in probability of link existence ($Pr[LE]$) for a random D2D link. The algorithm proposed the use of two different technologies (WCDMA and OFDMA) sharing the same resources to obtain overlaid communication, combining the WCDMA spread spectrum advantages and robustness to narrowband interference with OFDMA narrowband characteristics.

Results show that with the proper coordination scheme it is possible to decrease the mutual interference between the different links, resulting in some interesting advantages to the proposed algorithm when compared with previous works. First of all, it is possible to highlight the flexibility introduced to the D2D link, allowing an increase in link quality or in $Pr[LE]$ with a simple adaptation on processing gain.

Besides this flexible tradeoff the proposed relocation algorithm offers a considerable gain in $Pr[LE]$ even for high-rate D2D links, leading to improvements on the network efficiency, increasing the probability of resource sharing. Moreover the algorithm reflects a gain in the maximum distance between the D2D pair, specially when the $D2D_{Tx}$ is placed near the BS.

However, the benefits of the proposed algorithm can be achieved only through a good network coordination, which reflects on processing and signaling costs.

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