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Suppression of Cyclic Prefix in Down-Link LTE like Systems to Increase Capacity

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Abstract—**In this paper it is presented a proposal to increase the capacity of Down-Link (DL) transmissions in Long Term Evolution (LTE) like systems based on Multiple-Input Multiple-Output (MIMO)-Orthogonal Frequency Division Multiplexing (OFDM). The augment of the data rate is achieved with the total or partial suppression of the Cyclic Prefix (CP), which requires the use of a variable number of samples without conveying any information. The proposal is based on an iterative cancellation of the main impairments that the CP suppression supposes, the Inter Symbol and Inter Carrier Interferences. The interference mitigation procedure demands adequate channel estimations obtained in two different stages. Firstly, this new scheme requires the utilization of a preamble symbol appended to the beginning of the data transmission, which enables an initial Maximum Likelihood channel estimation. Secondly, time-variant channels will be estimated using a Least Squares estimator by the use of scattered pilots within the LTE frame structure. Through simulations it has been demonstrated that, despite the interferences arisen due to the CP suppression, our proposal attains adequate channel estimations which converge to theoretical bounds and the overall system obtains values of Bit Error Rate similar to the ideal situation of not suppressing the CP. It is also presented that considering the typical values of CP in the LTE standard the increment of the capacity employing this strategy can range between 7% and 25%.**

Keywords*—*LTE, MIMO-OFDM, Insufficient Cyclic Prefix, Channel Estimation, Interference Cancellation

I. INTRODUCTION

Current implementation in public mobile networks of the Long Term Evolution (LTE) standard [1] supposes a dramatic breakthrough due to, mainly, the higher bit rate which is able to provide. Its definition has been developed in parallel to the appearance of brand new terminals that demand increasing amounts of data and allowing the user to access new services and applications independently of its location.

These requested high data rates can be attained by the inclusion of the Orthogonal Frequency Division Multiplexing (OFDM) in the LTE standard as the selected modulation scheme in the Down-Link (DL). Also, the concept of using multiple antennas both in transmission and reception, known as Multiple-Input Multiple-Output (MIMO), has also been introduced as an option, enabling even higher binary rates above 100 Mbps.

In this paper we focus on exploring and analyzing the viability of augmenting the capacity in LTE-like systems in the DL, where MIMO-OFDM can be considered. To achieve this, we propose the partial or total suppression of the Cyclic Prefix (CP) which gives rise to a direct increment of the data rate. The standard copes with the possibility of setting two different CP, long and short, depending on how much disruptive the channel is, reaching in some cases up to $1/4$ of the symbol time.

The main impairment of total or partially suppressing the CP, named insufficient CP in the sequel, is the appearance of Inter Symbol and Inter Carrier Interferences, ISI and ICI respectively. Therefore, the execution of an efficient interference cancellation of the ISI and ICI will result in an appreciable increase in the data rate. This interference cancellation has been previously dealt with in the literature in OFDM systems, both Single-Input Single-Output (SISO) and MIMO [2][3][4]. However, previous contributions always consider an ideal situation in the symbols of the frame which allocate the preamble utilized to perform the channel estimation, *i.e.*, these preamble symbols always have a sufficiently long CP. Some other contributions consider the case of performing the channel estimation by preambles whose CP is shorter than the channel length [3][4][5] but they do not handle the Pilot Aided (P/A) channel estimation, by scattered pilot symbols, as it is required in the LTE standard. On the other hand, contributions coping with P/A channel estimation strategies with insufficient CP [6] do not cover the MIMO-OFDM case, they are not focused on LTE standards and they do not address initial procedures for channel estimation. Therefore, to increase the system capacity of a LTE system based on MIMO-OFDM we propose the reduction or even suppression of the CP in any kind of OFDM symbol, either those carrying scattered pilots for channel estimation or those conveying only user data. We will apply an iterative interference cancellation which successively improves the P/A channel estimation so that the Bit Error Rate (BER) of the system is not affected by the erroneous channel estimation that pilot symbols without CP involve.

The appraisal of the proposal will be done by simulations and, apart from the analysis of the BER versus Signal to Noise Ratio (SNR), the Mean Squared Error (MSE) of the P/A channel estimations will be obtained in order to prove how the successive interference cancellation leads to quasi ideal values of simulated MSE converging to theoretical MSEs.

The remainder of this paper is organized as follows. Section

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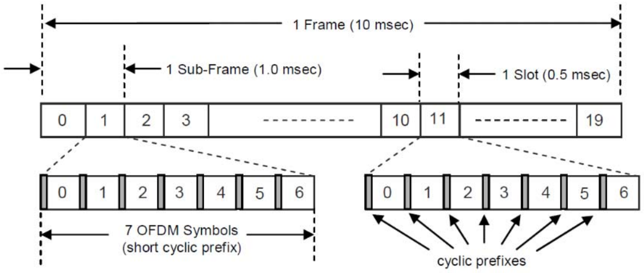

Fig. 1. Frame structure Type 1 in LTE [7].

II makes a brief summary of the basic parameters of the LTE physical layer. Section III presents the signal model and introduces the structure of the proposal, including the employed channels estimators and the iterative interference cancellation algorithm. In section IV, simulation results are provided and in section V some conclusions are drawn.

Notation: Uppercase (lowercase) boldface letters express matrices (vectors), $(\cdot)^H$ represents Hermitian operation, $|\cdot|$ means absolute value, $\mathbf{0}_{M\times N}$ is an $M \times N$ null matrix and $\langle\cdot\rangle_N$ stands for the modulo-N operation. We will refer to $\mathbf{x}$ as time-domain vectors and to $\tilde{\mathbf{x}}$ as frequency-domain vectors.

II. DOWN-LINK LTE PHYSICAL LAYER DESCRIPTION

Following, we present a summarized description of the LTE physical layer [1] which will be used to assess, by simulations, the performance of our proposal to increase the capacity of LTE DL transmissions.

Despite the fact that the standard defines two different types of frames depending on the intended duplexing, Frequency Division Duplexing (FDD) or Time Division Duplexing (TDD), we will introduce and analyze our proposal under the framework of FDD, since the majority of deployed systems follow this configuration.

The corresponding frame structure for FDD is denoted in the standard as Type 1 and its distribution is shown in Fig. 1. A long or short CP can be selected depending on the behavior of the channel which implies a slot configuration with 6 or 7 OFDM symbols, respectively. The latter is depicted in Fig. 1 and it is the structure that we have chosen to evaluate our proposal. It implies a CP of 10 samples for the first symbol within the slot and 9 samples for the remaining six symbols. The transmission bandwidth varies between 1.4 MHz and 20 MHz, where a number of sub-carriers ranging from 128 and 2048 can be allocated. In order to speed up our simulations we have selected 128 sub-carriers. The specific number of 12 sub-carriers are grouped on a slot-by-slot basis to form Physical Resource Blocks (PRB). Each element in the PRB grid for an antenna port is called a Resource Element and it is uniquely identified by the index pair (sub-carrier, symbol) in a slot. The PRB grid is sketched in Fig. 2.

Channel estimation is performed on a P/A basis by the use of Reference Signals (RS) distributed in a scattered fashion within the PRB grid as shown in Fig. 2. When the base station transmits with two antennas, such as in our proposal based on MIMO, the configuration is slightly different since when the first antenna is transmitting a RS the other one is in idle state.

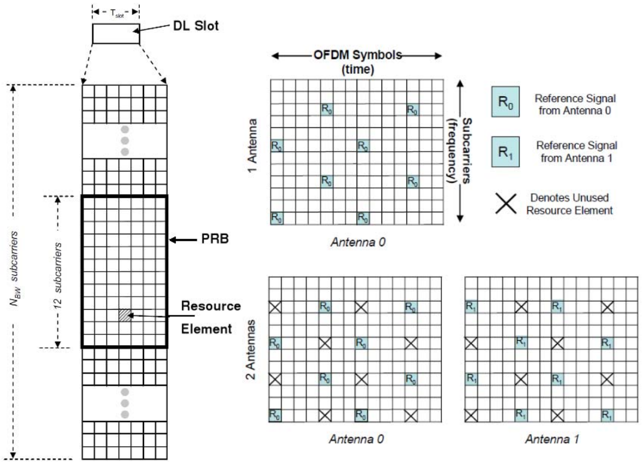

Fig. 2. Physical Resource Block (PRB) and Reference Signals (RS) [7].

These RS allow to estimate the Channel Impulse Response (CIR) which will be used to equalize the received data.

The standard specifies QPSK, 16-QAM or 64-QAM for data modulation while the Pseudo Random (PN) sequences used as RS are defined by a length-31 Gold sequence[1].

III. SIGNAL MODEL

In this section a generic MIMO-OFDM system will be considered with N_t and N_r transmit and receive antennas, respectively. The signal model is constructed utilizing the time-domain symbols, which are converted from the frequency-domain symbols using an N-length Inverse Discrete Fourier Transform (IDFT) operation, being N the number of sub-carriers. The insufficient CP condition addressed in this paper introduces two additional terms in the general expression of the received signal. Consequently, once the insufficient CP has been removed, the received signal at the j-th antenna, $j = 1, 2, \cdots N_r$, at the ℓ-th OFDM symbol time can be formulated as

$$\begin{aligned}\tilde{\mathbf{r}}_j(\ell) = & \textstyle\sum_{i=1}^{N_t} \mathbf{F}_N \mathbf{H}_{ji} \mathbf{F}_N^H \tilde{\mathbf{x}}_i(\ell) + \\ & + \textstyle\sum_{i=1}^{N_t} \mathbf{F}_N \mathbf{H}_{ji}^{ISI} \mathbf{F}_N^H \tilde{\mathbf{x}}_i(\ell-1) - \\ & - \textstyle\sum_{i=1}^{N_t} \mathbf{F}_N \mathbf{H}_{ji}^{ICI} \mathbf{F}_N^H \tilde{\mathbf{x}}_i(\ell) + \tilde{\mathbf{w}}_j(\ell),\end{aligned} \qquad (1)$$

where $\tilde{\mathbf{r}}_j(\ell)$ is an $N \times 1$ vector with the frequency-domain received signal; $\mathbf{F}_N$ is the DFT matrix of size $N \times N$; $\mathbf{H}_{ji}$, with $i = 1, 2, \cdots, N_t$, and $j = 1, 2, \cdots, N_r$, is an $N \times N$ circulant matrix which consists of the CIRs $\mathbf{h}_{ji}$ of size $L \times 1$ between the i-th transmit and the j-th receive antennas, where L denotes the channel length and each entry (s, t) is given by $\mathbf{h}_{ji,\langle s-t\rangle_N}$, with $0 \leq s \leq N-1$ and $0 \leq t \leq N-1$; $\tilde{\mathbf{x}}_i(\ell)$ represents an $N \times 1$ vector with the frequency-domain transmitted signal from the i-th antenna; the ISI and ICI disturbances occasioned by the previous and current symbols $\tilde{\mathbf{x}}_i(\ell-1)$ and $\tilde{\mathbf{x}}_i(\ell)$ are given by $\mathbf{H}_{ji}^{ISI}$ and $\mathbf{H}_{ji}^{ICI}$ respectively; finally, $\tilde{\mathbf{w}}_j(\ell)$ accounts for the $N \times 1$ Gaussian noise component with zero mean and σ_n^2 variance at the j-th receive antenna at the ℓ-th symbol time. The wanted signal is denoted by the first term between brackets in (1), while the second and third terms describe the ISI and ICI, respectively.

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[1] The reader is referred to the LTE standard [1] for a more detailed description of the physical parameters.

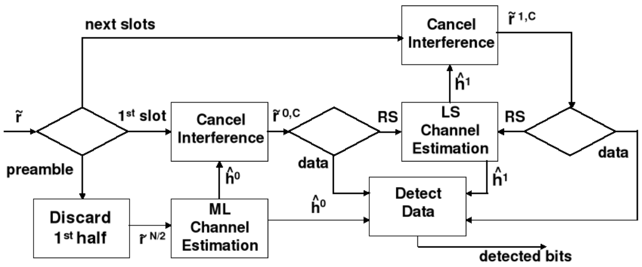

Fig. 3. Block Diagram of the Proposed Reception Scheme

1) Initial Channel Estimation: At the receiver side, our proposal makes use of an initial Maximum Likelihood (ML) channel estimation based on a preamble consisting in a known N-length OFDM symbol also with insufficient CP, where odd sub-carriers are set to null values giving rise to a time-domain signal with two equal halves [5]. This is the only proposed strategy out of the standardized physical layer of the LTE, but easy to implement due to its simplicity. Expression (1) corresponding to this preamble can be converted to time-domain as

$$\mathbf{r}_j(\ell)=\sum_{i=1}^{N_t}\mathbf{H}_{ji}\mathbf{x}_i(\ell)+\sum_{i=1}^{N_t}\mathbf{H}_{ji}^{ISI}\mathbf{x}_i(\ell-1)-\sum_{i=1}^{N_t}\mathbf{H}_{ji}^{ICI}\mathbf{x}_i(\ell)+\mathbf{w}_j(\ell), \quad (2)$$

where $\mathbf{r}_j(\ell)=\mathbf{F}_N^H\tilde{\mathbf{r}}_j(\ell)$, $\mathbf{x}_i(\ell)=\mathbf{F}_N^H\tilde{\mathbf{x}}_i(\ell)$ and $\mathbf{x}_i(\ell-1)=\mathbf{F}_N^H\tilde{\mathbf{x}}_i(\ell-1)$ are $N\times 1$ vectors with the time-domain received and transmitted signals after the IDFT operation. Hereafter, the OFDM symbol time index ℓ will be omitted for the sake of clarity.

This preamble mostly absorbs ISI and ICI contributions in its first half. Hence, discarding these first N/2 samples of the preamble, the corresponding terms to ISI and ICI in (1) can be considered null so that the expression of the second half of the received preamble can be expressed in matrix form as

$$\mathbf{r}_{N/2}=\mathbf{X}_{N/2}\mathbf{h}+\mathbf{w}_{N/2} \quad (3)$$

where $\mathbf{r}_{N/2}$ is an $(\frac{N}{2}N_r)\times 1$ vector whose j-th element $\mathbf{r}_{N/2,j}$, with $j=1,2,\cdots,N_r$, is the received signal at the j-th receive antenna given by a column $N/2$-vector. The column vector $\mathbf{h}$ of length (N_tN_rL) collects all the channel impulse responses $\mathbf{h}_{ji}$ and the matrix $\mathbf{X}_{N/2}$ is built as indicated in (4), at the top of next page, where $\mathbf{X}_{N/2,i}$ is an $\frac{N}{2}\times L$ circulant matrix for the i-th transmitter where the entry (s,t) is given by $\mathbf{x}_{N/2,i,\langle s-t\rangle_N}$, with $0\leq s\leq N/2-1$, $0\leq t\leq L-1$ and $\mathbf{x}_{N/2,i}$ being the last $N/2$ samples of $\mathbf{x}_i$. In this initial stage, the ML estimator is attained solving the resultant likelihood function

$$\boldsymbol{\Lambda}\left(\mathbf{r}_{N/2}|\mathbf{h}\right)=\frac{1}{\left(\pi\sigma_n^2\right)^{N/2}}\exp\left\{-\frac{1}{\sigma_n^2}\left(|\mathbf{r}_{N/2}-\mathbf{X}_{N/2}\mathbf{h}|^H|\mathbf{r}_{N/2}-\mathbf{X}_{N/2}\mathbf{h}|\right)\right\}, \quad (5)$$

leading to the ML estimation of the channel $\mathbf{h}$ given by

$$\hat{\mathbf{h}}^0=\left(\mathbf{X}_{N/2}^H\mathbf{X}_{N/2}\right)^{-1}\mathbf{X}_{N/2}^H\mathbf{r}_{N/2}. \quad (6)$$

This CIR estimation denoted by $\hat{\mathbf{h}}^0$ will be used to cancel the interferences of the first seven OFDM symbols corresponding to the *first slot* after the preamble, which also include scattered pilots at certain OFDM symbols, see Fig. 3 middle branch.

The cost of appending this initial preamble without CP, consisting of an OFDM symbol, is negligible with respect to all the transmitted slots.

2) Interference Cancellation: An interference cancellation procedure must be utilized to mitigate the distortion introduced due to an insufficient CP, as for instance the one described in [4]. The process consists in compensating and subtracting certain components corresponding to the ISI and ICI. Considering (1), this received signal in frequency-domain at the j-th antenna can be written in a reduced form by

$$\tilde{\mathbf{r}}_j=\sum\nolimits_{i=1}^{N_t}\tilde{\mathbf{r}}_{j,i}^U+\sum\nolimits_{i=1}^{N_t}\tilde{\mathbf{r}}_{j,i}^{ISI}-\sum\nolimits_{i=1}^{N_t}\tilde{\mathbf{r}}_{j,i}^{ICI}+\tilde{\mathbf{w}}_j, \quad (7)$$

where $\tilde{\mathbf{r}}_{j,i}^U$ is the useful term and $\tilde{\mathbf{r}}_{j,i}^{ISI}$ and $\tilde{\mathbf{r}}_{j,i}^{ICI}$ are the ISI and ICI components respectively. The process of cancellation is carried out iteratively and mainly consists of a Cancellation of the ISI, labeled as C_{ISI},

$$\tilde{\mathbf{r}}_j^{C_{ISI}}=\tilde{\mathbf{r}}_j-\sum\nolimits_{i=1}^{N_t}\tilde{\mathbf{r}}_{j,i}^{ISI}, \quad (8)$$

and a subsequent Compensation of the ICI by

$$\tilde{\mathbf{r}}_j^C=\tilde{\mathbf{r}}_j^{C_{ISI}}+\sum\nolimits_{i=1}^{N_t}\mathbf{C}_{j,i}, \quad (9)$$

through the use of the ICI compensation term, $\mathbf{C}_{j,i}$, that satisfies the following relation

$$\mathbf{C}_{j,i}+\tilde{\mathbf{r}}_{j,i}^U-\tilde{\mathbf{r}}_{j,i}^{ICI}=\tilde{\mathbf{x}}_i\mathbf{F}_N\mathbf{H}_{ji}. \quad (10)$$

This equality means that it is possible to recover the transmitted signal $\tilde{\mathbf{x}}_i$ simply multiplying by the frequency-domain channel matrix provided that the ICI compensation term is added to the received signal[2]. For the *first slot* after the preamble, the ISI and ICI allocated on the 7 OFDM symbols will be cancelled by the procedure explained above and using the previously estimated channel matrix $\hat{\mathbf{H}}_{ji}^0$ built with $\hat{\mathbf{h}}^0$. After this process we attain the seven interference cancelled symbols $\tilde{\mathbf{r}}_j^{0,C}$, which contains data at certain sub-carriers while pilots are conveyed in the remaining ones. Thus, complex symbols will be directed to either the data detection or to the next stage of P/A channel estimation, depending on if they are data or pilots, as shown in Fig. 3. For the *next slots*, the ISI and ICI allocated on those symbols will be cancelled with the same procedure but using the updated channel estimation $\hat{\mathbf{h}}^1$ obtained via scattered pilots (as described in III-3) from the previous slot.

3) Pilot Aided Channel Estimation: Following estimations are based on the P/A structure of RS distributed on the PRB grid according to the LTE standard. In this case we will perform the Least Squares (LS) channel estimation as indicated in [8]. Let us consider the expression of the received signal (1) in frequency-domain, but without the ISI and ICI terms since they will have been cancelled, given by

$$\tilde{\mathbf{r}}_j^C=\sum\nolimits_{i=1}^{N_t}\tilde{\mathbf{H}}_{ji}\tilde{\mathbf{x}}_i+\tilde{\mathbf{w}}_j, \quad (11)$$

where $\tilde{\mathbf{H}}_{ji}$ is a diagonal matrix with the frequency response $\tilde{\mathbf{h}}_{ji}$ as its diagonal. Now, the transmitted signal $\tilde{\mathbf{x}}_i=(\tilde{\mathbf{s}}_i\cup\tilde{\mathbf{p}}_i)$, where $\tilde{\mathbf{p}}_i$ is the $N_p\times 1$ vector corresponding to the transmitted RS pilots (with cardinality N_p) and $\tilde{\mathbf{s}}_i$ is an arbitrary $(N-N_p)\times 1$ data vector. Both vectors, $\tilde{\mathbf{s}}_i$ and $\tilde{\mathbf{p}}_i$ conform disjoint

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[2] This expression considers that the ISI term has been already subtracted and there is no noise in the system.

$$\mathbf{X}_{N/2}=\begin{bmatrix}\mathbf{X}_{N/2,1} & \mathbf{X}_{N/2,2} & \cdots & \mathbf{X}_{N/2,N_t} & \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{0}_{\frac{N}{2}\times L}\\ \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{X}_{N/2,1} & \mathbf{X}_{N/2,2} & \cdots & \mathbf{X}_{N/2,N_t} & \cdots & \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{0}_{\frac{N}{2}\times L}\\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots & \ddots & \vdots\\ \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{0}_{\frac{N}{2}\times L} & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{0}_{\frac{N}{2}\times L} & \cdots & \mathbf{X}_{N/2,1} & \mathbf{X}_{N/2,2} & \cdots & \mathbf{X}_{N/2,N_t}\end{bmatrix}, \quad (4)$$

sets, *i.e.*, zeros in $\tilde{\mathbf{p}}_i$ where $\tilde{\mathbf{s}}_i$ contains data and vice versa. Hence, the expression (11) can be transformed in

$$\tilde{\mathbf{r}}_j^C=\sum\nolimits_{i=1}^{N_t}(\tilde{\mathbf{s}}_i\cup\tilde{\mathbf{p}}_i)\mathbf{F}_{0:L-1}\tilde{\mathbf{h}}_{ji}+\tilde{\mathbf{w}}_j, \quad (12)$$

where $\mathbf{F}_{0:L-1}$ are the first L columns of $\mathbf{F}_N$. Then, we attain the simplified form of the LS channel estimation by

$$\hat{\mathbf{h}}_j^1=\bar{\mathbf{P}}^{\dagger}\bar{\mathbf{r}}_j^C. \quad (13)$$

In this expression the pseudo inverse matrix $\bar{\mathbf{P}}^{\dagger}=\left(\bar{\mathbf{P}}^H\bar{\mathbf{P}}\right)^{-1}\bar{\mathbf{P}}$ and $\bar{\mathbf{P}}=[\bar{\mathbf{p}}_1\bar{\mathbf{F}}_{0:L-1}\cdots\bar{\mathbf{p}}_{N_t}\bar{\mathbf{F}}_{0:L-1}]$, with $\bar{\mathbf{p}}_i$ being the diagonal matrix with the N_p pilot positions of $\tilde{\mathbf{p}}_i$. $\bar{\mathbf{F}}_{0:L-1}$ and $\bar{\mathbf{r}}_j^C$ are the corresponding N_p rows of $\tilde{\mathbf{F}}_{0:L-1}$ and $\tilde{\mathbf{r}}_j$, respectively. This CIR estimation $\hat{\mathbf{h}}_j^1$, see Fig. 3 upper branch, will be used in the interference cancellation of *next slots*, also including data or scattered RS, to obtain the received signal free of interferences denoted by $\tilde{\mathbf{r}}_j^{1,C}$ in Fig. 3.

The analysis of these two different estimations, $\hat{\mathbf{h}}^0$ and $\hat{\mathbf{h}}^1$, will be performed by the MSE of the channel estimation calculated as

$$\text{MSE}\{\hat{\mathbf{h}}\}=\frac{1}{N_tN_rL}\text{E}\left\{\left(\hat{\mathbf{h}}-\mathbf{h}\right)^H\left(\hat{\mathbf{h}}-\mathbf{h}\right)\right\}. \quad (14)$$

4) Data Detection: After the process of interference cancellation, performed with either $\tilde{\mathbf{h}}^0$ or $\tilde{\mathbf{h}}^1$, the next stage consists in detecting data with ML criterion in a symbol-by-symbol basis in order to calculate the BER of the system. The estimated CIRs are transformed into frequency-domain in order to equalize the received data in a sub-carrier basis. In this way the detected signal for the k-th sub-carrier index, with $k=0,1,\cdots,N-1$, is given by

$$\mathbf{d}(k)=\begin{bmatrix}\tilde{\mathbf{h}}_{1,1}(k) & \cdots & \tilde{\mathbf{h}}_{1,N_r}(k)\\ \vdots & \vdots & \vdots\\ \tilde{\mathbf{h}}_{N_t,1}(k) & \cdots & \tilde{\mathbf{h}}_{N_t,N_r}(k)\end{bmatrix}^{-1}\begin{bmatrix}\tilde{\mathbf{r}}_1(k)\\ \vdots\\ \tilde{\mathbf{r}}_{N_r}(k)\end{bmatrix} \quad (15)$$

IV. RESULTS

This section presents the simulation results to prove the capability of our current proposal to increase the capacity of a LTE system by the suppression of the CP. The simulations have been carried out considering a 2 × 2 MIMO-OFDM system consisting of two transmit and two receive antennas. The selected number of sub-carriers has been $N = 128$ corresponding to a LTE bandwidth of 1.5 MHz, all of them considered as useful sub-carriers. The frame and PRB structure are those shown in Fig. 1. The simulated channels between the antennas are based on individual Tapped Delay Line models following an exponential profile, widely used for implementing the multi-path channels [9], whose length has been adjusted to $L = 9$ taps, the corresponding to short CP. For the simulations a partial suppression of the CP has been supposed to assess an intermediate situation selecting the value of $CP = 2$. It is assumed that the channel does not vary within the duration of a time slot, represented in Fig. 1. The data have been considered to be modulated according to the 16-QAM scheme and normal PN sequences have been used as preamble and pilots, these latter in lieu of length-31 Gold sequences as the standard requires. It is worth noting that these results are obtained without considering any channel coding scheme.

The evaluation has been firstly done by the MSE indicated in (14) of the two channel estimations, $\hat{\mathbf{h}}^0$ obtained with the initial preamble, denoted as MSE$_{N/2}$ in Fig. 4, and $\hat{\mathbf{h}}^1$ obtained with the scattered RS by successive iterations of the interference cancellation process, denoted as MSE$_P^{P/A}$ in the same figure for a variable number of iterations $t = \{1, 2, 3\}$. Fig. 4 clearly shows that the initial channel estimation $\hat{\mathbf{h}}^0$ converges to theoretical bounds and consequently it will be suitable to be the basis to commence the interference cancellation for the symbols belonging to the *first slot*. If there is not interference cancellation in the scattered RS employed to obtain the P/A estimation $\hat{\mathbf{h}}^1$, the MSE shows an error floor in the high SNR region, MSE$_P^{P/A}t = 0$ curve. Nevertheless, as the number of iterations of the interference cancellation increases, MSE$_P^{P/A}t = \{1, 2, 3\}$ curves, the P/A estimations considerably improve converging to theoretical bounds as well.

Next, Figs. 5 and 6 depict the BER of the system in four different situations. Firstly, the BER is represented in both figures for the case of insufficient CP without implementing any interference cancellation, which is denoted as BER$_N$. Secondly, Fig. 5 represents the BER of the symbols in the *first slot* with insufficient CP and performing interference cancellation that uses the channel estimation obtained only by a preamble, $\hat{\mathbf{h}}^0$. And thirdly, Fig. 6 represents the BER of the *next slots*, with insufficient CP, P/A channel estimation and interference cancellation following the structure shown in Fig. 3. For calculating the BER, the number of iterations of the interference cancellation procedure also ranges on $t = \{1, 2, 3\}$. Additionally, the ideal case of sufficient CP (SCP) is also shown, curves BER$_{SCP}$. It can be seen that after three iterations, $t = 3$, of the interference cancellation process the BER converges to the SCP case for the data of the *first slot*, Fig. 5, and for the data in the *next slots*, Fig. 6. The comparison of these two figures evidence that our proposal produces similar results for channel estimations attained with the scattered RS of the LTE standard in comparison with those obtained by the initial preamble, taking into account that this latter employs a whole symbol for the estimation.

The partial suppression of the CP, and similarly for the total one, leads to the expected increment in overall data rate and in that way is demonstrated by the figures. As an example, for the case of a complete suppression of the short CP configuration defined in the standard, $CP = 9$, the enhancement reaches

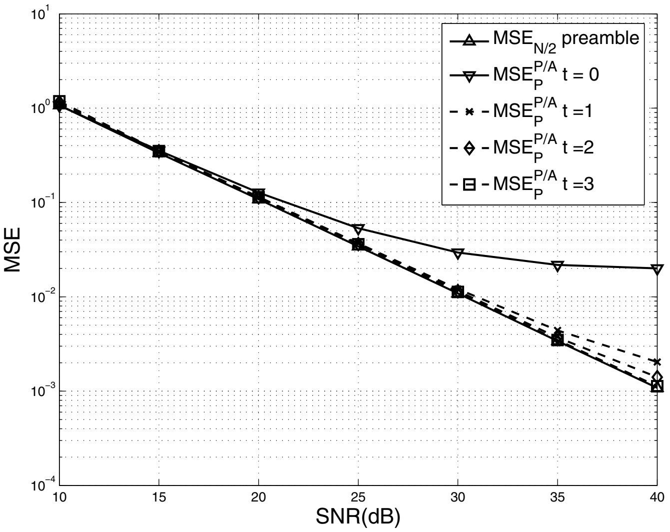

Fig. 4. MSE of the employed channel estimations.

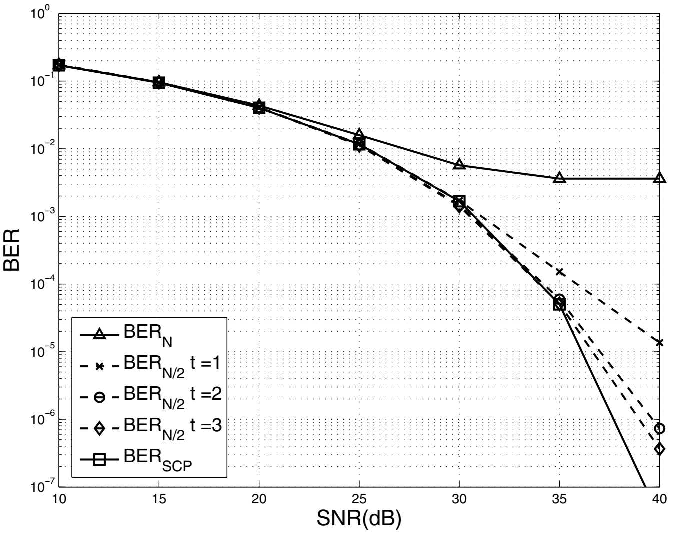

Fig. 5. BER comparison for the data allocated in *first slot*.

the 7% while for the case of the long CP, $CP = 32$, it supposes a dramatic 25% of data rate increment, considering the configuration of $N = 128$ sub-carriers. This notable data rate increase overcomes the drawback that our proposal supposes, an increment in complexity. Nevertheless, current efficient hardware platforms may allow practical implementation of our proposal.

V. CONCLUSIONS

A new proposal to increment the data rate in the DL of LTE like systems based on MIMO-OFDM without CP has been presented in this paper. The main impairment of using the total or partial suppression of the CP, the appearance of ISI and ICI, has been overcome appending a complete OFDM symbol to the beginning of the transmission to be used as a preamble and executing an interference cancellation process which improves the channel estimation and the data detection. This proposed strategy permits an initial estimation and iterative interference cancellation in the symbols of the first slot. This leads to subsequent P/A estimations using the scattered RS as defined in the LTE standard and additional interference cancellations for all the remaining slots. It has been demonstrated that adequate channels estimations can be obtained using this structure, which jointly with the execution of the interference cancellation give rise to a BER behavior of the system similar to the case of utilizing sufficient CP. Consequently, the increment of the capacity, due to the suppression of the CP, can range between 7% and 25% depending on how much disruptive the channel is.

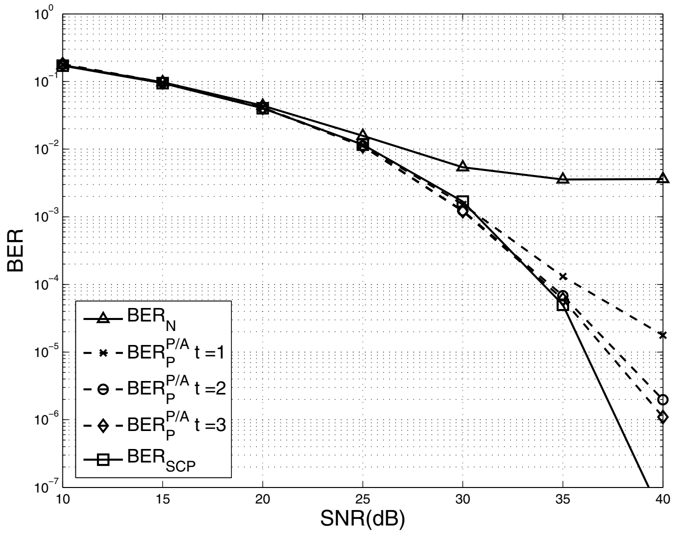

Fig. 6. BER comparison for the data allocated in *next slots*.

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