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ANALYSISOF OFDMA AND SC-FDMA SIGNALS IN HOMOGENEOUS NETWORK MODEL

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Abstract-The goal is to introduce new degree of freedom to introduce the co - existence between two signals. They are Orthogonal Frequency Division Multiple Access (OFDMA) and Single Carrier – Frequency Division Multiple Access (SC-FDMA) signals. To achieve this, the frequency and power domains are employed to reveal the characteristics of the coexistence of OFDMA and SC-FDMA signals based on a c-SIC receiver. Then, the closed form expressions of the average bit error rate (BER) are derived as a baseline.

Index terms-Co-existence, interference cancellation, LTE-A, orthogonal frequency division multiple access (OFDMA), single carrier-frequency division multiple access (SC-FDMA), SIC.

I.INTRODUCTION

EVOLUTION of wireless services enabled advanced applicationsand shifted the paradigms of research in this field from voice to data centric.Mainly, there are orthogonal multiple accessing (OMA) and non-orthogonal multiple accessing (NOMA) schemes. TraditionalOMA schemes for homogeneous networks (i.e., time domain or frequency domain multiple access) hold mobile stations (MSs) that are claiming access to the network until the RBs are released by other MSs[1].Another approach iscell range expansion, which utilizes time domain for resource sharing between smallcell base station (sBS) and macrocell base station (mBS) via use of almost blank sub frames in the same context to offload mMSs to the sBS.To achieve this, the frequency and powerdomains are employed to reveal the characteristics of the coexistence of OFDMA and SC-FDMA signals based on a c-SIC receiver. Then, the closed form expressions of the average bit error rate (BER) are derived as a baseline.

II.SYSTEM MODEL

A. Homogeneous Network Model

The nth subcarrier ($n \in [n_1, n_2]$) of the received composite signal of user m and user k at the BS is

$$y_n = \sqrt{p_{m,n}} x_{m,n} h_{m,n} + \sqrt{p_{k,n}} x_{k,n} h_{k,n} + \eta_n \qquad (1)$$

where$p_{m,n}$and $p_{k,n}$are the received powers, $h_{m,n}$and $h_{k,n}$are the channel frequency responses of the signals of user m and user k at the n^{th} subcarrier, and $\eta_n$is the independent andidentically distributed complex additive white Gaussian noise(AWGN) with σ_η^2variance at the n^{th} subcarrier.Thus, transmit powers can be tuned for the MSs considering the characteristics of the wireless channel.

III. ANALYSIS OF CO-EXISTENCE UNDER C-SIC

The signalsof user m and user k are co-existing at the indices $n \in [n_1, n_2]$either at the optimum sampling points of their subcarriers. First, the co-existence interference of OFDMA signal isanalysed for the c-successive interference cancellation (SIC) processing.

A. Analysing the Interference on OFDMA Symbols

Analysis of co-existing OFDMA signals is quite straightforwardsince the subcarriers $x_{k,n}$and $x_{m,n}$are the symbols $s_{k,n}$and

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$s_{m,n}$respectively. Thus, the error on the nth symbol of user k due to user m's symbol is

$$\xi_{k,n} = s_{m,n}\emptyset_{m,n} \qquad (2)$$

The error on the user m's symbol due to the regeneratedsymbol of user k, $\hat{s}_{k,n}$, is

$$\xi_{m,n} = (s_{k,n} - \hat{s}_{k,n})\emptyset_{k,n} \qquad (3)$$

Accordingly, the error terms in (2) and (3) are affected by the received power and the modulation scheme of the pairing signal. If the transmittedsymbols are assumed to be uniformly distributed, the error terms also have uniform distribution. Consequently, the combined distribution of the pairing signal and the noise becomes Gaussian mixture uniform distribution in (2) and (3).

B. Analysing the Interference on SC-FDMA Symbols

Analysis of co-existing SC-FDMA signals is a bit deviousdue to DFT spreading. Considering SC-FDMA/SC-FDMA overlapping scenario, user k's symbols are obtained after $N_k$point IDFT of $\beta_{k,n}$for subcarriers, $\forall n \in [k_1, k_2]$, which is

$$\alpha_{k,r} = \frac{1}{\sqrt{N_k}}\sum_{n=k_1}^{k_2}\left(x_{k,n} + x_{m,n}\emptyset_{m,n} + \eta_{k,n}\right) e^{j\pi r(n-k_1)/N_k} = s_{k,r} + \xi_{k,r} + \widehat{\omega}_{k,r} \qquad (4)$$

where$r$ is user k's symbol index, $\xi_{k,r}$is the error term causedby the symbols of user m and $\widehat{\omega}_{k,r}$is the IDFT of noise term. The error term, $\xi_{k,r}$, in (4) can be expressed in terms of user m's symbols, which is

$$\xi_{k,r} = \frac{1}{\sqrt{N_k N_m}}\sum_{n=n_1}^{n_2}\sum_{l=0}^{N_m-1} s_{m,l}\emptyset_{m,n} e^{j2\pi\left(\frac{r(n-k_1)}{N_k} - \frac{l(n-m_1)}{N_m}\right)} \qquad (5)$$

wherel is user m's symbol index. All symbols of user m affect all symbols of user k in the form of error. The statistical distributionof $\xi_{k,r}$in AWGN channel can be thought as Gaussian due to DFT/IDFT operation. Christo Ananth et al. [3] discussed about Improved Particle Swarm Optimization. The fuzzy filter based on particle swarm optimization is used to remove the high density image impulse noise, which occur during the transmission, data acquisition and processing. The proposed system has a fuzzy filter which has the parallel fuzzy inference mechanism, fuzzy mean process, and a fuzzy composition process. In particular, by using no-reference Q metric, the particle swarm optimization learning is sufficient to optimize the parameter necessitated by the particle swarm optimization based fuzzy filter, therefore the proposed fuzzy filter can cope with particle situation where the assumption of existence of "ground-truth" reference does not hold. The merging of the particle swarm optimization with the fuzzy filter helps to build an auto tuning mechanism for the fuzzy filter without any prior knowledge regarding the noise and the true image. Thus the reference measures are not need for removing the noise and in restoring the image. The final output image (Restored image) confirm that the fuzzy filter based on particle swarm optimization attain the excellent quality of restored images in term of peak signal-to-noise ratio, mean absolute error and mean square error even when the noise rate is above 0.5 and without having any reference measures.

IV. ANALYSIS OF BER FOR C-SIC

The analysis of the error terms in the proposed co-existenceschemes enables to define the SINRs of the co-existing signals. Accordingly, characterization of the SINR of the co-existing Signals leads to the derivation of the BER of those signals. Although the SINR is defined for each subcarrier traditionally, the average SINR can also be defined for a user by considering all subcarriers. Thus, the SINR of user k's signal in AWGN channel is obtained by considering non-overlapping and coexisting subcarriers, which is

$$\gamma_k = \sum_{\substack{n=k_1 \\ n\notin[n_1,n_2]}}^{k_2} \frac{p_{m,n}}{\sigma_\eta^2} + \sum_{n=n_1}^{n_2} \frac{p_{k,n}}{p_{m,n}+\sigma_\eta^2} \qquad (6)$$

Similarly, the SINR of user m's signal is

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$$\gamma_m = \sum_{\substack{n=m_1 \\ n\notin[n_1,n_2]}}^{m_2} \frac{p_{m,n}}{\sigma_\eta^2} + \sum_{n=n_1}^{n_2} \frac{p_{m,n}}{p_{k,n}\left|x_{k,n}-\hat{x}_{k,n}\right|^2+\sigma_\eta^2} \quad (7)$$

Note that if all subcarriers overlap, the first terms disappearin (6) and (7). A generalized form of the BER based on the SINR of a user can be given by the weighted sum of the BER of non-overlapping and coexisting subcarriers as

$$\mathrm{P_{r_u}} = \frac{N_{D,u}}{N_u}\mathrm{P_{r_{D,u}}} + \frac{N_{x,u}}{N_u}\mathrm{P_{r_{x,u}}} \quad (8)$$

where $N_u$is the number subcarriers of user u, $N_{D,u}$ and $N_{I,u}$are the numbers of non-overlapping and co-existing subcarriers,$\mathrm{Pr}_{D,u}$ and $\mathrm{Pr}_{I,u}$ are the BERs of non-overlapping and Co-existing subcarriers of user u respectively. Note that, the derivation of $\mathrm{Pr}_{D\ u}$can be found in AWGN channel. If the impact of interference can assumed to be Gaussian, $Pr_{I,u}$ has the similar form. However, each co-existence scheme has different characteristics and the derivation of BER varies.

A. Co-Existence of OFDMA Signals

In AWGN channel, the BER of the non-overlapping subcarriers, $\mathrm{Pr}_{D,k}$, is straightforward [15]. However, the BER ofthe a co-existing symbols of user k is altered by the ratio of the received power of overlapping subcarriers, $p_{m,n}/p_{k,n}$, the variance of the noise, σ_η^2, and the symbol value of the paired symbol, $s_{m,n}$, in (4). These terms contribute in the error probability and are integrated into Marcum Q-function to derive the BER of user k's signal. Since $p_{m,n}$, $p_{k,n}$ and $\sigma_\eta^2$are assumed to be known, the average error that is introduced by symbols of user m is calculated. Assume that the coexisting symbol pair is defined as (c_m, c_k). For instance, the combination of symbols for BPSK modulation is $\forall(c_m,\ c_k)\ \epsilon C = \{(-1,-1),\ (-1,\ 1),\ (1,-1),(1,1)\}$. This particular case resembles the BER of pulse amplitude modulation which can be found in [15]. Thus, a more generalized form of the BER ofuser k's signal is

$$\mathrm{P_{r_{D,k}}} = Q\left(\sqrt{\frac{p^k}{\sigma_\eta^2}}\right) \quad (9)$$

$$P_{r_{x,k}} = \frac{1}{N_c}\sum_C Q\left(\sqrt{\frac{|p_k c_k + p_m c_m|}{\sigma_\eta^2}}\right) \quad (10)$$

$$\mathrm{P_{r_k}} = \frac{N_k - N_o}{N_k}\mathrm{P_{r_{D,k}}} + \frac{N_o}{N_k}P_{r_{x,k}} \quad (11)$$

Where$N_o$is the number of co-existing subcarriers, $\mathrm{Pr}_{D,k}$and $\mathrm{Pr}_{I,k}$ are the average BER of the co-existing and non-overlapping Subcarriers of user k respectively.

B. Co-Existence of SC-FDMA Signals

The error terms in the distributionof the error are uniform mixture Gaussian. For the cases where Gaussian distribution is dominant the BER expression reduces to a single Q-function. The error power caused by user m is scaled by N_o/N_k and distributed over the symbols of user k. In this case, the average BER of user k is

$$P_{r_k} = Q\left(\sqrt{\frac{p_k}{p_m\frac{N_o}{N_k}+\sigma_\eta^2}}\right) = P_{r_{x,k}} \quad (12)$$

The average BER of user m's signal is limited by the interference caused by user k's signal regeneration errors and the noise.The power of regeneration error is obtained by multiplying the normalized expected power of a symbol decision error, $P_\psi$user k's signal power, p_k, and overlap ratio, N_o/N_k. Thus, the average BER of user m is

$$P_{r_m} = Q\left(\sqrt{\frac{p_m}{p_\psi P_{r_{x,k}} p_k \frac{N_x}{N_m}+\sigma_\eta^2}}\right) \quad (13)$$

On the other hand, when the uniform distributed componentsare dominant, the BER of user k and user $m$is same as OFDMA/OFDMA co-existence in (11). When uniform and Gaussian distributed components of the error terms are effective, the BERs can be obtained by introducing the BER expressions for uniform and Gaussian components after scaling.

C. Co-Existence of OFDMA and SC-FDMA Signals

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The error terms are modelled by GA for OFDMA andSC-FDMA co-existence cases in the previous section. Thus, the BER of the co-existing symbols of user *k* in (12) is simplified to

$$P_{r_k} = \frac{N_k - N_0}{N_k} Q\left(\sqrt{\frac{p_k}{\sigma_\eta^2}}\right) + \frac{N_0}{N_k} Q\left(\sqrt{\frac{p_k}{p_m + \sigma_\eta^2}}\right) \quad (14)$$

due to Gaussian distribution of the error terms and the noise.The BER of user *m* is defined by the average symbol decision error of user *k*, P_ψ, which is distributed over all symbols of user *m*. There are$N_o$number of overlapping regenerated subcarriers of user *k* with power of p_k. These subcarriers cause interference with probability of $P_{r_{I,k}}$based on the average power of symbol decision error. Therefore, the average BER of user *m* is same as in (13). The last scenario for BER analysis is the co-existence of SC-FDMA/OFDMA signals for user *k*/user*m*respectively. The BER of user *k* is obtained as in (12) by following the same steps. On the other hand, the average BER of user *m*'s signal is

$$P_{r_m} = \frac{N_m - N_0}{N_m} P_{r_{D,m}} + \frac{N_0}{N_m} Q\left(\sqrt{\frac{p_m}{p_\psi P_{r_{I,k}} p_k + \sigma_\eta^2}}\right) \quad (15)$$

In summary, the error term on the SC-FDMA signal isdistributed over all symbols. The distribution of the error term has Gaussian statistics if the co-existing pair is an OFDMA signal. However, if the co-existing pair is an SC-FDMA signal, the error term has a uniform mixture Gaussian statistics. Also, the uniform or Gaussian distribution becomes dominant based on the co-existence of SC-FDMA signals. If the co-existing pairs are both OFDMA signals, the error term has uniform distributed statistics.

V. SIMULATIONS

A. Results Performance

First, the BER performance of the proposed co-existenceapproaches are analysed based on the c-SIC. The signals of user *m* and user *k*are allocated to 512 of total 1024 subcarriers. These signals are co-existing with different overlap ratios and can employ OFDMA (MC) and SC-FDMA (SC) schemes for comparison. The signal-to-noise-ratio (SNR) of the signal of user *m* is fixed at 5 dB and the SNR of user *k*'s signal is varied. Then, the BER of the co-existing signals for all co-existence cases are compared.

A) Bit error rate performance of OFDMA and SC-FDMA:

The BER performance of the c-SIC receiver is presentedfor an overlap ratio of 1/8 without frequency offset SC/SC and MC/MC co-existence cases have the best and the worst BER curves respectively. The BER performance of SC/MC co-existence is better than MC/SC co-existence. This is due to employing SC-FDMA signal for user *k* (the signal with larger SNR) which can compensate the error introduced by user *m*'s signal in this particular case. As SNR increases, the BER of user *m*'s signal merges to the BER bound of AWGN channel for all co-existence cases. In This case, the SNR ofuser*m*is set to 20 dB and the SNR of user *k* is varied.

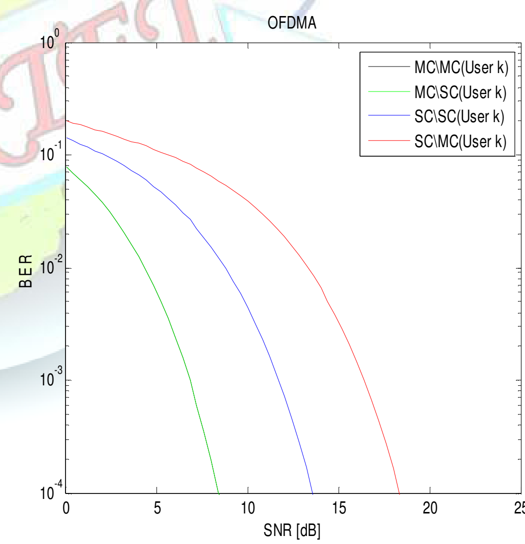

Fig 1 Bit error rate performance of OFDMA.

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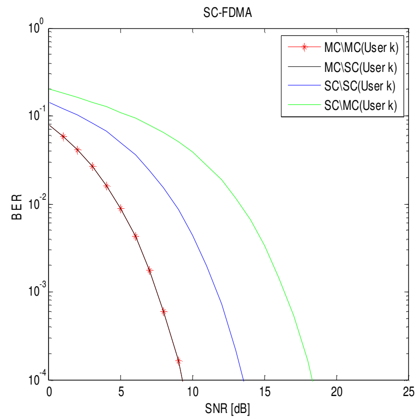

Fig 2 Bit error rate performance of SC-FDMA.

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