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Title: Uplink Interference Cancellation of Layered Superposed OFDMA (LS-OFDMA) Transmissions

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Source:

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Abstract:

We present a new framework for allowing multiple users to share the frequency-time resources in the OFDMA uplink without the use of multiple receive antennas. Single Antenna Interference Cancellation for OFDMA uplink is motivated by paying a closer look to the two-user rate region problem. Next we present the Layered Superposed OFDMA (LS-OFDMA) design adopted by the Ultra Mobile Broadband (UMB) 3GPP2 specifications [1]. LS-OFDMA is validated with link simulation results that demonstrate the feasibility of an Iterative Soft Interference Cancellation receiver for two layers in the AWGN channel.

Purpose: To modify the 802.16m simulation methodology document.

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1 Introduction

Multiple access in current and emerging 4G wireless communications systems for wide-area networks are mostly based on OFDMA communications. Current and emerging WiMax profiles as well as UMB use OFDMA in the uplink direction while LTE adopted a modified version of OFDMA that uses a precoder (SC-FDMA).

In traditional OFDMA, the signals transmitted from different users within the same sector do not interfere with each other since they are explicitly assigned by a centralized scheduler. At the same time though, OFDMA signals interfere across sector boundaries. It is also common to observe that OFDMA systems have to assign larger frequency resources to lower SINR users (those at the edge of the cell) in order to achieve fairness. The later observation motivated designers to employ schemes that can reuse the frequency-time across spatial dimensions, such as Spatial Division Multiple Access (SDMA), therefore smoothing the unfairness in near-far resource allocations.

In this paper we provide the foundation of a scheme, called Layered Superposition that similar to SDMA allows the reuse of uplink resources without the expense of spatial degrees of freedom. Rather, the degrees of freedom that we exploit are obtained from the differences in the codeword structure between near and far user-sets or layers. In this respect, LS-OFDMA complements SDMA schemes in that in a base station with multiple receive antennas SDMA and LS-OFDMA can simultaneously exploit codeword dimensions and spatial dimensions. Codeword dimensions can be made robust via a number of techniques such as:

- Different encoder polynomials of the Parallel Concatenated Convolutional Codes (PCCC) or more practically,
- Differences in code rate after puncturing and/or repetition. This is automatically achieved by assignment of different modulation and coding schemes to interfering users.
- User-specific scrambling the channel encoder output or equivalently,
- Allowing for user-specific offsets in the addressing of channel interleaver look-up tables.
- Frequency hopping patterns.

In terms of base station receiver design, real Successive Interference Cancellation (SIC), that reconstructs the interfering signals based on a successful packet decoding has been shown to be practical and implementable even for CDMA modems that usually involve tens of users. Iterative techniques can further enhance the SIC performance. Both SIC and iterative joint detection schemes are feasible for LS-OFDMA as it involves only few layers to be cancelled.

2 LS-OFDMA Concept

Let us assume a base station with a single receive antenna. Extensions with multiple receive antennas and combinations of LS-OFDMA with SDMA techniques will be made evident after describing the basic concept.

The base station broadly divide users in terms of layers based on achievable spectral efficiency (SE) estimates. For example, it is straightforward to define two layers: a high SE layer that would include users that are closer to the base station and a low SE layer for users that are at the cell edge.

Within the layer, the base station allocates orthogonal resources to the multiplexed users. Note that OFDMA can achieve intra-layer fairness since the allocations are between users with similar achievable received SINRs. Between layers the base station allows cross-layer interference by allocating the same resources to all layers. The LS-OFDMA concept is shown pictorially in Fig.1.

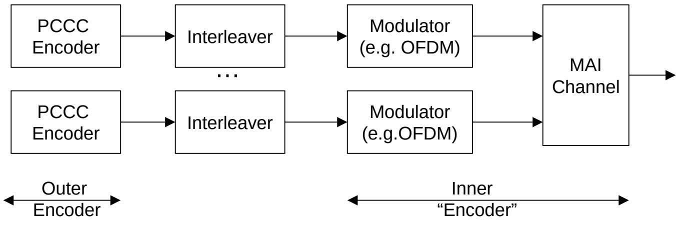

Figure 1: Principle of LS-OFDMA with two layers

Interference cancellation is used to separate the layers. The assignment of a user to a cancellation layer is decided by the base station scheduler based on averaged achievable SE information. Such user assignments are usually far slower than the assignment of resources that takes place every transmission time interval i.e. every approximately 1ms. In the case of two layers the pilot patterns are orthogonal, allowing for channel estimates without the inter-layer interference. In the case of more than two layers, the pilot pattern is scrambled with a layer specific Walsh function to minimize resource wastage due to pilot i.e. share the pilot resources between the layers but allow some interference reduction capability due to scrambling.

3 LS-OFDMA Design Options

Due to the frequency hopping that is employed in the OFDMA uplink to enhance frequency and interference diversity, a couple of options can be envisioned for LS-OFDMA.

3.1 Independent Cross-Layer Hopping

According to the first option, each layer is hopping independently from the other layers. This is shown graphically in Fig. 2.

Because of the layer hopping, the interfering symbols from the other layer do not form a valid code-words. This helps during the single-user decoding and achieves faster convergence. In addition, when one user from an earlier layer terminates, the interference to a bunch of users on the other layers is reduced, improving their effective code-rate (decodability). In other words, the effects of a single user decoding are amortized over a range of users on the other layers, which is desirable from a fairness point of view. The interference variability between the users in the subsequent layers is reduced this means that the rate predictability for those users is easier and more accurate.

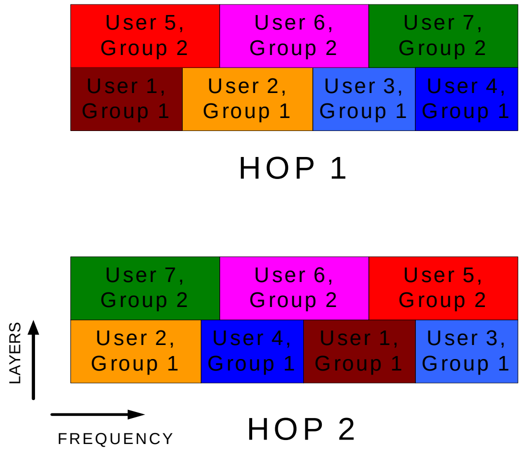

Figure 2: Independent Layer Hopping Option

3.2 Coordinated Cross-Layer Hopping

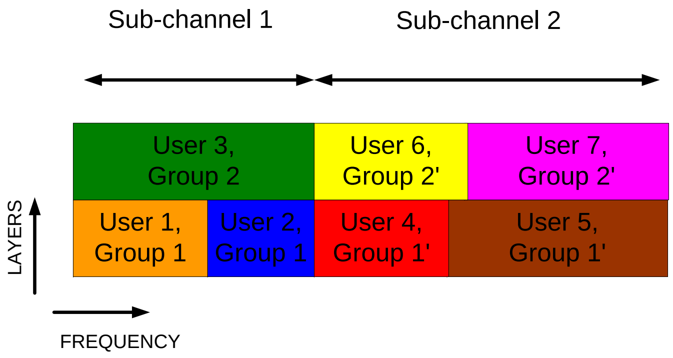

Figure 3: Coordinated Layer Hopping Option

The independent hopping approach averages out the interference and the IC gains across users and over the whole code block. Another approach is to plan the interfering users such that each user interferes with the same set of users all the time as shown in Fig.3. The idea is to have a joint decoder for the typically small number of users that iteratively goes across all the users and improves the LLRs of all users jointly. With independent hopping and SIC reception, users did not see any decoding benefit till an earlier layer user decoded successfully. In the joint decoding approach, all users see incremental improvements in LLR as the iterations increase.

4 Receiver Architectures

For the independent cross-layer hopping option, the well known SIC receiver can be employed. Here we focus on the coordinated case where an Iterative Soft Interference Canceller (ISIC) can be used as a Joint Detector.

The structure of Fig.4 uses independent single user channel decoders to feedback extrinsic information regarding the *coded bit* of each user that will enable to Joint Maximum A Posteriori (JMAP) Soft Input Soft Output (SISO) detector to separate the two user signals.

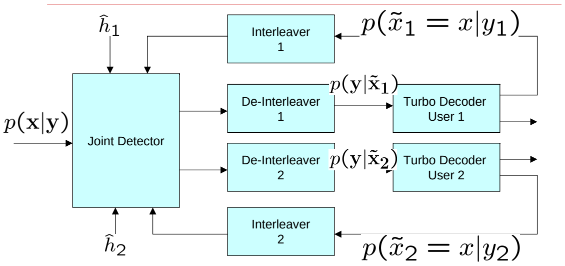

Figure 4: ISIC Signal Flow Diagram for 2 Users

4.1 J-SISO Algorithm

The system under study can be effectively represented by a serial concatenated system that consists of a PCCC channel encoder, a user-specific (channel) interleaver and the multiple access interference (MAI) channel. We assume that fading is constant over one subframe of T_f ms, thus, the channel is memoryless (AWGN) over the duration of the code block.

Starting from the problem of decoding the transmitted codeword $\mathbf{x}$, the Bayes theorem states that its posterior probability (APP) can be written as,

$$P(\mathbf{x}|\mathbf{y}) = \frac{\mathbf{P}(\mathbf{y}|\mathbf{x})\mathbf{P}(\mathbf{x})}{\mathbf{P}(\mathbf{y})} \tag{1}$$

For J interferering signals, the likelihood function is a J-dim Gaussian distribution,

$$P(\mathbf{y}|\mathbf{x}) = \frac{\mathbf{1}}{\pi\,\det[\mathbf{R_J}]} \exp\left[(\mathbf{y}-\mathbf{x})^{\mathbf{T}}\mathbf{R_J^{-1}}(\mathbf{y}-\mathbf{x})\right] \tag{2}$$

where $\mathbf{R_J}$ is the correlation matrix between interfering signals. For J=2, it is a straightforward extension to the single dimensional Gaussian channel likelihood function as shown in Fig.5 for the case of joint BPSK transmissions.

Notice that the 4 peaks are in the 4 possible BPSK modulation symbol combinations i.e. (+1,+1), (+1,-1), (-1,+1), (-1,-1). Iterations will condition this pdf on the most probably transmitted symbols. In other words, the Iterative Joint Detector will generate the marginal probabilities $p(\mathbf{y}|\mathbf{x_k})$ that is the input to the Turbo decoder of the k-th user. The turbo decoder except from the APPs of the information bits, it is modified to also produce the APPs of the parity bits. The output of the Turbo

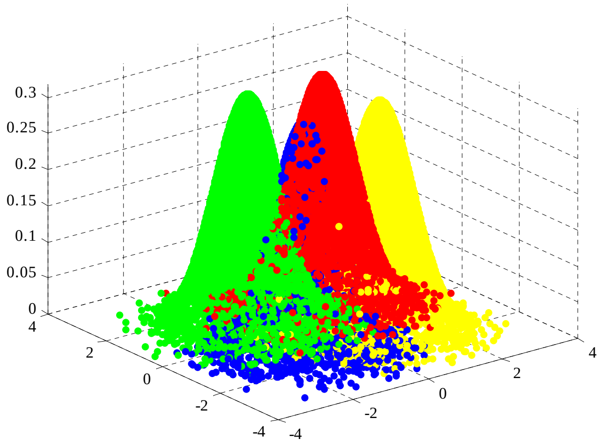

Figure 5: Example Branch Metric Function for 2 BPSK Layers

decoder is therefore the APPs of $p(x_k = x|y_k)$ across the coded block N_{ce}. These probabilities are then used as prior information to the joint detector in the next iteration.

The branch metric for the jth layer is,

$$p_j(n) = \sum_{m_1=1}^{M_1} \cdots \sum_{m_{j-1}=1}^{M_{j-1}} \sum_{m_{j+1}}^{M_{j+1}} \mu(x_1, x_2, ..., x_K) \prod_{i=1, i\neq j}^{J} Pr(x_i) \tag{3}$$

where μ is given by,

$$\mu(x_1(n), x_2(n), ..., x_J(n)) = p(y|x_1(n), x_2(n), .., x_J(n)) = exp(-|y - \sum_j A_j(n) x_j(n)|^2) \tag{4}$$

Note that although the discussion up to now focused on APPs, the real implementation is done using LLRs. The prior code bit LLRs will be used by the Joint Detector to form prior modulation symbol LLRs depending on the label of each constellation point.

5 Simulation Results

A two-user LS-OFDMA system without HARQ was simulated for AWGN channels as a proof of concept for the ISIC receiver. CRC-based power control for a target PER (10%) is included. Multiple scenarios were simulated with varying outer and inner iterations such as the total number of iterations is limited to $N_{outer}x(N_{turbo} - N_{outer})$ where $N_{turbo} = 8$. Scenario one is the superposition of QAM-16 $r_1 = 1/2$ and QPSK $r_2 = 1/5$ with $A_1 = 128$ and $A_2 = 128$ bits block size respectively. The second scenario was the superposition of QPSK $r_1 = 1/5$ and QPSK $r_2 = 1/5$ with $A_1 = 128$ and $A_2 = 128$ bits block respectively. The third scenario differs from the second scenario in that a user specific offset in the interleaving pattern is introduced. The forth scenario is the superposition of QAM-16 $r_1 = 1/2$

and QPSK $r_2 = 1/5$ with $A_1 = 1024$ and $A_2 = 128$ bits block size respectively. The fifth scenario is the superposition of QPSK $r_1 = 3/4$ and QPSK $r_2 = 1/5$ with $A_1 = 1024$ and $A_2 = 128$ bits block respectively. The sixth scenario differs from the previous scenario in that it refers to a no-cancellation receiver i.e. the receiver that does not have the J-SISO in the frontend.

Table 1: LS-OFDMA in AWGN Results (PER Target = 10%)

Scenario	**Req.** E_s/N_t **(dB)** Layer 1	**Req.** E_s/N_t **(dB)** Layer 2
1	5.84 /6.98	1.42/-3.38
2	13.07	11.65
3	-0.17	-0.14
4	9.57 / 6.79	4.64 / N/A
5	5.64	-0.85
6	10.34	7.81

In some scenarios two values are mentioned separated by "‘/"’. The first corresponds to the case of superposition while the second corresponds to the result of the corresponding layer if no superposition is present i.e. no other layer to interfere.

References

[1] P. Monogioudis and S. Nagaraj, “Iterative Soft Interference Cancellation (ISIC) for LS-OFDMA”, Lucent Technologies Submission to 3GPP2 WG3, *ftp.3gpp2.org*,July 2006.

[2] S. Nagaraj and P. Monogioudis, “Uplink Interference Cancellation of Layered Superposed OFDMA (LS-OFDMA) Transmissions”, To appear, WMPC-2007, India, Dec 2007.