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Title: Layered Superposed OFDMA (LS-OFDMA) Interference Mitigation

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Abstract:
We present the design and performance of Layered Superposed OFDMA that can provide *free-riding effects* when OFDMA users with aggressive MCSs are scheduled on top of users with less aggressive MCSs.

Purpose: To include in the SDD the signaling options that are required for performing IC for OFDMA at the BS.

Standards Board Patent Committee (http://standards.ieee.org/board/pat)

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LS-OFDMA Concept

- In this contribution 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.
- 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 effective 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,
  - Frequency hopping patterns.

Motivation for LS-OFDMA - I

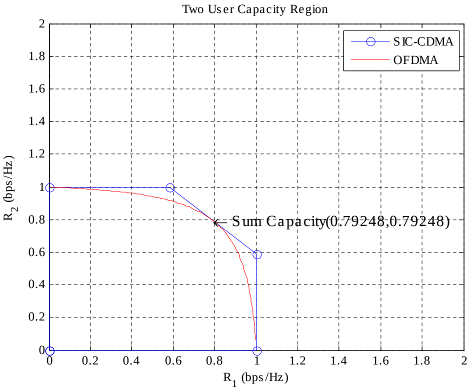


Figure: SIC and OFDMA Capacity Region for $\gamma_1 = \gamma_2 = 0$ dB

- The capacity region of two users with equal received SINRs ($\gamma_1 = \gamma_2 = 0$ dB) detected with a SIC receiver. Superimposed is also plotted the capacity region of OFDMA.

Motivation for LS-OFDMA - II

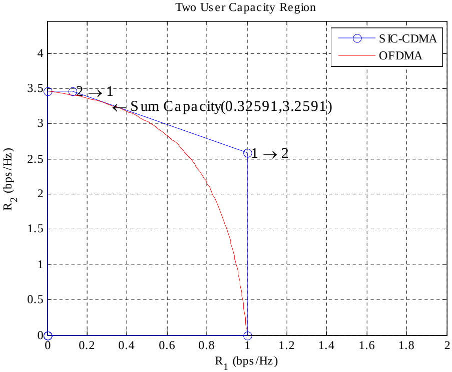


Figure: SIC and OFDMA Capacity Region for $\gamma_1 = 0$ dB and $\gamma_2 = 10$ dB

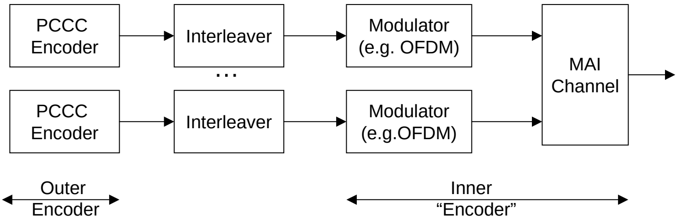
- The capacity region of two users with $\gamma_1 = 0$ dB and $\gamma_2 = 10$ dB, detected with the SIC receiver.

Motivation for LS-OFDMA - III

- OFDMA achieves the sum capacity only when the resources are allocated proportionally to the received SINRs and as can be understood by this example, OFDMA results in an unfair rate allocation for the weak user when the difference of received user SINRs is large.
- Motivated by this observation, we attempt an improvement of OFDMA spectral efficiency and fairness by employing IC in the OFDMA UL.
- Note that the degree of unfairness is of course highly dependent on this simple model. In reality the power (interference) control used in the OFDMA UL can sigfnifiucantly change the fairness relationship between UL users.

LS-OFDMA Layers

- 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. Between layers the base station allows cross-layer interference by allocating the same resources to all layers. In the case of two layers the pilot patterns are orthogonal, allowing for channel estimates without the inter-layer interference.



Cross-Layer Hopping

A couple of options exist at the disposal of the operator.

- In the **independent cross-layer hopping** option shown pictorially in the next slide, each layer is hopping independently from the other layers. 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 *f*airness 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.

Independent Cross-Layer Hopping

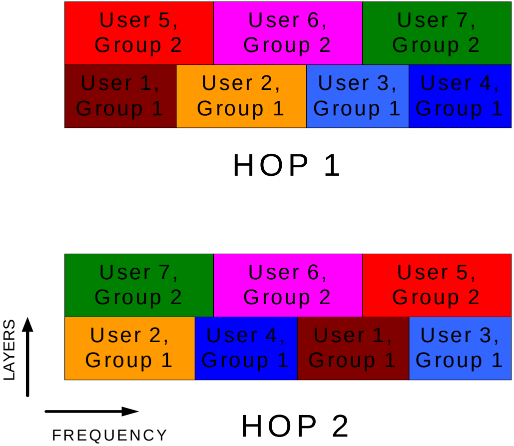
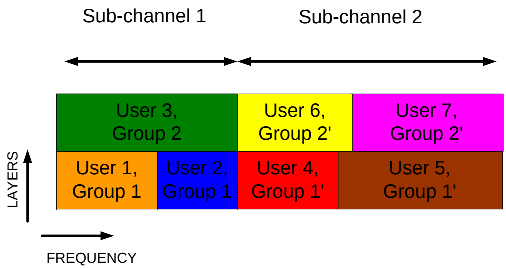


Figure: Independent Layer Hopping Option

Coordinated Cross-Layer Hopping

- In the **coordinated cross-layer hopping** we plan the interfering users such that each user interferes with the same set of users all the time (until it is terminated). 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.



ISIC

In the coordinated case, an Iterative Soft Interference Canceller (ISIC) can be used as a Joint Detector. Independent single user channel decoders 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.

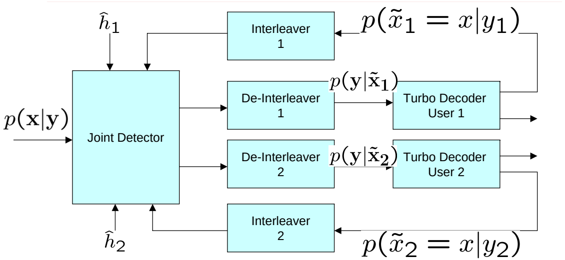


Figure: ISIC Signal Flow Diagram for 2 Users

J-SISO Algorithm (I)

- 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.

J-SISO Algorithm (II)

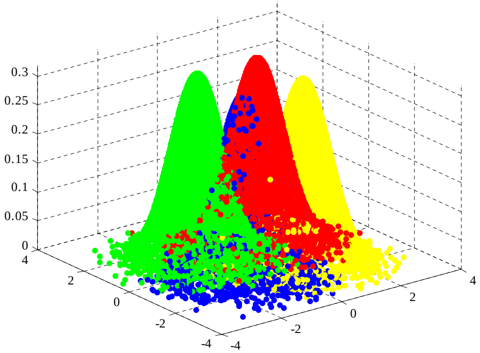


Figure: Example Branch Metric Function for 2 BPSK Layers

- For J=2, it is a straightforward extension to the single dimensional Gaussian channel likelihood function as shown in this figure 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),

J-SISO Algorithm (III)

- 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 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,

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

where μ is given by,

$$\mu(x_1(n), x_2(n), ..., x_J(n)) = p(y|x_1(n), x_2(n), .., x_J(n)) \quad (4)$$

$$= exp(-|y - \sum A_j(n) x_j(n)|^2) \quad (5)$$

ISIC 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 $N_{turbo} = 8$.

1. 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.
2. 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.
3. The third scenario differs from the second scenario in that a user specific offset in the interleaving pattern is introduced.
4. 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.
5. 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.
6. The sixth scenario refers to a no-cancellation receiver i.e. the receiver that does not have the J-SISO in the frontend.

ISIC Results

Table: 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.