Radio resource allocation in OFDMA networks

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Abstract

We propose a distributed resource allocation (RA) scheme for the uplink of a cellular multi-carrier multi-format system based on the message passing (MP) technique. In the proposed approach each transmitter iteratively sends and receives information messages to/from the base station with the goal of achieving an optimal RA strategy. The exchanged messages are the solution of small distributed allocation problems. Hence, despite the NP-hardness of the original RA problem, they distribute the computational effort in the cell among all the transmitters and the base station. The proposed solution offers good results also in a multi-cellular environment in which the inter-cell interference can drastically impair the overall performances.

Introduction

Orthogonal frequency division multiple access (OFDMA) scheme is one of the most efficient technique for realizing future generation broadband wireless networks. In OFDMA, each user is allocated a different subset of orthogonal subcarriers and, if the transmitter possesses full knowledge of channel state information (CSI), the subcarriers can be assigned to the various users following a certain optimality criterion. One of the major drawback of RA schemes is that their complexity is in general high and tends to grow larger with the number of users. Message passing (MP) is a technique used to solve complex problems, e.g. marginalization tasks, by distributing the computational load among several nodes. In a RA scenario, MP entails generating messages that embed the solution of small distributed allocation problems and exchanging them between users and the BS until an allocation decision is taken, without the need of a central controller.

Problem Formulation

We formulate the radio resource allocation problem (RRAP) as a constrained minimization problem, in which subcarriers and transmission formats must be assigned to user n, while fulfilling a specific rate request R_n and respecting the exclusivity of channel assignment. Specifically, the variables of RRAP are collected into the vector $\mathbf{x} = [x_{1,1}, \dots, x_{N,F}]$ where $x_{n,f} \in \{0, \dots, Q\}$ corresponds to a transmission format $i_{x_{n,f}}$ that involves a data rate $B\eta(x_{n,f})$ and a transmitted power $P(x_{n,f})$. RRAP can be formulated as the following integer programming problem (ILP).

$$\text{minimize} \sum_{n,f} P_{n,f}(x_{n,f})$$

$$\text{subject to} \sum_{n} \mathscr{I}(x_{n,f}) \leq 1 \qquad \forall f \in \mathscr{F} \qquad \text{(C1)}$$

$$\sum_{f} B\eta(x_{n,f}) \geq R_n \qquad \forall n \in \mathscr{N} \qquad \text{(C2)}$$

$$x_{n,f} \in \{0, \dots, Q\} \qquad \forall n \in \mathscr{N}, f \in \mathscr{F} \qquad \text{(C3)}$$

Theorem 1 RRAP is strongly NP-hard even when only two transmission formats are available.

Proof: See [4].

Theorem 1 For a given ε>1, no polynomial-time ε-approximation algorithm exists for RRAP.

Proof: See [4].

MP formulation for resource allocation

To solve RRAP with a MP scheme, we reformulate it as a minimum cost problem, where the unfulfillment of constraints (C1) and (C2) outputs an infinite cost. The structure of the problem can be captured by a factor graph. For each subcarrier and user, constraints (C1) and (C2) are translated into

$$C_f(\mathbf{x}) = \begin{cases} 0 & \text{if } \sum_{n \in \mathscr{N}} \mathscr{I}(x_{n,f}) \leq 1 \\ +\infty & \text{otherwise} \end{cases} \qquad W_n(\mathbf{x}) = \begin{cases} \sum_{f \in \mathscr{F}} P_{n,f}(x_{n,f}) & \text{if } \sum_{f \in \mathscr{F}} B\eta(x_{n,f}) \geq R_n \\ +\infty & \text{otherwise} \end{cases}$$

and RRAP becomes

$$\min_{\mathbf{x}} \left(\sum_{f \in \mathscr{F}} C_f(\mathbf{x}) + \sum_{n \in \mathscr{N}} W_n(\mathbf{x}) \right)$$

Invoking to the generalized distributive law, it is possible to derive the following MP rule for the multi-format (MF) min-sum problem [1]

$$m_{C_\ell \to x_{j,\ell}}(x_{j,\ell}) = \min \sum_{n \in \mathscr{N}, n \neq j} m_{x_{n,\ell} \to C_\ell}(x_{n,\ell}) \qquad (1)$$

$$\text{subject to} \sum_{n \in \mathscr{N}} \mathscr{I}(x_{n,\ell}) \leq 1$$

$$m_{W_u \to x_{u,v}}(x_{u,v}) = P_{u,v}(x_{u,v}) + \min \sum_{f \in \mathscr{F}, f \neq v} P_{u,f}(x_{u,f}) + m_{x_{u,f} \to W_u}(x_{u,f}) \qquad (2)$$

$$\text{subject to} \sum_{f \in \mathscr{F}} B\eta(x_{u,f}) \geq R_u$$

and retrieve the corresponding marginal $\tau_{n,f}(x_{n,f}) = m_{W_n \to x_{n,f}}(x_{n,f}) + m_{C_f \to x_{n,f}}(x_{n,f})$ that allows to compute the allocation variable

$$\hat{x}_{n,f} = \arg\min_{x_{n,f}} \{\tau_{n,f}(x_{n,f})\}$$

Problem (1) and (2) can be efficiently solved by appealing to a dynamic programming formula [1]. Unluckily, the MP procedure is not guaranteed to converge if the underlying factor graph is not a tree, hence we need to recur to a peeling strategy [1]. Nevertheless, under the assumption of a single transmission format (SF), it is possible to devise a simplified reweighted MP strategy that establishes a contraction mapping in the space of messages and hence converges also in cycle-graphs [2]

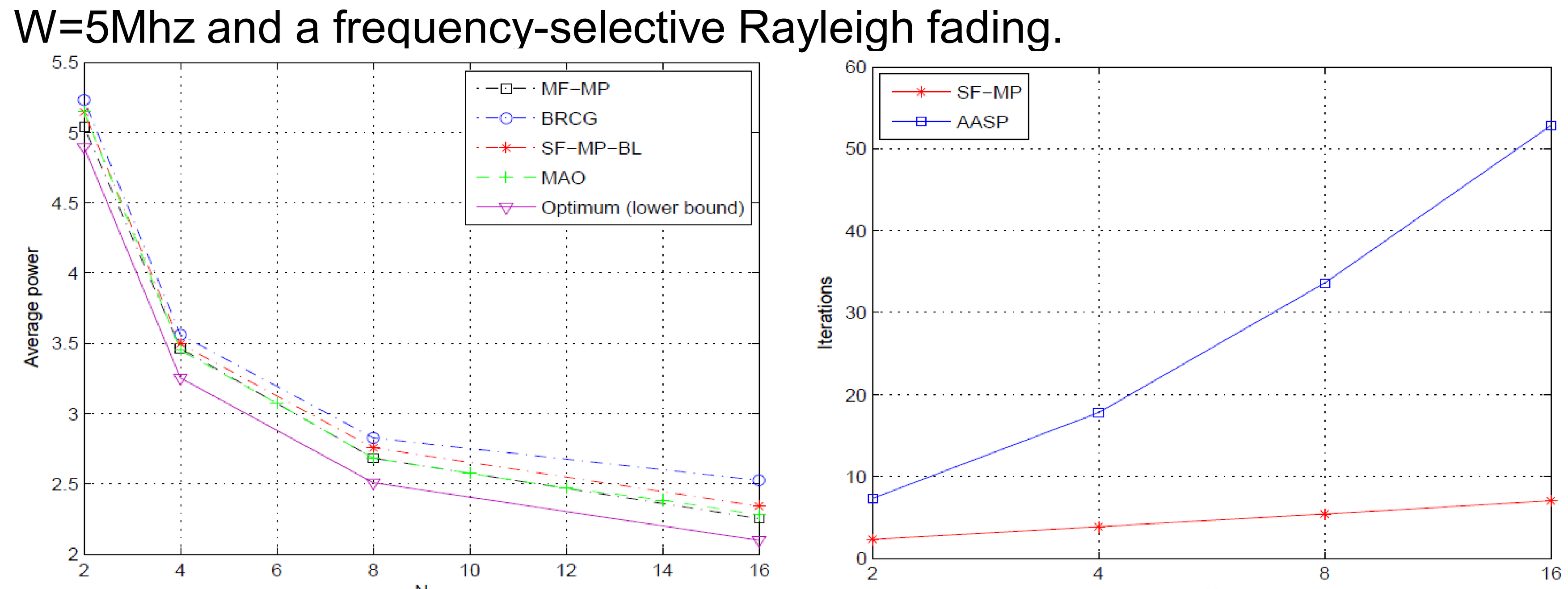
$$\begin{cases} \mu_{n,f}^{(t+1)} = P_{n,f} - \rho \left(P_{n,j} + \tilde{\mu}_{j,n}^{(t)} \right)_{r^{\text{th}} \setminus f} - (1-\rho) \left(P_{n,f} + \tilde{\mu}_{f,n}^{(t)} \right) \\ \tilde{\mu}_{f,n}^{(t+1)} = -\rho \min_{i, i \neq n} \mu_{i,f}^{(t+1)} - (1-\rho) \mu_{n,f}^{(t+1)} \end{cases}$$

$$\tau_{n,f}^{(t+1)} = \mu_{n,f}^{(t+1)} + \tilde{\mu}_{f,n}^{(t+1)} \qquad \hat{x}_{n,f}^{(t+1)} = \begin{cases} 1 & \text{if } \tau_{n,f}^{(t+1)} < 0 \\ 0 & \text{otherwise} \end{cases}$$

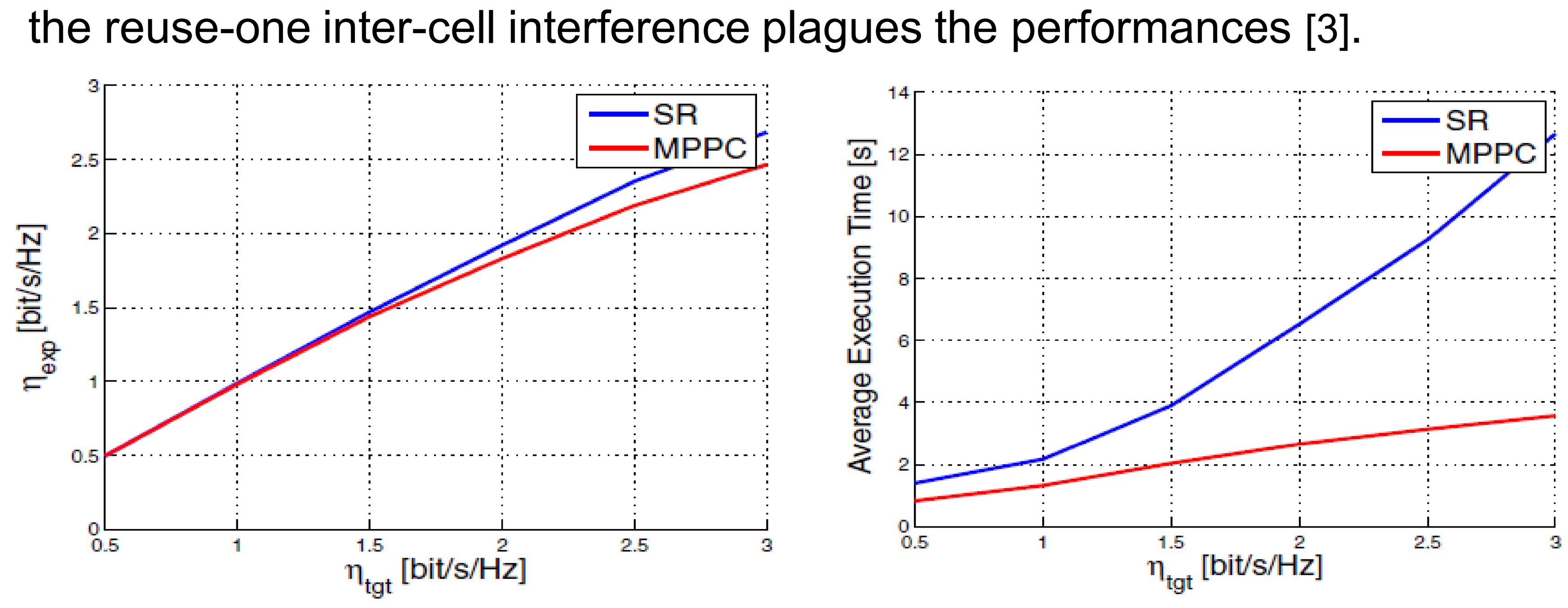
Afterwards, it is possible to perform a bit loading (BL) procedure to satisfy the rate request of each user.

Results

In this Section, we consider a single cell of radius R=500m, a bandwidth W=5Mhz and a frequency-selective Rayleigh fading.



While achieving similar performances to alternatives the computational complexity of MF-MP is at least ten times smaller. The SF-MP-BL still offers good performances, with a significant reduction in the number of iterations. It is interesting to apply the SF-MP algorithm in a multi-cellular scenario in which the reuse-one inter-cell interference plagues the performances [3].



References

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