Self-Organizing Fractional Power Control for Interference Coordination in OFDMA Networks

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Outline

1. Background and Related work
2. The model
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Background and motivation

- As wireless networks become denser, inter-cell interference strongly limits capacity.
- Inter-Cell Interference Coordination (ICIC) is assumed to be a major feature of future networks.
- ICIC mechanisms are diverse:
  - static frequency planning
  - inter-cell scheduling
  - dynamic beam forming and network MIMO
  - interference cancellation and iterative receivers
- Neighbouring cells are linked through an interface, trade-off between ICIC performance and computing power, signalling load and required delay.
- We describe a light-weight distributed ICIC mechanism for OFDMA-based networks, with small overhead and no tight delay requirement.
Network capacity improvement through various ICIC techniques has received much attention in the literature:

- Static frequency planning (1)
- Inter-cell scheduling (2)
- Fractional power control (3)
- Dynamic beam forming (4)


The model

- We consider a downlink Orthogonal Frequency-Division Multiple Access (OFDMA) network and an File Transfer Protocol (FTP) service
- $N_{BS}$ Base Station (BS), full reuse
- The bandwidth is divided into $N_p$ Resource Blocks (RBs), and RBs are grouped into $N_b$ sub-bands
- We write $P_s^{(b)}$ is the power emitted by BS $s$ on a RB of band $b$
The model: SINR and data rate calculation

- The SINR of user $i$ on a RB of band $b$ can be calculated by:

$$S_{s,i}^{(b)} = \frac{h_{s,i}P_s^{(b)}}{N_0^2 + \sum_{s' \in N_s} h_{s',i}P_{s'}^{(b)}}$$ (1)

- Given modulation and coding schemes, a link curve $\phi$ can be obtained.

- Narrowband Rayleigh fading is considered.

- The mean data rate on a RB of band $b$ is calculated by averaging on fading states:

$$\Psi(S_{s,i}^{(b)}) = \frac{N_p}{N_b} \int_0^{+\infty} \Phi(xs_{s,i}^{(b)})e^{-x} dx = \frac{N_p}{N_b S_{s,i}^{(b)}} L_{\Phi} \left( \frac{1}{S_{s,i}^{(b)}} \right)$$ (2)
We consider an opportunistic scheduler which picks for transmission the user maximizing its instantaneous to mean data rate

$$\arg \max_i \frac{r_{i,t_m+1}^{(p)}}{\bar{r}_{i,t_m}}$$

A lower bound of the corresponding diversity gain can be calculated in closed form:

$$\bar{r}_{i,PF} = \sum_{b=1}^{N_b} \sum_{k=0}^{N_u(s)-1} \binom{N_u(s)-1}{k} \frac{(-1)^k}{k+1} \psi \left( \frac{S_{s,i}^{(b)}}{k+1} \right)$$

(4)
Problem formulation

- Users arrive at random instants according to a point process to receive a file and leave upon file transfer completion.
- We want to optimize flow-level QoS metrics such as: stability region, blocking rate, file transfer time.
- We adopt a greedy approach: for each configuration of users, we define a utility function $U$ depending on the users data rates, and we optimize it with respect to transmit powers.

$$\text{maximize } U = \sum_s U_s \quad (5)$$

subject to $0 \leq P_s^{(b)} \leq P_{\text{max}}$, $1 \leq s \leq N_{\text{BS}}$, $1 \leq b \leq N_b$

and $g_l((P_s^{(b)})_{1 \leq b \leq N_b}) \leq 0$, $1 \leq s \leq N_{\text{BS}}$, $1 \leq l \leq N_l$
We choose an $\alpha$-fair form of utility \[^5\]

Let $\alpha \geq 0$ the fairness parameter, $d > 0$ a small constant and $f_\alpha(x) = \frac{(x+d)^{1-\alpha}-1}{1-\alpha}$ if $\alpha \neq 1$ and $f_1(x) = \log(x + d)$.

$$U_s = \sum_{i=1}^{N_u(s)} f_\alpha(\overline{r}_i)$$

The previous problem is usually too hard to solve “on-line”, so we simply look for local maxima.

A local maximum can be found in a distributed fashion using a projected gradient descent:

$$\pi_s(0) \in \mathcal{P}_s, \quad \pi_s(t + 1) = \left[ \pi_s(t) + \mu \nabla_s U(\pi_s(t)) \right]^+$$  \hspace{1cm} (7)
Every 1s, the utility function derivatives are exchanged between neighbouring stations through an interface. The signalling load per station is proportional to the number of bands times the number of neighbours (less than 1$kb/s$). Interface delay is expected to be below 50$ms$ $\ll 1s$, which is fine for the proposed algorithm.
Simulation

- The algorithm is implemented in a multi-cell OFDMA network simulator.
- Three schemes are compared:
  - “Reuse 1”: the base line algorithm
  - “Soft Reuse”: a static solution
  - “FFR”: the proposed dynamic algorithm
- $\alpha = 2$ is used, which is equivalent to maximizing the “instantaneous delay”
Simulation results

Figure: BCR of the network, $\alpha = 2$

Figure: Mean FTT in the network, $\alpha = 2$
Simulation results (cont’d)

**Figure:** c.d.f of FTT of all users in the network, $\alpha = 2$

**Figure:** Trade-off between FTT and BCR for $\alpha = 0$
Conclusion

- A light-weight distributed algorithm for ICIC in OFDMA networks has been shown, and its performance gains have been assessed.
- It’s simplicity makes it a good candidate as a base line for algorithms which necessitate more coordination, fast station-to-station interface and computing power.
- Possible future directions: optimal value of $\alpha$ for elastic traffic, mathematical proof of convergence/optimality at the flow level.