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

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Outline

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

Related work

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])

[1] A. Gjendemsj et al. "Binary Power Control for Sum Rate Maximization over Multiple Interfering Links". In: *Wireless Communications, IEEE Transactions on* 7.8 (2008), pp. 3164 –3173.

[2] Thomas Bonald, Sem Borst, and Alexandre Proutiere. "Inter-cell scheduling in wireless data networks". In: *in Proc. European Wireless*. 2005, pp. 566–572.

[3] A.L. Stolyar and H. Viswanathan. "Self-Organizing Dynamic Fractional Frequency Reuse for Best-Effort Traffic through Distributed Inter-Cell Coordination". In: *INFOCOM 2009, IEEE*. 2009, pp. 1287 –1295.

[4] G. Wunder et al. "Self-organizing distributed inter-cell beam coordination in cellular networks with best effort traffic". In: *WiOpt 2010*. 2010, pp. 295 –302.

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:

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

- Given modulation and coding schemes, a link curve ϕ 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:

$$\Psi(S_{s,i}^{(b)}) = \frac{N_p}{N_b} \int_0^{+\infty} \Phi(x S_{s,i}^{(b)}) e^{-x} dx = \frac{N_p}{N_b S_{s,i}^{(b)}} L_\Phi \left(\frac{1}{S_{s,i}^{(b)}} \right) \tag{2}$$

The model: proportional fair scheduling

- We consider an opportunistic scheduler which picks for transmission the user maximizing its instantaneous to mean data rate

$$\arg\max_i \frac{r^{(p)}_{i,t_{m+1}}}{\overline{r}_{i,t_m}} \quad (3)$$

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

$$\overline{r}_{i,PF} = \sum_{b=1}^{N_b} \sum_{k=0}^{N_u(s)-1} \binom{N_u(s)-1}{k} \frac{(-1)^k}{k+1} \Psi\left(\frac{S^{(b)}_{s,i}}{k+1}\right) \quad (4)$$

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

$$\text{maximize } U = \sum_{s} U_s \tag{5}$$

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

$$\text{and } g_l((P_s^{(b)})_{1 \leq b \leq N_b}) \leq 0 \ , \ 1 \leq s \leq N_{BS} \ , \ 1 \leq l \leq N_l$$

Utility definition

- We choose an α-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 $f_1(x) = \log(x+d)$.

$$U_s = \sum_{i=1}^{N_u(s)} f_\alpha(\bar{r}_i) \tag{6}$$

[5] J. Mo and J. Warland. “Fair End-to-End Window Based Congestion Control”. In: *IEEE transactions networking* 8 (2000), pp. 556–566.

Distributed optimization

- 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:

$$\pi_s(0) \in \mathcal{P}_s \ , \ \pi_s(t+1) = \left[\pi_s(t) + \mu \vec{\nabla}_s U(\pi_s(t))\right]^+ \qquad (7)$$

Signalling load

- 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 $1kb/s$)
- Interface delay is expected to be below $50ms << 1s$, 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

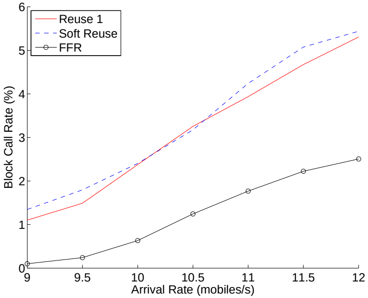

Figure: BCR of the network, $\alpha = 2$

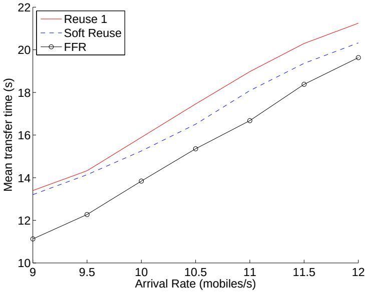

Figure: Mean FTT in the network, $\alpha = 2$

Simulation results(cont'd)

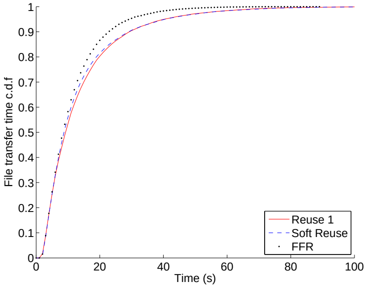

Figure: c.d.f of FTT of all users in the network, $\alpha = 2$

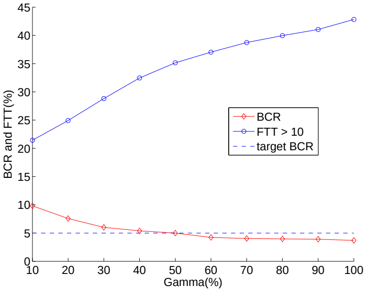

Figure: Trade-off between FTT and BCR for $\alpha = 0$

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 α for elastic traffic, mathematical proof of convergence/optimality at the flow level