Comments on the coupling of interference coordination and resource allocation in OFDMA networks

James Gross, Han Zhou

VDE Fachgruppe 5.2.4 / Stuttgart

06.10.2010

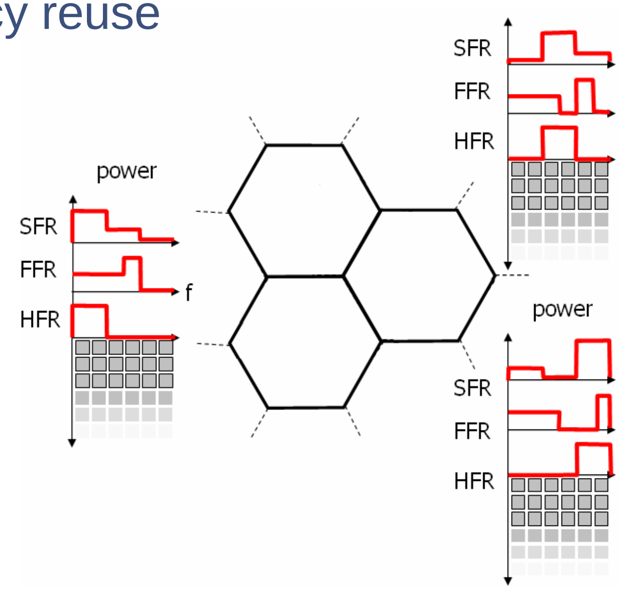
UMIC

RWTH AACHEN UNIVERSITY

FACHGRUPPE INFORMATIK

Motivation I

- **Reuse 1 networks can benefit from power masking**
- **Different power mask concepts studied in the literature:**
  - Hard frequency reuse
  - Fractional frequency reuse
  - Soft frequency reuse



- **Well known that FFR and SFR outperform HFR and flat power masks significantly**

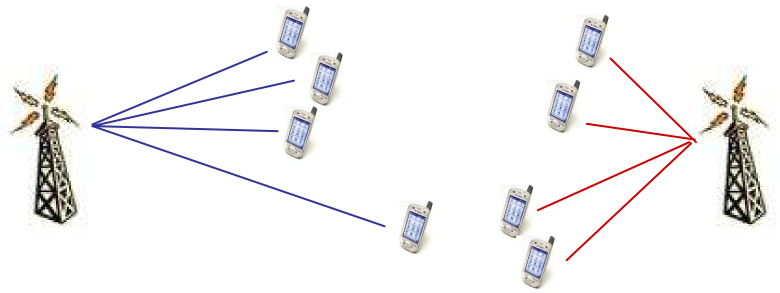
M. Bohge, J. Gross, A. Wolisz, "Optimal Power Masking in Soft Frequency Reuse based OFDMA Networks," in *Proc. of European Wireless Conference (EW'09)*, Alborg, Denmark, May 2009.

Motivation II

- **However, static power masking (either FFR or SFR) is vulnerable to load imbalances in the cells**

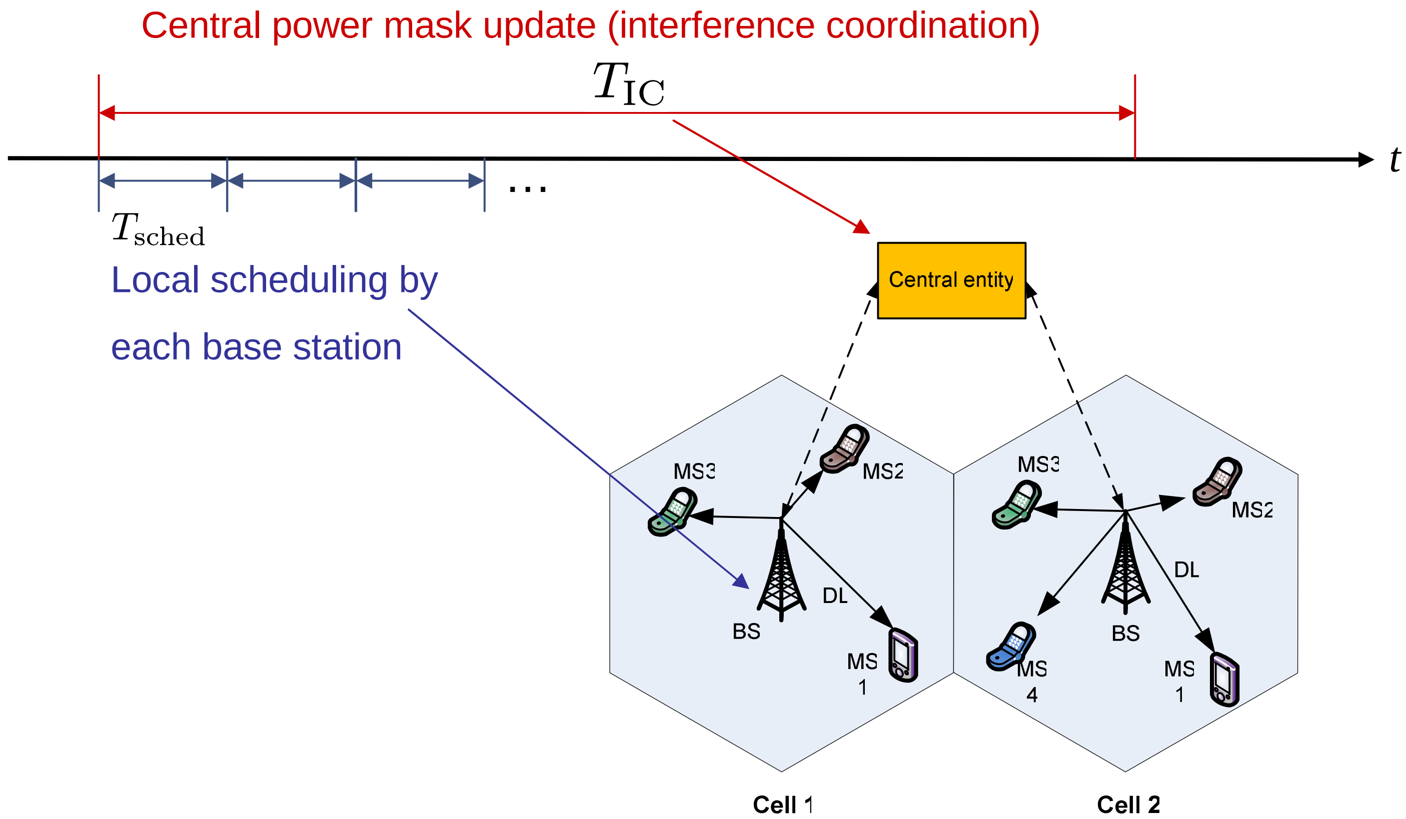
  ➔ Concepts like adaptive soft frequency reuse currently discussed

  Main idea: Update periodically the power masks according to load



- **Within each period base stations perform local scheduling**
- **<u>Contribution of this talk: Dependence between local scheduling and power masking</u>**
  - Do we need to account for the multi-user scheduling gain?
  - What should be guidelines?

System Model



- Mapping of instant. SINR to rate, i.e. $\mathcal{F}(\gamma) = \log_2(1+\gamma)\cdot\gamma)$
- Load: VoIP packet flows, maximum queueing delay of 50 ms
- Only considering the downlink in the following

Local Scheduling

- **BS performs local scheduling independently every T_{sched} :**
  - Power mask (power setting per RB from central entity)
  - Current channel state information (SINR feedback per RB)
  - Queue state
  - Objective: minimize the queuing delay by RB assignment

$$\max \quad \sum_j \sum_q y_{j,q} \cdot d_{j,q}$$

$$\text{s. t.} \quad \sum_n x_{j,n} \cdot \mathcal{F}(\gamma_{j,n}) \geq \sum_q y_{j,q} \cdot S_{j,q} \ , \ \forall j$$

$$\sum_j x_{j,n} \leq 1 \ , \ \forall n$$

j : Terminal index
n : RB index
q : Packet index
γ : SINR
d : Packet delay
s : Packet size
x : RB assignment (0/1)
y : Packet assignment (0/1)

Interference Coordination (IC)

- **‚Central entity' updates power masks for several cells every T_{IC}**
  - Power masks generated based on signal and interference gains
  - Objective: Maximize minimum rate among all terminals (for VoIP support)

$$
\begin{aligned}
\max \quad & \epsilon \\
\text{s. t.} \quad & \sum_n x_{j,n,k} \cdot \mathrm{E}\left[\mathcal{F}\left(\gamma_{j,n,k}\right)\right] \geq \epsilon\ ,\ \forall j,k \\
& \sum_j x_{j,n,k} \leq 1\ ,\ \forall n,k \\
& \sum_n p_{n,k} \leq P_{\max}\ ,\ \forall k
\end{aligned}
$$

j : Terminal index
n : RB index
k : Cell index
γ : SINR
P : Transmit power budget
x : RB assignment
p : Power assignment

  - Note: Only power masks reported back to base stations

Coupling IC with Scheduling

- **What is a good expression for** $\mathrm{E}\left[\mathcal{F}\left(\gamma\right)\right] = \mathrm{E}\left[\log_2\left(1+\gamma\right)\right]$ **?**
  - Assume exponentially distributed signal and interference gains:

$$g^s \sim \mathrm{Exp}(\tfrac{1}{\rho^s}) \qquad g^i \sim \mathrm{Exp}(\tfrac{1}{\rho^i})$$

  - Fixing transmit powers yields a new random variable as SINR:

$$\gamma = \frac{p^s \cdot g^s}{p^i \cdot g^i + \sigma^2}$$

  - PDF $$f_\gamma(y) = \left[\frac{\sigma^2}{P_I y + P_S} + \frac{P_I P_S}{(P_I y + P_S)^2}\right] \cdot e^{-\frac{\sigma^2}{P_S} y}$$

  - CDF $$F_\gamma(y) = 1 - \frac{P_S}{P_I y + P_S} \cdot e^{-\frac{\sigma^2}{P_S} y}$$

where $$P_S = p^s \cdot \rho^s \qquad P_I = p^i \cdot \rho^i$$

F. Naghibi and J. Gross, "How bad is interference in IEEE 802.16e systems?," in *Proc. of the 16th European Wireless Conference (EW'10)*, Lucca, Italy, April 2010.

Coupling IC with Scheduling II

- Naive evaluation: simply divide average received power by average interference power

$$\mathrm{E}\left[\mathcal{F}\left(\gamma\right)\right] = \log_2\left(1 + \frac{P_S}{P_I+\sigma^2}\right)$$

- Static evaluation: Accounting for the true average of the ‚capacitated' SINR r.v. yields instead:

$$\mathrm{E}\left[\mathcal{F}\left(\gamma\right)\right] = \int_0^\infty \log_2\left(1+\gamma\right) \cdot \left[\frac{\sigma^2}{P_I\cdot\gamma+P_S} + \frac{P_S\cdot P_I}{\left(P_I\cdot\gamma+P_S\right)^2}\right] \cdot e^{-\frac{\sigma^2\cdot\gamma}{P_S}} d\gamma$$

- However, base stations are performing dynamic resource allocation !

Coupling IC with Scheduling III

- **How to account for multiuser scheduling gain?**
  - Typical resource blocks assigned by local scheduling are much better than represented by the ‚static' SINR r.v.
  - Use order statistics to account for scheduling gain:

$$\mathrm{E}\left[\mathcal{F}\left(\gamma\right)\right] = \int_0^\infty \log_2\left(1+\gamma\right)\cdot A\left[1-\frac{P_S}{P_I\cdot\gamma+P_S}\cdot e^{-\frac{\sigma^2\cdot\gamma}{P_S}}\right]^{A-1}\cdot \left[\frac{\sigma^2}{P_I\cdot\gamma+P_S}+\frac{P_S\cdot P_I}{(P_I\cdot\gamma+P_S)^2}\right]\cdot e^{-\frac{\sigma^2\cdot\gamma}{P_S}}d\gamma$$

  - Parameter to control: A

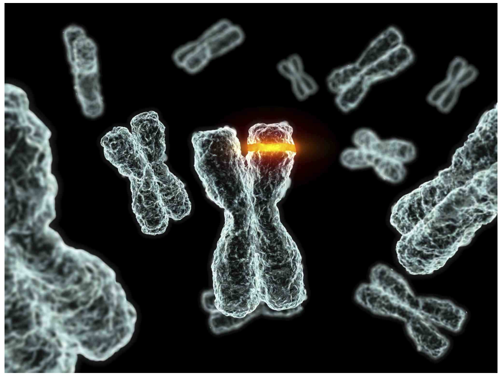
- **Refer to this as dynamic evaluation**

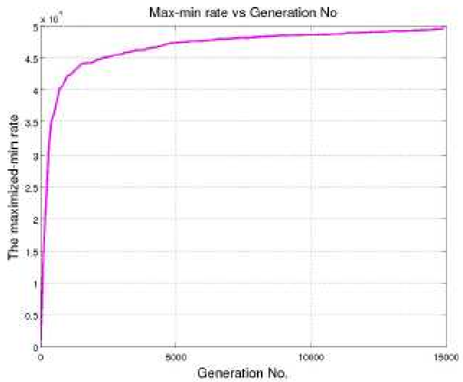
J. Gross, "Admission Control based on OFDMA Channel Transformation," in *Proc. of 10th IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, Kos, Greece, June 2009.

Computation of Power Masks

- **Recall the power mask optimization problem: gets quite complex with above expression for expected capacity!**

- **Power masks are computed by genetic algorithm**





- **Optimization variables (power masks and resource block assignments) taken as <u>chromosome</u>:**
  - Then repeat the cycle (= 1 generation):
    Selection → Crossover and Mutation → Correction → Evaluation
  - Best chromosomes of previous phase taken as input for next power mask generation

Performance Evaluation

Evaluate performance by simulations

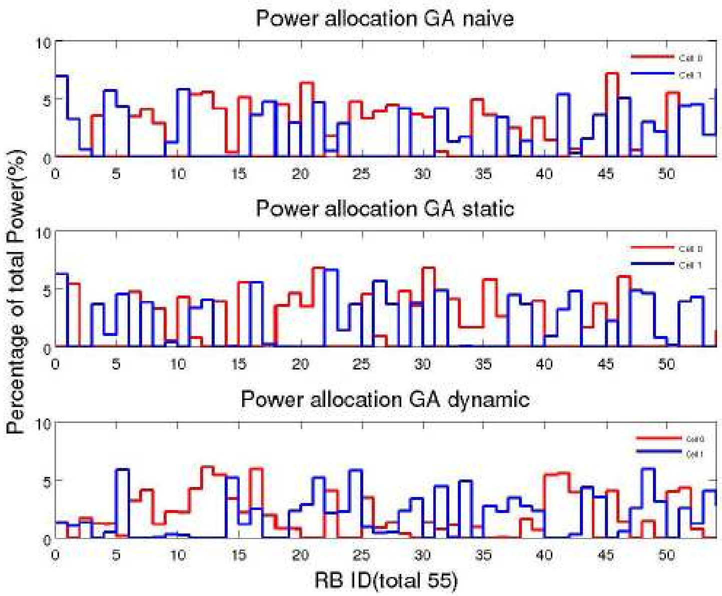
- Parameter:
  - 2 cell scenario (only one sector), 600 terminals
  - VoIP packet size 288 bits, IAT of 20 ms per flow
  - Local scheduling every 1 ms
  - Power mask update every 100 ms
  - Equal path loss/shadowing/fading model for all terminals
  - Packet dropping threshold: 50 ms

- Metrics:
  - Average drop rate
  - ECDF of the packet delay

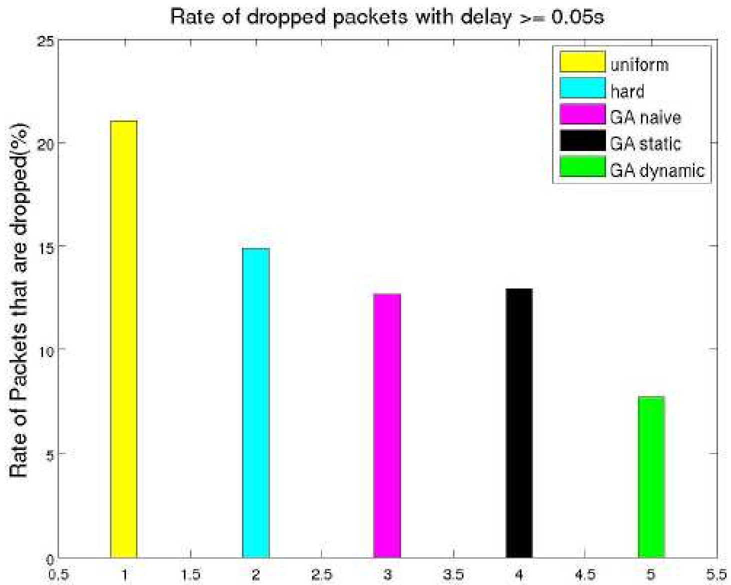
- Compared schemes:
  - Uniform power mask
  - Reuse 2
  - Adaptive power mask (naive, static, dynamic)

Performance Evaluation II

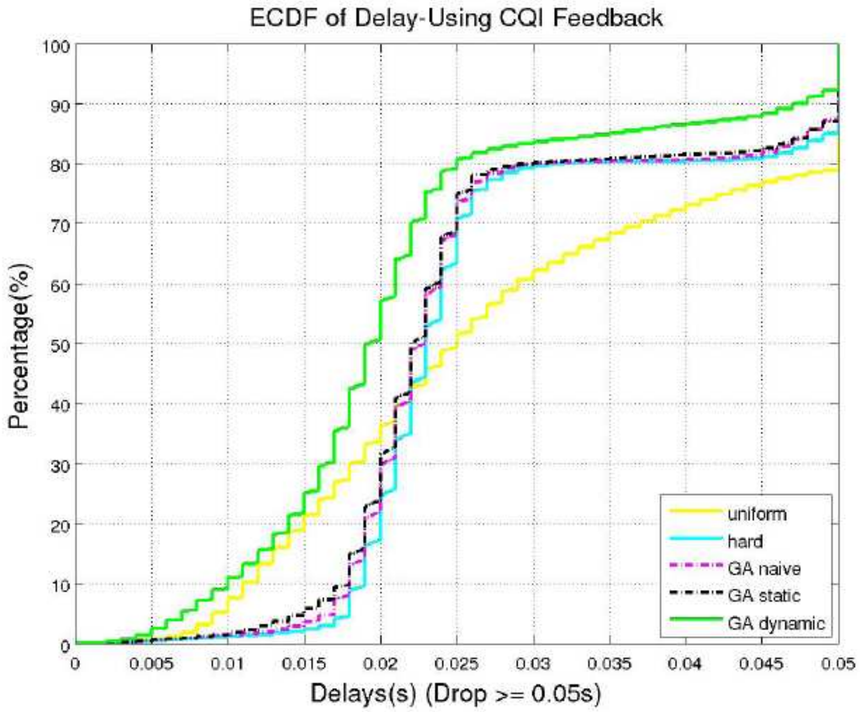
Power masks



Packet drop rate



Performance Evaluation III



~ 50 more VoIP clients supported if scheduling gain taken into account!

Conclusions

- **Accounting for multi-user diversity scheduling in interference coordination is crucial!**
  - Otherwise, no gain seen from interference coordination!
  - Is there a correct way of coupling IC with resource allocation? Order statistics is a candidate to do so …
  - Not shown here: some performance dependency on the factor A

- **Adaptive SFR can yield significant performance gain**
  - Work in progress:
    - Tune GA to get better results
    - Switch to scenario with more cells