Autonomous Uplink Intercell Interference Coordination in OFDMA-based Wireless Systems

Mai Kafafy and Khaled Elsayed
Department of Electronics and Communications Engineering
Cairo University, Egypt

WiOpt 11th Intl. Symposium on Modeling and Optimization in Mobile, Ad Hoc, and Wireless Networks
Tsukuba Science City, Japan
14 May, 2013
Agenda.

1. Introduction.
2. System Model.
5. Solution Techniques.
7. Conclusions.
8. Future Work.
1. Introduction

- Traditional wireless systems (AMPS, DAMPS, GSM) use FRF of N.

- Each cell assigned $1/N$ of the total BW.

- Adjacent cells use different frequency bands

  😊 Almost no ICI.

  😞 Low spectral efficiency.
1. Introduction.

- LTE deploys FRF of 1.
- Each cell uses the whole BW.
- Adjacent cells transmit on the same frequency band.

😊 Best spectral efficiency.
😊 ICI deteriorates the rates of cell-edge users.
1. Introduction.

ICI mitigation techniques

- Cell Coordination based allocation schemes
  - Centralized
  - Distributed
  - Autonomous

- Fractional (Soft) Frequency Reuse
1. Introduction

**FFR**

The inner band is of Reuse–1, while the outer band is of Reuse–N (3 for example)

😍 FFR reduces the spectral efficiency
1. Introduction

SFR

Attempts to utilize spectrum more efficiently than FFR.

Still not the best spectral efficient scheme.
1. Introduction

- Centralized Resource Allocation.

- Best spectral efficiency and optimal allocation.
- Too complex calculations,
- extensive signaling on the back haul between BSs, and,
- intolerable large delay.
2. System Model

- OFDMA-based with $K$ RBs (Assigned according to PF scheme).

- Terminal–$i$ transmits on RB–$k$ with power $p_{ik}$.

- $h_{ji}^k$ is the channel gain between terminal–$j$ and BS–$i$ on RB–$k$.

- $\sigma^2_{k,s(i)}$ is the noise power density on RB–$k$ between terminal–$i$ and its serving BS–$s(i)$.
3. Centralized Resource Allocation

The most common approach is to maximize weighed sum of the user’s rates in the whole system

Maximize

$$\sum_{i=1}^{M} w_i \sum_{k=1}^{K} \log_2(1 + \frac{p_{ik} h_{ii}^k}{\sigma_{k,s(i)}^2 + \sum_{j=1}^{M} p_{jk} h_{ji}^k})$$

Subject to

$$0 \leq \sum_{k=1}^{K} p_{ik} \leq p_{max}$$

For all users
3. Centralized Resource Allocation

\[
\max_{\vec{P}} f(\vec{P}) - g(\vec{P})
\]

Subject to

\[
0 \leq \sum_{k=1}^{K} p_{ik} \leq p_{\text{max}}
\]

For all users

\[
f(\vec{P}) = \sum_{i=1}^{M} w_i \sum_{k=1}^{K} \log_2 \left( \sigma^2_{k,s(i)} + \sum_{j=1}^{M} p_{jk} h_{ji}^k \right),
\]

\[
g(\vec{P}) = \sum_{i=1}^{M} w_i \sum_{k=1}^{K} \log_2 \left( \sigma^2_{k,s(i)} + \sum_{\substack{j=1 \atop j \neq i}}^{M} p_{jk} h_{ji}^k \right).
\]
3. Centralized Resource Allocation

One of the methods (which we adopt for comparison) is through DC programing

\[
\max_{\vec{P}} f(\vec{P}) - g(\vec{P}^k) - \nabla g^T(\vec{P}^k).\vec{P} + \nabla g^T(\vec{P}^k).\vec{P}^k \\
\equiv \\
\max_{\vec{P}} f(\vec{P}) - \nabla g^T(\vec{P}^k).\vec{P}
\]

Convex!

S.t. \( 0 \leq \sum_{k=1}^{K} p_{ik} \leq p_{max} \)
3. Centralized Resource Allocation

Franke–Wolfe procedure for Weighted Sum Throughput– Maximization:

1. K=0.
2. Set $\vec{P}^0$ and calculate $R(\vec{P}^0)$.
3. Solve the convex problem using any software package and let $\vec{P}^k = \vec{P}^*$. 
4. Calculate $R(\vec{P}^k)$.
5. K=k+1.
6. Stop if $|R(\vec{P}^{k-1}) - R(\vec{P}^{k-1})| \leq \epsilon$ else go to step (3)
3. Centralized Resource Allocation

- Needs to exchange frequent extensive messages indicating power allocation, interference signals, and achieved rates between cells.

**IMPractical!!**

- How to find an Efficient Autonomous resource allocation scheme?
Define the two following terms:

1. **Leakage power of the cell.**
2. **Signal to noise and leakage ratios** \((\zeta_{i,k})\) **of the terminal** \(-i\) **on RB** \(-k\).

\[
U_S = \sum_{i \in I_S} \sum_{k=1}^{K} \zeta_{i,k}.
\]

- \(p_i\): the total power of Terminal \(-i\).
- \(g_{i,m}\): the path-loss and shadowing between BS \(-m\) and Terminal \(-i\).
Now, the problem at every BS is autonomous and convex:

\[
\begin{align*}
\text{Minimize} \quad & -U_s = - \sum_{i \in I_s} \sum_{k=1}^{K} \frac{p_{i,k} h_{i,s}^k}{\sigma_{s,k}^2 + p_{i,k} G_{i,s}} \\
\text{Subject to} \quad & \sum_{i \in I_s} \sum_{k=1}^{K} G_{i,s} p_{i,k} \leq T \\
& \sum_{k=1}^{K} p_{i,k} \leq P_{\max} \quad \forall i \in I_s
\end{align*}
\]

\(G_{i,s} = \sum_{m \neq s} g_{i,m}\) is the leakage power density of terminal \(i\).

\(T\) is the interference limit.
5. Solution Techniques

☐ Lagrangian approximate based solution:
Solving the KKT equations does not give a closed form solution.

☐ Suboptimal solution:
Assuming the interference constraint is satisfied with equality, we reach a closed form solution.

\[ p_{i,k} = f(\text{noise power, RB gain, Interference limit, leakage power}) \]
5. Solution Techniques

The power allocated to UE $i$ on RB $k$ is given as follows:

$$p_{i,k} = \max \left( \frac{1}{G_{i,s}} \left[ \frac{\sigma_k^2 h_{i,s}^k}{\mu^* G_{i,s}} - \sigma_{s,k}^2 \right], 0 \right), \quad k = 1, 2, ..., K, \quad i \in I_s$$

$$\mu^* = \left( \frac{\sum_{i \in I_s} \sum_{k=1}^{K} \frac{\sigma_k^2 h_{i,s}^k}{G_{i,s}}}{T + |I_s| \sum_{k=1}^{K} \sigma_{s,k}^2} \right)^2$$

$h_{i,s}^k$ is the channel gain between terminal $i$ and its serving BS–S on RB $k$.

$G_{i,s}$ is the leakage power density of terminal $i$.

$T$ is the interference limit.
Minimize $f_o(\vec{P})$

Subject to

$\forall i \in I_s$

$T_i(\vec{P}) \leq T$

$T_i(\vec{P}) \leq P_{max}$

Minimize $f(\vec{P})$

\[= f_o(\vec{P}) - \eta^T \log (T - T_\{T\}(\vec{P})) - \sum_{i \in I_s} \eta^p_i \log (P_{max} - f_i(\vec{P}))\]

Can be solved iteratively using Newton’s method.
6. Performance Evaluation

- System layout

Red dot: BS
Black dot: UE
Blue line: link between UE and its serving BS
6. Performance Evaluation

- **System parameters**
  - Noise power density = $-174$ dbm/Hz.
  - Number of RBs = 15 RB.
  - Maximum power per user = 24 dbm.
  - 20 UEs are uniformly distributed over a 250m X 250m square area centred at the origin.
  - Typical urban macro cell scenario using the WINNER II channel model.
6. Performance Evaluation

![Graph showing spectral efficiency vs. interference limit (dBm)]

- Logbarrier
- SubOptimal
- EPA
- Cent (PF)
6. Performance Evaluation

![Graph showing spectral efficiency vs. interference limit (dBm)]

- Logbarrier
- SubOptimal
- EPA
- Cent (PF)
6. Performance Evaluation

![Graph showing performance evaluation for Logbarrier, SubOptimal, EPA, and Cent (PF) with interference limit (dBm) on the x-axis and 10-percentile (bits/sec/Hz) on the y-axis.](image)

- Logbarrier
- SubOptimal
- EPA
- Cent (PF)
6. Performance Evaluation

Users distribution at -90 dbm.
6. Performance Evaluation

Users distribution at -110 dbm.
6. Performance Evaluation

![Graph showing performance evaluation with Logbarrier, SubOptimal, EPA, and Cent (PF) markers. The graph plots geometric average (bits/sec/Hz) against 10 percentile (bits/sec/Hz) with an interference limit increase noted.](image)

---

Mai Kafafy and Khaled Elsayed  
Cairo University
6. Performance Evaluation

Cell radius decreases

- Logbarrier
- SubOptimal
- EPA

10 Percentile (bits/sec/Hz)

Geometric average (bits/sec/Hz)
7. Conclusions

- We have proposed two autonomous resource allocation schemes:
  1. Closed form suboptimal autonomous resource allocation.
- They exhibit better performance than EPA especially at low interference constraints.
- They also show an acceptable performance compared with centralized resource allocation.
8. Future Work

- The Overlad Indicator (OI) signal in the LTE standard should be a good measure to update the value of the interference limit $T$.

- A different interference limit can be defined for every RB or for every participating cell depending on cell type and required coverage.

- Evaluation in a HetNet environment with unsymmetric dynamic traffic.
Questions?

Thank You!

mali@4gpp-project.net