Interferene Coordination in OFDMA Networks

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• Introduction and motivation
  - Requirements and challenges in cellular networks
  - Introduction to OFDMA networks

• Interference mitigation techniques
  - Fractional Frequency Reuse (FFR)
  - Interference Coordination (IFCO)

• Coordinated Fractional Frequency Reuse
  - Concept and architecture
  - Algorithm description

• Performance Evaluation
  - Comparison with conventional systems
Scenario

- Cellular OFDMA network according to 3GPP Long Term Evolution (LTE) or IEEE 802.16e (WiMAX)

Requirements

- High aggregate throughput serve as many users as possible
- High cell edge throughput good performance even with weak signal

Major problem: Inter-cellular interference
Orthogonal Frequency Division Multiple Access

- Based on Orthogonal Frequency Division Multiplex (OFDM)
  - subdivision of frequency spectrum into subcarriers
  - well suitable for multi-path fading environments
- Basis of several emerging cellular standards
e.g., 802.16e/m (WiMAX), 3GPP LTE
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Example: 802.16e MAC Layer ("mobile WiMAX")
- Frequency-diverse (PUSC zone, FUSC zone) and
  frequency-selective modes (AMC zone)
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Example: 802.16e MAC Layer ("mobile WiMAX")
- Frequency-diverse (PUSC zone, FUSC zone) and
  frequency-selective modes (AMC zone)
- AMC zone (Adaptive Modulation and Coding)
  - allocation of consecutive subchannels for the
    transmission to one terminal
  - allocations have rectangular shapes
    - allows frequency-selective scheduling
    - well suitable for interference coordination
Interference in Cellular Networks

- Major issue in OFDMA: inter-cellular interference
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Interference in Cellular Networks

- Major issue in OFDMA: inter-cellular interference
  - standard solution: frequency reuse pattern
  - optimization: Reuse Partitioning / Fractional Frequency Reuse (FFR)
  - Usage of directional antennas to lower inter-cellular interference
    - Additional coordination necessary
    - interference coordination (IFCO)
Classification w.r.t. time-scale of operation (3GPP)

- **Static schemes**
  - static planning of interference situation in network
  - does not adapt to present load situation
  - example: Reuse Partitioning / Fractional Frequency Reuse

- **Semi-static schemes**
  - self-configured coordination (level of days \( \Rightarrow \) almost static)
  - cell load adaptive coordination (level of minutes)
  - user load adaptive coordination (level of hundreds of milli seconds)

- **Dynamic schemes**
  - fully synchronized scheduling
  - coordination takes place every frame or every few frames
  \( \Rightarrow \) well suitable if only sectors of one base station are coordinated
Classification wrt. degree of distribution

• Global schemes
  - base stations have no power of decision
  - omniscient entity, which is capable of performing scheduling decisions in all cells on a per-frame basis

• Distributed schemes with central entity
  - base stations have (limited) power of decision
  - ideal: central component acquires system state and distributes scheduling decisions every frame
  - realistic: central component acquires system state and distributes scheduling decisions e.g. once per second

• Decentralized schemes (without central component)
  information exchange among base stations
  - via signaling network
  - via mobile terminals

• Decentralized schemes, using only local state information
Conventional Fractional Frequency Reuse (FFR)

- Assignment of mobiles to reuse 1 or 3 based on position or SINR
- Reuse 1 & reuse 3 areas may or may not be on same frequency range
- Power levels may or may not be adjusted depending on area
Conventional Fractional Frequency Reuse (FFR)

- Assignment of mobiles to reuse 1 or 3 based on position or SINR
- Choice of reuse partition depending on cell sector (static)

- Reuse 1 & reuse 3 areas may or may not be on same frequency range
- Power levels may or may not be adjusted depending on area
Coordinated Fractional Frequency Reuse

**Idea:** Reduce interference by optimized and coordinated dynamic choice of reuse partition (semi static or dynamic)

 RootState coordination
• Base stations communicate relevant information to central coordinator
• Central coordinator assigns mobile terminals to resource partitions in a coordinated fashion
• **Approach**
  - construction of an interference graph $G$ in central coordinator
    - nodes $m_i \in M$
    - edges $e_{ij} \in E$ (non-directional)
  - assignment of resource partitions based on interference graph
  - communication of resource partitions to base stations

• **Interference graph**
  - based on global knowledge collected from all base stations
  - edges represent critical interference relations in-between terminals
    - connected terminals should not be served on the same resource (time/frequency slot)
Creation of Interference Graph

- Mobile terminal $m_5$
- Mobile terminal $m_{10}$
- Mobile terminal $m_2$
- Mobile terminal $m_{12}$

Cell border

Interference

Interference Levels:
- $m_5$: -83 dBm
- $m_8$: -89 dBm
- $m_{10}$: -91 dBm
- $m_9$: -92 dBm
- $m_{22}$: -94 dBm
Creation of Interference Graph

- Calculation of signal strength of interferers for a particular mobile terminal $m_j$

<table>
<thead>
<tr>
<th>Interference by Mobile Terminal</th>
<th>Interference Level</th>
</tr>
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<tbody>
<tr>
<td>$m_2$</td>
<td>-80 dBm</td>
</tr>
<tr>
<td>$m_{12}$</td>
<td>-93 dBm</td>
</tr>
<tr>
<td>$m_8$</td>
<td>-94 dBm</td>
</tr>
<tr>
<td>$m_{20}$</td>
<td>-99 dBm</td>
</tr>
<tr>
<td>$m_{42}$</td>
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Creation of Interference Graph

- Calculation of signal strength of interferers for a particular mobile terminal \( m_j \)
- Blocking of strongest interferers such that a desired minimum SIR \( D_S \) is achieved
Creation of Interference Graph

- Calculation of signal strength of interferers for a particular mobile terminal $m_j$
- Blocking of strongest interferers such that a desired minimum SIR $D_S$ is achieved
- Blocked terminals are connected by edge in interference graph
• Treat resource partitions as colors of graph
• Resource partitions can be assigned to mobile terminals by coloring of the interference graph
  - graph coloring is NP hard
  - large number of heuristics: genetic algorithms, simulated annealing, tabu search, other heuristics (e.g., Dsatur)
Virtual frame duration must be adapted to number of colors
**Procedure**
- Communication of all required information to central coordinator
- Calculation of interference graph
- Graph Coloring
- Communication of colors to base stations
- Mapping of colors to resource partitions

**Important Parameters**
- update period: \( T_{C,\text{period}} \)
- delay: \( T_{C,\text{delay}} \)
Performance Evaluation

- Event-driven simulation model implemented using IKR SimLib
- Hexagonal scenario described before with wrap-around
- Mobility model
  - 9 mobile terminals per cell sector
  - 30 km/h, random direction mobility model
- Traffic model
  - Greedy traffic sources in downlink direction
  - Throughput measured at IP level
- Detailed MAC and Physical layer model with path loss and shadowing
- Metrics:
  - Aggregate sector throughput
does not take into account fairness towards cell edge users
  - 5% quantile of the individual throughputs of all mobiles
    - Terminals close to cell center have high throughput
    - Terminals close to cell edge have low throughput
      \( \text{corresponds to throughput of terminals close to cell edge} \)
• Reuse 3 system achieves good **aggregate** performance and good **cell edge** performance
• **Reuse 1 system** achieves better *aggregate* performance but falls short with respect to *cell edge* performance.
Throughput Performance

- **Conventional Fractional Frequency Reuse, locally coordinated**
  - achieves great increase in aggregate performance
  - falls short with respect to cell edge performance
• **Coordinated Fractional Frequency Reuse**
  - achieves good increase in *aggregate* and *cell edge* performance
  - allows to trade off cell edge and aggregate performance on a high level
Impact of Signaling Delays

- Increased signaling delay $T_{C,\text{period}}$
  - leads to graceful degradation of cell edge performance
  - has much less impact on aggregate performance (not shown here)
**Impact of Signaling Delays**

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Area Throughput

Reuse 3

Coordinated FFR

- Big increase close to base stations
- Good coverage at cell edge with coordinated FFR

$T_{C,\text{period}} = 2s$, $T_{C,\text{delay}} = 1s$
$D_{S,o} = 0\text{dB}$, $D_{S,i} = 20\text{dB}$
• **Frequency spectrum is one of the most precious resources**
  - operators strive to get maximum performance out of limited spectrum

• **Possible solutions**
  - denser planning of base station grid
    - high additional cost
  - deployment of advanced algorithms, such as interference coordination
    - capacity improvements achievable by much lower cost

• **Coordinated Fractional Frequency Reuse**
  - algorithm for distributed and dynamic interference coordination
  - low complexity scheme based on central coordinator
    - communication with central coordinator in intervals in the order of \( \geq 500 \text{ ms} \)
  - performance improvements of about 50% (compared to Reuse 3)
    - with respect to aggregate throughput (maintaining cell edge throughput)
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