Increasing Capacity of Cellular WiMAX Networks by Interference Coordination

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Outline

• 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)
Orthogonal Frequency Division Multiple Access

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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
- Major issue in OFDMA: inter-cellular interference
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  - standard solution: frequency reuse pattern
  - disadvantage: waste of precious frequency resources
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    disadvantage: waste of precious frequency resources
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Major issue in OFDMA: inter-cellular interference
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- optimization: Fractional Frequency Reuse (FFR)
- Usage of directional antennas to lower inter-cellular interference
  Additional coordination necessary interference coordination (IFCO)
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
Idea: Reduce interference by optimized and coordinated dynamic choice of reuse partition (semi static or dynamic)

interference coordination
• Base stations communicate relevant information to central coordinator
• Central coordinator assigns mobile terminals to resource partitions in a coordinated fashion
Coordination of Resource 3 Partitions

- **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 $m_{12}$

Cell border

Interference levels:
- $m_5$: -83 dBm
- $m_{10}$: -89 dBm
- $m_{12}$: -91 dBm
- $m_9$: -92 dBm
- $m_{42}$: -94 dBm
Creation of Interference Graph

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

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<tr>
<td>$m_{12}$</td>
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<tr>
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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

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Cell border

Mobile terminal $m_{12}$

Interference blocked by interference graph

Mobile terminal $m_5$

Interference level

Calculation of signal strength of interferers for a particular mobile terminal $m_j$
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
Assignment of Resource Partitions

- 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)
Mapping of colors to Resource Partitions

![Diagram showing mapping of colors to resource partitions]

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

Scenario

• 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
  ✶ corresponds to throughput of terminals close to cell edge
• Reuse 3 system achieves good **aggregate** performance and good **cell edge** performance
Throughput Performance

- Reuse 1 system achieves better aggregate performance but falls short with respect to cell edge performance.
• **Conventional Fractional Frequency Reuse, locally coordinated**
  - achieves great increase in aggregate performance
  - falls short with respect to cell edge performance
Throughput 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

- Increased signaling delays $T_{C,period}$ and $T_{C,delay}$
  - lead to graceful degradation of cell edge performance
  - have much less impact on aggregate performance (not shown here)
Big increase close to base stations
Good coverage at cell edge with coordinated FFR

$T_{C,\text{period}} = 2s, \quad T_{C,\text{delay}} = 1s$

$D_{S,o} = 0dB, \quad D_{S,i} = 20dB$
• **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 $\geq 500$ ms
  - performance improvements of about 50% (compared to Reuse 3)
    - with respect to aggregate throughput (maintaining cell edge throughput)
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