Interference in Femtocell Networks

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ELEN E6951 Wireless & Mobile Networking II
April 13th 2009
Overview

• **Wireless cellular networks**
  • Current challenges in cellular networks

• **Femtocell networks**
  • Network architecture
  • Technical aspects
  • Pros and cons in femtocell networks

• **Interference in femtocell networks**
  • Example: Interference in WiMAX femtocell networks
  • Challenges for interference cancellation/mitigation

• **Current solutions**
Wireless cellular networks (briefly…)

- Wireless access network made up of a number of cells
- Each cell served by a fixed transmitter (base station BS)
- Users usually access the network through a certain dedicated resource (carrier frequency, time-slot, code)
- Cells used to increase and improve coverage
- BSs connected to core network through Base Station Controllers (BSC)
- BSC perform Radio Resource Management operations such as access control, handover between cells, etc.
Wireless cellular networks (briefly...)

- Two “current” examples:
  - GSM (2G)
    - 900 and 1800MHz
    - FDMA(125 channels)/TDMA(8 time slots) and FDD
    - Enhancements (2.5G): GPRS, EDGE
  - UMTS (3G)
    - 1885–2025 MHz (uplink) and 2110–2200 MHz (downlink)
    - W-CDMA
- Widely deployed and used everywhere (each one of your cellphones)
Wireless cellular networks: current challenges

• New trends in cellular networks...
  • New “multimedia” services
    • Video streaming
    • Web 2.0 (MySpace, Facebook, Twitter…)
    • etc
  • Cellphones indispensable in everyday life
    • E-mail
    • Mobile Internet
    • Google maps to find that restaurant where I am supposed to be in 10 minutes
    • etc
• Demands for higher data rates and capacity!
• Wireless capacity has doubled every 30 months over the last 104 years [1]
• How to increase capacity?
  • 25x improvement from wider spectrum
  • 5x improvement by dividing the spectrum into smaller slices
  • 5x improvement by designing better modulation schemes
  • 1600x gain through reduced cell sizes and transmit distance

Macro-cell → Micro-cell → Pico-cell → …

Femtocell networks

- Network infrastructure for micro-ization of cellular networks is very expensive
- Solution → user deployed base stations (femtocells)
- Users purchase and install themselves a small low-power BS at their apartment/office
- About 46% of the mobile users will be covered
Femtocell networks: network architecture

- How does this work?
- Two-tier network
  - Femtocell APs overlaying on top of the macrocell network
  - Hierarchical cell structure
  - Location of the FCs is “unknown” to the network operator
  - FCs connect to the core network through an IP backhaul (local broadband access: DSL, cable, etc)
Femtocell networks: technical aspects

- Femtocell AP:
  - Low transmitted power
  - Low range
  - Indoors
  - IP backhaul connection to the core network through the broadband access the user already has at home
  - Target cost 100$
    - To ensure widely deployment (users have to buy it)
    - Much simpler than a “regular” cellular BS
    - Not synchronized with the rest of the network
  - Average of 2 to 4 users per FC
  - Already being manufactured by some vendors
    - 32 million FC base stations expected to be deployed by 2012 [1]

## Femtocell networks: technical aspects

### Specifications

#### Standards/Compliance
- 3GPP Spec Version: 3GPP Release 8, 2005 & 6e
- 3G Radio Interface: UMTS WCDMA, 3G

#### User
- Maximum Number of Users: 20 users in idle mode
- Cell Radius: 15m - 25m in a typical in-building deployment scenario
- UE Speed: ≤ 0.6 mile/hour

#### Traffic Channels
- 2.4 Kbps and 15.6 Kbps
- 12.2 Kbps AAM voice, bidirectional (four users)
- 64 Kbps circuit-switched multimedia, bidirectional (four users)
- 64 Kbps packet switched data, bidirectional (four users)
- 64 Kbps downlink packet-switched data
- 64 Kbps uplink (four users)
- 40.96 Kbps downlink packet-switched data
- 128 Kbps uplink (two users)

#### HSUPA Channels
- Maximum Number of Codes: 10
- Supported UE categories: 1, 2, 5, 11, 12
- Peak Data Rate: 2.8 Mbps (upgradable to 7.2 Mbps)
- Maximum: 256 Kbps and 256 Kbps
- HSUPA Channels: Future support for HSUPA (optional feature delivered by software upgrade)

#### Radio Access Layer
- NAI (Non Access Stratum): DS, SGS, CC, GM, MAX, GM4M
- AS (Access Stratum): PDP, RNC, RLG, MAC
- Transport Channels: BCCH, PCH, RACH, PACCH, DCCH, HS-DSCH
- Physical Channels: DSCH, CCCH, PCCPCH, DPCCH, PICH, PRACH, OFDCH, HS-DSCH

#### Physical Layer
- Frequency Band: Band 1: 1900 MHz
- Transmit Power: 12 dBm Maximum
- Node B Performance: Compliant with 3GPP 25.141
- Requirements for Local Area Node B (excluding max. TX power)
- Dynamic Power Control: DC, DC and RF

#### Networking Layer
- Security: IPsec ESP/IVPv2 with NAT traversal, 3GPP-APN
- Protocols: IP, IP/6, ARP, ICMPv6/TOCP
- Voice Gateway: SIP, MGCP, TCP/UDP
- Core Network Interface: 3GPP 23.140 and 3GPP 24.140
- Rf/IMS compliant

#### Logical Interfaces
- Radio Network Interface: 3G UMA (variant), Iub (optional)

#### External Interfaces
- SIM Card: Push-insert, push-to-release type SIM card holder
- Number of Antennas: 1 (internal to the unit)

#### Environmental
- Operating Temperature: -20°C to 45°C (12°F to 113°F)
- Storage Temperature: -20°C to 70°C (-4°F to 158°F)
- Relative Humidity: 20% - 90% Non-Condensing
- External Power: 12 VDC (1000mA)
- Power: 12 VDC at 3.25A maximum from external power supply adapter (100 - 240VAC 60 - 60Hz)
- Acoustic Noise: <38 dB

#### Weight and Dimensions
- Weight: 0.8 lb (400g)
- Dimensions: 7.8 x 4.5 x 2.3 in (199 mm x 118 mm x 58 mm)
- Horizontal desktop placement or vertical standing

*All features, functionality, and product specifications are subject to change without notice or obligation.*
**Femtocell networks: pros and cons**

**Improvements:**
- Femtocells cover indoor area (50<R_FC<200 m) → high coverage and better signal reception for indoor users (better QoS)
- Indoor FC users transmit much less power → great savings in battery life
- Most indoor users connected through FCs → more “room” and capacity in the MC and better QoS in the MC.
  - In CDMA-based networks this is specially good because indoor users are the ones causing the highest amount of interference
- “Zero cost” to the network operator
- Network operator can offer cheaper services through the FCs

**New challenges:**
- FC BSs not synchronized → handoff MC↔FC?
- How will the backhaul provide acceptable QoS?
- Location tracking for emergency (911) phone calls?
- Open or closed access? (Can a pedestrian next to your building transmit through your FC if there’s no MC signal? Can this user do at least an emergency call through your FC?)
- Interference
- etc
Interference in femtocell networks

- Cross-tier interference!!!
- 3 extra degrees of complexity in the interference problem
  - MC user to FC BS (Figure 1)
  - FC user to MC BS (Figure 2)
  - FC to FC (Figure 3)
Interference in femtocell networks

- It gets even worse in a multi-cellular scenario... [2]

Example: interference in WiMAX femtocell networks

- What happens if FCs are deployed and nothing is done? [3]

<table>
<thead>
<tr>
<th>Coverage (%)</th>
<th>Large cell scenario</th>
<th>Sparse deployment</th>
<th>Dense deployment</th>
<th>Sparse deployment</th>
<th>Dense deployment</th>
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<tbody>
<tr>
<td></td>
<td>Public</td>
<td>Private</td>
<td>Public</td>
<td>Private</td>
<td>Public</td>
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<tr>
<td>Indoor</td>
<td>99.7992</td>
<td>99.7992</td>
<td>98.3728</td>
<td>93.787</td>
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<td>75.4035</td>
<td>75.2498</td>
<td>72.9183</td>
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<td>10 dBm</td>
<td>20 dBm</td>
<td></td>
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<tr>
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<tr>
<td>Indoor</td>
<td>100</td>
<td>99.0385</td>
<td>94.1568</td>
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<td>68.6395</td>
<td>67.2374</td>
<td>37.7432</td>
<td>69.4581</td>
</tr>
</tbody>
</table>

Table 1. Indoor/outdoor coverage in different simulation scenarios.

Interference very problematic for MC (outdoor) users in small cell (urban) scenarios, specially if FCs are “private”.

Current solutions

- Not much work done about interference in femtocell networks
- Work mostly focusing in 4G femtocells
  - OFDMA
  - WiMAX (WiBro in Korea)
- Distributed algorithms (FCs not synchronized with the rest of the network)
- Some analytical works
  - Channel models
  - Interference model
  - \( \rightarrow \) Per tier outage probability
  - \( \rightarrow \) Coverage

Current solutions

- All the proposed solutions use a spectrum division
  - Cross-tier interference $\rightarrow$ Interference avoidance strategy better than Interference suppression (in a randomly deployed femtocell network)
- Reserve a section of the available spectrum for the FCs and the rest for the MCs [4]
  - Femtocells only use a portion of the reserved spectrum
    - Randomly selected
    - Frequency-ALOHA (a number of femtocells “competing” for a shared medium)
  - Maximize Area Spectral Efficiency (ASE) [bps/Hz/m²] as a function of $\rho$ (ratio spectrum for FCs to total available spectrum)

Current solutions

- Problems with a spectrum division:
  - Femtocells are by definition indoors (apartment, offices, etc)
  - Estimated an average of 2 to 4 users per FC.
  - Users spend most of the time either at work or at home, plus some other time outdoors.
  - Subcarriers reserved for FCs are idle most of the time

  Waste of bandwidth!!!

- New ideas (final project)
  - Interference caused by a MC user depends on the tx power.
  - Tx power depends on the distance (path loss) to the BS
  - Classify users depending on distance (path loss)
  - Allocate frequencies according to the MC kind of user → cross-tier interference cancellation/mitigation
  - FC users only interfere with users within neighboring FCs
  - FCs are not synchronized with the rest of the network → distributed approach
  - Game theoretical approach for the frequency allocation in the FCs
  - Directive antennas
References


