ENHANCED DISTRIBUTED RESOURCE ALLOCATION AND INTERFERENCE MANAGEMENT IN LTE FEMTOCELL NETWORKS

Vanlin Sathya, Harsha Vardhan G, Hemanth N, Bala K and Bheemarjuna Reddy Tamma
Networked Wireless Systems Laboratory
Dept. of Computer Science and Engineering
Indian Institute of Technology (IIT) Hyderabad, India
Outline

✓ Motivation for LTE Femto Cells
✓ Interference Problems
✓ Existing solutions for Inter-cell Interference Management
✓ Proposed Solution: Variable Radius Algorithm
✓ Experimental Setup
✓ Performance Results
✓ Summary and Future Directions
**LTE Targets**

- Higher performance
  - 100 Mbit/s peak downlink, 50 Mbit/s peak uplink
  - 1G/s for LTE-Advanced
  - Better cell edge performance
  - Reduced latency (to 10 ms) for better user experience
  - Scalable bandwidth up to 20 MHz

- Backwards compatible
  - Works with GSM/EDGE/UMTS systems
  - Utilizes existing 2G and 3G spectrum and new spectrum
  - Supports handover and roaming to existing mobile networks

- Reduced capex/opex via simple architecture
  - Reuse of existing sites and multi-vendor sourcing

- Diverse requirements
  - TDD (unpaired) and FDD (paired) spectrum modes with reuse 1
  - Mobility up to 350 kmph
  - Variety of terminals (phones, tablets, PCs, cameras → IoT)
Trend 1

- In future video traffic will contribute to 70% of total cellular traffic.
- 20% of traffic will be because of mobile data.

So, BW demand is ever increasing.

Source: CISCO
Trend 2

Issues in indoors:

- Poor cellular coverage
- So, low data rates

Most of traffic is from Indoor users
How to address growing Indoor traffic demands?

Crowdsourcing approach:

- End-users install small base stations (a.k.a. Femto cell nodes) inside their homes/offices
- Femtos (a.k.a. Home eNodeBs/HeNBs) are connected to EPC via broadband Internet connection of users
- End-users traffic is diverted through Femtos when they are inside their homes/offices
- Typical range of Femto is 30 m for homes and 100 m for enterprise deployments
- A home Femto can serve up to 7 end-users whereas enterprise Femto can serve up to 40 end-users
- So, win-win situation for both mobile operator and end-users
Heterogeneous LTE Network

Small Cells:
- Femto Cells
- Pico Cells
- Relays
- Remoto Radio Heads

But, if all use same frequency, it leads to interference
1) With Macro BSs in the Architecture

2) Without Macro BSs in the Architecture
Cross-tier Interference Problem

Example of *cross-tier interference* between the macro cell and femto cells located inside it.

It is solved typically by allocated different spectrum for Macros and Femtos.
Co-tier Interference Problem

Example of co-tier interference among femto cells.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>UE</td>
<td>C</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

HeNB→ A, B, C

We propose a solution to address this co-tier interference problem among Femtos inside enterprise building in this work.
Effect of interference?

Good SINR $\rightarrow$ Good CQI $\rightarrow$ Higher Modulation Scheme $\rightarrow$ Higher Data Rate

Source: ONF
Radio Resource Allocation Schemes

- Two types of frequency reuse techniques to reduce co-tier interference among Macros/Femtos.
  - Fractional Frequency Reuse (FFR)
  - Soft Frequency Reuse (SFR)

Radio Resources:
- Base Station allocates BW as Resource Blocks (RBs) to UEs
- One RB: 12 Sub-carriers * 7 OFDM symbols
Fractional Frequency Reuse (FFR)

- Inner and Outer (cell-edge) regions in each cell.
- Low Tx power in Inner region compared to Outer region.
- Frequency reuse 1 for Inner region spectrum band.
- Frequency reuse 3 for Outer region spectrum band.

**Resource Allocation: (say @ F1)**

- UE in Inner Region: Any of free W0+W3 RBs at low power.
- UE in Outer Region: Any of free RBs from only W3 RBs at high power.

**Drawback of FFR:** Spectrum is not used efficiently in each cell.
**Soft Frequency Reuse (SFR)**

- Like FFR, logical Inner and Outer regions in each cell
- SFR has effective frequency reuse factor of 1 per cell
- Interference between neighboring cells is reduced.

**Resource Allocation: (say @ F1)**

- UE in Inner Region: Any of free $W=W_0+W_1+W_2$ RBs at low power
- UE in Outer Region: Any of free RBs in $W_2$ RBs at higher power
Drawbacks of SFR

- Spectrum is statically distributed in each of femto cells inner and outer regions
- Load distribution within femto cell is not taken into account during allocation of spectrum band to different femtos
- Not possible to allocate spectrum bands differently for different cells due to interference issues
- Compare to Macro BSs because of ad-hoc and dense deployments, Femtos suffer from more co-tier interference problem
- So, SFR has to be optimized further for Femto Nets by using 3GPP ICIC mechanism
Inter-cell Interference-Coordination (ICIC in 3GPP Release 8)

- Addresses co-tier interference problem among Macro BSs with frequency reuse 1 by using X2 interface
- BS talks over X2 with neighbors and allocates non-interfering subcarriers (RBs) to users in Outer region
- RB Allocation Scheme:
  - UE in Inner region: Any of free RBs like SFR discussed earlier → no restriction
  - UE in Outer region: Any of free RBs which are not being allocated by interfering cells for their Outer region UEs
- Theoretically, it is impossible for UEs at the edge of two neighboring BSs to use same RBs
- Observation: Only need to coordinate with other BSs while allocating RBs for UEs in the Outer region
**Issues with ICIC**

- **How is Inner/Outer region defined?**
  - Beyond scope of 3GPP ICIC mechanism
  - So, many solutions are encouraged!

- **Our Idea:** dynamic increase/decrease of Inner (Outer) region by taking into account **UE mobility, load variation, and interference from other Femto cells**
  - Decrease Inner region conservatively (wish to have only Inner region for unrestricted RB allocation and improved system throughput)
  - Increase Inner region aggressively
  - We look into the problem of when to increase/decrease Inner region in our work

- **In 3GPP Rel. 11, X2 interface is introduced between Femtos of enterprise Femto Nets in case of open access**
- **Later, eICIC mechanisms are proposed to further address interference problem**
PROPOSED SOLUTION
Femto cells with overlapping areas
Proposed Work: VR Algorithm

- Like in SFR/ICIC, in VR Algo for enterprise Femto cells,
  - Inner region: Reuse is One
  - But Outer region: Reuse may be more than one and depends on RBs usage in interfering Femto cells

- In order to increase system throughput, the inner (hence outer) region is varied dynamically

- RBs are not allocated statically for Inner/Outer regions, but shared dynamically

- Initially, Femto has only One region → Inner region with radius $r \leftarrow R$

- Cell edge UEs may get low SINR, so report low CQIs
VR Algorithm: Decreasing Inner region

- Average CQI at distance $d$ from the Femto center
  - Draw inner and outer circles with radius $(d-\delta)$ and $(d+\delta)$
  - Average out CQI values of UEs present in strip with $2\delta$ width
- At $d=R$, suppose condition average CQI $\geq CQI_{Threshold}$ fails
- Sort avg. CQIs in increasing order (decreasing $d$ values)
- Find largest $d$ (say $\gamma$) with its average CQI $> CQI_{Threshold}$
- New Inner region radius is
  $$r \leftarrow (r + \gamma) / 2$$
- So, decreasing Inner region conservatively
Example: Decreasing Inner region(s)

- **E-eNB**
- *: User
- Outer Region (----): High TX Power
- Inner Region (white): Low TX power
**VR Algorithm: Increasing Inner region**

- Define Fail Ratio (FR) of Outer region as 
  \[ FR = \frac{\text{Rejected Requests (RR)}}{\text{Accepted Requests (AR)}} \]
  where \( RR \leftarrow \text{Rejected UE Requests for RBs} \)
  \( AR \leftarrow \text{Accepted UE Requests for RBs} \)

- Due to mobility and load variations, FR may become greater than \( FR_{Threshold} \) for Outer region

- Check whether Inner region could be increased by \( \delta' \) by bringing in \( \frac{RR-AR}{2} \) UEs from Outer to Inner region \( \rightarrow \) living with interference among Femtos to increase FR

- If so, \( FR < FR_{Threshold} \) is satisfied

- New Inner region radius is 
  \( r \leftarrow r + \delta' \)
Example: Increasing Inner region(s)
Experimental Setup

- The NS-3 simulator is used

  ✓ Six apartment buildings, each containing a Femto BS deployed randomly.

- In real life, even static users will have some mobility, so set UE speed to 0.1m/s

- However, as we are not studying handovers in this work, we restricted the motion of each UE within a single room.
## Simulation Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Femto Cells</td>
<td>6</td>
</tr>
<tr>
<td>Number of UEs Per Femto</td>
<td>10, 15</td>
</tr>
<tr>
<td>UE Deployment</td>
<td>Random</td>
</tr>
<tr>
<td>Femto Coverage Range</td>
<td>70 m</td>
</tr>
<tr>
<td>Femto Bandwidth</td>
<td>5MHz (25 RBs)</td>
</tr>
<tr>
<td>Duplexing Mode</td>
<td>FDD</td>
</tr>
<tr>
<td>RB Allocation Algorithms</td>
<td>FFR, PF (Static ICIC), VR+PF</td>
</tr>
<tr>
<td>Simulated Traffic</td>
<td>Downlink (CBR Video)</td>
</tr>
<tr>
<td>Mobility of Mobile UEs</td>
<td>1m/s</td>
</tr>
<tr>
<td>Mobility of Static UEs</td>
<td>0.1m/s</td>
</tr>
<tr>
<td>Mobility Model</td>
<td>Building Mobility Model</td>
</tr>
<tr>
<td>Application Data Rate</td>
<td>4 Mbps</td>
</tr>
<tr>
<td>LTE Frame Duration</td>
<td>10 ms</td>
</tr>
<tr>
<td>Scheduling Interval (TTI)</td>
<td>1 ms</td>
</tr>
</tbody>
</table>
Positions of Six Femtos and 90 Users in Femto Net
SINR Heat Maps of Six Femtos in Femto Net
Average throughput for 90 static indoor users is increased by 29 % when VR algorithm is employed on top of PF scheduling.
Average throughput is increased by 37% when VR algorithm is employed on PF.

VR algorithm is good for mobile scenarios.
Area Spectrum Efficiency for 90 Static Flows

![Graph showing area spectrum efficiency for different femto IDs and techniques]
Area Spectrum Efficiency for 90 Mobile Flows

![Chart showing area spectrum efficiency for 90 mobile flows with different femto IDs and various performance metrics.]
Summary and Future Directions

- Proposed an efficient resource allocation algorithm by varying Inner (and hence Outer region) of Femtos dynamically
- Experimental results demonstrated superiority of proposed solution compared to existing solutions
- Studying energy efficiency of proposed solution
- Studying effect of traffic loads and communication delay over X2 interface on overall system throughput
- Applying proposed VR algorithm even for Macro BSs and studying performance in HetNets
- Extension to eICIC and so on ...
Acknowledgments

- This work was funded by the Deity, Govt. of India (Grant No. 13(6)/2010CC&BT)
- IIT Hyderabad
THANK YOU!

Feedback ?

tbr@iith.ac.in