Heterogeneous Networks
A new paradigm for increasing cellular capacity

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Wireless data traffic is increasing exponentially

Source: Informa Telecoms & Media
Revenue growth is slowing.

Source: T-Mobile
Radio Link Improvement is Slowing, What is Next?

Topology will provide gains beyond technology

IS-95 vs. AMPS

LTE versus HSPA+ & EV-DO

Focus needs to be spectral efficiency/area/cost
Terminology

- **Macro** – conventional base stations that use dedicated backhaul and open to public access. *Typical transmit power ~43 dBm; antenna gain ~12-15 dBi.*

- **Pico** – low power base stations that use dedicated backhaul connections and open to public access. Typical transmit power range from ~ 23 dBm-30 dBm, 0-5 dBi antenna gain;

- **Femto** – consumer-deployable base stations that utilize consumer’s broadband connection as backhaul; femto base stations may have restricted association. *Typical transmit power < 23dBm.*

- **Relays**– base stations using the same spectrum as backhaul and access. *Similar power as Pico’s.*

- **Heterogeneous Network**: A deployment that supports macros, picos, femtos and relays in the same spectrum.

- **UE = User Equipment**
Macro-centric Planned Network Expansions Are Complex And Iterative

- **Network topologies change with time**
  - Varying traffic demand and RF environment
- **Cell splitting needed to maintain uniform user experience by overcoming capacity and link budget limitations.**
- **Indoor coverage very challenging**
- **Site acquisition is difficult**
Deployment Model Vision: Heterogeneous Networks

- **Target coverage with Macro base stations for initial deployments**
- **Pico/Femto and Relay stations added for incremental capacity growth, richer user experience and in-building coverage**
- **Pico, Femto and Relay base stations can offer flexible site acquisition with low power base stations**
- **Relays & Femtos provide coverage extension and capacity with little to no incremental backhaul expense**

Heterogeneous networks create significant challenges in interference management. Overcoming these challenges is the focus of this talk.
Macro-Pico base station Coexistence Creates Challenging RF Environment

- More “cell-edge” created by Pico base stations within macro coverage
- In conventional cellular systems (e.g: 3G, LTE) UE associates with a base station with best DL SINR
  - UE with larger Macro SINR may have lower path loss to pico base stations thus causing significant UL interference at the lower power base stations.
  - Pico/femto cell coverage is limited (significantly) in the presence of macro coverage.
Home Femtos with Restricted Association Leads To Complex Co-channel Deployments

- Unplanned deployments of home femtos with restricted association creates significant interference scenarios
  - DL of macro UE can be jammed due to close proximity to femto
  - UL transmissions from macro UE can severely impede femto
  - Severe interference may exist between femto’s and their UEs
Relays Create Additional Interference Challenges

- Relays create extra “cell-edge” similar to a Pico base station
- Multiple relay nodes can have different duplexing schedules which create interference.
Relay and Femto’s Support Non-traditional Backhaul Connections

- **Handoff decisions need to take backhaul availability into consideration**
- **Relays use over-the-air (OTA) link to Macro base stations as backhaul connection**
  - Need to take OTA backhaul into considerations when choosing between relay access and direct access
  - Direct access to macro by UEs in relay coverage may cause significant interference with relay base station
- **Femto uses customer’s broadband connections for backhaul**
  - Femto’s need to support non-carrier-grade backhaul in terms of outage and bandwidth
Some techniques for enhancing performance with heterogeneous networks

- *Range Extension using Intelligent Association Algorithms*

- *Dynamic resource reservation/load balancing across base stations.*
Range Extension using Intelligent Association

- **Range extension can be used to expand coverage area for low-power base station**
  - UE association is determined by minimal path loss
- **Intelligent association achieves better spectrum efficiency and network capacity**
  - Lower interference per bit to the network on both DL and UL
  - Achieve better spatial reuse efficiency similar to cell splitting
    - Multiple Pico/Femto nodes can simultaneously use the resource vacated by the macro base station
  - Lower traffic load on macro base station
- **Enabling techniques**
  - Deep penetration synchronization signals
  - Deep penetration control channels
  - Adaptive Resource Reservation
Distributed Adaptive Resource Partitioning Algorithm

- **Resource partitioning should adapt to network loading, backhaul availability, topology, SINR conditions at UE/base station, mobility, QoS, traffic patterns, etc.**
- **Distributed, adaptive resource partitioning schemes are essential to manage interference and optimize throughput performance in heterogeneous networks**
  - The nodes in the network negotiate their resource reservation by sending messages to each other
  - The resource request/grant messages can be sent over backhaul connections or OTA
- **Slowly adaptive resource negotiation algorithm**
  - Based on node load status and feedback from active UEs
  - Works in a longer time scale (hundreds of msec)
  - Partitioning can be applied to both control resources and traffic resources
- **Dynamically adaptive resource negotiation algorithm**
  - Further improves the user experience with bursty traffic
  - Resources can be temporarily loaned between nodes
  - Requires OTA signaling
Simulation Scenario: Hierarchical cells, Macro-Pico co-existence

Picos are randomly dropped within macro coverage.
Mixed Macro and Pico/Relay Deployment

- Evaluation methodology proposed for LTE-A in R1-084026
- 10 MHz FDD spectrum
- 2x2 MIMO
- 19 cell wrap around, 500m site-to-site distance
- 1 macro base station per cell
- UE density: 25 UEs in each macro cell
- 10 Pico/Relay per macro cell unless specified otherwise
  - Uniform layout: UEs and Pico/Relays randomly dropped within macro cell
  - Hotspot layout: 80% UEs are placed within 28.9 meters from corresponding Pico/Relay nodes
- Pathloss model
  - Macro to UE: 128 + 37.6*logD
  - Macro to Relay: 124.5 + 37.6*logD
  - Relay to UE: 140.7 + 36.7*logD
- Building penetration loss 20 dB
- Log-normal shadowing and TU3 fading channel modelled
- Noise figure at UE: 10 dB
- Noise figure at base station: 5 dB
- Full Buffer Traffic Model with EGOS scheduler
- Throughput shown reflects respective overhead

<table>
<thead>
<tr>
<th></th>
<th>Macro eNB</th>
<th>Pico / Relay</th>
<th>UE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum PA Power (dBm)</td>
<td>46</td>
<td>30</td>
<td>23</td>
</tr>
<tr>
<td>Antenna Gain (dB)</td>
<td>16</td>
<td>5</td>
<td>-1</td>
</tr>
<tr>
<td>Connector Loss (dB)</td>
<td>2</td>
<td>0</td>
<td>0</td>
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Range Extension Brings the Network Closer to UEs

- **Compared to LTE Rel-8 association, range extension reduces the propagation pathloss from base station to UEs**
- **Smaller pathloss lowers interference per bit to the network**

Pathloss excluding eNB transmission antenna gains
10 picos, 25 UEs, uniform random layout
Based on proposed LTE-A evaluation methodology in R1-084026
Range Extension Allows More UEs to Benefit Directly from Low-power base stations

- **With default association method in LTE Rel 8, only a small fraction of UEs are served by Pico nodes**
- **Range extension enables more equitable distribution of air resource to each UE**

<table>
<thead>
<tr>
<th>Percentage of UEs associated with Picos</th>
<th>Uniform layout</th>
<th>Hotspot layout</th>
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<tbody>
<tr>
<td>Rel 8 Association</td>
<td>1.3%</td>
<td>28%</td>
</tr>
<tr>
<td>Range Extension</td>
<td>24%</td>
<td>65%</td>
</tr>
<tr>
<td></td>
<td>40%</td>
<td>6.2%</td>
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<td></td>
<td>65%</td>
<td>28%</td>
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*Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, 2x2 MIMO, 25 UEs, uniform random or hotspot layout*
DL Performance

改善通过共道异构部署使用LTE Rel-8集中在少数用户。

较小数量的Picos与提出的Techniques相比相对同频道部署使用10 Picos/Macro在边缘到中位数。

<table>
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<tr>
<th>Pico density</th>
<th>Gain of cell edge data rates</th>
<th>Gain of median users rates</th>
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<tr>
<td>10 Picos / Macro</td>
<td>82 %</td>
<td>183 %</td>
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根据提出的LTE-A评估方法学在R1-084026
10 MHz FDD, 2x2 MIMO UE, uniform random layout
Picos and UEs randomly dropped in Macro cell
UL Performance

A small fraction of users benefit from co-channel heterogeneous deployment using LTE Rel-8 at expense of other users.

Smaller numbers of Picos with proposed techniques outperform Rel-8 co-channel deployment using 10 Picos/Macro at 10% to median.

UL user data rates with resource partitioning compared to LTE Rel-8 co-channel deployment of Macro + 10 Picos

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<tr>
<td>10 Picos / Macro</td>
<td>160 %</td>
<td>406 %</td>
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Resource partitioning for this simulation is fixed throughout the network.

Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, uniform random layout, single TX antenna UE
Picos and UEs randomly dropped in Macro cell
Macro + Relay Deployment

- **Decode and Forward Relay**
  - Behaves like a MS on the backhaul link with directional patch antenna (Shown below)
  - Behaves like an BS on the access link with backhaul limitation

Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, 2x2 MIMO UE, Relays using 2 Rx donor antennas, uniform layout
DL partitioning between access/direct link and relay backhaul is 8:2
Relay Performance

Gains in DL User Data Rate Compared to Macro-only LTE

Based on proposed LTE-A evaluation methodology in R1-084026
10 MHz FDD, 2x2 MIMO UE, Relays using 2 Rx donor antennas, uniform layout
DL partitioning between access/direct link and relay backhaul is 8:2
Conclusion

- There is a need for substantial increase in cellular capacity.
- Radio link improvements alone cannot meet the traffic requirements.
- Focus should be on increasing cell density cost effectively using heterogenous networks.
- Optimizing heterogeneous network performance requires a rethinking of the cellular design paradigm.
- Techniques such as range extension and adaptive resource partitioning promise substantial gains in capacity.

- Interference management for heterogeneous networks is a promising area for wireless research.
Thank You