Evolution in Mobile Radio Networks
Multiple Antenna Systems & Flexible Networks

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The thirst for mobile data will continue to grow exponentially

- 3D, high- and ultra-high definition screens
- Video integrated everywhere
- Digital universe continues to grow exponentially
- Everything from and on the cloud
- Billions of connected objects
Content

- Multiple antennas
- Network architecture
- Liquid Net for mass events
Multiple Antennas

- Antenna configurations
- Antenna vs. antenna port
- Multiple receiving antennas
- MIMO & multiuser MIMO
- Beam forming
- Hybrid beam forming
Antenna Configurations

**Base station antennas**
- Omni-directional
- Directional (≈λ/2)
  - vertical: tilt, adaptive
  - horizontal: sector, beam forming
- Diversity
  - Orthogonal polarization
  - Spacing segments (≥λ)

**Terminal antennas**
- Single omni-directional antenna
- Two cross-polarized antennas

2 TX pipes
2x2 MIMO

4 TX Pipes
4x2 MIMO / 4x4 MIMO

8 TX Pipes
Beamforming
Antenna vs. Antenna Port

Example

Antenna port
- Each port bears its own pilot
- Data are mapped to port according pre-coding rules

TX pipe
- Several antenna segments can be connected by a common TX pipe

Antenna
- HF signal of TX pipes is transmitted on air

Terminal 'sees' logical antenna ports, not physical antennas
Multiple Receiving Antennas
CIR & SINR as Measure for Radio Quality

Carrier to Interference Ratio: Measured at RX antenna

\[
\text{CIR} = \frac{\text{carrier power at RX antenna}}{\text{interference power at RX antenna}}
\]

- No mutual dependency of RX antennas
- Impact from TX diversity

Signal to Noise and Interference Ratio: Measured at equalizer output

\[
\text{SINR} = \frac{\text{signal power at equalizer output}}{\text{interference + noise power at equalizer output}}
\]

- RX combining gain
- Impact from TX diversity
Multiple Receiving Antennas

Power of received signal (coherent): \[ P_S = |w_1 \cdot r_1 + w_2 \cdot r_2|^2 \approx |s + s|^2 = 4|s|^2 \]

Power of noise & interference (incoherent): \[ P_I = |w_1 \cdot i_1 + w_2 \cdot i_2|^2 \approx |i_1|^2 + |i_2|^2 \approx 2|i_1|^2 \]
Multiple Receiving Antennas
Equalizing at Single Receiving Antenna

OFDM : Operation per PRB
- Narrow band signal
- Operation in frequency domain
→ Weight is complex scalar

Restoring TX symbol
- Phase alignment: $w \sim h^*$
- Unbiasing: $|w| = 1/|h|$
Multiple Receiving Antennas Combined Equalizing

Maximum Ratio Combining
- Equalizing 'per antenna' : $h_i^*/(i_i^i*^)$
- Adding of equalized signals

Interference Rejection Combining
- Combined equalizing
- Constraint : maximize SINR

TX symbol

$w_1$

$w_2$

$\text{combining & unbiasing}$

$\text{IRC : } P_{\text{carrier}}$
$\text{IRC : } P_{\text{interference}}$
$\text{MRC : } P_{\text{carrier}}$
$\text{MRC : } P_{\text{interference}}$

$\begin{align*}
\text{Combining } & = w_1^*h_1 + w_2^*h_2 \\
& = (w_1^*h_1 + w_2^*i_2)^* + (w_1^*i_1 + w_2^*i_2)^* \\
= & w_1^*(h_1 + i_2^*i_1) + w_2^*(h_2 + i_1^*i_2) \\
\text{Unbiasing } & = w_1^*(h_1 + i_2^*i_1) \\
\end{align*}$
Multiple Receiving Antennas
IRC LTE FDD 4RX – Post Equalizer Powers

- MRC shows higher carrier power than IRC
- MRC shows much higher interference power than IRC
Multiple Receiving Antennas
IRC LTE FDD 4RX – CIR and SINR

- CIR of MRC and IRC aligned (measured at antenna, i.e., before equalizer)
- SINR much better for IRC compared to MRC (measured at equalizer output)
MIMO & Multiuser MIMO

Singleuser MIMO (e.g. DL)
- Diversity by spatial antenna separation or polarization
- Maximum number of data streams limited by number of TX and RX antennas
- Multiple streams differ in RX signal strength which limits the maximum achievable data rate
- Closed loop: Antenna phase factor information is signalled by UE

Multiuser MIMO (e.g. UL)
- Transmission of single streams to different UEs
- UE selection such as to assign the strongest stream to each of them
- High data rates possible on both streams
Beam Forming

Multiple TX antennas
- RX signal strength depends on phase differences of incoming signals
- Optimization of phase difference for single terminal already on TX side
  - Requires good channel knowledge for each TX to RX antenna path
  - Applied only for TDD systems (same physical channel for UL and DL)
- Multiple terminals can be served in parallel with different beams

Uniform linear array, 6 elements, 0.5λ spacing, antenna pattern in dB
Hybrid Beam Forming

Short term weights $w$ for mapping code words to data layers.

Long term weights $u$ for beam forming.

Example

- 4 X-Pol segments, i.e., 8 antennas at all
- Polarization $\rightarrow$ MIMO
- Spatial diversity $\rightarrow$ beam forming
- Effective weights: \((\text{short term weights}) \times (\text{long term weights})\)
  $\rightarrow$ MIMO & BF : hybrid
Network Architecture

- Co-ordinated Multipoint (CoMP)
- Distributed Antennas
- Supercell
- Heterogeneous Networks (HetNet)
- Carrier Aggregation
Co-ordinated Multipoint (CoMP) Step 1: Co-Sited

Logical separation of antenna point from cell
- More cell antennas w/o new antenna locations
- Low technical effort, at least in uplink (MRC / IRC)

Requirement:
- Remote radio head (RRH)
- Fast data connection to all Antenna Points (AP)

eNodeB w/o CoMP

<table>
<thead>
<tr>
<th>Cell 0</th>
<th>RX 0</th>
<th>RX 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP 0</td>
<td>Ant 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ant 1</td>
</tr>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ant 1</td>
</tr>
<tr>
<td>Cell 2</td>
<td>RX 0</td>
<td>RX 1</td>
</tr>
<tr>
<td>AP 2</td>
<td>Ant 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ant 1</td>
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</tbody>
</table>

eNodeB with CoMP

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<td></td>
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CoMP Simulation Results for UL Inter-Site CoMP

- Each cell has 2 own antennas
- Each cell has access to antenna points of the 2 co-located cells
- At maximum 4 antennas are used for combining (MRC)
Co-ordinated Multipoint (CoMP)
Step 2: Inter-Site CoMP

**Intra-site CoMP**
- eNodeB located at antenna points
- Sharing antenna points of cells hosted in same eNodeB
- Interface within eNodeB

**Inter-site CoMP**
- Many remote antenna points
- All accessible in each cell
- Fast data connection to all Antenna Points (AP)
- Interface within eNodeB

*source: 3GPP TR 36.819 V11.1.0 (2011-12)*
Distributed Antenna Systems (DAS)

- Hosting multiple wireless operators and technologies
- DAS infrastructure provided by venue
- Operators attach their RF Head antenna ports to the DAS node

Example: Stadium with 12 cells each with six antennas

High Carrier to Interference Ratio (CIR) indicates antenna locations

Supercell

- Installation of additional cells
  - Coverage holes
  - Insertion of additional cells
  - Increase capacity
  - Decrease cell size
- Cell fragmentation
  - High number of hand-overs
  - High inter-cell interference
- Combining different cells to one logical supercell
Heterogeneous Networks (HetNet)

- Challenge: Traffic hot spot within an existing network
- Solution: Placing small cells inside the network
- Applicable: Office buildings, railway stations, parking area, shopping centre

- High interference because of overlapping cells within the same frequency band
- Interference management
  - Interference Rejection Combining (IRC)
  - Enhanced Inter-Cell Interference Coordination (eICIC)
  - …
Heterogenous Networks Simulation Results

- Average cell throughput decreases (no simple scaling with # of cells)
- Total cell throughput increases (more cells)

Downlink

- Total cell throughput
- Average cell throughput
Carrier Aggregation

Smart phones cause bursty traffic:
- Big variation of required radio resources
  - Over time
  - Between cells
  - Between frequency layers

At any time significant unused resources while other parts are in overload.

Aggregation of multiple carriers
- Diversity gain from scheduling on best carrier(s)
- Pooling & load balancing
  - Increased throughput
  - Decreased delay

Liquid Net for Mass Events

- Traffic Profiles at Mass Events
- Liquid Net Measures
Traffic Profiles at Mass Events

Typical challenges at mass events:
- Large number of people using smart phones to share pictures
- This creates traffic profiles that differ from typical ones:
  - Higher uplink traffic
  - More frequent packet transmission

Examples:
- Huge sports event in UK: >25GB of data per hour
- Korean fireworks festival: >150GB of data per hour
- 6-day Hajj pilgrimage: >100TB

Liquid Net Measures

- Appropriate parameterization
  - Cell parameters
  - Control channels
  - Signalling
- Increasing number of cells
  - Overlapping of cells increases interference
  - Careful cell planning recommended
- Usage of active antennas for flexible beam steering, e.g., vertical sectorization
- Distributed Antenna Systems
- Smart Wi-Fi Capacity

Conclusion

- High smart phone penetration
- Completely new user behaviour
  - High data traffic with small packages
  - High upload traffic at mass events
- There is not a single technical solution.
- A bundle of technical possibilities available

Intelligent & flexible application of all these solutions makes the radio network running.
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