Long Term Evolution - 4G Wireless Communications

Teck Hu

Wireless Core Technology
Outline

Introduction to 3G and 4G
- 3GPP Standardization Process

Wireless Challenges and LTE
- Review of Wireless Communications
- Technologies in LTE

LTE-Advanced
- Objectives & Requirements
- Overview of LTE-Advanced

Beyond LTE Advanced
Introduction to 3G and 4G

Approximate timeline:

“Second Generation”

“Third Generation”

“Fourth Generation”

3GPP

GSM GPRS  EDGE

TD-SCDMA (China)  UMTS  HSDPA  HSUPA  HSPA+

Release 99  4  5  6  7  8  9  10  11 ...

3GPP2

3GPP2

IS-95  CDMA 2000  CDMA EVDO  CDMA EVDO Rev A  CDMA EVDO Rev B

Tight interworking

IEEE

TDMA/FDMA  CDMA  OFDM

802.16 2004 “fixed WiMAX”  802.16 e “mobile WiMAX”  802.16 m
Key Trends in 3GPP Standardization

Two parallel activities ongoing in 3GPP:

- **UMTS Wideband CDMA (WCDMA) Evolution**
  - Retaining competitiveness in a 5MHz bandwidth
  - Release 99 = “3G”
  - Releases 5 to 8 = “3.5G”

- **Long-Term Evolution (LTE)**
  - Technology revolution: new air interface + network architecture
    - “3.99G”?
  - LTE-Advanced
    - 4G at last?
Evolving Radio Interface Technology

• Cellular Developments:
  – HSPA+
  – Long-Term Evolution
  – LTE-A
LTE Timeline

Inauguration Workshop November 2004
Requirements were finalised 3rd June 2005
Outline concept-descriptions agreed 21st June 2005
Multiple-Access Schemes (UL and DL) chosen in Dec 2005
Study phase closed in Sept 2006
  - Evaluation of key techniques for LTE complete
Detailed specification work began in Oct 2006
First Release of LTE Specifications is Release 8.
  - Specifications virtually complete at end of 2008
First deployment December 2009
A new system, developed in parallel with WCDMA evolution
  - A revolution in the Radio Access Network
  - A stepping-stone to a “4G” air interface
  - Enables Operators to restructure their networks in preparation for 4G
3GPP: 3rd Generation Partnership Project

- Formed in 1999 and is collaboration of many Standards bodies;
  http://www.3gpp.org
The Role of Standards

- Interoperability
- Facilitates control of access to spectrum
- Economies of scale
- Transcends national boundaries
- Generates new markets
- Low barrier to entry promotes competition

Disadvantages

- Potentially slow
- IPR issues
LTE Targets

100Mbps downlink / 50Mbps uplink
- But strong pressure from some Operators for:
  - Uniform service provision
  - Improved cell-edge performance

2 to 4 times the spectral efficiency (bits/s per Hz) of UMTS Rel-6

Reduced delays
- IP layer one-way packet latency as low of 5ms

Flexible use of spectrum allocations
- Up to 20MHz bandwidth
- Scalable bandwidth
  - e.g. 1.4MHz, 3MHz, 5MHz, 10MHz, 15MHz, 20MHz
- New spectrum allocations will be required (e.g. in 2.5 - 3GHz region)
- All terminals to support at least 20MHz bandwidth (receive and transmit)
- Early deployments likely to be around 2.6GHz (Europe) and 700MHz (USA)
  - Also reuse of existing UMTS and GSM spectrum

Strong pressure for common design for operation in paired and unpaired spectrum
Application Trends for LTE

The following are enabled by 3.5G, and greatly enhanced by LTE:

- Growth in Packet Data traffic
  - E-mail, Web-browsing, Photos and Videos, Interactive gaming
- Voice moving to packet-switching: VoIP
  - Reduced costs for Operators

Broadcast services

- Business case not yet established
- DVB-H already available in some terminals
- But few cellular Operators own spectrum for DVB-H
- Hence interest in cellular broadcast
  - MBMS (Multimedia Broadcast / Multicast Service)
  - Quality may be lower than DVB-H, but cheaper for Operators and enables Operators to retain control
  - Not in first release of LTE
Wireless Challenges and LTE
Fundamentals of Wireless Communications

Shannon Channel Capacity (AWGN, noise limited channel)

- \[ C = BW \cdot \log_2(1 + \frac{S}{N}) \]

- Rewriting with link bandwidth utilization \( \mu = \frac{\text{Data rates}}{\text{Bandwidth}} \):

\[ \frac{E_b}{N_o} \geq \min\left(\frac{E_b}{N_o}\right) = \frac{2^\mu - 1}{\mu} \]

- For efficient use of SNR, the transmission bandwidth should be at least the same order as the Data Rates

- At low SNR, capacity grows proportional with SNR. At high SNR, capacity grows logarithmically with SNR
Fundamentals of Wireless Communications (cont)

Graph 1: Minimum Required Eb/No vs Bandwidth Utilization

Graph 2: Normalized Capacity (C/BW) vs SNR (dB)

- Bandwidth Limited
- Power Limited
Operating Regions and Trade-Offs

- If required SNR is available, any data rate can be in theory be achieved.
- Any increase in Data Rate will require at least the same relative increase in SNR. Two regions can be viewed: power limited and bandwidth limited.

- Power Limited Region
  - E.g. Mobile at Cell edge or when low bandwidth utilization
  - Solution: Increase the received power: Beamforming technique, reduced cell size, Receive Combining

- Bandwidth Limited Region
  - E.g. Mobile close to BS or in Small Cell
  - Any increase of bandwidth will reduce the required SNR for a certain data rate
  - Solution: Improved the spectral efficiency of the technique: reduced the required Eb/No per bit/s: Spatial multiplexing, Diversity
Challenges for LTE

- Peak rates and Peak Spectral Efficiency
- Cell Throughput and Spectral Efficiency
- Voice Capacity
- Mobility and Cell Ranges
- Broadcast Mode Performance
- User Plane Latency
- Control Plane Latency and Capacity
- Spectrum Allocation and Duplex Modes
- Terminal Cost and Complexity
- Network Architecture Requirements
## LTE Key Performance Requirements Targets

<table>
<thead>
<tr>
<th></th>
<th>DL</th>
<th>Absolute Requirement</th>
<th>Release 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Transmission rate</td>
<td>&gt; 100 Mbps</td>
<td></td>
<td>14.4 Mbps</td>
</tr>
<tr>
<td>Peak Efficiency</td>
<td>&gt; 5 bps/Hz</td>
<td></td>
<td>3 bps/Hz</td>
</tr>
<tr>
<td>Average Cell Spectral Efficiency</td>
<td>&gt; 1.6-2.1 bps/Hz/cell</td>
<td></td>
<td>0.53</td>
</tr>
<tr>
<td>Cell Edge Spectral Efficiency</td>
<td>&gt; 0.04-0.06 bps/Hz/user</td>
<td></td>
<td>0.02</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>UL</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Transmission rate</td>
<td>&gt; 50 Mbps</td>
<td></td>
<td>11 Mbps</td>
</tr>
<tr>
<td>Peak Efficiency</td>
<td>&gt; 2.5 bps/Hz</td>
<td></td>
<td>2 bps/Hz</td>
</tr>
<tr>
<td>Average Cell Spectral Efficiency</td>
<td>&gt; 0.66-1.0 bps/Hz/cell</td>
<td></td>
<td>0.33</td>
</tr>
<tr>
<td>Cell Edge Spectral Efficiency</td>
<td>&gt; 0.02-0.03 bps/Hz/cell</td>
<td></td>
<td>0.01</td>
</tr>
</tbody>
</table>
Main Technologies in LTE - 1

- **Multicarrier Technology**
  - Spectral Efficiency Consideration and Higher Peak Rates
  - DL: OFDMA vs. Multiple WCDMA
  - UL: SC-FDMA vs. OFDMA vs. Multiple WCDMA
  - Benefits
    - Flexible in spectrum usage
    - Frequency domain user scheduling, in addition to time domain scheduling
    - Fractional FR and Interference Coordination
    - Robust to frequency selective channels and friendly to broadcast networks

- **Multiple Antenna Technology**
  - Spatial Multiplexing Gains, Array Gains and Diversity Gains
  - Gains scales with minimum of number of antennas at receiver and transmitter, but in suitable radio propagation environments
Main Technologies in LTE - 2

- Packet Switched Technology
  - It is a complete packet-oriented multi-service system
  - Fast Channel State feedback
  - Dynamic Link Adaptation
  - Scheduling exploiting multi-user diversity
  - Fast Retransmission Protocol i.e. HARQ
  - With LTE
    - Adaptive Scheduling in both frequency and spatial dimensions
    - Adaptation of MIMO configuration including selection the number of spatial layers
    - Several modes of fast channel state reporting
LTE Features Overview - 1

- **Downlink OFDMA**
  - Flexible channel-dependent multi-user resource allocation in time-and-frequency

- **Uplink SC-FDMA**
  - Intra-Cell orthogonality and reduced PAPR; Uplink SRS facilitates uplink scheduling and uplink orthogonal demod Reference Signals supports MU-MIMO

- **Interference Management (Frequency ReUse 1 system)**
  - Cell Reference Signal (CRS) with cell-specific frequency offset
  - PHICH and PCFICH with cell-specific frequency offset
  - Interference Coordination between base stations in both DL (RNTP) and UL (HII and OI)
  - Fractional Power Control in UL together with Frequency domain (RB) resource allocation

- **Semi-Persistent Scheduling**
LTE Features Overview - 2

- Downlink Spatial Multiplexing and Diversity
- Uplink Multi-User MIMO
- Multi-User and Adaptive Retransmission
  - Short frame duration (1ms) for low HARQ RTT
LTE Multiple Access Schemes: Combination of OFDMA and TDMA

LTE uses a combination of OFDMA and Time Division Multiple Access (TDMA)

- Resources are partitioned between users in the time-frequency plane
Orthogonal Frequency Division Multiplexing (OFDM)

- Gives high data-rate of broadband transmission, with low receiver complexity of narrow-band transmissions.
- High-rate data stream is serial-to-parallel converted and modulated onto $N$ subcarriers of different frequencies.
- Results in $N$ parallel symbols of duration $N$-times the original symbol duration.
  - Makes symbol duration longer than the channel delay spread.
Frequency-domain orthogonality

The $N$ sub-carriers are orthogonal in the frequency domain:

• This enables the receiver to compensate the channel gain for each sub-carrier independently:

Adapted from material by Andrea Ancora
Cyclic prefix to avoid inter-symbol interference

Inter-symbol interference (due to the channel delay spread) can be contained within a short *guard interval* at the start of each symbol

In OFDM, the guard interval is a *cyclic prefix*

- A replica of the last samples is inserted at the beginning of each symbol.
Low-complexity implementation

Inverse Fourier Transform converts from modulated sub-carriers to time-domain transmitted signal

Fourier Transform carries out the receive operation

Low complexity if \( N \) is a power of 2

- Fast Fourier Transform has complexity proportional to \( N \log_2 N \)
OFDM dimensioning in LTE

- Normal sub-carrier spacing is 15kHz
  - Constant regardless of bandwidth
  - 2 cyclic prefix lengths
    - Short (5µs) for small cells
    - Long (17µs) for large cells and broadcast
- 7.5kHz sub-carrier spacing for dedicated MBMS carriers (33µs CP)
  (not in Release 8)

LTE slot: 0.5 ms
15360 samples
(Sampling frequency $f_s = 30.72$ MHz)

Normal CP
$\Delta f = 15$ KHz

Extended CP
$\Delta f = 15$ KHz

Extended CP
$\Delta f = 7.5$ KHz

Adapted from material by Andrea Ancora
OFDM Advantages and Disadvantages

Advantages

- Low complexity equalization, $O(N \cdot \log_2 N)$, compared to CDMA case, $O(N^2)$, with same performance.
- Transmitter and receiver architecture easily scale with system bandwidth, i.e. by increase of FFT order.
- Robust against narrow-band co-channel interference, i.e. suppressing only some sub-channels.
- Robust against inter-symbol interference (ISI) and channel selectivity due by multi-path propagation.
- High spectral efficiency, as almost the whole available frequency band can be utilized.
- Efficient implementation using FFT, i.e. numerically stable and supporting digital processing. Low sensitivity to time synchronization errors.

Disadvantages

- Sensitive to Doppler & frequency synchronization problems.
- High peak-to-average-power ratio (PAPR), requiring high dynamic linear transmitter circuitry suffering from poor power efficiency.
MIMO Techniques and Modes in LTE

Three types of gain from multiple antennas

- Diversity gain
- Array/Beamforming gain
- Spatial Multiplexing gain

- Multiple antenna techniques
  - Single-user MIMO (SU-MIMO)
  - Multi-user MIMO (MU-MIMO)
  - Co-operative multi-point transmission (CoMP)
Multiple Antenna Gains (1) Diversity

- Receive diversity or transmit diversity

- Improves robustness against multipath fading
  - Channel gain needs to be decorrelated between the antennas
    - i.e. sufficient spatial separation

- Transmit diversity typically uses orthogonal transmissions from the transmit antennas
  
  - Switched Antenna Transmit Diversity (SATD)
    - Can be open-loop or closed-loop
    - Supported in LTE uplink

  - Alamouti-type schemes:
    - Open-loop
    - Space-Frequency Block Codes (SFBC)
      - Supported in LTE downlink
Receive diversity

- Improves the statistics of the received SINR

- Signals from the receive antennas are weighted and combined

\[
SNR = \frac{(E(|h_1|^2) + \ldots + E(|h_N|^2))\sigma_s^2}{\sigma_n^2} = N \frac{E(|h|^2)}{\sigma_n^2} \sigma_s^2
\]

- Typically by Maximal Ratio Combining (MRC)
  - Each received signal is co-phased and weighted by its received SINR
  - Multiply by the complex conjugate of the channel gain
  - Maximises the received SNR

- Other combining weights may aim at minimizing interference - *interference nulling*
Space Frequency Block Code (SFBC)

Space-Time Block Codes use different symbols in the time domain instead of different subcarriers in the frequency domain:
Alamouti-type codes (continued)

- Orthogonal codes with full diversity only exist for 2 transmit antennas
- For 4 transmit antennas, LTE uses a combination of SFBC and Frequency-Switched Transmit Diversity (FSTD)
  - 2 SFBC schemes mapped to different pairs of sub-carriers:

\[
\begin{bmatrix}
    s_1 & s_2 & 0 & 0 \\
    0 & 0 & s_3 & s_4 \\
    -s_2^* & s_1^* & 0 & 0 \\
    0 & 0 & -s_4^* & s_3^*
\end{bmatrix}
\]
Array gain

- Concentrates energy in one or more given directions
- At the transmitter, precoding is used to *beamform* the transmitted signal
  - Constructive superposition in the desired direction
- Typically relies on feedback from the receiver to adapt the precoding weights
  - Can also be used to minimise interference
    - Destructive superposition in the undesired direction
MIMO - Spatial Multiplexing

With Multiple antenna at the receiver and transmitter, one option is to use it as Receive and Transmit Beamforming

- With $N_R$ and $N_T$, in ideal radio propagation, you have $N_R \times N_T$ array or beamforming gain.

- But, data rate starts to saturate and inefficient use of spectrum (spectral efficiency is low)

Instead, possible to create $N_L = \min(N_R, N_T)$ parallel channel each with $N_L$ lower SNR with Capacity/channel:

$$C = BW \cdot \log_2 \left(1 + \frac{N_R}{N_L} \frac{S}{N} \right)$$

$$C = N_L \cdot \log_2 \left(1 + \frac{N_R}{N_L} \frac{S}{N} \right) \approx \min(N_T, N_R)$$
Spatial Multiplexing gain

- Transmission of multiple signal streams to one or more users using multiple spatial layers created by combinations of the available antennas
- Simplest scheme transmits a different signal from each antenna

\[
\begin{align*}
\begin{bmatrix}
  h_{11} \\
  h_{12} \\
  h_{21} \\
  h_{22}
\end{bmatrix}
\begin{bmatrix}
  t_1 \\
  t_2
\end{bmatrix}
&=
\begin{bmatrix}
  r_1 \\
  r_2
\end{bmatrix}
\end{align*}
\]

Receiver inverts channel matrix \( H \) to recover transmitted signals:

\[
H^{-1}H\begin{bmatrix}
  t_1 \\
  t_2
\end{bmatrix}
= H^{-1}\begin{bmatrix}
  r_1 \\
  r_2
\end{bmatrix}
\]
MIMO - Spatial Multiplexing (cont)

A max of $N_T$ different signals that can be transmitted with a receiver capable of suppressing a maximum of $N_R - 1$ interference:

- Capacity proportional to minimum of number of Transmit and Receive antennas

Considerations:

- Low SNR region where it is power limited: already proportional increase in data rate with SNR

- Very sensitive to channel matrix invertibility and the closer the channel matrix to singular matrix, the larger the increase in noise e.g. multipath channel with close to identical independent distribution is good but not line of sight channel.

- Spatial multiplexing order in realistic channel $< N_L$, a function of the properties of the $N_R \times N_T$ channel matrix
  - If $N_L$ is less then combined beamforming and spatial multiplexing can be used: preCorder based spatial multiplexing
Spatial multiplexing - 2

- More advanced schemes use beamforming + spatial multiplexing
- Each data stream is transmitted from a combination of the available antennas

- Relies on there being multiple directions via which the signal can reach the receiver
MU-MIMO (cont)

- Advanced schemes may use a combination of beamforming and interference nulling:
SU-MIMO vs. Multi-user MIMO

SU-MIMO
Multi-stream transmission to a single user to maximise user throughput

MU-MIMO
Multi-stream transmission to multiple users to maximise cell throughput
Feedback Signalling for MIMO

- **PMI (Precoding Matrix Indicator)**
  - Indicates the UE’s preferred precoding matrix
  - Selected from a finite “codebook” of precoding matrices
  - Each precoding matrix corresponds to a set of beams

- **CQI (Channel Quality Indicator)**
  - Indicates the supportable rate (Modulation and Coding Scheme - MCS) corresponding to the PMI

- **RI (Rank Indicator)**
  - Indicates the number of spatial layers supported by the channel (rank of the channel matrix)
Progression of MIMO schemes

- SINGLE CELL SISO
- SINGLE CELL SIMO/MISO
- SINGLE CELL SU MIMO
- SINGLE CELL MU MIMO
- MU MIMO WITH INTER CELL INTERFERENCE
- COOPERATIVE MULTICELL MU MIMO
LTE Release 8 Performance - Downlink, SU-MIMO

- **Case 1**
- **Case 3**

### Antenna Configuration: 2x2
- Case 1: 3.2, 3.5, 2.7
- Case 3: 3.3, 3.6, 2.8

### Antenna Configuration: 4x2
- Case 1: 4.4, 4.6
- Case 3: 4.8

### Antenna Configuration: 4x4
- Case 1: 5.0, 5.0
- Case 3: 5.0, 5.0

Gains over HSDPA (x)
LTE Release 8 Performance - Uplink, Rel-8 SIMO

Antenna Configuration

Gains over HSUPA (x)

Case 1  Case 3
1x2  2.2  2.2
1x4  3.3  3.3

Antenna Configuration

Gains over HSUPA (x)

Case 1  Case 3
1x2  2.5  2.0
1x4  5.5  4.2
LTE Advanced (LTE-A)
LTE-Advanced Motivations and Objectives

Peak data rate
- 1 Gbps data rate achieved by 4x4 MIMO and transmission bandwidth wider than approximately 70 MHz

Peak spectrum efficiency
- DL: Rel. 8 LTE satisfies IMT-Advanced requirement
- UL: Need to double from Release 8 to satisfy IMT-Advanced requirement
Performance Requirements

Peak data rate
- 1 Gbps data rate achieved by 4x4 MIMO and transmission bandwidth wider than approximately 70 MHz

Peak spectrum efficiency
- DL: Rel. 8 LTE satisfies IMT-Advanced requirement
- UL: Need to double from Release 8 to satisfy IMT-Advanced requirement

<table>
<thead>
<tr>
<th></th>
<th>Rel. 8 LTE</th>
<th>LTE-Advanced</th>
<th>IMT-Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak data rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL</td>
<td>300 Mbps</td>
<td>1 Gbps</td>
<td>1 Gbps(*)</td>
</tr>
<tr>
<td>UL</td>
<td>75 Mbps</td>
<td>500 Mbps</td>
<td></td>
</tr>
<tr>
<td>Peak spectrum efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>[bps/Hz]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DL</td>
<td>15</td>
<td>30.6</td>
<td>15</td>
</tr>
<tr>
<td>UL</td>
<td>3.75</td>
<td>16.8</td>
<td>6.75</td>
</tr>
</tbody>
</table>
Performance Requirements (Cont’d)

Capacity and cell-edge user throughput

- Targets for LTE-Advanced were set considering gain of 1.4 to 1.6 from Release 8 LTE performance

<table>
<thead>
<tr>
<th>Ant. Config.</th>
<th>Rel. 8 LTE</th>
<th>LTE-Advanced</th>
<th>IMT-Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL 2-by-2</td>
<td>1.69</td>
<td>2.4</td>
<td>–</td>
</tr>
<tr>
<td>DL 4-by-2</td>
<td>1.87</td>
<td>x1.4-1.6</td>
<td>2.6</td>
</tr>
<tr>
<td>DL 4-by-4</td>
<td>2.67</td>
<td>3.7</td>
<td>2.2</td>
</tr>
<tr>
<td>UL 1-by-2</td>
<td>0.74</td>
<td>1.2</td>
<td>–</td>
</tr>
<tr>
<td>UL 2-by-4</td>
<td>–</td>
<td>2.0</td>
<td>1.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ant. Config.</th>
<th>Rel. 8 LTE</th>
<th>LTE-Advanced</th>
<th>IMT-Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL 2-by-2</td>
<td>0.05</td>
<td>0.07</td>
<td>–</td>
</tr>
<tr>
<td>DL 4-by-2</td>
<td>0.06</td>
<td>0.09</td>
<td>0.06</td>
</tr>
<tr>
<td>DL 4-by-4</td>
<td>0.08</td>
<td>0.12</td>
<td>–</td>
</tr>
<tr>
<td>UL 1-by-2</td>
<td>0.024</td>
<td>0.04</td>
<td>–</td>
</tr>
<tr>
<td>UL 2-by-4</td>
<td>–</td>
<td>0.07</td>
<td>0.03</td>
</tr>
</tbody>
</table>
LTE-A Features Overview

Carrier Aggregation
- To support greater bit rates through larger & fragmented spectrum;
  Transmission bandwidth up to 100MHz

Heterogeneous Networks
- Use of multiple layer Networks and Range Expansion

Enhanced Downlink Multiple Antenna Transmissions
- Spectral Eff: 15 bits/s/Hz: from 4 to 8 layers for SU-MIMO

Enhanced Uplink Multiple Antenna Transmissions
- Spectral Eff: 15 bits/s/Hz: from 1 to 4 layers for SU-MIMO

Cooperative Multipoint Transmissions
Carrier Aggregation

- **Motivations:**
  - Satisfy requirements for peak data rate
    - Multiple Component Carriers (CCs) up to 100 MHz
  - Spectrum aggregation
    - Enables diverse spectrum assignments to be exploited jointly
    - Both contiguous and non-contiguous aggregation supported
  - Support heterogeneous network deployment
    - Cross-carrier scheduling for control channel interference management
- **Each CC is backward compatible with Rel-8 LTE**
  - Low complexity
  - Supports legacy terminals
Heterogeneous Networks (HetNet)

Heterogeneous Networks with low power RRH (CoMP Scenario 3)/Pico Cell
Heterogeneous Networks with low power RRH of same cell ID as Macro Cell (CoMP Scenario 4)/
Range Expansion - Pico UE SINR

Configuration 4b with 4 picocells

CDF

SINR (dB)

0 dB CRE bias
6 dB CRE bias
12 dB CRE bias
18 dB CRE bias
Hot-Spot vs. Uniform Traffic (ref: R4-112411)

57 Macro Cells, 2 Picos per Macro Cell, BIAS15dB, RX2 VPOL, TX4 VPOL, 2…5 ABS

- Spectral Efficiency [bit/s/Hz/cell]
- Cell Border Throughput [kbit/s]

Legend:
- no ABS, overall
- no ABS, macro
- no ABS, pico
- ABS, overall
- ABS, macro
- ABS, pico
DL Interference Scenario

Without RE, both UE A & UE B would be served by MeNB due to higher Tx power from MeNB

With RE, both UE A & UE B is now being served by Pico eNB eventhough it received stronger signal from MeNB

- Hence its DL SINR is lowered but PeNB coverage is increased
UL Interference Scenario

Without RE, UE A uplink transmission would interfere with the UE-B to Pico eNB transmission

- With RE, UE A would be served by Pico eNB
- With RE, UE-B UL SINR is improved!

With RE, UE B is now being served by Pico eNB eventhough it is far from Pico eNB. Hence its interference to MeNB is now higher
Relay

- **Objective:** Supports deployment of cells in areas where wired backhaul is not available or very expensive - *Coverage Extension*

- **In Homogeneous deployments, it may have the following challenges:**
  - Severe propagation loss due to higher frequency bands
  - Poor cell edge coverage
  - Potential coverage hole

- **In a Macro-Relay deployments:**
  - Decode and forward scheme
  - Break a low quality link into multiple better links
  - Enhance the throughput of cell edge users
  - Extend cell range & Longer battery life
Type 1 In-Band Relay

- Relay node (RN) creates a separate cell distinct from the donor cell
  - UE receives/transmits control signals for scheduling and HARQ from/to RN
  - RN appears as a Rel-8 LTE eNB to Rel-8 LTE UEs
- Transmission from eNB to Relay and Relay to UE are separated in time. This is achieved through MBSFN subframes configuration for the UEs.
  - In MBSFN subframes, no actual MBSFN transmissions take place to the UE
  - Instead, these subframes are used by the Un link to send data from eNB to RN
- Restrictions on the sub-frames that can be configured as MBSFN
Beyond LTE-Advanced

Mobile Data rates expected to double annually & ARPU is to be flat & Spectrum will be capped at some point. So..

- Spectral Efficiency and Cost Efficiency
- Advanced Signal Processing
- Offloading
- Denser Heterogeneous Networks

Options?

- Higher bits/s/Hz: Network MIMO, CoMP...
- Offloading: to WiFi, Device to Device, Cognitive Radio..
Coordinated MultiPoint (CoMP) Transmission and Reception

Also known as Cooperative MIMO

- Goal is improve User experience, especially Cell-Edge Users

- Downlink CoMP
  - Information exchange protocols between eNBs
  - Feedback (CSI) enhancements: Multicell Channel State Feedback from the UE

- Uplink CoMP
  - Mostly realizable in current Network implementation
  - Receiver Processing and Backhaul Coordination
Cooperative MultiPoint Transmissions (CoMP)

- **Joint processing (JP)**
  - Joint transmission (JT): PDSCH is transmitted from multiple cells with precoding using DM-RS among coordinated cells;
  - Data is available at each point in CoMP cooperating set and data transmission occurs from one or multiple transmission points.
  - Network MIMO: simultaneous transmissions of data packets to one or more UEs from multiple cells with co-phasing

- **Coordinated scheduling/beamforming (CS/CB)**
  - PDSCH transmitted only from 1 cell; scheduling/beamforming is coordinated among cells
  - e.g. Opportunistic beamforming

![Diagram showing joint transmission and coordinated scheduling/beamforming](image-url)
CoMP Scenarios

Scenario 1: Homogeneous network with intra-site CoMP

Scenario 2: Homogeneous network with high Tx pwr “RRHs”

Scenario 3: Heterogeneous network with low power “RRHs”

Scenario 4: Low-power “RRHs” within Macrocell coverage
Performance Gains of CoMP and Hetnet

- CoMP CB S4
- CoMP CB S3
- HetNet with 6dB bias and optimized UE scheduling
- HetNet with 6dB bias and 1 ABS
- HetNet with 6dB bias and 3 ABS
- HetNet with 0 bias and no ABS
- Macro only

Graph showing cell edge user spectral efficiency (bps/s/Hz/user) vs. cell average user spectral efficiency (bps/s/Hz/user).
References & Further Reading

- www.3GPP.org