LTE-Advanced research in 3GPP

GIGA seminar ’08
4.12.2008
Tommi Koivisto
tommi.koivisto@nokia.com
Outline

• Background and LTE-Advanced schedule

• LTE-Advanced requirements set by 3GPP

• Technologies under investigation for fulfilling the LTE-Advanced requirements:
  • System bandwidth extension beyond 20 MHz
  • Uplink multiple access scheme
  • Uplink MIMO
  • New features for LTE-Advanced downlink
  • Cooperative MIMO
  • Relays

• Summary
Background – LTE

• 3GPP has almost finalized the LTE specifications (Release 8), and is now in the correction phase.

• LTE key features:
  • Utilizes OFDMA in downlink and DFT-S-OFDMA (aka SC-FDMA) in uplink.
  • Bandwidths ranging from 1.4 MHz up to 20 MHz.
  • Both TDD and FDD modes are supported.
  • Optimized for voice services and large cells, works even with very high mobility.
  • Channel-aware scheduling to take advantage of the multi-user diversity. Link adaptation for setting the modulation and coding scheme according to channel conditions.
  • Uplink power control for reducing interference.
  • Turbo coding utilized together with Hybrid ARQ retransmissions.
  • Up to 4x4 single-user MIMO support in downlink (no SU-MIMO support in uplink):
    • Open-loop spatial multiplexing, closed-loop precoded spatial multiplexing, rank-1 beamforming and transmit diversity supported.
    • Multi-user MIMO supported both in uplink and downlink.

• With these features, current LTE supports 100 Mbit/s data rates, with peak data rates reaching 300 Mbit/s.
Background – LTE-Advanced

• ITU-R has issued a Circular Letter to invite candidate Radio Interface Technologies for IMT-Advanced.

• In the circular letter, key features of IMT-Advanced are listed. From physical layer perspective, one important requirement is stated as: “enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research)”

• To enhance LTE features further to fulfill all IMT-Advanced requirements and hence become an IMT-Advanced technology, 3GPP has started a new Study Item on LTE-Advanced in March 2008.

• Currently, 3GPP RAN Working Group 1 is studying and evaluating the performance of the relevant technology components.
3GPP schedule vs. ITU-R schedule

3GPP early ITU-R submission approved.
Submit a complete technology proposal to ITU-R.
Study Item technical report approved in 3GPP. Submit final proposal to ITU-R, including performance evaluation.

<table>
<thead>
<tr>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>3GPP RAN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#38</td>
<td>#39</td>
<td>#40</td>
<td>#41</td>
<td>#42</td>
</tr>
<tr>
<td>WS</td>
<td>2nd WS</td>
<td>Work Item</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ITU-R WP5D

|  | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | #11 | #12 |

“Early proposal” submission.
“Complete technology” submission.
“Final” submission.
LTE-Advanced requirements

• 3GPP has already set its own requirements for LTE-Advanced.

• The main high-level requirements are
  • to meet/exceed IMT-Advanced capabilities
  • 3GPP operator requirements for the evolution of E-UTRA

• Backwards compatibility requirements:
  • A Release 8 E-UTRA terminal can work in an Advanced E-UTRAN,
  • an Advanced E-UTRA terminal can work in an Release 8 E-UTRAN and
  • non-backward compatible elements could be considered based on TSG RAN decision.

• => Any new features need to be considered as extensions to current LTE, i.e. not breaking the existing functionality!
  • This sets certain restrictions for introduction of new technologies.

See TR 36.913 for all requirements!
**Spectrum efficiency requirements**

- Peak spectrum efficiency targets are 30 bps/Hz for DL and 15 bps/Hz for UL, with MIMO configurations 8x8 and 4x4, respectively.

- Average spectrum efficiency:

<table>
<thead>
<tr>
<th>Case 1 (bps/Hz/cell)</th>
<th>LTE-Advanced target</th>
<th>Rel'8 LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1x2</td>
<td>1.2</td>
<td>0.79</td>
</tr>
<tr>
<td>2x4</td>
<td>2.0</td>
<td>NA</td>
</tr>
<tr>
<td><strong>DL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2x2</td>
<td>2.4</td>
<td>1.54</td>
</tr>
<tr>
<td>4x2</td>
<td>2.6</td>
<td>1.64</td>
</tr>
<tr>
<td>4x4</td>
<td>3.7</td>
<td>2.75</td>
</tr>
</tbody>
</table>

- Cell edge spectrum efficiency:
  - Note that cell edge and average spectrum efficiency targets are supposed to be achieved simultaneously!

<table>
<thead>
<tr>
<th>Case 1 (bps/Hz/cell)</th>
<th>LTE-Advanced target</th>
<th>Rel'8 LTE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1x2</td>
<td>0.04</td>
<td>0.033</td>
</tr>
<tr>
<td>2x4</td>
<td>0.07</td>
<td>NA</td>
</tr>
<tr>
<td><strong>DL</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2x2</td>
<td>0.07</td>
<td>0.058</td>
</tr>
<tr>
<td>4x2</td>
<td>0.09</td>
<td>0.060</td>
</tr>
<tr>
<td>4x4</td>
<td>0.12</td>
<td>0.099</td>
</tr>
</tbody>
</table>

**“Case 1” simulation scenario:**
- Macro-cell scenario
- Hexagonal grid of 19 eNBs, 3 sectors each (57 cells)
- Inter-site distance 500 m
- Carrier frequency 2 GHz
LTE-Advanced technologies
Bandwidth extension beyond 20 MHz

• To reach the high peak data rate targets of 1 Gbps in DL and 500 Mbps in UL, the bandwidth is being extended from the current max. 20 MHz up to 100 MHz.
  • Wider bandwidth also provides increased data rates for terminals in worse channel conditions.

• To meet the backwards compatibility requirements with Release 8 LTE, carrier aggregation is being considered as the method to extend the bandwidth.

• Here, we combine N Rel’8 bandwidth “chunks”, or component carriers, together to form N x LTE BW, for example 5 x 20 MHz = 100 MHz etc.

• LTE terminals receive/transmit on one component carrier, whereas LTE-Advanced terminals may receive/transmit on multiple component carriers simultaneously to reach the higher bandwidths.
  • Simple transmission/reception of extended bandwidth possible by a single IFFT/FFT pair.
Transmission chain for aggregated bandwidth

- Release 8 transmission chain consist of:
  - Segmentation of transport blocks obtained from higher layers (MAC) into code blocks.
  - Turbo coding of each code block, CRC attachment
  - Modulation (QPSK/16QAM/64QAM)
  - Layer mapping for transmit diversity / spatial multiplexing
  - Precoding, mapping onto physical resource blocks (subset of OFDM symbols and subcarriers)

- For extended bandwidth, this structure is simply copied for each component carrier:
  - Provides “automatically” frequency domain link adaptation on component carrier basis (not supported by LTE).
  - Better hybrid ARQ performance for wide bandwidth.

- The main research issues are related to efficient control signaling to support wider bandwidth.
Uplink multiple access schemes

- Release 8 LTE utilizes DFT-S-OFDMA (SC-FDMA) in uplink.
- Bandwidth extension alone means that uplink multiple access (UL MA) scheme needs to be revisited.
- The multiple access schemes being investigated are:
  - Clustered DFT-S-OFDMA
  - N x DFT-S-OFDMA
  - OFDMA
- Mainly following aspects are being evaluated:
  - Performance, especially with UL MIMO
  - Receiver complexity
  - Peak-to-average power ratio
  - System design flexibility
- Note: Rel’8 DFT-S-OFDMA will remain due to backwards compatibility requirement!
MIMO performance of OFDMA vs. DFT-S-OFDMA

• Since UL MIMO is also being introduced, the MIMO performance of OFDMA vs. DFT-S-OFDMA based schemes is currently being debated.

• It is well known that with MMSE receiver and certain antenna configurations, the MIMO performance of OFDMA is better than of DFT-S-OFDMA.
  • But with 2x4 the performance is very close to equal.

• However, MMSE is not considered a state-of-the-art receiver for modern base stations.
  • Better performance is obtained with turbo equalization.
  • E.g. MMSE combined with successive interference cancellation using turbo decoder soft outputs has been considered as a practical receiver.

• With state-of-the-art receivers, the MIMO performance differences of the studied UL MA schemes have been found negligible.
MIMO performance of OFDMA vs. DFT-S-OFDMA

• Another argument in favour of OFDMA is that it enables simple ML receivers.

• But, it turns out that with current and near future technology, ML receivers are still too complex even for OFDMA.

• And in fact, turbo equalization using soft outputs from turbo decoder actually outperforms symbol-level ML, also for OFDMA.

• So far no conclusion has been reached on the uplink multiple access scheme!
  • Agreement expected in January 3GPP RAN WG1 meeting.
UL MIMO for LTE-Advanced

- Uplink single-user MIMO is being introduced in order to increase the data rate and improve coverage.
  - UL SU-MIMO was considered already for Release 8 LTE, but compared to the added benefit, it was found too expensive for the terminals due to need of multiple power amplifiers.
  - Now, up to 4 TX antenna transmission will be specified for LTE-Advanced uplink.
- The same (type of) schemes will likely be supported as in downlink:
  - Transmit diversity
  - Closed-loop rank-1 phase beamforming and also precoded spatial multiplexing (frequency selective / non-selective)
  - Open-loop spatial multiplexing
  - Rank adaptation for best matching to the channel conditions

- Key research challenges for UL MIMO:
  - Design of TX diversity schemes with low PAPR for all channels (data/control).
    - The schemes should preserve the SC-FDMA signal characteristics and be compatible with the frame structure.
  - Efficient channel state / precoding information feedback versus signaling overhead, for closed-loop operation.
    - Here TDD may have a slight advantage over FDD due to channel reciprocity.
New features for LTE-Advanced downlink

- On link level, LTE Rel’8 downlink is already very close to the capacity (considering implementation margins). The bit rates can mainly be improved by extending the bandwidth.

\[ C = \max_{R} \log_2 \det \left( I_M + \frac{E_s}{MN_o} HRH^H \right) \]

- Precoding can not be optimized much further; power allocation optimization is possible however requires signaling of power offsets and on the other hand does not give much benefit.
- SINR is given by the operating conditions, but can be affected via system-level techniques.
- Receiver side technique are also already quite optimal: MMSE receiver combined with successive interference cancellation (SIC) is the baseline receiver for MIMO in 3GPP studies.
- Increasing the number of TX (RX) antennas is possible and being considered. However, in practical environments most MIMO gains seem to be already obtained with 4TX configuration.

- Hence, on link level, not many enhancements can be considered to give significant performance gain over LTE downlink!
  - Thus, for example no changes to channel coding are expected in LTE-Advanced.
  - Some single-cell DL MIMO enhancements are still being considered.
- **On system level the performance can possibly be improved** by inter-cell interference mitigating/coordinating techniques that enhance SINR conditions, cooperative MIMO, relays...
Multi-user MIMO enhancements

- Multi-user MIMO can provide spatial multi-user diversity and outperform single-user MIMO in terms of bps/Hz, if designed properly.

- Base station with UE channel state information may schedule multiple users on the same radio resources and use e.g. zero-forcing precoding or block-diagonalization to null out the inter-user interference.

- In Rel’8 LTE, MU-MIMO support is sub-optimal:
  - Precoding is based on the SU-MIMO codebook (no zero-forcing) and rank-1 SU-MIMO CQI report is used also for MU-MIMO.
  - UE does not know about the precoder of the interferer.
  - UE is unaware of the interference when reporting CQI measurement, hence reported CQI is too optimistic.

- Hence, in principle it is possible to enhance MU-MIMO in LTE-Advanced by e.g.
  - Better interference cancelling in the precoding (e.g. ZF) and/or
  - Signaling the interfering precoders so that the UEs can suppress residual interference using e.g. an LMMSE receiver.
  - Enhance CQI reporting such that interference is taken into account (UE needs to be interference-aware when measuring CQI).

- Key challenges in MU-MIMO design:
  - The interference can not be nulled out perfectly in practice – codebook and feedback design play a major role in this.
  - Terminals would need to be aware of the inter-user interference when reporting CQI – this seems difficult.

CQI = Channel Quality Indicator
PMI = Precoding Matrix Indicator

SU-MIMO
UN-Prec-5RB-MMSE
UN-Prec-FBW-MMSE
UN Prec 5RB MRC
UN-Prec-FBW-MRC

Average sector throughput [Mbps]

TX correlation

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

12 12.5 13 13.5 14 14.5 15 15.5 16

2x2, TU channel, 3GPP Case 1, 10 MHz BW, Rel’8 codebook, 20 UEs / sector.
Support of eight transmit antennas

• Release 8 supports four TX antennas and thus 4x4 MIMO.

• LTE-Advanced specification will support eight transmit antennas and 8x8 MIMO (!). The supported MIMO modes will follow Release 8 LTE:
  • Closed-loop spatial multiplexing operation is likely the main MIMO mode for 8 TX antenna usage – precoding gain is available also for more practical setups such as 8x2.
  • Open-loop spatial multiplexing will also be supported for simpler MIMO operation and for terminals with less accurate channel state information.
  • Transmit diversity saturates when going beyond four TX antennas – especially with real channel estimation the gains are close to zero.

• Key challenges with adding support for eight transmit antennas:
  • Accurate channel estimation for channel state information (CQI/PMI) reporting and demodulation purposes, with decent overhead. Release 8 4 TX reference signal overhead is already >14%!
  • Codebook design for closed-loop operation: Terminal needs to determine the preferred precoding matrix which requires tremendous amount of calculation and processing if the codebook is large (which it is with 8 TX antennas).
  • Power amplifier imbalances caused by Release 8 –compatible transmissions which need to be transmitted only from four TX antennas. => Antenna virtualization techniques to help.
Channel reciprocity for TDD DL MIMO

• Release 8 LTE supports SVD-based beamforming (rank-1 transmission) using channel reciprocity for obtaining the channel state information.
  • Since there is no codebook for this, **UE-specific** reference signals are required and supported for one stream.

• In LTE-Advanced, extension to rank>1 SVD-precoded transmissions will likely happen.
  • Here, we first estimate the channel covariance per each N PRBs (N>=1, total Nf subcarriers) as

\[ R = \frac{1}{N_f} \sum_{i=f_0}^{f_1} H^T(i)H^*(i) \]

  • Then, the optimal precoding matrix for rank-p transmission is obtained from the p eigenvectors corresponding to p largest eigenvalues of \( R \).

• Also multi-user MIMO using channel reciprocity is being evaluated.

• **Key challenges with channel reciprocity utilization:**
  • TX/RX RF mismatches destroy the channel reciprocity, hence good RF calibration is crucial for the performance.
  • CQI reporting is difficult since the UE will not know the precoder at the time of reporting.
  • Additional overhead from UE-specific reference signals – how to keep it low without degrading the demodulation performance too much?

\( SVD = \text{Singular Value Decomposition} \)
\( PRB = \text{Physical Resource Block} \)
Cooperative MIMO

- Co-channel interference limits the single-cell MIMO gains.
- To mitigate the interference, transmissions in multiple cells can be done cooperatively.
  - In addition, multiple users are scheduled on the same radio resources (“multi-cell multi-user MIMO”).

- In LTE-Advanced, a set of cells (under one or several base stations) cooperate together to improve the SINR perceived by the terminals.

- In downlink, e.g. cooperative zero-forcing beamforming or block diagonalization can be used to null the inter-user interference.

- Cooperation is also studied for uplink.
  - Multi-cell joint detection
  - MU-MIMO pairing / grouping over multiple cells
  - Interference cancellation
Cooperative MIMO – key research challenges

• Very strict requirements on the backhaul capacity and latency:
  • Downlink: both data and channel state information need to be available in all cooperating base stations.
  • Uplink: receiver soft outputs may need to be exchanged between the base stations.

• Multi-cell channel estimation is needed for channel state feedback purposes:
  • Arranging reference signals with tolerable overhead for channel estimation of large number of antennas seems extremely challenging.
  • Heavy channel estimation (and precoding calculation) capabilities required by the terminals, e.g. all antennas of up to 2-5 cells!

• Uplink resources for feedback transmission are very scarce.
  • Channel state feedback needs to be very limited in order to not to fill uplink capacity with control.
  • Especially with cell edge terminals (that may be power-limited) serious challenges are faced. Note that cell edge terminals are exactly the ones that are benefiting most from cooperation!

• Similar problems as with single-cell multi-user MIMO:
  • Since channel state information at base stations can never be perfect, CQI reporting becomes tricky as inter-user interference nulling can not be perfect.
    • If the inter-user interference is unknown, accurate CQI reporting is difficult?
    • Hence for good performance, (candidate?) interferer precoding weights may be needed already at CQI reporting phase?
Relays in LTE-Advanced

• In frequency reuse-1 networks, cell edge spectrum efficiency is very low compared to average spectrum efficiency
  • E.g. LTE DL 2x2: 0.058 bps/Hz for 5% cell edge, 1.54 bps/Hz average.
  • This is due to heavy co-channel interference at cell edge.

• Relays can be used for improving the SINR conditions at cell edge with low additional infrastructure cost.
  • Hence relays are being considered for LTE-Advanced as a tool to improve cell edge performance and fill coverage “holes”.

• Main research challenge may be to keep backwards compatibility.
Relays in LTE-Advanced

- In LTE-Advanced the main focus is on single-hop relays.
- Type of relay is still being discussed, but one main candidate is a L3 relay (“self-backhauling”):
  - Each relay looks like an independent cell, backhaul provided by an in-band connection to the serving base station.
Summary: LTE-Advanced technical concepts

- Bandwidth is being extended in order to provide both higher average and peak data rates.
  - Used bandwidth extension method provides automatic frequency domain link adaptation and RRM, thereby matching the transmissions better to the channel conditions.

- Uplink multiple access scheme is being refined to support extended bandwidth.
  - OFDMA is being studied mainly from UL MIMO performance point of view.

- Uplink MIMO will be introduced for increasing uplink spectrum efficiency further.

- Potential performance gain factors in LTE-Advanced downlink are
  - Multi-user MIMO enhancements => better utilization of spatial multi-user diversity.
  - SVD-based precoding in TDD => more precise utilization of channel state information at the transmitter.
  - Support of eight transmit antennas

- Cooperative MIMO techniques are being studied for overcoming co-channel interference effects.

- Relays are being introduced for improving cell edge SINR conditions and performance.

- **With these techniques, the target is to improve average cell spectral efficiency by 50% in both UL and DL!**
Further information

1. TR 36.814, “Further advancements for E-UTRA, physical layer aspects”, soon to be available at http://www.3gpp.org