Carrier Aggregation and MU-MIMO: outcomes from SAMURAI project

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Outline

- Motivation
- The SAMURAI project
- Overview on the investigated techniques
  - Multi-User MIMO
  - Carrier Aggregation
- Into the Real World
- Conclusion
Motivation

- Exponential increase in mobile data traffic
- LTE-Advanced promises downlink of 1Gbps low mobility and 100Mbps in high mobility conditions
- Practical implementations are still far from theoretical limit
The SAMURAI Project

- Spectrum Aggregation and Multi-User MIMO: ReAl-world Impact

- Two main research lines:
  - Increase in spectral efficiency: MU-MIMO
  - Spectrum exploitation: Carrier Aggregation (CA)

- Industrial feasibility as main goal:
  - MU-MIMO and CA PHY Proof-of-Concept (PoC)
  - Autonomous Component Carrier Selection (ACCS) PoC
MU-MIMO in LTE Systems

Interference-aware receiver is essential for robust MU-MIMO performance.

No practical MU-MIMO deployments yet!

Type and accuracy of feedback information are crucial for the reliability of MU-MIMO systems LTE systems.
MU-MIMO in LTE Systems

**LTE Release 8:**
- Transmission mode 5: fixed codebook precoding, *wideband PMI feedback*
- Limited codebook size: 4 for 2 TX antennas, 16 for 4 TX antennas
- One layer per user
- Large residual multi-user interference

**LTE Release 9&10:**
- Transmission modes 8 and 9: user-specific precoding using DM-RS
- Higher granularity feedback
- Flexible codebooks
- New DCI format supports transparent switching between SU and MU-MIMO (Rel10)

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Multi-user interference remains an issue -> need for advanced interference aware receiver design!

DM-RS = downlink demodulation reference symbol; DCI = downlink control information
SAMURAI Interference aware receiver

- Approximate max-log MAP receiver
- Based on matched filter outputs, no division operations
- Inherently exploits the structure of the interference instead of Gaussian assumption
- Applicable to single-antenna UEs as well
- Implemented in fixed-point C


Interference unaware receiver unreliable in MU-MIMO transmission.

With SAMURAI IA Receiver MU-MIMO works even for high modulation order!
Complexity Performance Trade-Off

SAMURAI IA Receiver: optimum MU-MIMO performance and low deployment costs!

poor performance-complexity trade-offs for conventional MF and Max Log MAP.
MU-MIMO CQI Feedback

- **Issue:** The same SU-MIMO feedback used for MU-MIMO -> low overhead but limits MU-MIMO gains

- **SAMURAI approach:** apply interference aware receiver, improve post-processing SINR and report accurate CQI -> multi-user interference considered in CQI calculation

To achieve high performance MU-MIMO feedback required!

SU-MIMO feedback limits MU-MIMO gains!

Only applicable in Rel.9&10 due to the user specific signaling (DMRS)
MU-MIMO proof of concept

- **Goal:** demonstrate the feasibility of MU-MIMO using advanced receiver techniques

- **Platform:** Eurecom OpenAirInterface
  - Software defined radio
  - Open-source implementation of LTE Rel. 8.6

UE: CBMIMO1 card with antennas

eNB: Express MIMO card with amplifiers and antennas
MU-MIMO proof of concept

- Use of LTE Rel. 8 transmission mode 5
- Use of feedback mode 1-2 instead of 3-1 for exploiting sub-band Precoding Matrix Indication (PMI) information
  - Sub-band CQI and wideband PMI not enough for exploiting the full potential of the designed receivers
- Use of custom Downlink Control Information (DCI)
  - Signals UE to use the precoder(s) according to subband PMI(s) indicated in the latest feedback report
- Use of SAMURAI Interference Aware Receiver
- Use of MU-MIMO scheduler that switches dynamically between MU-MIMO and SU-MIMO depending upon number of orthogonal subbands
MU-MIMO PoC: First Results

- **Link-level** performance comparison of TM 1, 5, and modified TM 5 with IA receiver on OpenAirInterface platform (software simulation)

![Graph showing BLER vs SNR for SCM-C channel, MCS 9 with NTX=2, NRX=1, 25 PRBs. The graph indicates a 5dB gain at 10% BLER with IA receiver.]

- NTX=2, NRX=1, 25 PRBs
MU-MIMO PoC: First Results

- **System-level** performance comparison of TM 2, 5, and modified TM 5 with IA receiver on OpenAirInterface platform (software simulation)

![Graph showing average system throughput for different scenarios](image)

**Fig 2. AVERAGE SYSTEM THROUGHPUT FOR DIFFERENT SCENARIOS**

With high number of users, the scheduler achieves the best case even with real channel conditions
MU-MIMO PoC: Ongoing work

- **Real-time** performance evaluation on Express MIMO boards and Agilent PXB channel emulator ongoing
**Carrier Aggregation**

- LTE Rel-10 allows aggregation of up to 5 20MHz component carriers (CC)
- Each CC appears as a Rel-8 serving cell to Rel-8 UEs
  - Synchronization and reference signals
  - System Information
  - Backwards compatible bandwidths

- Data aggregation in MAC layer
  - Separate HARQ processes and feedback
  - Individual transmission modes (modulation and coding)
CA Challenges

- Transceiver design challenge
  - 3GPP specifies >30 operating bands, 6 bandwidths, and up to 5 CCs
  - Contiguous vs. non-contiguous
  - Intra-band vs. inter-band
  - very high number of combinations need to be supported

- Network management challenge
  - How to exploit multiple carriers adaptively and autonomously in self organized networks
  - Load balancing and scheduling for multiple CCs
CA with OpenAirInterface

- Express MIMO with LIME RF frontend supports up to 4 CCs with up to 20MHz bandwidth
  - 300MHz-3.9GHz tuning range per CC
  - Inter- or intra-band
  - Contiguous and non-contiguous

- Already demonstrated 2 x 5 MHz CCs
CA on OAI: ongoing and future work

- Integration of RRC signaling
- Scheduling and load balancing for multiple CCs
- CA for Inter-cell interference coordination (ICIC)
  - Autonomous Component Carrier Selection in a network of home eNBs (femto cells)
  - Cross-carrier scheduling for ICIC in heterogeneous networks
Conclusions

- To exploit MU-MIMO gains in LTE and LTE-Advanced, we need
  - Interference aware receivers
  - Sub-band feedback
  - Adaptive scheduling

- Carrier aggregation is a big challenge
  - On the PHY level
  - On the network level

- OpenAirInterface experimental platform used to make our research more credible