AI for Massive MIMO
Cambridge Wireless Event

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Agenda:
• Fundamentals of Advanced Antenna Systems
• The Role of AI in Massive MIMO Evolution
What is Massive MIMO?
Sector antennas with many transmitters and receivers providing significant improvements over legacy RAN.

2T2R Passive Antenna (2G, 3G, 4G)

With fewer antennas the EM energy can only be radiated almost the same amount in all directions.

64T64R Massive MIMO (5G)

Larger antenna array allows shaping and directing EM energy towards the users (beamforming).

Source: BT
**LTE MIMO**

MIMO first appeared in 3GPP 4G LTE Rel-8 with subsequent enhancements appearing in later LTE-A releases.

**LTE Rel-8 MIMO**
- Support of downlink multi-antenna transmission schemes with up to 4 antenna ports.
- CS-RS required for multiple processes resulting in always-on design and very large overhead.
- Precoding operation based on codebook with users using the same CS-RS for MIMO.

**LTE-A Rel-9/10 MIMO**
- Uplink MIMO was introduced and number of ports was increased to 8 in the downlink.
- New reference signals CSI-RS (for CSI acquisition) & DM-RS (for UE-specific demodulation).
- Full flexibility at the eNB to perform downlink precoding including non-codebook-based.

**LTE-A Rel-11/12 MIMO**
- Support for CoMP allowing for transmission & reception from multiple distribution points (cells or RRHS) where the eNB can configure UE with multiple CSI-RS resources.
- The addition of QCL/TCI provide antenna deployment flexibility (centralised vs distributed).

Source: 3GPP
LTE FD-MIMO
Massive MIMO was introduced in 3GPP 4G LTE-A Rel-13/14 providing the means to design and deploy AAS.

LTE-A Rel-13/14 FD-MIMO
- Enhancements on the number of downlink CSI-RS ports (up to 32 for non-precoded and up to 8 for precoded).
- Precoding codebook enhancements in order to facilitate more accurate channel sounding.
- Active antenna systems (AAS) with 2D arrays allow for beamforming in both vertical and horizontal directions.
- These enhancements laid the groundwork for Massive MIMO operation specifications in 5G NR.

An illustrative example of AAS with 64 TXRUs each with two cross-polarised antenna elements allowing vertical & horizontal beamforming. There are different CSI-RS transmission and feedback strategies for channel sounding.
NR MIMO
Designed to improve sub-6 GHz performance, facilitate mmWave band operation & enable new verticals.

NR Rel-15 MIMO
• CS-RS dropped in favour of tailored beam-based and user-specific reference signals (CSI-RS, DMRS, PTRS, SRS).
• Support of two CSI types: Type 1 (smaller overhead for SU-MIMO) and Type II (finer granularity intended for MU-MIMO).

NR Rel-16 MIMO
• Improved features including overhead reduction of Type II CSI, M-TRP for non-ideal backhaul, M-TRP for URLLC, and multi-beam operation enhancements.

NR Rel-17 MIMO (ongoing)
• Further expanding NR-MIMO for V2X, NRU, >52.6 GHz, Power Savings, High Speed Train, Non-Terrestrial-Networks, etc.

Massive MIMO Evolution
• Multi-antenna panels, massive arrays (> 256 antennas), intelligent reflective surfaces, liquid antennas? AI will likely play a key role…

NR allows for multiple steerable analog beams per cell. Source: Keysight, 5G Testing: 3GPP Beam Management.

Massive MIMO in Practice
The significant theoretical vs practical performance difference underpins the need for technology innovation.

Figure description:
• Spectral efficiency (SE) is the data in bits per second that can be carried over 1 Hz of radio spectrum.
• The figures shows the SE performance of a single cell site under different number of antennas and signal processing (precoding) schemes.
• “DPC” achieves the theoretical capacity; “ZF” shows performance reminiscent of existing AAS; the two points capture certain trials and testbeds; SISO is the baseline single-antenna performance.

The gap between performance in theory versus practice highlights the need for more advanced signal processing algorithms and RF design. A key challenge in Massive MIMO optimisation is the inherent system complexity, which can be overcome by incorporating AI capabilities.
AI-based Radio Access Network
There are different RAN classes where AI can play a role.

Artificial Intelligence
- Machine Learning
- Deep Learning

Massive MIMO

RAN Management
- Non-Real-Time
  > seconds
  - Beam patterns
  - Physical resource blocks usage
  - Beam failure and recovery

RAN Operation
- Near-Real-Time
  50 ms – 1 s
  - Interference management
  - Traffic steering
  - Handover and cell-edge performance

RAN Air-Interface
- Real-Time
  50 µs – 20 ms
  - Modified scheduling
  - PHY signal processing & array design
  - Cellular association

Optimisation
Simplification
AI for Massive MIMO
AI algorithms and policies can help manage Massive MIMO complexity and to optimise performance.

- Precoding and Scheduling
- Channel Estimation and Detection
- Smart Interference Management & Handover
- Broadcast Beam Optimisation
- Spectrum Sensing & Anomaly Detection
- Energy Efficiency Optimisation
- Intelligent Reflective Surfaces
- Cell-less Massive MIMO

Applying advanced deep learning models on large over-the-air channel data sets can lead to significant Massive MIMO performance gains over classical ML and conventional signal processing/RF methods.
Open Massive MIMO
RAN disaggregation and openness provides the flexibility to implement AI-based solutions for Massive MIMO.

- PHY processes are in the O-DU and O- RU, controlled via open interfaces by the O-CU, Near-RT RIC, and Non-RT RIC.
- Massive MIMO could be deployed as a single O- RU under common O-DU (conventional Massive MIMO).
- Enabling platform for evolution towards distributed and cell-less Massive MIMO with multiple O-RUs under a common O-DU or O-CU.
- Configuration exchanges between elements provide the means to implement and combine AI algorithms and policies onto the Non-RT, near-RT and (integrated into DU stack) RT RICs.
- Opportunities in improving Massive MIMO coverage/capacity performance, energy efficiency, deployment and management cost, as well as enabling differentiated services should be targeted.
AIMM Project
Collaborative European project looking at the applications of AI for 5G NR Massive MIMO and beyond.

Title: AIMM (AI-enabled Massive MIMO)
Project Coordinator: Arman Shojaeifard (InterDigital)
Project Status: Running
Clusters: UK, Germany, France, Canada
Duration: 2 years
Start Date: Oct 2020
End Date: Sep 2022
Budget (total): 4,732 K€
Effort: 44.83 PY
# Partners: 12
# Work-Packages: 6
Project-ID: C2019/2-5
Website: https://www.celticnext.eu/project-aimm/
Twitter: @AIMM_project
InterDigital Areas of Focus
Developing wireless technology for Intelligent Holographic MIMO and Metasurfaces.

- AI-based PHY algorithms for Massive MIMO & Metasurfaces (AIMM)
- Intelligent Holographic MIMO transceivers (jointly with University of Southampton and Royal Academy of Engineering)
- Intelligent Radio Surfaces (jointly with 6GFLAGSHIP Finland)
- Standardization roadmapping for specification in future releases of 3GPP and next generations of WiFi
Thanks very much for listening!

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