5G Testbeds: Bristol & Lund MaMIMO Examples

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bristol.ac.uk/smart   bristol.ac.uk/engineering/research/csn/
Summary

• 5G Use Cases & Terminology
• New Radio (NR) KPIs
• NR Physical Layer:
  • Key attributes & Spectrum
• Sub-6GHz NR
  • Massive MIMO
  • Test-beds & Spectrum Efficiency
  • Mobility & Operational Imperfections
• Take Aways
5G Scenarios and Use Cases

Enhanced Mobile Broadband (eMBB)

• Data driven applications
• 2 billion people on social media

Goals:
• 10-20 Gbps peak
• 100 Mbps whenever needed
• 10000x more traffic
• Macro and small cells
• Support for high mobility (500 km/h)
• Network energy saving by 100 times
5G Scenarios and Use Cases

Enhanced Mobile Broadband (eMBB)
- Data driven applications
- 2 billion people on social media

Massive Machine Communication (mMTC)
- 30 billion “things” connected
- Low cost, low energy

Goals:
- High density (105 to 106 per km²)
- Long range
- Low data rate (1 - 100 kbps)
- M2M ultra low cost
- 10 years battery
- Asynchronous access
## 5G Scenarios and Use Cases

<table>
<thead>
<tr>
<th>Enhanced Mobile Broadband (eMBB)</th>
<th>Massive Machine Communication (mMTC)</th>
<th>Ultra Reliability and Low Latency (URLLC)</th>
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| ![Enhanced Mobile Broadband](image) | • Date Driven Applications  
• 2 billion people on social media | • Ultra responsive  
• <1 ms air interface latency  
• 5 ms E2E latency  
• Ultra reliable (99.9999%)  
• Low to medium data rates (50 kbps - 10 Mbps)  
• High speed mobility |
| ![Massive Machine Communication](image) | • 30 billion “things” connected  
• Low cost, low energy | ![Ultra Reliability and Low Latency](image) |

### eMBB
- Date Driven Applications
- 2 billion people on social media

### mMTC
- 30 billion “things” connected
- Low cost, low energy

### URLLC
- Ultra responsive
- <1 ms air interface latency
- 5 ms E2E latency
- Ultra reliable (99.9999%)
- Low to medium data rates (50 kbps - 10 Mbps)
- High speed mobility
5G – Networked Society

- **NR Specifications:**
  - 10Gbit/s Peak
  - 100Mbit/s, where ever needed
  - X100 – x1000 Capacity
  - X10 battery life
  - Reduced Latency (0.5ms)

- **5G Physical Layer Requires:**
  - Enhanced Spectrum Efficiency for sub-6GHz
  - Use of New Spectrum: Millimetre wave bands
Conventional Cellular Radio

- Multiple users share same time, frequency or code resources
Exploiting the Spatial Domain

- Accurate spatial multiplexing for multiple access
  - Same Radio Channel, Same time (slot)
  - Space Division Multiple Access (SDMA)
- Increased spectral efficiency and network capacity
Large Antenna Arrays: Massive MIMO

Basestation or Access Point

- > 50 (M) antennas serving a few (K) users (simultaneously)
- Simple Signal Processing, power and spectrum efficient
- Essential for sub-6GHz wireless connectivity
More than simple beamforming: Marzetta Massive MIMO

https://www.youtube.com/watch?v=hAXtMNzGs5U
LuMaMi – Lund University Massive MIMO testbed

- 100 coherent RF chains
- Flexible architecture based on NI platform and software radios
- Supports 10 (later extended to 12) simultaneous single antenna users in the same time-frequency resource block
- Real time operation in the 3.7 GHz band, 20 MHz bandwidth
- Taking Massive MIMO from the lab to reality for the first time.
Massive MIMO Frame Structure: TDD
First Real Time Results – Oct 2014 Uplink

Received signal constellations – LOS & four users 2 m separation

ZF detector

MRC detector

Received signal constellations – NLOS & four users within 15 cm radius

ZF detector

MRC detector
National Instruments Massive MIMO test-bed

- 128 Programmable Radio Heads
- 20MHz Bandwidth
- ‘LTE’ like interface
- 1.2 – 6.0GHz Carrier
  - 3.51GHz used
- 4 Racks of 32 Radios
  - Data consolidation
- Channel processing
  - 24 Clients
- Massive MIMO signal processing supporting
  - 12 clients
Bristol’s First System Deployment (March 2016)

- Client Separation 2.5 - 6 Wavelengths
- Equal Transmit Power
Spectrum Efficiency Results (10<sup>th</sup> March 2016):

- Eigen Structure
- Individual Spatial Stream Rx Magnitude
- Frequency Domain profiles
- Power Delay profiles

12 streams of 256 QAM!

http://www.bristol.ac.uk/news/2016/march/massive-mimo.html
Facebook & Massive MIMO (13th April 2016)

- ARIES (Antenna Radio Integration for Efficiency in Spectrum)
- Rural wireless Internet
- Specifications & Efficiency
  - 96 antenna element array
  - 24 users
  - 71 bits/s/Hz

2nd Deployment (Wed 11th May 2016)

22 users running 256 QAM in 20MHz Channel
Using same frame structure as before:
• 145.6 bits/s/Hz
• Sum rate of 2.916 Gbps

http://spectrum.ieee.org/tech-talk/com/wireless/5g-researchers-achieve-new-spectrum-efficiency-record
http://www.bris.ac.uk/2016/may/5g-wireless-spectrum-efficiency.html

128 element (32 x 4) dual polar patch array
Mobility Trials & Spatial Correlation

https://www.youtube.com/watch?v=Qp877-PAQSG
Mobility and Massive MIMO

Car 2 speed: 29 km/h  Pilot Symbol Capture Interval: 5ms


www.youtube.com/watch?v=wPPMrr4rHmo
Massive MIMO: Spectrum Efficiency Gains

- Aggressive Spatial Multiplexing gains are by means of ‘Pairwise Orthogonality’
Channel Hardening Effects & Pairwise Orthogonality

Accurate CSI

[Diagram of a network setup with multiple devices and a section showing a 3D graph]
Channel Hardening Effects & Pairwise Orthogonality

Accurate CSI +
Channel Hardening Effects & Pairwise Orthogonality

Inaccurate CSI +

OR

Accurate CSI +
Channel Hardening Effects & Pairwise Orthogonality

- Inaccurate CSI
- Accurate CSI

OR
Channel Hardening Effects & Pairwise Orthogonality

Inter-user Interference

Inaccurate CSI +

OR

Accurate CSI +
Massive MIMO: Spectrum Efficiency Gains

- Aggressive Spatial Multiplexing gains are by means of ‘Pairwise Orthogonality’
- Errors in Channel State Information (CSI), Reciprocity Calibration and hardware imperfections degrade the spatial orthogonality of massive MIMO systems as well as ‘Spatial Location of Users’.
- Grouping and scheduling users to:
  - Minimise impact of spatial stream interference
  - Dynamically optimise Quality of Service for multiple users
  - Plus, needs to be robust to errors.
EVM Prediction Method for a Single Cell Ma-MIMO

- Predicting the EVM value for different number of users without the need of retransmitting data each time the number of users is changed.

\[ SINR \approx \frac{1}{EVM_{RMS}^2} \]  

[1], [2]

- This method allows the EVM to be used for the Ma-MIMO algorithms to cover the impact of inaccurate CSI and Spatial Correlation.

- This EVM prediction method can be used for user grouping and power control algorithms.

DCMS 5G Testbeds & Trials Programme 5G
Layered Realities Weekend (17th & 18th April 2018)

http://www.bristol.ac.uk/news/2018/march/5gexperience.html
https://www.youtube.com/watch?v=7Qzv_TtyKMU

bristol.ac.uk
### Real-time Results for User Grouping

- **Link quality**
  - Reliable live HD video streams
  - EVM < 13 (video is uncoded)

<table>
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<th>Number of Groups</th>
<th>MCS</th>
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<td></td>
<td>UL</td>
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</tr>
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<td>Maximizing SE</td>
<td>6</td>
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<td></td>
<td></td>
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<td>64-QAM</td>
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<td>Link quality</td>
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Take Aways:

• 5G New Radio ‘Exploits the Spatial Domain’ via large antenna arrays
  • Sub-6GHz ‘aggressive’ spatial multiplying for enhanced spectrum efficiency
  • Lund’s and Bristol’s research influenced 3GPP and the adoption of TDD
  • Commercial deployments of MaMIMO use Beamforming rather than Marzetta’s full spatial signal processing, much lower spectrum efficiencies observed.
Channel hardening

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• 5G New Radio ‘Exploits the Spatial Domain’ via large antenna arrays
  • Sub-6GHz ‘aggressive’ spatial multiplying for enhanced spectrum efficiency
  • Lund’s and Bristol’s research influenced 3GPP and the adoption of TDD
  • Commercial deployments of MaMIMO use Beamforming rather than Marzetta’s full spatial signal processing, much lower spectrum efficiencies observed.
• Also:
  • Difficult to load operational networks to observe ‘high spectrum efficiencies’
  • Beamforming doesn’t support tightly cluster users
• Future activities through CELTIC funding:
  • Distributed MaMIMO
  • Application of AI techniques to enhanced scheduling and robustness
Take Aways: What about Millimetre Wave?

- Experimental work in COST IRACON largely focused on channel characterisation
  - Reflection ……. Diffusion Scatter
  - Spatial Channel Dynamics ……. How to implement cost effective OTA
- Application of millimetre wave:

https://www.youtube.com/watch?v=OIDOi hcqJZg

Any Questions?