5G Testbeds: Bristol & Lund MaMIMO Examples

Mark Beach, Fredrik Tufvesson, Ove Edfors, et al

Communications Systems & Networks Group
Smart Internet Lab
University of Bristol, UK

m.a.beach@bristol.ac.uk, fredrik.tufvesson@eit.lth.se, ove.edfors@eit.lth.se

COST IRACON Final Workshop, Louvain-la-Neuve, Belgium
Tuesday 28th January 2020

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 km^2)
- Long range
- Low data rate (1 -100 kbps)
- M2M ultra low cost
- 10 years battery
- Asynchronous access

5G Scenarios and Use Cases

Enhanced Mobile Broadband (eMBB)

- Date Driven Applications
- 2 billion people on social media

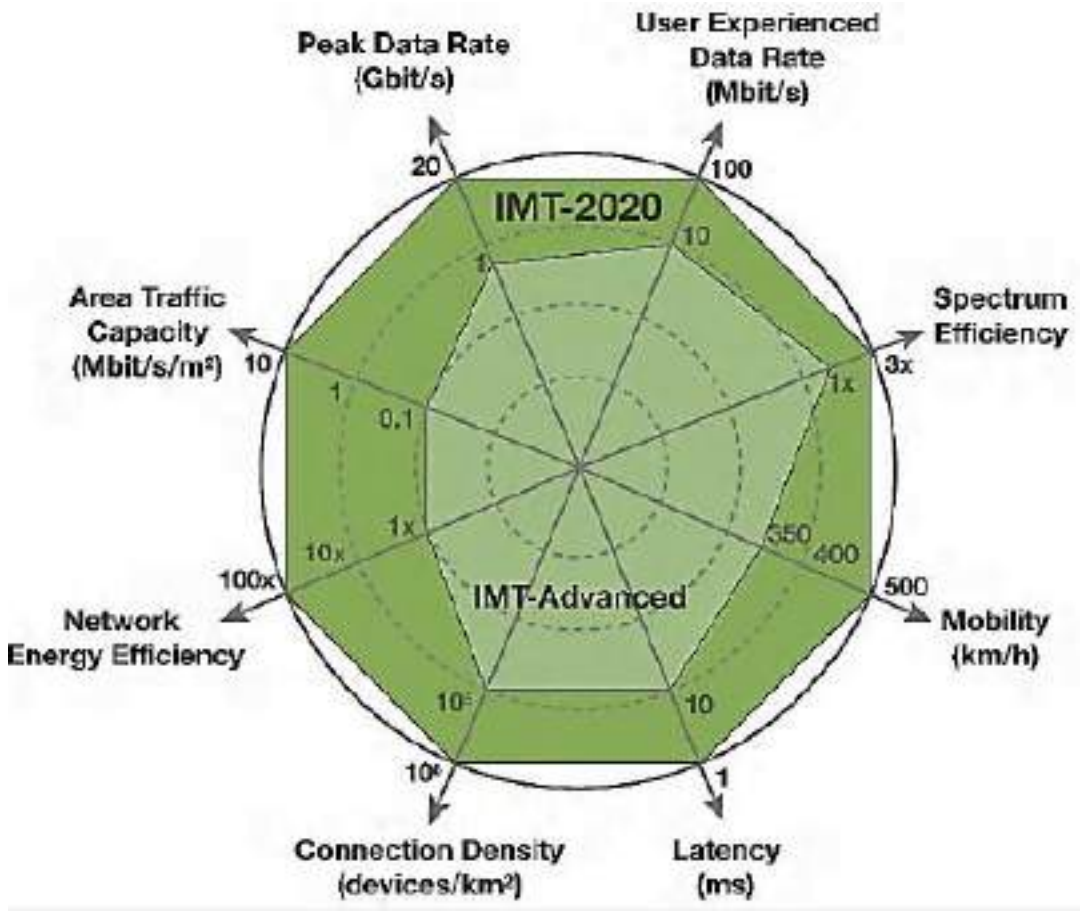
Massive Machine Communication (mMTC)

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

Ultra Reliability and Low Latency (URLLC)

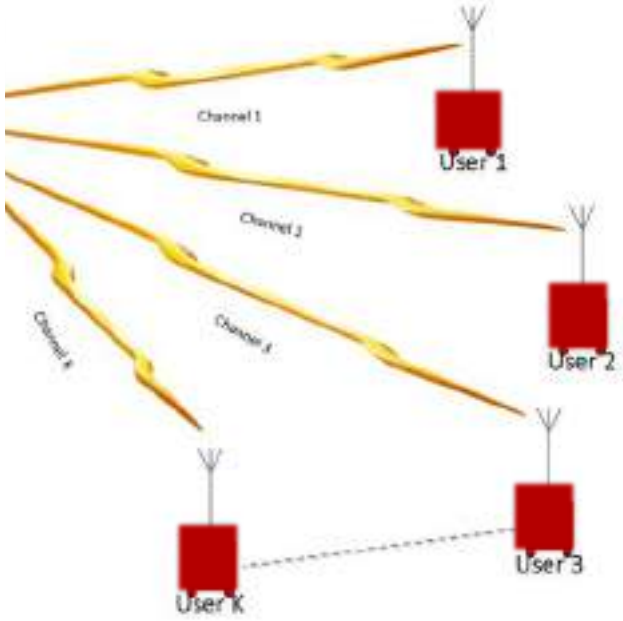
- Ultra responsive
- <1 ms air interface latency
- 5 ms E2E latency
- Ultra reliable (99.9999%)
- Low to medium data rates (50 kbps - 10 Mbps)
- High speed mobility

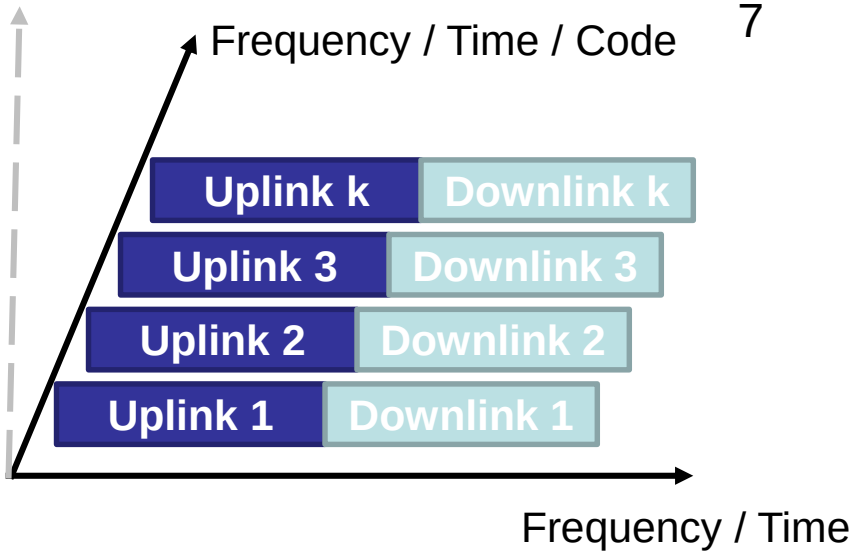
5G – Networked Society



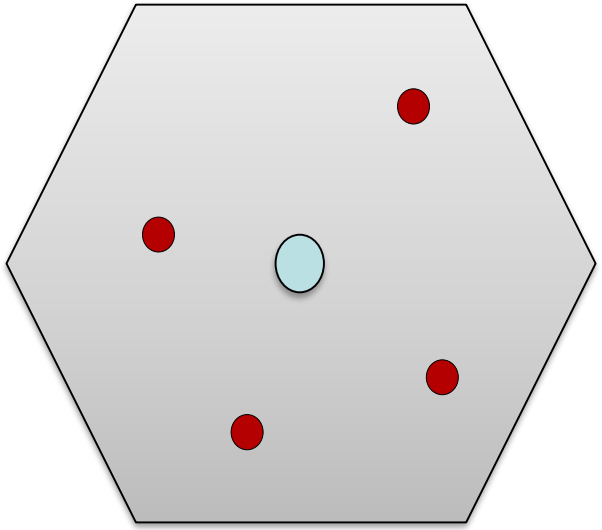
- NR Specifications:
  - 10Gbit/s Peak
  - 100Mbit/s, where ever needed
  - X100 – x1000 Capacity
  - X10 battery life
  - Reduced Latency (0.5ms)
- 5G Physical Layer Requires:
  - Enhanced Spectrum Efficiency for sub-6GHz
  - Use of New Spectrum: Millimetre wave bands

Conventional Cellular Radio



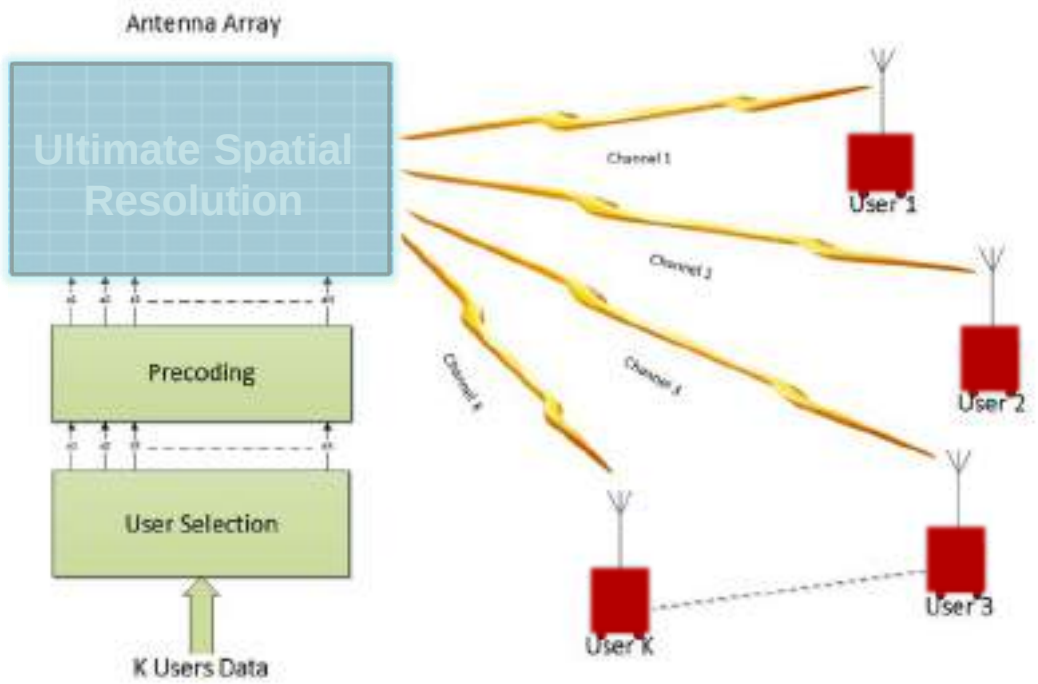


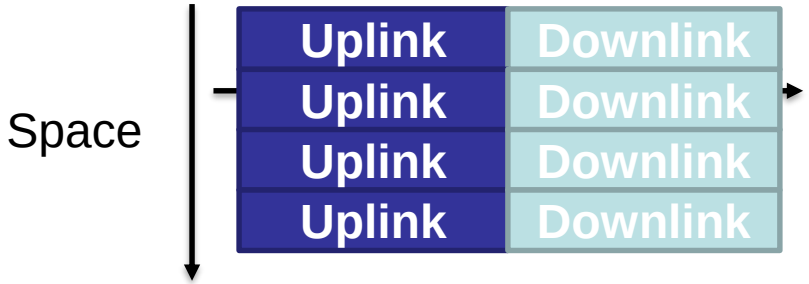
Cellular View



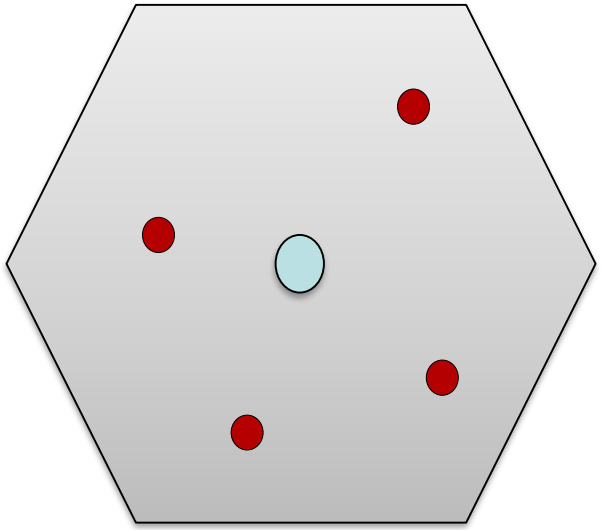
- Multiple users share same time, frequency or code resources

Exploiting the Spatial Domain



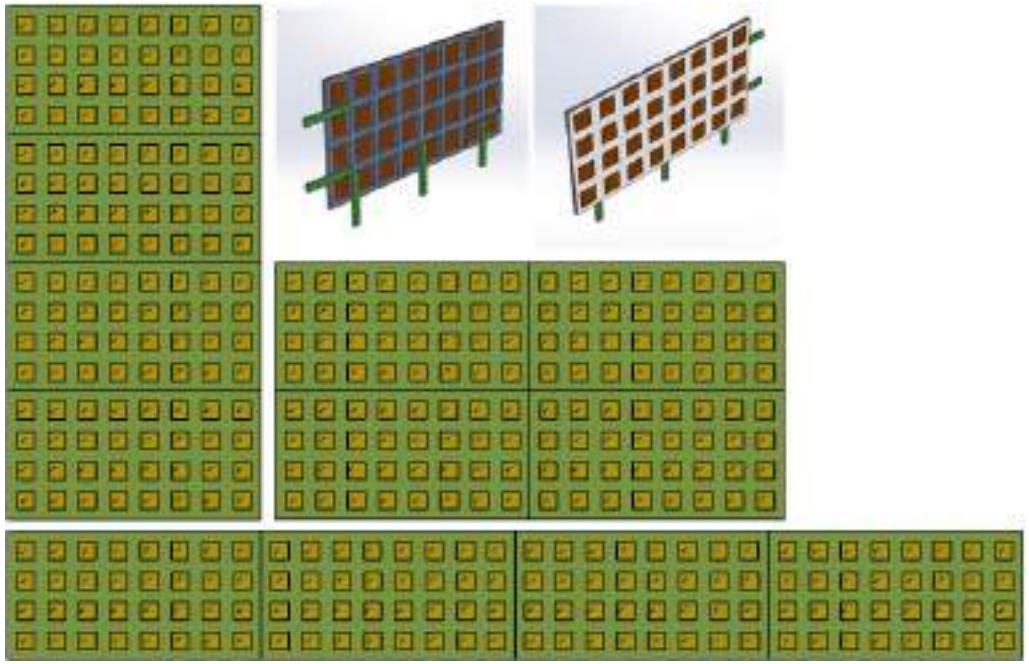


Cellular View



- 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

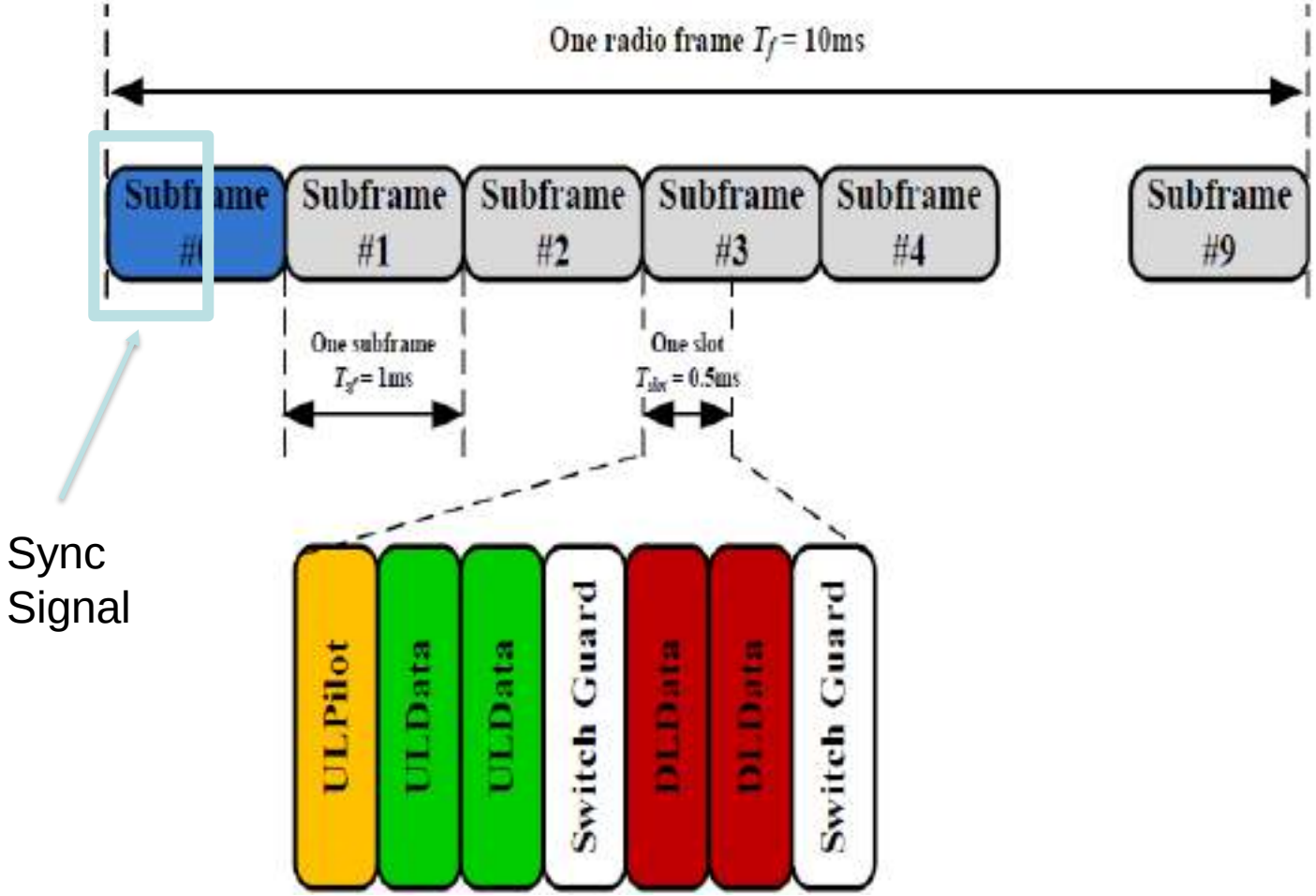
MVB Courtyard Environment Modelled for Visualisation

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.

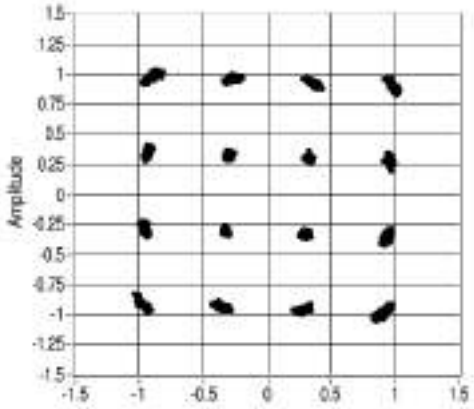
Massive MIMO Frame Structure: TDD

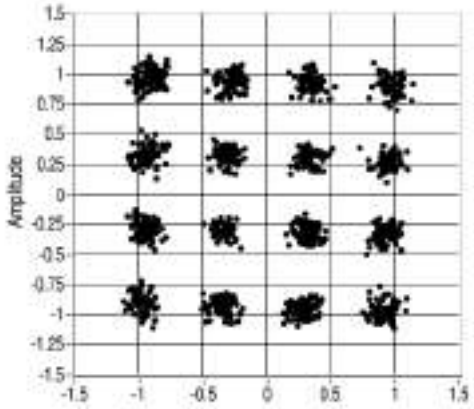


First Real Time Results – Oct 2014 Uplink

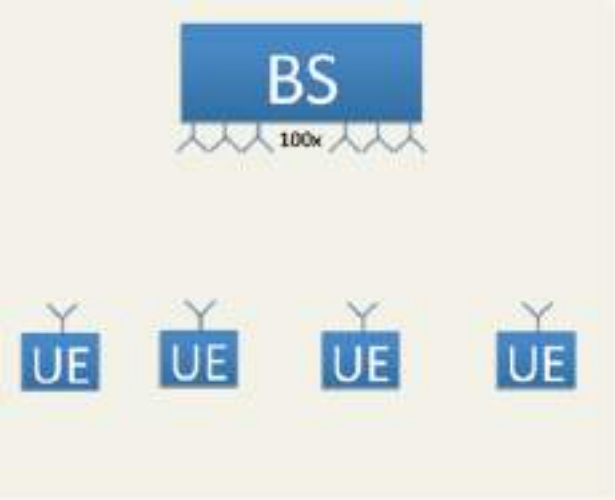
Received signal constellations – LOS & four users 2 m separation

ZF detector



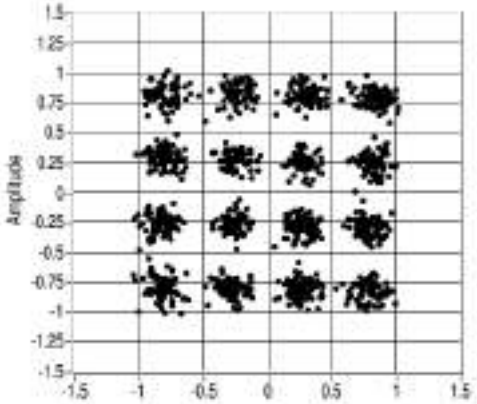


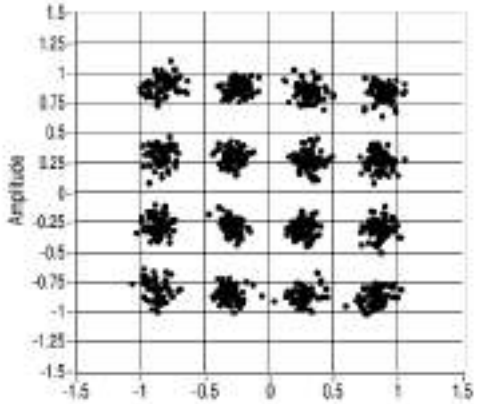
MRC detector



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

ZF detector





MRC detector

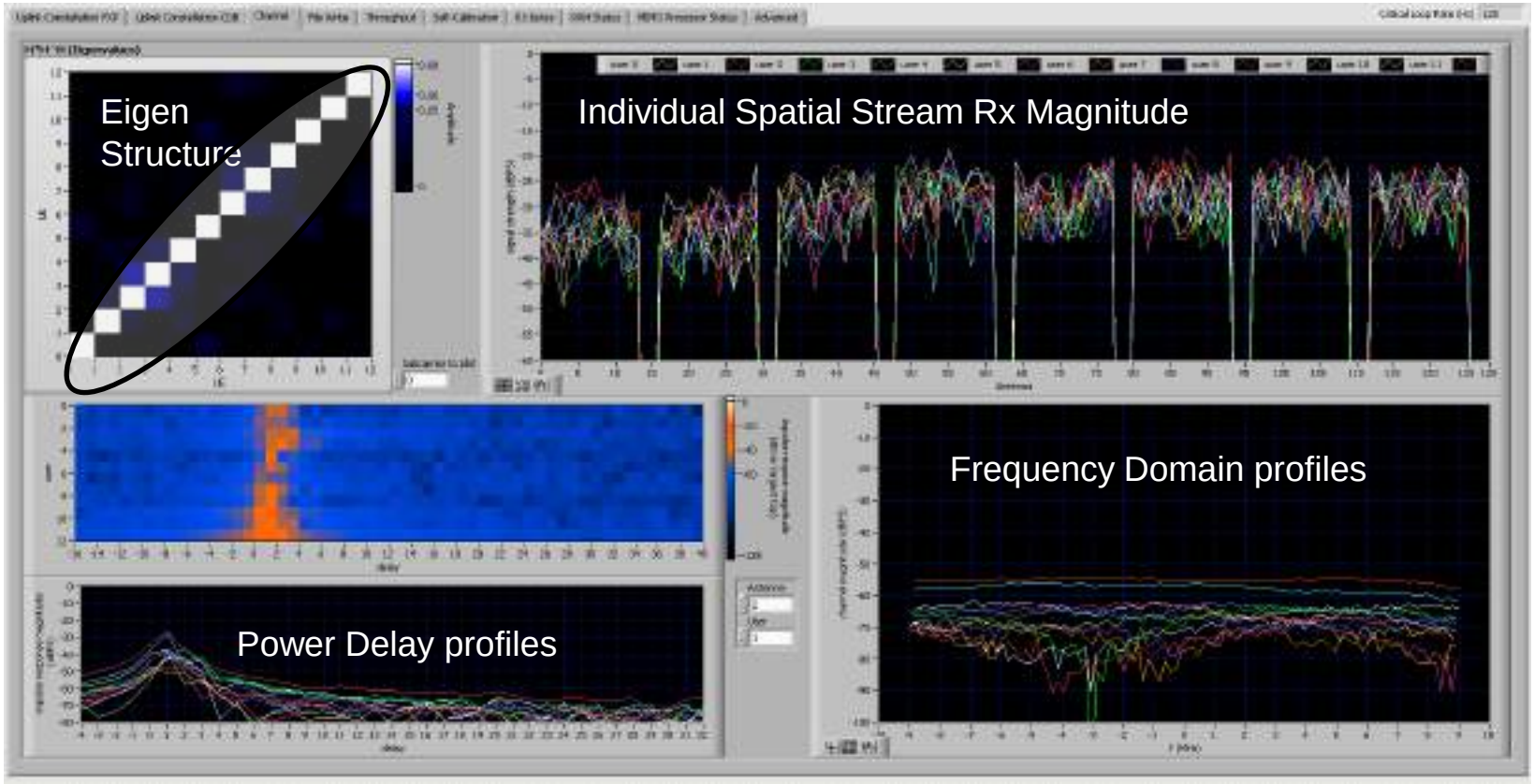
National Instruments Massive MIMO test-bed

- 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 (10th March 2016):



12 streams of 256 QAM!

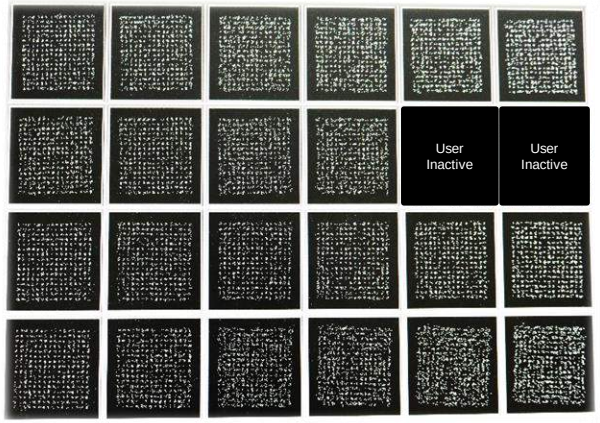
http://www.bristol.ac.uk/news/2016/march/massive-mimo.html

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

http://www.wired.com/2016/04/facebooks-massive-new-antennas-can-beam-internet-miles/

2nd Deployment (Wed 11th May 2016)



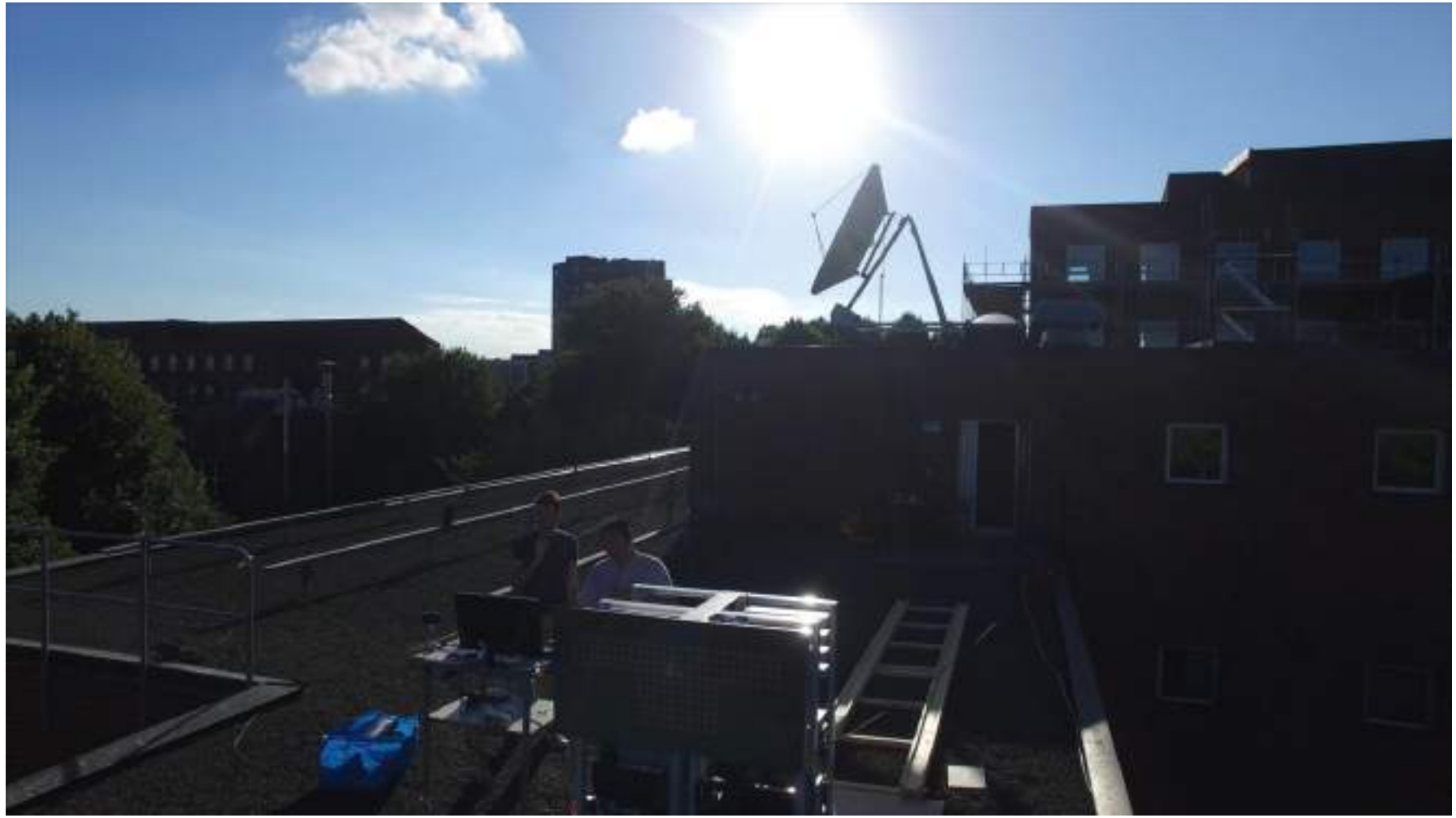
22 users running 256 QAM in 20MHz Channel
Using same frame structure as before:

- 145.6 bits/s/Hz
- Sum rate of 2.915 Gbps

Our 2nd World Record

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

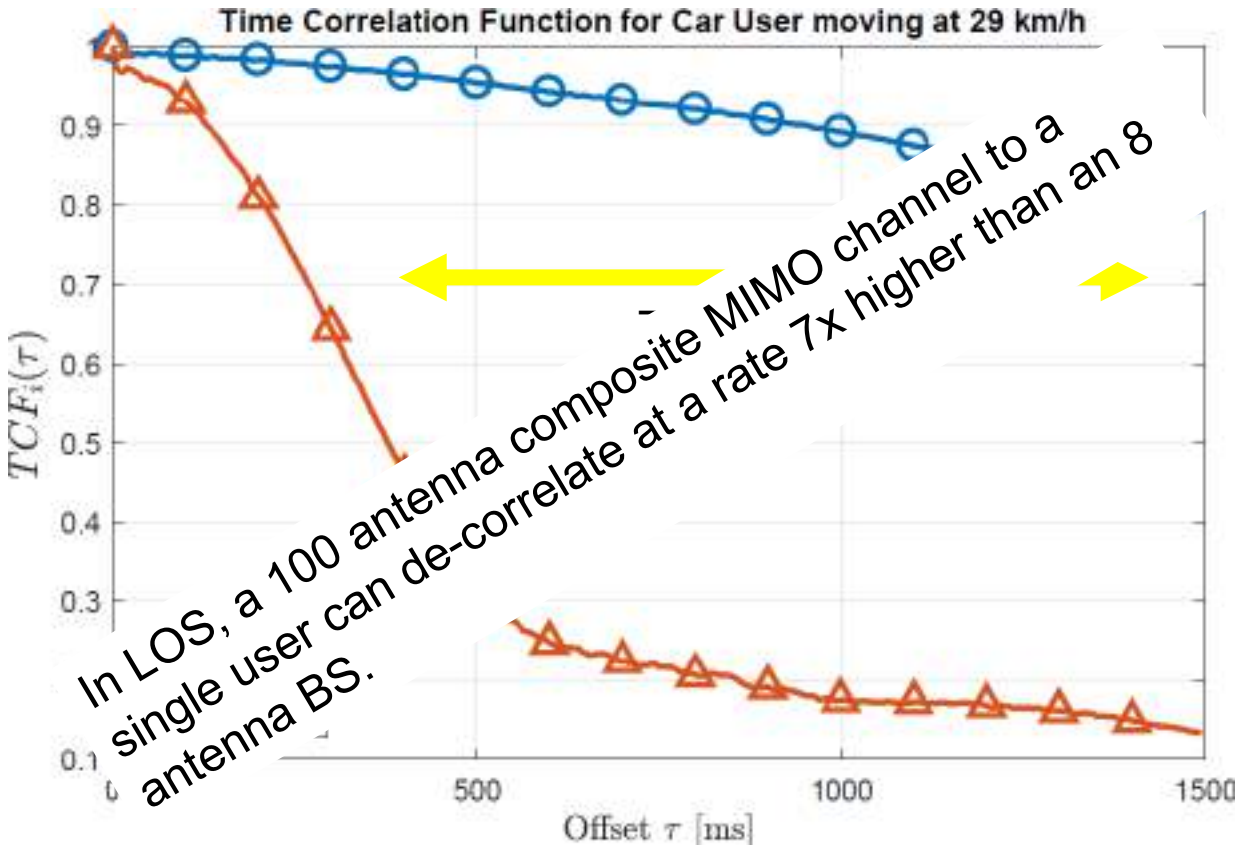
Mobility Trials & Spatial Correlation



https://www.youtube.com/watch?v=Qp877-PAQSg

Mobility and Massive MIMO

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

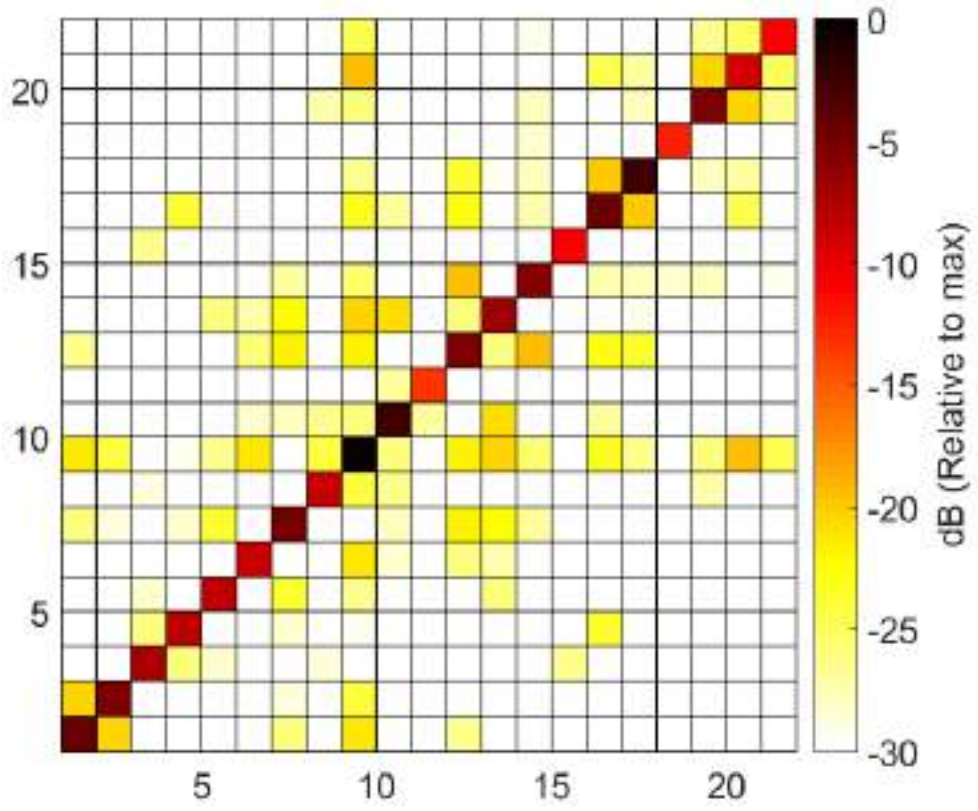


Paul Harris et al, 'Performance Characterization of a Real-Time Massive MIMO System With LOS Mobile Channels'
IEEE JSAC, Volume: 35 Issue: 6, pp1244 - 1253 , June 2017

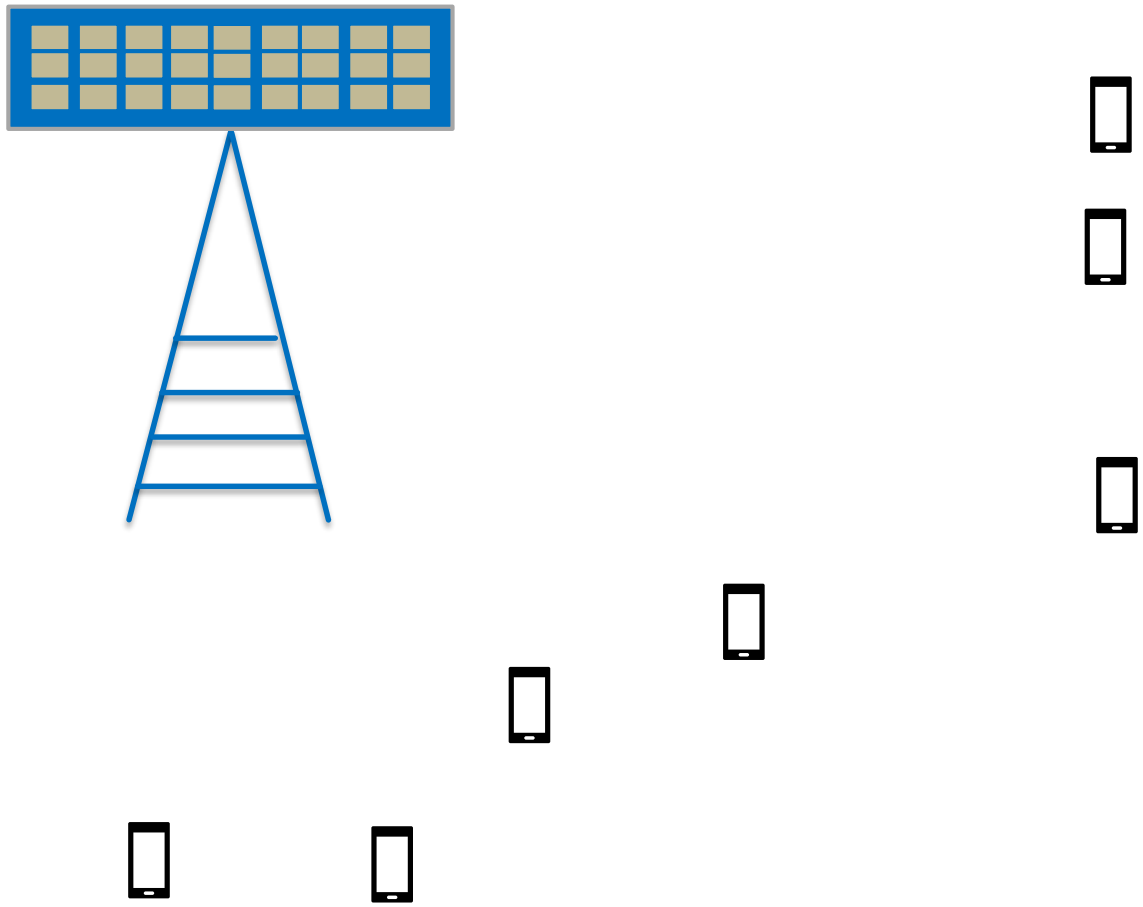
www.youtube.com/watch?v=wPPMrr4rHmo

Massive MIMO: Spectrum Efficiency Gains

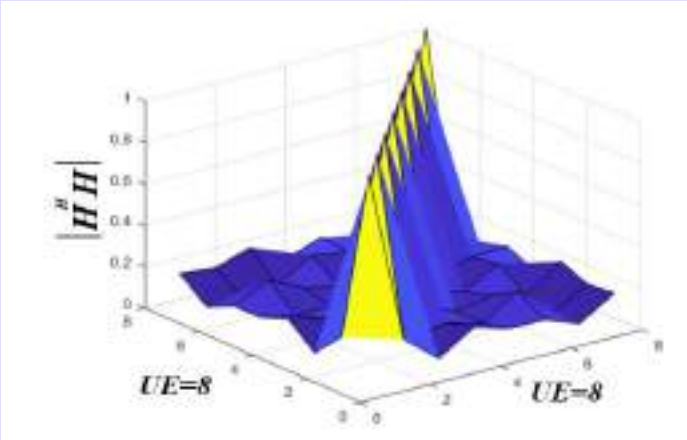
- Aggressive Spatial Multiplexing gains are by means of ‘Pairwise Orthogonality’



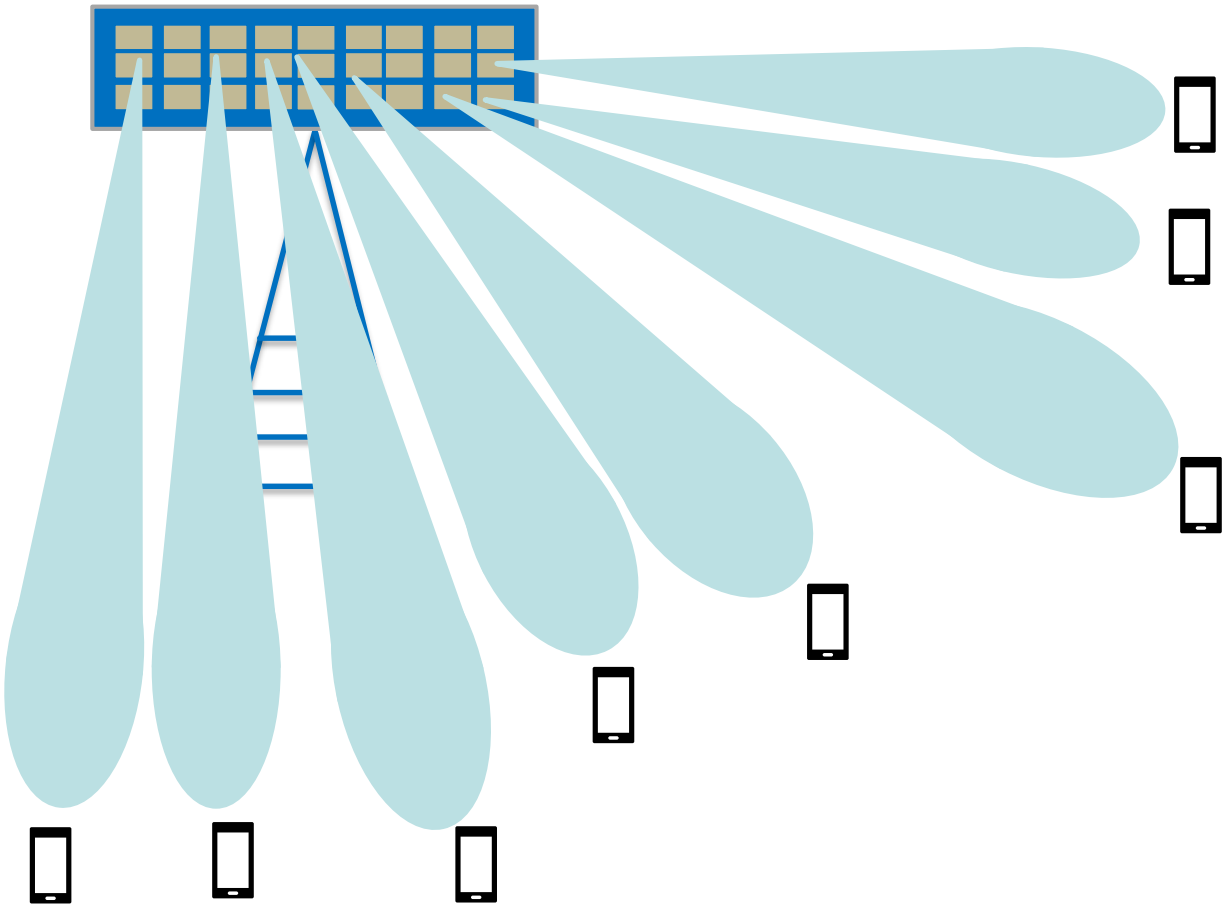
Channel Hardening Effects & Pairwise Orthogonality



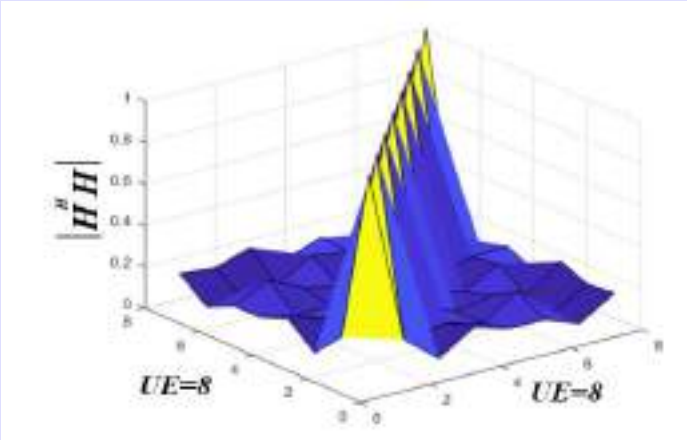
Accurate CSI +



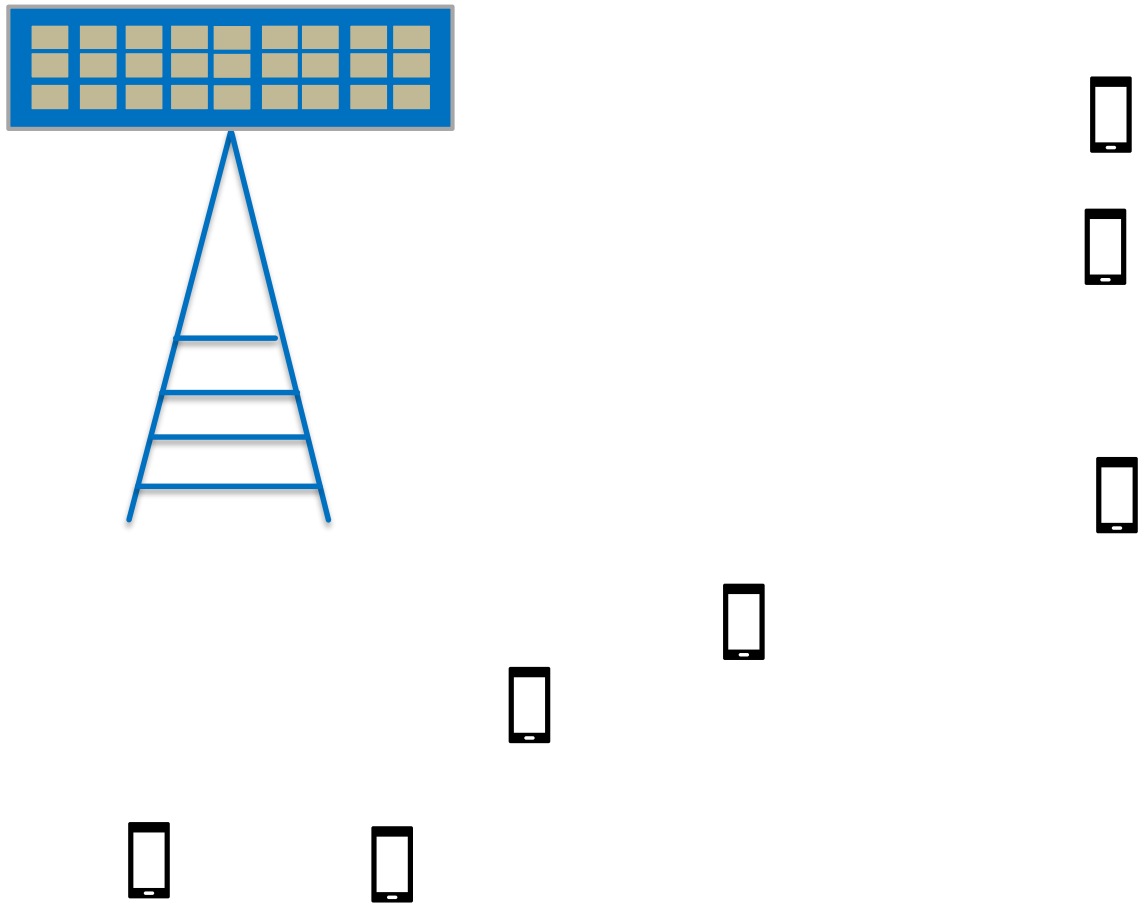
Channel Hardening Effects & Pairwise Orthogonality



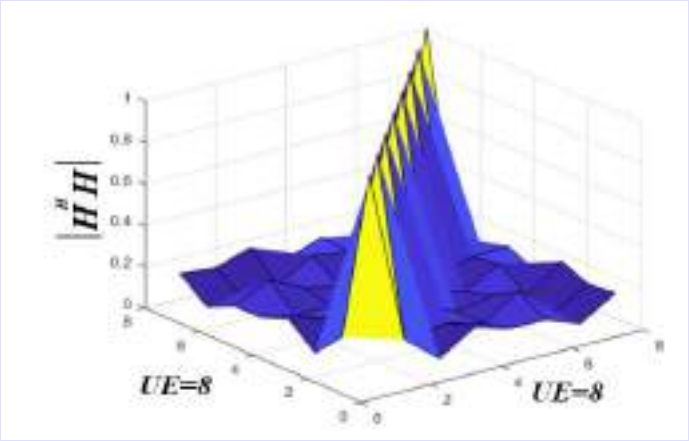
Accurate CSI +



Channel Hardening Effects & Pairwise Orthogonality

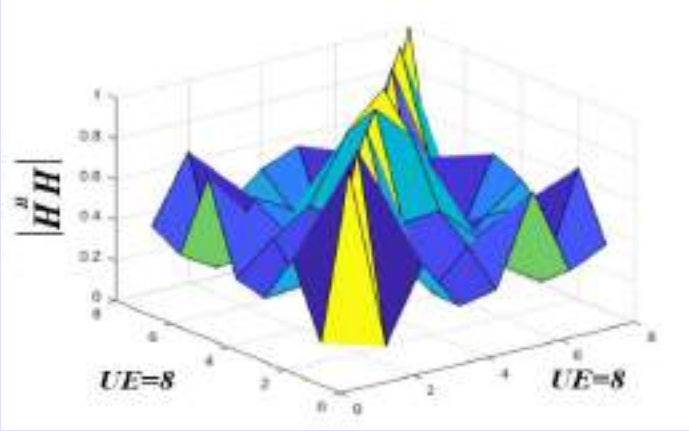


Inaccurate CSI +

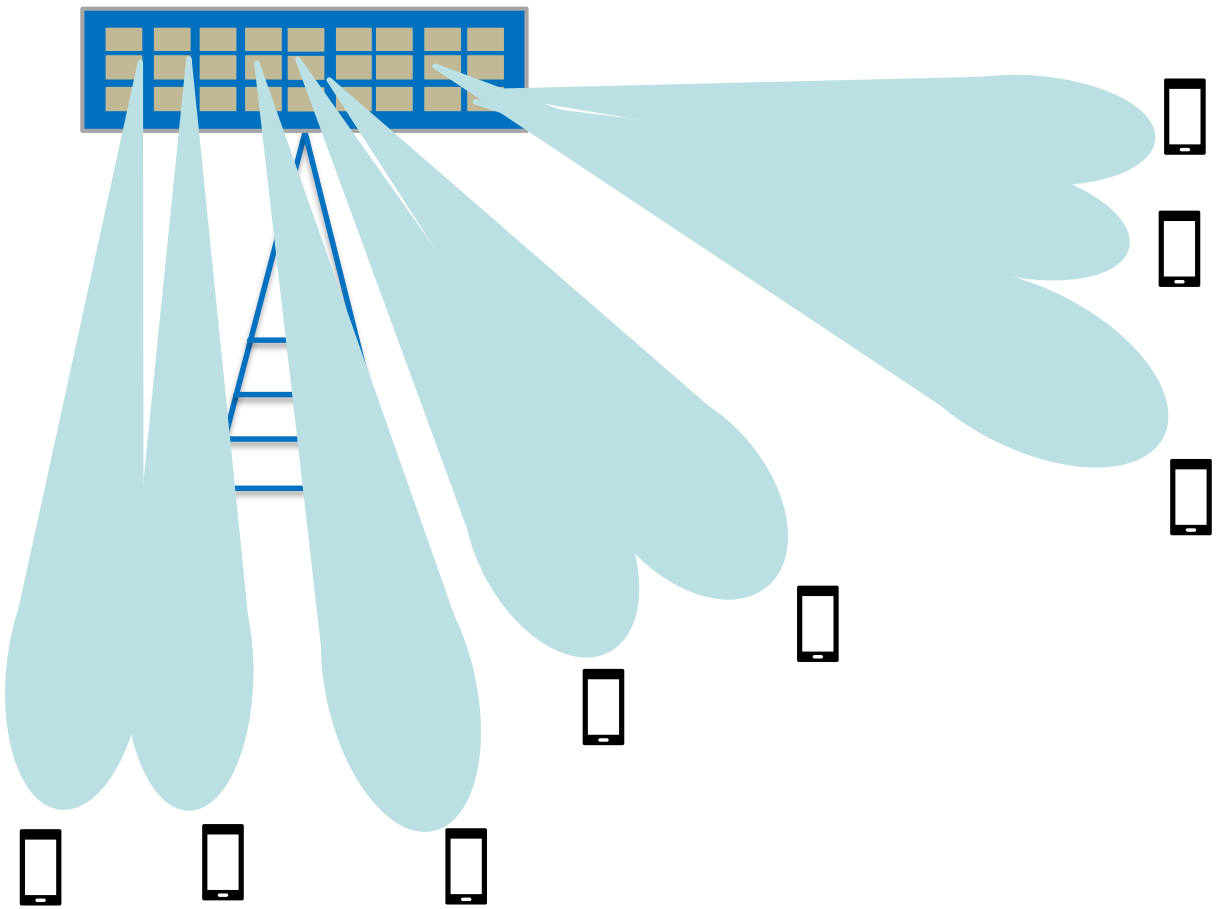


OR

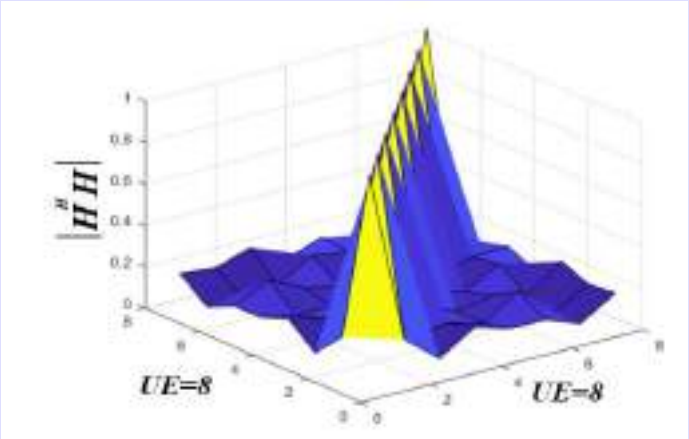
Accurate CSI +



Channel Hardening Effects & Pairwise Orthogonality

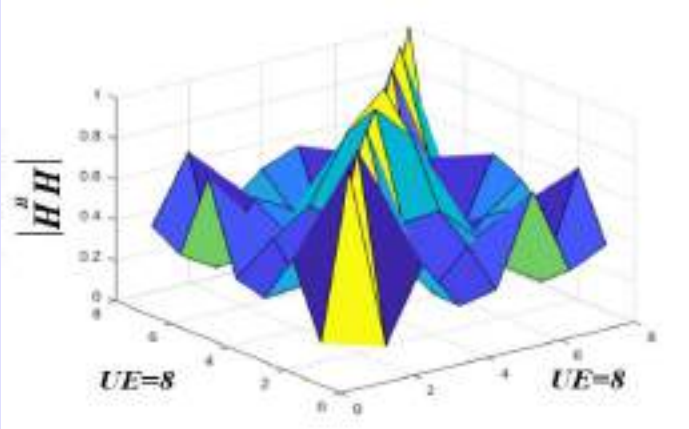


Inaccurate CSI +

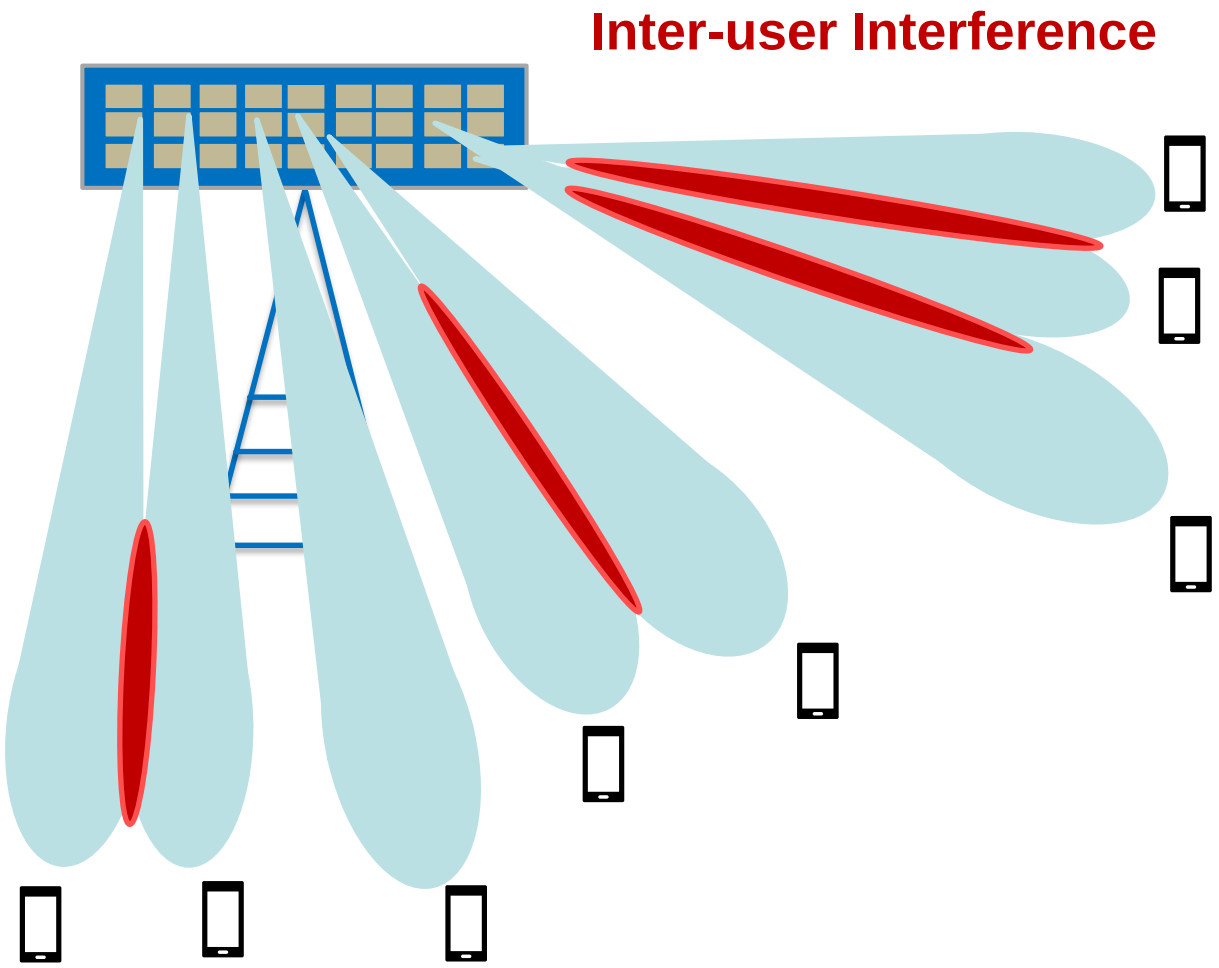


OR

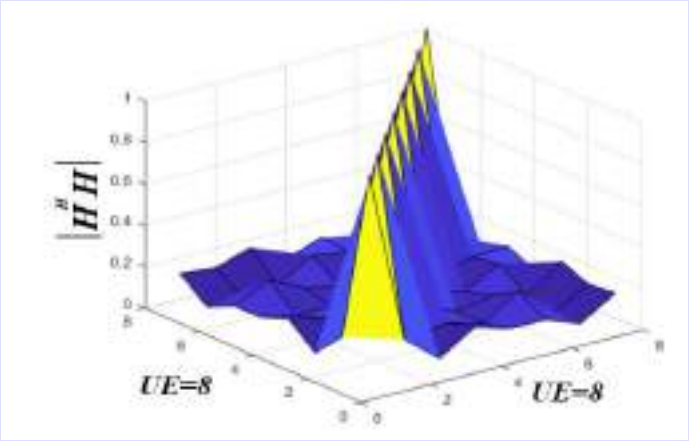
Accurate CSI +



Channel Hardening Effects & Pairwise Orthogonality

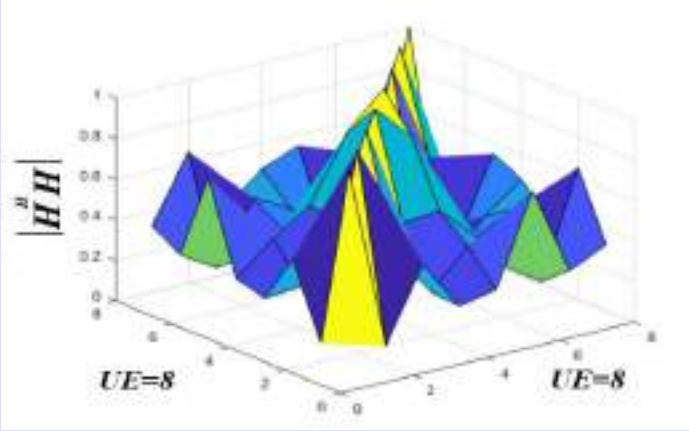


Inaccurate CSI +



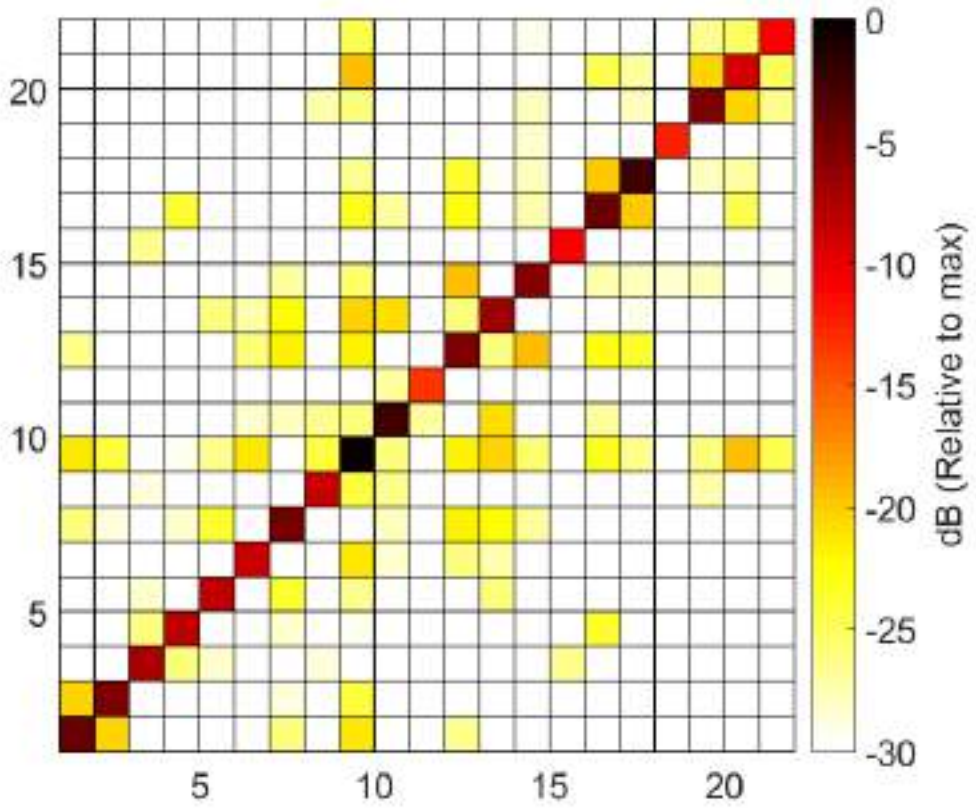
OR

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

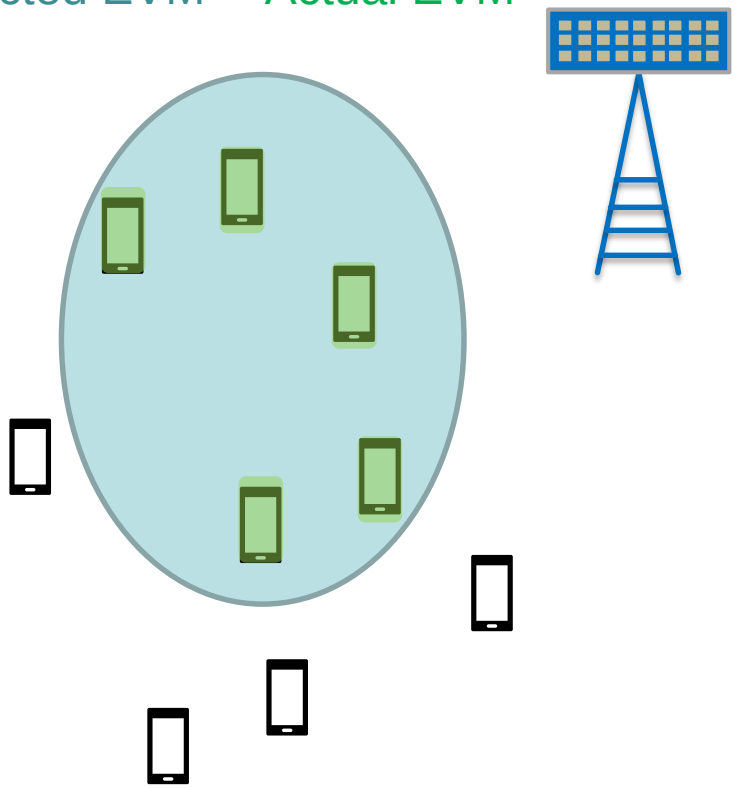
- Predicting the EVM value for different number of users without the need of retransmitting data each time the number of users is changed.

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

- 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.

Predicted EVM ≈ Actual EVM



[1]: H. A. Mahmoud et al,"Error vector magnitude to SNR conversion for non data-aided receivers," *IEEE Trans Wireless Comms*.
[2]: T. W. C. Brown et al "Prediction of SINR using BER and EVM for Massive MIMO Applications", EuCAP2018

DCMS 5G Testbeds & Trials Programme 5G

Layered Realities Weekend (17th & 18th April 2018)

http://www.bristol.ac.uk/news/2018/march/5gexperience.html

University of BRISTOL

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)

	Max EVM		Number of Groups		MCS	
	UL	DL	UL	DL	UL	DL
Maximizing SE	6	8	4	6	64-QAM	16-QAM
Link quality	12	12	2	4	QPSK	QPSK
Maximizing number of simultaneous users	16	16	1	3	QPSK	QPSK
Deactivate user grouping	16	35	1	1	QPSK	QPSK

	Uncoded UL throughput (Mbps)	Uncoded DL throughput (Mbps)	Spectral efficiency (bits/s/Hz)
Maximizing SE	182	64	12.3
Link quality	135.3	53.2	9.4
Maximizing number of simultaneous UEs	84	58.6	7.1
Deactivate user grouping	84	0	4.2

Real-time Results for User Grouping

- Link quality
- Maximizing SE

	Max EVM		Number of Groups		MCS	
	UL	DL	UL	DL	UL	DL
Maximizing SE	6	8	4	6	64-QAM	16-QAM
Link quality	12	12	2	4	QPSK	QPSK
Maximizing number of simultaneous users	16	16	1	3	QPSK	QPSK
Deactivate user grouping	16	35	1	1	QPSK	QPSK

	Uncoded UL throughput (Mbps)	Uncoded DL throughput (Mbps)	Spectral efficiency (bits/s/Hz)
Maximizing SE	182	64	12.3
Link quality	135.3	53.2	9.4
Maximizing number of simultaneous UEs	84	58.6	7.1
Deactivate user grouping	84	0	4.2

Real-time Results for User Grouping

- Link quality
- Maximizing SE
- Maximizing number of simultaneous UEs

	Max EVM		Number of Groups		MCS	
	UL	DL	UL	DL	UL	DL
Maximizing SE	6	8	4	6	64-QAM	16-QAM
Link quality	12	12	2	4	QPSK	QPSK
Maximizing number of simultaneous users	16	16	1	3	QPSK	QPSK
Deactivate user grouping	16	35	1	1	QPSK	QPSK

	Uncoded UL throughput (Mbps)	Uncoded DL throughput (Mbps)	Spectral efficiency (bits/s/Hz)
Maximizing SE	182	64	12.3
Link quality	135.3	53.2	9.4
Maximizing number of simultaneous UEs	84	58.6	7.1
Deactivate user grouping	84	0	4.2

Real-time Results for User Grouping

- Link quality
- Maximizing SE
- Maximizing number of simultaneous UEs
- Deactivate user grouping

	Max EVM		Number of Groups		MCS	
	UL	DL	UL	DL	UL	DL
Maximizing SE	6	8	4	6	64-QAM	16-QAM
Link quality	12	12	2	4	QPSK	QPSK
Maximizing number of simultaneous users	16	16	1	3	QPSK	QPSK
Deactivate user grouping	16	35	1	1	QPSK	QPSK

	Uncoded UL throughput (Mbps)	Uncoded DL throughput (Mbps)	Spectral efficiency (bits/s/Hz)
Maximizing SE	182	64	12.3
Link quality	135.3	53.2	9.4
Maximizing number of simultaneous UEs	84	58.6	7.1
Deactivate user grouping	84	0	4.2

Real-time Results for User Grouping

- Link quality
- Maximizing SE
- Maximizing number of simultaneous UEs
- Deactivate user grouping

IEEE Access

Adaptive User Grouping Based on EVM Prediction for Efficient & Robust Massive MIMO in TDD

WAEL BOUKLEY HASAN, (Member, IEEE), PAUL HARRIS, (Member, IEEE), HENRY BROMELL, (Student Member, IEEE), ANGELA DOUFEXI, (Member, IEEE), MARK BEACH, (Member, IEEE)

ABSTRACT

INDEX TERMS Massive MIMO, 5G, User Grouping, Channel Estimation, EVM Prediction, SINR Estimation, Quality of Service.

I. INTRODUCTION

Stop Press: Paper published in IEEE Access

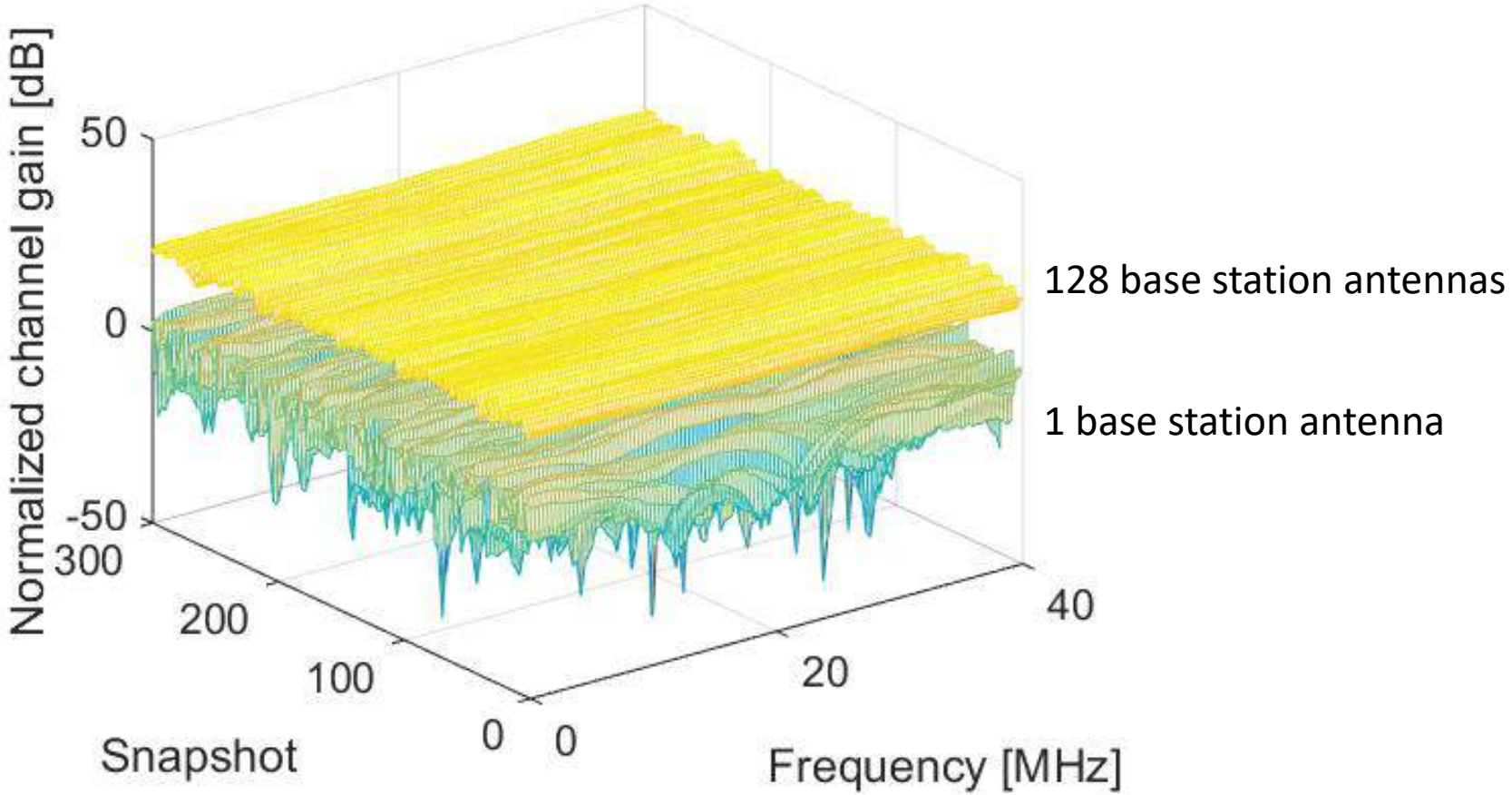
	Max EVM		Number of Groups		MCS	
	UL	DL	UL	DL	UL	DL
	6	8	4	6	64-QAM	16-QAM
	12	12	2	4	QPSK	QPSK
	16	16	1	3	QPSK	QPSK
ng	16	35	1	1	QPSK	QPSK

	Uncoded UL throughput (Mbps)	Uncoded DL throughput (Mbps)	Spectral efficiency (bits/s/Hz)
	182	64	12.3
	135.3	53.2	9.4
	84	58.6	7.1
ng	84	0	4.2

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 that Marzetta’s full spatial signal processing, much lower spectrum efficiencies observed.

Channel hardening



S. Gunnarsson et al. "Channel Hardening in Massive MIMO-A Measurement Based Analysis," Proc. SPAWC, Kalamata, 2018.

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 that 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:

News and media

Awards

Latest news

Media library

Media contacts

FirstGroup and Blu Wireless partnering to provide superfast 5G Wi-Fi on trains

25 Feb 2019

First use of 5G technology on trains to enable faster, high-quality streaming required by most smart phones

Offers a unique opportunity to improve connectivity for rail infrastructure as well as customers

As demand for fast reliable Wi-Fi on public transport grows exponentially, FirstGroup and Blu Wireless are today announcing a project to significantly-boost the quality of connectivity on trains, by pioneering the use of 5G technology on the railway. The new technology is so powerful it will enable reliable streaming, rapid browsing and connectivity to cloud-based applications like Office 365 – keeping pace with the requirements of devices that many customers take for granted.

https://www.youtube.com/watch?v=OlDOihcqJZg

https://www.firstgroupplc.com/news-and-media/latest-news/2019/25-02-19.aspx

Any Questions?