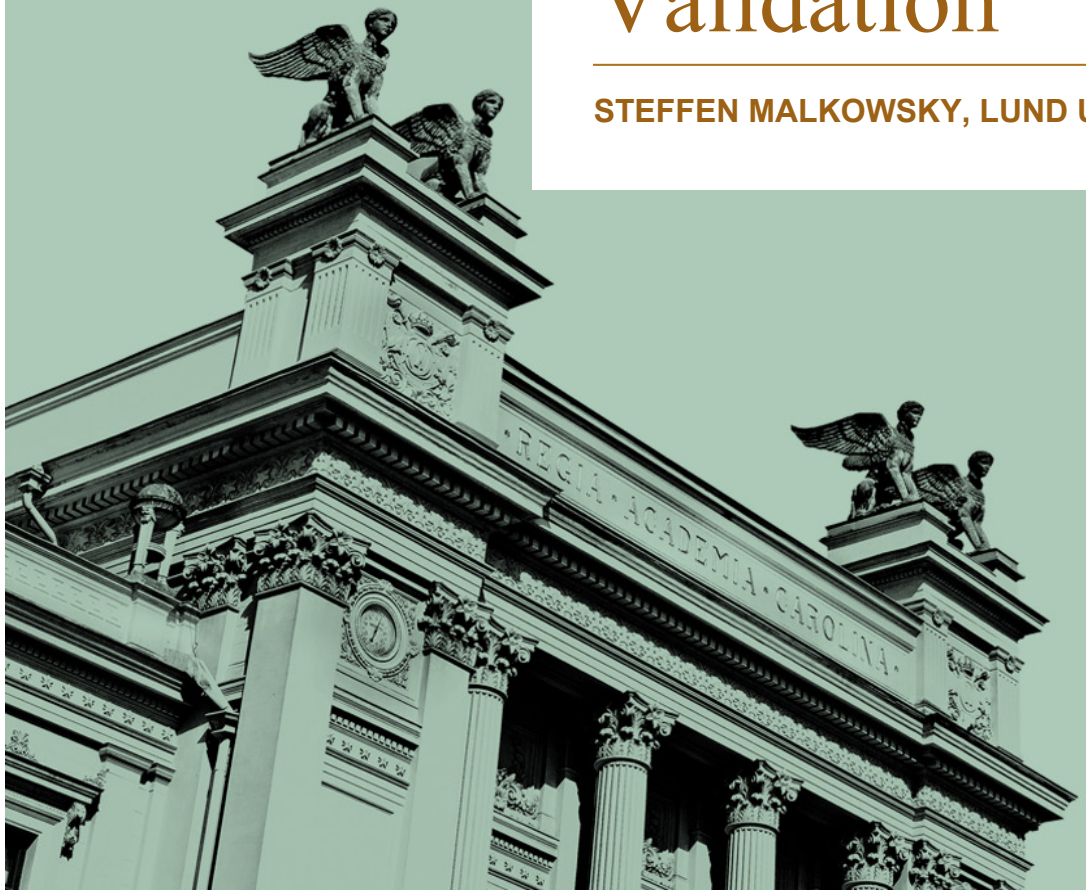
Massive MIMO testbed: Validation

STEFFEN MALKOWSKY, LUND UNIVERSITY, SWEDEN



Why do we need a testbed?

- Theoretical results show that massive MIMO has very promising features for future wireless generation, however they cannot answer all questions:

1) How does it perform under real-life conditions?

2) How can we model massive MIMO channels?

3) Implementation challenges/issues?

4) Required reciprocity calibration accuracy?

5) Is pilot contamination a problem?

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LUMAMI TESTBED

LuMaMi Testbed: Parameters

- 100 BS antennas
- Serving up to 12 UEs
- 50 SDRs + 6 SDRs as UEs
- 4 Central Processing units performing MIMO processing
- 3.7 GHz carrier frequency
- LTE-like parameters
- Uncoded transmission

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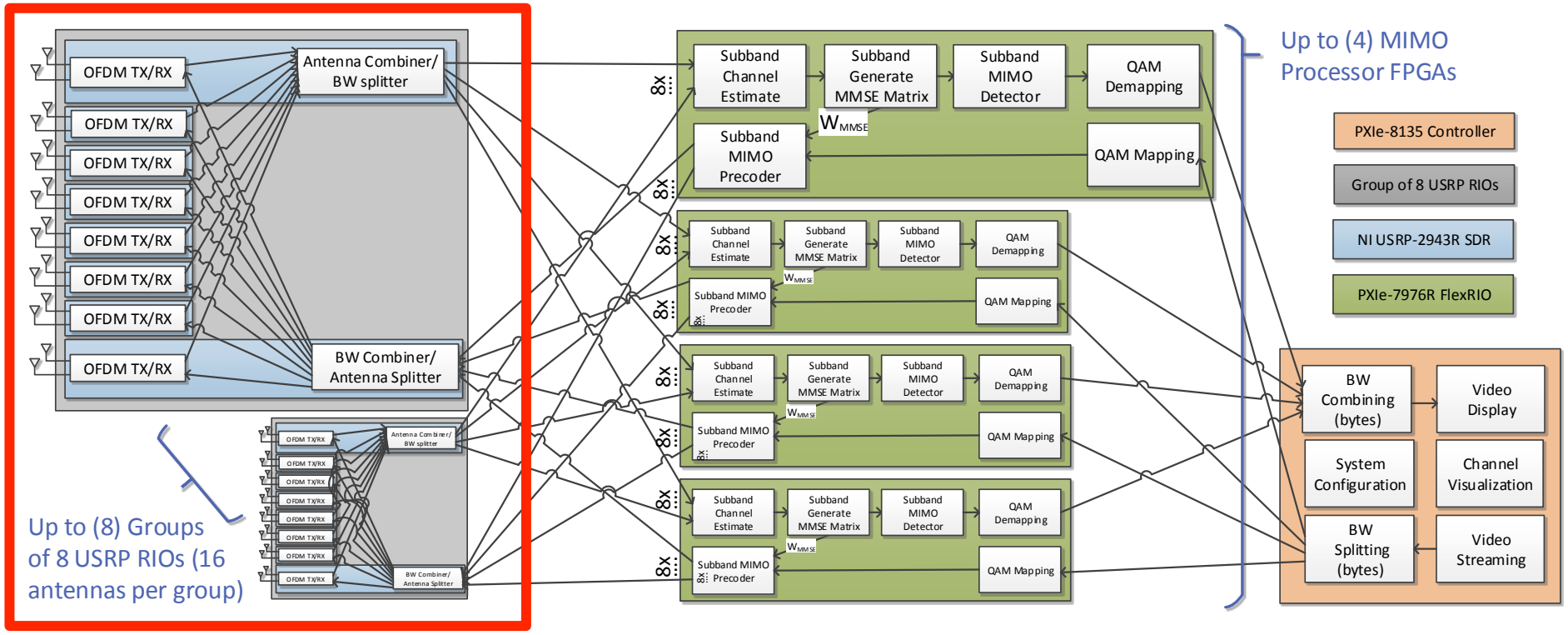
LuMaMi Testbed: Processing



- Per-antenna (OFDM) processing performed on USRP SDR
- Data of up to 8 USRPs combined and send to centralized processing

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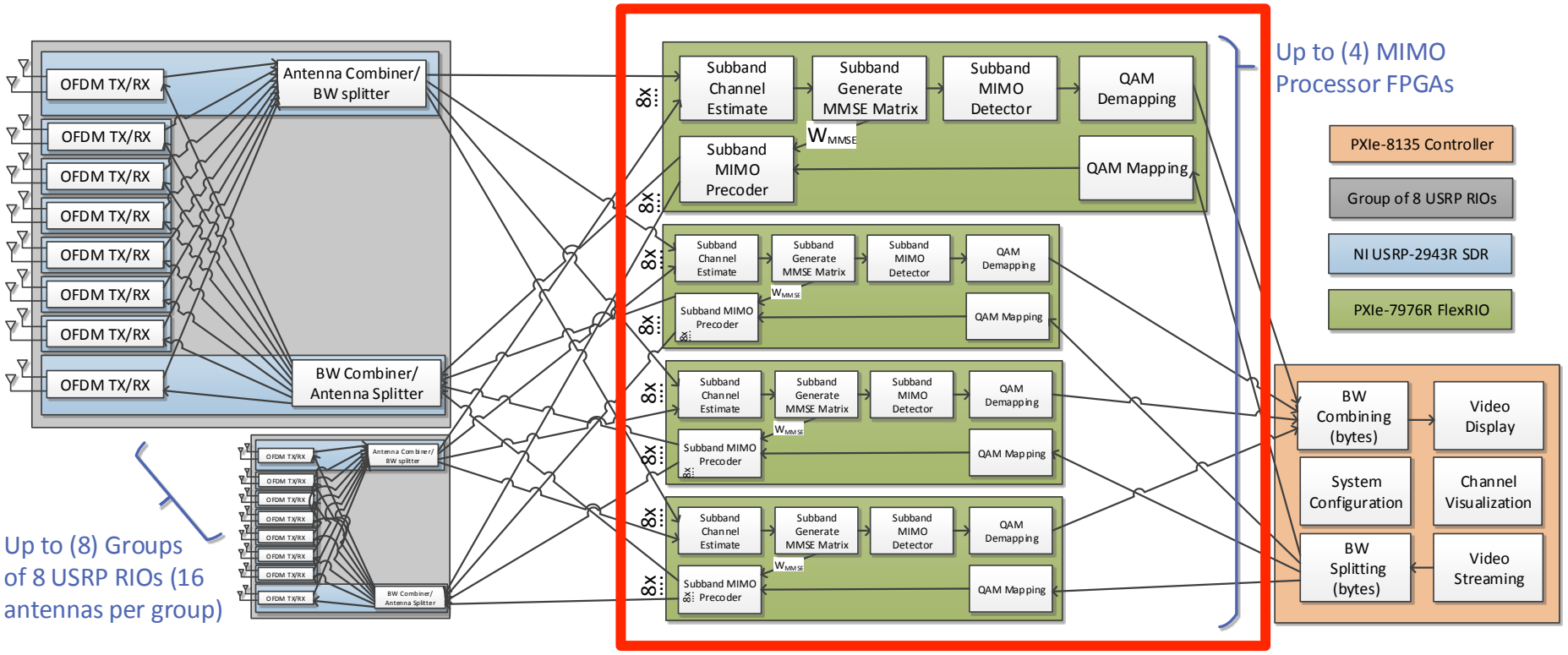
LuMaMi Testbed: Processing



- Centralized processing distributed over 4 units, each working on ¼ bandwidth
- 3 detector types implemented: MRC/MRT, ZF and regularized ZF

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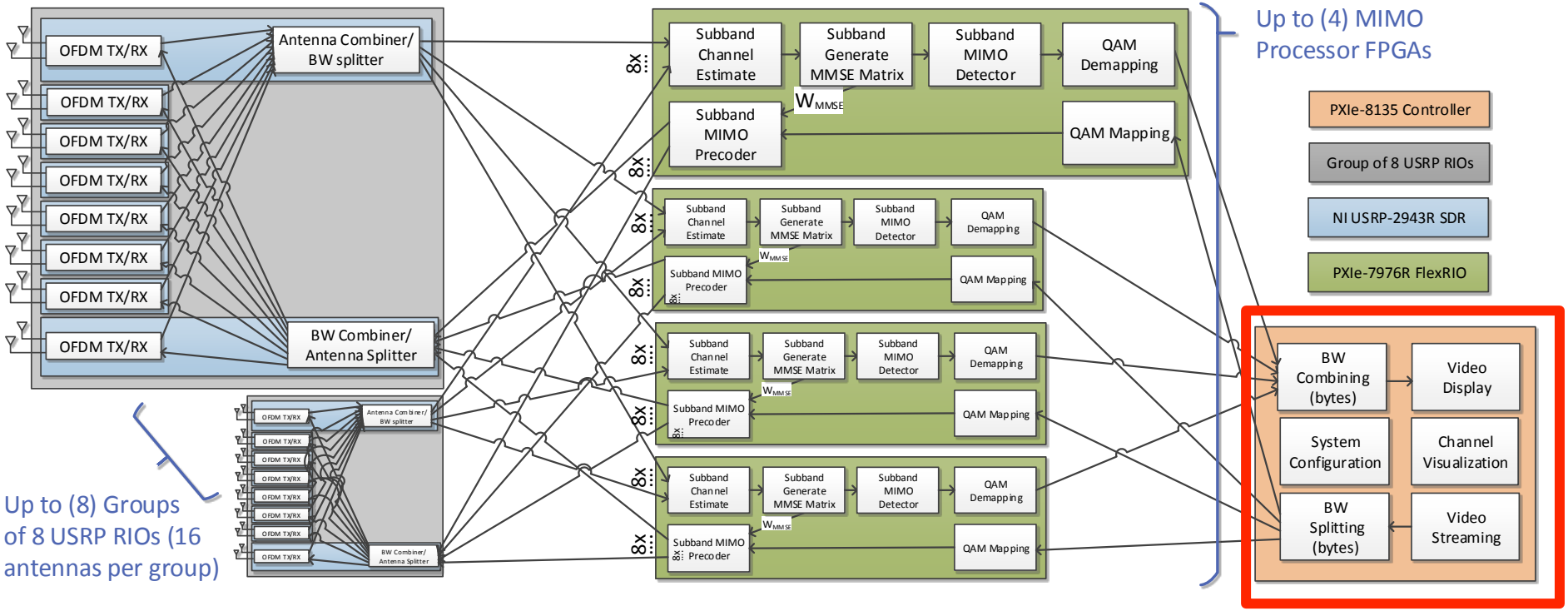
LuMaMi Testbed: Processing



- A standard windows computer hosts the complete system
- Configures system
- Visualizes parameters, e.g. channel impulse response and acts as source and sink for video streams

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FOUR TESTS

Indoor Measurements

- Serving 12 users in groups of 4 on UL and DL in a lecture hall
- Record BERs while sweeping amplifier gains (0-30 dB)
  - UL: Sweep the gain of the UEs transmitter
  - DL: Sweep the gain of the BS transmitters
- 18 Million bits transmitted per step
- Compare performance of MRC/MRT vs. ZF

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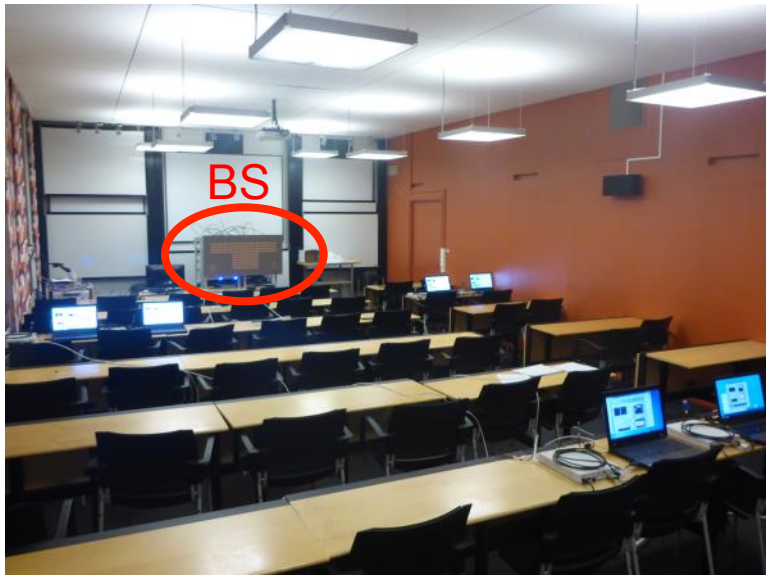
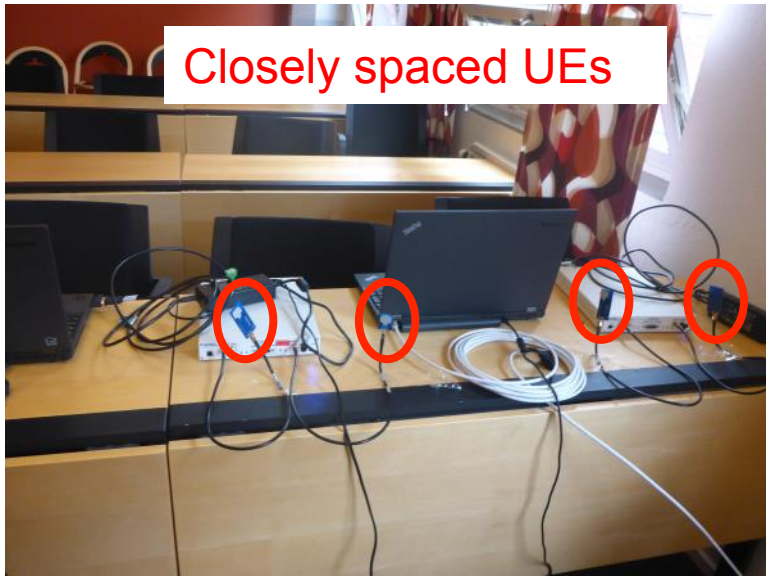
Setup



Base station placed at the front of the lecture hall

Users are distributed in groups of 4 with close spacing inside each group



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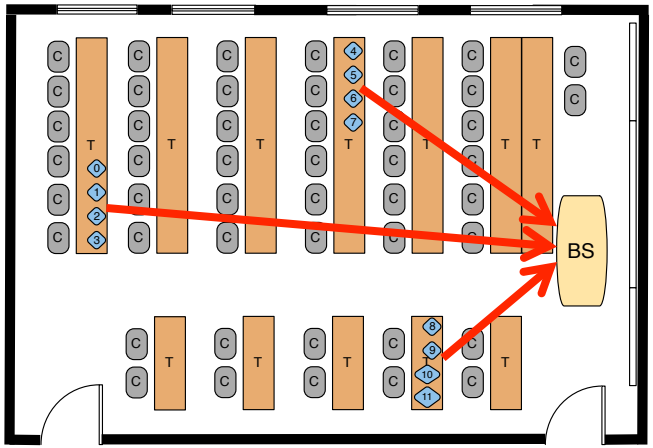
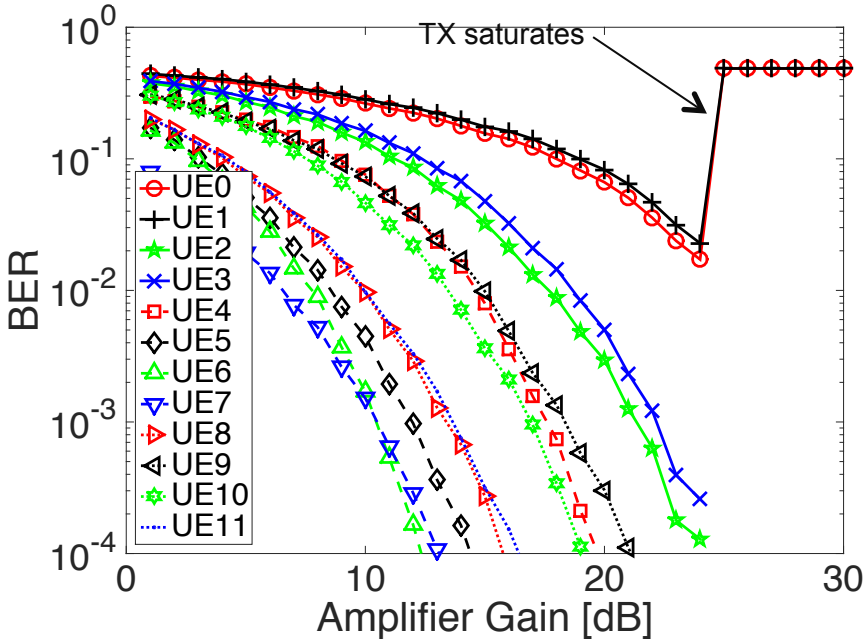
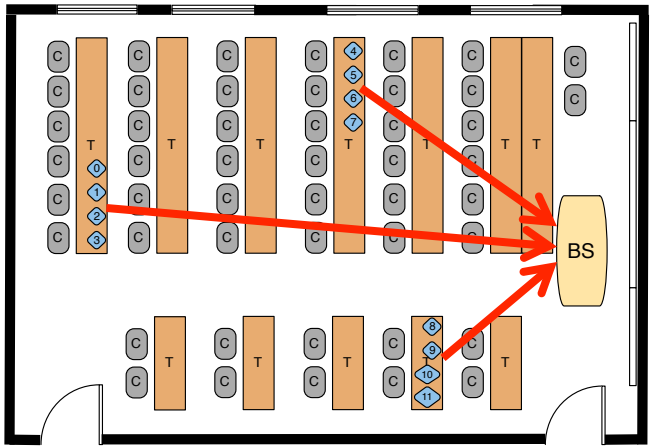
Uplink BERs (QPSK)

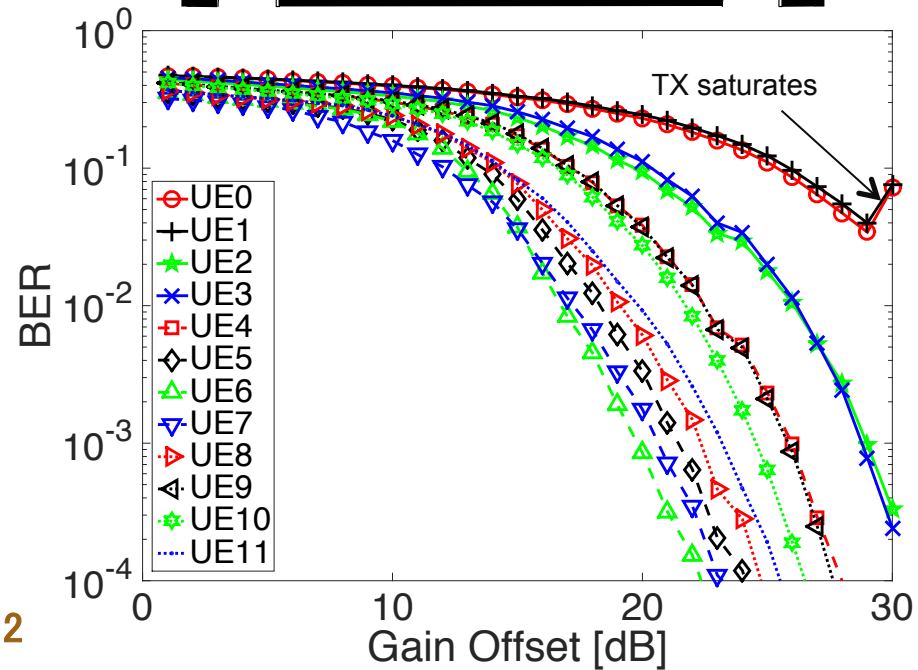




- ZF detector
- Close by users (UE8-11) show best BERs
- Far users (UE0-UE3) show worst performance
- UE0/1 interference limited
  - Bad performance at full power close to saturation

Uplink BERs (16-QAM)





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- Close by users (UE8-11) shows best BERs
- Far users (UE0-UE3) show worst performance
- UE0/1 interference limited
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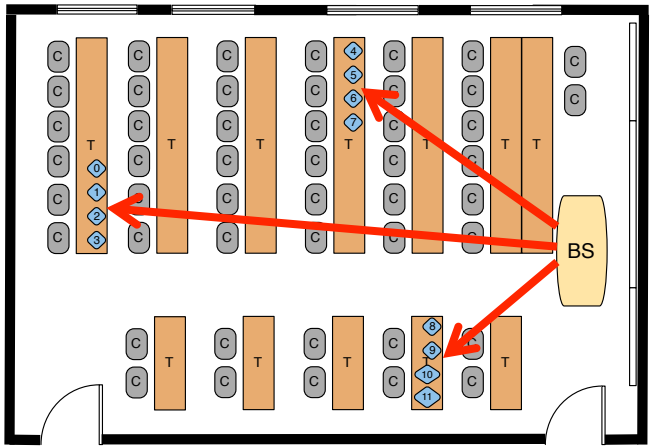
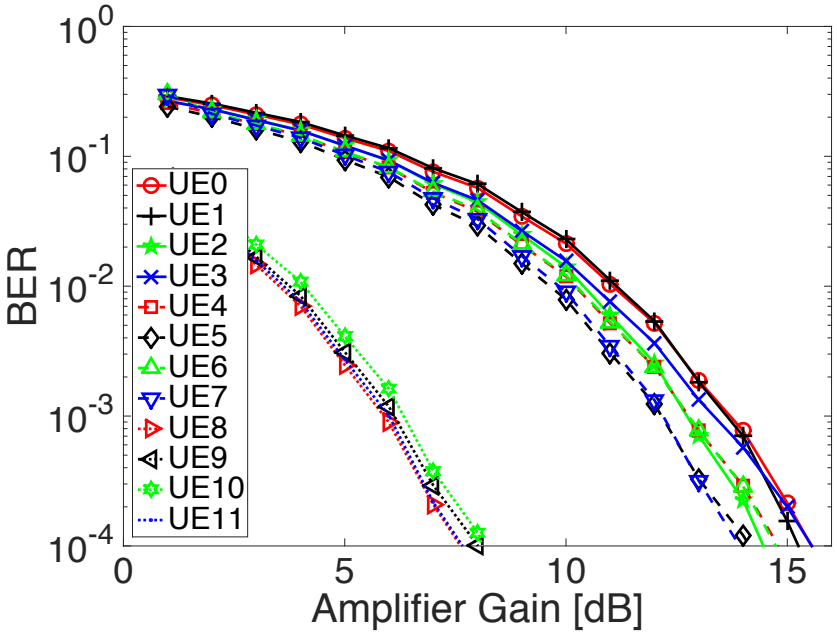
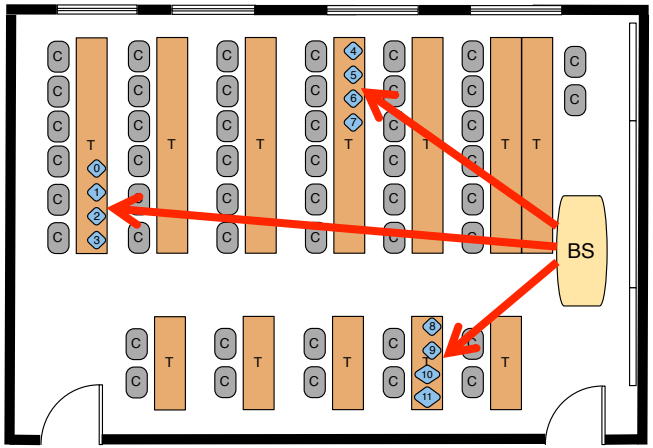
Downlink BERs (QPSK)

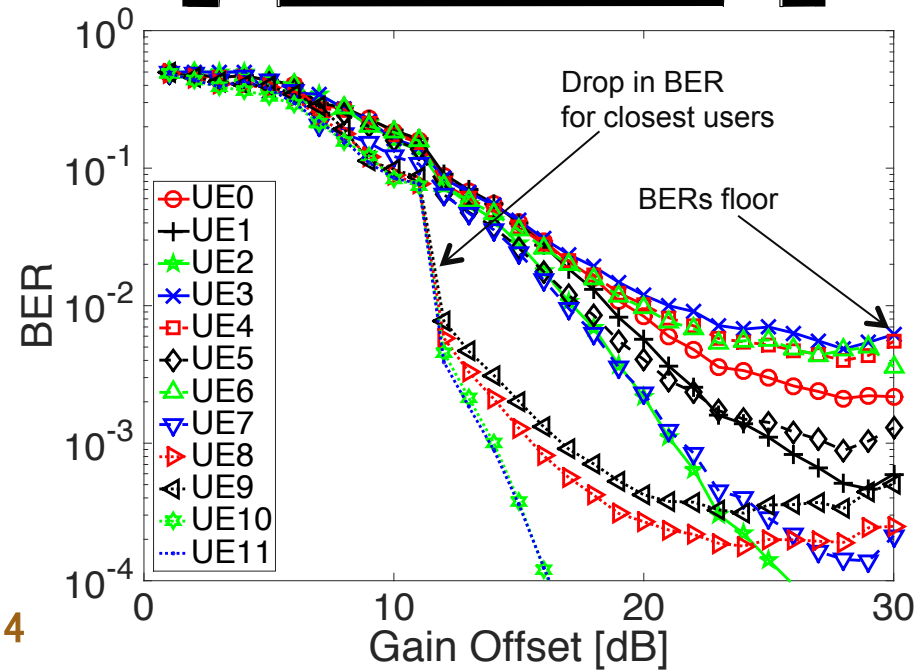




- ZF precoder
- Close by users (UE8-11) shows best BERs
- Other users (UE0-7) show similar performance
- High performance difference between UE8-11 and the UE0-7

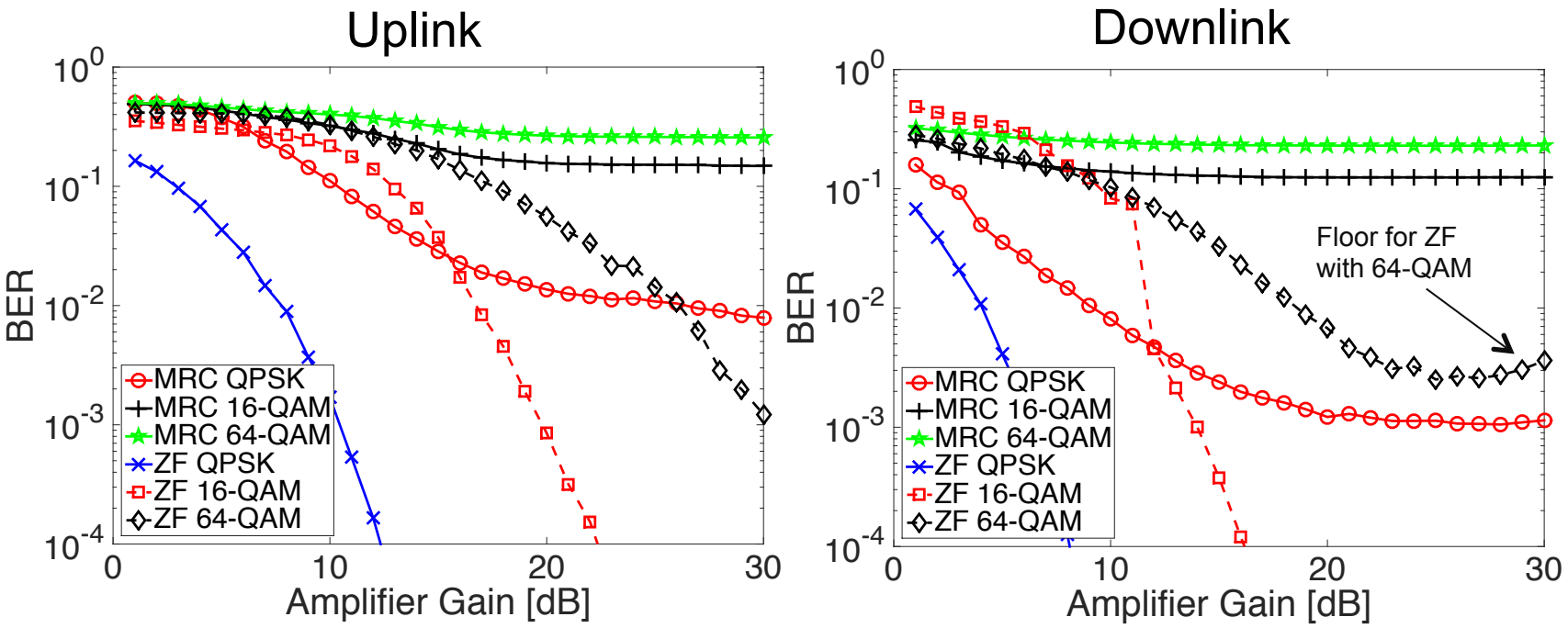
Downlink BERs (16-QAM)





- ZF detector
- Close by users (UE8-11) show best BERs
- Almost all users show a significant BER floor
  - Performance limited by reciprocity calibration accuracy and/or interference

ZF vs. MRC/MRT



- MRC/MRT showing significant error floors
  - Usable in practical systems?
- ZF far superior in real-life channels

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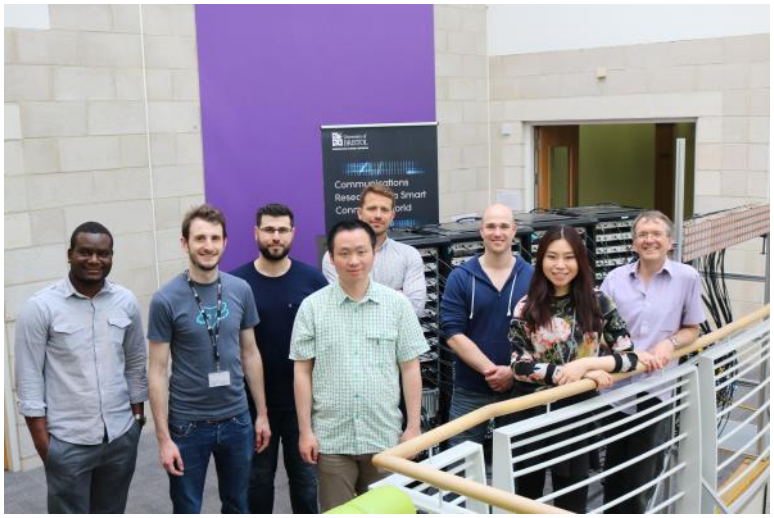
Collaborative Measurements in Bristol

- First joint measurement campaign with Lund University and University of Bristol in May 2016
- Based on Bristol MaMi system with 128 antennas
- How many users can be served simultaneously?
- What spectral efficiency can be achieved?



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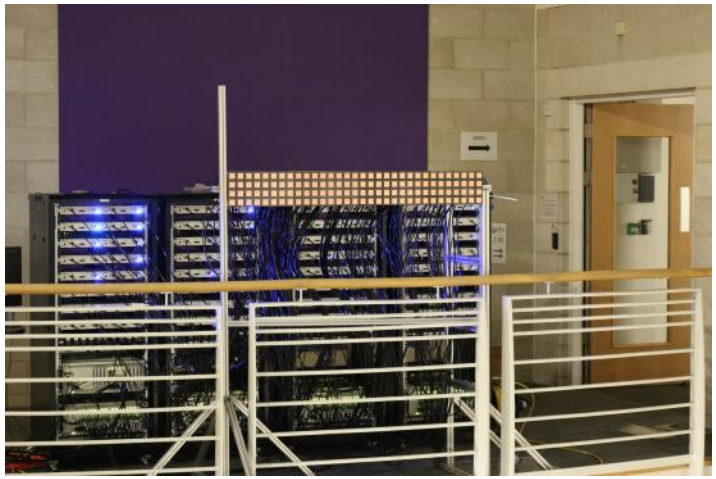
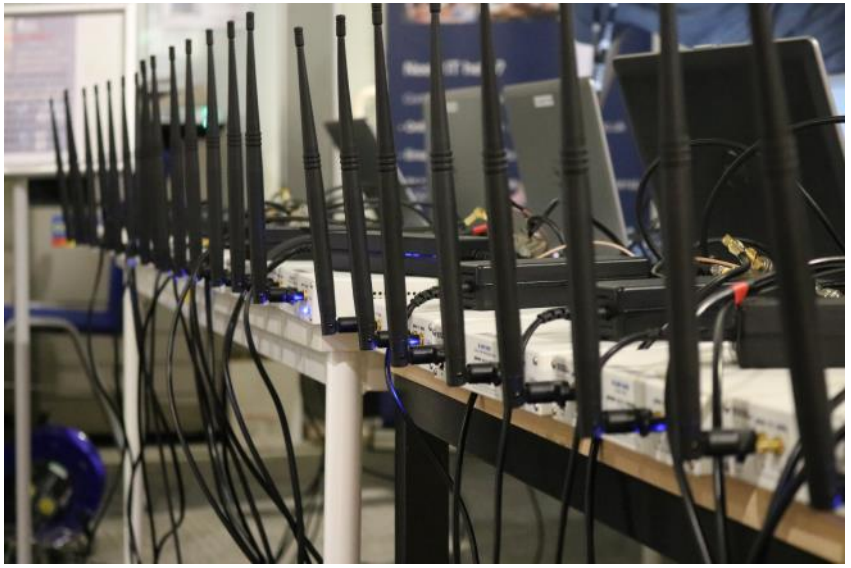
Setup

Base station



Closely spaced users



Overall setup from base station view

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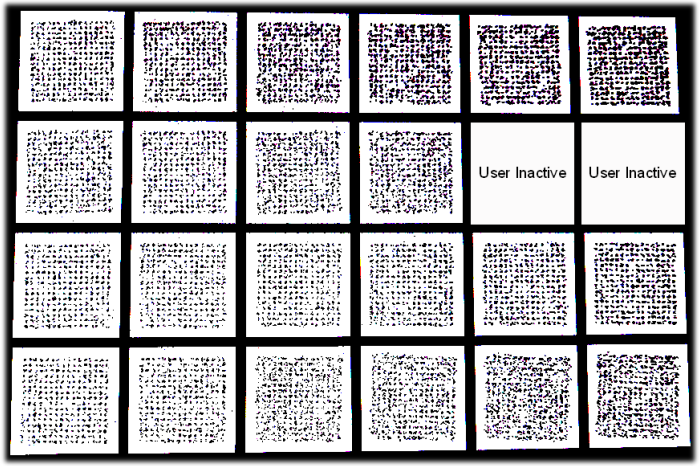
Results

- 22 users served simultaneously using 256-QAM
- Uncoded transmission
- Equating a spectral efficiency of 145 b/s/Hz



World record spectral efficiency

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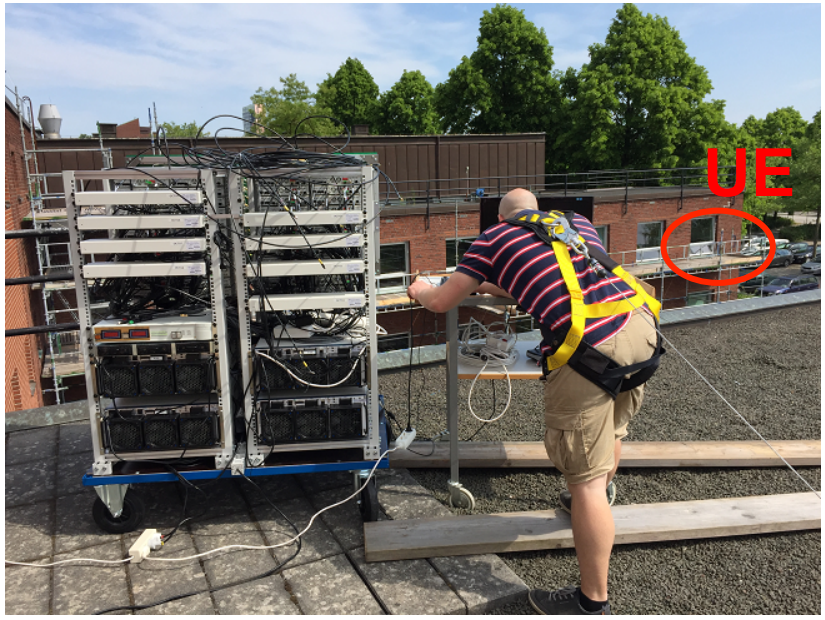
First Outdoor Trial I

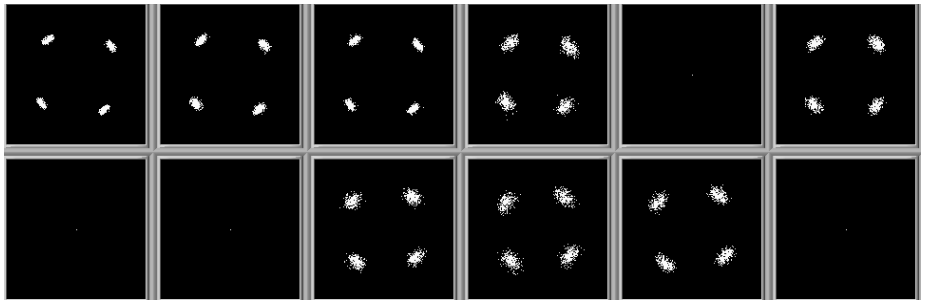
- First outdoor test to see whether reciprocity calibration and over-the-air synchronization works outdoor
- Focus on achieving good UL and DL constellations with up to 8 users and an additional moving user



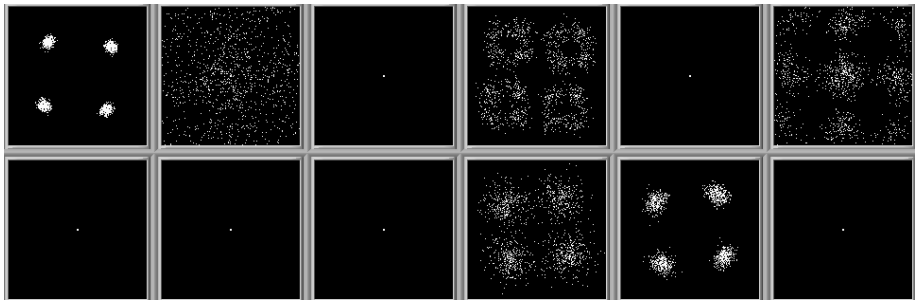
First Outdoor Trial III

UL constellations on BS

ZF



MRC



DL constellations with ZF

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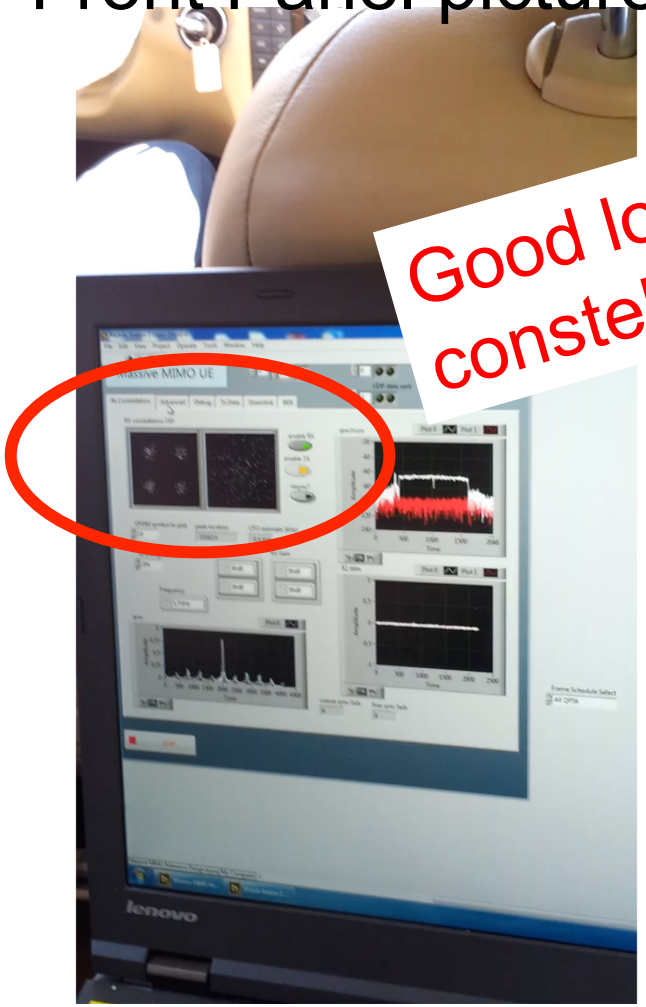
First Outdoor Trial III

One user in car

Front Panel picture



Good looking constellation

Joint Mobility Trials in Lund

- Together with a team from University of Bristol we performed the first mobility test using the LuMaMi testbed
- Goal was to analyze how well massive MIMO works in dynamic environments
- Tests were performed with up to 12 users, some mounted on cars (up to 40 km/h) and some mounted on cycle carts (walking speed)
- Uplink channel data, BERs and LabVIEW front panels were recorded

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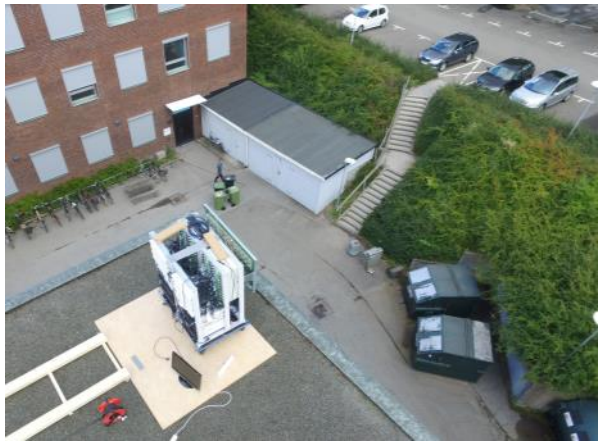
Setup / Equipment

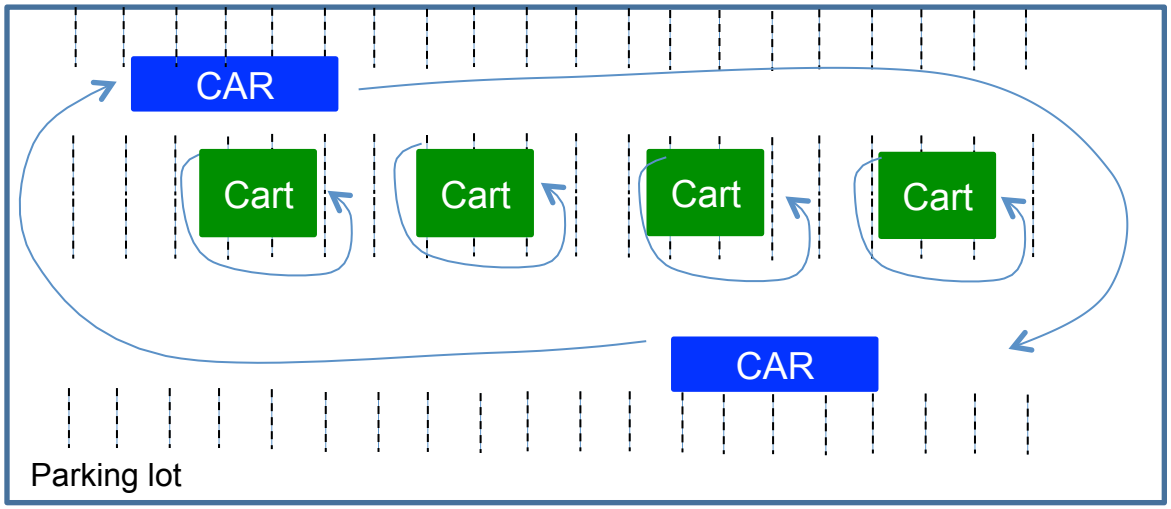
Base station deployed on rooftop



Users mounted on cycle cart

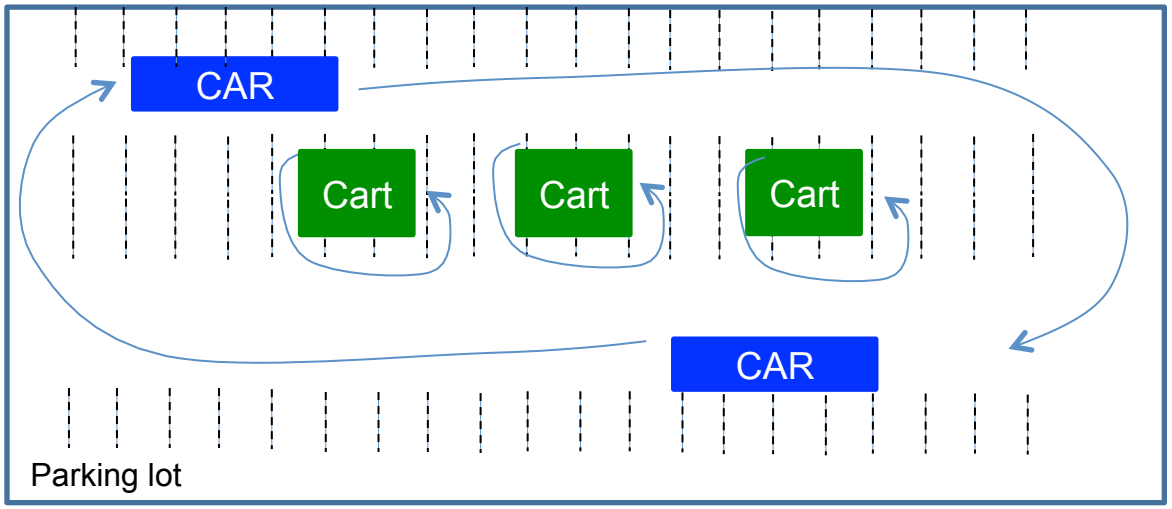
Users mounted on cars

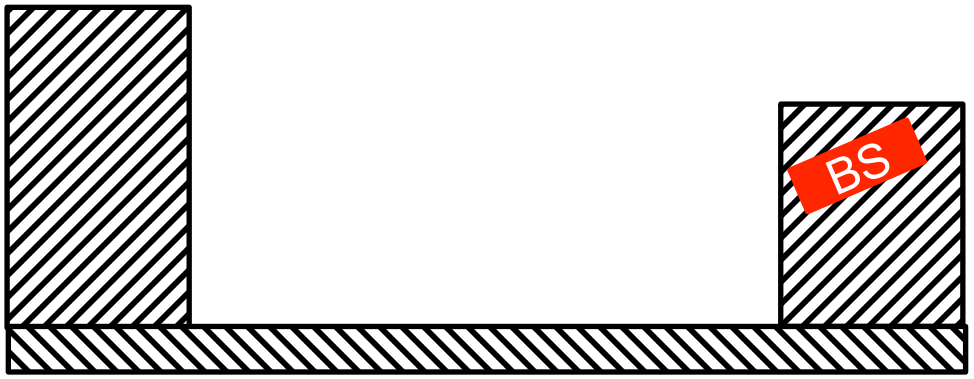
Different tested scenarios I



- Gradually adding users while observing performance

Different tested scenarios II





- Scenario with 6 users as pedestrians and 4 users on cars
- Video including live BERs and constellations
- Playback recorded channel data

10 user mobility test video

PLEASE CHECK OUT FOLLOWING LINK

https://www.youtube.com/watch?v=wPPMrr4rHmo

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Conclusions

- The LuMaMi testbed is fully functional and working for UL and DL transmission
- In a joint campaign Lund University and University of Bristol achieved a new world record for spectral efficiency
- Indoor measurements showed that even with 100 antennas at the BS, MRC/MRT show significantly worse performance than ZF
- Mobility measurements showed that massive MIMO works for moving users with relatively good BER performance on UL and DL (more analysis to be performed)

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Frame Structure