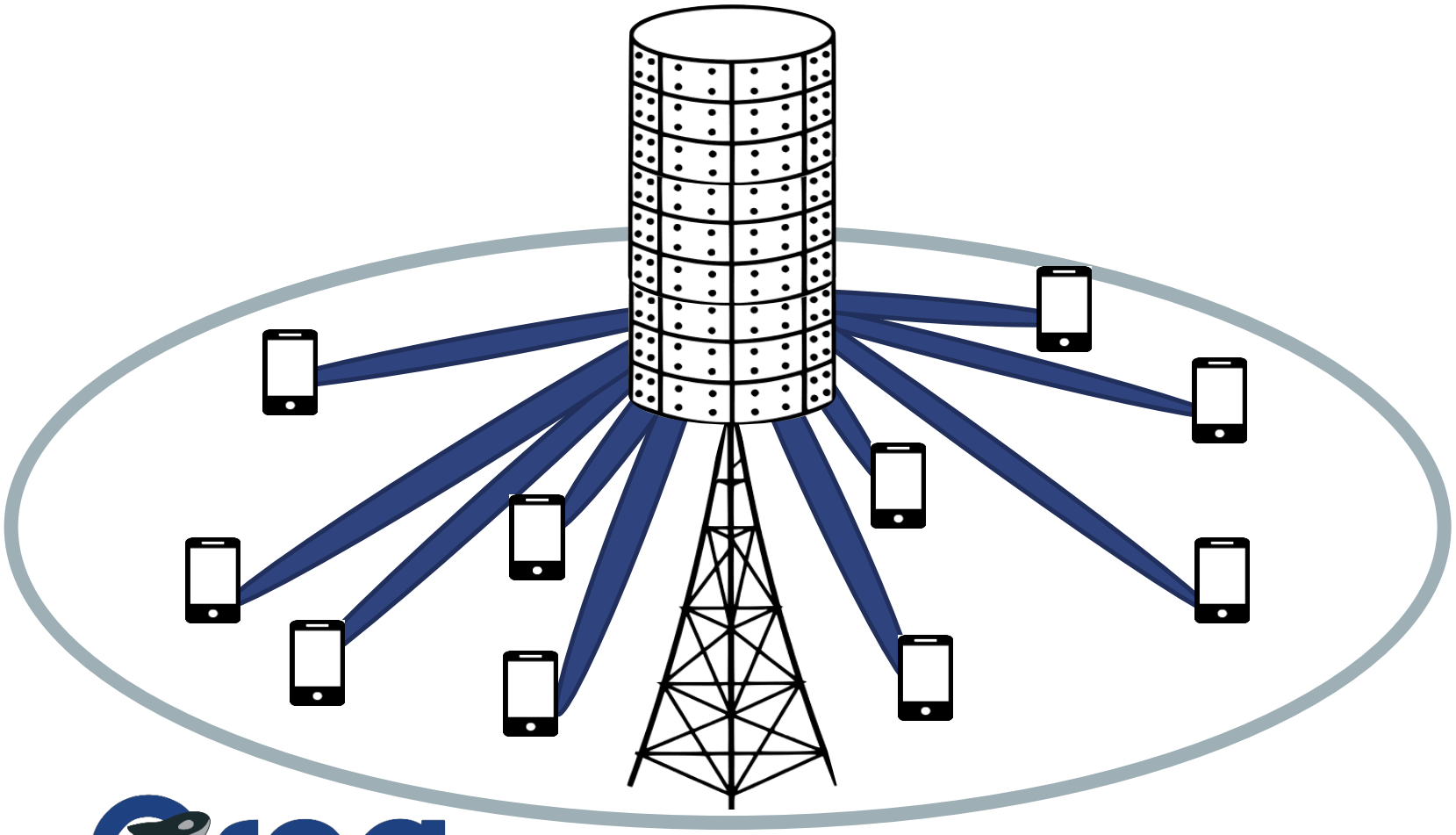
KU LEUVEN

From Massive MIMO to distributed to mmWave Hybrid MIMO on SDR

Sofie Pollin and Andrea Guevara, Sibren De Bast, Achiel Colpaert

November 14 2019

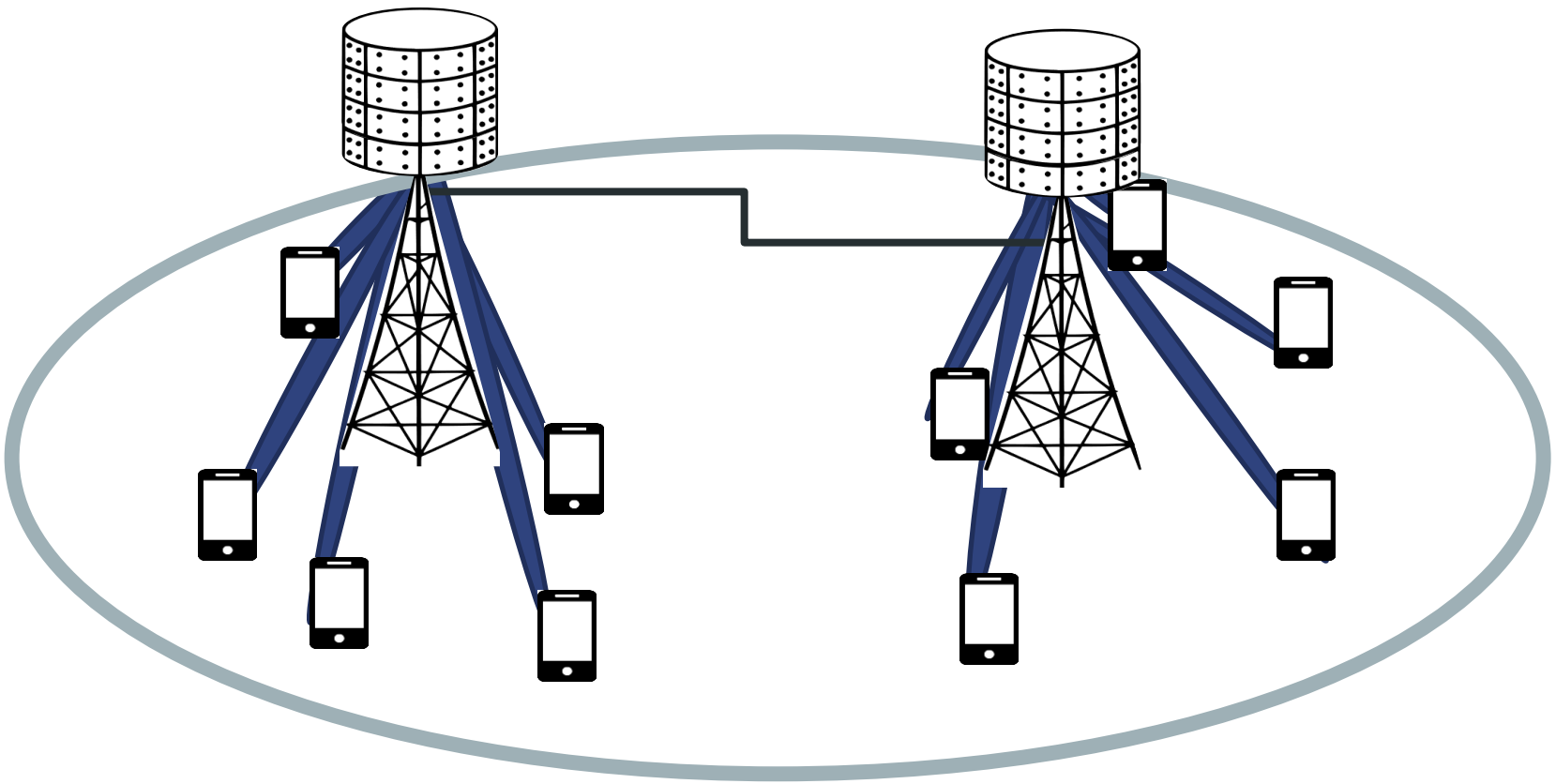
Centralised Massive MIMO



Massive MIMO topologies

Collocated	Distributed
• Central processing • Less demanding backhaul	• Exploiting diversity • Reducing shadow fading

Distributed Massive MIMO
Not (yet) cell free



Massive MIMO topologies	
Collocated • Central processing • Less demanding backhaul	Distributed • Exploiting diversity • Reducing shadow fading

Outline

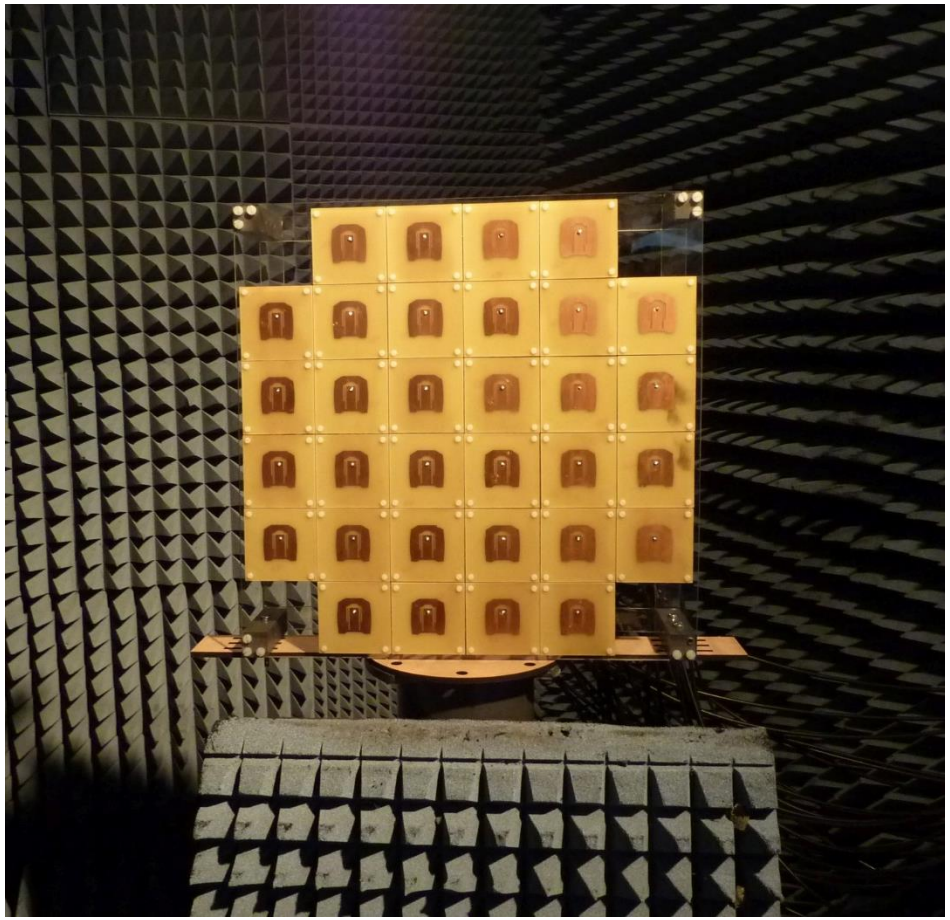
Architecture

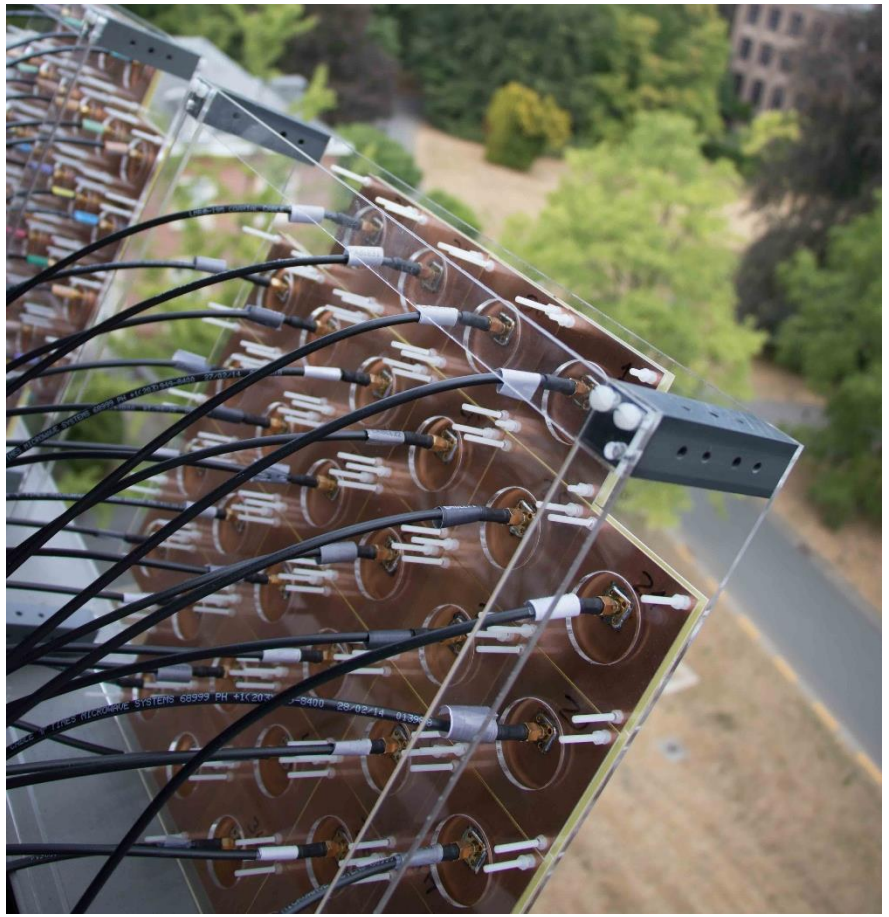
Datasets

Results

Architecture

KU Leuven Distributed Massive MIMO testbed

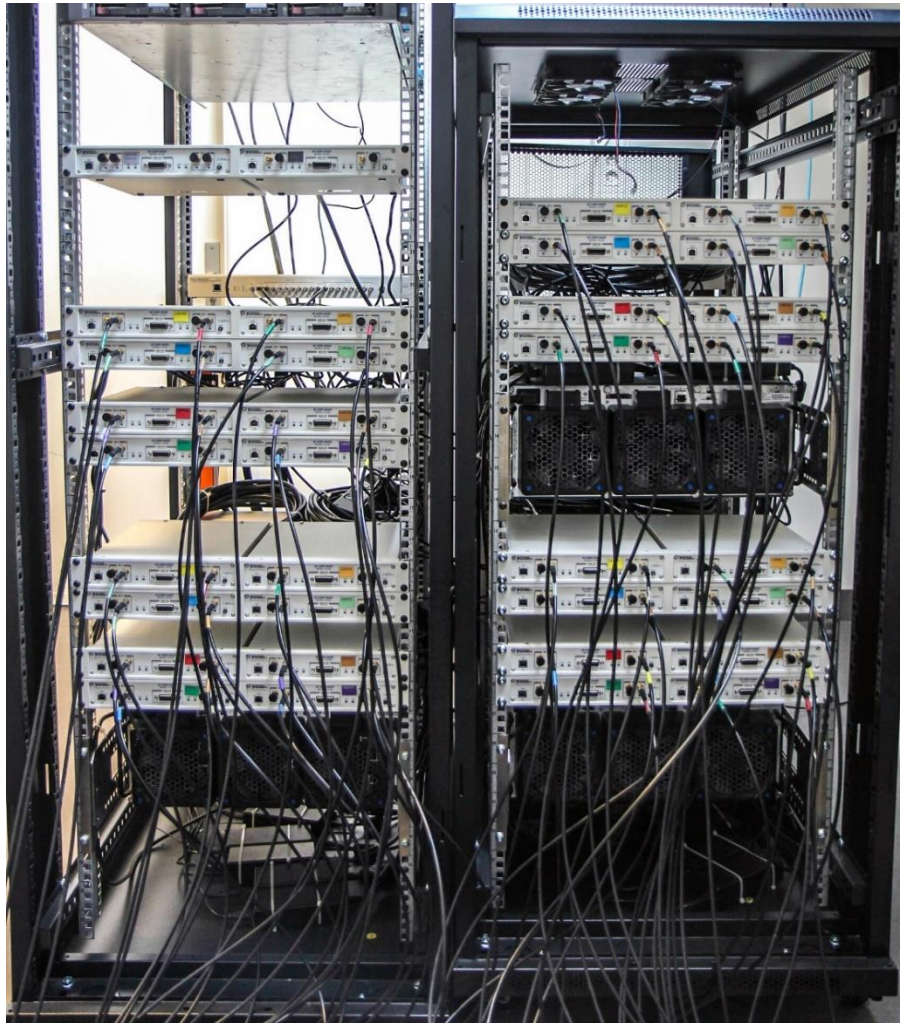




Antennas

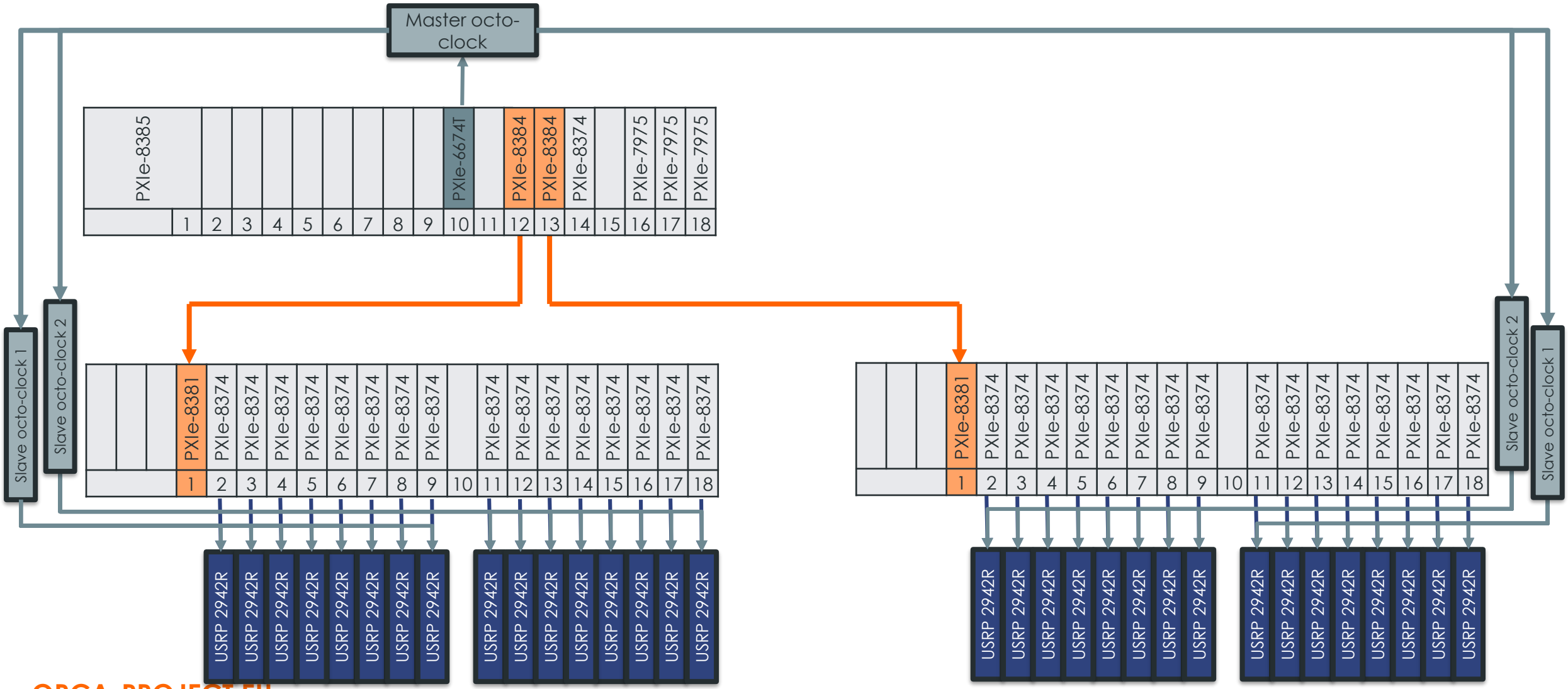
- 64 patch antennas
- distributed in two arrays

KU Leuven Distributed Massive MIMO testbed

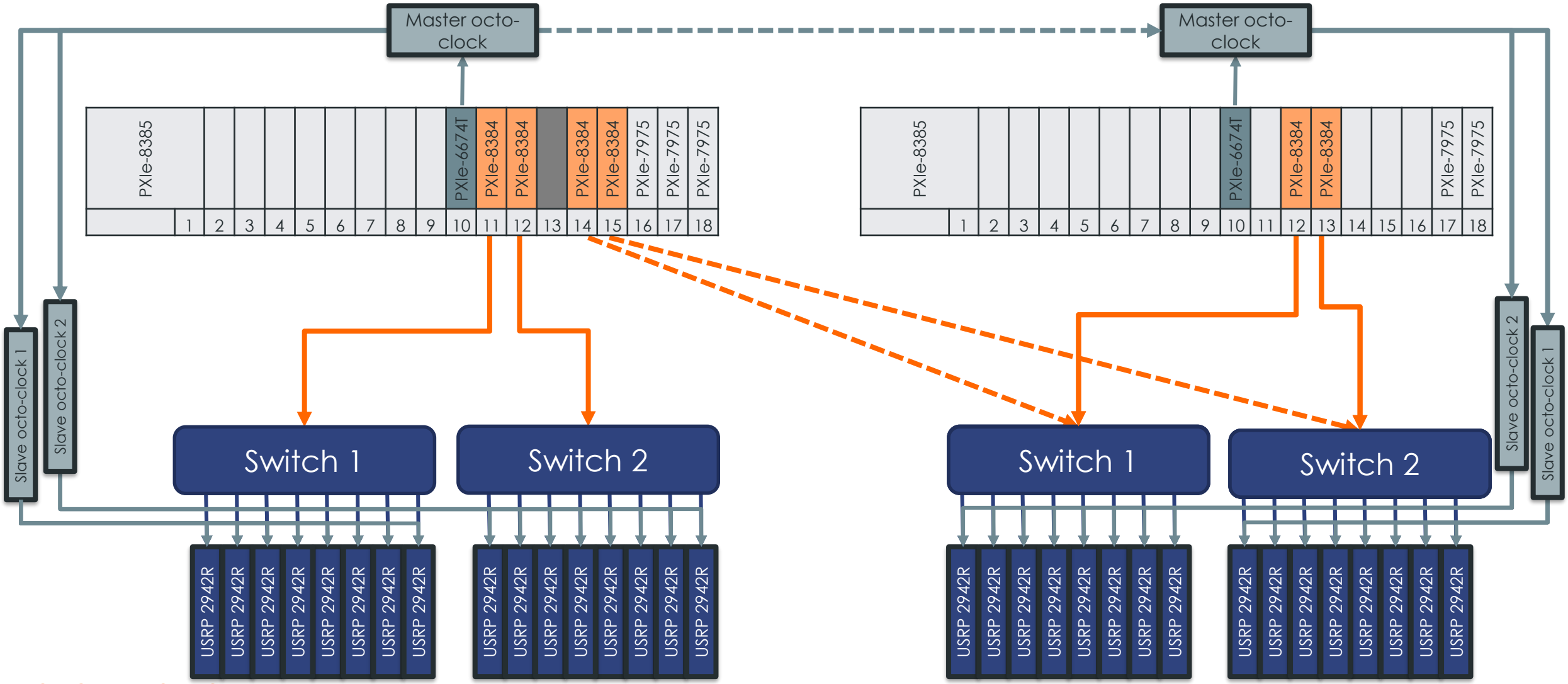


Front End & Core		
Type	Number	Location
NI USRP-2942R	32	Front End
NI PXIe-8135	1	Core
NI PXIe-7975R Flex Rio	2	Core
Central frequency: 2.61GHz		
Bandwidth: 40MHz		

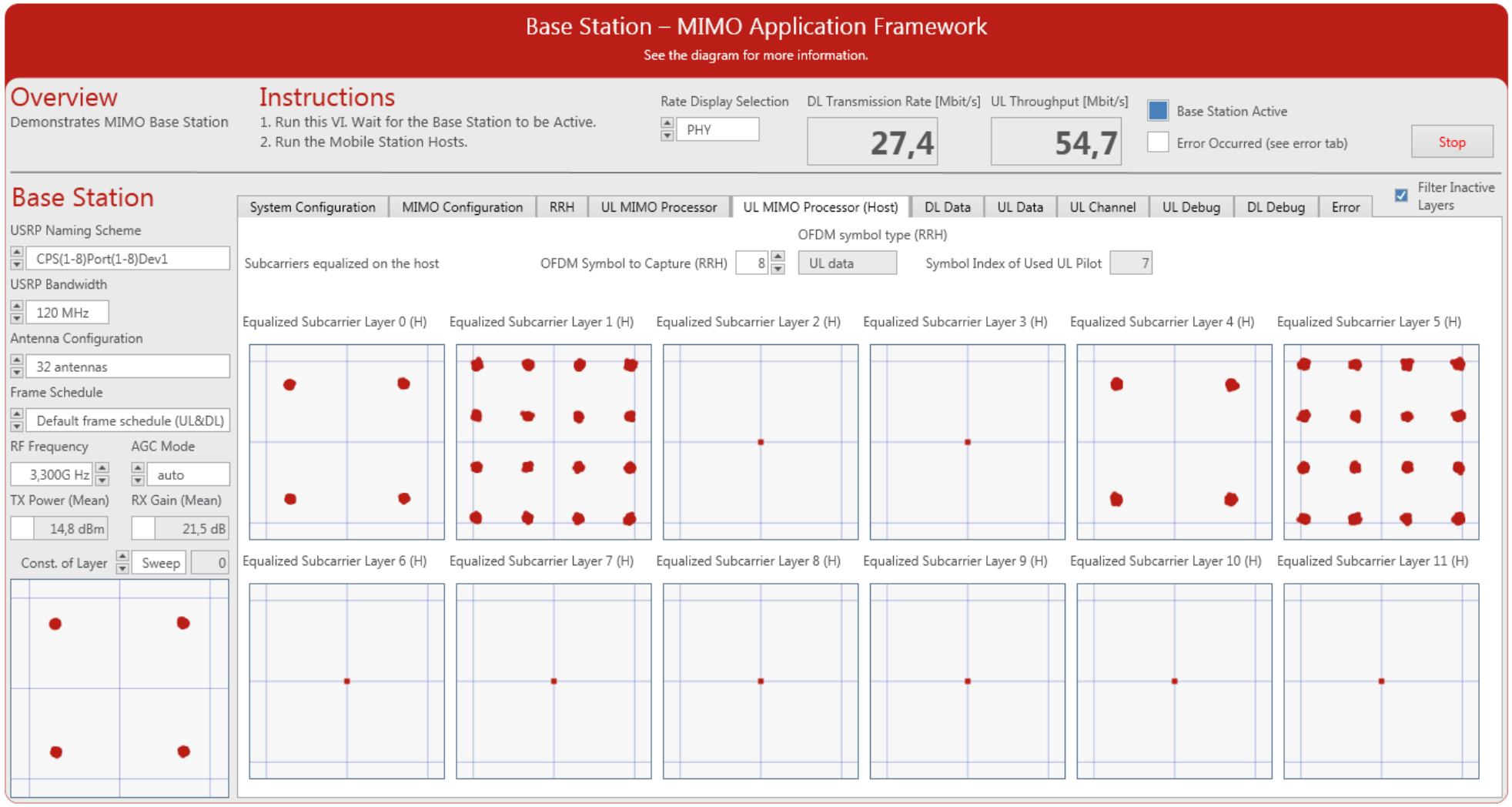
Hardware distribution



Updated Testbed: Fully Distributed MIMO

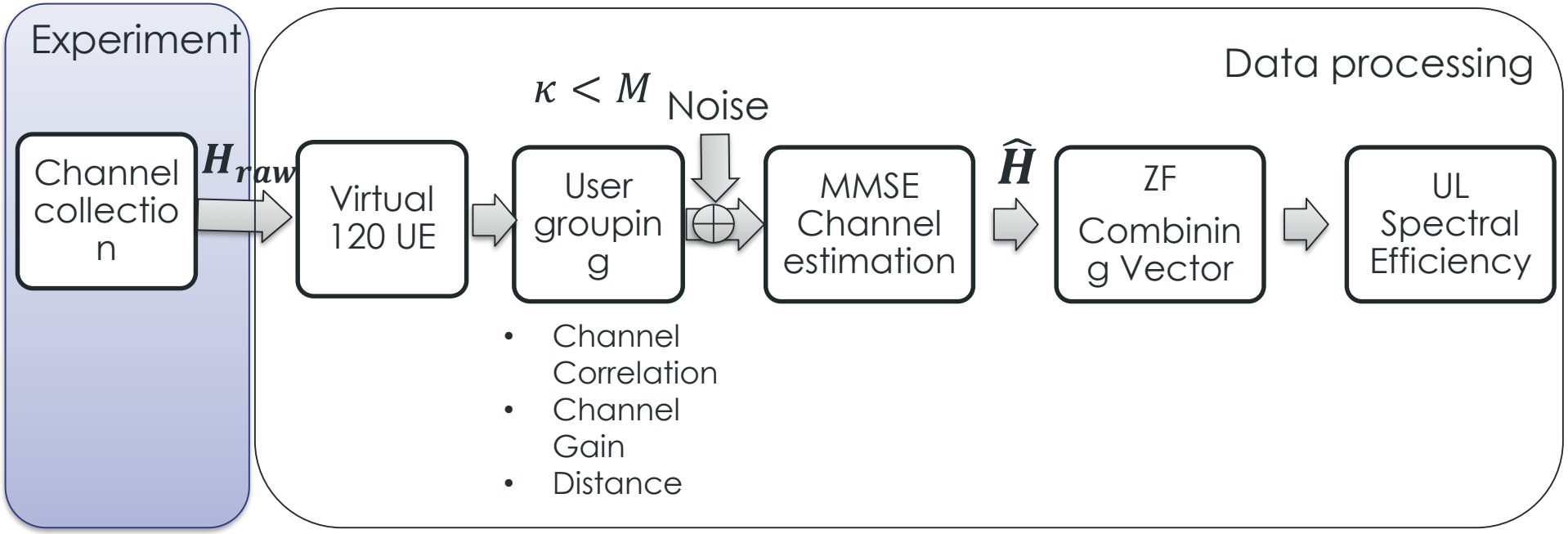


Software


Base Station – MIMO Application Framework
See the diagram for more information.
Overview
Demonstrates MIMO Base Station
Instructions
1. Run this VI. Wait for the Base Station to be Active.
2. Run the Mobile Station Hosts.
Rate Display Selection
PHY
DL Transmission Rate [Mbit/s]
27,4
UL Throughput [Mbit/s]
54,7
Base Station Active
Error Occurred (see error tab)
Stop
Base Station
USRP Naming Scheme
CPS(1-8)Port(1-8)Dev1
USRP Bandwidth
120 MHz
Antenna Configuration
32 antennas
Frame Schedule
Default frame schedule (UL&DL)
RF Frequency
3,300G Hz
AGC Mode
auto
TX Power (Mean)
14,8 dBm
RX Gain (Mean)
21,5 dB
Const. of Layer
Sweep
0
System Configuration
MIMO Configuration
RRH
UL MIMO Processor
UL MIMO Processor (Host)
DL Data
UL Data
UL Channel
UL Debug
DL Debug
Error
Filter Inactive Layers
Subcarriers equalized on the host
OFDM Symbol to Capture (RRH)
8
OFDM symbol type (RRH)
UL data
Symbol Index of Used UL Pilot
7
Equalized Subcarrier Layer 0 (H)
Equalized Subcarrier Layer 1 (H)
Equalized Subcarrier Layer 2 (H)
Equalized Subcarrier Layer 3 (H)
Equalized Subcarrier Layer 4 (H)
Equalized Subcarrier Layer 5 (H)
Equalized Subcarrier Layer 6 (H)
Equalized Subcarrier Layer 7 (H)
Equalized Subcarrier Layer 8 (H)
Equalized Subcarrier Layer 9 (H)
Equalized Subcarrier Layer 10 (H)
Equalized Subcarrier Layer 11 (H)

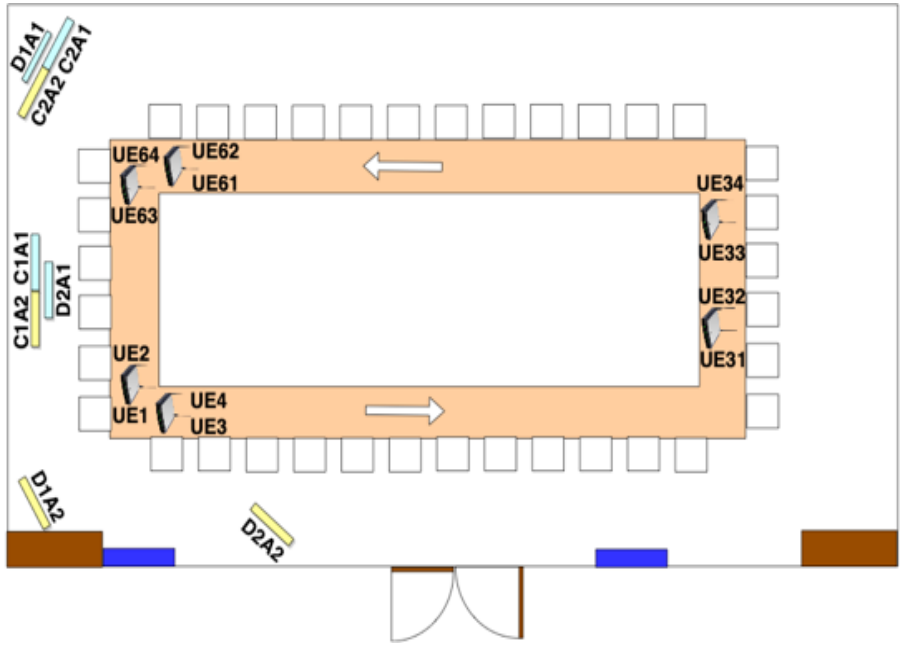
Datasets

Data Processing



Dataset Collection

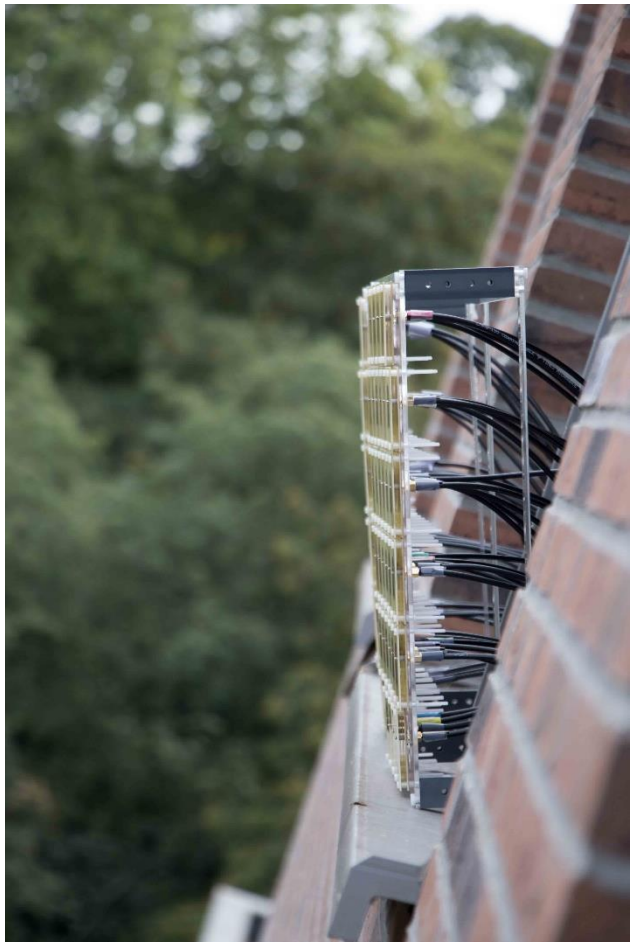
Meeting Room



Dataset Collection

Meeting Room

Outdoor

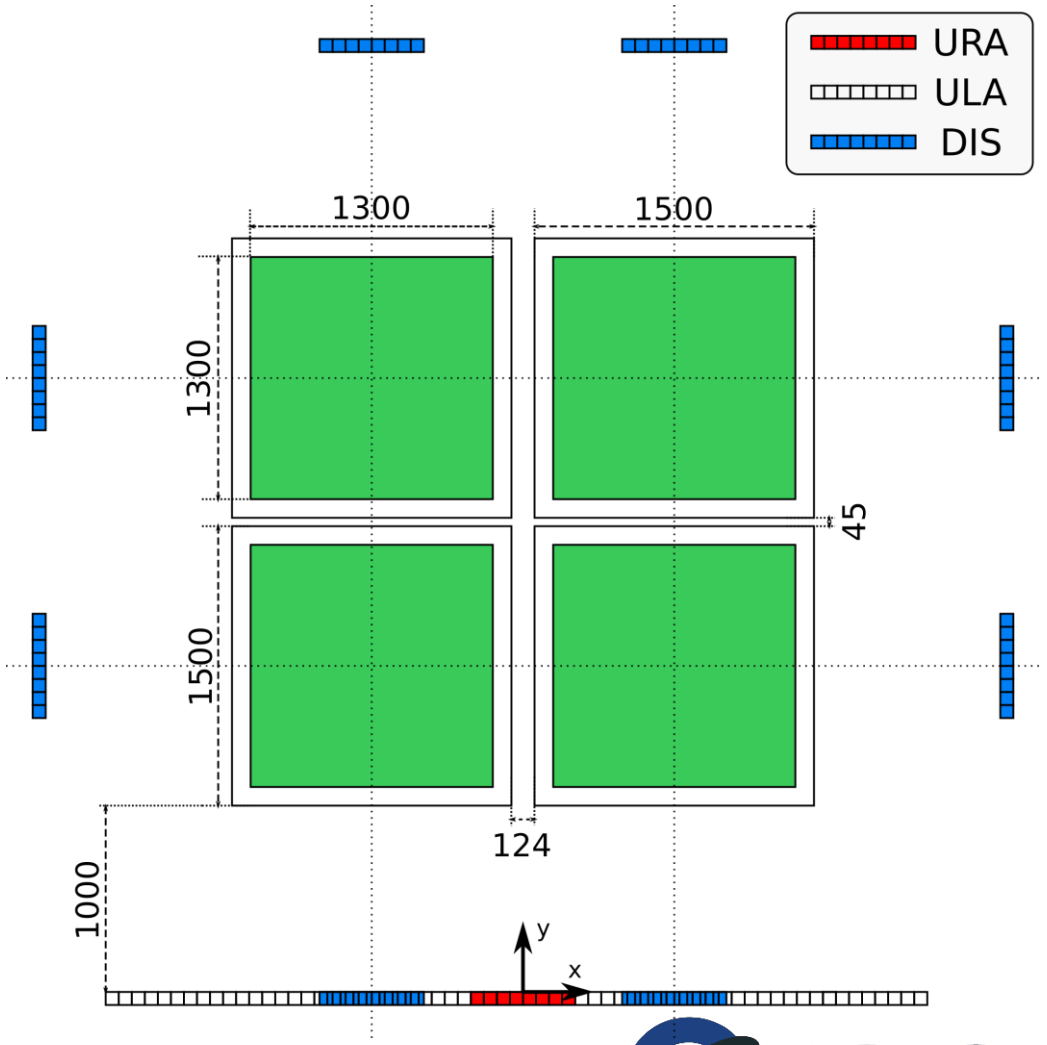


Dataset Collection

Meeting Room

Outdoor

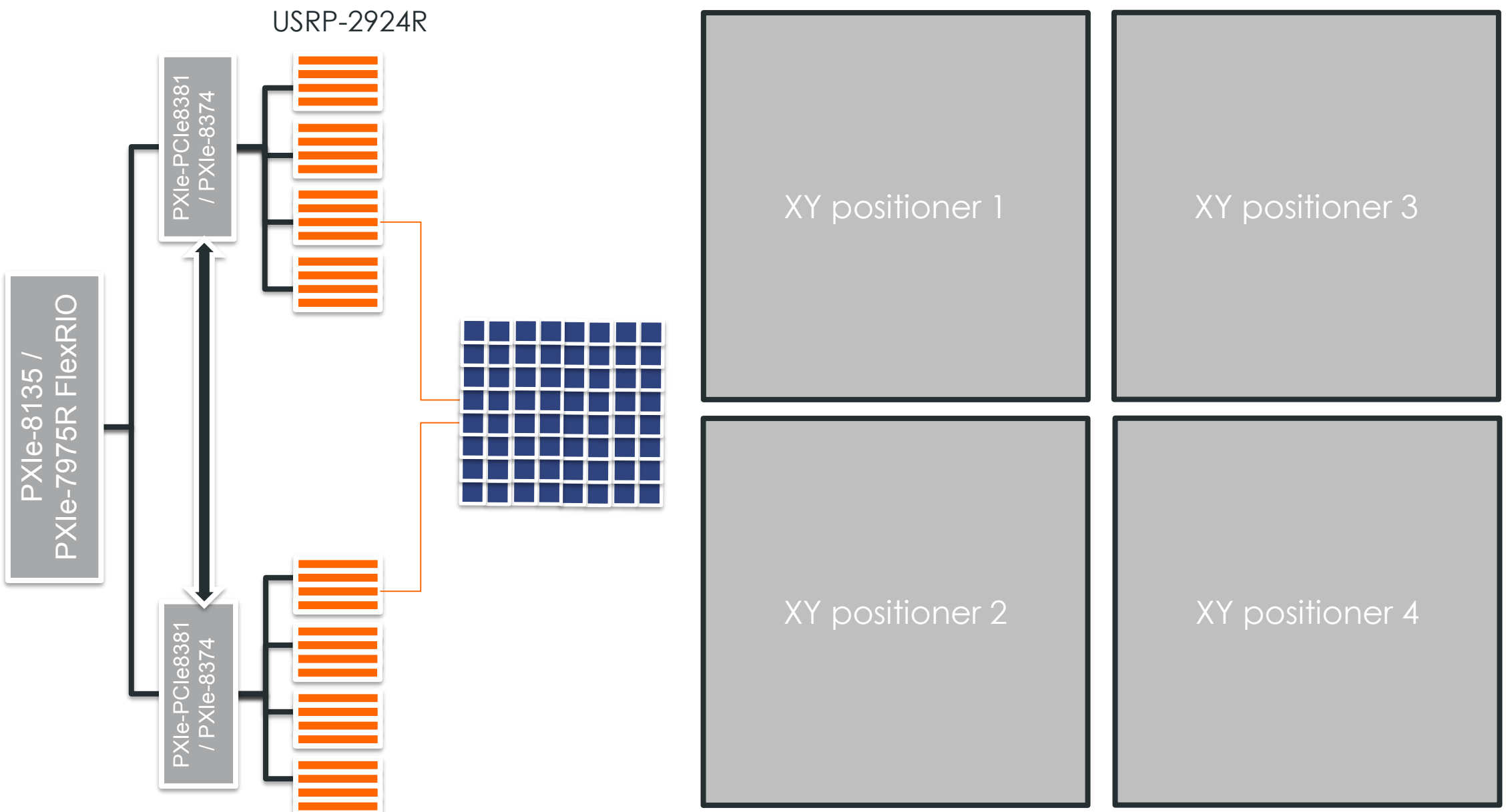
Localisation



ANTENNA CONFIGURATION

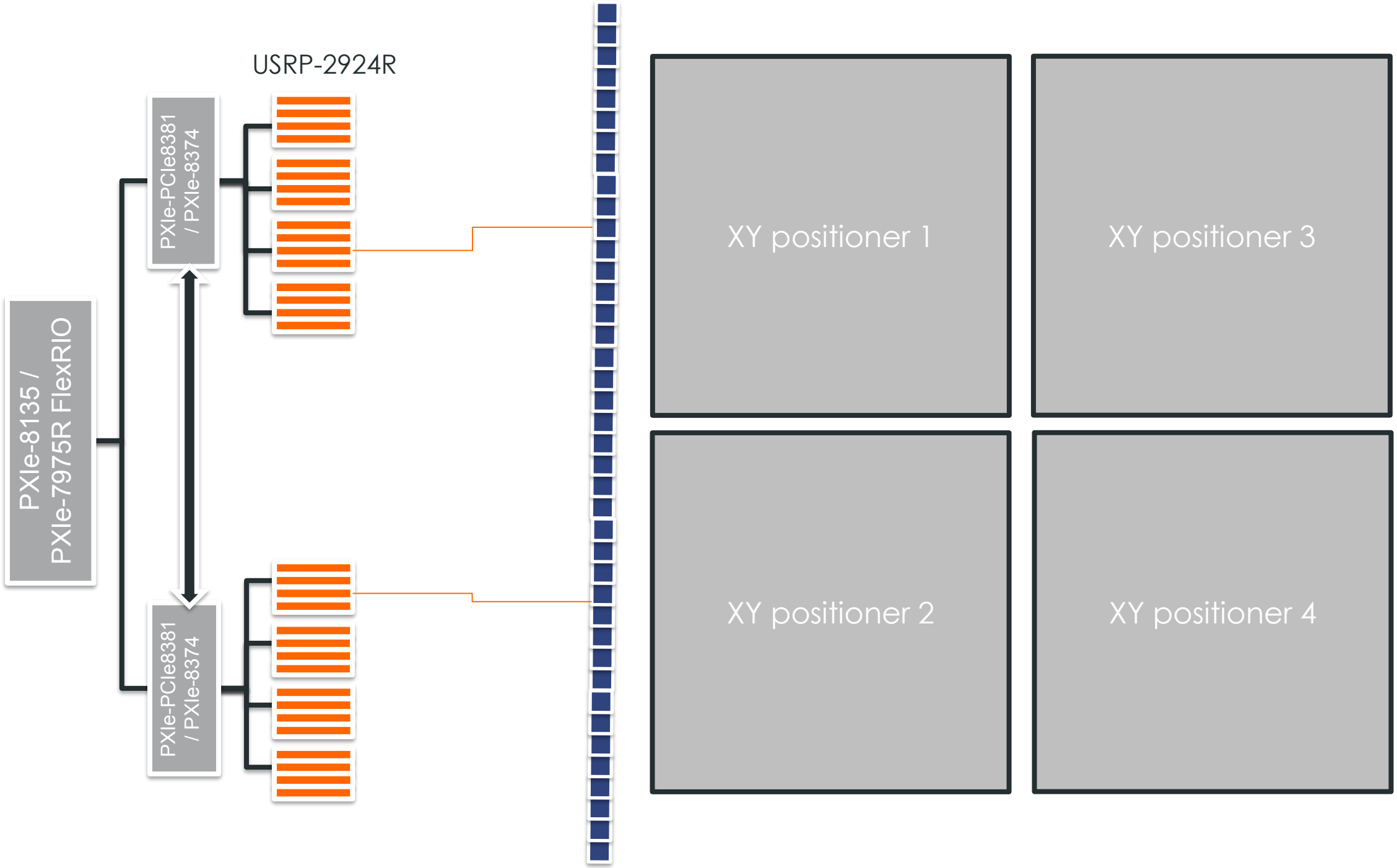
LOS CENTRALIZED
64 ANTENNAS

8X8 ARRAY

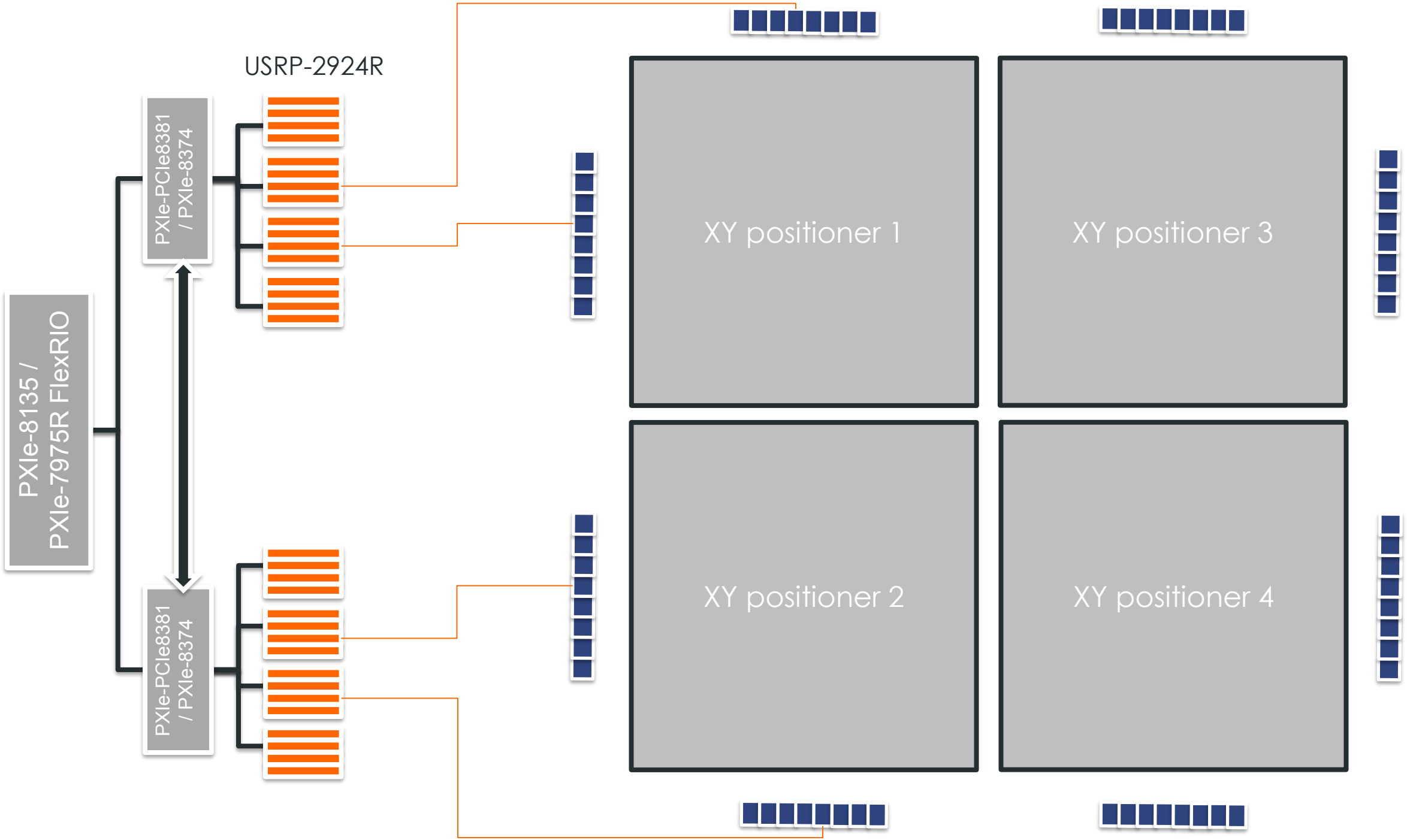

USRP-2924R
PXIe-8135 /
PXIe-7975R FlexRIO
PXIe-PCIe8381
/ PXIe-8374
PXIe-PCIe8381
/ PXIe-8374
XY positioner 1
XY positioner 3
XY positioner 2
XY positioner 4

LOS CENTRALIZED ULA 64 ANTENNAS

1X64 ARRAY

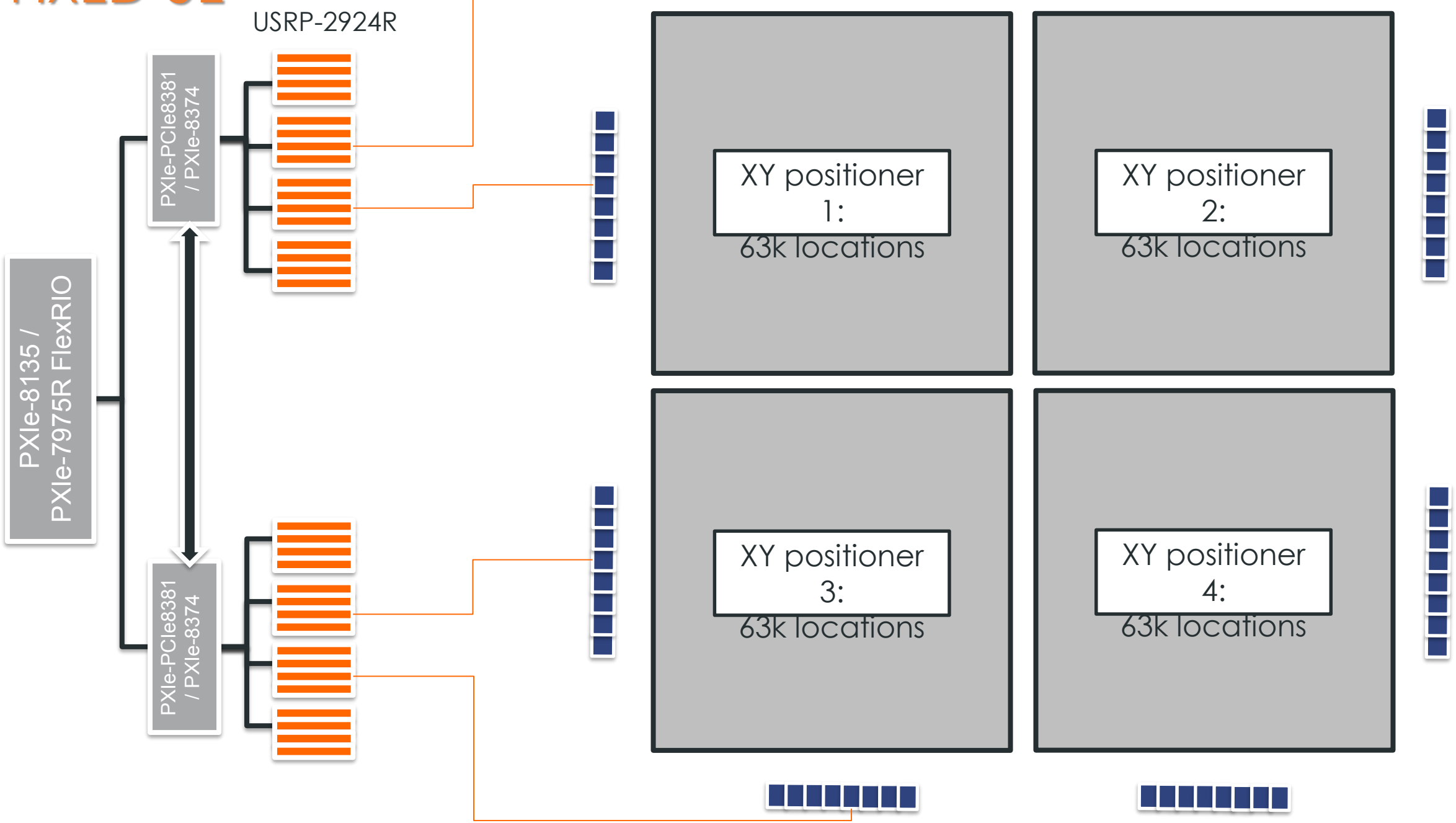

USRP-2924R
PXIe-PCIe8381
/ PXIe-8374
PXIe-8135 /
PXIe-7975R FlexRIO
PXIe-PCIe8381
/ PXIe-8374
XY positioner 1
XY positioner 3
XY positioner 2
XY positioner 4

LOS ULA DISTRIBUTED
8 ARRAYS 1X8

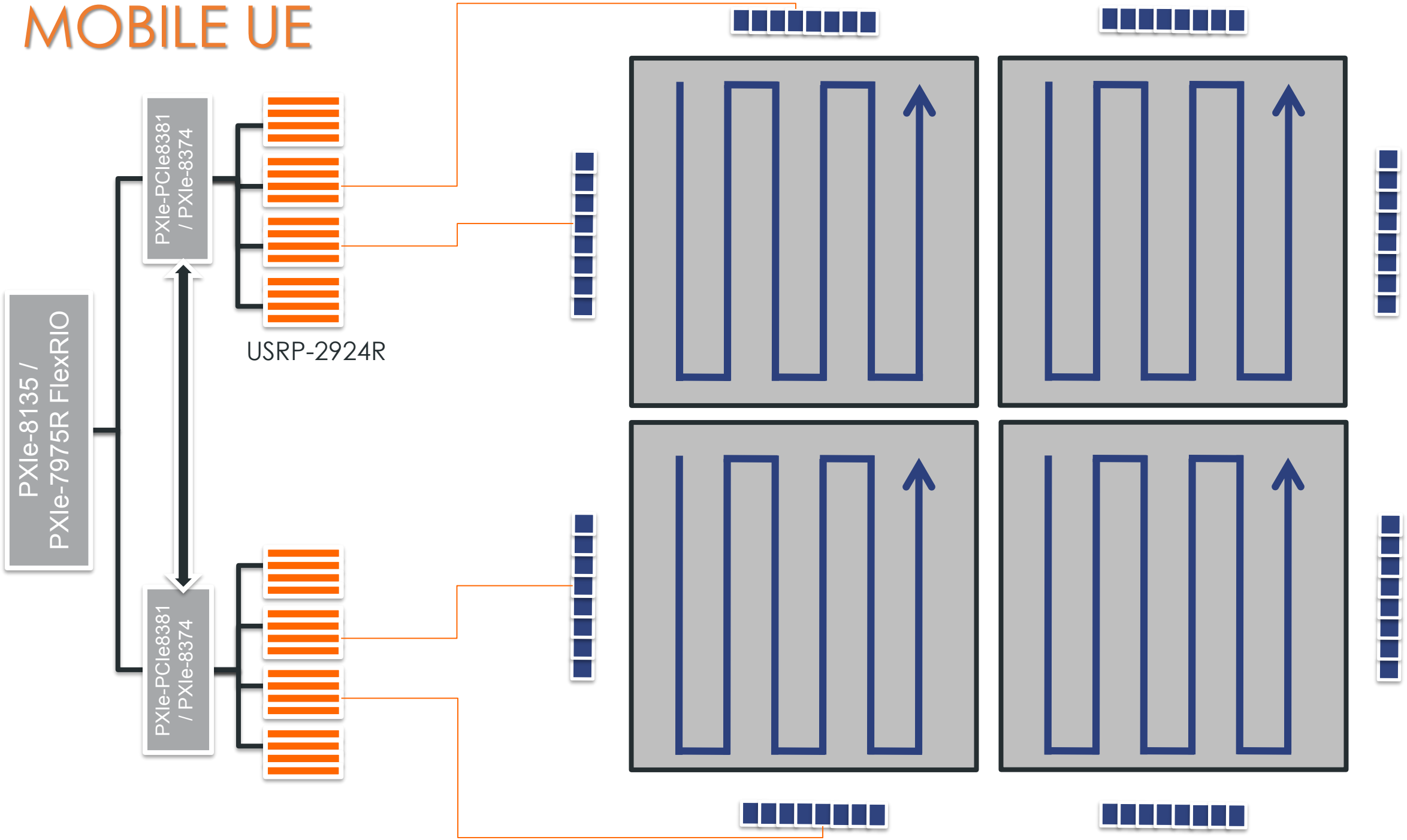

USRP-2924R
PXIe-PCIe8381
/ PXIe-8374
PXIe-8135 /
PXIe-7975R FlexRIO
PXIe-PCIe8381
/ PXIe-8374
XY positioner 1
XY positioner 3
XY positioner 2
XY positioner 4

UE LOCATION

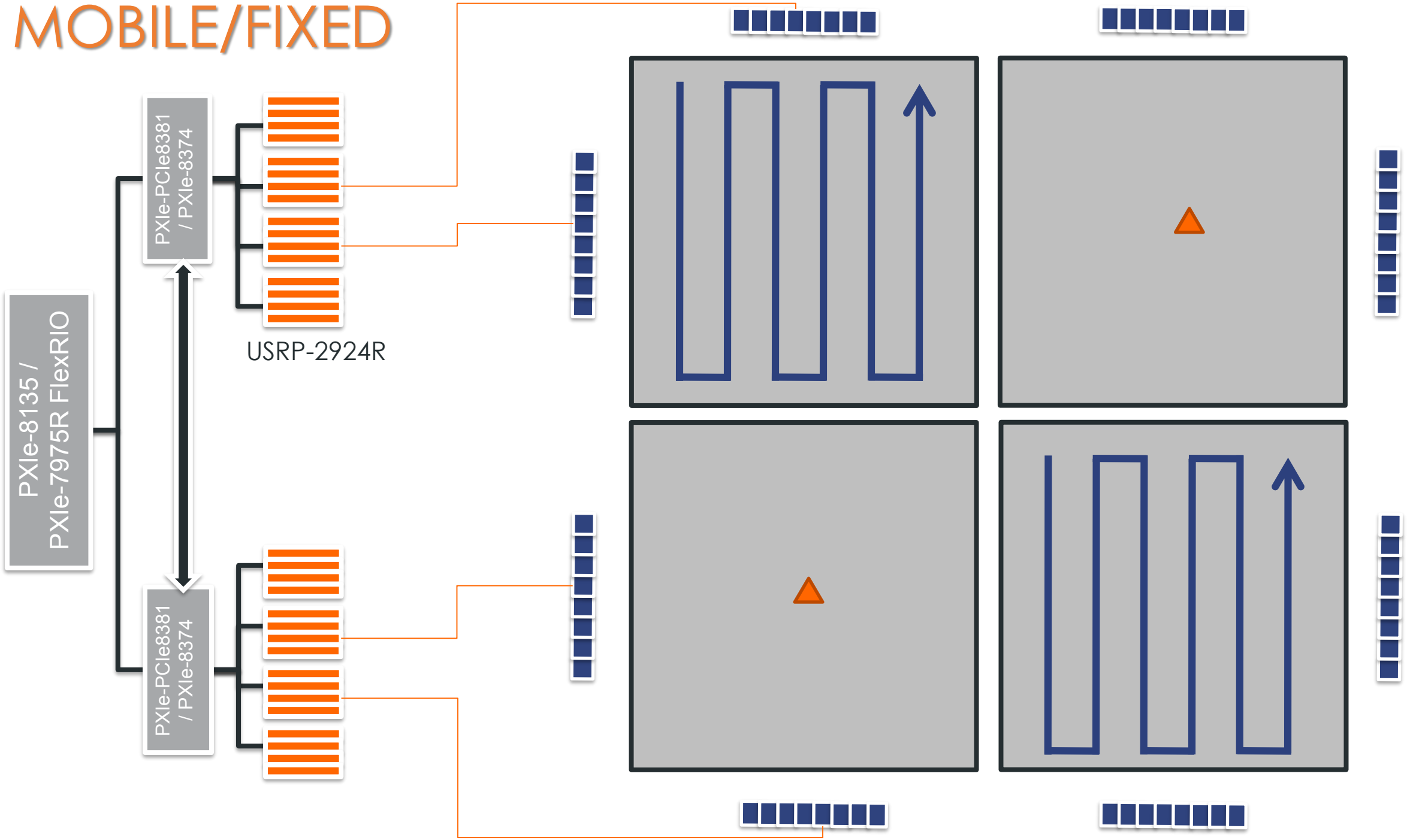
FIXED UE


USRP-2924R
PXIe-PCIe8381 / PXIe-8374
PXIe-8135 / PXIe-7975R FlexRIO
PXIe-PCIe8381 / PXIe-8374
XY positioner 1: 63k locations
XY positioner 2: 63k locations
XY positioner 3: 63k locations
XY positioner 4: 63k locations

MOBILE UE

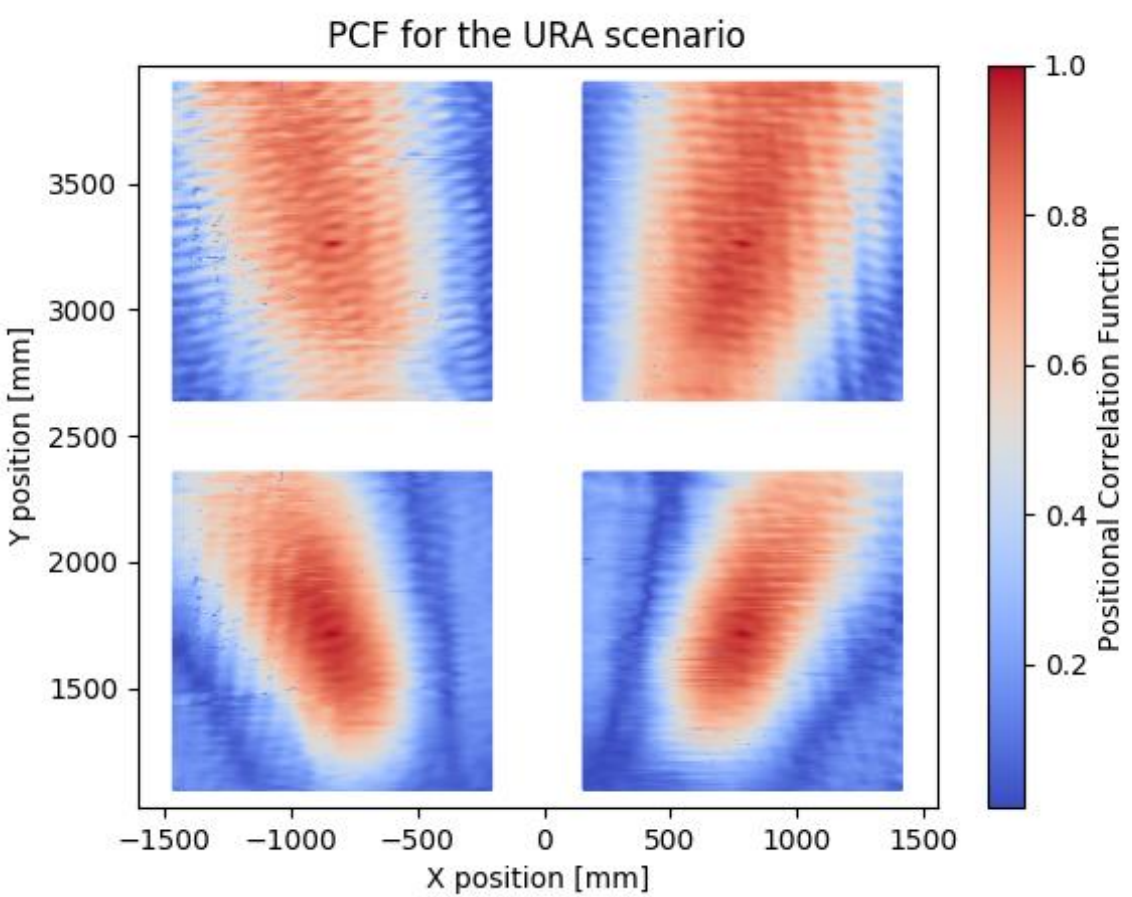

PXIe-8135 /
PXIe-7975R FlexRIO
PXIe-PCIe8381
/ PXIe-8374
PXIe-PCIe8381
/ PXIe-8374
USRP-2924R

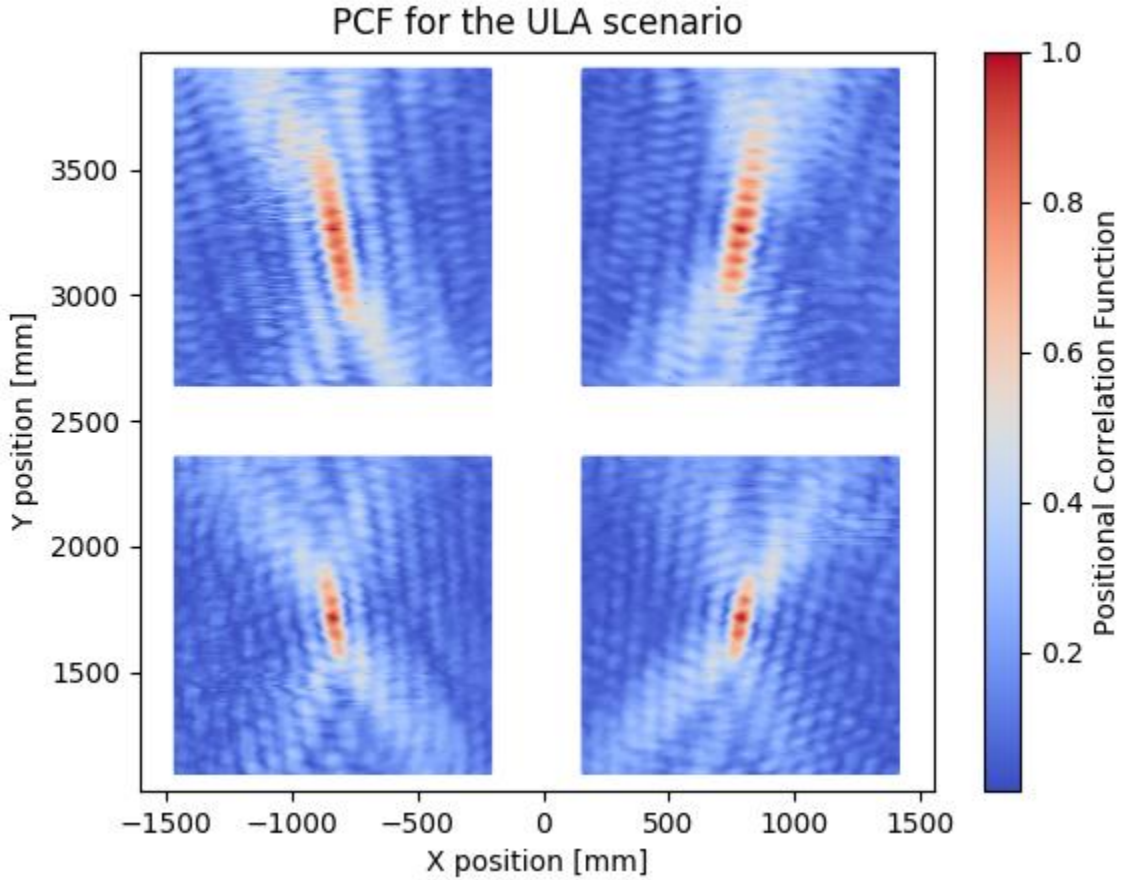
MOBILE/FIXED



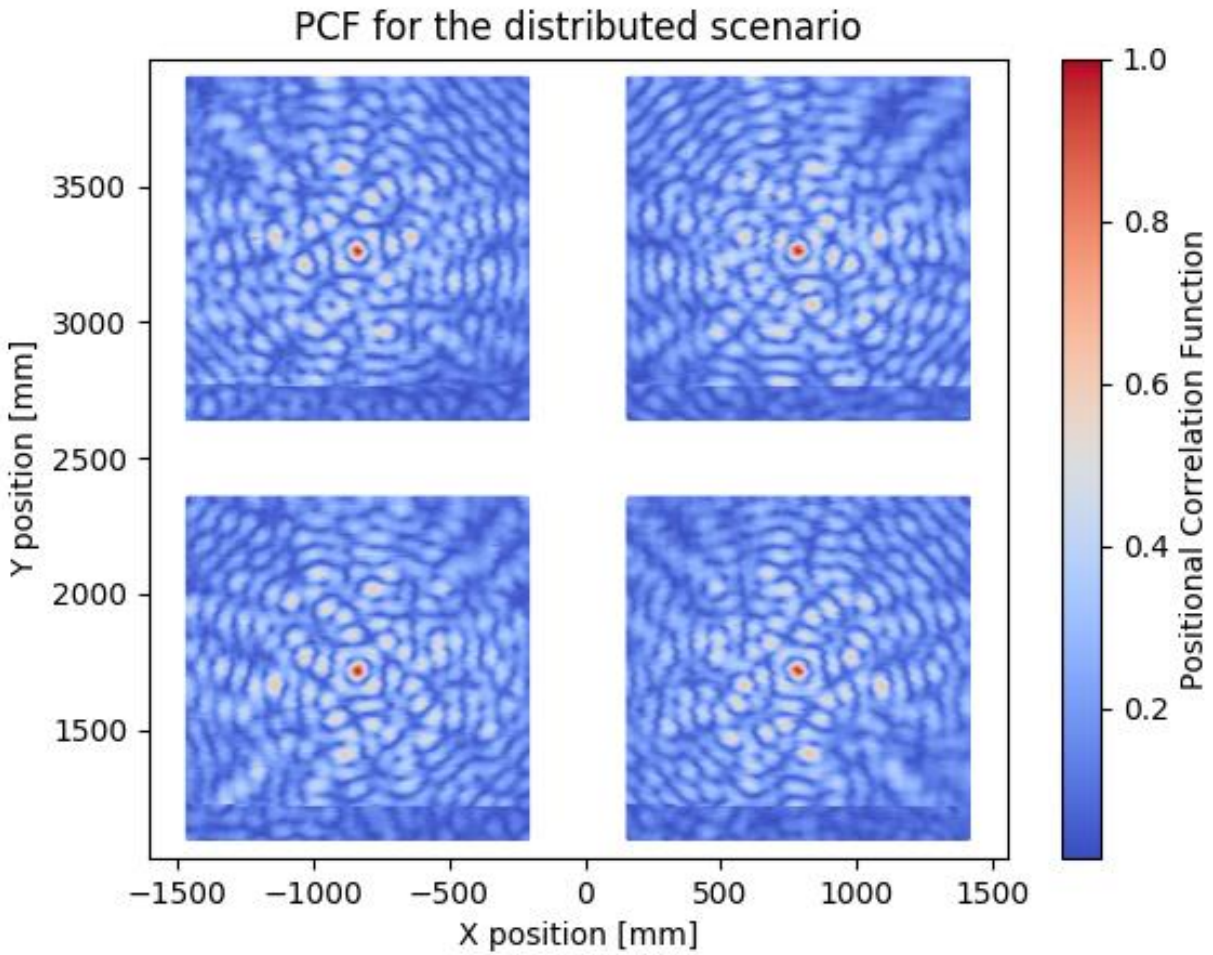
RESULTS

Position Correlation Function



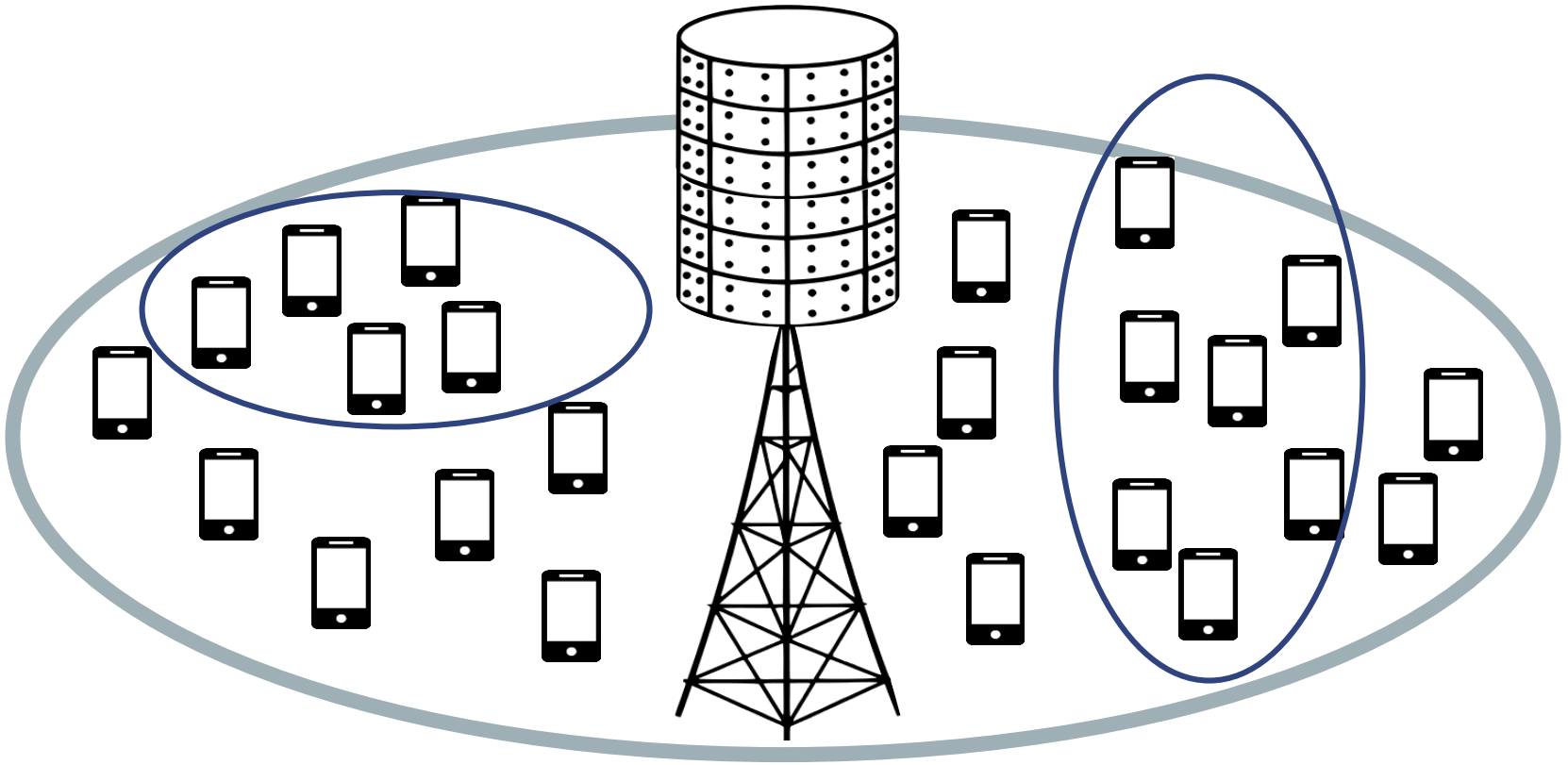


Position Correlation Function



User grouping

User grouping. It is the task of forming subset of users ($\kappa \in K$), according a compatibility criterion, to maximize the resource allocation.



Castaneda, E., Silva, A., Gameiro, A., & Kountouris, M. (2016). An overview on resource allocation techniques for multi-user MIMO systems. *IEEE Communications Surveys & Tutorials*, *19*(1), 239-284.

User grouping

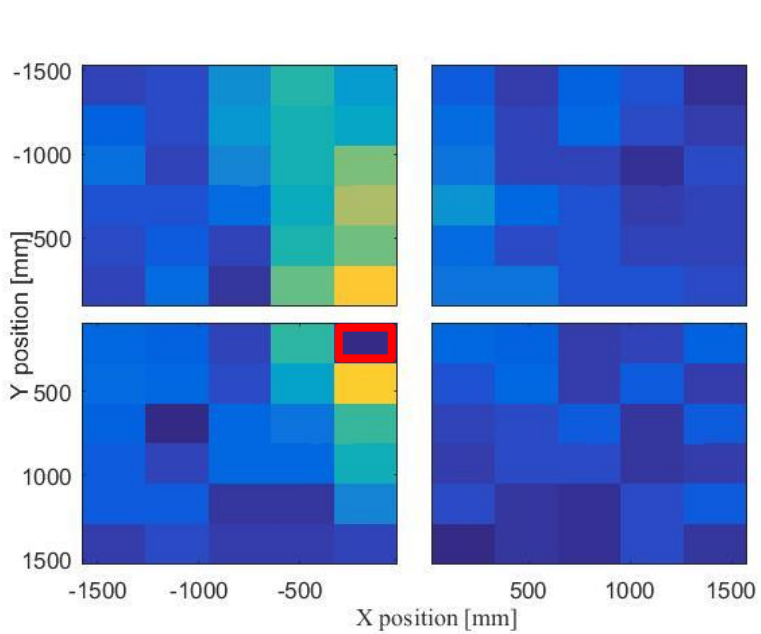
User grouping. It is the task of forming subset of users ($\kappa \in K$), according a compatibility criterion, to maximize the resource allocation.

$$f\left(\mathbf{H}(\kappa)\right)$$

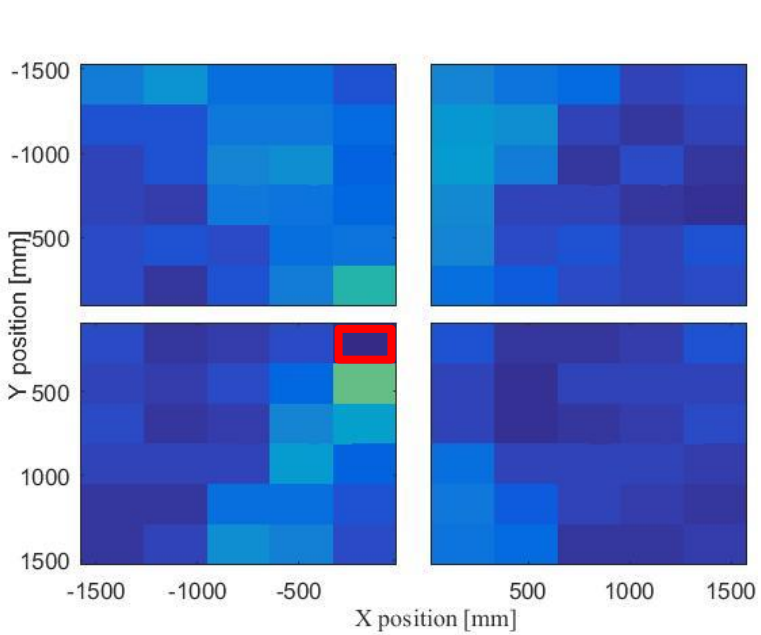
Effective channel gains $\beta = \mathrm{E}\{\|\boldsymbol{h}\|^2\}$	**Favorable propagation / IU channel correlation** $\Upsilon_j = \mathrm{E}\{\mathbf{H}^H\mathbf{H}\}$
Chan, P. W., & Cheng, R. S. (2007). Capacity maximization for zero-forcing MIMO-OFDMA downlink systems with multiuser diversity. *IEEE Transactions on Wireless Communications*, 6(5), 1880-1889.	Castañeda, E., Silva, A., Samano-Robles, R., & Gameiro, A. (2015). Distributed linear precoding and user selection in coordinated multicell systems. IEEE transactions on Vehicular Technology, 65(7), 4887-4899.
Lau, V. K., & Kwok, Y. K. R. (2006). *Channel-adaptive technologies and cross-layer designs for wireless systems with multiple antennas: theory and applications* (Vol. 85). John Wiley & Sons.	Bayesteh, A., & Khandani, A. K. (2008). On the user selection for MIMO broadcast channels. IEEE Transactions on Information Theory, 54(3), 1086-1107.
Shi, Y., Yu, Q., Meng, W., & Zhang, Z. (2014). Maximum product of effective channel gains: an innovative user selection algorithm for downlink multi-user multiple input and multiple output. Wireless Communications and Mobile Computing, 14(18), 1732-1740.	Fuchs, M., Del Galdo, G., & Haardt, M. (2007). Low-complexity space–time–frequency scheduling for MIMO systems with SDMA. IEEE Transactions on Vehicular Technology, 56(5), 2775-2784.

User Grouping – Channel Correlation

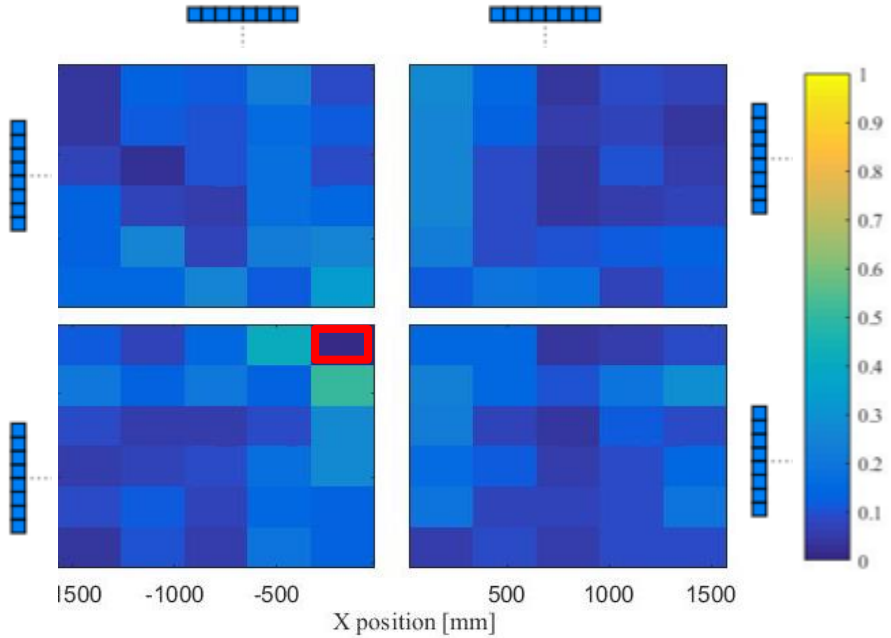
Metric: Favorable propagation $\Upsilon_j = \mathrm{E}\left\{ \frac{\hat{\boldsymbol{h}}_{ref}{}^{\mathrm{H}} . \hat{\boldsymbol{h}}_j}{\sqrt{\mathrm{E}\left\{\left\|\hat{\boldsymbol{h}}_{ref}\right\|^2\right\}\mathrm{E}\left\{\left\|\hat{\boldsymbol{h}}_j\right\|^2\right\}}} \right\}$



URA

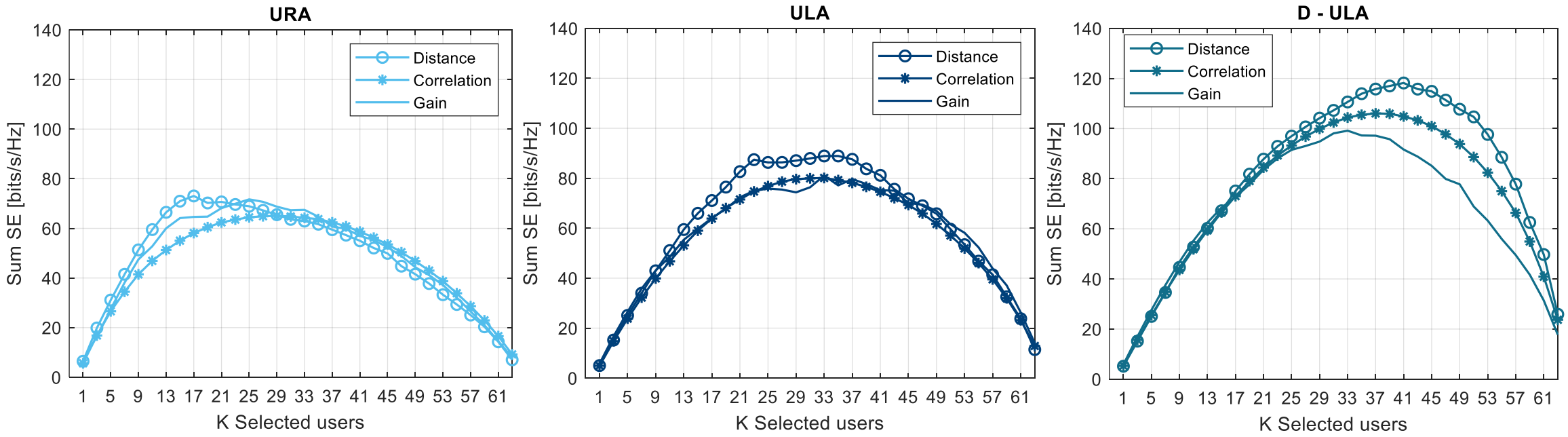


ULA

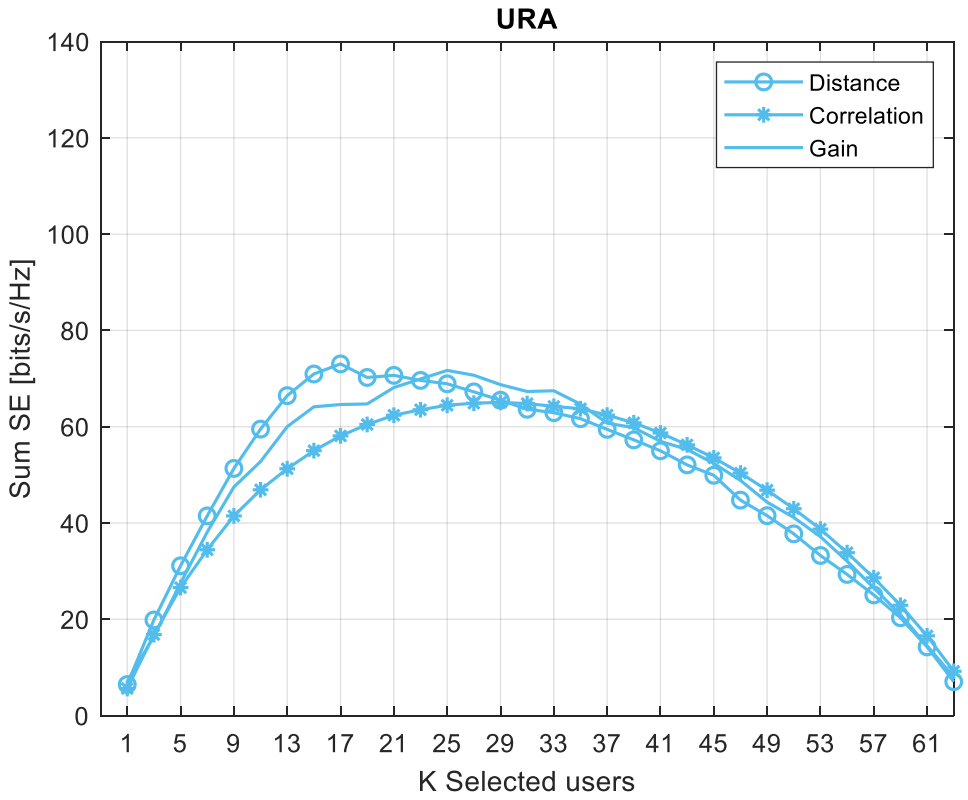


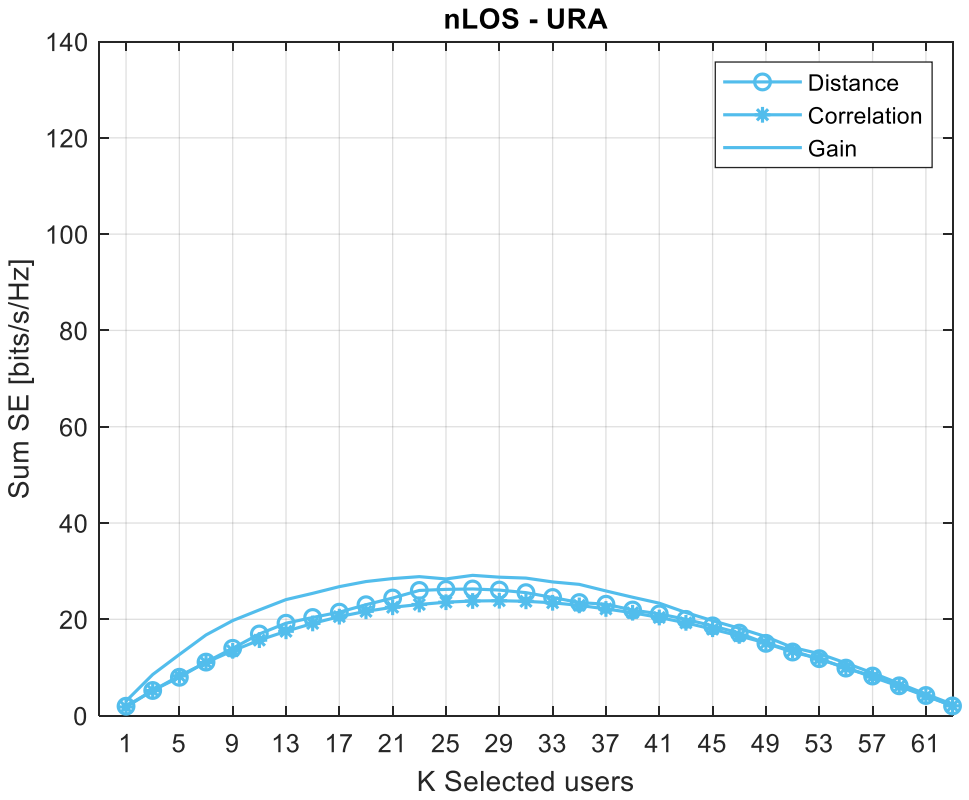
D-ULA

Spectral Efficiency per cell (ZF)



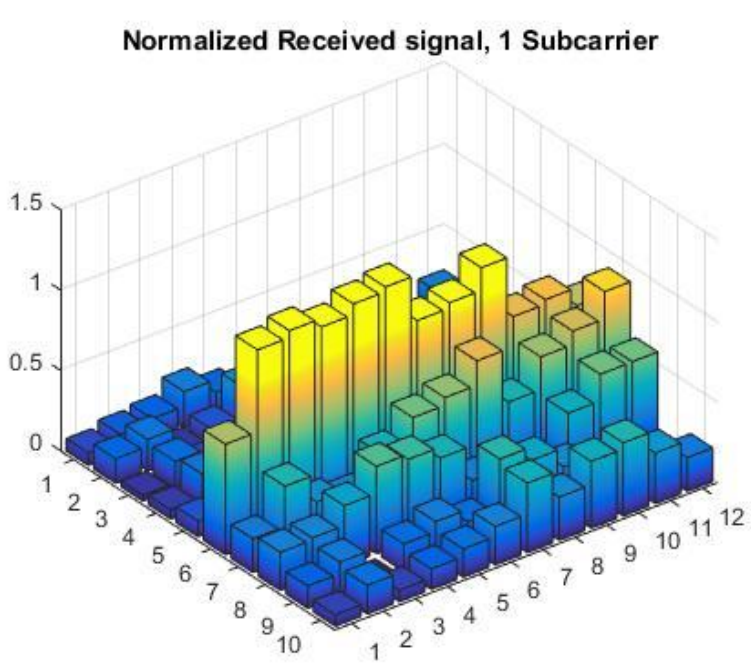
Spectral Efficiency per cell LoS vs nLoS (ZF)



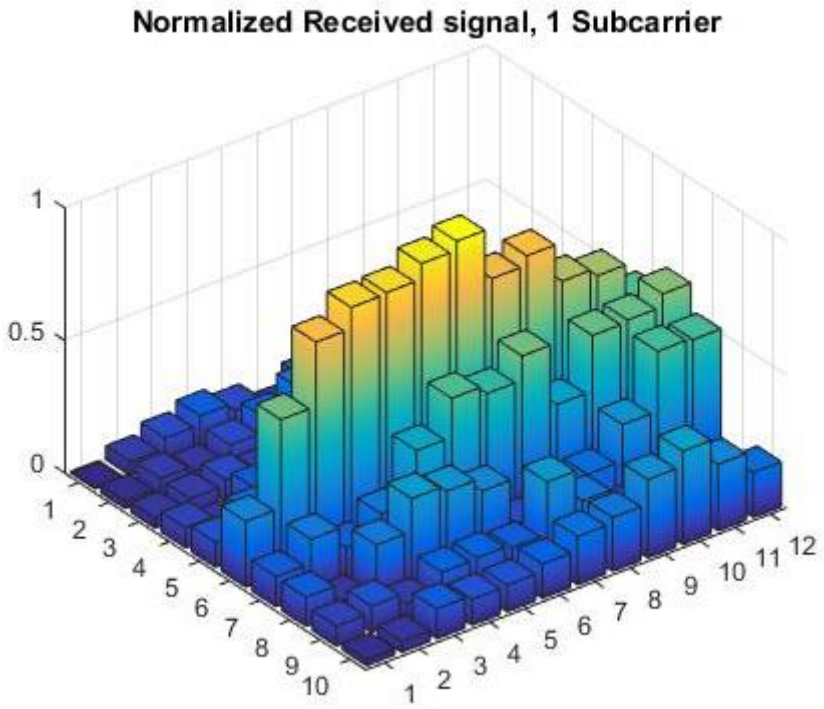


MR beamforming - URA

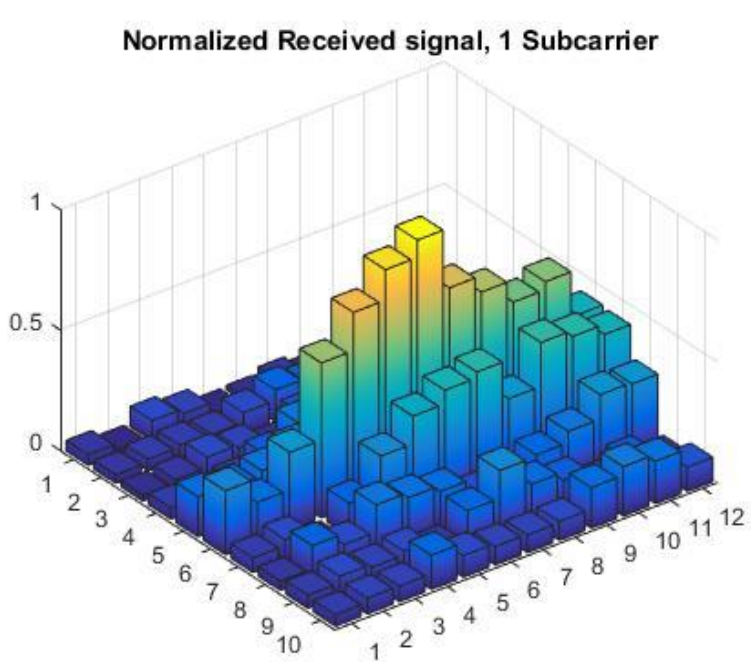
16 antennas



32 antennas

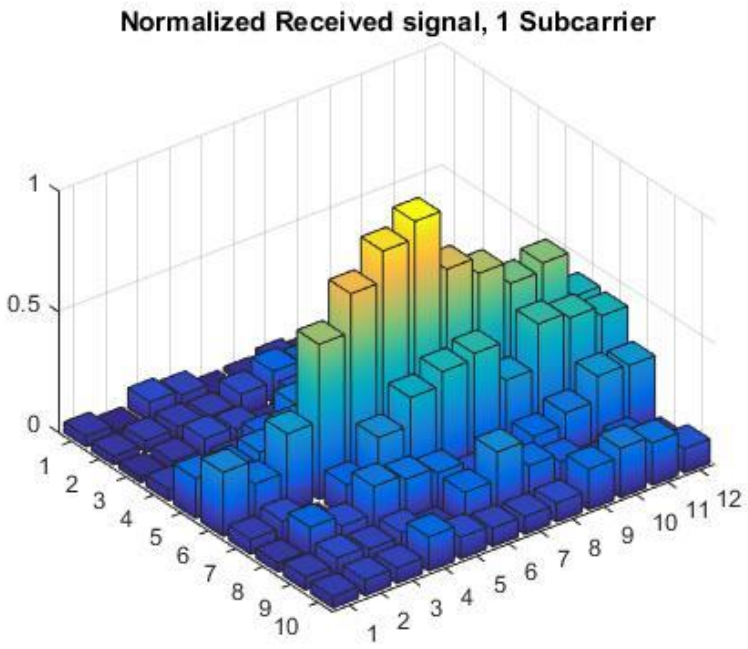


64 antennas

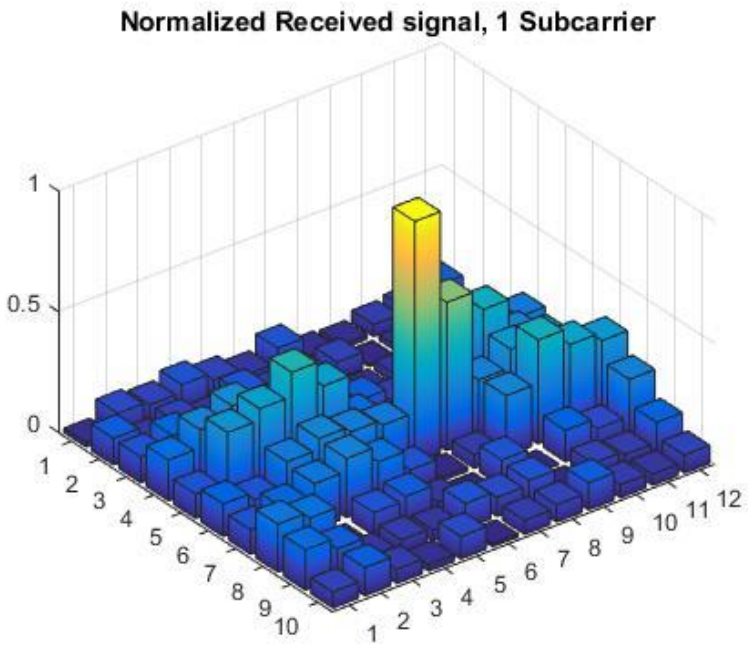


MR beamforming

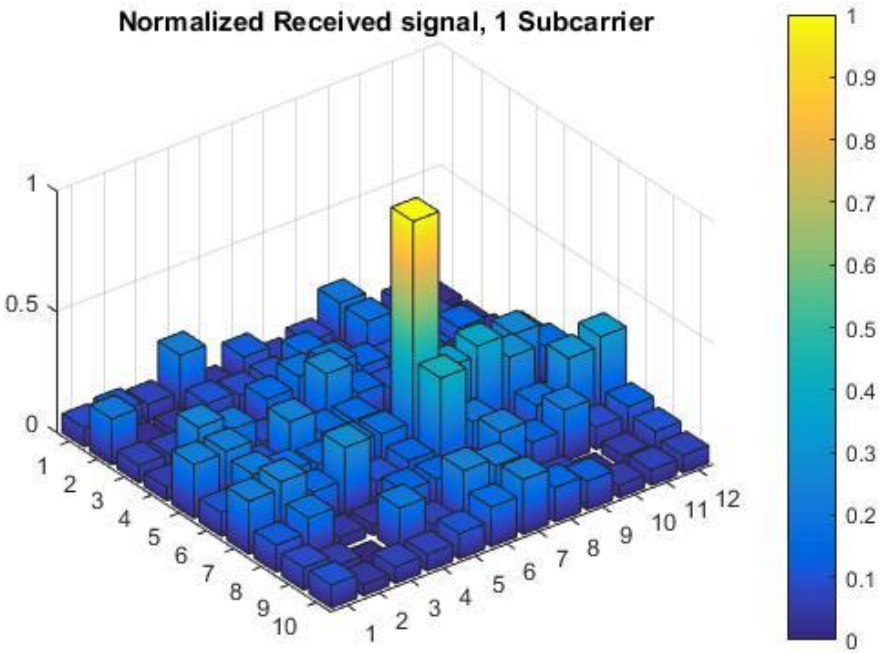
URA



ULA



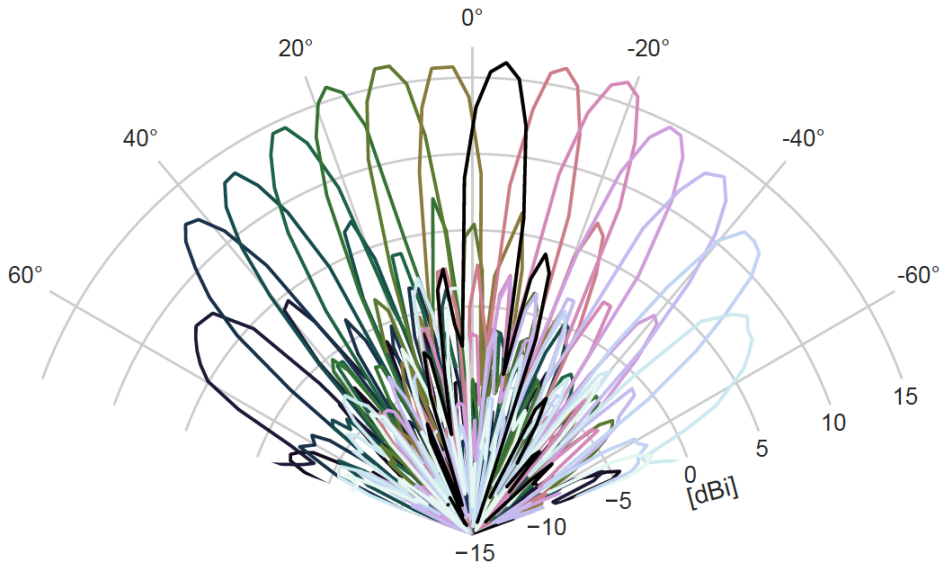
D-ULA

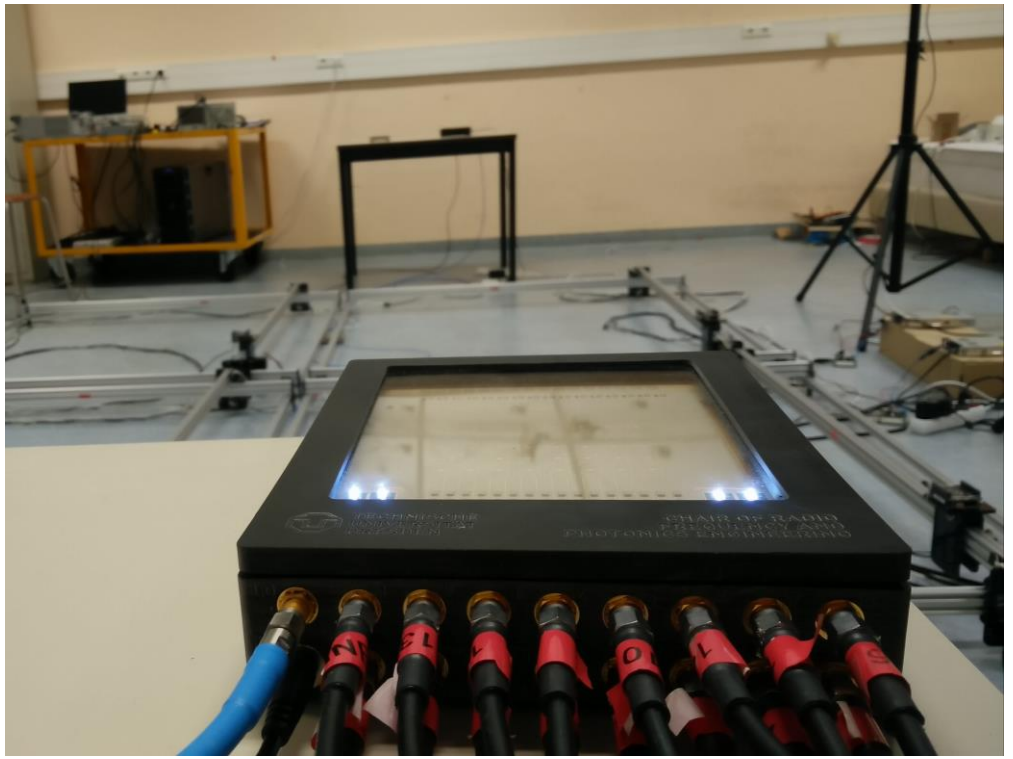


mmWAVE EXTENSION

mmWave Phased Array convertor

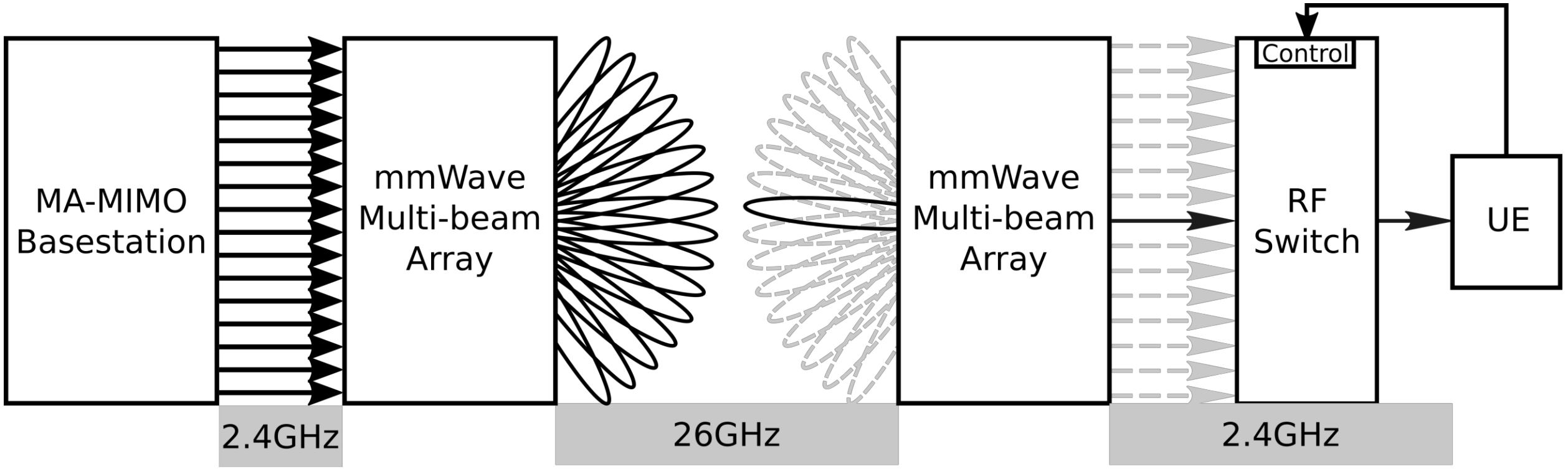
5G Lab GERMANY | TECHNISCHE UNIVERSITÄT DRESDEN



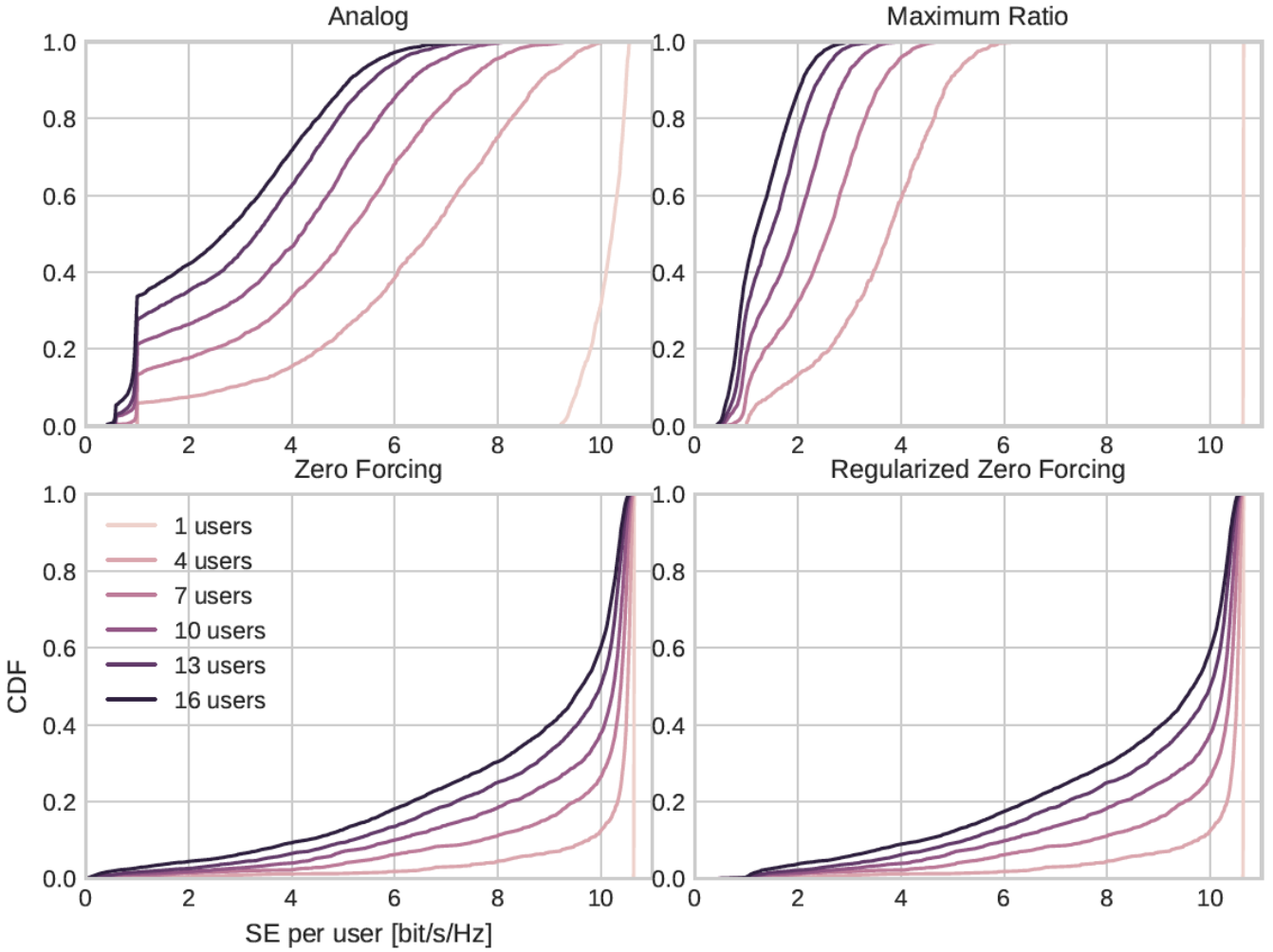


Orca

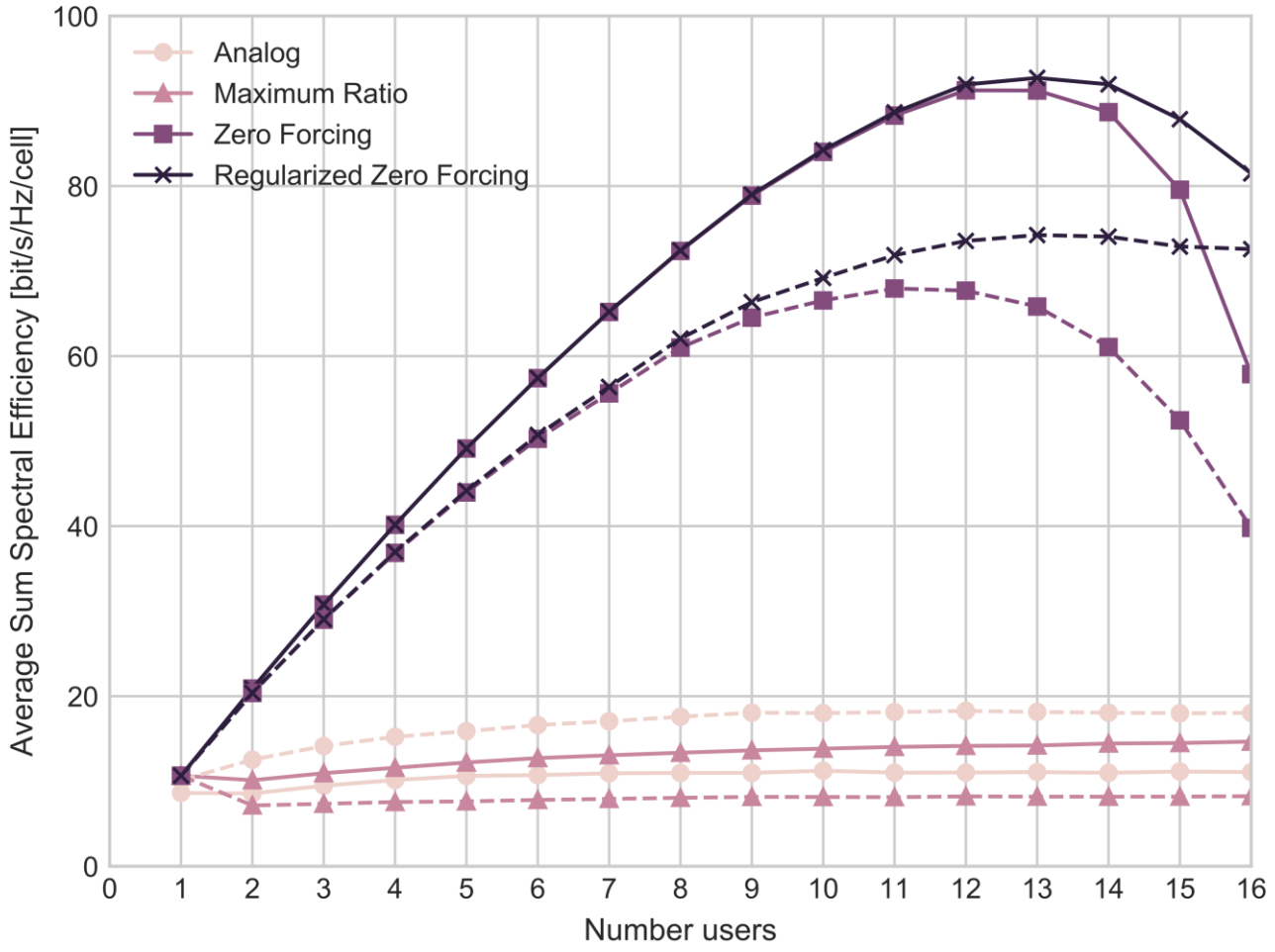
Proposed architecture: Multi-beam phased array at basestation



Perfect Channel State Information



Fixed precoding on measured channels



LOCALISATION

CNN for localisation

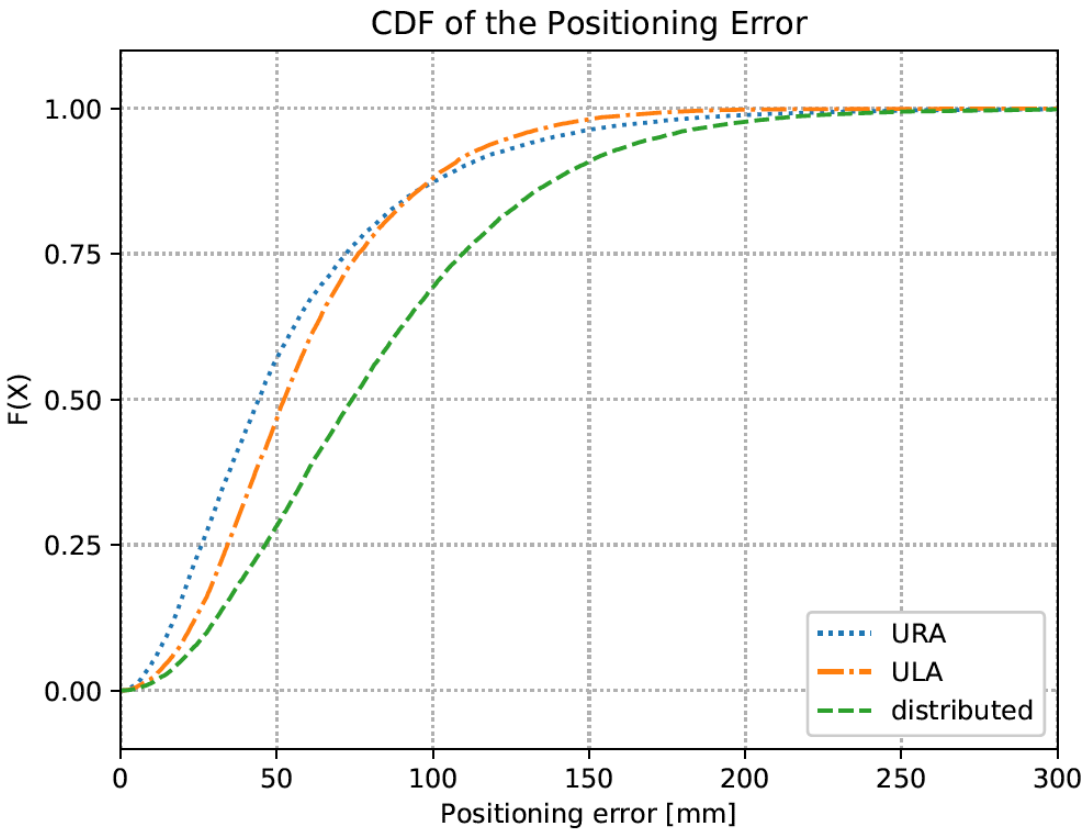


TABLE I

MEAN ERROR THE POSITIONING PERFORMANCE OF THE PROPOSED SYSTEM, MEASURED ON THE TESTSET OF THE DIFFERENT SCENARIOS.

URA	8 antennas	16 antennas	32 antennas	64 antennas
ME [mm]	230.08	120.73	85.19	55.35
ME [λ]	2.008	1.053	0.744	0.483

ULA	8 antennas	16 antennas	32 antennas	64 antennas
ME [mm]	244.80	132.87	77.87	59.05
ME [λ]	2.137	1.160	0.680	0.515

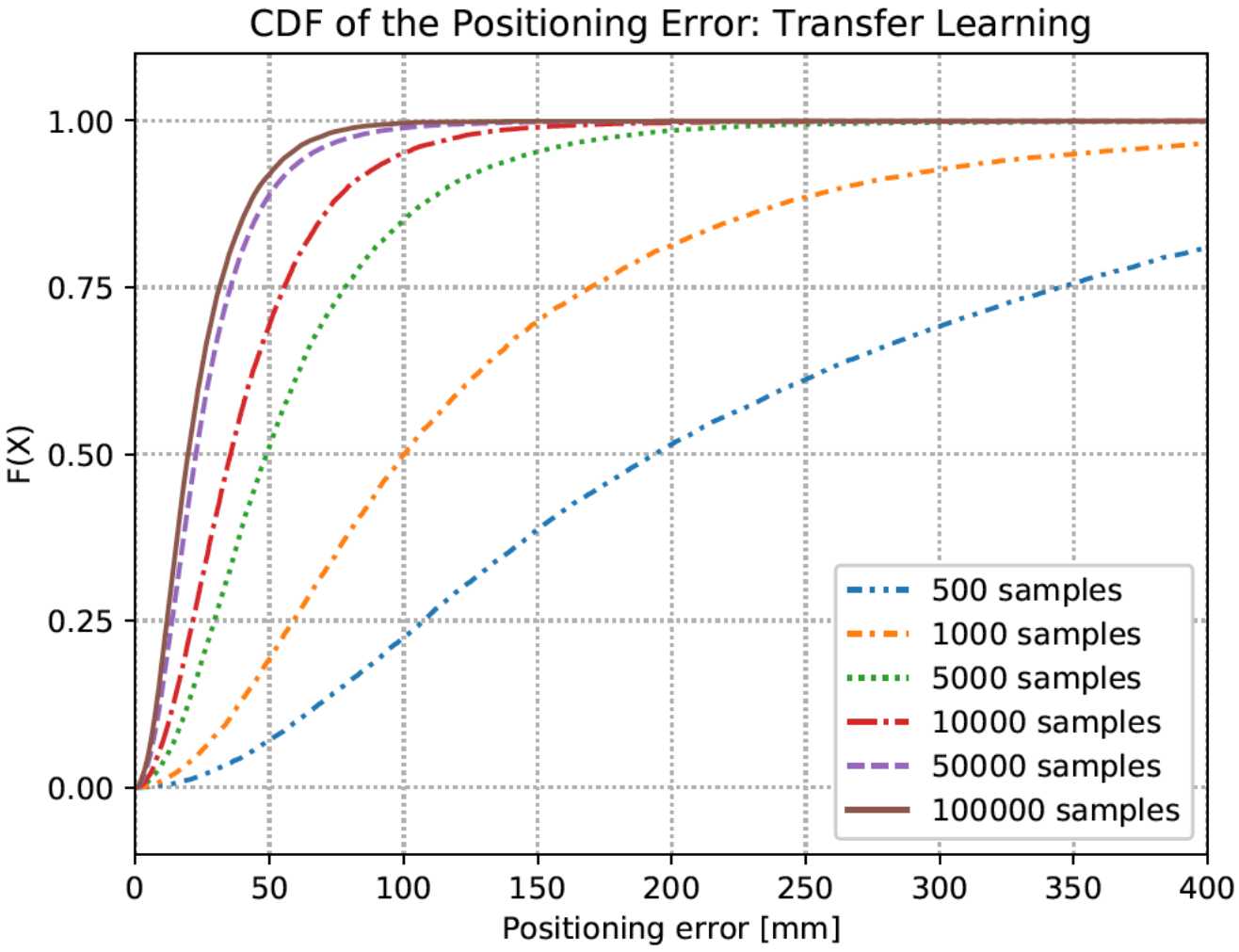
DIS	8 antennas	16 antennas	32 antennas	64 antennas
ME [mm]	197.62	152.37	130.64	82.30
ME [λ]	1.725	1.33	1.14	0.718

Transfer learning: URA to ULA

First two layers are reused, and trained further

First layers learn low level features (e.g., spatial relevant features that don't depend on the antenna topology)

Low layers learn how to combine spatial features into a position estimate (depending on the array topology)



Transfer learning outperforms traditional learning

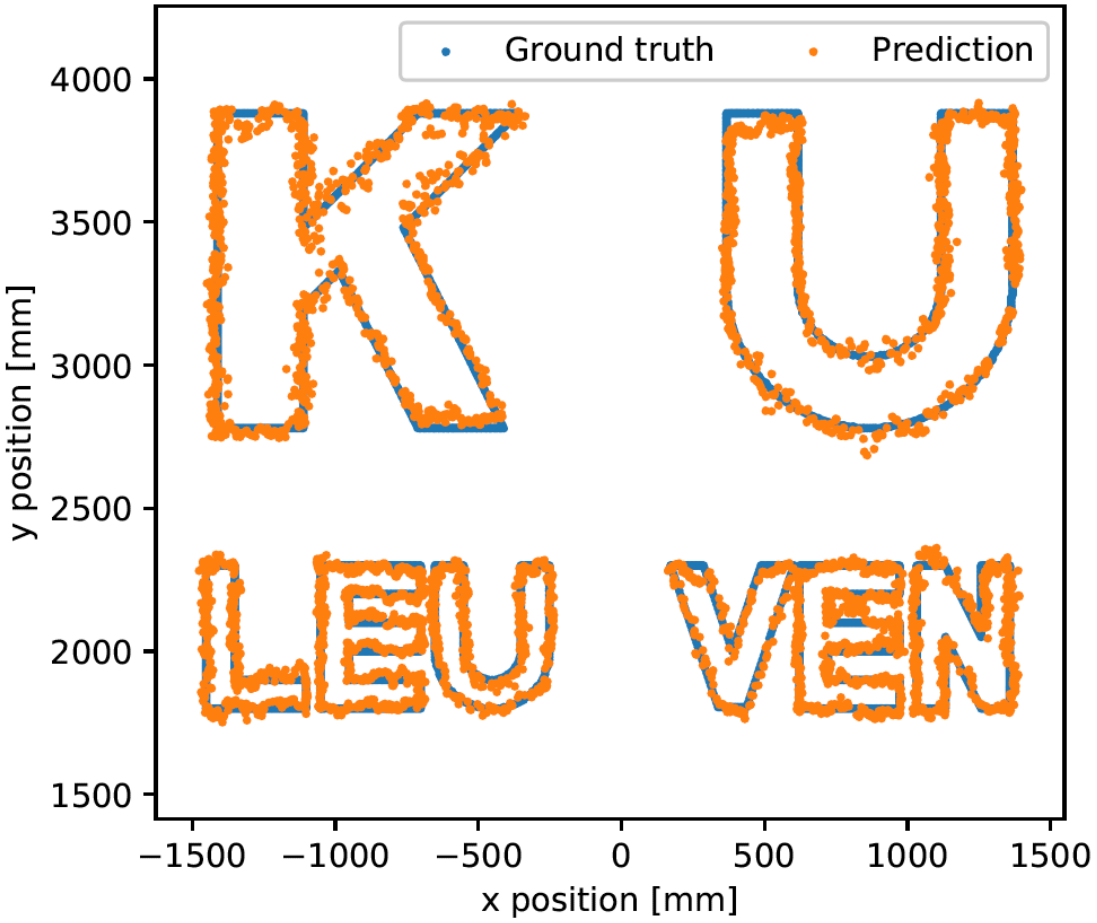


TABLE II
MEAN ERROR WHEN USING TRANSFER LEARNING IN FUNCTION OF THE NUMBER OF USED TRAINING SAMPLES.

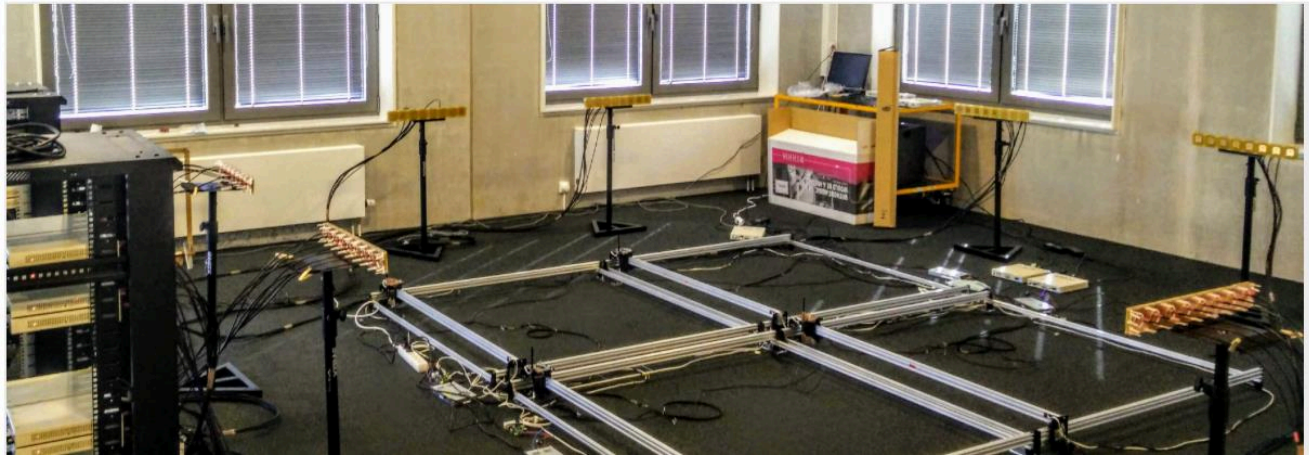
# samples	500	1000	5000	10000	50000	100000
ME [mm]	253.5	132.0	60.90	42.79	27.89	23.92
ME [λ]	2.21	1.15	0.53	0.37	0.243	0.209

https://homes.esat.kuleuven.be/~sdebast/

PUBLICATIONS

Find a list containing all my publications here.

READ MORE



MASSIVE MIMO CSI DATASET

This dataset contains thousands of Channel State Information samples collected using the KU Leuven massive MIMO testbed.

READ MORE

Conclusions

We split our testbed

- 3 Antenna topologies
- LoS and NLoS
- Very dense UE position sampling

We have data

We use it for

- Multi-cell Massive MIMO
- Localisation

THANK YOU
FOR YOUR ATTENTION

ORCA-PROJECT.EU

This project received funding from the European Union's Horizon2020
research and innovation programme under grant agreement No 732174