Full-Dimension MIMO: Status and Challenges in Design and Implementation

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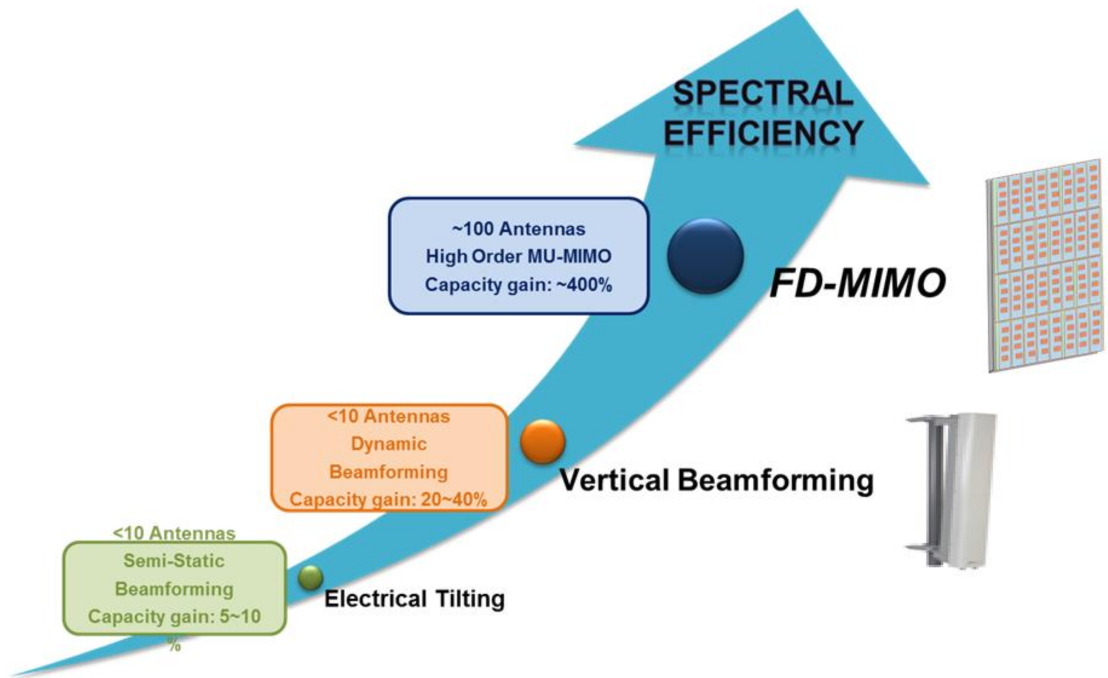
Outline

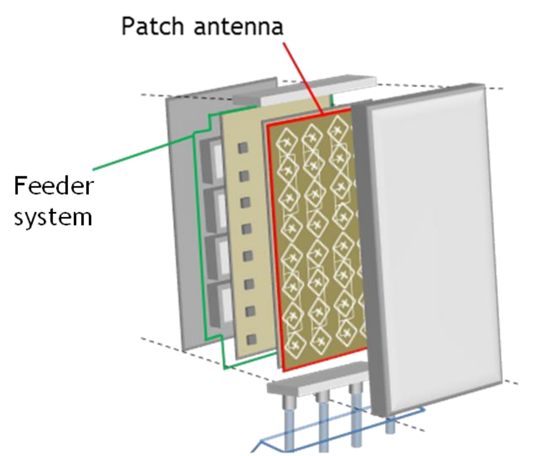
1 Current Status of FD-MIMO

2 Challenges of FD-MIMO

Background of Full-Dimension MIMO

- **Theory Behind: Massive MIMO***
  - Spatial resolution increases as number of eNB antennas
  - Narrow beam transmission with little MU interference
- **Active Antenna Array (AAA)**
  - 2D vs. 1D AAA

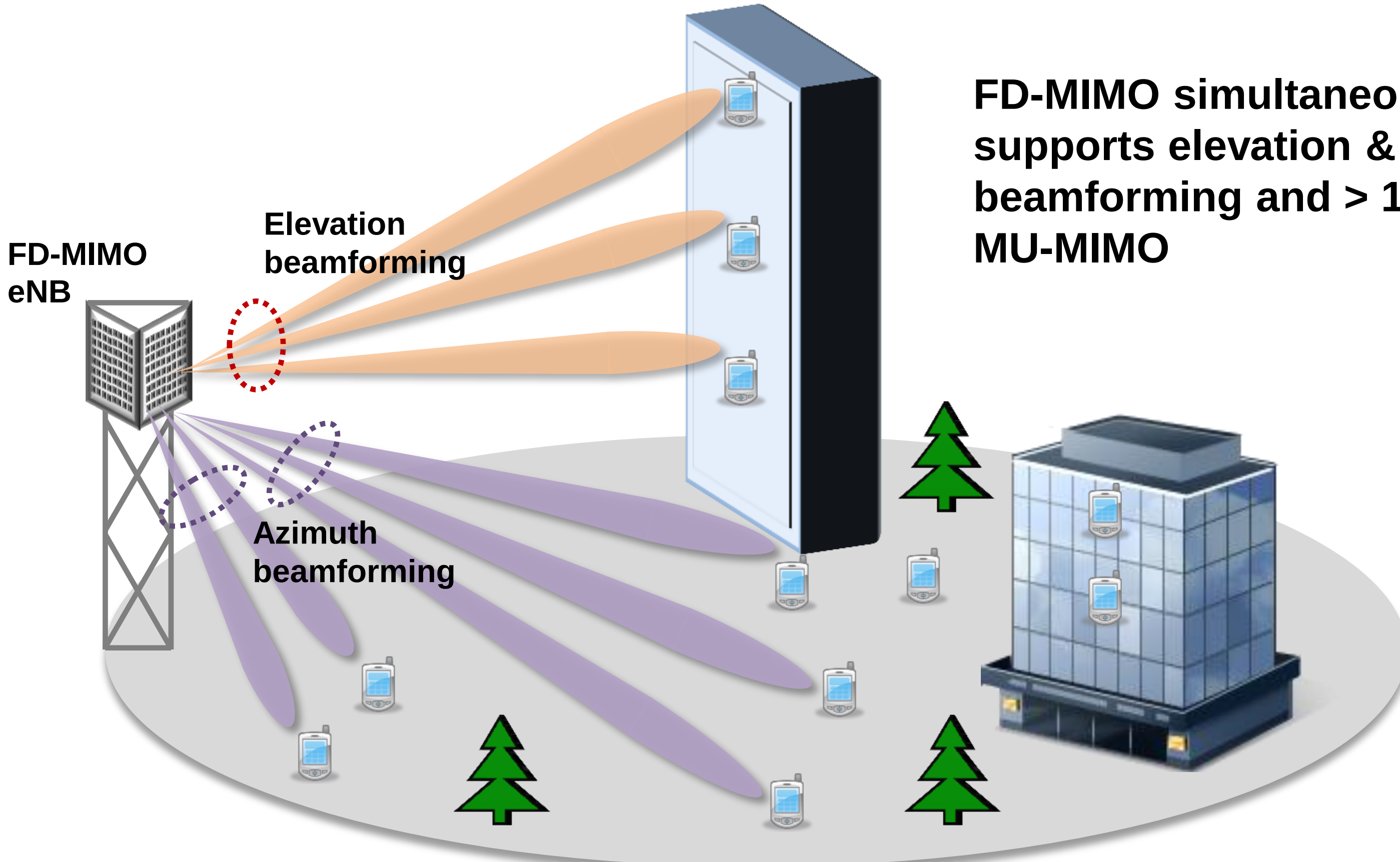




FD-MIMO / 3D-MIMO / Massive MIMO

**Marzetta, “Non-cooperative cellular wireless with unlimited numbers of base station antennas,” IEEE TWireless Nov. 2010*

Full-Dimension MIMO (FD-MIMO)

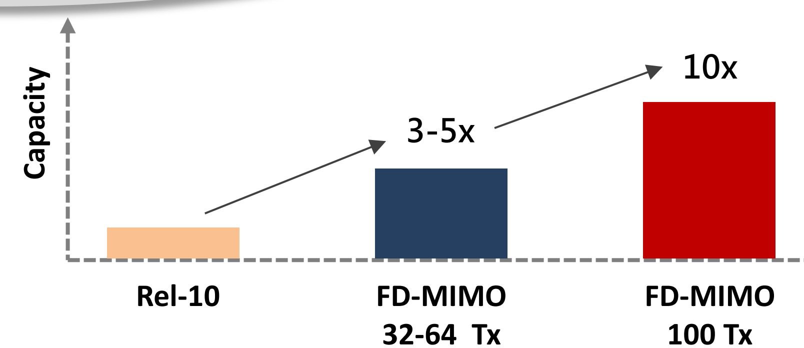


FD-MIMO simultaneously supports elevation & azimuth beamforming and > 10 UEs MU-MIMO

2-dimentional AAA & ~100 antennas

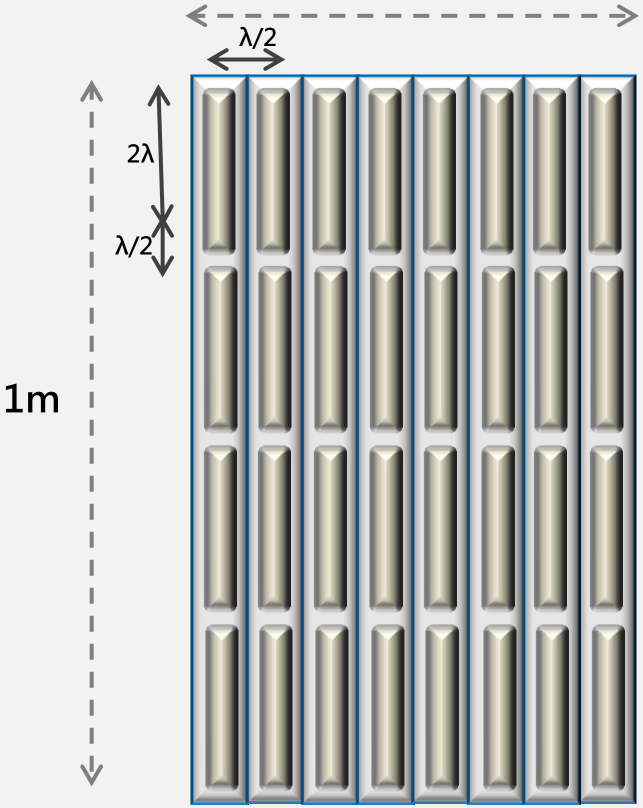
MU-MIMO with 10s of UEs

3D-spatial channel model



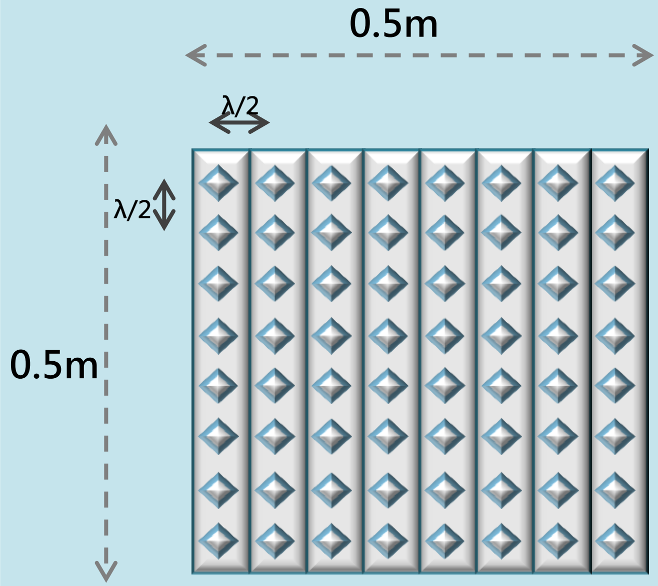
SAMSUNG

FD-MIMO 2D AAS Form Factor Examples



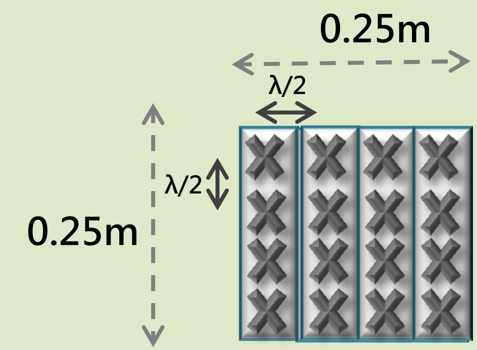
Eg. 1: 8x4 array with each element
4 antennas with analog beamforming

Urban Macro



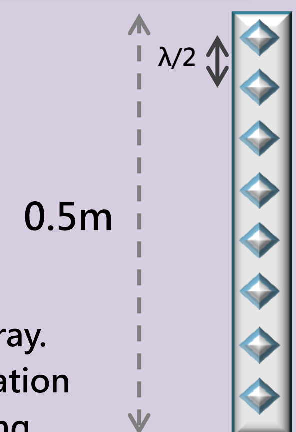
Eg.2: 8x8 array with full digital
beamforming across 64 elements

Urban Micro



Eg.3: 8x8 array with cross-pol.
Digital beamforming 64 elements.

Small Cell



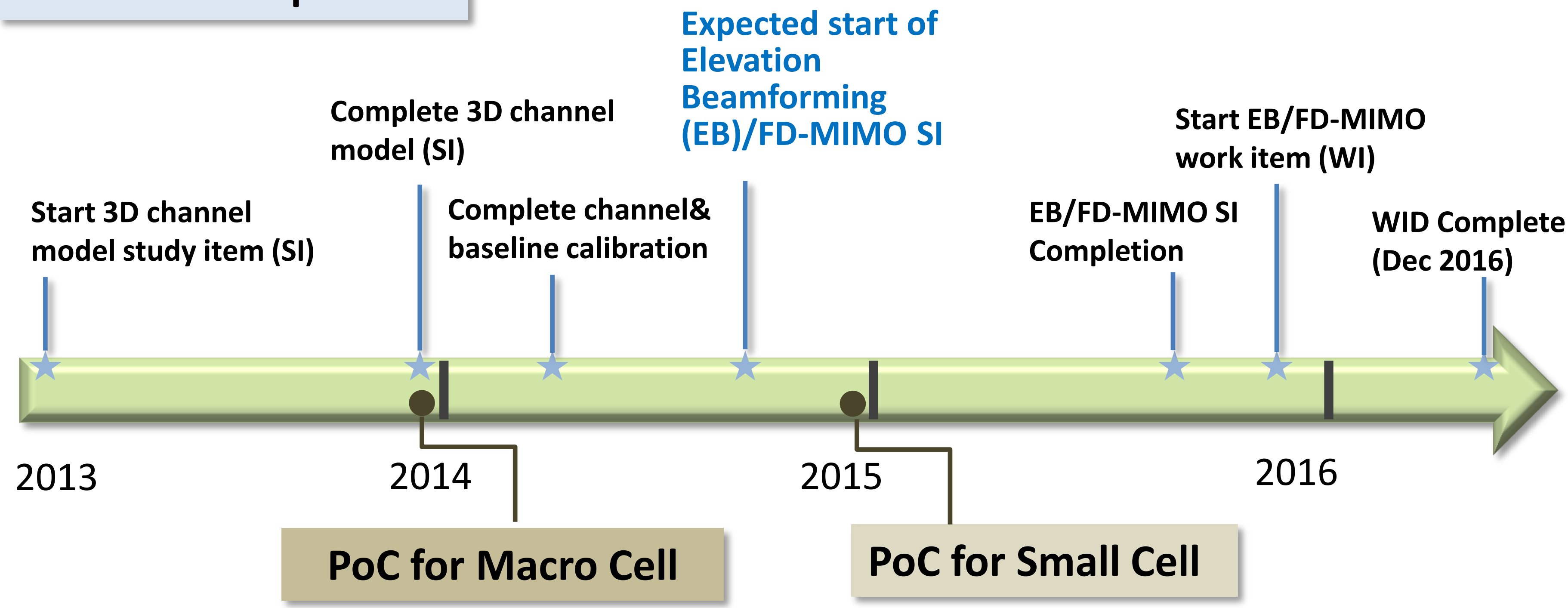
Eg.4: 1x8 array.
Digital elevation
beamforming

λ=12cm
@ 2.5GHz

FD-MIMO antenna panel form factor is well within practical range

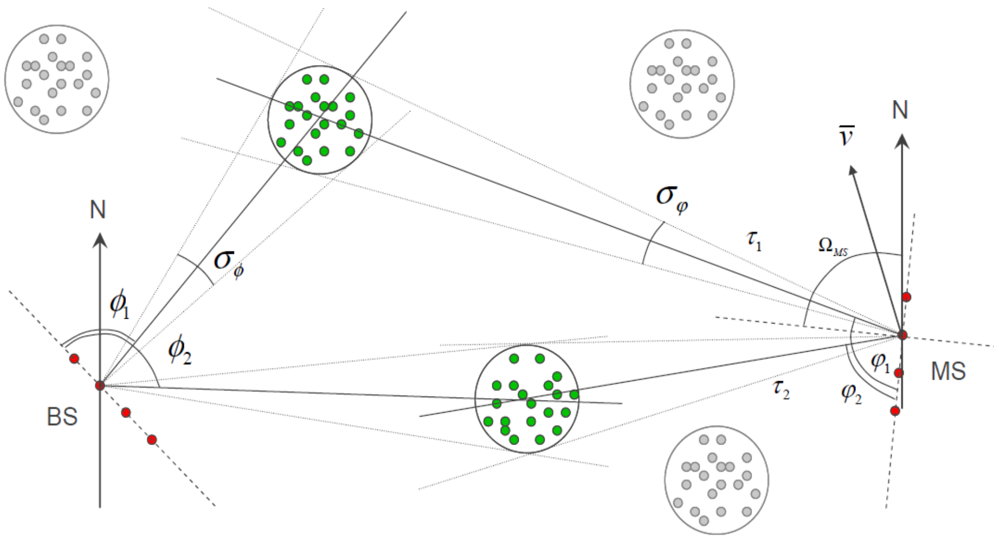
Industry Status and 3GPP roadmap

3GPP development



1^{st} FD-MIMO Prototype:
32 antenna LTE base-station

3-Dimension (3D) Channel Model



Spatial channel model (SCM)

In SCM, channel is a composite response of cluster/subclusters to Tx/Rx antennas:

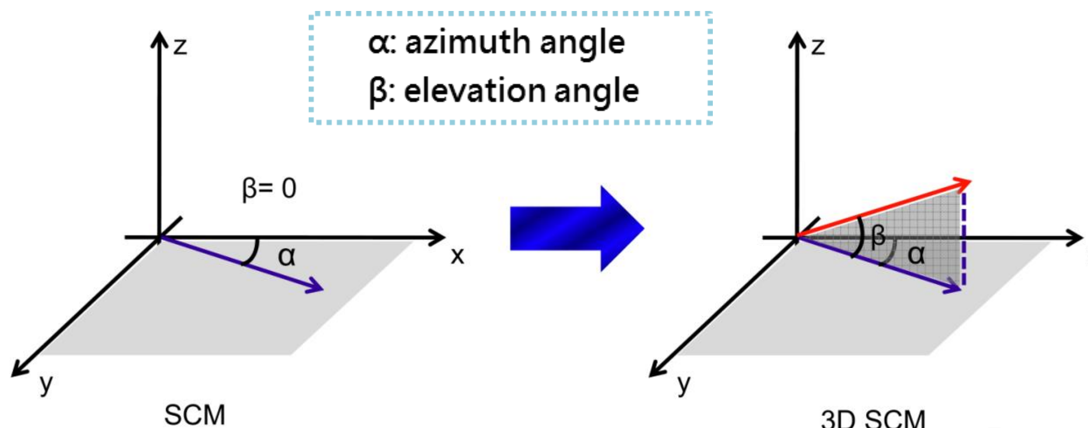
- Number of cluster/subclusters
- Delay of clusters
- Power of clusters
- Phases (due to e.g. reflection)
- **Angle of Departure/Arrival (AoD/AoA)**

Note:

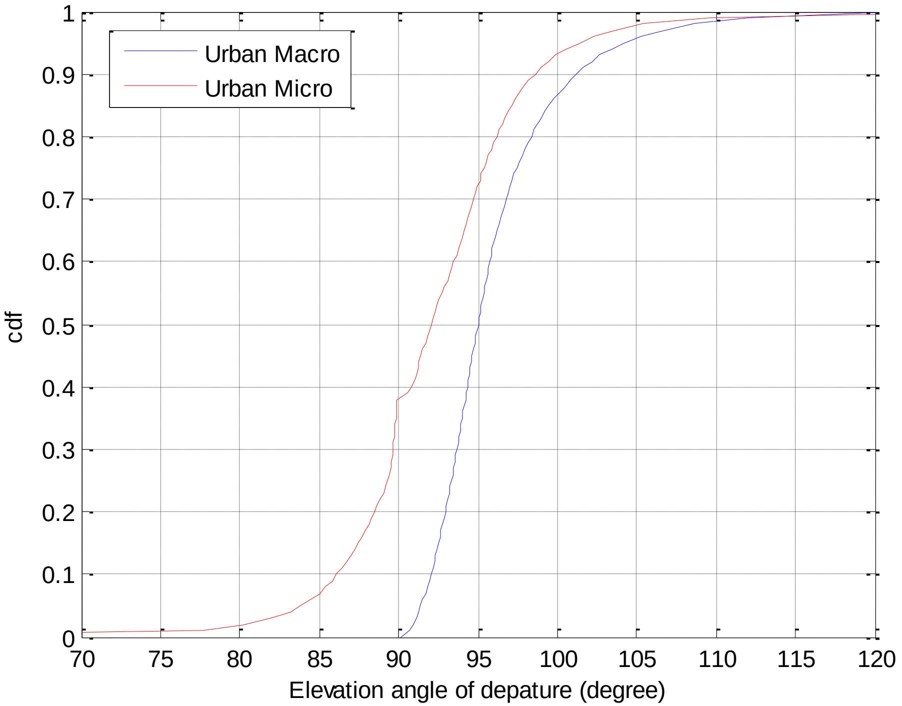
AoA/AoD critically determines channel correlations

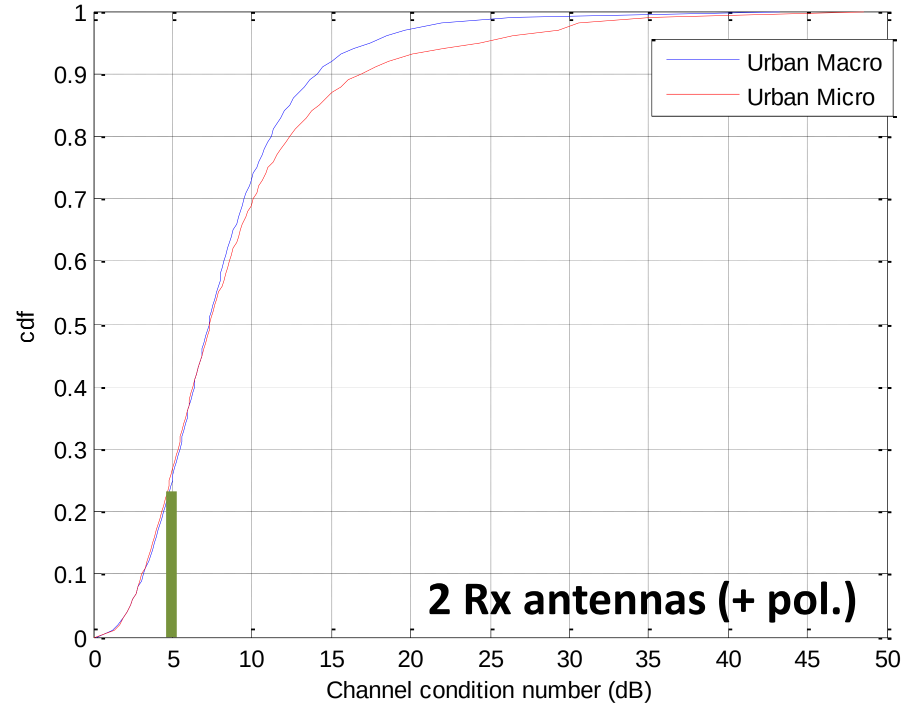
2D model assumes all clusters zero elevation angles and cannot describe elevation differences.

3D model captures elevation angles and thus clusters can be distinguished in elevation domain



Statistics in 3GPP 3D Channel Model





- Elevation angle (w.r.t. zenith) has a range of 30-deg for UMa and 50-deg for UMi
- 80% channels have condition number > 5dB

Note: see “3GPP TR 36.873” for more details of 3D channel model and UE distribution.

System-Level Simulator (SLS) Evaluation

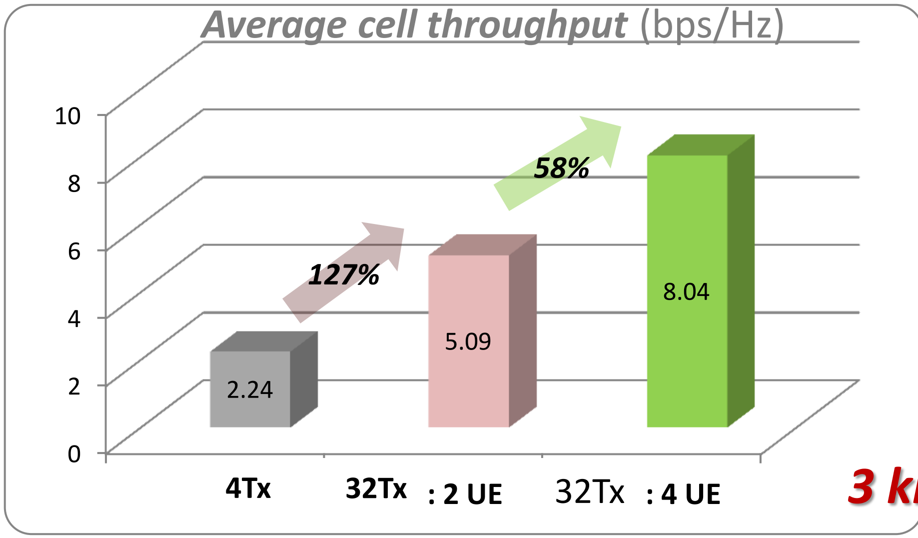
Simulation Setup:

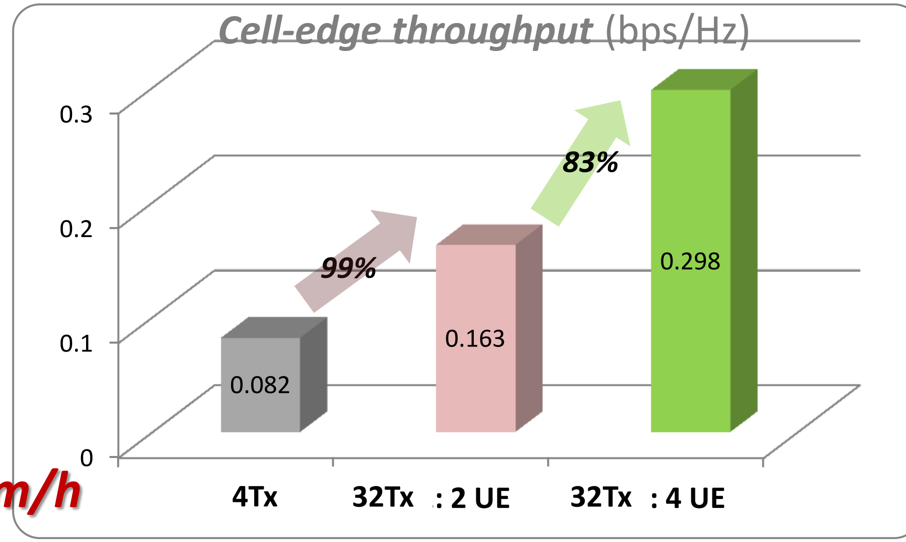
- 3D ITU, UMa
- 57 sectors with K=10 UEs per sector
- Center frequency 2GHz, bandwidth 10MHz
- UE speed 3km/h or 30km/h, uniformly distributed
- 40 drops, 4s per drop
- UE: 2 Rx, 1Tx

- Overhead: 20%
- Ideal SRS estimation
- 4 ms scheduling delay
- Normalized by # of DL subframes
- Baseline: SU-MIMO with rank1

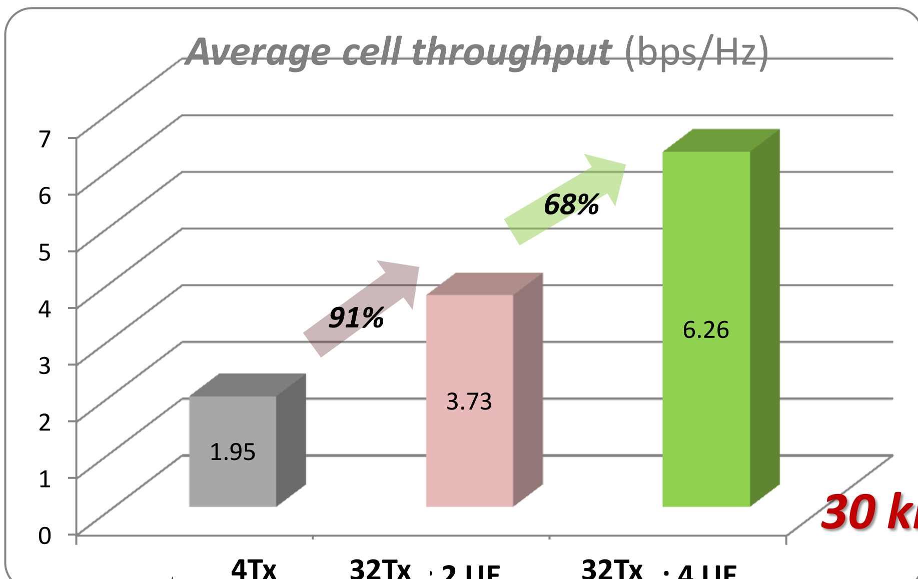
eNB antenna configuration (HxV)	4x1 (baseline)	8x4
Sub-array gain	17 dBi	12 dBi
Azimuth beamwidth	70-deg	70-deg
Elevation beamwidth	10-deg	30-deg
Front-to-back radio	25 dB	25 dB
Electrical downtilt	12-deg	12-deg

SLS Simulation Results (Up to 4 UE MU-MIMO)

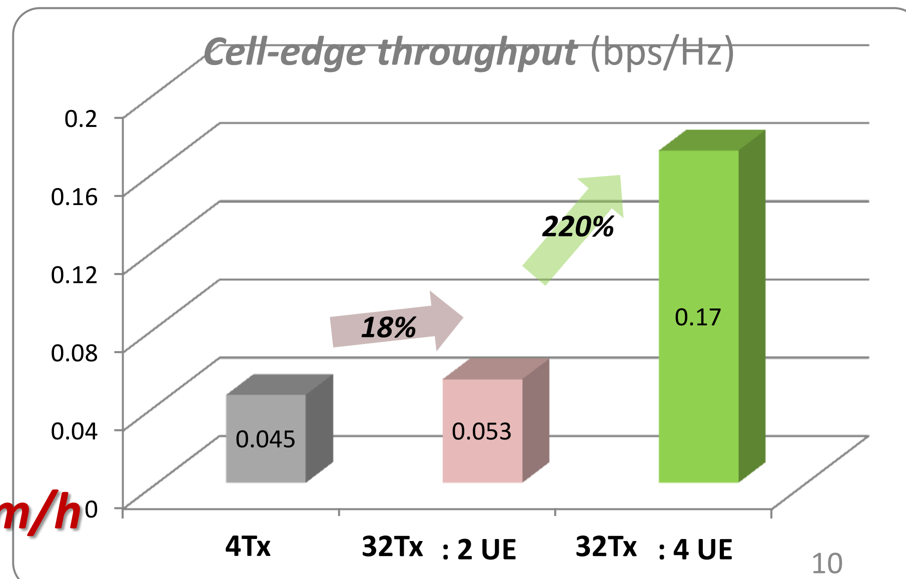




3 km/h



30 km/h



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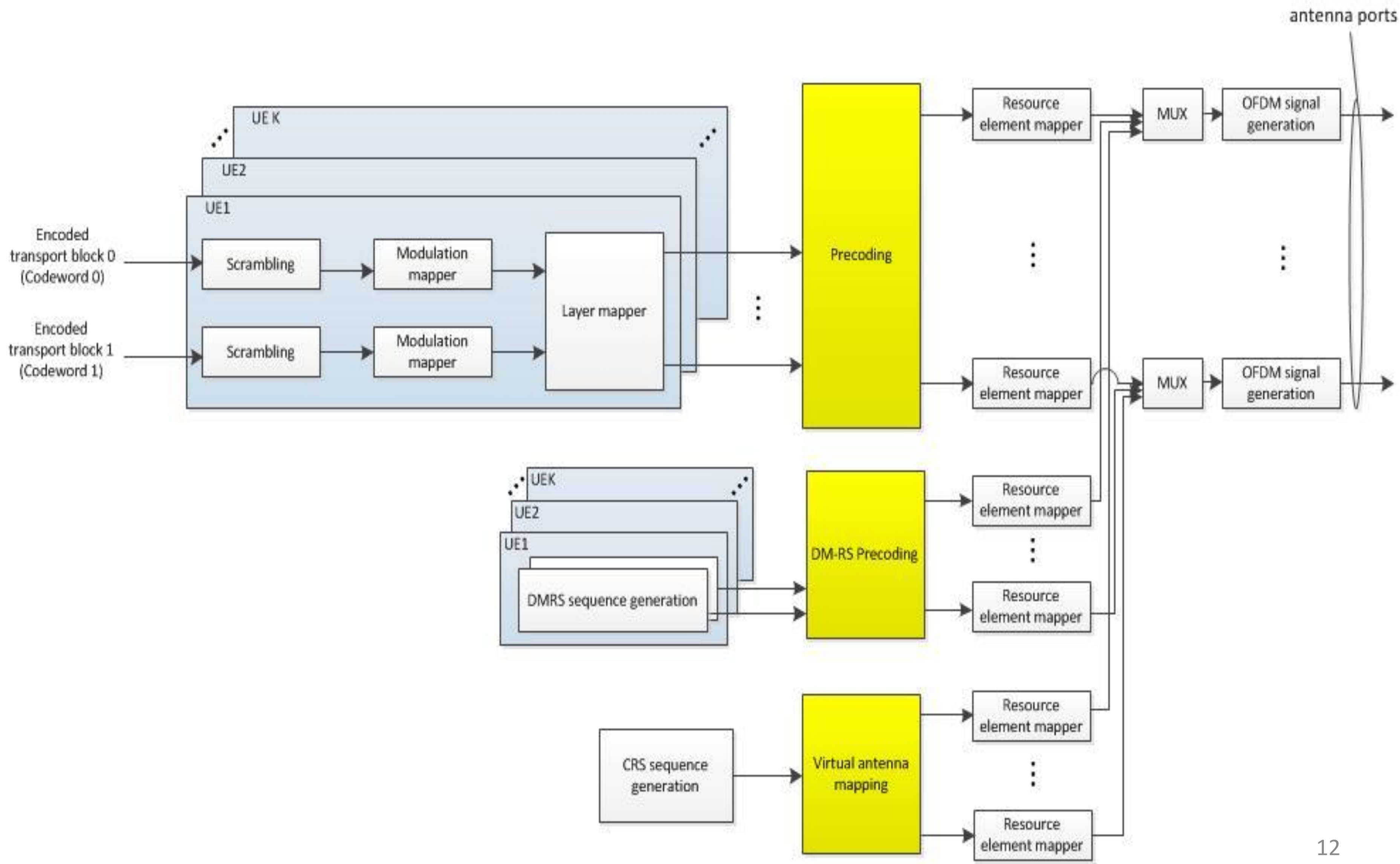
2 Challenges of FD-MIMO

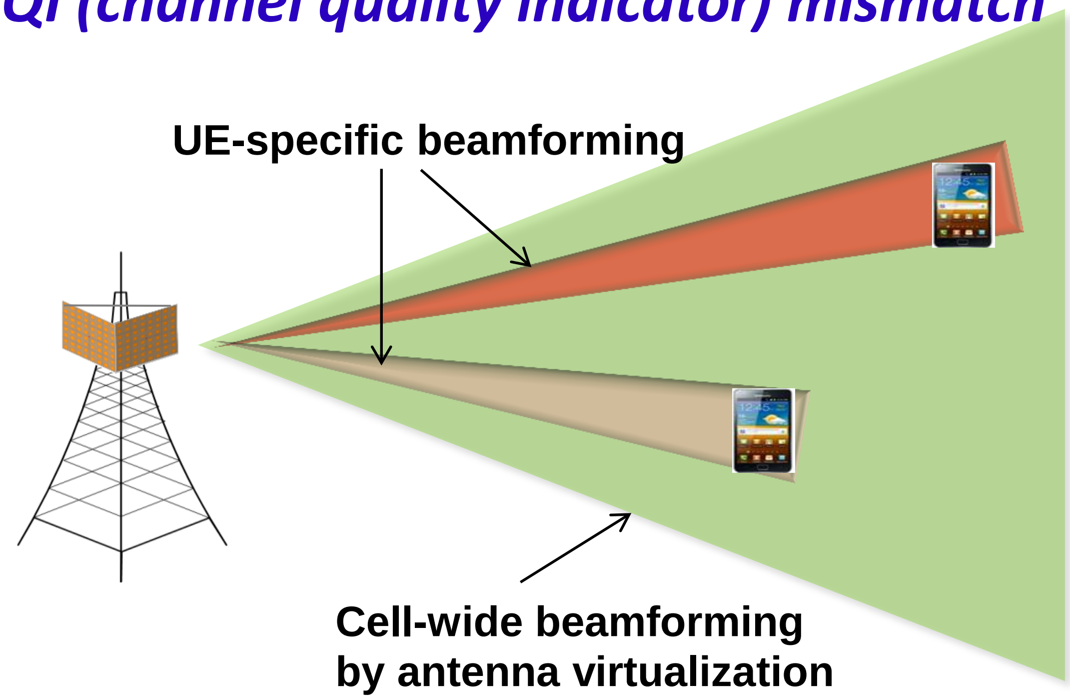
FD-MIMO Framework in LTE/LTE-A



Antenna Virtualization & CQI Prediction

Issue: (1) How to generate wide beam from a large array

(2) CQI (channel quality indicator) mismatch

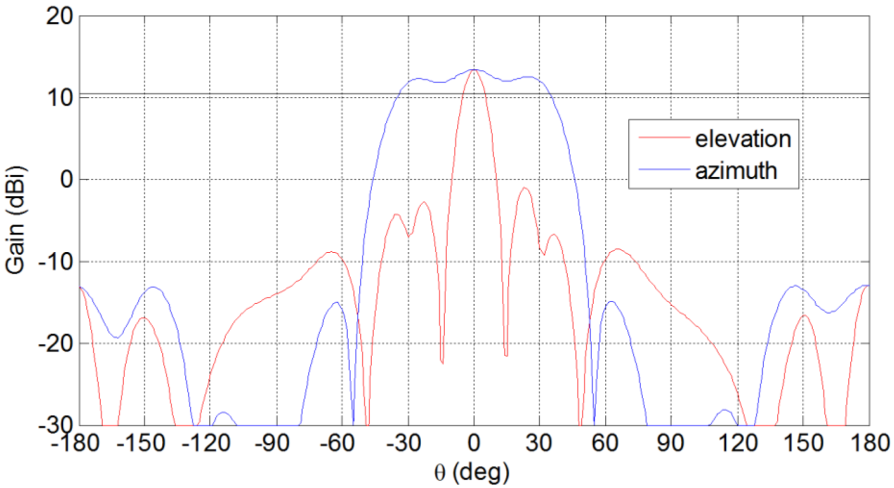


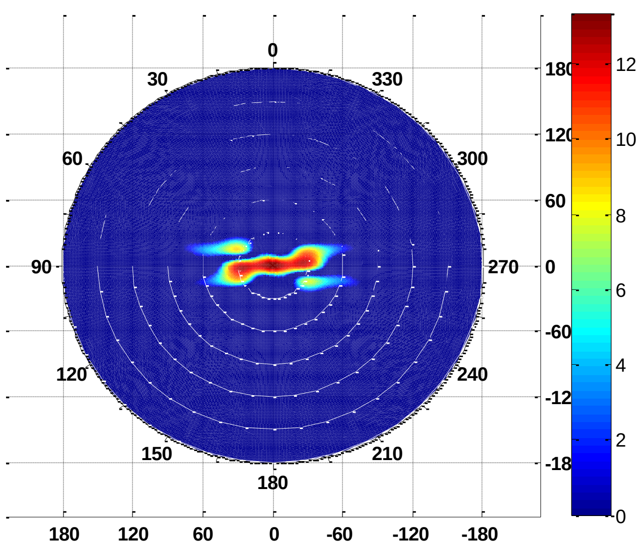
- Wide-beam (ant. virtualization) for control signal (coverage)
- Narrow-beam (precoding) for data signal
- UE CQI* is measured based on wide-beam

*CQI is a UE feedback value and is essential for eNB to decide transmission scheme, code rate, modulation for each UE.

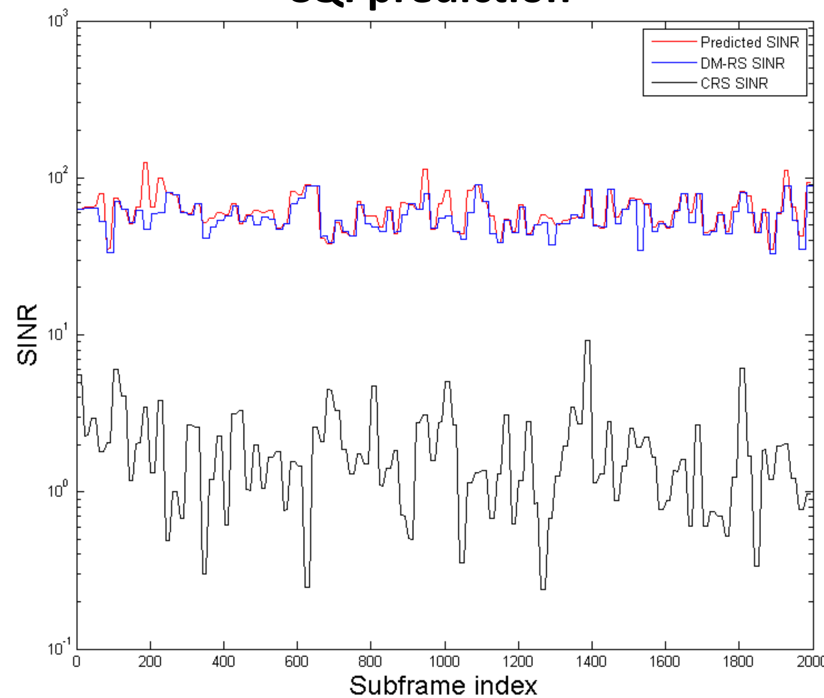
Antenna Virtualization & CQI Prediction (2)

Synthesized antenna virtual pattern (32 ant.)





CQI prediction

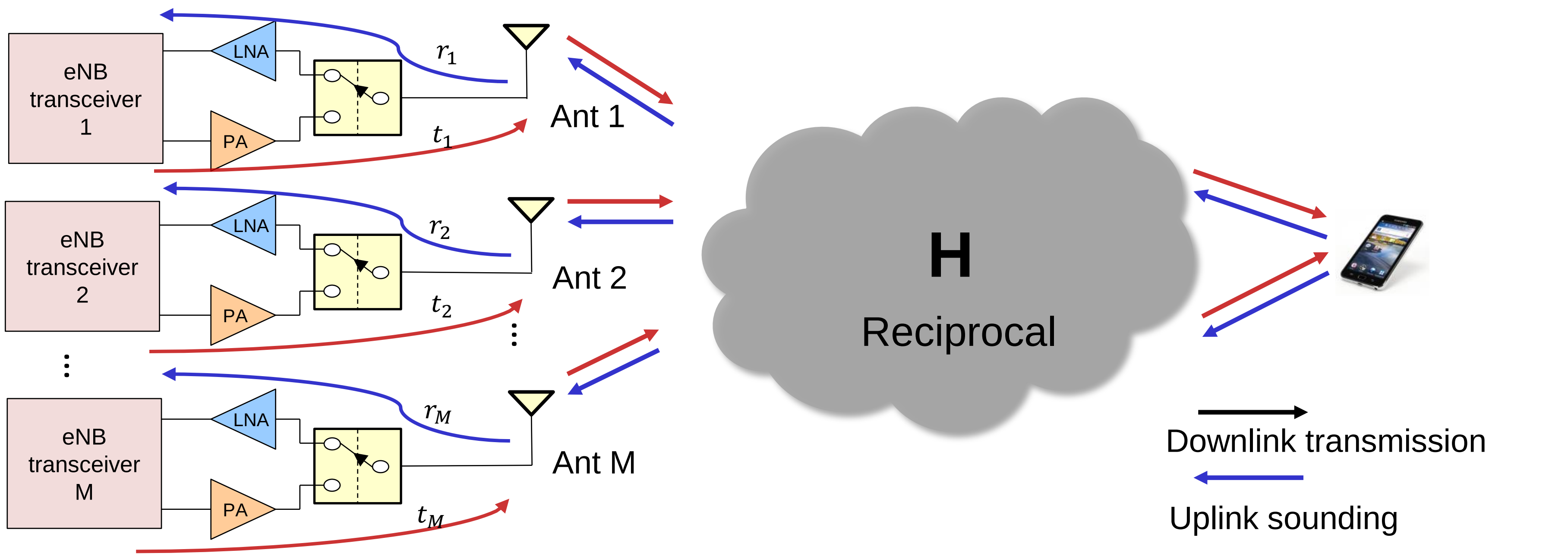


$$\rho_{predict} = \frac{|\boldsymbol{h}_k \boldsymbol{w}_k|^2}{|\boldsymbol{h}_k \boldsymbol{w}_0|^2} \rho_{measured}$$

Mean of error: **0.0941**

Var. of error: **0.0424**

FD-MIMO in TDD: Antenna Calibration



Calibration requirement:

Joint Tx/Rx calibration

$$t_1 - r_1 = \cdots = t_M - r_M$$

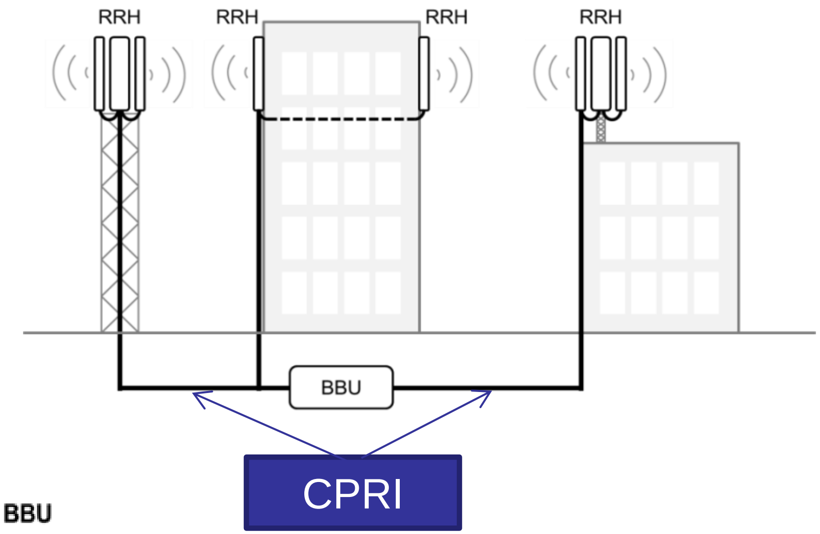
Independent Tx/Rx calibration

$$t_1 = \cdots = t_M, \; r_1 = \cdots = r_M$$

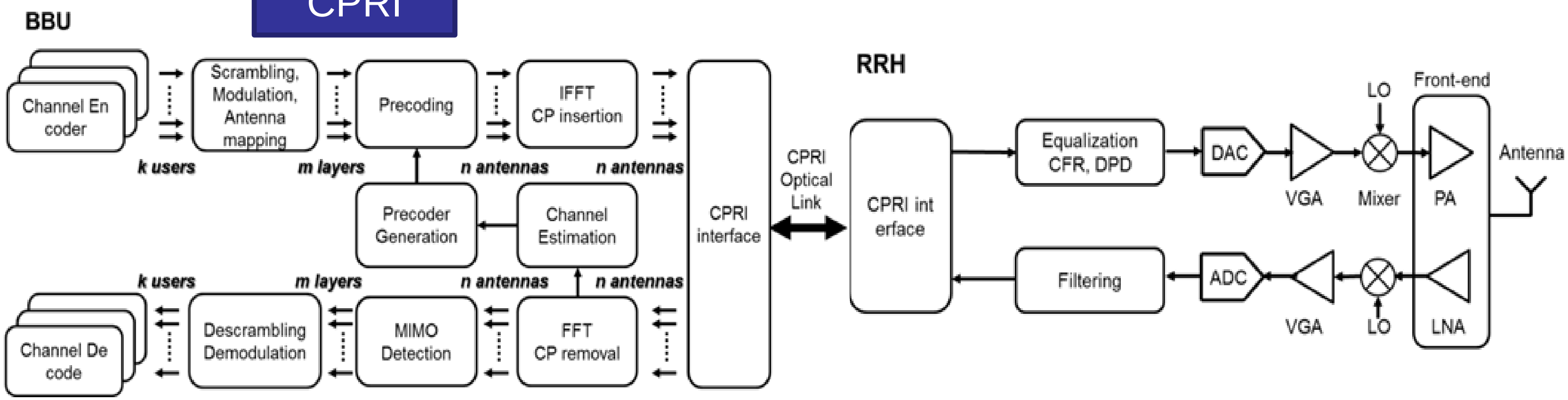
Challenges:

- Inherent error in calibration circuit
- Complexity grows with antennas
- Prefer independent Tx/Rx calibration

Front-haul Complexity



Number of sectors	3
System bandwidth (MHz)	20
Sampling rate (Msps)	30.72
Bit width per I/Q-branch	16
Number of TX antennas (paths)	32
CPRI throughput (Gbps)	**~96**



Possible Solutions:

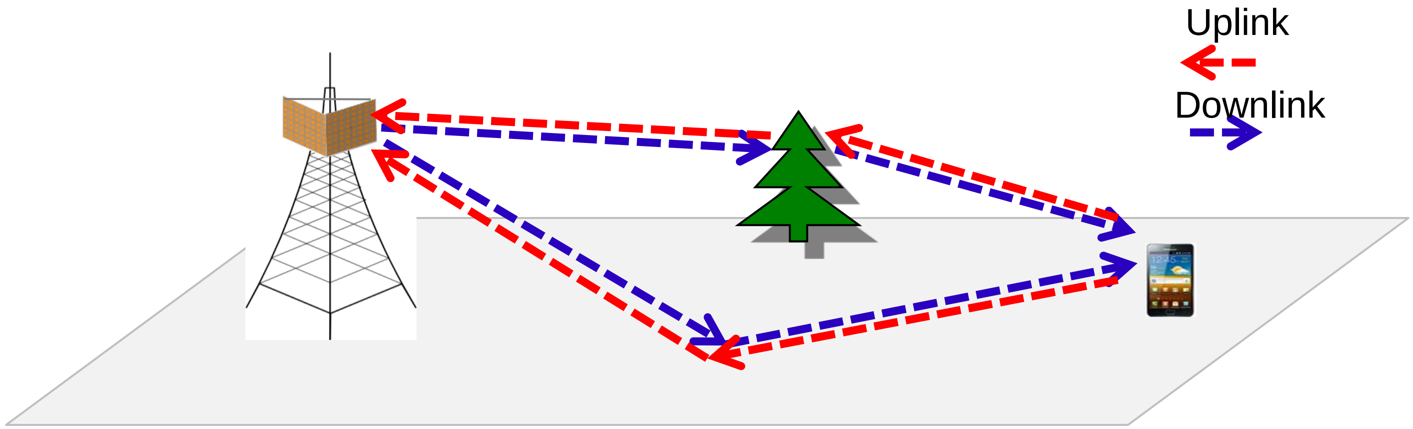
- Front-haul (CPRI) compression
- New baseband architectures

FD-MIMO in FDD: Exploit Uplink Correlation

Issue: CSI (channel state information) acquisition

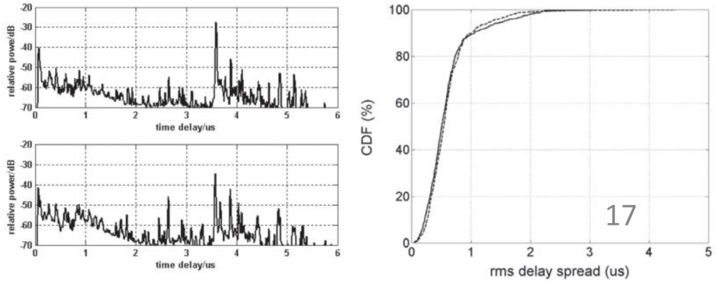
- ❑ CSI acquired by training & feedback in FDD LTE/LTE-A
- ❑ Pilot & feedback bits proportional to # of Tx antennas

Possible to use uplink channel for downlink precoding?



- ❑ Uplink & downlink channels are correlated
- ❑ FD-MIMO can measure uplink better

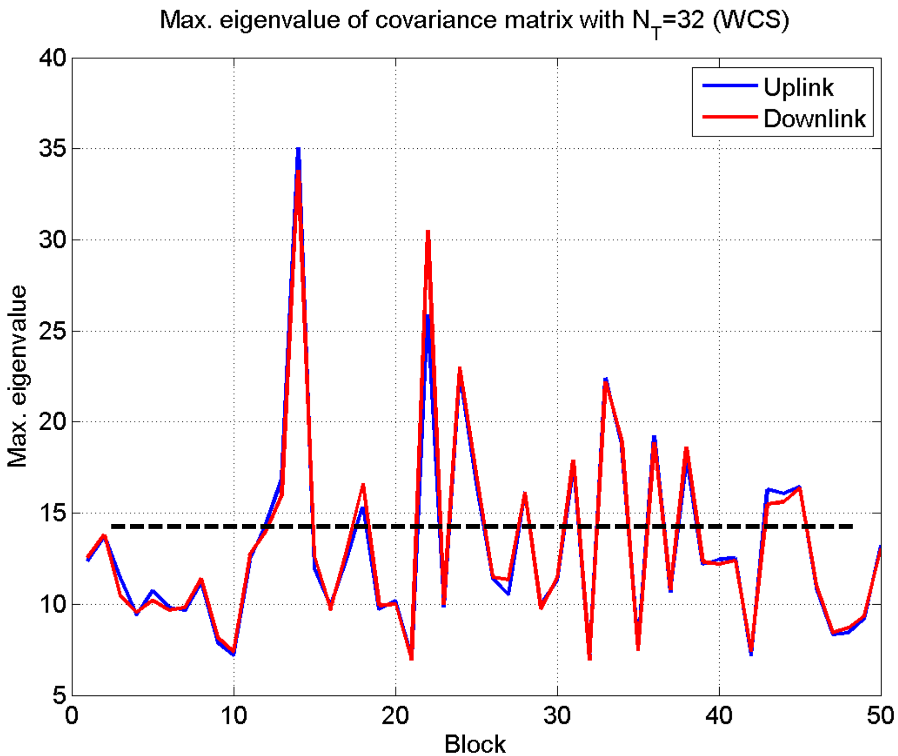
*Sana Salous and Hulya Gokalp, "Medium- and Large-Scale Characterization of UMTS-Allocated Frequency Division Duplex Channels", IEEE TVT.



FD-MIMO in FDD: Exploit Uplink Correlation (2)

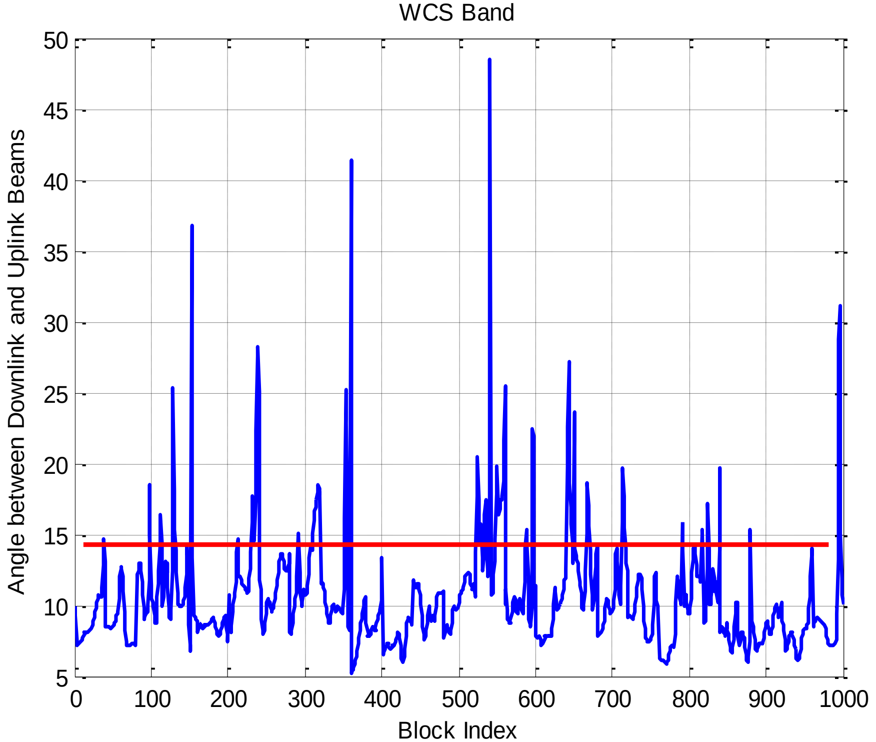
- **Duplex distance:** 45 MHz. **Channel condition:** NLOS.

  Downlink: 2300 MHz; uplink: 2250MHz



Correlation Coefficient = 0.995

CQI: Highly correlated



$\mathbf{Pr(Angle < 30^0) = 99.6\%}$

PMI*: Highly correlated

*PMI (Precoding Matrix Indicator): quantized channel direction.

Other Challenges in FD-MIMO

Feedback and codebook design in FDD

- How to reduce overhead by exploiting channel correlation in azimuth and elevation domain?
- Possible to combine with uplink measurement to provide better accuracy?

Uplink sounding in TDD

- How to accurately estimate a large number of channels?
- How to reduce channel estimation complexity?

Scheduling & precoding complexity

- How to optimally schedule ~10 MU-MIMO UEs without exponentially increasing complexity?

Summary

- Full-dimension MIMO is a promising technology to significantly improve cellular capacity (by x3-5)
- Challenges ahead include system design and implementation
- “The Next Big Thing is Here” in wireless industry

THANK YOU!