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# Hybrid Analog and Digital Precoding in Millimeter Wave Massive MIMO Systems with Realistic Hardware and Channel Constraints

Mohamed Shehata, Matthieu Crussière, Maryline H elard, Patrice Pajusco,  
Bernard Uguen

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M. Shehata<sup>1</sup>, M. Crussière<sup>1</sup>, M. H elard<sup>1</sup>, P. Pajusco<sup>2</sup>, B. Uguen<sup>3</sup>  
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## Abstract

**Millimeter-Wave** (mmWave) systems recently attracted attention as one of the key enablers for the Fifth Generation (5G) networks. The small wavelength at mmWave frequencies enables deploying massive Multiple Input Multiple Output (MIMO) antenna arrays with reasonable form factor. However, **Massive MIMO** mmWave systems suffer from a lot of practical limitations, specifically due to **channel** and **hardware** characteristics at such high frequencies. In this poster we propose multiple solutions to design a realistic massive MIMO cellular system that takes into account the imposed **limitations** and achieves considerable **gains** in terms of spectral efficiency.

## Research Objectives

**Transmit Beamforming**  
Different Architectures (Digital-Analog-Hybrid)

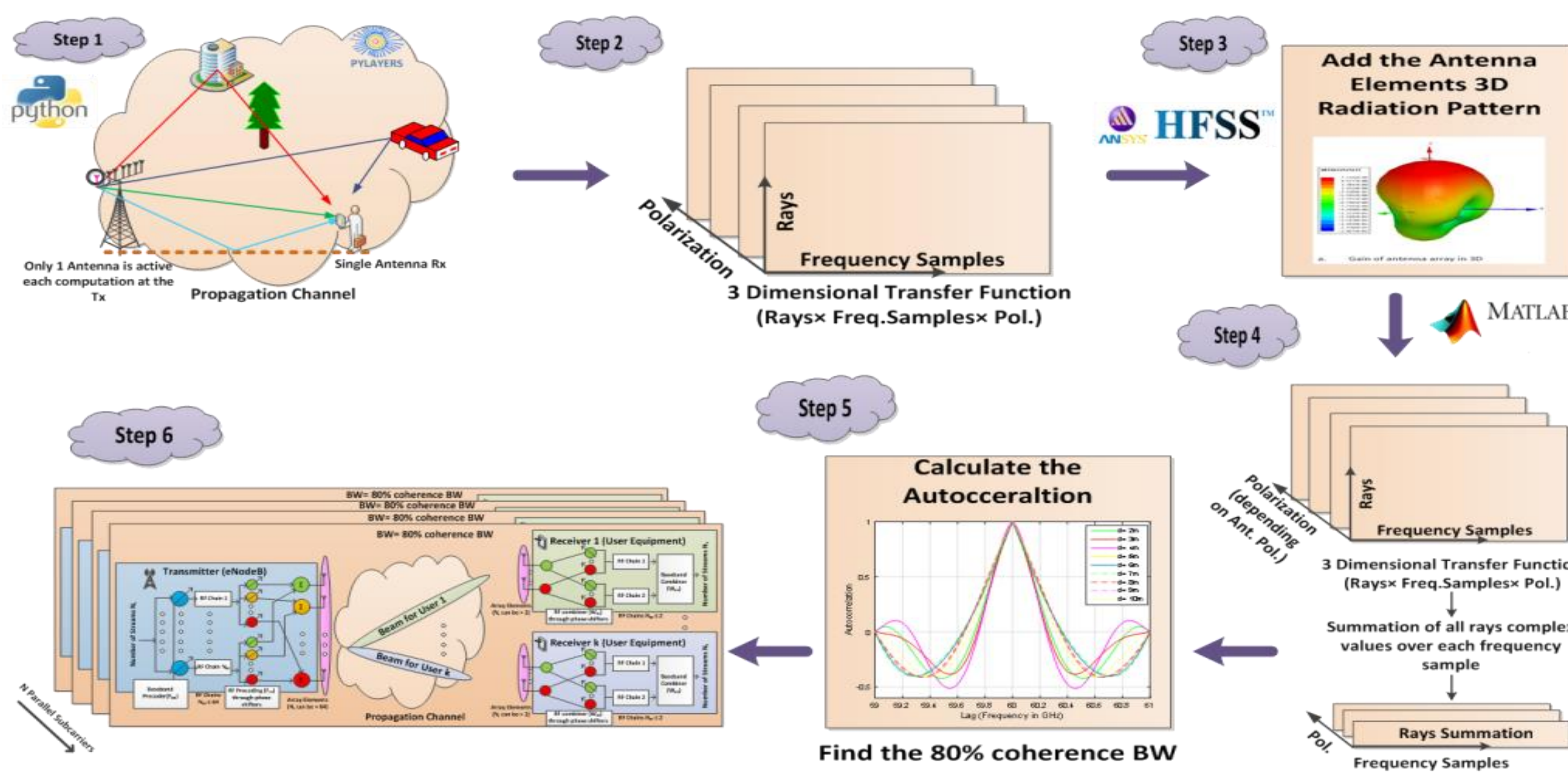
**Channel Estimation**  
Spatial sparsity of channel – Compressive Sensing

**Course Quantization**  
Analog to Digital Converters (ADCs) with few quantization bits (Large BandWidth (BW) – low Signal to Noise Ratio (SNR))

**Analog Impairments**  
Phase Shifters' limitatons (constant amplitude – quantized phases – power loss)

**Antenna Array**  
Directive Antennas to compensate for severe pathloss. Array structures that provide direct access to the beamspace (Lens Array – Butler Matrix)

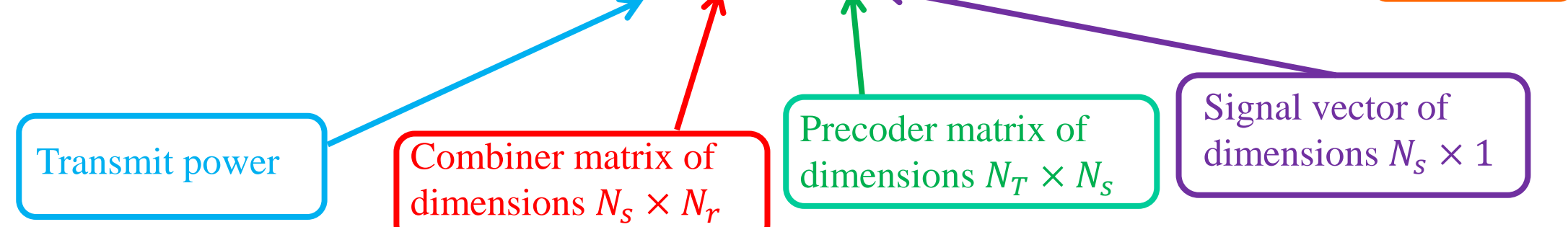
## System & Channel Model



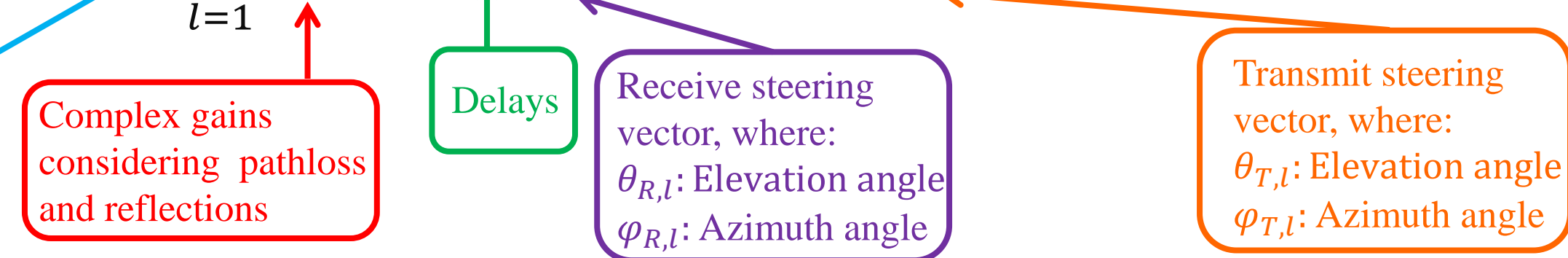
### Simulation Chain Architecture

- Multi-User (MU) MIMO system with  $K$  User Equipments (UEs) each equipped with  $N_r$  antennas.
- The transmitting Base Station (BS) is equipped with  $N_T$  antennas & serving each UE with  $N_s$  streams.
- The received signal vector  $y$  is given as follows (we omit the UE index  $k$  for clarity):

$$y = \sqrt{\rho} W^H H F s + W^H n$$

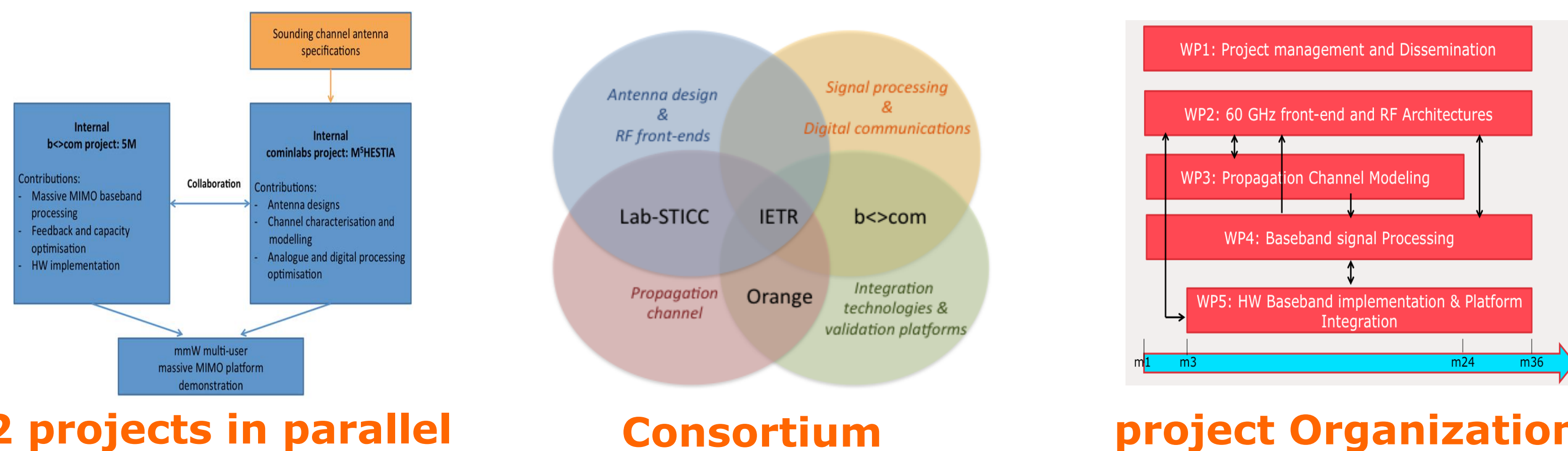


$$H = \sum_{l=1}^{N_p} \alpha_l e^{-j2\pi f \tau_l} a_R(\theta_{R,l}, \phi_{R,l}) a_T^H(\theta_{T,l}, \phi_{T,l})$$

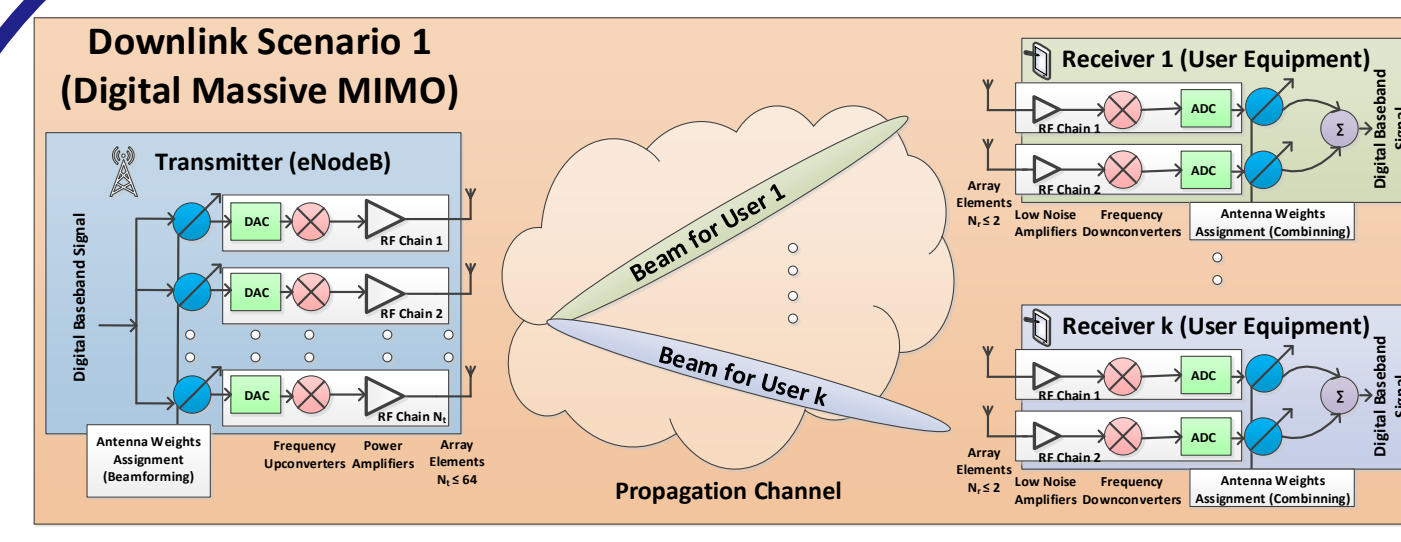


## M<sup>5</sup>HESTIA

**M<sup>5</sup>HESTIA**: Milli-Meter-wave Multi-user Massive MIMO Hybrid Equipment for Sounding, Transmissions and hardware Implementation.



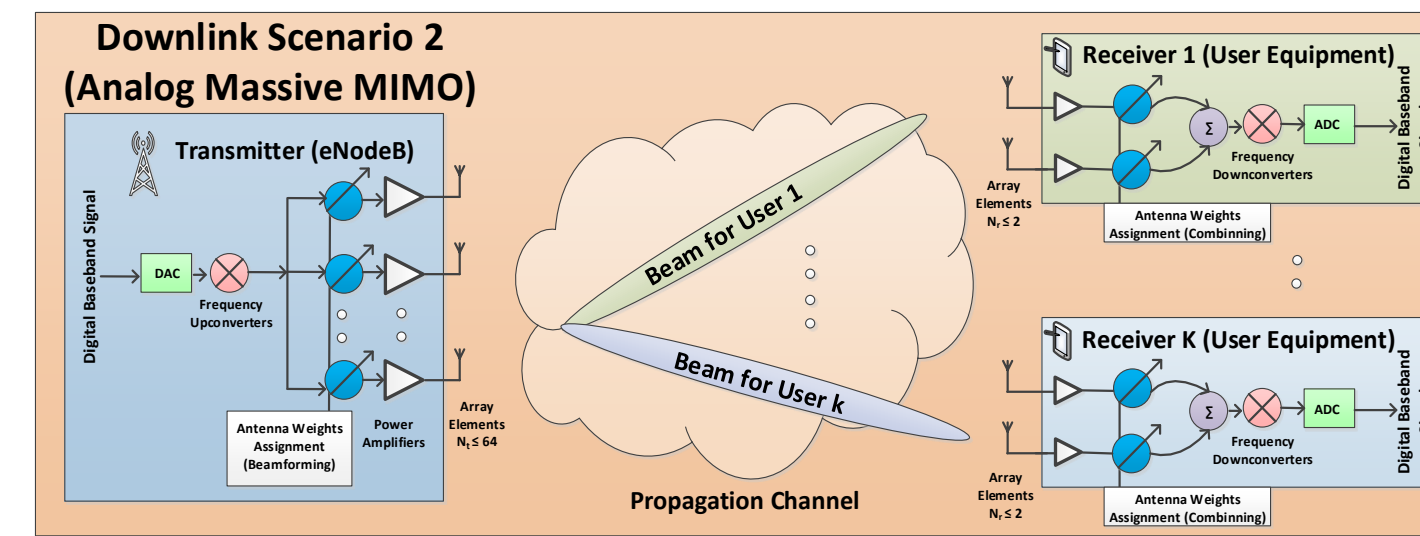
## Beamforming Scenarios



### Digital Beamforming

$$y = \sqrt{\rho} W_{BB}^H H F_{BS} s + W_{BB}^H n$$

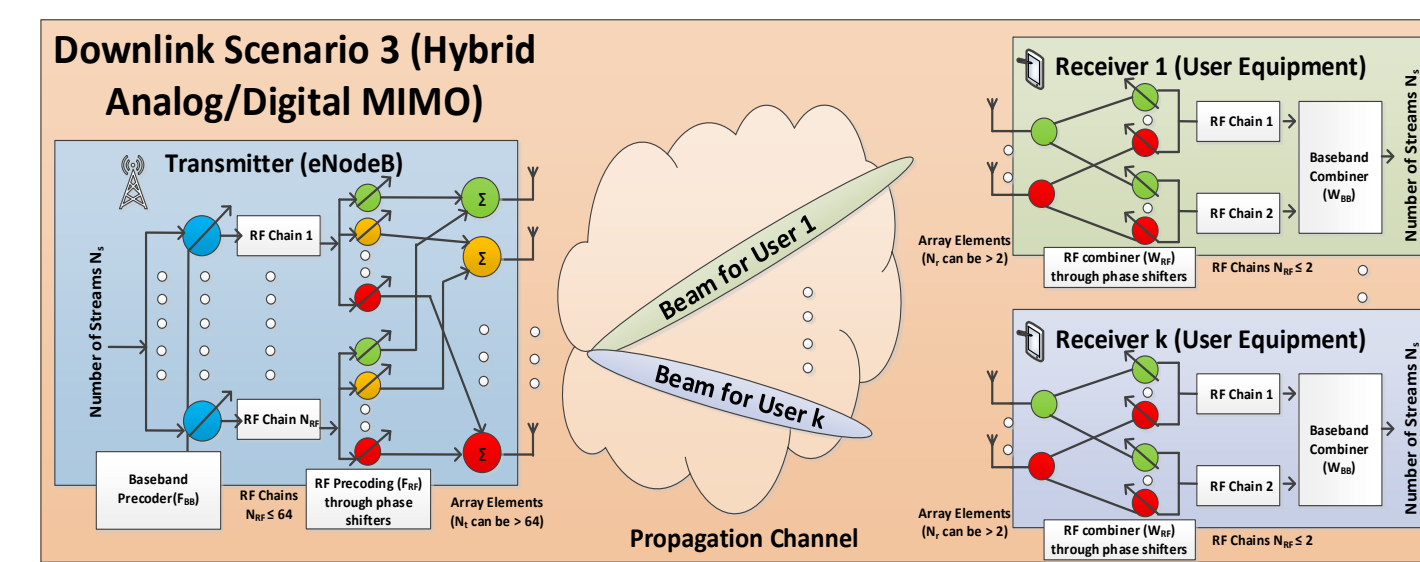
Total transmit power constraint:  $\|F_{BS}\|_F^2 \leq 1$



### Analog Beamforming

$$y = \sqrt{\rho} W_{RF}^H H F_{RF} s + W_{RF}^H n$$

Phase shifters constraints (constant Amplitude & quantized angles):  $F_{RF} \in \mathcal{F}_{RF}, W_{RF} \in \mathcal{W}_{RF}$



### Hybrid Beamforming

$$y = \sqrt{\rho} W_{BB}^H W_{RF}^H H F_{BS} s + W_{BB}^H W_{RF}^H n$$

Total transmit power constraint:  $\|F_{BS}\|_F^2 \leq 1$   
Phase shifters constraints (constant Amplitude & quantized angles):  $F_{RF} \in \mathcal{F}_{RF}, W_{RF} \in \mathcal{W}_{RF}$

### Advantages

- Can serve interference free MU scenarios with number of UEs =  $N_T$
- A lot of existing digital precoding techniques exist in the literature

### Disadvantages

- RF chain is required for each antenna
- This applies limitations on implementing Massive MIMO mmWave systems, since RF chains are complex and power hungry in mmwave regime

### Advantages

- Low hardware complexity and power consumption (Only 1 RF chain is required)
- Can increase the link budget
- Can serve MU scenarios through multiplexing in Time/Frequency

### Disadvantages

- Can't support MU MIMO scenarios with spatial multiplexing
- Therefore it is not favourable from Spectral Efficiency (SE) point of view

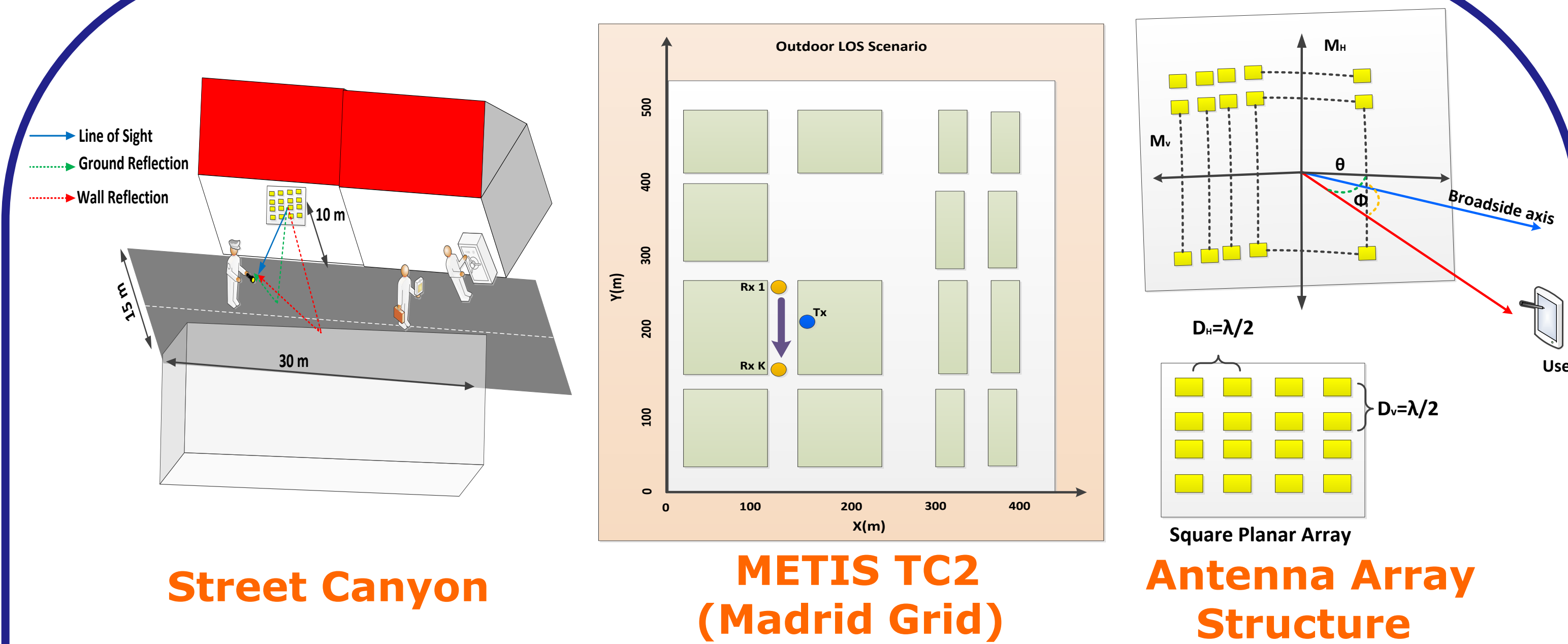
### Advantages

- Can employ much more transmit antennas than the number of RF chains
- Henceforth, can achieve higher transmit gain compared to digital systems with the same number of RF chains (hardware complexity)

### Disadvantages

- Analog impairments due to the power loss and limited resolution of phase shifters

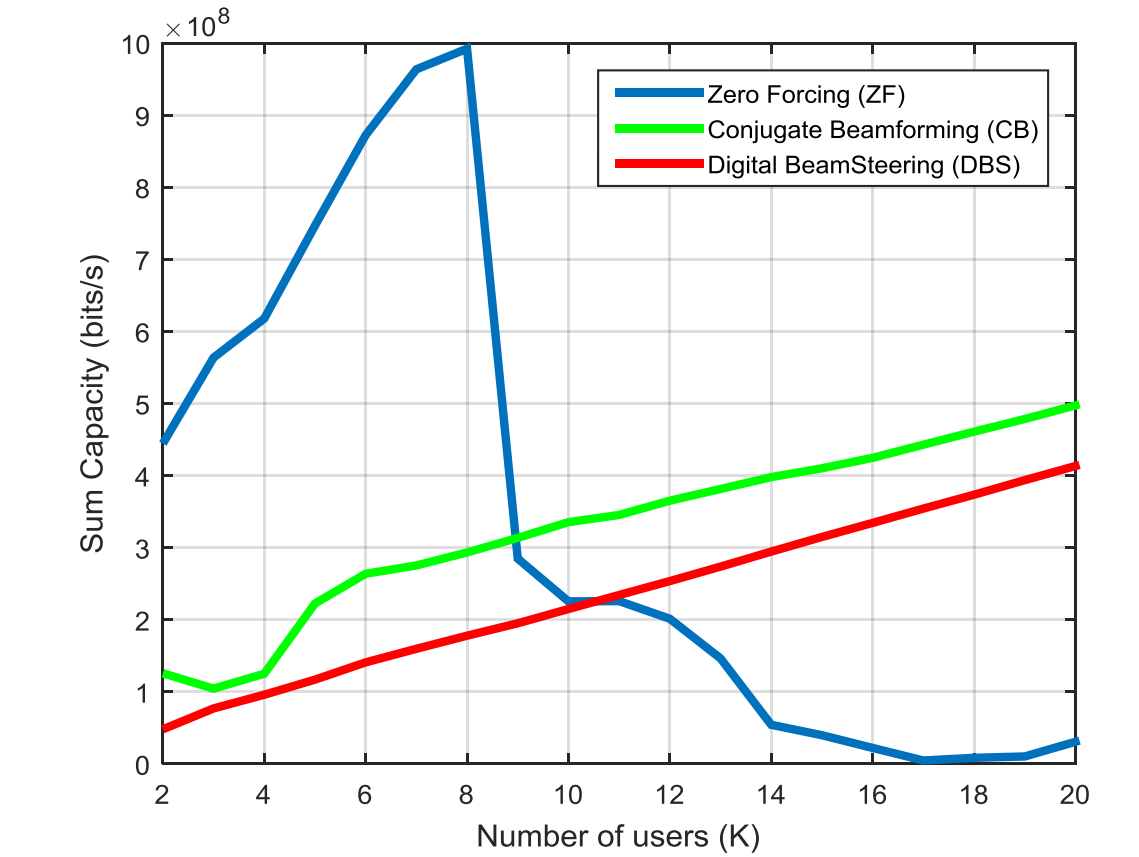
## Initial Results



| Precoding | Complexity | $W_{RF}$                     | Maximize |
|-----------|------------|------------------------------|----------|
| CB        | ++         | $H_{T_s}^H$                  | SNR      |
| ZF        | +++        | $H_{T_s}^H (H_n H_n^H)^{-1}$ | SIR      |
| DBS       | +          | $A^H$                        | SNR      |

### Simulation Parameters:

- Environment: Street Canyon
- System: MU-MIMO
- Channel Model: PyLayers [1]
- Antenna Array height: 10m
- Antenna Spacing:  $\frac{\lambda}{2}$
- Scenario: Outdoor LoS
- Center Frequency: 60 GHz
- Inter-carrier spacing: 20 MHz
- Transmit Antennas: 16
- Receive Antennas: 1
- UEs interdistance: 1m
- Transmit Power: 26 dbm



### Conclusion:

- ZF overperforms CB and DBS in sum capacity when the number of UEs is smaller than the channel rank.
- CB and DBS still achieve high sum capacity in mmWave systems even with exceeding the degrees of freedom with lower complexity compared to ZF.
- The main advantage of the DBS lies on estimating only  $2K$  angles instead of  $\frac{K \times N_T \times N_{FFT}}{N_{BC}}$  parameters in ZF and CB.

$K$ : the number of UEs,  $N_T$ : number of transmit antennas,  $N_{FFT}$ : number of subcarriers,  $N_{BC}$ : number of subcarriers per coherence BW

[1] PyLayers: An Open Source Dynamic Simulator for Indoor Propagation and Localization, N. Amiot, M. Laaraiedh, B. Uguen, Communications Workshops ICC 2013

## Authors

- 1 INSA, IETR, CNRS UMR 6164, Rennes, France
- 2 Institut Mines-Telecom, Telecom Bretagne, Brest, France
- 3 Universit e Rennes 1, IETR, CNRS UMR 6164, Rennes, France