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

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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)

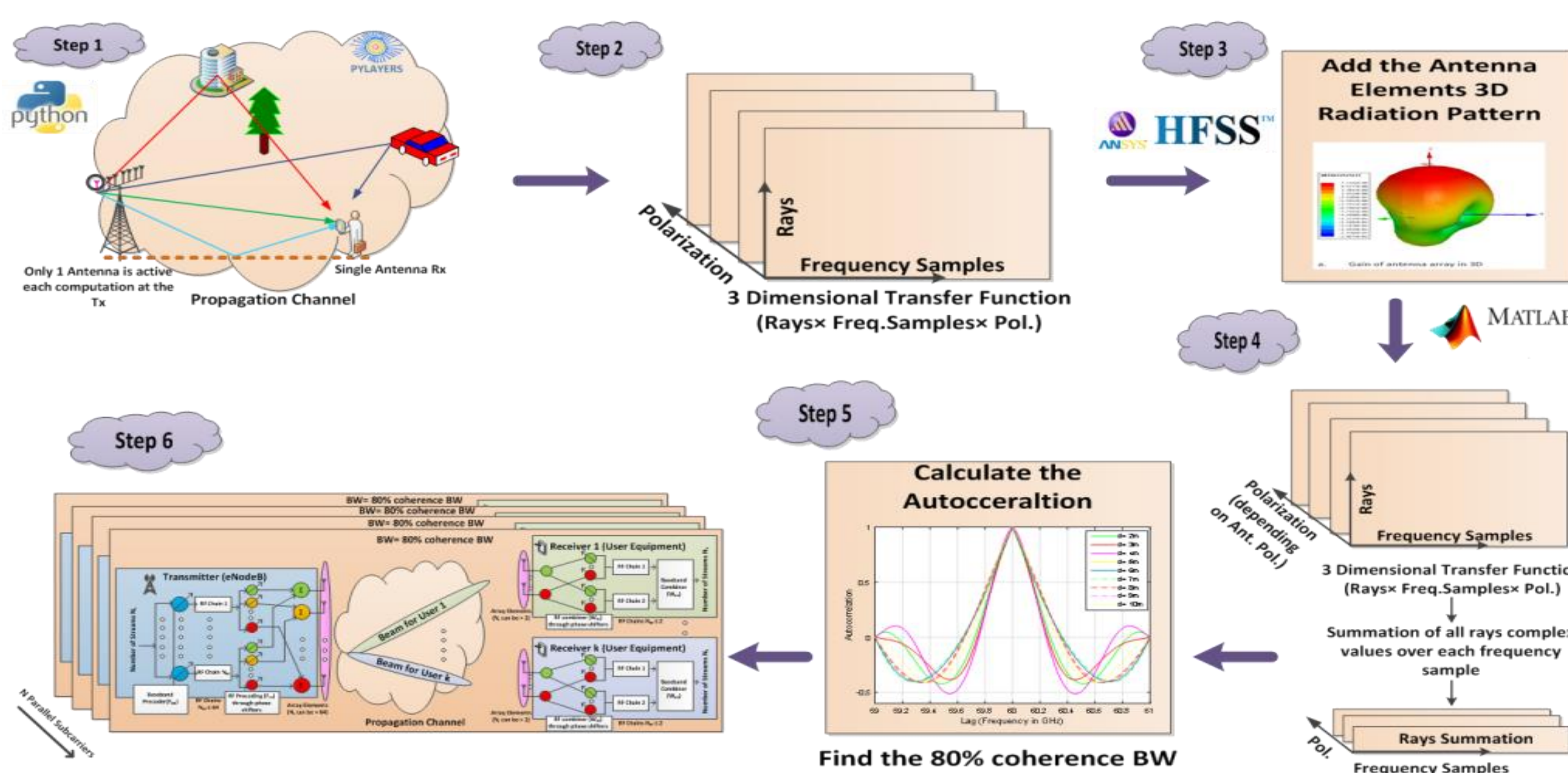
Channel Estimation
Spatial sparsity of channel – Compressive Sensing

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)

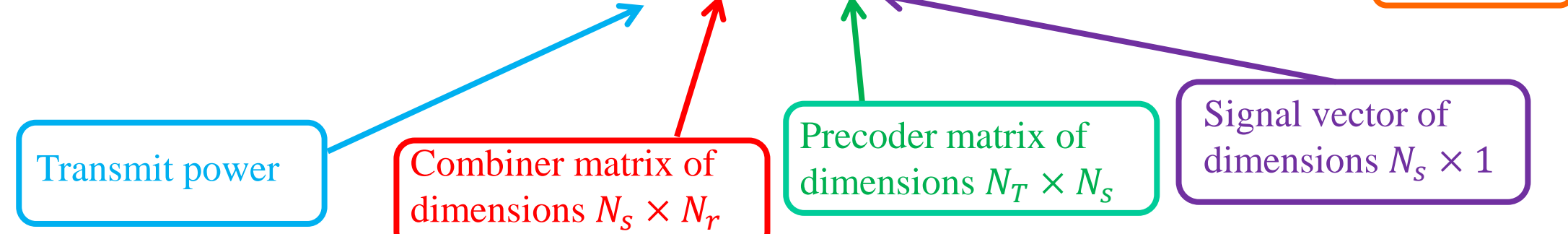
System & Channel Model



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):

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

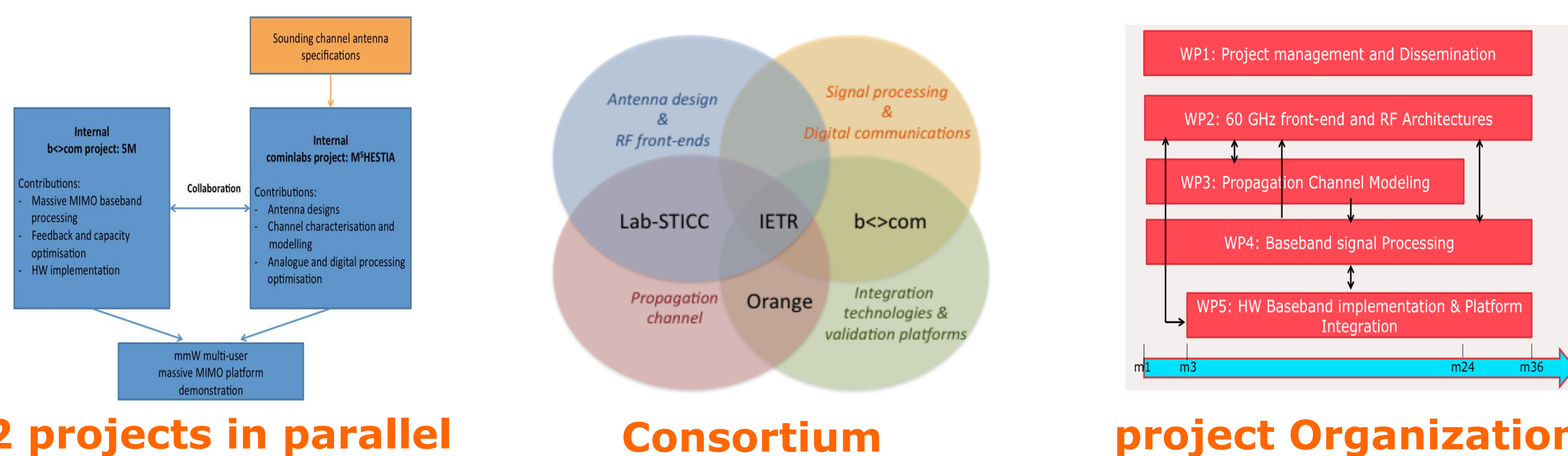


$$H = \sum_{l=1}^{N_p} \alpha_l e^{-j2\pi f \tau_l} a_R(\theta_{R,l}, \varphi_{R,l}) a_T^H(\theta_{T,l}, \varphi_{T,l})$$

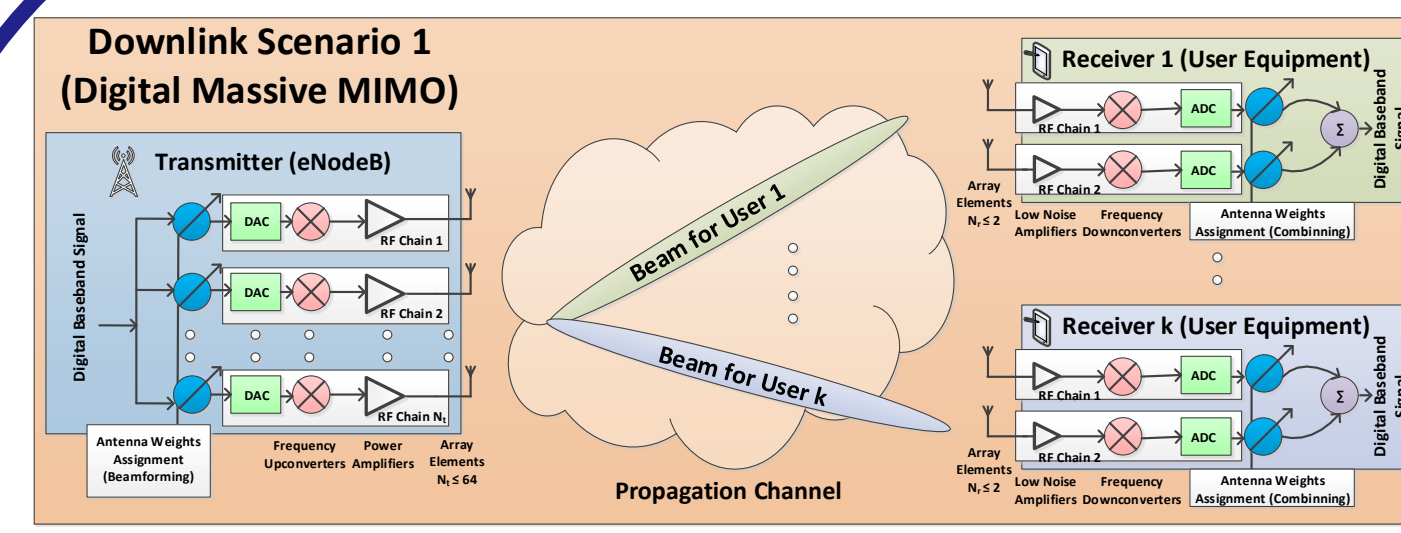
Number of paths: N_p
Complex gains considering pathloss and reflections: α_l
Delays: τ_l
Receive steering vector, where: $\theta_{R,l}$: Elevation angle, $\varphi_{R,l}$: Azimuth angle
Transmit steering vector, where: $\theta_{T,l}$: Elevation angle, $\varphi_{T,l}$: Azimuth angle

M⁵HESTIA

M⁵HESTIA: Milli-Meter-wave Multi-user Massive MIMO Hybrid Equipment for Sounding, Transmissions and hardware ImplementAtion.



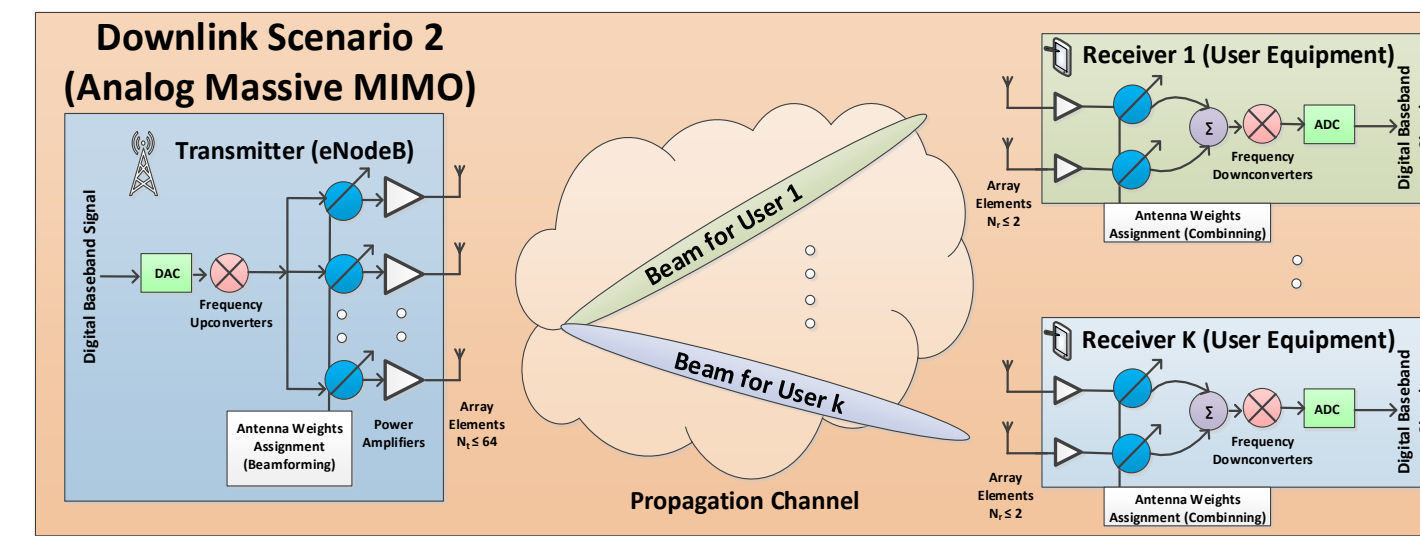
Beamforming Scenarios



Digital Beamforming

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

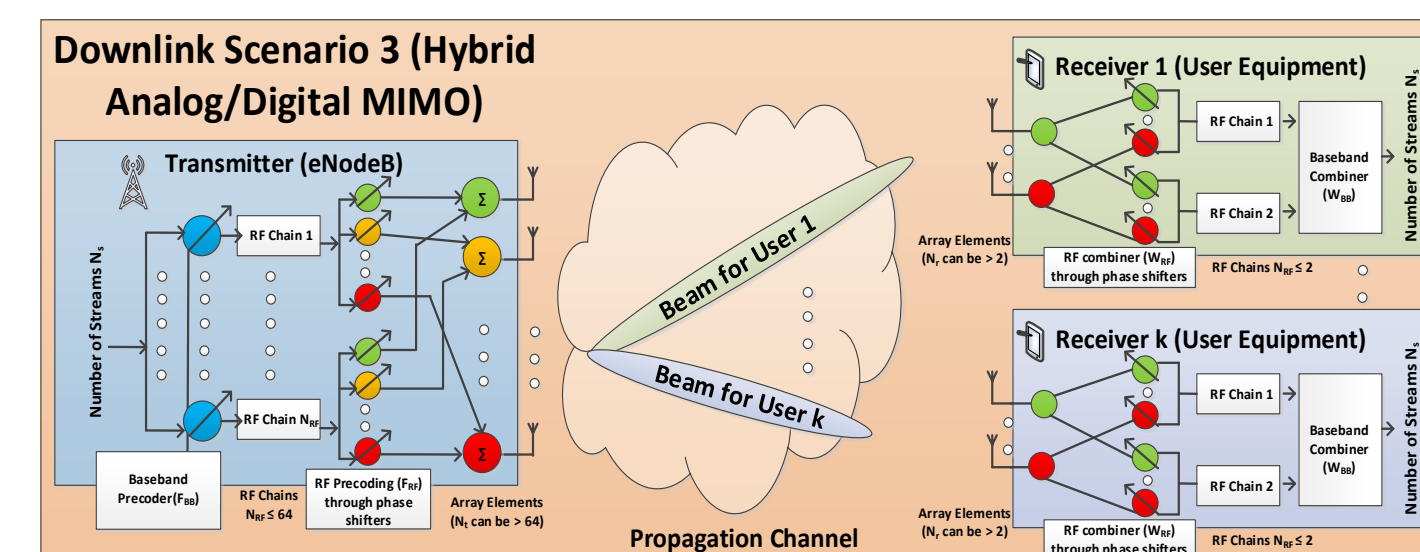
Total transmit power constraint: $\|F_{BB}\|_F^2 \leq 1$



Analog Beamforming

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

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



Hybrid Beamforming

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

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

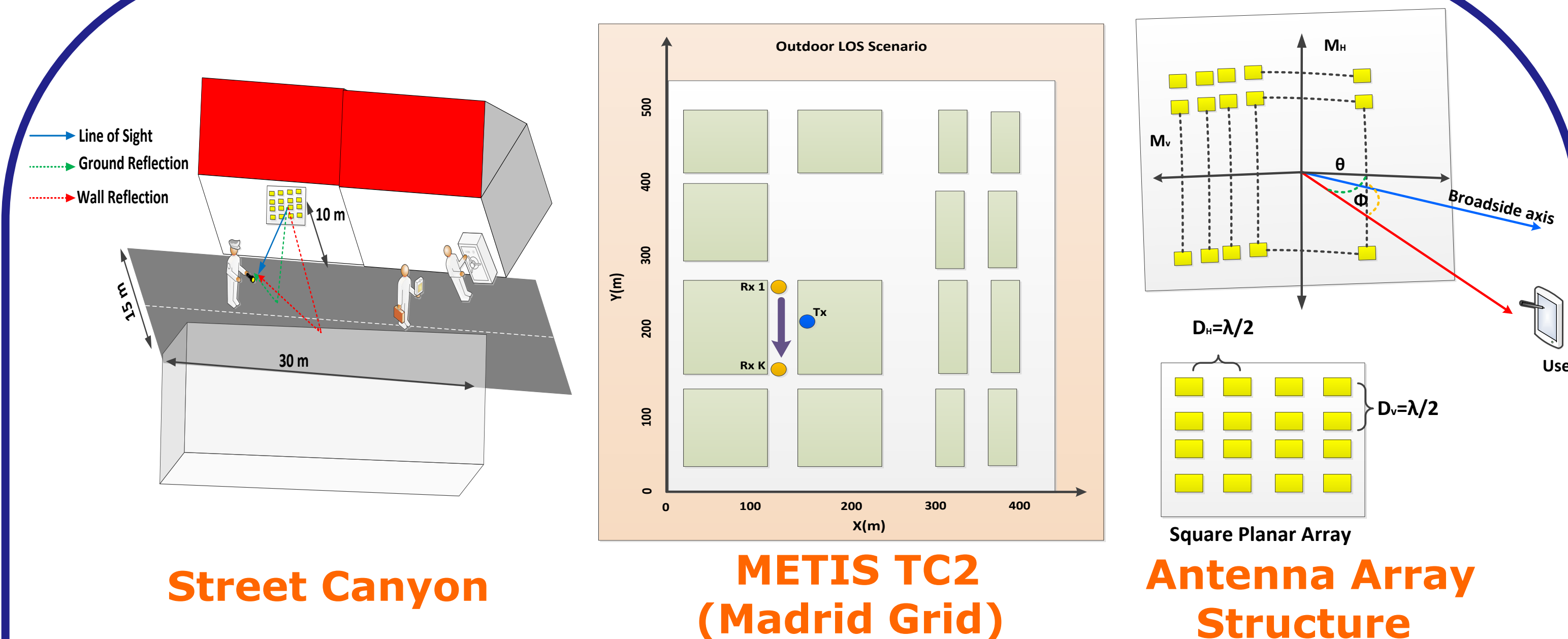
Advantages

- 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

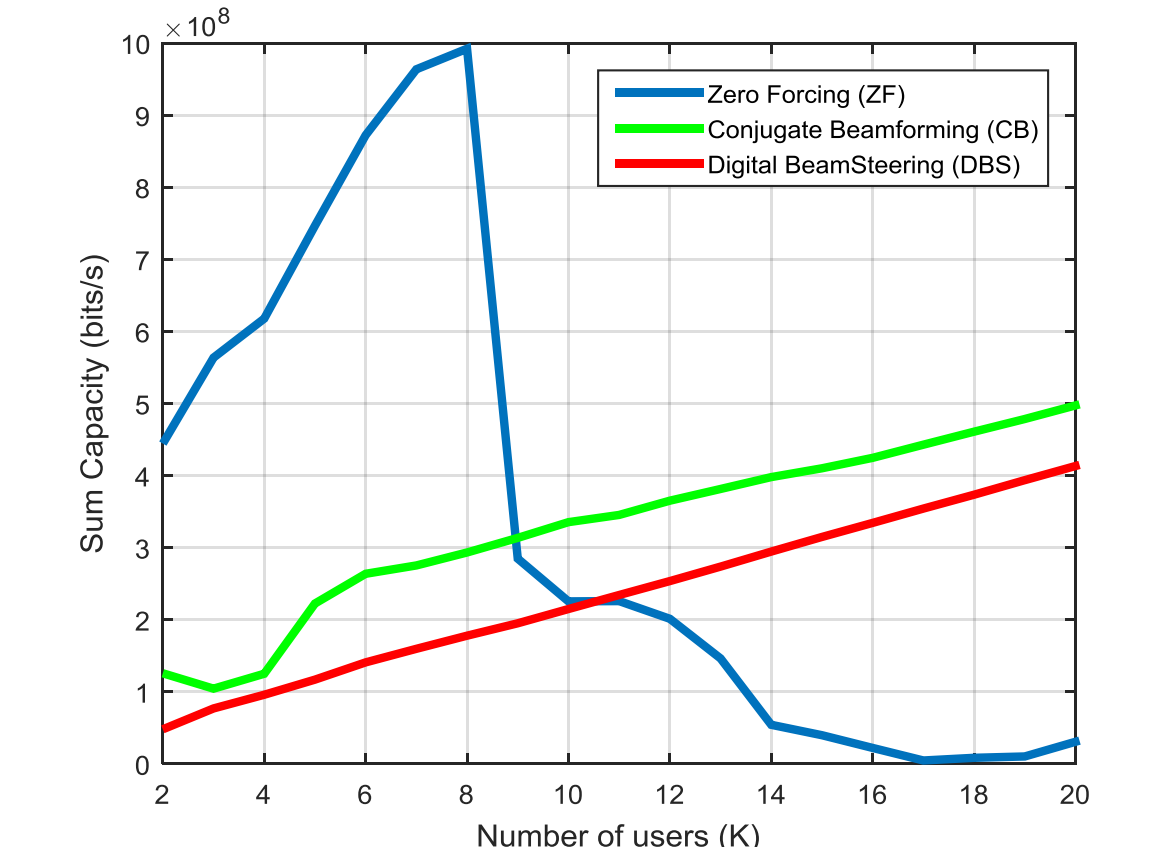
Initial Results



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

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