



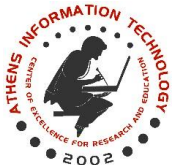
# IEEE 5G

## Terrestrial communication in the X/ K bands aided by hybrid antenna arrays and precoding techniques

Constantinos B. Papadias

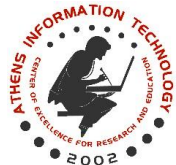
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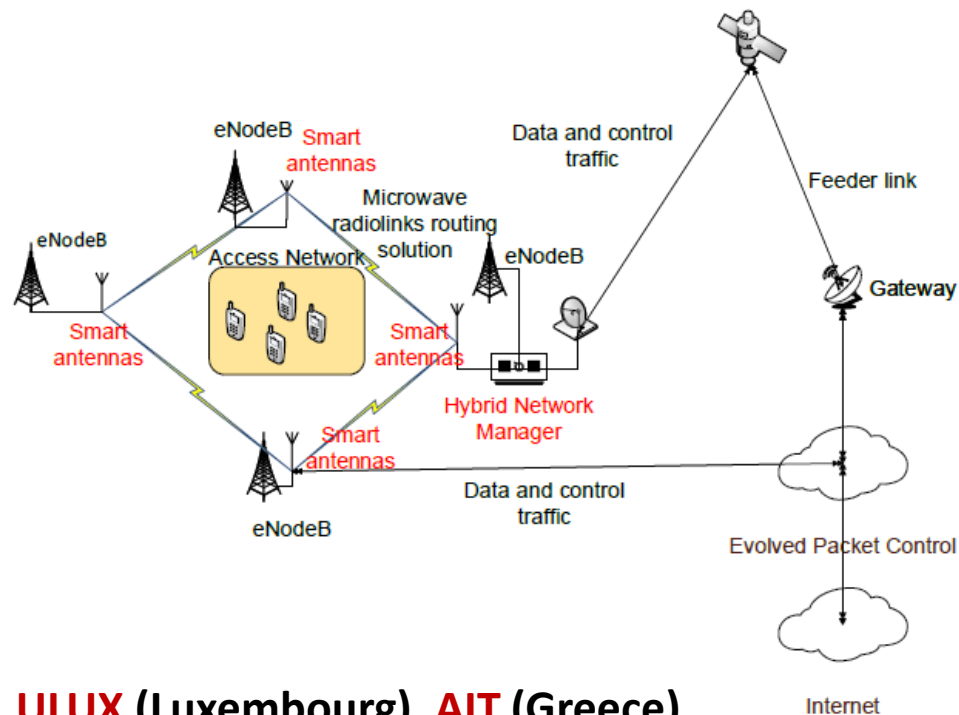
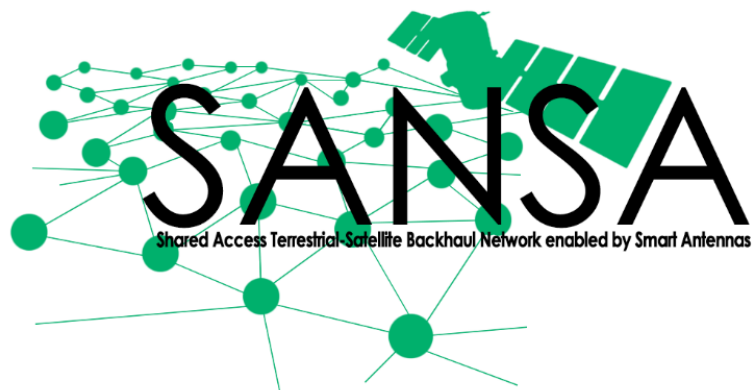
# Outline

- Background: **terrestrial & satellite-ground** communications  
(H2020 Project SANSA)
- **Objectives & focus**
- **Channel** modelling
- Antenna technology: **hybrid analog / digital** antenna arrays
- **Single-RF** solutions
- **Multiple-RF** solutions
- **Interference mitigation** techniques
- Summary / **conclusions**



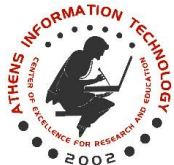
# SANSA H2020 Project & System Architecture

The aim of H2020 project **SANSA** is to improve the capacity, resilience, and coverage of mobile backhaul networks while maximizing, at the same time, their spectral and energy efficiency, in order to meet the Digital Agenda 2020 for the European Union requirements.



## Project partners:

**CTTC** (Spain), **Thales Alenia Space** (Spain), **ULUX** (Luxembourg), **AIT** (Greece), **Avanti** (UK), **OTE** (Greece), **Fraunhofer IIS** (Germany), **ViaSat** (Switzerland)



# SANSA Objectives

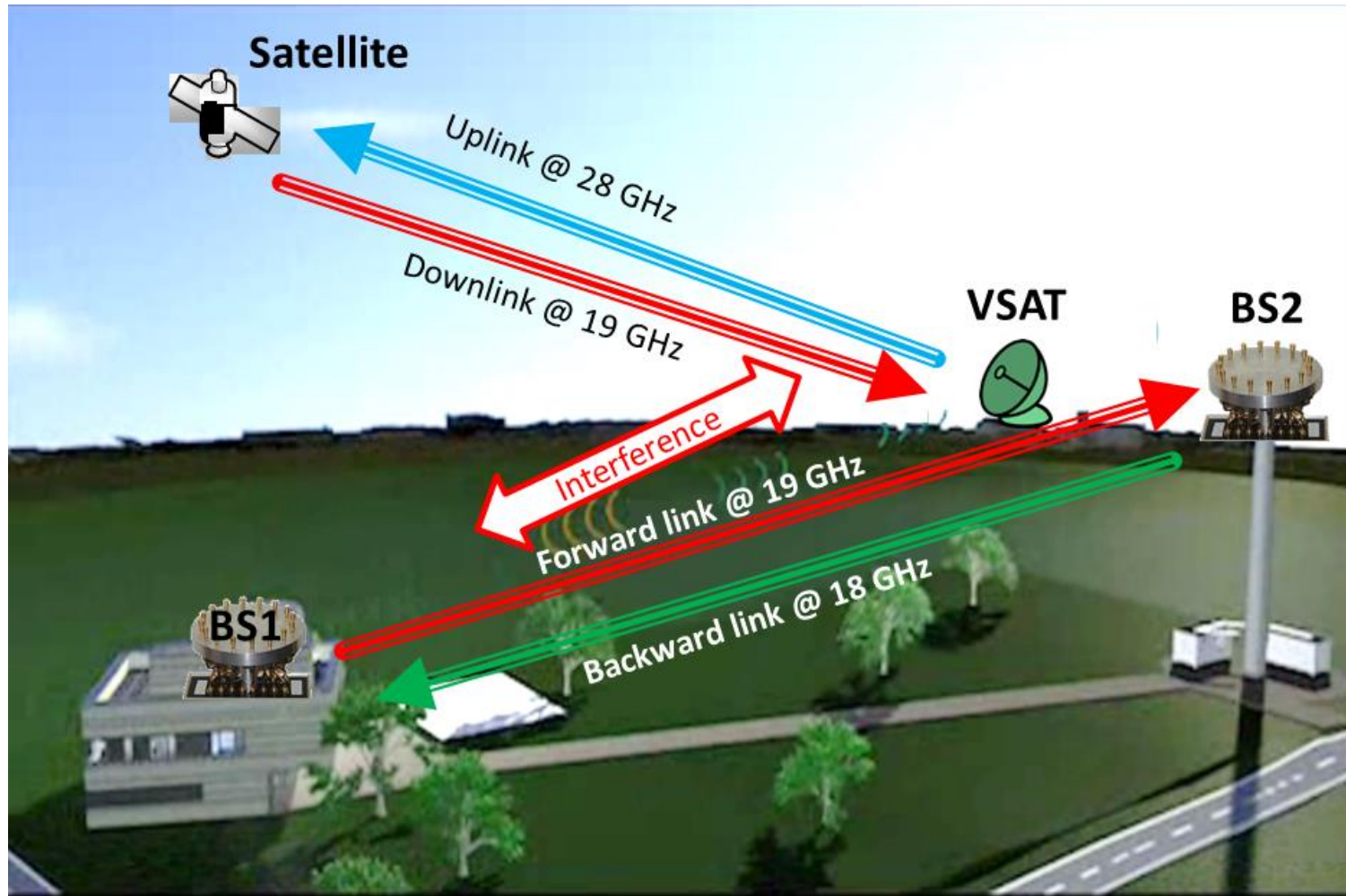
The SANSA paradigm promotes the development of **self-organizing hybrid terrestrial – satellite backhaul networks** that are capable of reconfiguring the terrestrial topology and jointly exploit the terrestrial and satellite links depending on the traffic demands.

The main SANSA objectives are to:

1. **Increase** the mobile backhaul network's **capacity** in view of the predicted traffic demands.
2. Drastically **improve** backhaul network **resilience** against link failures and congestion.
3. **Facilitate** the **deployment** of mobile networks both in sparsely and densely populated areas.
4. **Improve** the **spectral efficiency** in the extended **K/Ka-bands** for **backhaul operations**.
5. **Reduce** the **energy consumption** of mobile backhaul networks.
6. **Strengthen** the terrestrial and satellite operators' **market** and their related industries.



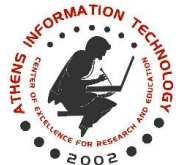
# Ground-satellite interference in SANSA



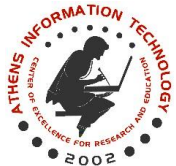
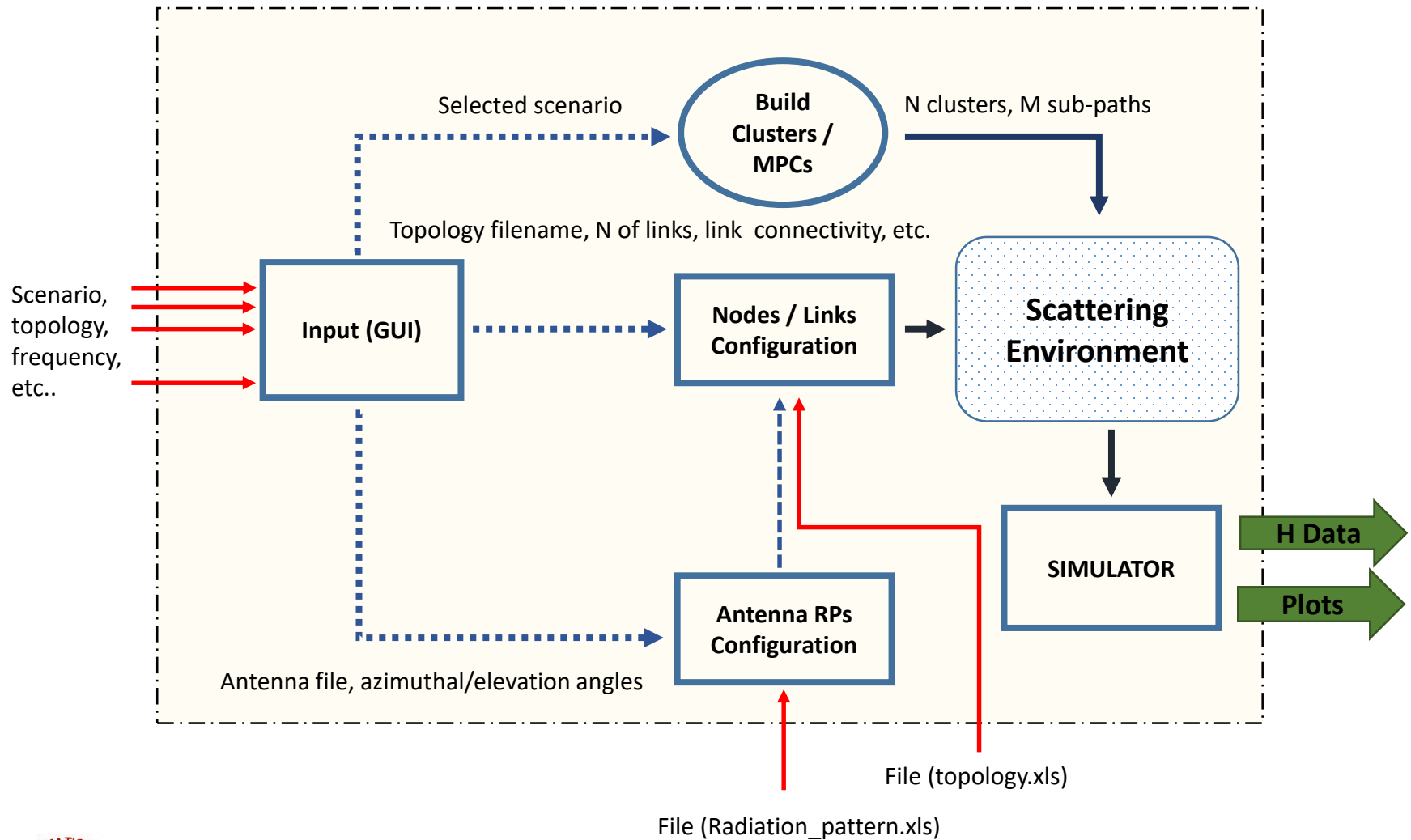
# Our focus in SANSA

- **Interference mitigation techniques** applied on P2MP and MP2MP networks (e.g. via precoder and beamforming designs).
- **Power allocation** of multi-antenna links under an interfered power constraint.
- **Antenna arrays** (e.g. phased, hybrid and parasitic) designs.
- **Coordinated MIMO** techniques

For these, we have developed a channel simulator that is suitable for the modelling of the corresponding links.



# Channel Simulator Architecture

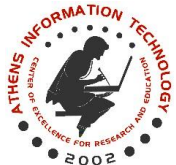


# SANSA Channel Model structure

We pursue a **semi-deterministic** approach wherein the node topology is given, whereas the clusters of scatterers are drawn from a statistical distribution [1][3].

The driving factors behind the development of the SANSA channel model simulator were:

1. The use of **topologies** such as the “Helsinki” or “Vienna” (**geometry based**) for benchmarking without the need of exhaustive sets of measurement data.
2. The need to include **steerable, narrow beam antennas** (smart antennas), hence the incorporation of the angular (spatial) dimension.
3. The desire to address a **variety** of propagation environments.



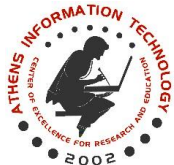
# Channel Model Configuration

## Inputs:

- Placement / Locations of the nodes (for site-specific topologies)
- Number of nodes and link configuration (Active links per network)
- Type of scenario (rural, suburban, urban, etc.)
- Link parameters (frequency, Tx power, rain rate [7][8], BW, speed, number of iterations, etc.)
- Antenna parameters (type, angles, simulated or measured radiation pattern data)

## Outputs:

- Channel Coefficients (for all links, including interfering links)
- Power Delay Profile (RMS Delay) per link and composite for given radiation patterns
- Doppler Effect
- Estimation of multipath component parameters (MPCs), such as AoD/AoA, path loss, phase, delay, etc.
- Exported file and plots with all simulated data



# Channel model software GUI screenshot

**19/28 GHz mmWAVE CHANNEL MODEL SIMULATOR**  
Athens Information Technology

Frequency (GHz)	Mode	Scenario	BW (MHz)	Samples (FFT)	N iterations	Rain rate (mm/hr)	Power (dBW)
19	Topology Sim	Rural	1.00	1.00	1.00	0.00	24.00

Number of Links: 8  Load Clusters from File

1x1.xlsx  
2x2.xlsx  
Helsinki.xlsx  
Helsinki\_eva.xlsx

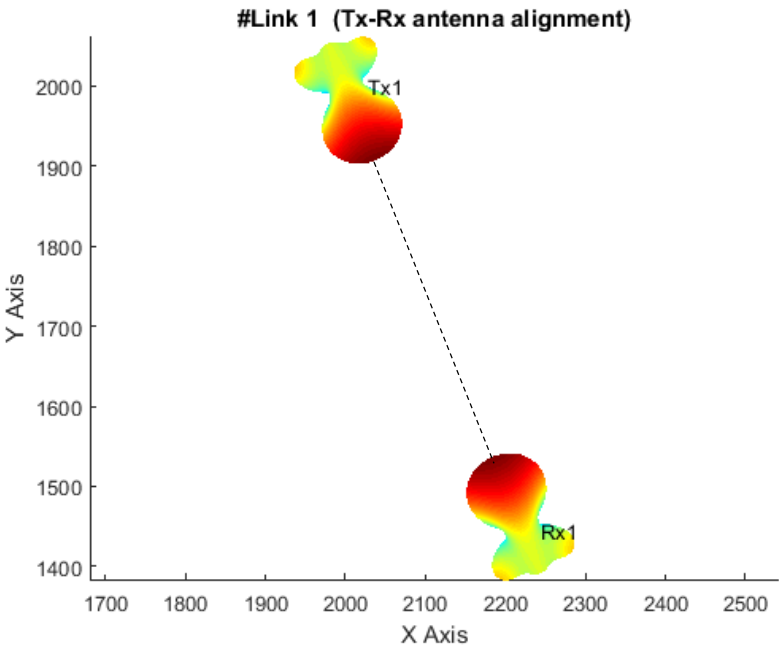
Link	Tx	Rx	Tx_RP	Tx(phi)	Tx(theta)	RP_Rx	Rx(phi)	Rx(theta)
1	Node_01	Node_02	bowtie.mat	274.03	92.83	bowtie.mat	94.03	87.17
2	Node_01	Node_03	bowtie.mat	348.36	90.82	bowtie.mat	168.36	89.18
3	Node_01	Node_05	bowtie.mat	330.05	95.11	bowtie.mat	150.05	84.89
4	Node_01	Node_08	bowtie.mat	39.38	91.75	bowtie.mat	219.38	88.25
5	Node_10	Node_02	bowtie.mat	217.53	90.39	bowtie.mat	37.53	89.61
6	Node_10	Node_03	bowtie.mat	283.68	89.83	bowtie.mat	103.68	90.17
7	Node_10	Node_05	bowtie.mat	206.41	90.63	bowtie.mat	26.41	89.37
8	Node_10	Node_08	bowtie.mat	140.93	90.89	bowtie.mat	320.93	89.11

Antenna Alignment:

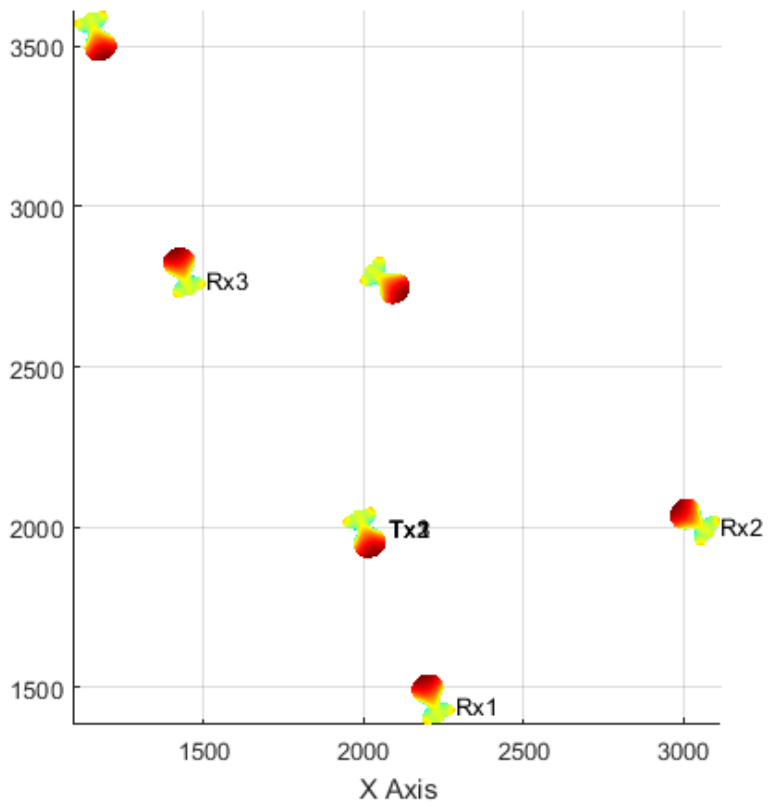
www.sansa-h2020.eu



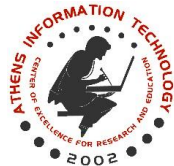
# Indicative antenna radiation patterns for given links



Link Setup (19GHz Bowtie Parasitic Antennas)

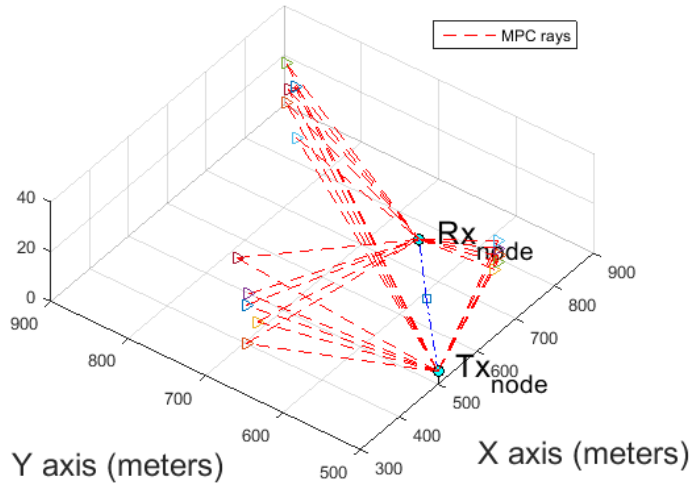


Network Setup (multiple P2P links)

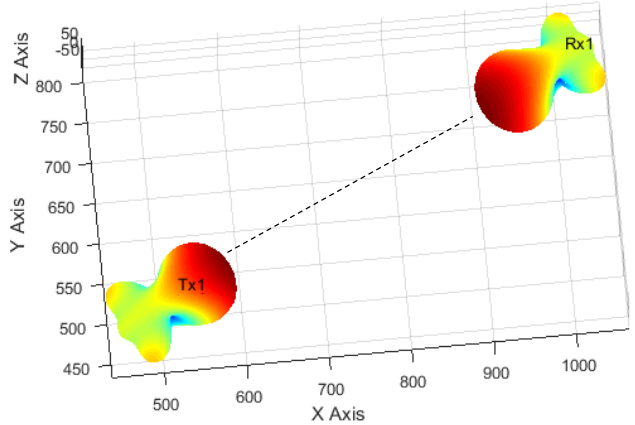
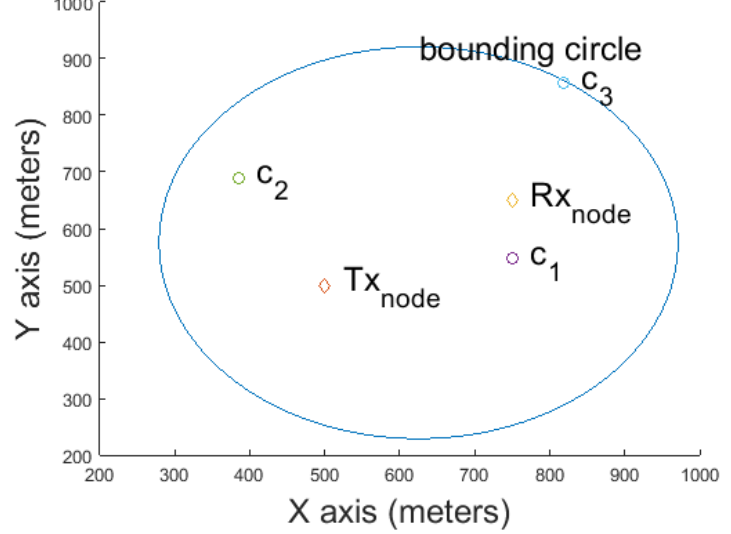


# Indicative results for a P2P Link

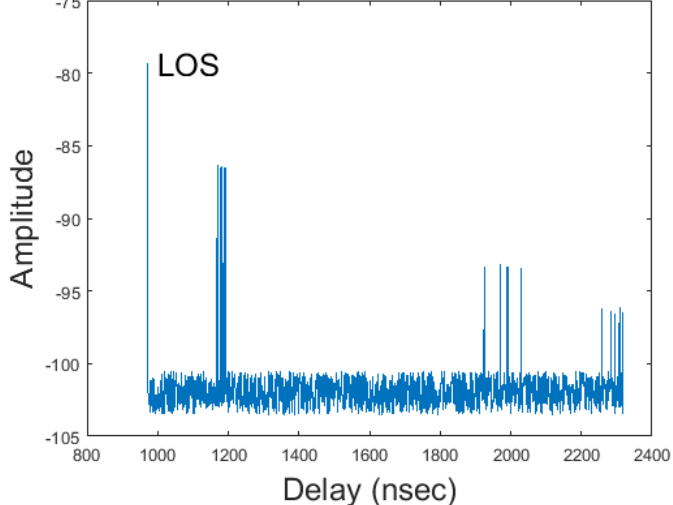
Scattering Enviroments (MPC rays)



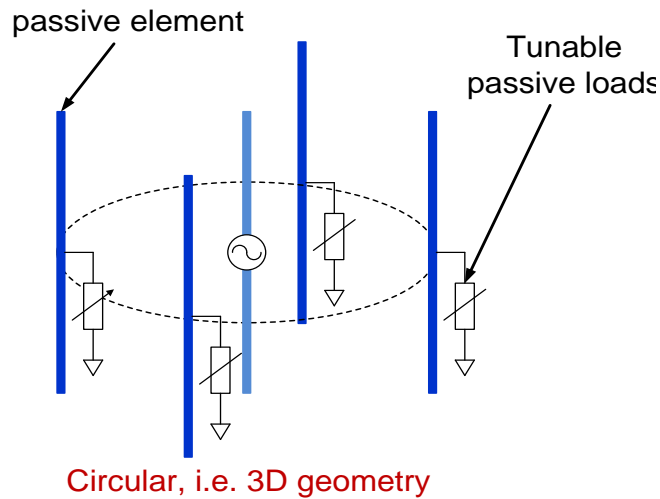
Clusters and Link Terminals - 2D Map Plot



PDP Plot



# Parasitic antenna arrays



The well-known baseband model of antenna arrays can be adopted as:

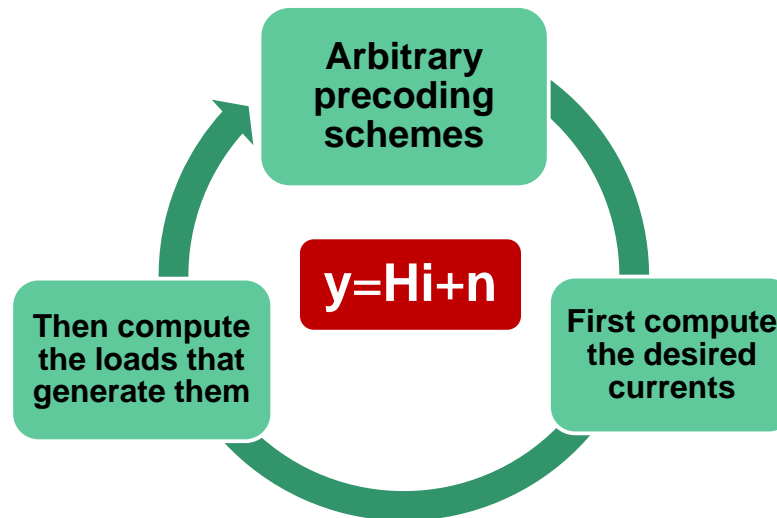
$$\mathbf{y} = \mathbf{H}\mathbf{i} + \mathbf{n}$$

where:

$$\mathbf{i} = (\mathbf{Z}_T + \mathbf{Z}_G)^{-1} \mathbf{v}_T$$

$$\mathbf{v}_T = [v_{T1} \quad 0 \quad \dots \quad 0]^T$$

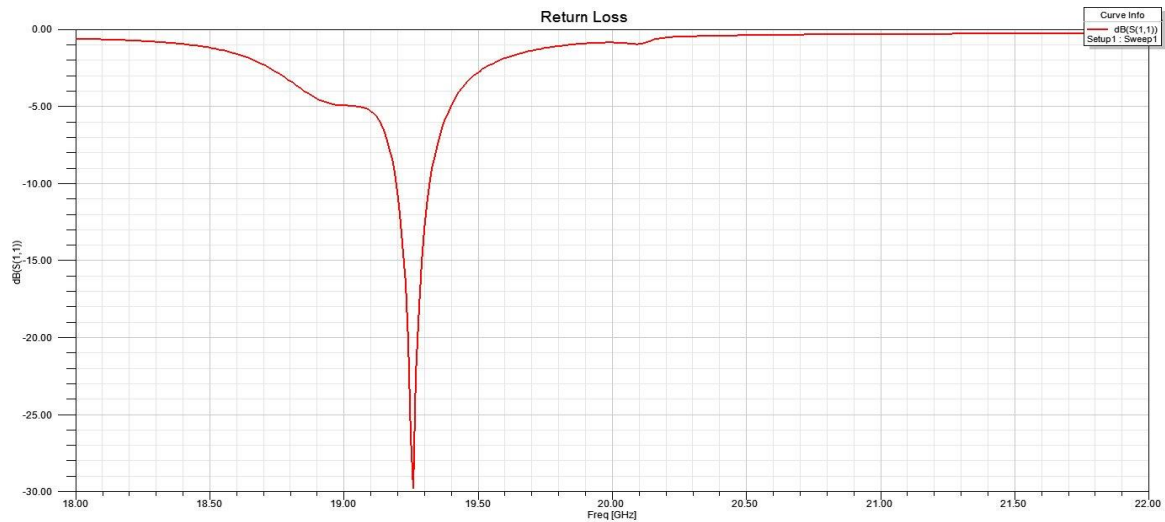
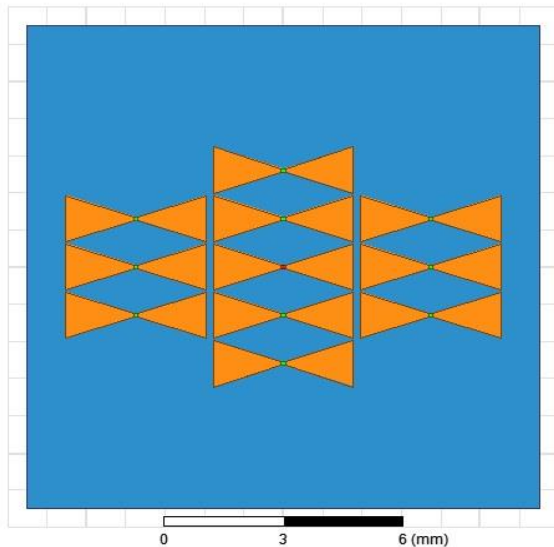
## Design methodology:



*V. Barousis, C. B. Papadias and R. R. Müller, "A new signal model for MIMO communication with compact parasitic arrays," In Proc. International Symposium on Communications, Control and Signal Processing, Athens, Greece, May 21-23, 2014.*

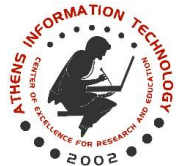
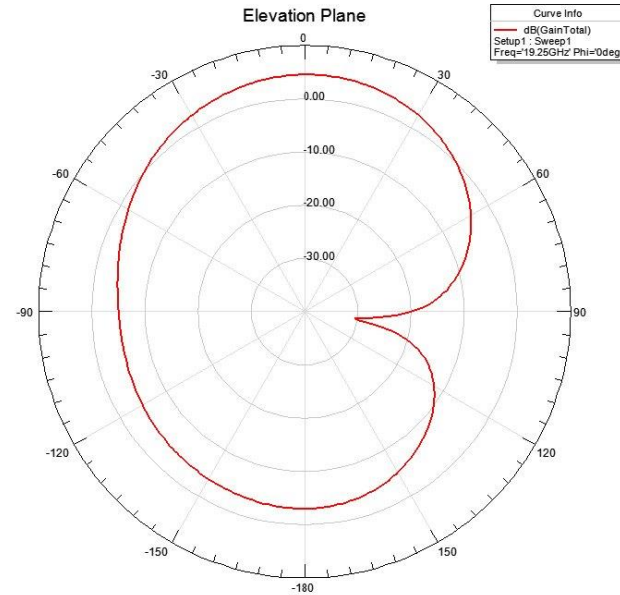
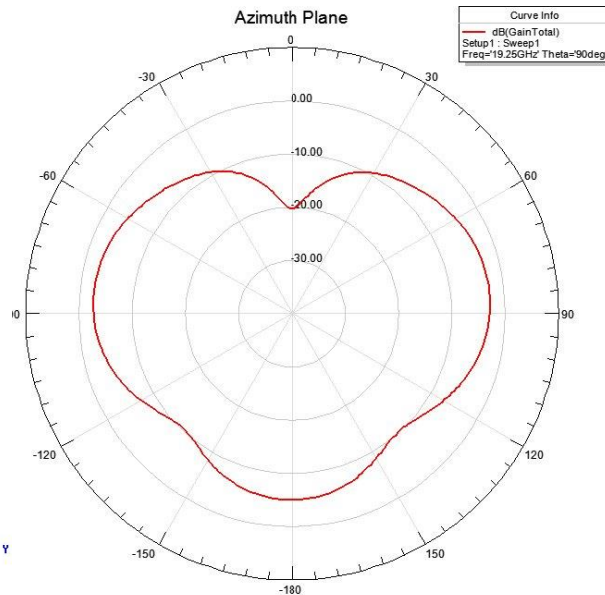
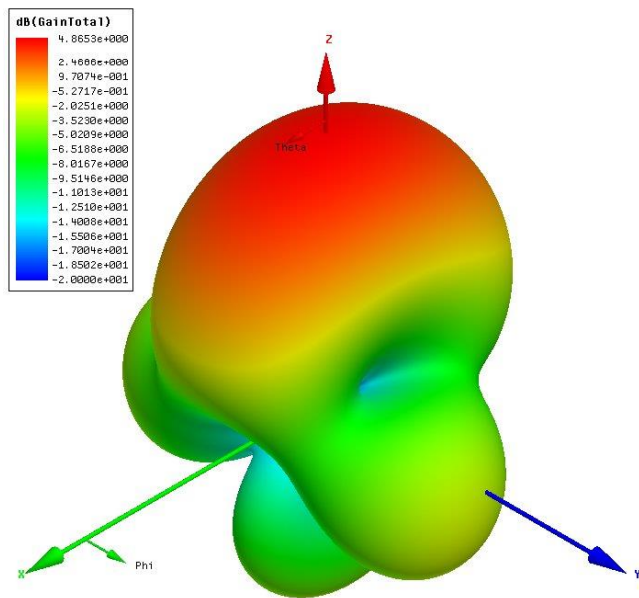
# 19.25GHz: Single-RF Parasitic antenna design

- Bowtie-like elements.
- 1 active element at the center and 10 parasitic elements around it, resonates at 19.25GHz.
- Overall dimensions: 13x13mm.



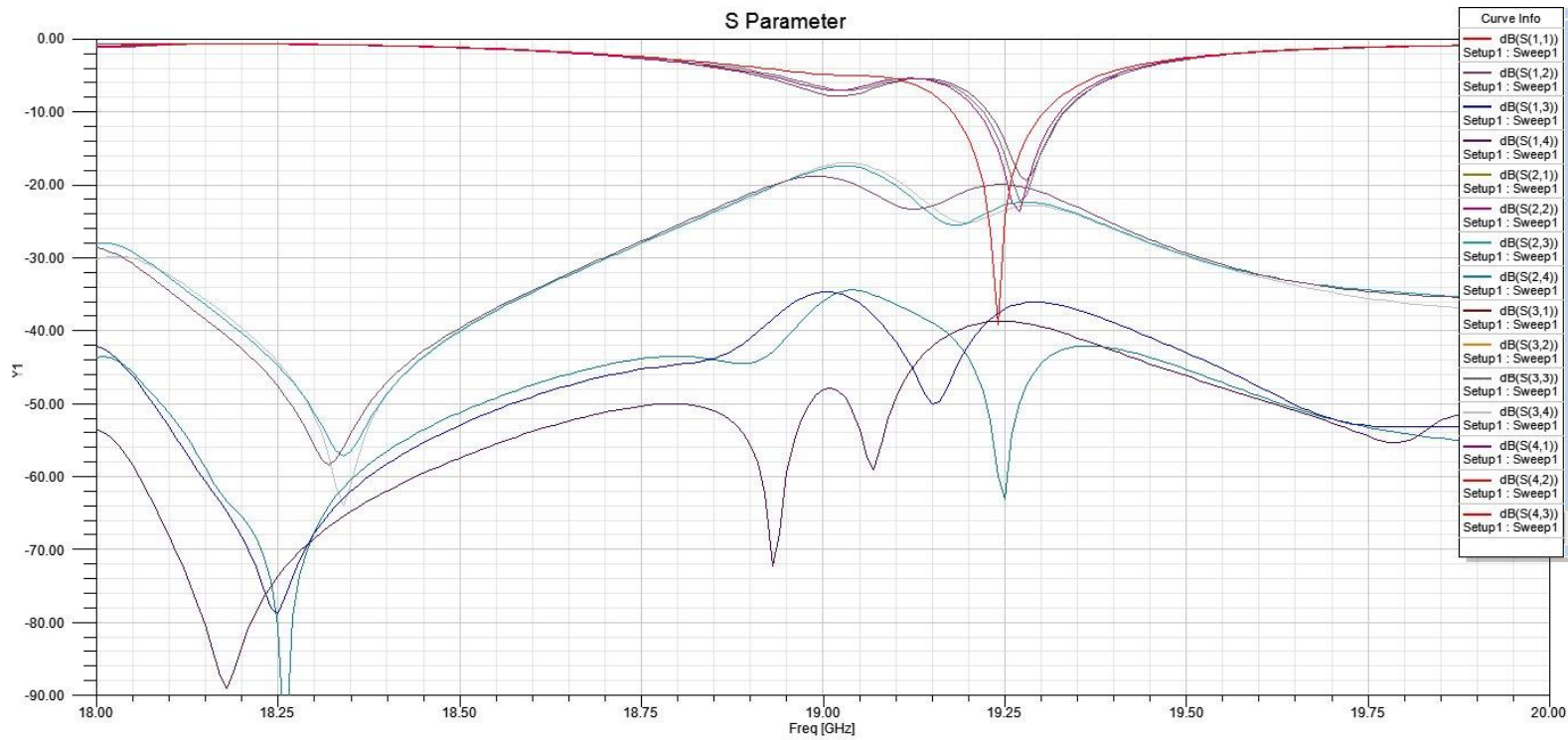
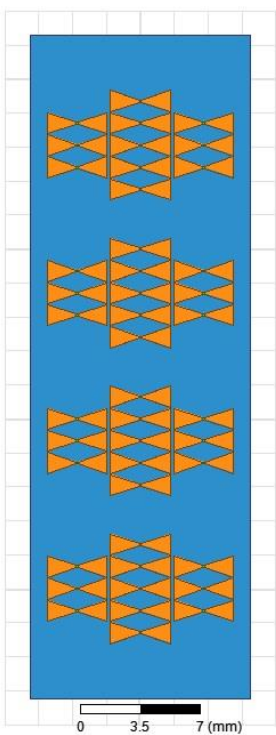
# Single-RF parameters & radiation patterns

- 3D far field radiation pattern, 4.88dBi gain.
- Azimuth plane.
- Elevation plane.
- Used for coordinated MIMO simulations.



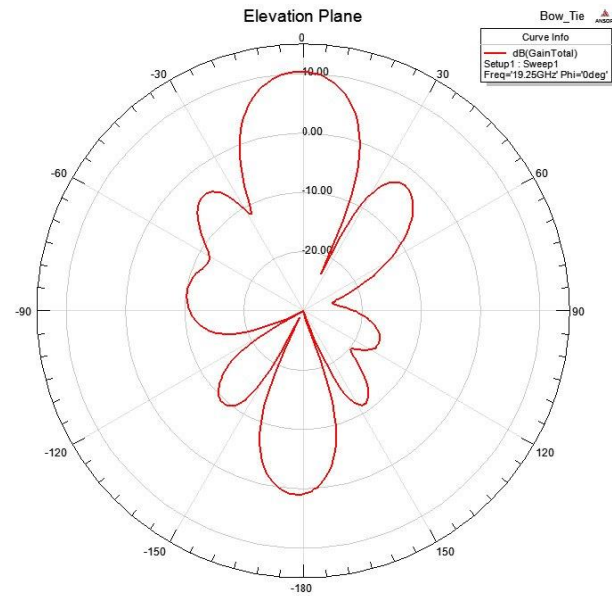
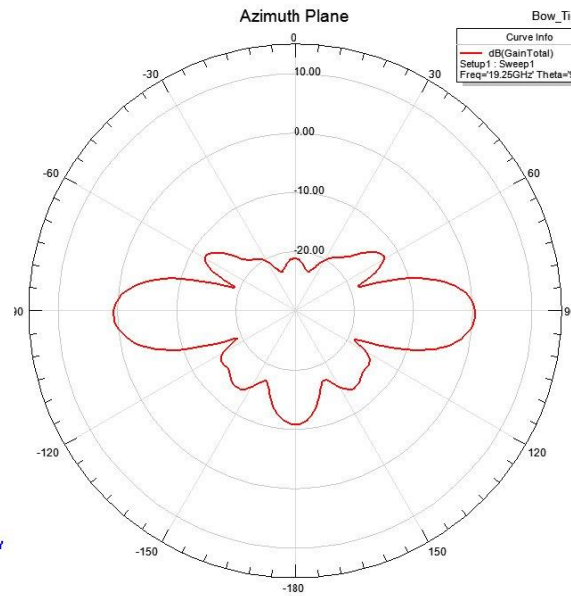
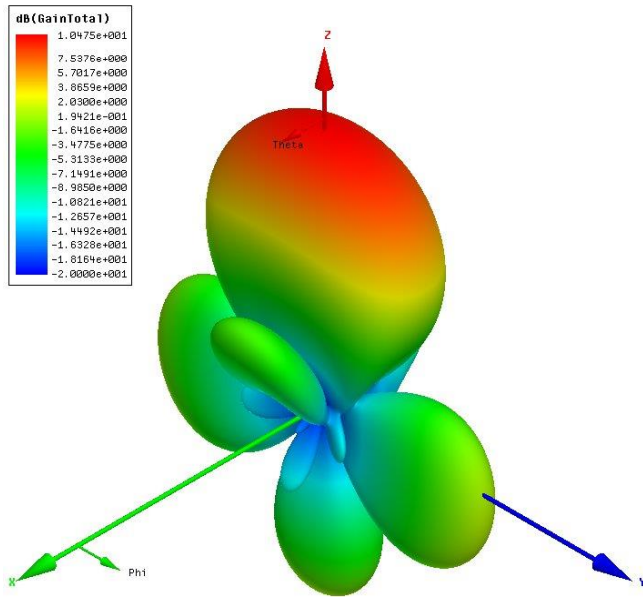
# Multi-Active / Multi-Pasive (MAMP) Array @ 19.25GHz

- 4 clusters of the initial parasitic antenna are used. Total of 4 active and 40 parasitic elements.
- Scattering parameters show good resonance at 19.25GHz and sufficient isolation between ports.
- Active inter-element distance is  $\lambda/2$ . Overall dimensions: 13x39mm.



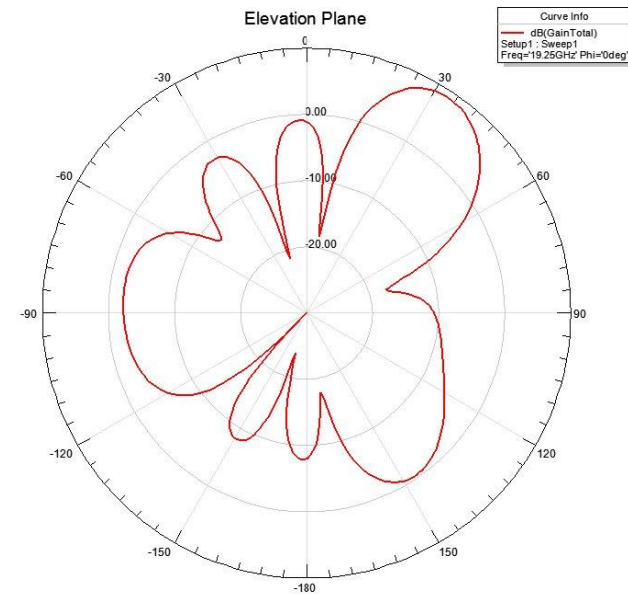
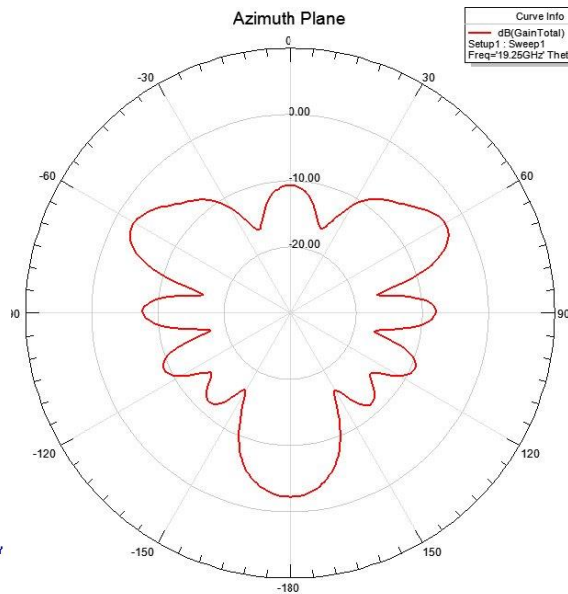
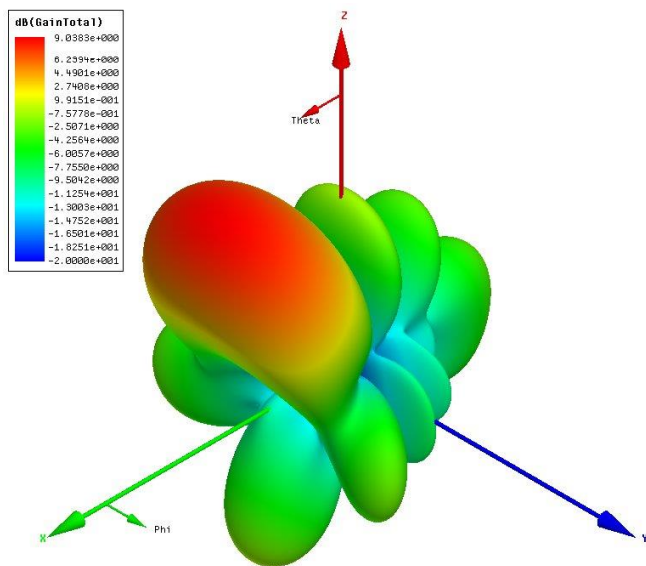
# MAMP parameters & radiation patterns

- 0deg rotation using weights in the baseband.
- 3D far field radiation pattern, 10.47dBi gain.
- Azimuth plane.
- Elevation plane.

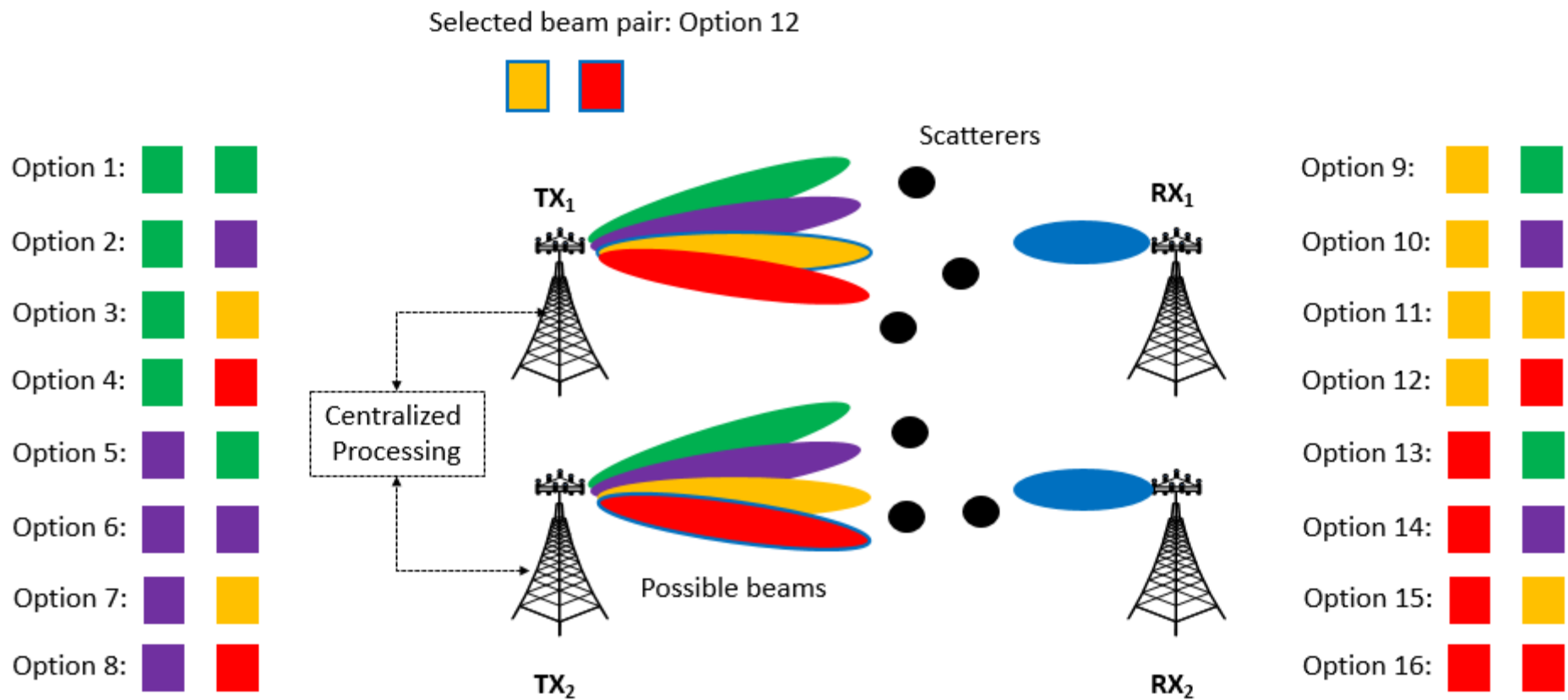


# MAMP parameters & radiation patterns (2)

- +45deg rotation using weights in the baseband.
- 3D far field radiation pattern, 9.38dBi gain.
- Azimuth plane.
- Elevation plane.



# Precoding: Cooperative MIMO and switching based on Parasitic Antenna Arrays



**2 TX-RX pairs, 4 beams per TX node (16 beam combinations in total)**



# Precoding & power allocation

**Zero Forcing:**

$$\mathbf{F}^{(\text{ZF})} = \mathbf{H}^+ = \mathbf{H}^\dagger (\mathbf{H}\mathbf{H}^\dagger)^{-1}.$$
$$\mathbf{W}^{(\text{ZF})} = \frac{\mathbf{F}^{(\text{ZF})}(:, k)}{\|\mathbf{F}^{(\text{ZF})}(:, k)\|}, \quad k = 1, 2, \dots, K.$$

**Regularized ZF:**

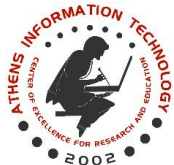
$$\mathbf{v}_k^{(\text{RZF})} = \mathbf{H}^\dagger \left( \frac{1}{p_k} \mathbf{I}_K + \mathbf{H}\mathbf{H}^\dagger \right)^{-1}, \quad k = 1, 2, \dots, K.$$

$$\mathbf{w}_k^{(\text{RZF})} = \frac{\mathbf{v}_k^{(\text{RZF})}}{\|\mathbf{v}_k^{(\text{RZF})}\|}, \quad k = 1, 2, \dots, K.$$

**Power Allocation:**

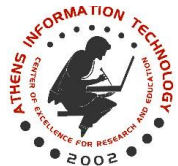
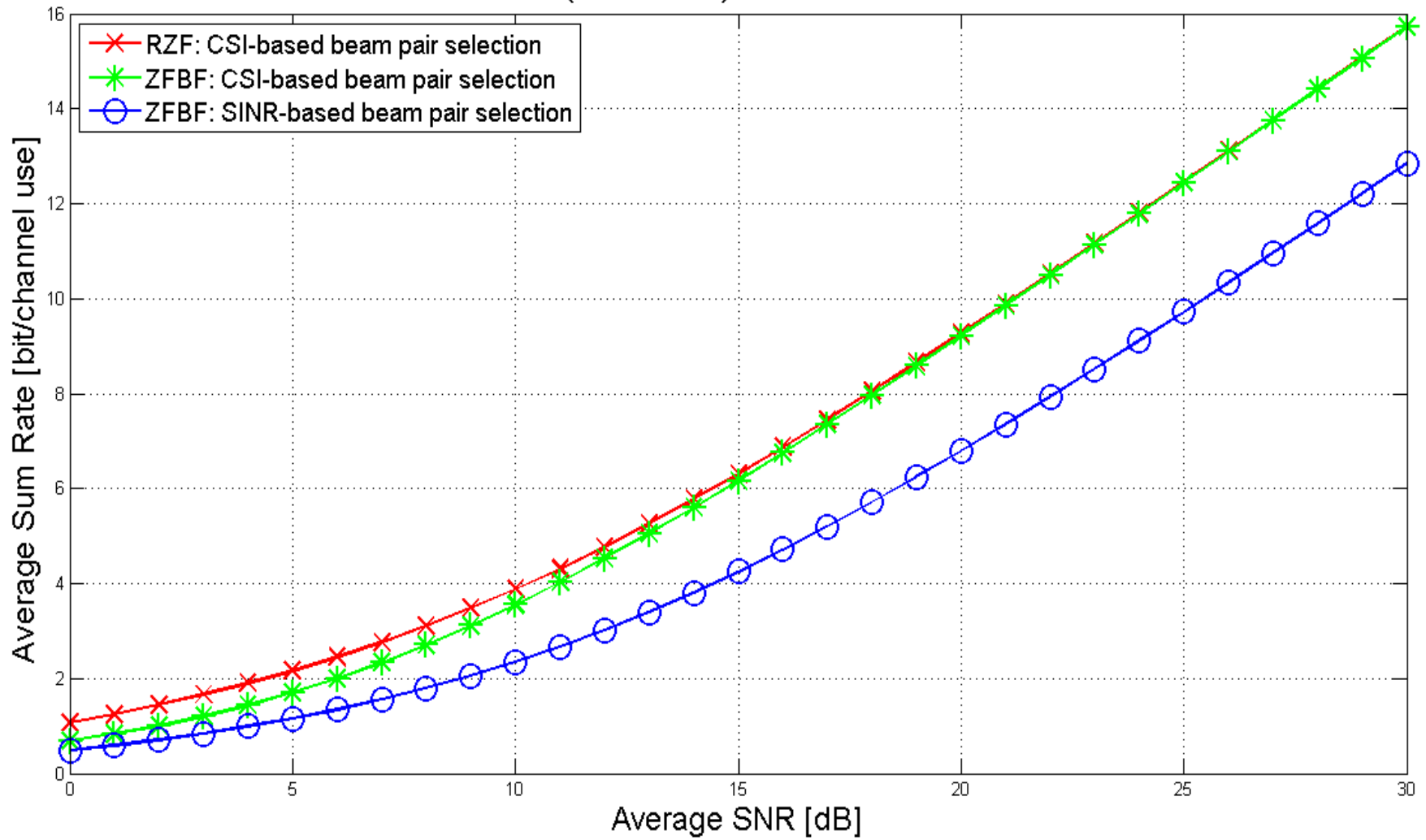
$$\text{maximize}_{p_k > 0} \quad R = \sum_{k=1}^K \log_2 (1 + \text{SINR}_k)$$

$$\text{subject to} \quad p_k \leq P. \quad p_k = \left[ v_k - \frac{\sigma_n^2}{h_k} \right]^+$$

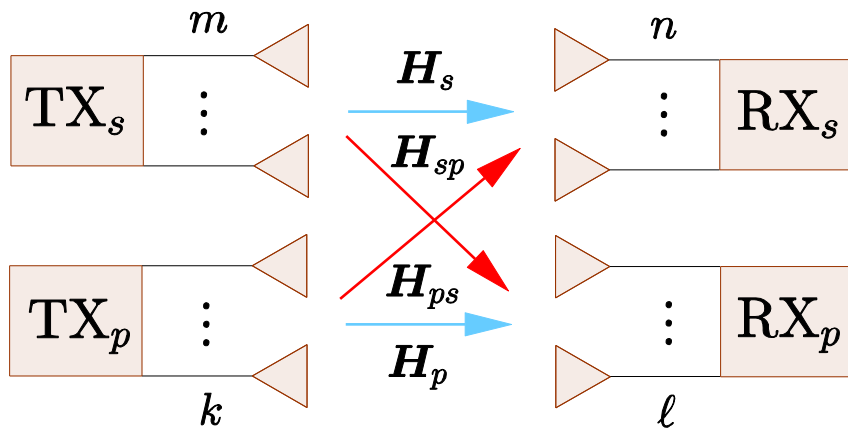


# Spectral Efficiencies

Coordinated MIMO (19.25 GHz): Joint Transmission over Beams



# Spatial multiplexing under an interfered receiver constraint



 Direct MIMO Channel  
 Cross MIMO Channel

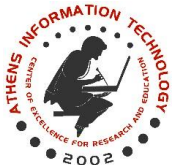
$$\begin{aligned}
 \mathbf{y}_s &= \mathbf{H}_s \mathbf{s} + \mathbf{H}_{ps} \mathbf{x} + \boldsymbol{\eta} \\
 \mathbf{y}_p &= \mathbf{H}_p \mathbf{x} + \mathbf{H}_{sp} \mathbf{s} + \mathbf{v}
 \end{aligned}$$

Maximization of the mutual information according to the decomposition of:

$$\mathbf{H}_s^\dagger \mathbf{R}_z^{-1} \mathbf{H}_s = \mathbf{U} \boldsymbol{\Lambda} \mathbf{U}^\dagger$$

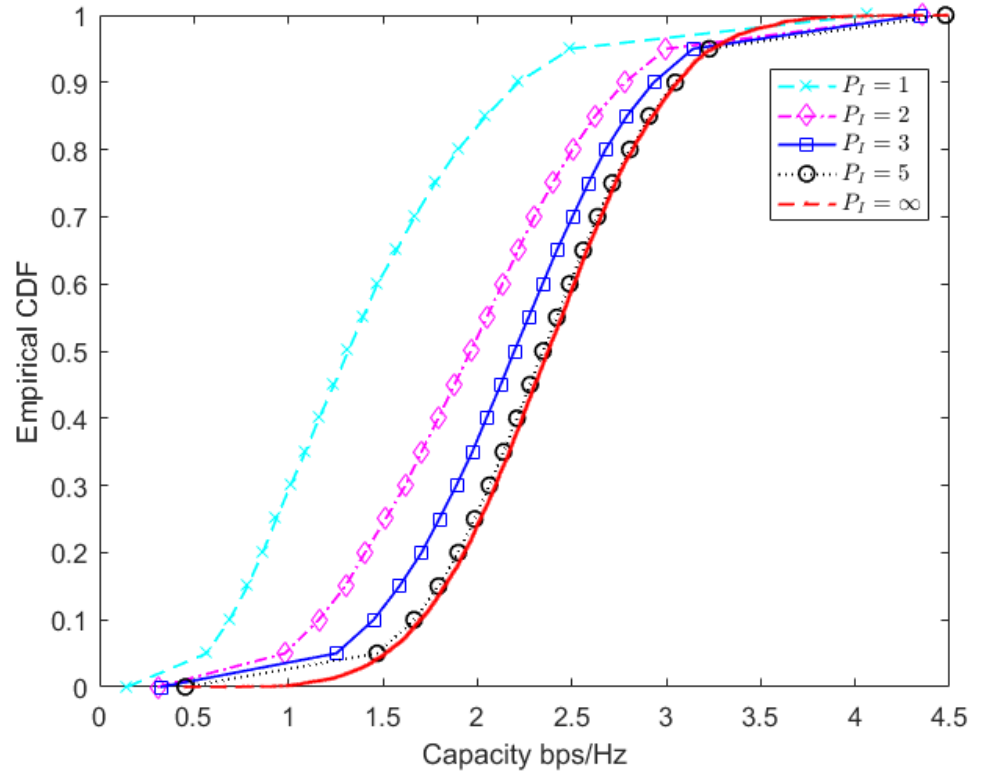
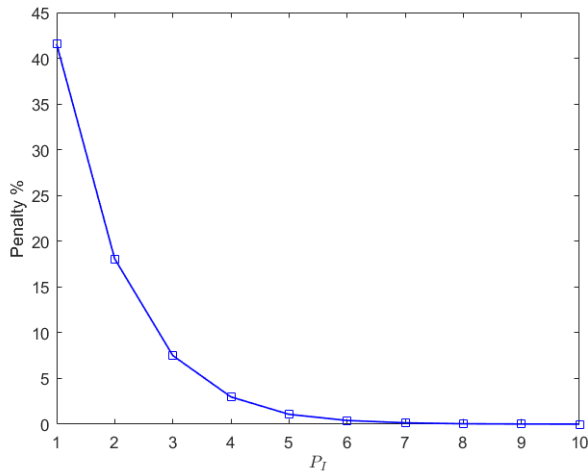
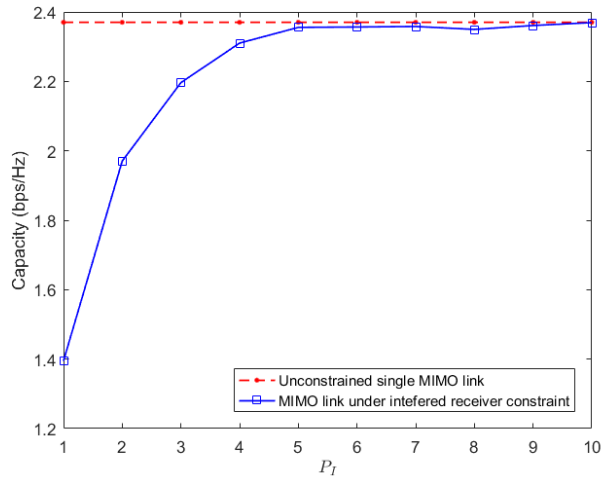
Convex Optimization Task:

$$\begin{aligned}
 & \max_{d_i} \sum_{i=1}^r \log_2(1 + \lambda_i d_i), \\
 \text{s.t.} \quad & d_i \geq 0, \\
 & \sum_{i=1}^r d_i \leq P, \\
 & \sum_{i=1}^r \alpha_i d_i \leq P_I.
 \end{aligned}$$



# Capacity gains

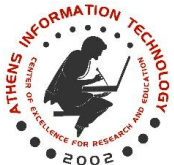
## Achieved Capacity and capacity loss %



**Empirical CDF's for various capacities achieved with different interference constraint values**

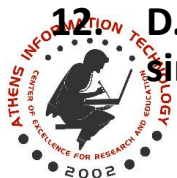
# Summary / conclusions

- Ground / satellite co-existence is a **challenging yet promising paradigm** for future 5G networks
- Antenna arrays of **low complexity** can be used in order to reduce the complexity and cost of ground station transceivers
- **Hybrid analog / digital** antenna arrays based on parasitic (single or multiple-RF) designs have been explored in this direction
- A combination of the derived hybrid antenna arrays and interference mitigation techniques shows a **promising low-complexity approach** in mitigating the interference in the corresponding setups



# References

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# Thank You!

