Full-Dimension MIMO Arrays with Large Spacings Between Elements

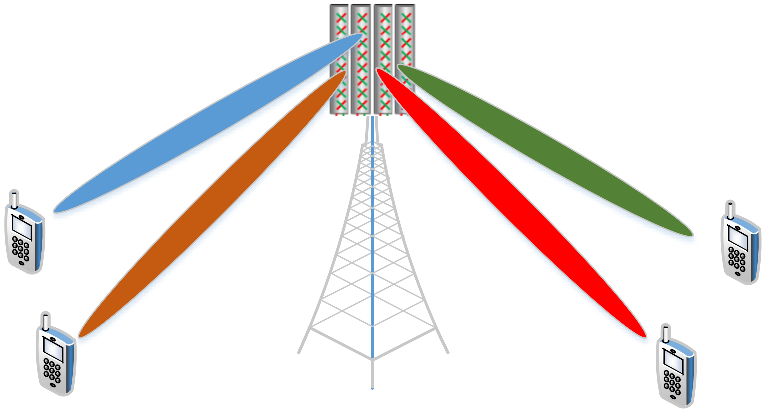
Xavier Artiga
Researcher
Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)

APS/URSI 2015, 22/07/2015

Outline

- Introduction to Massive MIMO and FD-MIMO
- Compact arrays with Kronecker channel model
- Linear arrays with spatial channel model (SCM)
- FD-arrays
- Conclusions

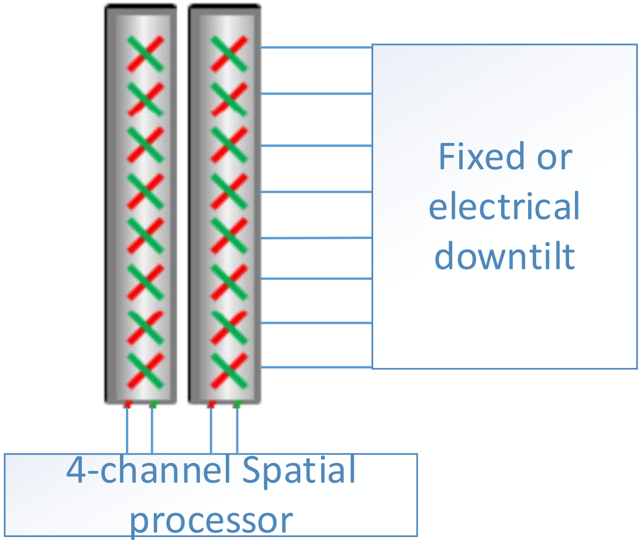
Massive MIMO



- Multiuser-MIMO using a number of BS antennas well in excess the number of active users.
- Benefits:
  - The effects of uncorrelated noise and fast fading vanish when the number of antennas increases without limit
  - In practice, array gains provide unprecedented capacity increase and/or transmission power save.
  - Simple linear precoding schemes such as MRT and ZF are near-optimal.
- Drawbacks:
  - In practice, hundreds of antennas are needed.
  - Implementation challenges related to cost, synchronization, channel estimation etc.
  - A solution for accommodating very large number of antennas in constrained practical BS physical spaces is needed!!!

Full dimension-MIMO

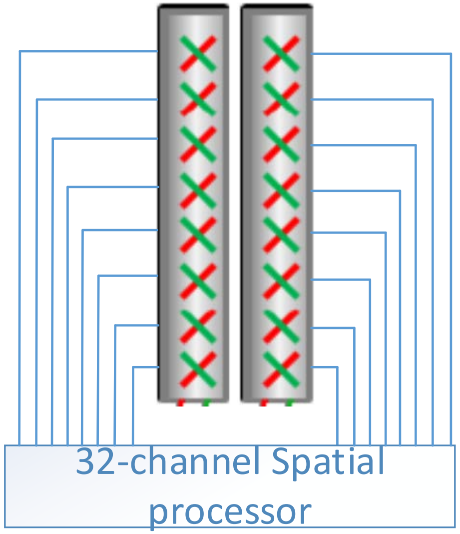
- Traditionally, vertical beamforming weights remain fixed for optimized coverage
- In FD-MIMO adaptive beamforming is performed in both azimuth and elevation dimensions
- FD-MIMO is an enabler for compact Massive MIMO antennas



Fixed or electrical downtilt

4-channel Spatial processor

Traditional MIMO



32-channel Spatial processor

FD-MIMO

Outline

- Introduction to Massive MIMO and FD-MIMO
- Compact arrays with Kronecker channel model
- Linear arrays with spatial channel model (SCM)
- FD-arrays
- Conclusions

System Model

- A base station equipped with an array of *M* antennas serving *K* single antenna user terminals (downlink transmission)
- Received signal:

$$\mathbf{x} = \mathbf{G}\mathbf{s} + \mathbf{w} \quad \text{with} \quad \mathrm{E}[\mathbf{w}\mathbf{w}^{\mathrm{H}}] = \sigma_{\mathrm{w}}^{2}\mathbf{I}$$

- Two pre-coders are considered in transmission:
  - Maximum ratio transmission (MRT): $\boldsymbol{s} = \sqrt{\frac{P}{trace(\boldsymbol{G}\boldsymbol{G}^{H})}}\boldsymbol{G}^{H}\boldsymbol{a}$
  - Zero Forcer: $\boldsymbol{s} = \sqrt{\frac{P}{trace((\boldsymbol{G}\boldsymbol{G}^{H})^{-1})}}\boldsymbol{G}^{H}(\boldsymbol{G}\boldsymbol{G}^{H})^{-1}\boldsymbol{a}$

with $\mathrm{E}[\mathbf{s}^{\mathrm{H}}\mathbf{s}] \le \mathrm{P}$

and $\rho = \frac{P}{\sigma_{w}^{2}}$

Artiga, X.; Devillers, B.; Perruisseau-Carrier, J., "On the selection of radiating elements for compact indoor massive-multiple input multiple output base stations," *Microwaves, Antennas & Propagation, IET* , vol.8, no.1, pp.1,9, January 8 2014

Kronecker Channel model

- Assuming:
  - Uncorrelated fading processes at Tx and Rx
  - Uncorrelated user terminals
  - Uniform 3D-APS and lossless antennas at the BS side
- The channel matrix becomes:

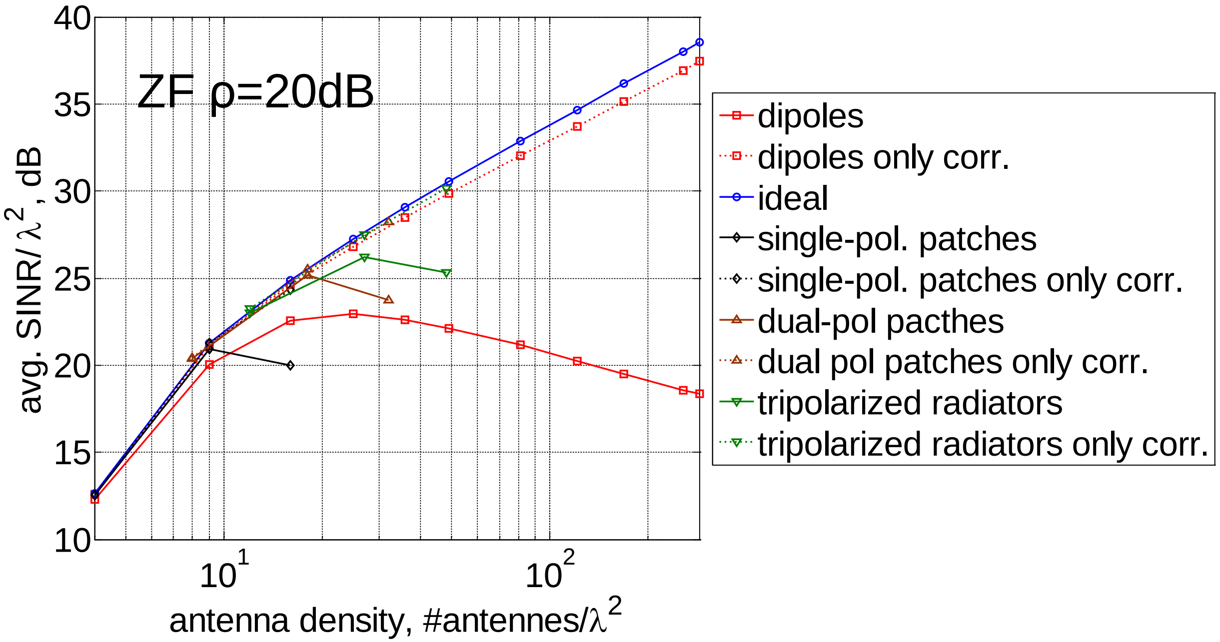
$\mathbf{G} = \mathbf{H}(\mathbf{X}_{\mathbf{T}}^{1/2})^{\mathrm{T}}$ where **H:** random matrix with Gaussian i.i.d. elements

And X_T is the Tx antennas covariance matrix:

$\mathbf{X}_{\mathbf{T}} = \mathrm{c}\left(\mathbf{I} - \mathbf{S}_{\mathbf{T}}\mathbf{S}_{\mathbf{T}}^{\mathrm{H}}\right)$ where $\mathbf{S}_T$ is the S-matrix of the Tx antenna system

Simulation results

- Average SINR per user is evaluated while increasing the number of antennas included in a physically constrained λxλ square array.
- $\mathbf{S}_T$ matrices are computed using ANSYS HFSS
- Single-port input impedance match and channel XPR=0dB are assumed
- *K*=4 uncorrelated users



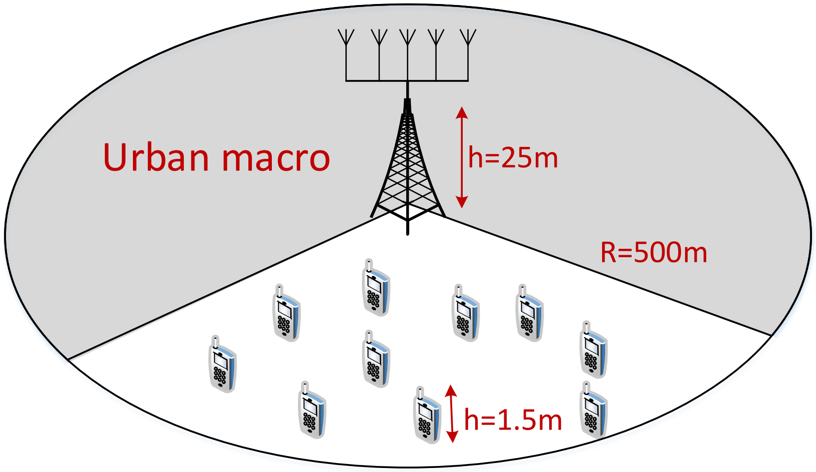
- An optimum antenna density is found regardless of the radiating element or the pre-coder
- Optimum inter-element distances are λ/4 for dipoles and λ/2 for patches
- Dual-polarized patches perform better than compact arrays of dipoles

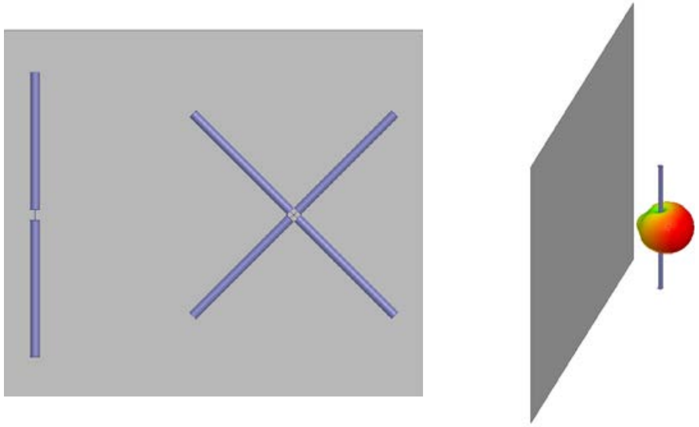
Outline

- Introduction to Massive MIMO and FD-MIMO
- Compact arrays with Kronecker channel model
- Linear arrays with spatial channel model (SCM)
- FD-arrays
- Conclusions

System model

- Downlink transmission on a single 120° sector.
- K=10 uniformly distributed users
- Urban macro 3D spatial channel model based on WINNER+.
- Realistic antenna pattern simulation using HFSS (vertical or crossed-dipoles backed with PEC).
- Omnidirectional ideal antennas assumed for the user terminals.
- Uniform power allocation



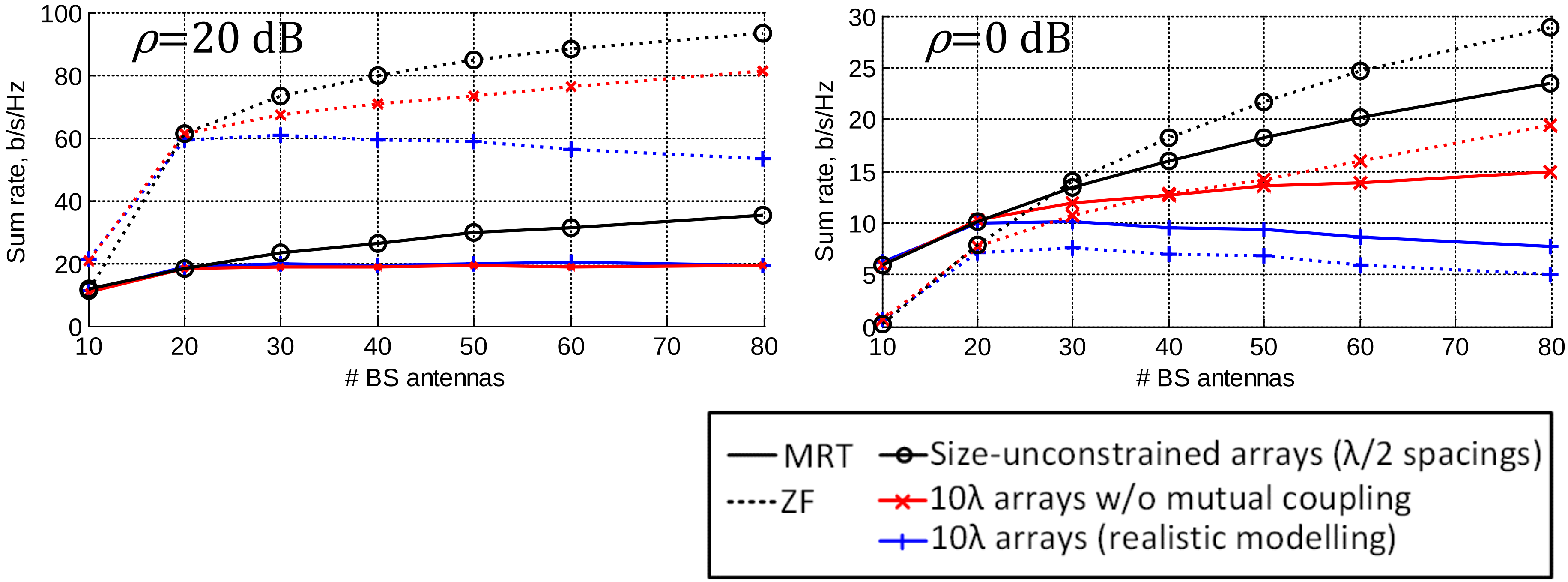


Artiga, X.; Perruisseau-Carrier, J.; Perez-Neira, A.I., "Antenna array configurations for massive MIMO outdoor base stations," *Sensor Array and Multichannel Signal Processing Workshop (SAM), 2014 IEEE 8th* , vol., no., pp.281,284, 22-25 June 2014

WINNER+, http://projects.celtic-initiative.org/winner+/

Simulation results

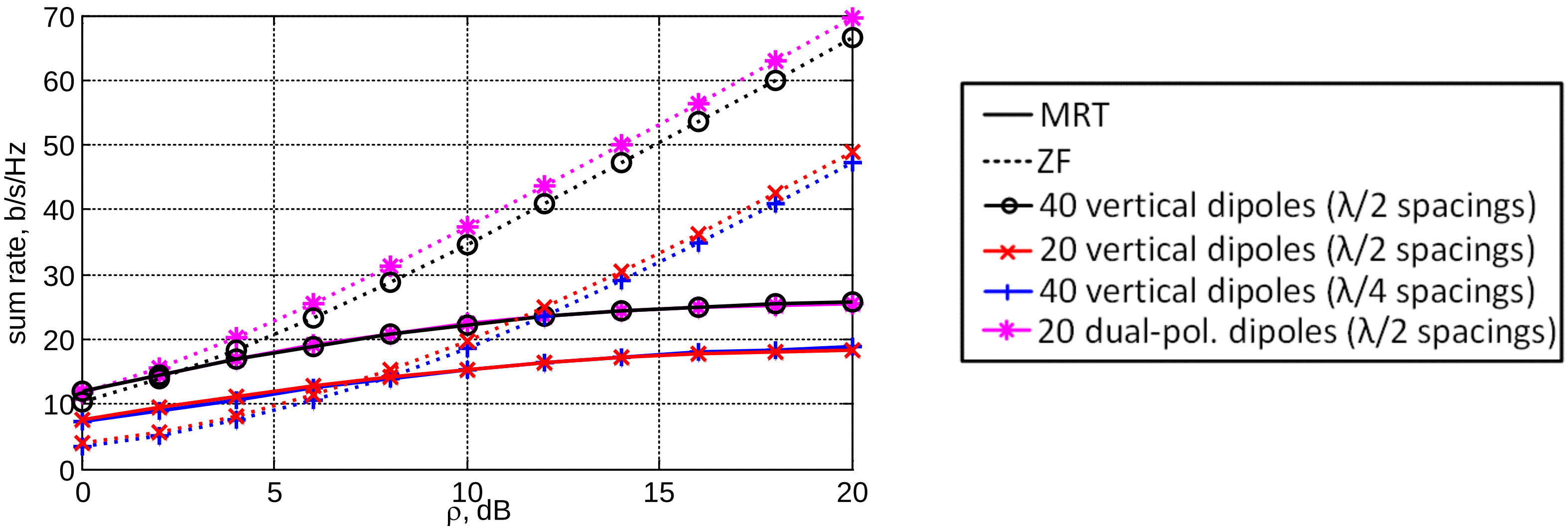
- **Compact arrays**
  - Horizontal arrays of vertical dipoles at BS
  - Vertical polarization of user terminals



Average sum rate is clearly degraded when inter-element spacing is reduced below λ/2- λ/3 due to mutual coupling and limited aperture effects

Simulation results

- **Dual polarized arrays**
  - Horizontal arrays of vertical dipoles or crossed-dipoles
  - Random polarization of user terminals



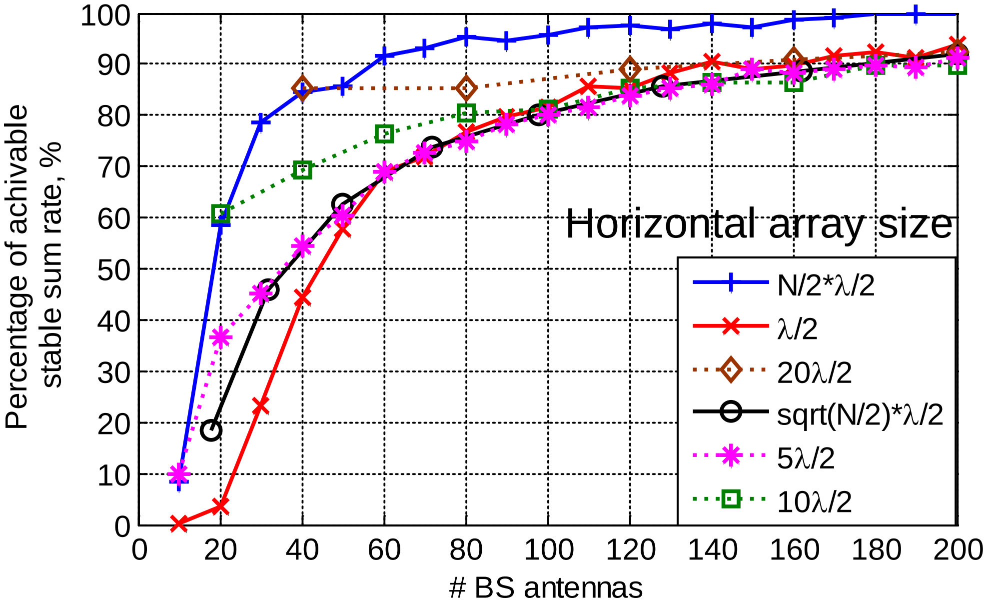
- Dual-polarized arrays clearly surpass compact and single-polarized solutions.
- The benefits of using polarization diversity for reducing the polarization losses exceed the increased array gains provided by double-length single-polarized arrays

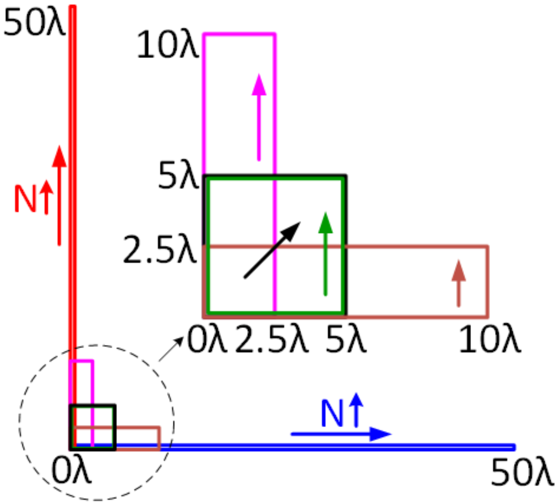
Outline

- Introduction to Massive MIMO and FD-MIMO
- Compact arrays with Kronecker channel model
- Linear arrays with spatial channel model (SCM)
- FD-arrays
- Conclusions

Full-dimension arrays

- Crossed dipole elements with inter-element distance of λ/2
- ZF pre-coding and ρ=100/N

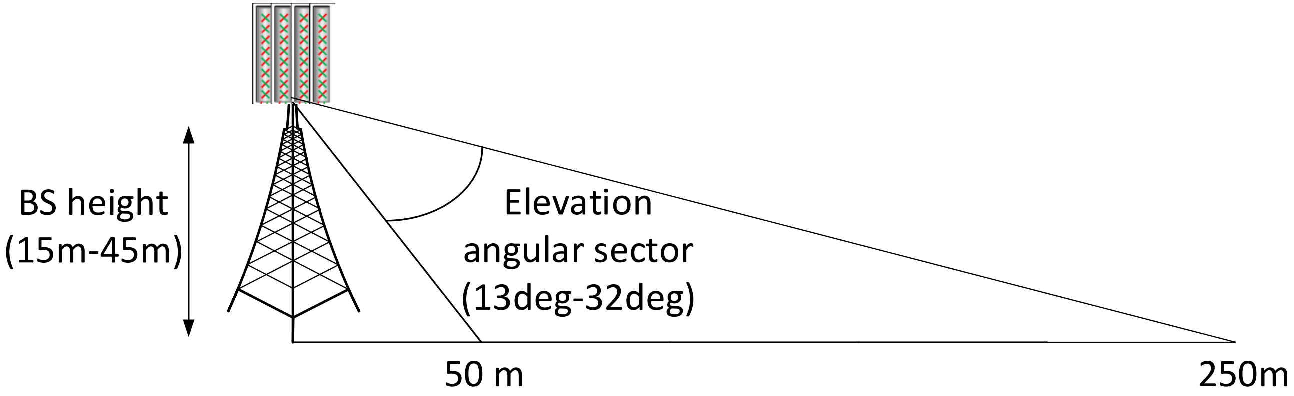




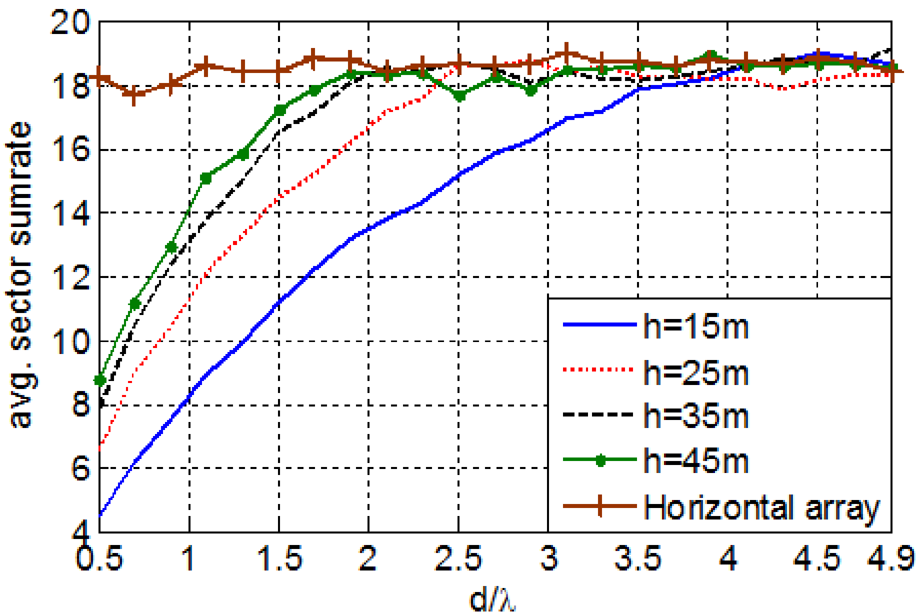
- ➢ Vertical beamforming allows reducing the horizontal size of the array but at the expense of increasing the number of elements.
- ➢ The reduced elevation angular sector limits the benefits of vertical beamforming.

FD-MIMO with large spacings

- Inter-element distances beyond λ/2 provide reduced beamwidths at the expense of the appearance of grating lobes
- **Which is the optimum spacing for elevation beamforming in FD-MIMO?**
- System model:
  - Vertical array with 16 antennas serving 4 users (downlink)
  - Ideal Isotropic and uncoupled radiators
  - Free-space propagation
  - MRT precoding
  - ρ=20dB
  - Variable BS height←→variable elevation angular sector



Free-space results

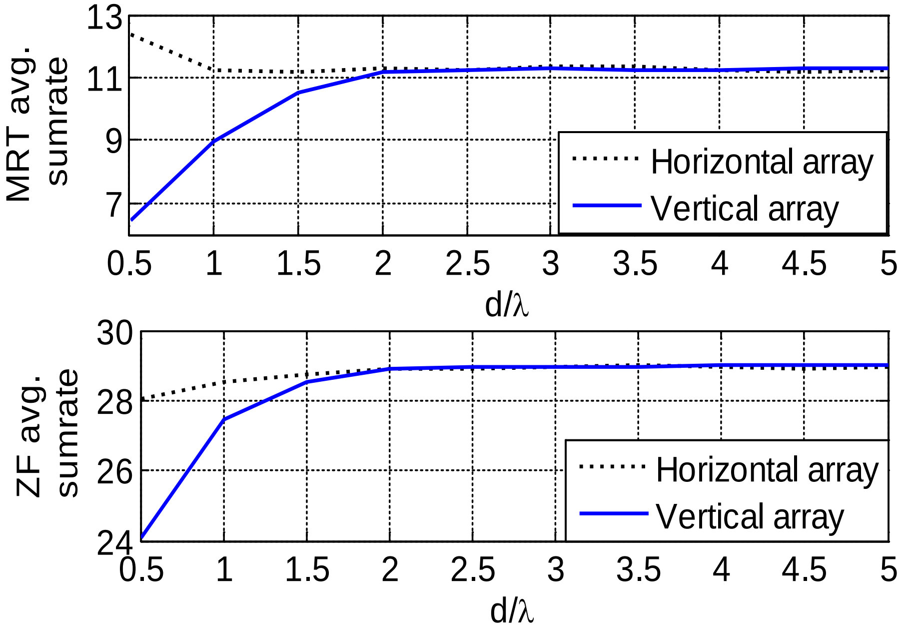


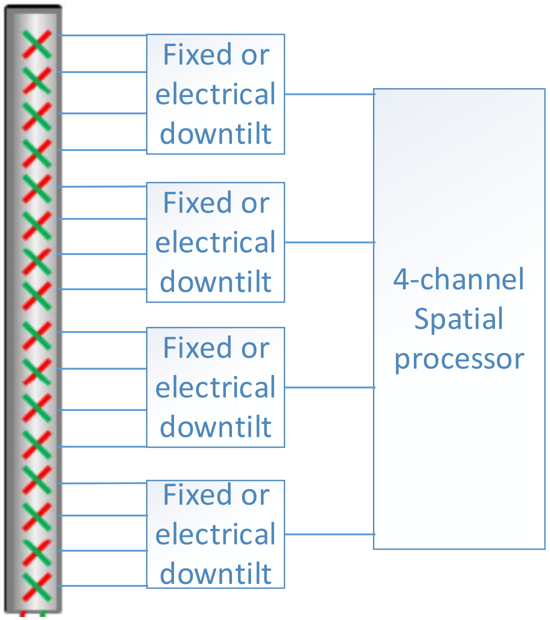
BS height (m)	Angular sector size (º)	Minimum antenna spacing creating grating lobes inside the sector of interest. (λ)
15	13	4.4
25	21	2.9
35	27	2.3
45	32	2.1
Horizontal array	120	0.6

- The directions of the grating lobes are calculated using: $\theta_{GL} = cos^{-1}\left(\pm\frac{m\lambda}{d} + cos(\theta)\right)$
- Sumrate increases with antenna spacing until grating lobes start falling inside sector of interest.
- Beyond this optimum point, benefits of reduced beamwidth cancel out with the appearance of grating lobes.

3D-SCM results

- BS height is set to 25m
- Linear arrays of 16 antenna elements formed by 8 pairs of 45º slanted cross-dipoles backed by a perfect conductor.
- K=4 user terminals with random polarization





- ➢ Hybrid analog/digital beamforming array solution can reduce the effects of GL out of the sector of interest

Conclusions

- Mutual coupling does not allow reducing the inter-element spacing below λ/2- λ/4 (depending on the scenario and the radiating elements).
- Polarization diversity provides better performance than reducing inter-element spacing.
- Polarization diversity provides better performance than using single polarization and doubling the size of the array.
- Elevation beamforming in FD-MIMO allows reducing the horizontal size of the array at the expense of the need of more antennas.
- Elevation beamforming is limited by reduced angular elevation sector.
- Optimum vertical element separation is the larger one for which the grating lobes still do not fall inside the sector of interest.

Thanks for your kind attention!

- Questions?

Xavier Artiga

Researcher

Centre Tecnològic de Telecomunicacions de Catalunya (CTTC)

xavier.artiga@cttc.es