Study of MIMO channel capacity for IST METRA models

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Motivation

•There is a need for increasing the system capacity in order to achieve the user demand for UMTS (Universal Mobile Telecommunications Systems)

•In regular SISO (Single Input Single Output) systems the channel capacity is limited by the signal to noise ratio

•MIMO (Multi Input Multi Output) systems show promising results in increasing channel capacity

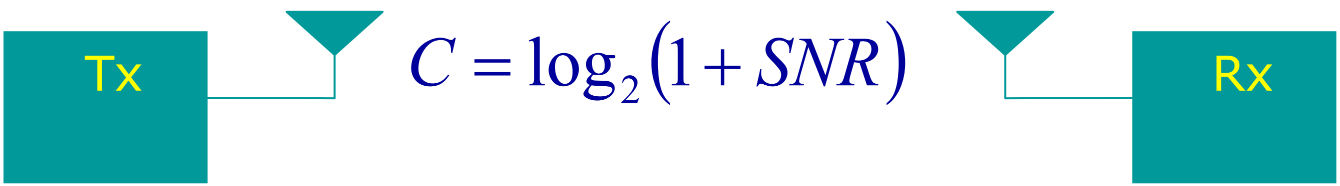
•Spatial diversity and multipath is exploited by the use of multiple antennas

Objectives

- To study the capacity improvement due to the MIMO implementation
- Only the spatial correlation for flat fading channels is analyzed, temporal correlation and frequency selective channels is for further studies
- IST METRA channel models are used and its capacity is analyzed via Matlab simulations.

SISO Capacity

•The channel capacity for a conventional SISO system is limited by Shannon’s formula:

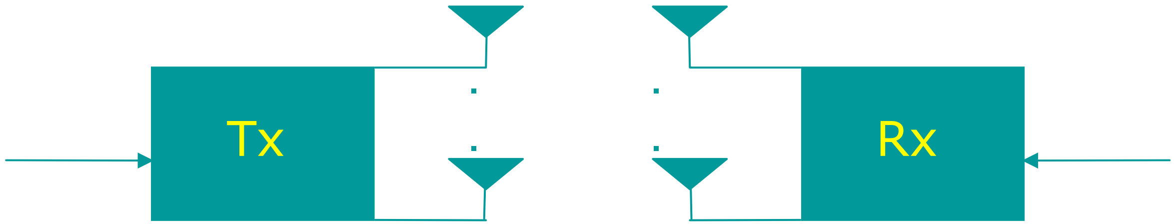


$$C = \log_2(1 + SNR)$$

- For constant AWGN the transmitted power should be doubled (3dB) for each additional required bps/Hz
- Going from 1 bps/Hz to 11 bps/Hz requires increasing the transmitted power 1024 times!!!

MIMO capacity

•**Transmitting multiple signals through multiple antennas:**



- **The total transmitted power is independent of the number of transmitter antennas for fair comparison**
- **Channel capacity according to Foschini's formula: depending on the channel matrix H**

$$C = \log_2 \det\left[\mathbf{I}_{n_R} + \left(\rho / n_T\right) \cdot \mathbf{H}^H \mathbf{H}\right]$$

MIMO channel models

• Deterministic models → based on a detailed description of the propagation environment

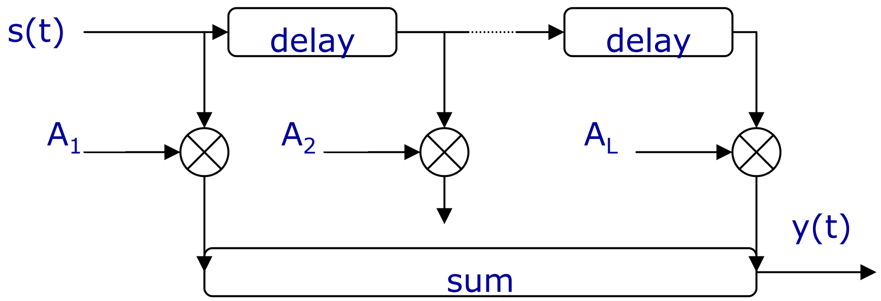
- Impulse response exploitation
- Ray tracing techniques

• Stochastic models → statistical modeling of the environments

- Based on geometry
- Parametrical
- Based on correlation

Stochastical model based on correlation

- **This model have been developed and validated by a European project related to MIMO called I-METRA**
- **Its based on a tapped delayed line**



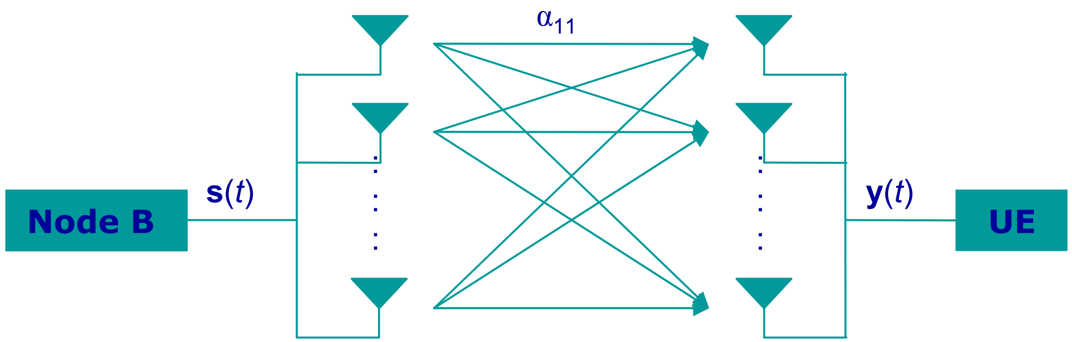
- **Power delay profile matching ITU channel recommendation**

Stochastical model based on correlation

•MIMO channel matrix describing the connection between B Node and UE, assuming a frequency selective channel

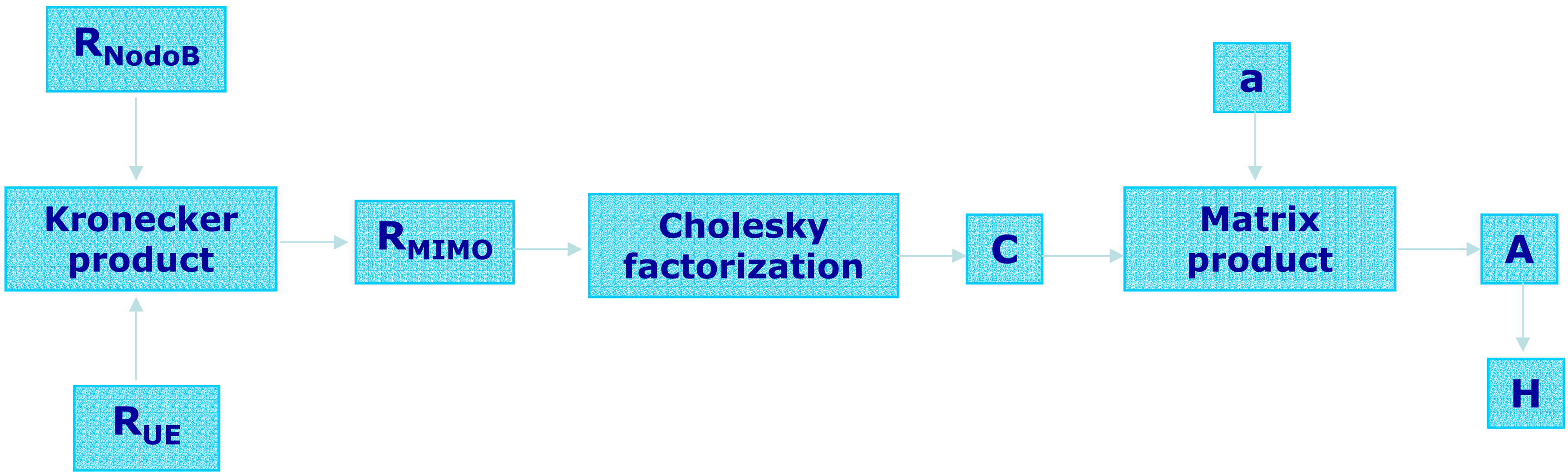
$$\mathbf{H}(\tau) = \sum_{l=1}^{L} \mathbf{A}_l \delta(\tau - \tau_l)$$

- Matrix $\mathbf{A}_l$ is defined by the complex transmission coefficients between antennas



Stochastical model based on correlation

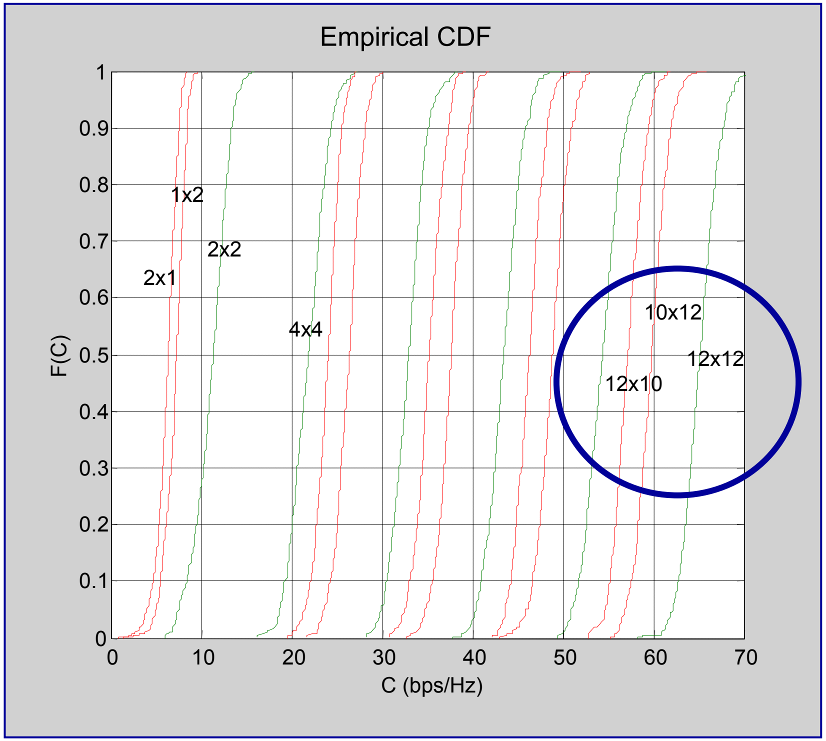
•The spatial correlation matrices are calculated based on parameters such as PAS (Power Azimuth Spectrum), AS (Azimuth Spread), AoA (Angle of Arrival) and the spacing among antennas



	Case 1 Rayleigh Uncorrelated	Case 2 (pedestrian A) Rice Correlated	Case 3 (vehicular A) Correlated	Case 4 (pedestrian B) Correlated
PDP	-	ITU Pedestrian A	ITU Vehicular A	ITU Pedestrian B
Number of Paths	1	4	6	6
Doppler Spectra	Classical	Classical	Laplace	Laplace
Speed	-	3-40-120 Km/h		
UE Topology	-	0.5 λ	0.5 λ	0.5 λ
UE PAS	-	Rice Component: K=6dB Uniform 360º	Laplacian AS=35 Uniform 360º	Laplacian AS=35 Uniform 360º
UE Movement Direction	-	0	22.5	-22.5
AoA	-	22.5	67.5	-67.5 for odd paths 22.5 for even paths
Node B Topology	-	Uniform Linear Array: 0.5 λ or 4 λ		
Node B PAS	-	Laplacian AS=5	Laplacian AS=10	Laplacian AS=15
Node B AoA	-	20º,5	20º,5	2,-20,10,-8,-33,31

Case 1. Uncorrelated environment

- CDF representation
- Capacity varies for SNR=20dB from 5 bps/Hz when configuration 1x1 to 65 bps/Hz when 12x12

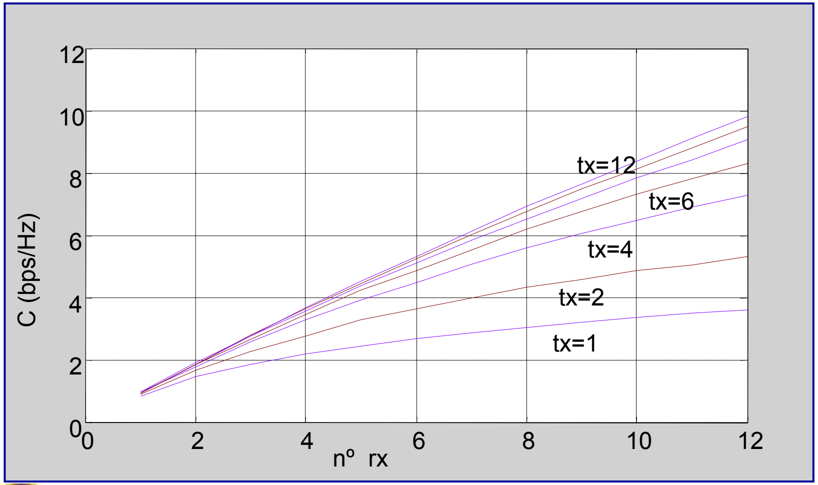


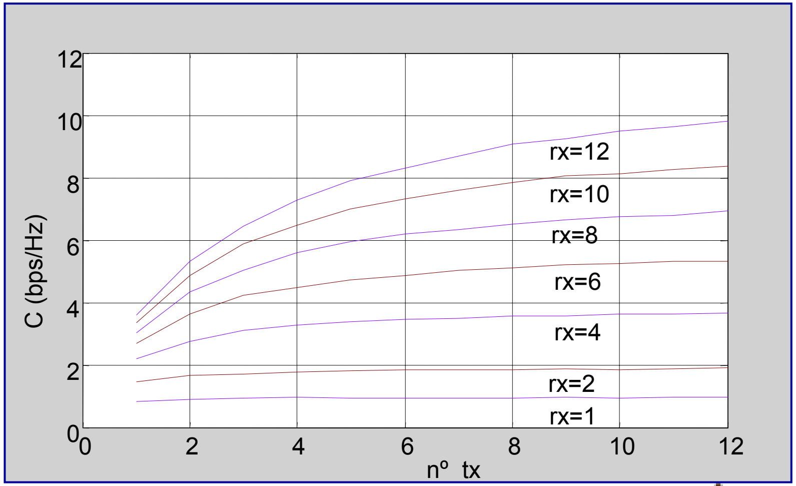
Case 1. Uncorrelated environment

•The capacity curves keeping constant the number of transmitters show higher slope when increasing the number of receiver than when keeping constant the number of receivers and increasing the number of transmitters

•The asymptotic value is reached before when keeping constant the number of receivers

SNR=0dB





Case 1. Uncorrelated environment

• **Transmitter diversity provides less capacity gain than the receiver diversity**

$$C = \log_2\left[1 + (\rho / n) \cdot \chi^2_{2n}\right]$$

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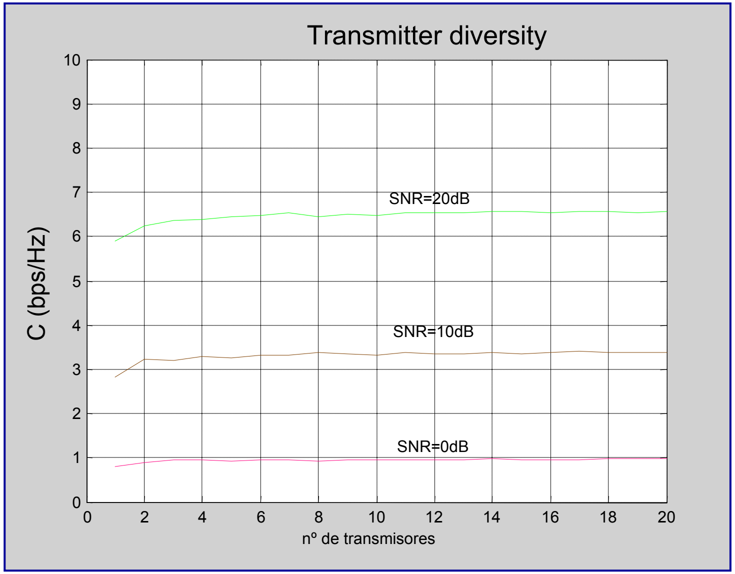
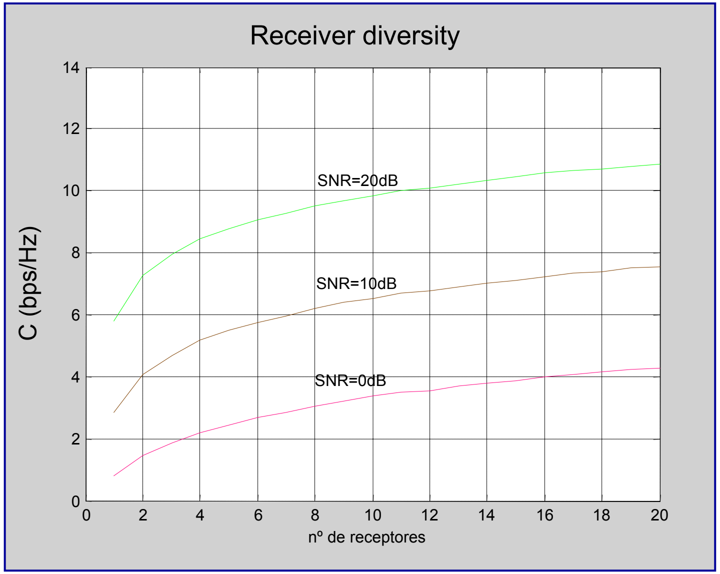
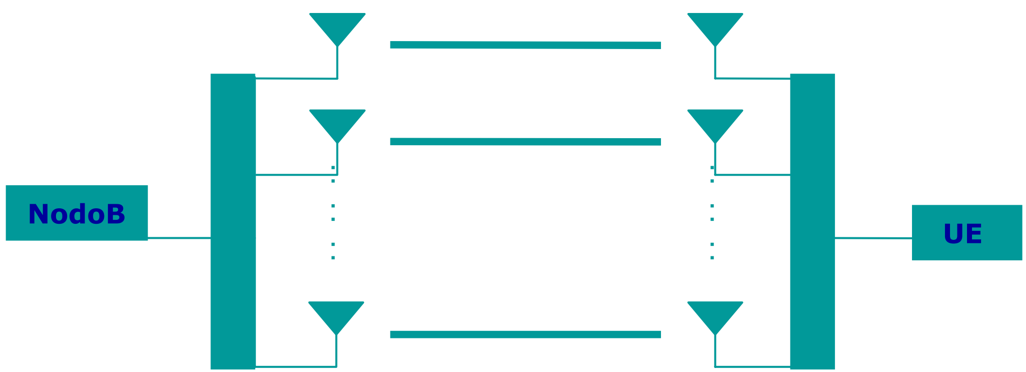




Case 1. Uncorrelated environment

- **When having** $n_T = n_R = n$
  - **Independent orthogonal parallel channels might be identified**

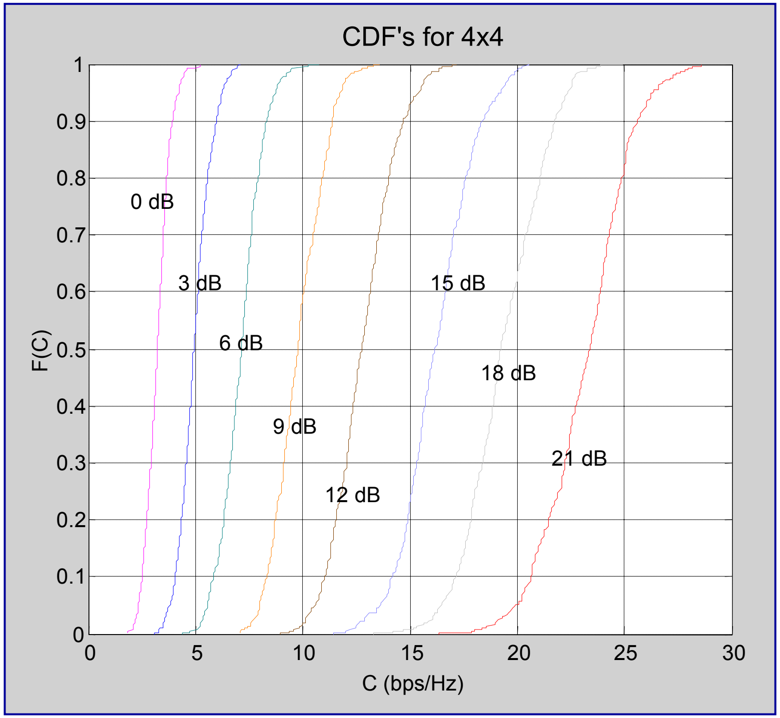
$$C = \log_2 \det\left[I_{n_R} + (\rho / n_T)\cdot H^H H\right] \rightarrow \quad C = n \cdot \log_2\left(1 + (\rho / n)\right)$$



Case 1. Uncorrelated environment

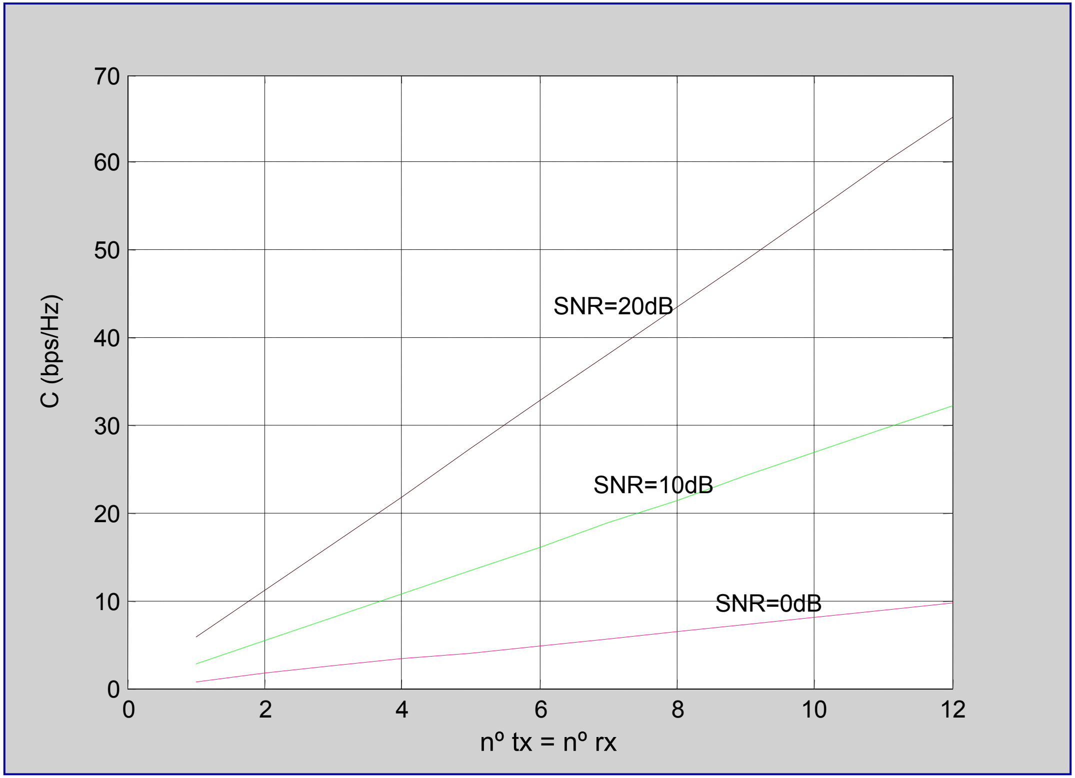
•When increasing the signal to noise ratio in 3 dBs the capacity grows in a factor of n bps/Hz, where n =min(nT,nR)

•For a SISO system, every 3 dBs increment the capacity in just 1 bps/Hz



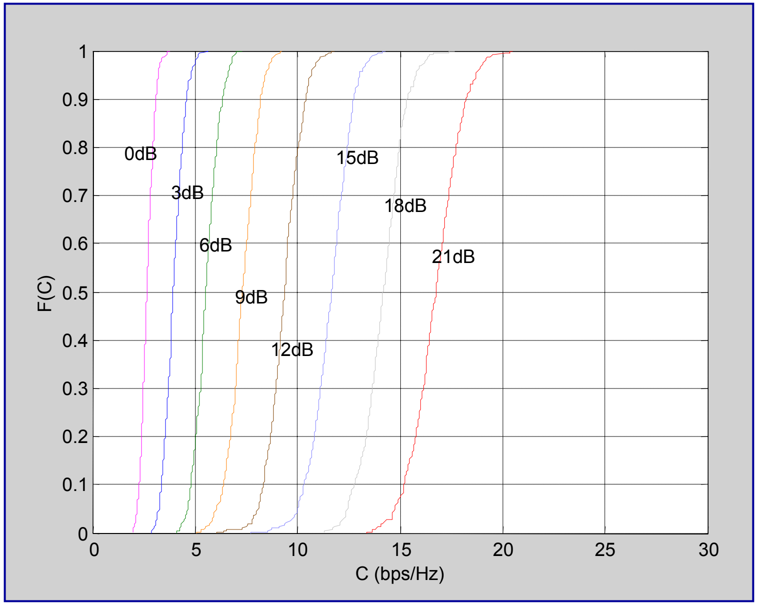
Case 1. Uncorrelated environment

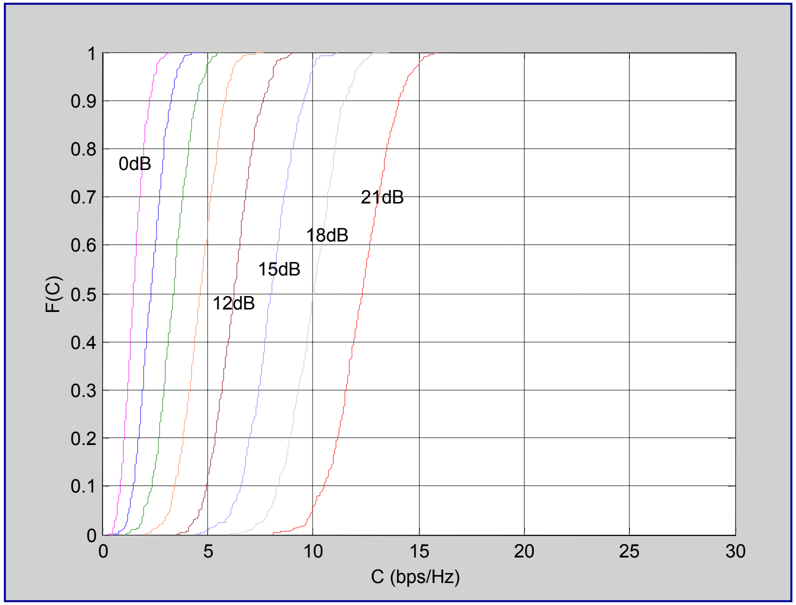
- There is a linear growth in the capacity when increasing the number of antennas
- The sum of n SISO channels is achieved



Case 2 and 3. Correlated environments

•The capacity growth for every 3dBs in the signal to noise ratio goes from 3 bps/Hz and 2 bps/Hz for case 2 and 3 respectively



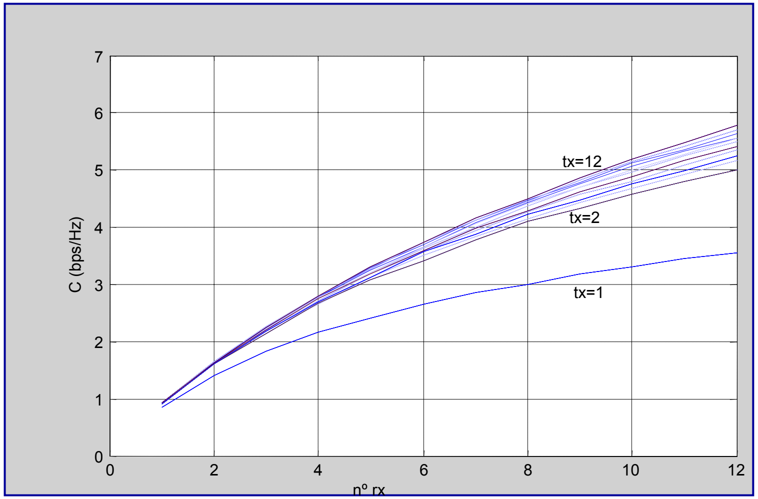


Case 2 and 3. Correlated environments

SNR=0dB

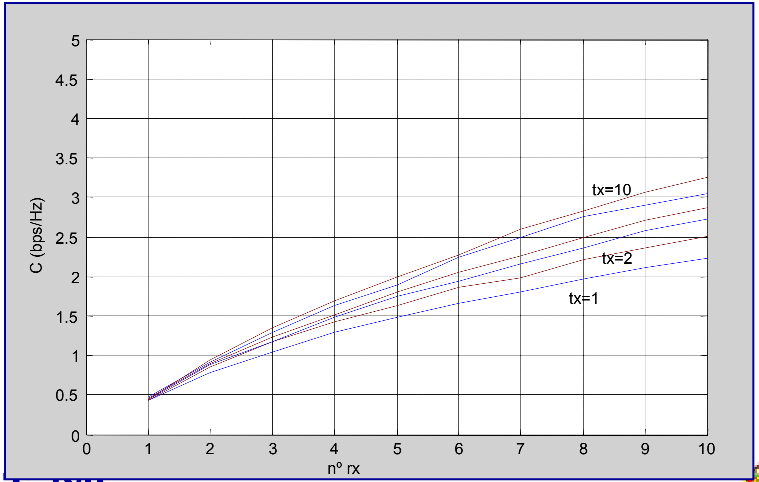
•For case 2:

LOS path→ shows less gain than case 1 but higher than case 3



•For case 3:

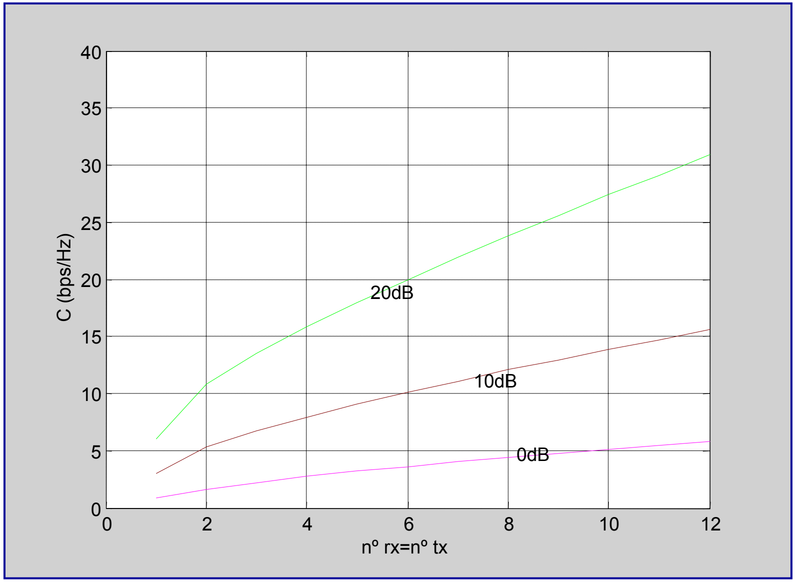
NLOS path → low gain, high correlation

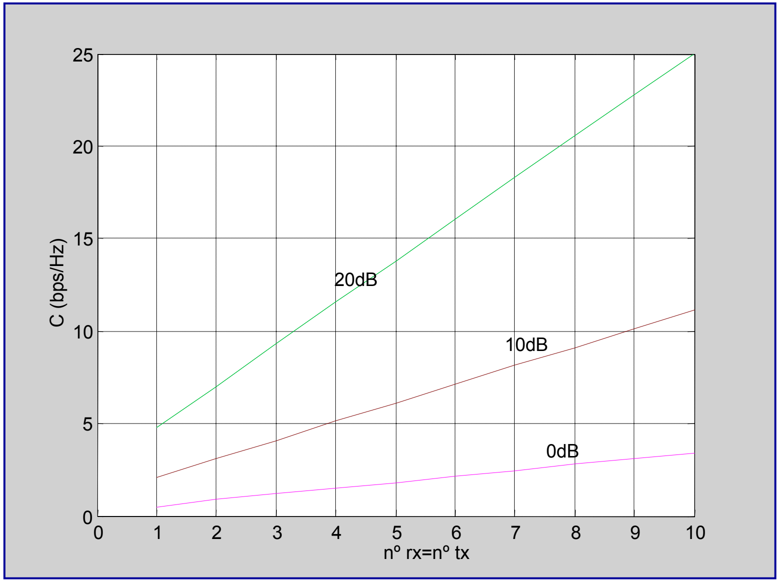


Case 2 and 3. Correlated environments

•For $n_T = n_R = n$

- **It is not possible to establish n parallel channels, the equivalent number of channels will depend on the level of correlation**
- **The increment is still lineal but with lower slope**

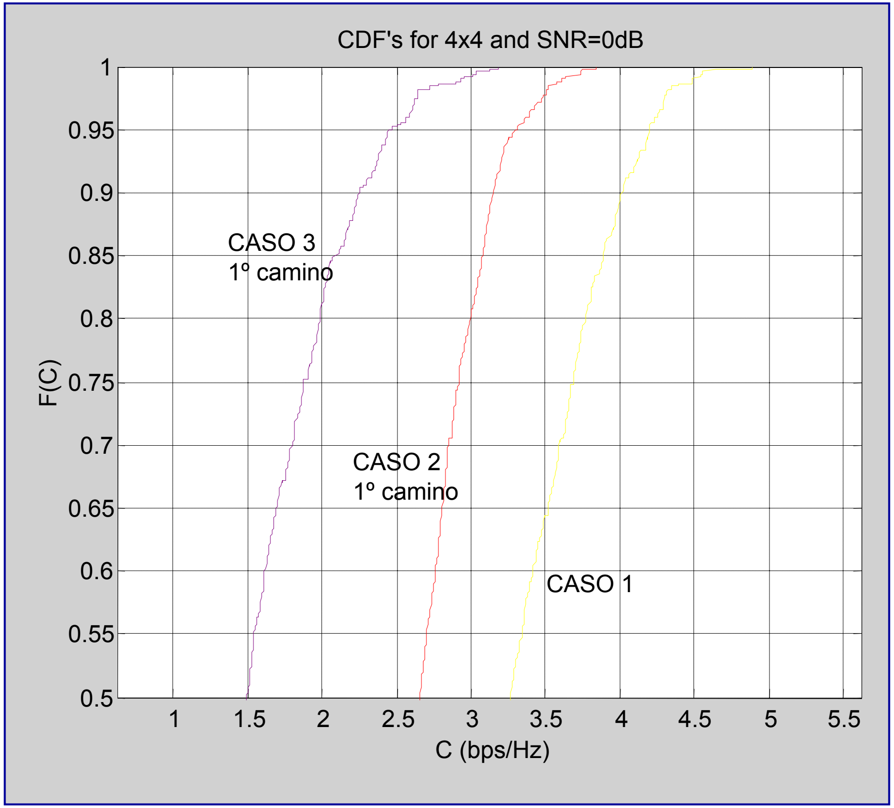




Comparison of all the models

•Spatial correlation affects the channel capacity

•Even though the achieved channel capacity is higher that what it is obtained for a SISO system



Conclusions

- Parallel independent channels might be accomplished by means of coding
- In real propagation environments the channel taps are correlated → capacity decreases depending on the level of correlation
- The capacity growth for each SNR 3 dBs in n bps/Hz while for correlated environments is lower.