Improving MIMO Spectral Efficiency in 4G Macro-Cellular Networks

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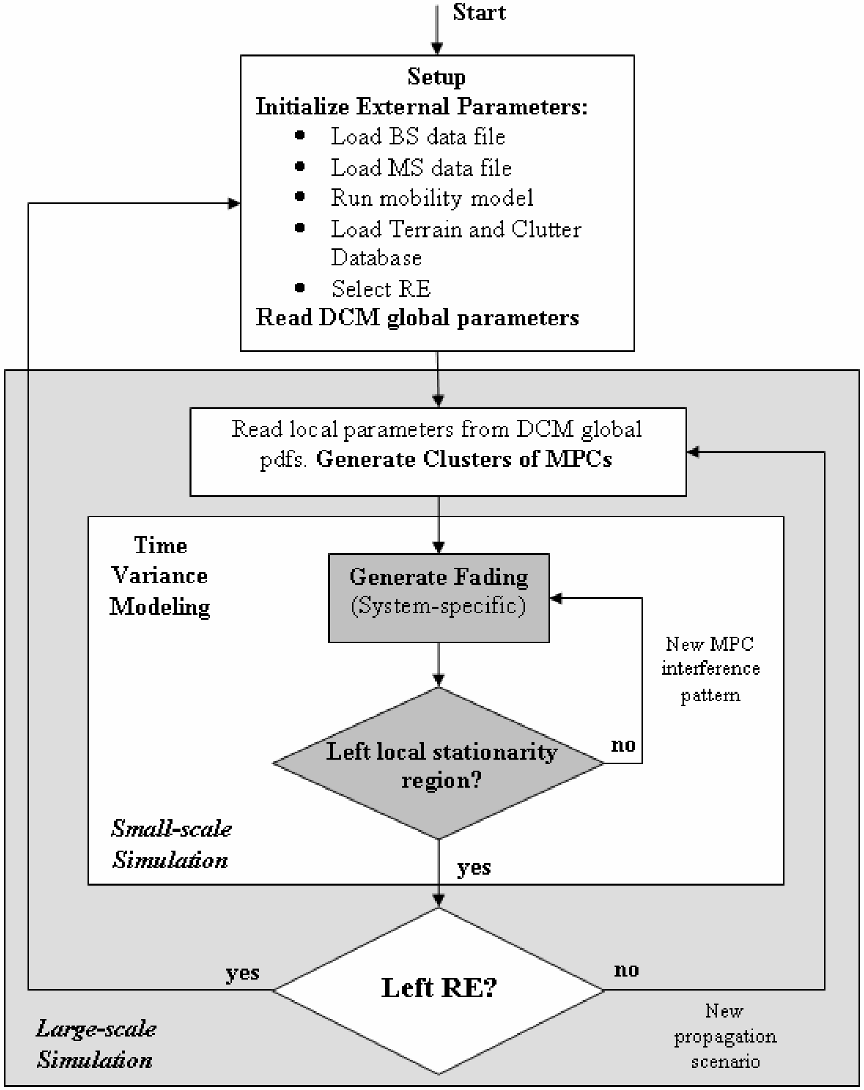
Outline

- Radio Channel Model Implementation
- The FS MIMO Channel Model
- LTE MIMO Channel Spectral Efficiency
- LTE Spectral Efficiency Expectation
- Simulation Results
- Conclusions

Channel Model Implementation (1/2)

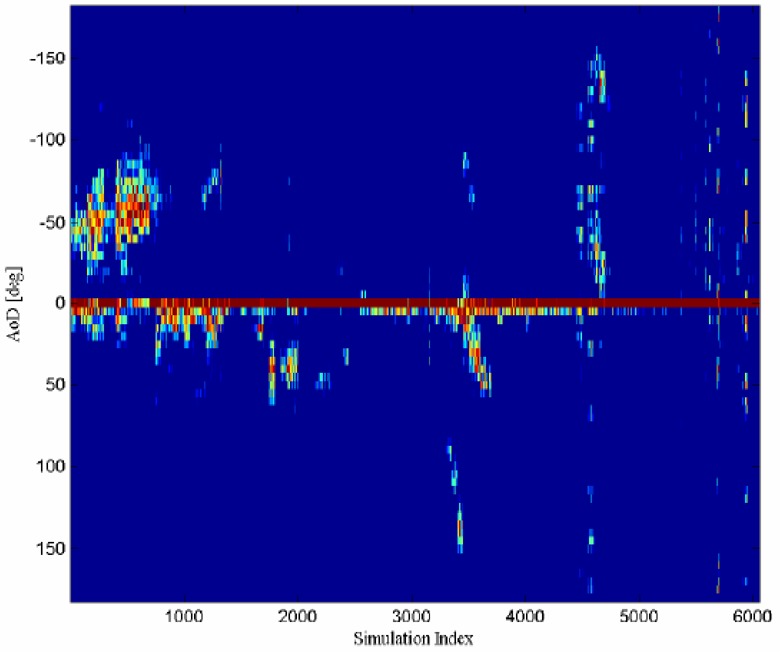
- The channel model is built over a previously developed directional channel model, which is an extension of COST 273 channel model.
- It introduces terrain and building information into radio channel simulation.



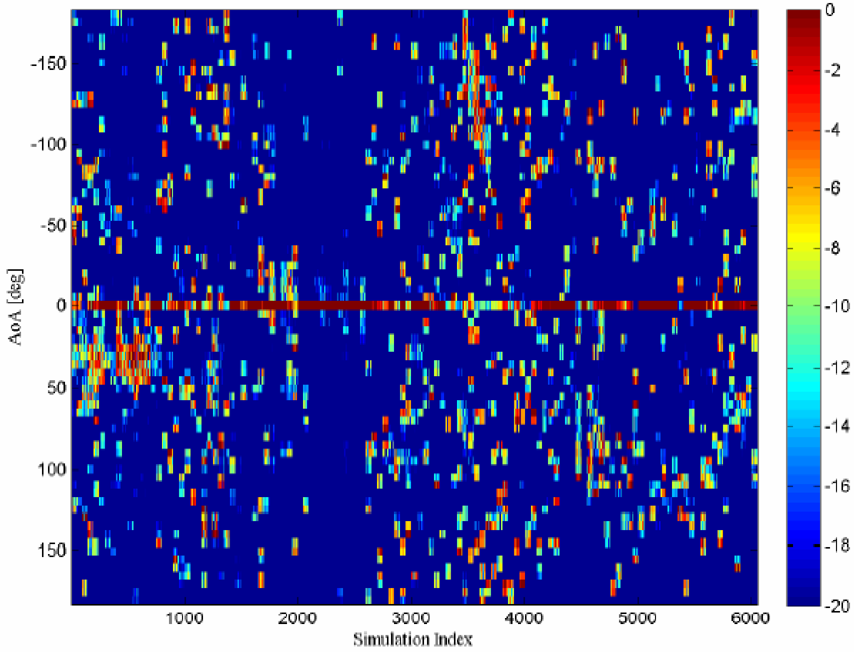
Simulator's block diagram.

Channel Model Implementation (2/2)

Large-Scale Variations and Clustering



Dynamic evolution of simulated power azimuth profile (AoD, at the BS) for a MS route in Lisbon using the extended COST 273 channel model.



Dynamic evolution of simulated power azimuth profile (AoA, at the MS) for a MS route in Lisbon using the extended COST 273 channel model.

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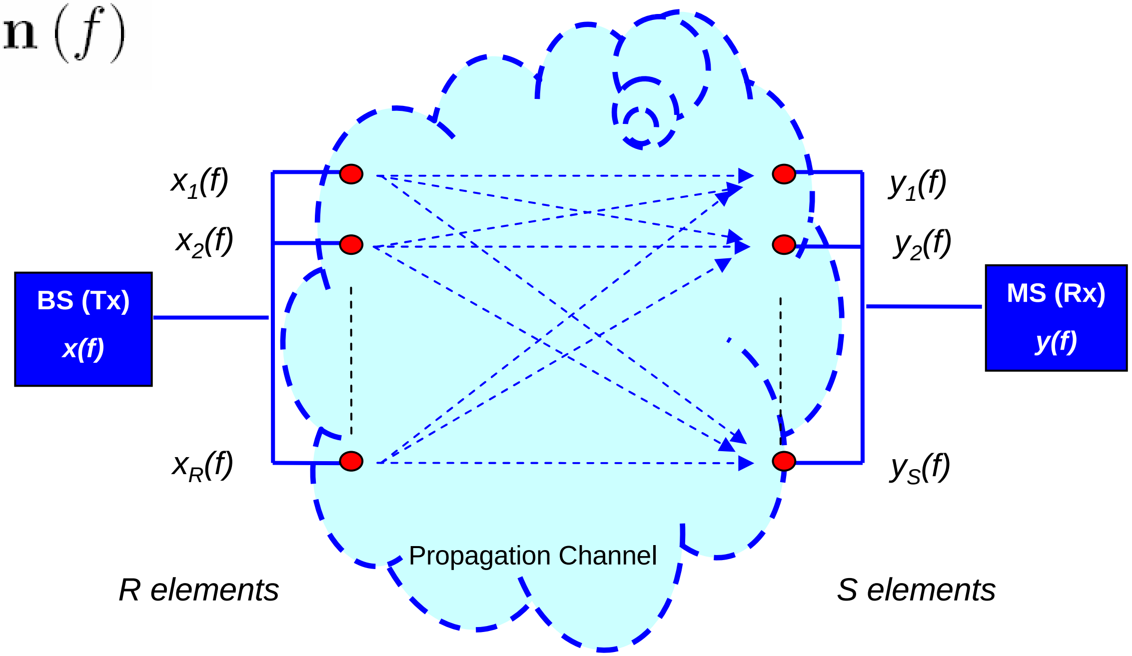
The FS MIMO Channel Model (1/4)

$$\mathbf{x}(f) = [x_1(f), x_2(f), ..., x_R(f)]^T$$

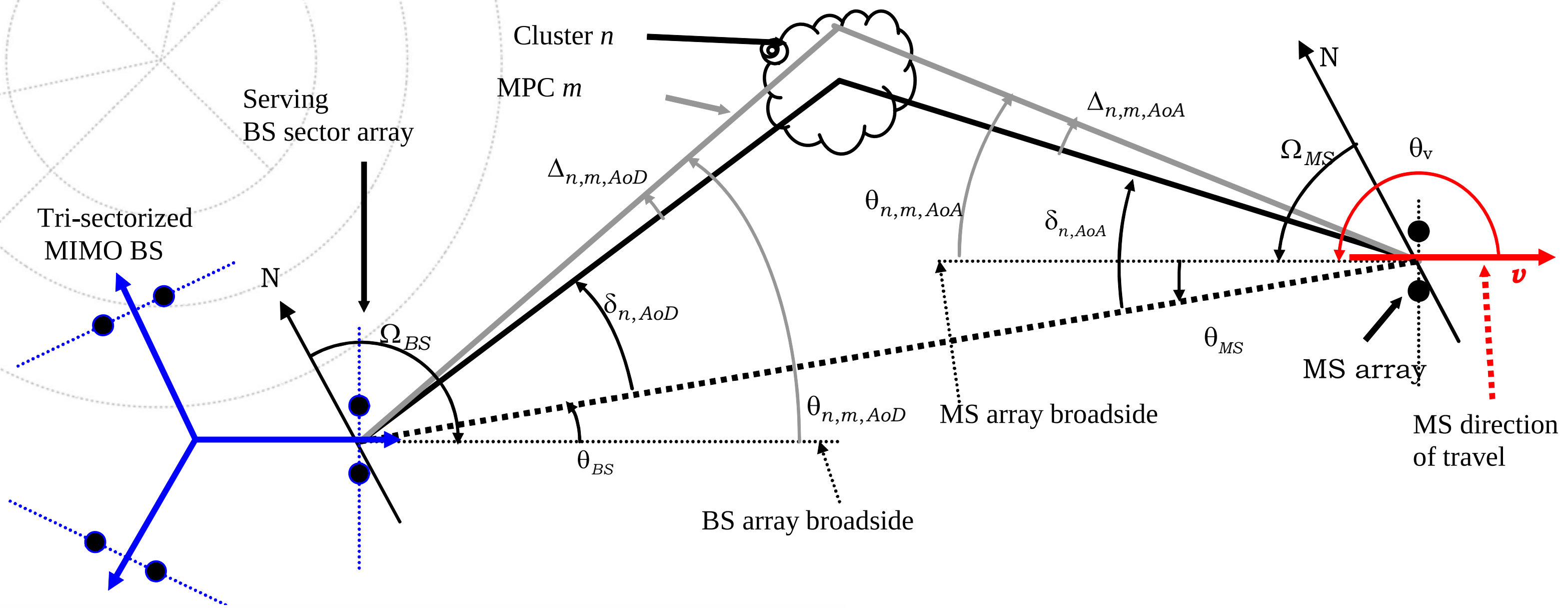
$$\mathbf{y}(f) = [y_1(f), y_2(f), ..., y_S(f)]^T$$

$$\mathbf{y}(f) = \mathbf{H}(f)\,\mathbf{x}(f) + \mathbf{n}(f)$$



The FS MIMO Channel Model (2/4)

Calculation of Channel Matrix H



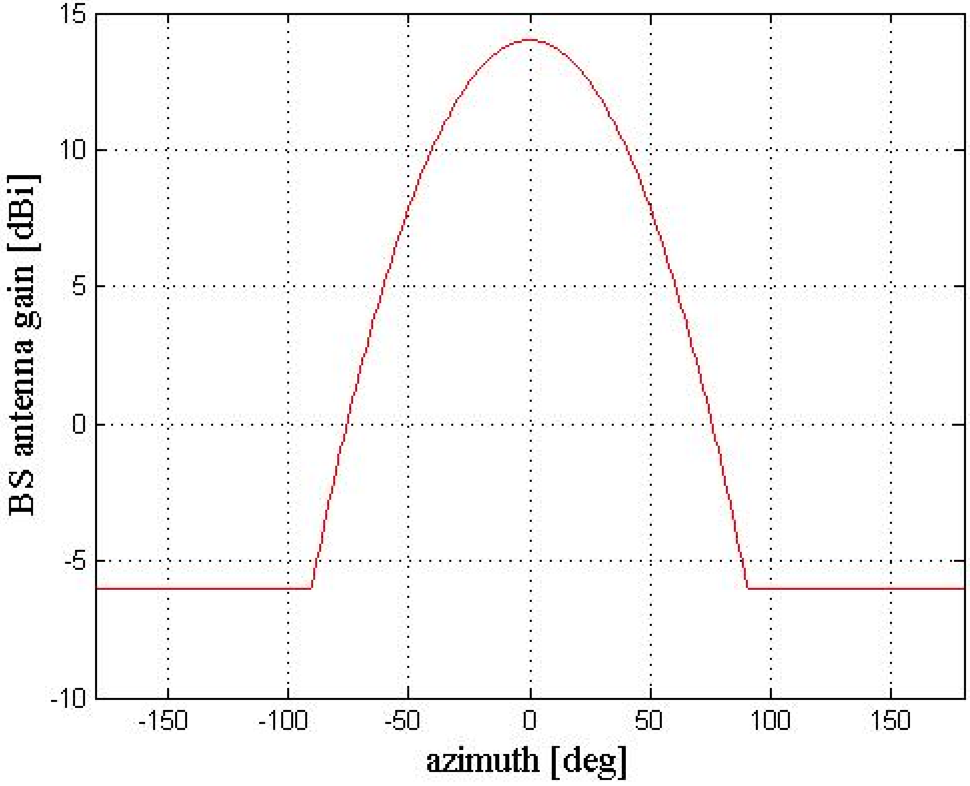
$$h_{s,r}(f) = \sum_{l=1}^{L}\sum_{n=1}^{N}\sum_{m=1}^{M} a_{n,m}\sqrt{G_{BS,r}(\theta_{n,m,AoD})}$$
$$\times \exp(-jkd_r \sin(\theta_{n,m,AoD}))\sqrt{G_{MS,s}(\theta_{n,m,AoA})}$$
$$\times \exp(-jkd_s \sin(\theta_{n,m,AoA}))\exp(-j\,2\pi f\tau_l)$$
$$\times \exp(-jk\,\|\vec{\mathbf{v}}\|\cos(\theta_{n,m,AoA}-\theta_v)) \times\ g(\tau_{n,m},\tau_l)$$

$$g(\tau_{n,m},\tau_l) = \begin{cases} 1 & \tau_{n,m}\in[\tau_{l-1},\tau_l[\\ 0 & other \end{cases}$$

$$\tau_l = \frac{1}{B}$$

The FS MIMO Channel Model (3/4)

The BS Antenna Model



$$G_{BS}(\theta) = G_{BS,\max} - \min\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$$

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The FS MIMO Channel Model (4/4)

EigenAnalysis

$$\mathbf{H}(f_q) = \mathbf{U}(f_q)\,\mathbf{\Sigma}(f_q)\,\mathbf{V}(f_q)^H$$

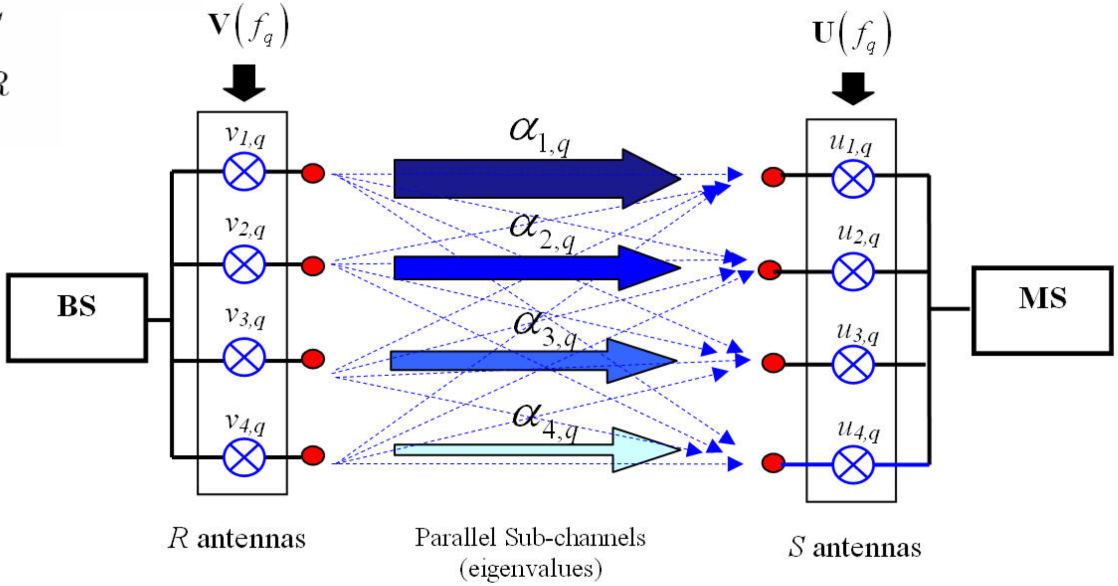
$$\mathbf{\Sigma}(f_q) = diagonal(\sigma_{1,q}, \sigma_{2,q}, ..., \sigma_{k,q})$$
$$\sigma_{1,q} \geq \sigma_{2,q} \geq ... \geq \sigma_{k,q} \geq 0$$

$$\mathbf{U}(f_q) = [\mathbf{u}_{1,q}, ..., \mathbf{u}_{S,q}] \in C^{S\times S}$$
$$\mathbf{V}(f_q) = [\mathbf{v}_{1,q}, ..., \mathbf{v}_{R,q}] \in C^{R\times R}$$

$$\gamma_{k,q} = \sigma_{k,q}^2$$

$$\Lambda_q = \frac{1}{SR}\sum_{s=1}^{S}\sum_{r=1}^{R}|h_{sr}(f_q)|^2$$

$$\alpha_{k,q} = \frac{\gamma_{k,q}}{\Lambda_q}$$



K_q

LTE MIMO FS Channel Spectral Efficiency (1/5)

$$C = \frac{\eta_{BW}}{Q} \sum_{k=1}^{K_q} \sum_{q=1}^{Q} \log_2 \left(1 + \alpha_{k,q} \beta_{k,q} \eta_{SNR} \frac{S}{N} \right)$$

- **It depends on:**

MIMO Channel (Eigenvalues)

Radio Link SNR (*S/N*)

Power Allocation Strategies:

Uniform

Spatial Water-filling

LTE Transmission Bandwidth

LTE System Bandwidth Efficiency

SNR Efficiency

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LTE MIMO FS Channel Spectral Efficiency (2/5)

LTE Bandwidth Efficiency

TABLE I
LTE SYSTEM BANDWIDTH EFFICIENCY.

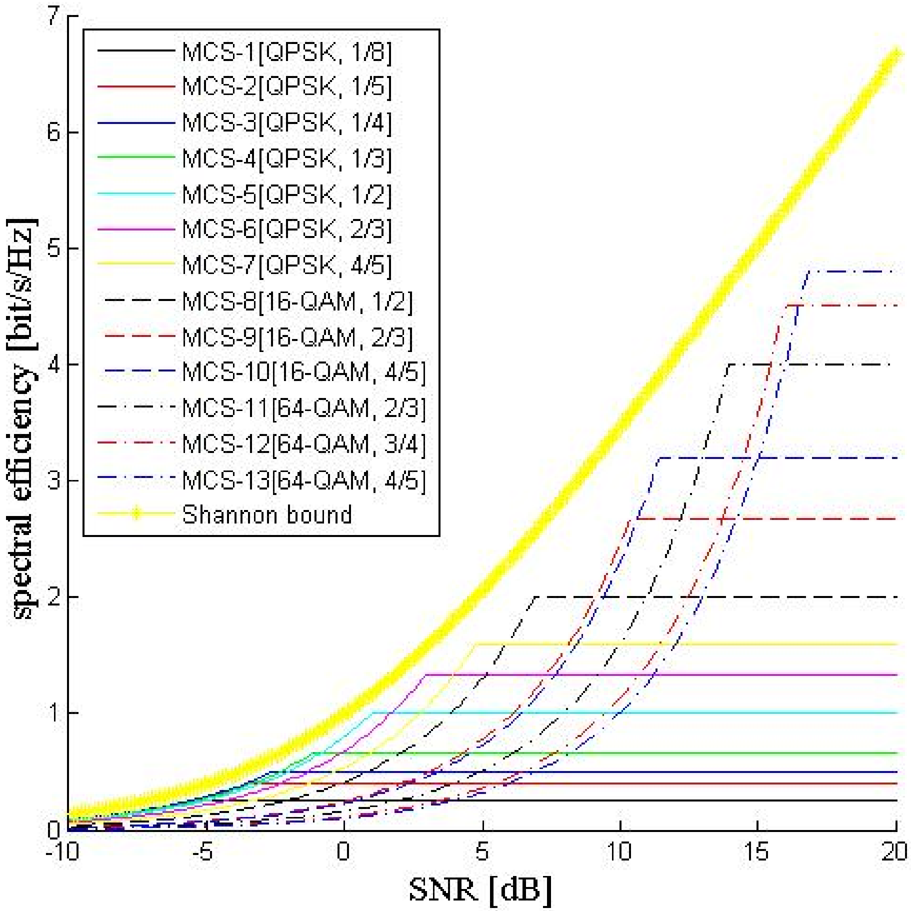
Bandwidth Efficiency	Nr. of TX antennas (r)			
	1	2	3	4
ACLR efficiency (η_{ACLR})	0.90			
CP efficiency (η_{CP})	0.93			
Reference signal efficiency ($\eta_{RS,r}$)	0.95	0.90	0.89	0.86
L1/L2 efficiency($\eta_{L1/L2}$)	0.78			
Total link-level efficiency ($\eta_{BW,r}$)	0.80	0.76	0.75	0.72
Total system-level efficiency	0.63	0.60	0.59	0.57

$$\eta_{BW,r} = \eta_{ACLR} \cdot \eta_{CP} \cdot \eta_{RS,r}$$

LTE MIMO FS Channel Spectral Efficiency (3/5)

LTE SNR Efficiency

- LTE uses Adaptive Modulation and Coding (AMC).
- SNR Efficiency will be determined using curve fitting over the LTE AMC composite spectral efficiency.



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LTE MIMO FS Channel Spectral Efficiency (4/5)

LTE SNR Efficiency

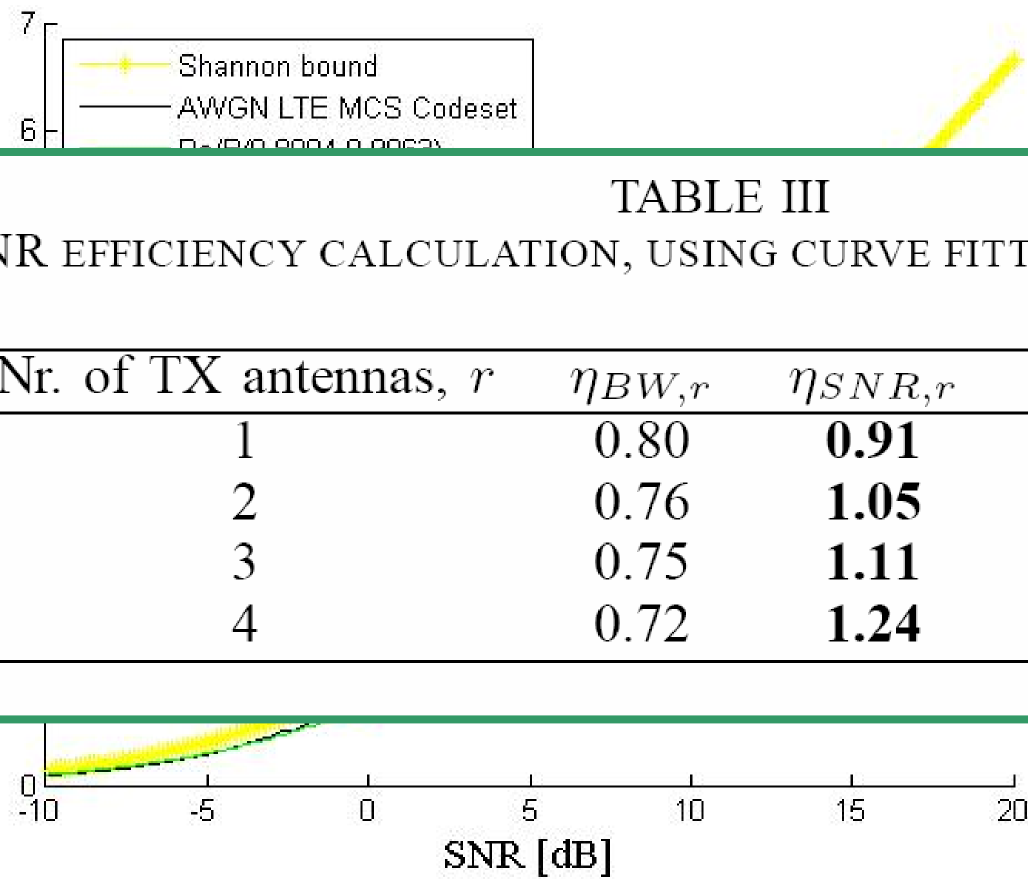


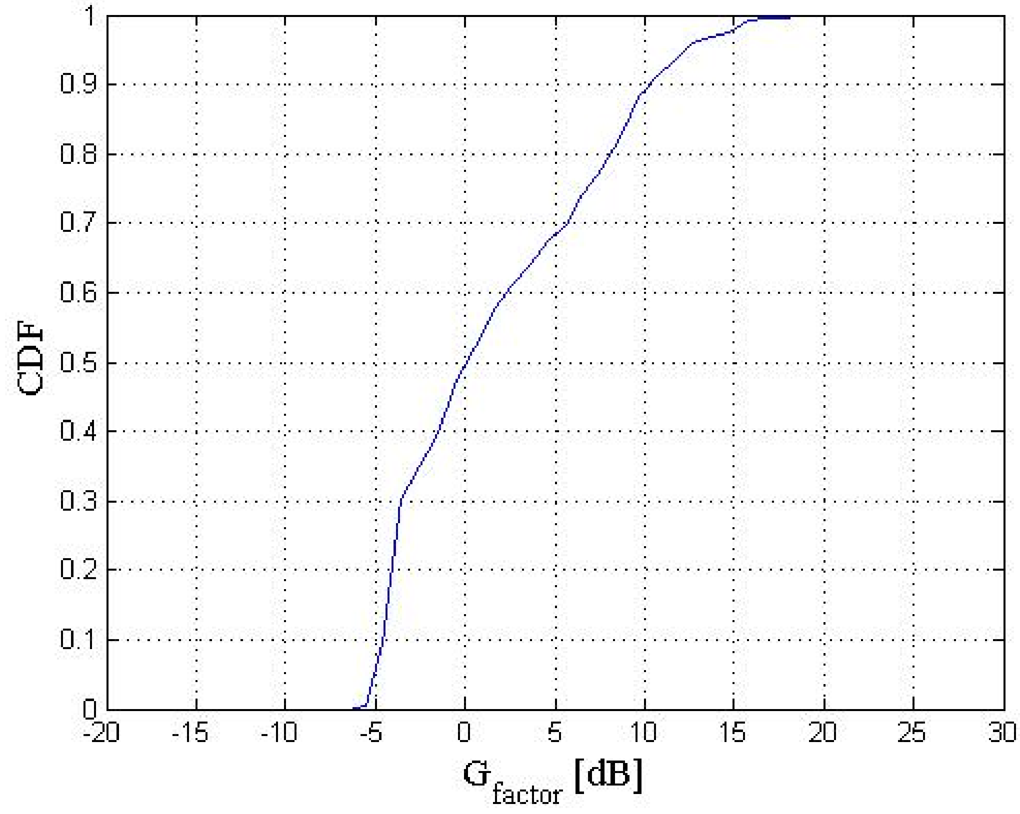
TABLE III
SNR EFFICIENCY CALCULATION, USING CURVE FITTING FOR LTE AWGN.

Nr. of TX antennas, r	$\eta_{BW,r}$	$\eta_{SNR,r}$	Correlation Coef.
1	0.80	**0.91**	0.9954
2	0.76	**1.05**	0.9947
3	0.75	**1.11**	0.9943
4	0.72	**1.24**	0.9930

LTE MIMO FS Channel Spectral Efficiency (5/5)

Radio Link SNR (*S/N*)

- **SNR is actually a SINR…**
- **SINR is dependent on the network geometry, retrieved by the G_{factor}.**



- **G_{factor} CDF for Lisbon Radio Environment**

LTE Spectral Efficiency Expectation (1/2)

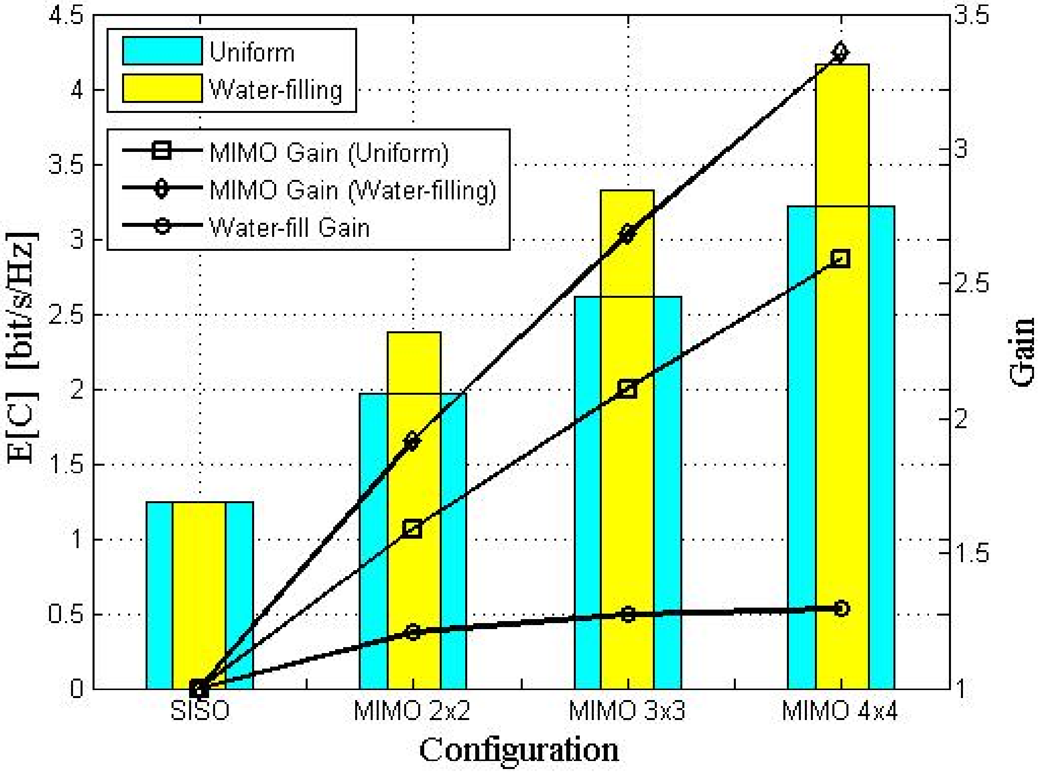
TABLE II
LTE DOWNLINK PHYSICAL LAYER PARAMETRIZATION.

Parameter	Value
Carrier Frequency [MHz]	2000
OFDM Parameters	short CP, 7 data symbol per 0.5 ms sub-frame, 1 ms TTI
Channel Model	Extended COST 273 DCM [8]
MCS	QPSK: 1/8, 1/5, 1/4, 1/3, 1/2,2/3,4/5 16-QAM: 1/2, 2/3, 4/5 64-QAM: 2/3, 3/4, 4/5
Channel Estimation	Ideal
Mobility	20 km/h average speed, vehicular [9]

MIMO LTE Spectral Efficiency Expectation (2/2)

$$E\left(C\right)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}...\int_{-\infty}^{+\infty}C\left(\alpha_{11},...,\alpha_{K_qQ},\frac{S}{N}\right)f\left(\alpha_{11}\right)...f\left(\alpha_{K_qQ}\right)f\left(\frac{S}{N}\right)d\alpha_{11}...d\alpha_{K_qQ}d\frac{S}{N}.$$

- **SISO spectral efficiency is 1.24 bit/s/Hz.**
- **MIMO spatial multiplexing and waterfilling produces a 92%, 169% and 235% average gain for MIMO 2x2, 3x3 e 4x4 configs.**



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Conclusions

- **This paper studies the MIMO capacity enhancement considering the UMTS DL LTE technology, for Lisbon Macro-cell RE.**
- **The MIMO spatial multiplexing concept is presented, and the associated LTE downlink capacity is calculated including the effects of system bandwidth and SNR efficiency.**
- **The SNR efficiency using AMC was approximated using curve fitting, where the used fitting function is an attenuated and truncated form of the Shannon bound.**
- **Starting with a SISO spectral efficiency of 1.24 bit/s/Hz, MIMO spatial multiplexing and waterfilling produces a 92%, 169% and 235% average gain for MIMO 2x2, 3x3 e 4x4 configs.**