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A SIMPLE APPROACH TO MIMO CHANNEL MODELLING

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ABSTRACT

A semi-statistical MIMO radio channel model is described, adequate for analysing multi-user environments, by simulating the channels between different users at the radio propagation level. The model is capable of simulating MIMO links between users, by allowing multiple antennas at mobile terminals and/or base stations. Results are shown for the influence of antenna spacing on MIMO capacity gain. For pico- and micro-cells, an increase in the number of antennas has a larger impact on capacity gain compared to macro-cells. Using the Geometrically Based Single Bounce Channel Model for micro-cell scenarios, a 20% variation in performance is obtained, depending on the orientation of antennas of both transmitter and receiver. For the macro-cell, a similar variation is seen, but only for the orientation of base station antennas.

1. INTRODUCTION

Radio propagation is an important aspect of any radio design or radio network planning. Channel models try to give a realistic representation of the radio propagation between two or more points, and can roughly be divided into two groups [1]: deterministic and stochastic models.

Deterministic models aim at predicting the channel characteristics for a specific location, by using information from the environment and the locations of the transmitter and receiver. This means that a deterministic model is only valid for the specific location, where it was modelled after. Stochastic models aim at modelling the statistical properties of the channel. Stochastical models are therefore more general, and the same model can often be used unchanged for many similar environments, e.g., rural, sub-urban and urban [2, 3, 4].

The model used in this work is a semi-stochastic one, as it uses some information from the environment to give more realistic results. For instance, for micro-cells, when modelling a scenario where the transmitter and the receiver are located in a street, the width of the street is used as a parameter. In contrast with deterministic models, the model shown here does not require detailed building information or street-layouts.

By implementing multiple antennas at transmitters and receivers, i.e., Multiple Input-Multiple Output (MIMO) with n_t and n_r antennas, one can increase the throughput of the system. With the simulator, the effects of MIMO [5] can be studied for different cell types, but also for multi-user scenarios [6]. In this work, MIMO has been applied in single user scenarios, in order to isolate the effects from MIMO and from multiple users.

This paper shows simulations obtained by a Geometrically Based Single Bounce Channel Model (GBSBCM) defined in Section 2. Simulation results are shown for pico-, micro- and macro-cells, which are modelled as the *Railway-Station-Scenario*, *City-Street-Scenario* and *Highway-Scenario*, respectively. These scenarios have been defined in the EU NoE IST-NEWCOM for the set of common scenarios [7] and in EU IST-FLOWS project [8], and are shown in Section 3. The calculations for the capacity and the relative capacity gain of MIMO over Single Input-Single Output (SISO) are presented in Section 4. The results for some MIMO simulations are shown in Section 5; this section also shows how these results have been used to simulate the effect on performance of using UMTS networks with MIMO. The conclusions of this work are drawn in Section 6.

2. GEOMETRICALLY BASED SINGLE BOUNCE CHANNEL MODEL

In the GBSBCM developed by IST/TUL [9], the propagation environment is composed of scatterers, which are grouped into clusters. Clusters are distributed inside the environment by means of the uniform distribution, while the scatterers inside the clusters follow a 2D Gaussian distribution. Among others, the number of clusters and the average number of scatterers within a cluster can be set with a parameter. The reflection coefficient of each scatterer can be described by its complex value, where the magnitude of the reflection coefficient is the attenuation, due to reflection losses, uniformly distributed in $[0,1]$. The phase of the reflection coefficient is an extra phase change, which is uniformly distributed in $[\,0,2\pi\,[$. Pico- and micro-cell environments consider a Line-of-Sight (LoS) signal, while the macro-cell does not. The micro-cell environment is modelled by an ellipse, whereas the pico- and macro-cell ones are modelled by circles. For both pico- and micro-cells, the Base Station (BS) and Mobile Terminal (MT) are located inside the area, whereas for the macro-cell only MTs are located inside the circle and the BS is outside. Fig.1 depicts the micro-cell scattering model.

The previously described model is implemented in C++ [5, 6], where a Channel Impulse Response (CIR) is calculated for each channel between MT-MT and MT-BS pairs. For each pair, a scatter region is defined, common clusters of scatterers for two or more regions having the same reflection coefficient. In the case of MIMO, the CIR is also calculated between all Tx and Rx antenna pairs of each region. In this

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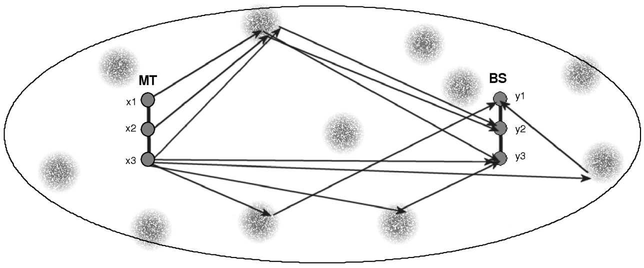


Figure 1: Micro-cell scattering model.

case, the exact location of the antennas is used to calculate the Directions of Departure (DoD) and Arrival (DoA), and the distances between transmitter and scatterer, and scatterer and receiver. However, time differences between the paths from a reflector to the receiver antennas are neglected. The Mutual coupling between antennas is not considered, which holds true in some cases [10].

3. SCENARIOS

Three different scenarios, which were previously defined in [7], are used in the simulations presented in this paper. The scenarios differ mainly in the size of the environment and the cluster density.

The *Railway-Station-Scenario*, Fig. 2, has many variants [7], but for these simulations the more simple pico-cell variant has been choosen. In this scenario, a single user is placed in the region. The BS for the pico-cell with a radius of 50 m is placed in the centre of the main hall, MTs being roughly 20 m away. Scatterers are located within the 50 m radius of the pico-cell and grouped into clusters.

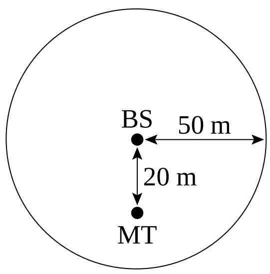


Figure 2: The regions in the *Railway-Station-Scenario*.

The *City-Street-Scenario*, Fig. 3, is a typical urban micro-cell one, modelled by a city street, where both MT and BS are located. The virtual street width, i.e., the width of the ellipse, was set to 160 m, while the real street width was 40 m. The virtual width allows for longer RMS delay spreads, as in this case the signal bouncing from a scatterer at the border of the ellipse has to travel a much longer distance than the signal bouncing from a scatterer located much closer to the LoS line.

The *Highway-Scenario*, Fig. 4, like the aforementioned ones, does not consider mobility. This seem contradictory with the scenario being a *Highway-Scenario*, but it is valid when the scenario models a traffic jam, as it is the case here. A number of cars (MTs) are placed along the highway, while the BT is located 2000 m away, which makes this an example of a macro-cell. In this paper, only one MT is active, which shows the effect of using multiple antennas for a single user scenario.

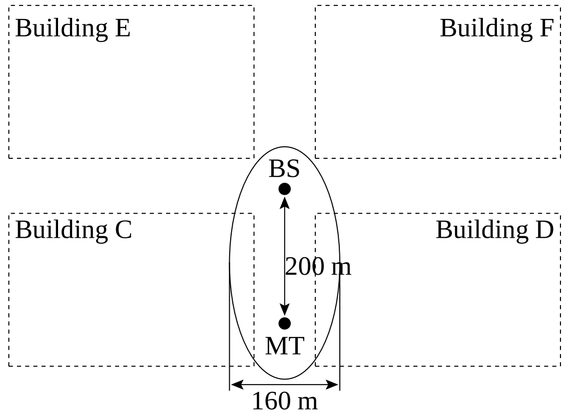


Figure 3: The regions in the *City-Street-Scenario*.

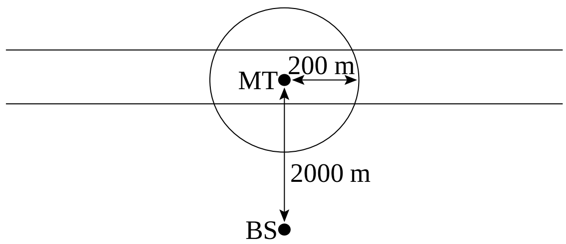


Figure 4: The regions in the *Highway-Scenario*.

4. RELATIVE MIMO CAPACITY GAIN

The capacity of a MIMO system is largely dependent on the correlation between the CIRs of the different antenna pairs. The upper bound is obtained when the CIRs between different antenna pairs are uncorrelated, while the lower bound is obtained when the CIRs of the antenna pairs are completely correlated. The upper and lower bounds for an $n_t \times n_r$ system are given by [11]:

$$C_{upper} = \min(n_t, n_r) \log_2(1+\rho) \tag{1}$$

and

$$C_{lower} = \log_2[1+\rho \cdot \min(n_t, n_r)] \tag{2}$$

where ρ is the Signal-to-Noise-Ratio (SNR). The capacity of a SISO system is given for reference, which is obtained by using Shannon's formula for the capacity of a band-limited system:

$$C_{SISO} = \log_2(1+\rho) \tag{3}$$

The MIMO channel capacity, C_{MIMO}, is calculated by [11]:

$$C_{MIMO} = log_2 \left\{ det \left[\mathbf{I}_M + \left(\frac{\rho}{N}\right) \mathbf{H}\mathbf{H}^H \right] \right\} \tag{4}$$

where $\mathbf{H}$ is the normalised channel transfer matrix related to the non-normalised channel transfer matrix $\mathbf{T}$ by

$$\mathbf{H} = \frac{\mathbf{T}}{g} \tag{5}$$

where g is defined by

$$g^2 = \mathrm{E}\left[|T|^2\right] = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}|\mathbf{T}_{mn}|^2 \tag{6}$$

The relative MIMO gain over SISO in terms of capacity has been calculated by:

$$G_{M/S} = \frac{C_{MIMO} - C_{SISO}}{C_{SISO}} \tag{7}$$

Based on simulation results, the Cumulative Distribution Function (CDF) of $G_{M/S}$ can be produced. The simulations were performed with the parameters given in Table 1 for all three scenarios.

Table 1: Parameters used for simulations.

Carrier frequency [GHz]	2
Bandwidth [MHz]	5
Time resolution (receive filter) [ns]	200
Antenna spacing	λ
Noise floor [dBm]	-150
SNR [dB]	10

5. SIMULATION RESULTS

MIMO systems have been numerically evaluated for all three scenarios, by varying the number of transmit and receive antennas as well as their orientation. The antennas are considered to be a linear array of dipoles with equidistant antenna spacing. Increasing the inter-antenna spacing increases capacity, up to an antenna spacing of λ, Fig. 5. After this distance, the increase in capacity is not so significant, hence, an antenna spacing of λ was used for the simulations unless noted differently.

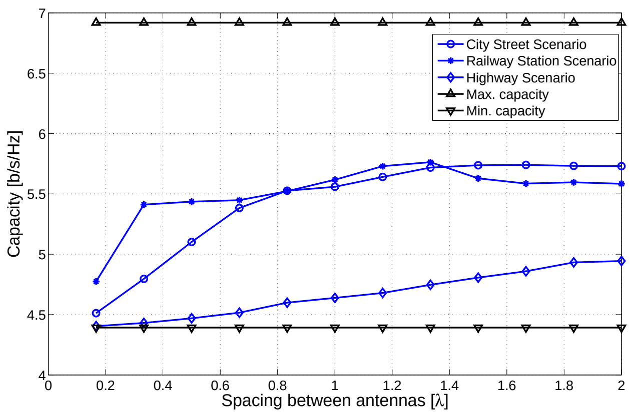


Figure 5: Capacity for different antenna spacings and scenarios for a 2 × 2 MIMO system in the uplink.

The influence of the number of antennas has been investigated for two different configurations. In the first one, the number of transmit antennas is equal to the number of receive antennas, i.e., $n_t = n_r$, while in the second one, the number of transmit and receive antennas are different, i.e., $n_t \neq n_r$.

Table 2: Relative MIMO Gain for scenarios with $n_t = n_r$.

$n_t \times n_r$	$G_{M/S}$		
	Highway-Scenario	*City-Street-Scenario*	*Railway-Station-Scenario*
2×2	1.3	1.6	1.5
4×4	2.8	2.6	1.9
6×6	2.4	3.7	3.5
8×8	2.8	4.5	4.5
10×10	3.3	5.3	5.4
12×12	3.7	6.0	6.4

As it can be seen in Table 2, the *Highway-Scenario* has the worst performance, which is expected has a much smaller DoA range. It can be said that, for macro-cell scenarios, the environment around the BS is not very rich in multipath components, which limits the gains that can be achieved with MIMO. The *Railway-Station-Scenario* and *City-Street-Scenario* have a much richer multipath environment around both the BS and the MT, as scatterers are located around them, resulting in a much higher MIMO capacity compared to the *Highway-Scenario*.

It is very unlikely that MTs will be adapted with a large number of antennas, due to the constraints on their physical size, but this constraint does not exist for the BS. Therefore, systems have been investigated when the BS has more antennas than the MT, i.e., $n_{BS} > n_{MT}$. These simulations were performed for the *City-Street-Scenario* and the *Railway-Station-Scenario* in the context of WLANs, whereas the results for Table 2 were performed in the context of UMTS. In WLAN, a macro-cell does not make much sense and simulations are only performed for the *City-Street-Scenario* and the *Railway-Station-Scenario*, Table 3.

Table 3: Relative MIMO Gain for scenarios with $n_t \neq n_r$.

$n_{BS} \times n_{MT}$	$G_{M/S}$			
	City-Street Scenario		*Railway-Station Scenario*	
	Downlink	Uplink	Downlink	Uplink
4×2	1.8	2.3	1.7	2.1
8×2	1.8	2.9	1.7	2.7
16×2	1.8	3.5	1.	3.48
8×4	3.1	3.9	2.8	3.9
16×4	3.2	5.1	3.1	4.91

The uplink performs slightly better than the downlink, which indicates that the number of receive antennas has a bigger influence on MIMO capacity than the number of transmit antennas. Considering the fact that MTs are usually more limited in transmit power than the BS, this could lead to a bigger increase in data rates for the uplink rather than the downlink, when using MIMO.

In the previous simulations, the arrays of transmit and receive antennas were perfectly aligned, Fig. 6. The orientation of transmit and receive antennas was also investigated, for a system with four omni-directional antennas at the BS and two at the MT. As shown in Fig. 6, the angle of 0° is found when the BS and MT antenna arrays are parallel.

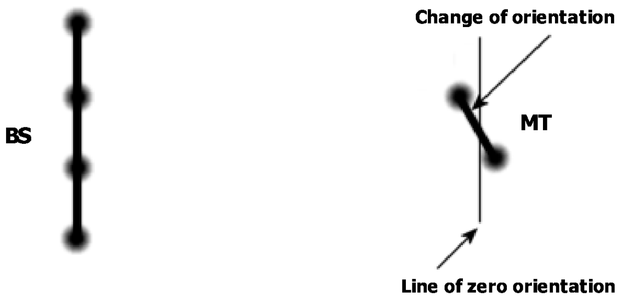


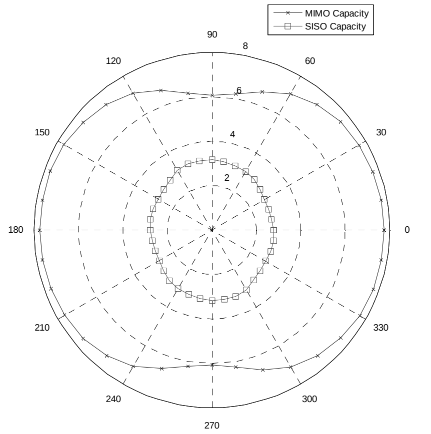
Figure 6: Orientation of the BS and MT antennas.

For the *City-Street-Scenario*, Fig. 7(a), the results for the BS and MT antenna array are very similar, where a 20% decay in capacity can be experienced when the antenna array of the BS and MT are perpendicular. The environment of the *City-Street-Scenario* is elliptical, where the BS and MT are located at the foci. This indicates that when either of the array of antennas at the BS or MT has an angle of 90° to the LoS, the correlation between the CIRs of the different antenna pairs becomes larger, reducing the MIMO gain.

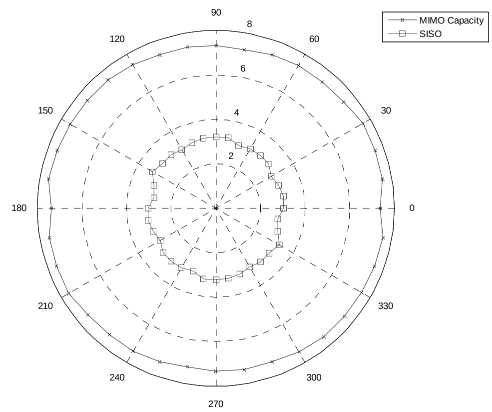
As it can be seen in Fig. 7(b), the behaviour for the *Railway-Station-Scenario* is different from the *City-Street-Scenario* case, because in the latter the environment is circular, where both BS and MT are located inside the circle, surrounded by clusters of scatterers. In fact, simulations have shown a slightly lower MIMO capacity for the case where the arrays of antennas at the BS and MT are parallel. Due to the smaller area, hence smaller distances between the BS and MT, the variation of the signal is much smaller, which results in an increase of the correlation of the CIRs of the antenna pairs. The difference between the maximum and minimum capacity obtained from the simulations is around 6% and can be found at 30°and 0°, respectively.

In the case of the *Highway-Scenario*, Fig. 7(c), the orientation of the BS has similar effects as for the *City-Street-Scenario*, while the orientation of the MT has no significant influence on capacity. For the BS, the largest capacity is obtained, when the angle of the array is perpendicular with the angle of the location of the MT. This can be expected, as the *Highway-Scenario* has a small DoA range, since the BS is located far away from the scattering environment and the MT. Rotating the array of antennas at the BS has a similar effect as reducing the DoA.

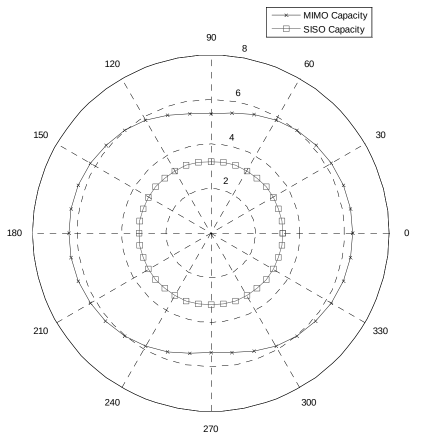
In the IST-FLOWS project, the MIMO capacity has been bridged to multi-modal terminals in a heterogeneous network [12, 13] and a UMTS one [14]. In order to facilitate MIMO in the existing UMTS and heterogeneous system simulators [15], the CDF of the relative MIMO gain was used. These simulations used the parameters given in Table 1, with



(a) Rotation of the MT antenna in the *City-Street-Scenario*.



(b) Rotation of the BS antenna in the *Railway-Station-Scenario*.



(c) Rotation of the BS antenna in the *Highway-Scenario*.

Figure 7: Capacity for different rotations of antennas.

the exception of the equidistant antenna spacing, which was set to 0.5λ. In the simulations to create the CDF for the relative MIMO capacity gain, the orientations of the BS and MT were set randomly. The orientation of the antennas for the BS and the MT were not taken into account in the UMTS simulator, as the differences were averaged out when running the simulation to obtain the CDF. The CDF of the relative MIMO gain was used to determine a realistic statistical MIMO gain, which directly increases the capacity of the cell. The simulator [15] needed only minor adjustments to implement the increase in cell capacity. Note that in the UMTS simulator, only micro-cells are considered. Fig. 8 shows the CDFs of the relative MIMO capacity gain for systems where $n_t \neq n_r$. As expected, the probability of a higher MIMO gain increases as the number of antennas increases. UMTS networks with 16 BS antennas, the largest number of antennas simulated, show a capacity increase of 5 times or larger compared to a SISO one for 60% of the cases.

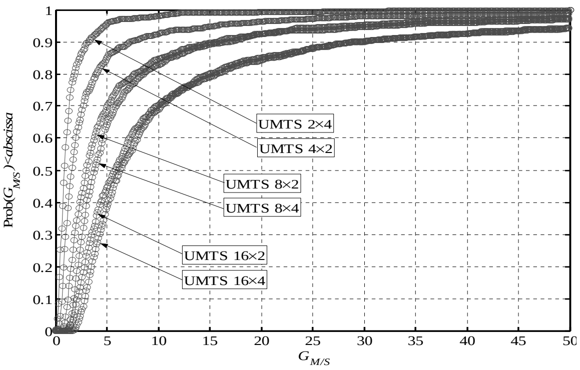


Figure 8: CDF of the relative MIMO capacity gain over SISO with $n_t \neq n_r$.

6. CONCLUSIONS

This paper describes some of the work that has been carried out by the Group for Research on Wireless at IST-IT/TUL on MIMO systems. A GBSBCM was developed and implemented, which is capable of simulating MIMO and multiuser environments, for pico-, micro- and macro-cells, or a combination thereof. A simple method has been shown to incorporate the results of the channel simulator into a UMTS simulator by increasing the cell capacity based on a statistical relative MIMO capacity gain. The statistical relative MIMO capacity gain is achieved by creating the CDF for the relative MIMO capacity gain, independent of the orientation of the antennas.

Results from the MIMO channel model show that the orientation of the antennas of the BS and the MT can have an influence on the MIMO capacity gain for micro- and macro-cells, while pico-cells do not show a significant difference. The MIMO gain, depending on the orientation of the antennas of the BS and the MT, can vary around 20% for the micro-cell scenarios. For the macro-cell, the orientation of the MT antenna is not significant, however, a 20% variation can be noticed for the BS antennas.

The relative MIMO capacity gain shows that a significant increase in cell capacity for UMTS can be obtained by using MIMO, when the BS has more antennas than the MT. Increase in capacity of more than 5 times the SISO one is found to occur 60% of the cases for a BS with 16 antennas and an MT with 4 antennas.

REFERENCES

[1] Ibnkahla,M. (ed.), *Signal Processing for Mobile Communications Handbook*, CRC Press, Boca Raton, FL, USA, 2004.

[2] Liberti,J. and Rappaport,T., *Smart Antennas for Wireless Communication: IS-95 and Third Generation CDMA Applications*, Prentice Hall, Upper Saddle River, NJ, USA, 1999.

[3] Vaughan,R. and Bach Andersen,J., *Channel Propagation and Antennas for Mobile Communications*, IEE Press, London, UK, 2003.

[4] Parsons,J. D., *The Mobile Radio Propagation Channel*, Pentech Press, London, UK, 1992.

[5] Kokoszkiewicz,H., *MIMO Geometrically Based Single Bounce Channel Model*, Master Thesis, IST/TUL, Lisbon, Portugal, Sep. 2005.

[6] Zubala,R., *Multiuser Geometrically Based Single Bounce Channel Model*, Master Thesis, IST/TUL, Lisbon, Portugal, Sep. 2005.

[7] Gil,J. M., Cardoso,F. C., Kuipers,B. W. M. and Correia,L. M., *Contribution for the Definition of Common Propagation Scenarios*, IST-NEWCOM Project Report IST-TUL WP-R2-032-02, Lisbon, Portugal, May 2005.

[8] Aguiar,J., Correia,L. M., Gil,J., Noll,J., karlsen,M., Svaet,S., Mously,T., Hunt,B., Raynes,D., Lehman,G., Müller,R., Hofstetter,H., Tröger,H. and Burr,A., *Definition of Scenarios*, IST-FLOWS Project Deliverable 1, IST/TUL, Lisbon, Portugal, Mar. 2002.

[9] Marques,M. G. and Correia,L. M., *A Wideband Directional Channel Model for Mobile Communication Systems*, in Chandran,S. (ed.), *Adaptive Antenna Arrays*, Springer Verlag, Berlin, Germany, 2004.

[10] Cardoso,F. D., Peixeiro,C., and Correia,L. M., "Influence of Antenna Array Coupling Effects on the Radio Channel Impulse Response in Mobile Communication Systems", in *Proc. of ConfTele'05 - 5th Conference on Telecommunications*, Tomar, Portugal, Apr. 2005.

[11] Kyritsi,P., *Multiple Element Antenna Systems in an Indoor Environment.*, Ph.D. Thesis, Stanford University, Stanford, CA, USA, 2001.

[12] Debbah,M., Gil,J., Fernandes,P., Venes,J., Cardoso,F., Marques,G. and Correia,L. M., *Final Report on Channel Models*, IST-FLOWS Project Deliverable 13, IST/TUL, Lisbon, Portugal, Nov. 8, 2004.

[13] Fernandes,P. and Correia,L. M., "Capacity Increase in Converging Mobile Communication Systems Through the Use of MIMO", in *Proc. of VTC'2005 Fall - IEEE 62nd Veh. Techn. Conf.*, Dallas, TX, USA, Sep. 2005.

[14] Fernandes,P., *Capacity Increase in Converging Mobile Communication Systems Through the Use of MIMO*, Master Thesis, IST/TUL, Lisbon, Portugal, Feb. 2005.

[15] Aguiar,J., *Traffic Analysis at the Radio Interface in Converging Mobile and Wireless Communication Systems*, Master Thesis, IST/TUL, Lisbon, Portugal, Jan. 2004.