Capacity Increase in UMTS/HSPA+ Through the Use of MIMO Systems

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Abstract— The main purpose of this work was to study the implementation of MIMO in UMTS/HSPA+, in terms of gain dependence on scenarios and other MIMO parameters. For this purpose, a model that accounts for different system and MIMO parameters, in a single user scenario, was developed, and implemented in a simulator. The model accounts for several parameters, such as, modulation, layers’ overheads, MIMO configuration and receiver, antenna spacing, type of antenna power fed, etc. The results show that for HSPA+ in DL, the use of MIMO 4×4 jointly with 16QAM and 64QAM enables to achieve throughputs up to 29.5 and 43.8 Mbps, respectively, while in UL the achievable throughputs are up to 23 Mbps. MIMO 2×2 on top of HSPA+ 64QAM offers 19.4 Mbps. These throughputs are achieved within a pico-cell scenario, being lower for the micro-cell one. For UL, within the micro-cell scenario, MIMO 2×4 presents better performance than the 4×4 one, for distances higher than 250 m. Split power fed in DL does not have a major impact on the throughput; however, for UL, the throughput related to the use of the 4×4 configuration with split power is 22% lower than the use of dedicated power.

Keywords: UMTS, HSPA+, MIMO, Scenario, Capacity.

I. INTRODUCTION

3rd Generation Partnership Project (3GPP) specified important evolution steps on top of Release 99, for Downlink and Uplink (DL and UL), these enhancements being commonly known as High Speed Packet Access (HSPA). High Speed Downlink Packet Access (HSDPA) was set as standard in Release 5 with initial peak data rate of 1.8 Mbps, increased to 3.6 Mbps during 2006, and by the end of 2007, 7.2 Mbps were available [1]. Nowadays the maximum peak data rate of 14.4 Mbps is already provided by some operators. Following the success accomplished in the DL by HSDPA, by the end of 2007 HSUPA was deployed, setting first the UL bit rates up to 1.45 Mbps and up to 5.7 Mbps in later releases [2]. Further HSPA evolution, also known as HSPA+, is specified in Release 7, allowing a maximum throughput of 28 Mbps in DL and 11 Mbps in UL, [3].

Multiple-Input Multiple-Output (MIMO) systems can enhance the previously mentioned radio systems, which are based on Single Input Single Output (SISO) systems. A MIMO system consists of a few input and output antennas. All pairs of input and output antennas establish parallel links between the receive and transmit sides. If the links are independent a gain of radio channel can be observed, and the Shannon border of the capacity for the Gaussian radio channel can be crossed, [4]. The independence of the links between input and output is related with the environment of propagation, which have major influence on the correlation between Channel Impulse Responses (CIRs). A decorrelation of the radio channels, i.e., links independence) can only exist in an environment, where a multipath phenomenon takes place, with the potential gain of a MIMO system depending on how strong this phenomenon is. The gain of a MIMO system is related with some parameters as the number of input and output antennas, spacing between them, and also time resolution of the Receiver (Rx).

Regarding the state of the art of MIMO on top of HSPA systems, some papers can be found, though, for HSPA+ information is hard to find, due to its recent standardization. It has been proved by [5] that the expected capacity gains that MIMO schemes, for HSDPA, can provide with more complex receivers lead to a reduced point-to-multipoint Multimedia Broadcast Multicast Service (MBMS) transmission power, and guarantee an optimal distribution of QoS independently of the MBMS mode. With the purpose of improving capacity and handle the near-far problem, a low complexity multi-user MIMO detector of QAM signals based on long scrambling codes is proposed by [6]. Simulations have shown that this proposal provides satisfactory performance enhancement, ensuring a promising technique for HSUPA, although the research in this field is still ongoing. In [7], a physical layer receiver system architecture is presented for baseband processing, aiming essentially at the practical implementation to meet the demanding computational requirements of MIMO, which are MIMO detection and high throughput turbo decoding. These two key components for MIMO implementation exist as fabricated silicon devices, and since the overall system complexity is manageable, all of the components could ultimately be integrated into a single chip solution for a MIMO HSDPA receiver capable of delivering DL packet data speeds up to 14.4 Mbps to an MT. The size of the antennas is also an important factor, if not the most important one. A Planar Inverted-F Antenna (PIFA) with fractal shaped edges configuration is presented in [8]. This type of antennas seems to be a viable option for mobile MIMO terminals, since they meet the requirements of size, present acceptable mutual coupling levels and do not have radiation patterns with strong directivity properties [8].
The main purpose of this work was to study the impact on capacity of UMTS/HSPA+ systems through the use of MIMO systems, and to inspect the MIMO implementation aspects. These objectives were accomplished through the development of a model which accounts for various MIMO parameters, and through collecting and analyzing information that provide solutions to MIMO implementation. The main results of the model are the SISO and MIMO application throughputs at a certain distance. Underlying the model development was the use of some previously developed ones, namely the Relative MIMO Gain (RMG) model, which makes use of the Geometrically Based Single Bounce (GBSB) channel model. However the RMG model do not contemplate SNR and antenna spacing variation, therefore simulations were performed for the RMG model in order to obtain correction values and/or functions that would account for these parameters variation as accurately as possible. Thus, in the developed model these variations are already taken into account. The model was afterwards implemented in a simulator, allowing several analyses regarding MIMO parameters variation. For a comparison purpose, the MIMO impact on earlier 3GPP releases is studied as well. The gain of a MIMO system should be checked in different conditions of propagation with dissimilar distributions of the scatterers. So, in this work the application of MIMO in different scenarios is analyzed, with three scenarios being considered: pico-, micro- and macro-cells.

This work was made in collaboration with the mobile operator Vodafone. Several technical details were discussed with the company. The type and content of the results analysis had also been discussed, with the presented analysis being the ones that fit better the aim of this work, therefore, providing the most relevant results.

In Section II the models for the theoretical calculations are described. The default scenario, as well as the results for some parameters variation, namely the antenna configuration and the type of antenna power fed, are presented and analyzed in Section III. In Section IV the main conclusions are drawn.

II. THEORETICAL MODELS

A. RMG model

In order to predict the improvements in capacity of using MIMO over SISO based on simulation results, the RMG Model was chosen, since it seems to be the one that fits better the demands and scope of this work. The RMG model is described in detail in [9]. The model considers isotropic antennas and is based on simulation results from a MIMO radio channel simulator which takes into account the GBSB channel model, that was developed by the Group of Research On Wireless (GROW) of Instituto Superior Técnico (IST). A detailed description of the GBSB channel model is presented in [10].

1) SNR Variation: Regarding the scope of this work, it is inherent the need to assess the influence on the RMG of the SNR variation. With the objective of doing so, 50 simulations were carried out, since it seemed to be a good compromise between time and results validity.

For the simulations, four different distances were taken into account, despite the fact that there are three different scenarios, though for the pico-cell scenario it is relevant to simulate two different distances regarding the different slopes of the RMG mean function, within this cell type [9]. The distances considered were 20 and 50 m for the pico-cell, 400 m for the micro-cell, and 1000 m for the macro-cell. Note that these values are about the middle distances for the four different RMG mean slopes, with the exception of the 2×2 MIMO system that presents an approximately constant behavior. The antenna configurations considered for simulation, were the 2×2, 2×4 (4×2) and the 4×4, since these are the configurations that fit better the demands of this work, besides being the ones that are more suitable to be implemented, due to problems that range from technical details (e.g., size constraints, limited power and detection complexity), to urban details like, the visual impact that, e.g., 8 antennas would have on the top of a building, not to mention 16.

Concerning the SNR variation, the range of values considered is from 5 to 30 dB, with an interval of 5 dB, hence, six different values were taken into account. The 10 dB value is considered, since it is the reference value, and the maximum SNR simulated value is 30 dB, since it is a value high enough to give a good perspective of the RMG behavior with different SNR values.

Regarding the simulation results, the differences between the RMG value for the default SNR value, and for the other ones considered, is of small relative magnitude, hence the possibility to consider no difference at all seems a valid option. However this option can not be taken for granted without stressing out the relative mean error to the default 10 dB of SNR value, for each of the considered antenna configurations. The only configuration that presents a relevant relative mean error is the 4×4 one. Therefore the function that accounts for the effect of the SNR variation on the RMG is given by (1), and it is only applicable to the 4×4 configuration, with the remaining ones having the default RMG value. Note that in (1), for SNR values higher than 30 dB it is assumed that the RMG takes the same value as for SNR equal to 30 dB, due to the lack of results for higher SNR values.

\[
G_{\text{MS,SNR}} = \begin{cases} 
1.0 & 5 \leq \rho_{\text{SNR}} < 10 \\
(0.00533 \times \rho_{\text{SNR}} + 0.9465) \times G_{\text{MS}}, & 10 \leq \rho_{\text{SNR}} \leq 30 \\
1.1064 \times G_{\text{MS}}, & \rho_{\text{SNR}} > 30 
\end{cases}
\]  

(1)

2) Antenna Spacing Variation: In order to account for the antenna spacing effect, which is the same of accounting for the correlation of the signals due to the more or less space between the BS or MT antennas, two different cases of antenna spacing have been considered, namely λ and λ/2; thus, four different cases are possible, when combining the different spacing in the Tx and Rx, where the λ-λ (BS-MT) case is the default one.

Similar to the evaluation of the SNR variation effect, 50 simulations were performed, with the simulation results for the different antenna spacing also presenting differences to the default value of low relative magnitude. However, despite the option of considering no difference due to antenna spacing, the relative mean error to the default antenna spacing has been
calculated. The error for not considering the antenna spacing in the cases of 2×2 and 2×4 (4×2), is below 6%, which is assumed to be negligible, hence, no difference is considered related to the default RMG. For the 4×4 antenna configuration, the errors presented for the λ×λ/2 case are also negligible, while for the λ/2×λ and λ/2×λ/2 situations, in a micro-cell scenario the effects due to not considering any difference are significant, having values of 7.5 and 9%, respectively. Therefore, the effect has to be considered.

The function that describes the effect of the different antenna spacing for the 4×4 systems is given by (2), while for the other three configurations the default value of the RMG is considered.

\[
G_{\text{MIMO}} = \begin{cases} 
1.0 \times G_{\text{MIMO}}, & \text{BS spacing} = \lambda, \quad \text{MT spacing} = \lambda \\
1.0 \times G_{\text{MIMO}}, & \text{BS spacing} = \lambda/2, \quad \text{MT spacing} = \lambda/2 \\
0.975 \times G_{\text{MIMO}}, & \text{BS spacing} = \lambda/2, \quad \text{MT spacing} = \lambda \\
0.955 \times G_{\text{MIMO}}, & \text{BS spacing} = \lambda/2, \quad \text{MT spacing} = \lambda/2 
\end{cases}
\]

(2)

B. Link model

Regarding the scope of this work, a model to calculate the throughput as a function of distance has been developed, with the result being the link model. The link model can be divided into two major throughput calculations:

- SISO;
- MIMO.

The throughput is calculated considering that there is only one user in the cell (single user situation), and four different systems are taken into account, namely Release 99, HSDPA, HSUPA and HSPA+. Moreover, besides DL and UL being defined for Release 99 and HSPA+, the model contemplates the different number of High Speed Physical Downlink Shared Channel (HS-PDSCH) codes for HSDPA, and two optional modulations for HSUPA the Binary Phase Shift Keying (BPSK) or Quaternary Phase Shift Keying (QPSK), and 16 Quadrature Amplitude Modulation (QAM) or 64QAM for HSPA+ DL.

The objective of this model is to calculate the throughput of the previously described systems for a certain scenario when using MIMO. Inherently to the definition of each scenario, a set of distances are considered, and for each distance the correspondent SINR or \( E/No \) is mapped onto throughput, based on the SINR curves in [1] for HSDPA, whereas for HSUPA with BPSK, the available throughput is calculated based on the \( E/No \) curve for FRC6 from [1], and based on the \( E/No \) curve from [11] for the QPSK modulation. Regarding HSPA+ DL and UL, the throughput is calculated based on the SINR and \( E/No \) curves presented in [12] and [11], respectively.

SNR, as well as all the parameters that are associated to it (e.g. EIRP and path loss), are calculated based on the link budget presented in [10], the path loss being calculated based on the COST231 Waldisch-Illegami model [13]. The interference margin is not considered, due to a single user situation. Furthermore, besides the model being based on a snapshot of the link at a certain distance, the slow and fast fading margins were taken into account, with the former being described by a Gaussian distribution and the latter by a Rayleigh one.

Underlying the objective of the link model is the need to compare SISO and MIMO systems in terms of throughput as a function of distance. With this in mind, the model gives both as result. The SISO throughput, \( T_{\text{SISO}} \), as a function of distance is given by (3), while (4) gives the MIMO throughput, \( T_{\text{MIMO}} \). In (3), an ML SISO detector is used, with the limitation of being BPSK for all systems, an approximation that has to be made due to the lack of coherent information; however, doing this can only increase the SISO throughput, since for lower order modulations the BER is lower, 

\[
T_{\text{SISO}} = T_r \times \left[ (1-O_{\text{MAC&RLC}}) \times (1-O_{\text{app}}) \times (1-\beta_{\text{SISO}}(\varnothing)) \right].
\]

(3)

where:

- \( O_{\text{MAC&RLC}} \): MAC and RLC overheads;
- \( O_{\text{app}} \): Application overhead;
- \( T_r \): physical layer throughput;
- \( \beta_{\text{SISO}} \): BER function for the SISO detector;

\[
T_{\text{MIMO}} = T_r \times \left[ (1-O_{\text{MAC&RLC}}) \times (1-O_{\text{app}}) \times (1-\beta_{\text{MIMO}}(\varnothing)) \right] \times G_{\text{MIMO}}(d_{\text{spacing}}, \lambda_{\text{spacing}}),
\]

(4)

where:

- \( \beta_{\text{MIMO}} \): BER function for the MIMO detector.

The main differences presented in (4) related to (3), are that in the former a different MIMO detector is used for each system, with the possibility of being a ML one or a ZF or MMSE for some modulations, and the RMG model is used to calculate the effects of MIMO in the final throughput. The set of detector functions used for each antenna configuration and/or modulation is presented in [10]. For a 4×4 MIMO system, the RMG model is affected by some constants, regarding the effect of SNR variation and antenna spacing presented in Subsection A.1 and A.2, respectively. As a consequence, for this configuration the RMG takes the form of:

\[
G_{\text{MIMO 4x4}} = G_{\text{MIMO}}(4,4, d_{\text{spacing}}) \times G_{\text{MIMO}}(4,4, \lambda_{\text{spacing}}),
\]

(5)

The relative mean error of not considering the SNR variation from the default value of 10 dB, for the other antenna configurations, is below 5%, while for the fact of not considering the correlation effect, due to variation of the antenna spacing from the default value \( \lambda \), for the other antenna configurations, the relative mean error is below 6%, as described in Subsection A.1 and A.2, respectively.

It should be pointed out that (3) and (4) do not account for the detection percentage, i.e., in some situations the signal might not be detected/received, hence, it has to be retransmitted, making use of resources that were supposed to transmit new data instead of retransmitting the former one, consequently lowering the final application throughput. Therefore, the implementation of the link model in a simulator platform leads to a certain throughput per unit distance, that in fact does not account for this retransmission, though the throughput might be 0 Mbps, meaning that the signal has not been detected, which enables the detection percentage calculation and to further account for it. The procedure to calculate the final throughput, \( T_f \), regarding the detection percentages and the average simulated throughput is given by:

\[
T_f = T_r \times P_d.
\]

(6)
where:
- $T$: average simulated throughput;
- $P_d$: detection percentage, defined as:
  \[ P_d = \frac{N_{ds}}{N_{ts}}, \]  
  (7)

where:
- $N_{ds}$: number of detected signals;
- $N_{ts}$: number of total signals.

Though, one must bear in mind that this analysis is a best case approach to reality, since it is assumed that the data that was not transmitted at first attempt will be certainly transmitted at the second one, which might not happen in reality. In other words, it is assumed that one retransmission is enough to transmit the data.

### III. RESULTS ANALYSIS

#### A. Scenarios

As the main objective of this work is to assess the MIMO impact on the UMTS/HSPA+ capacity, a set of simulation scenarios was conceived in order to measure and compare this impact, regarding several MIMO parameters variation, as well as the type of system. Bearing this in mind, a default scenario was chosen, over which one performs the parameters variation and comparisons. The system and MIMO parameters considered for the default scenario are presented in Table I, whereas, the parameters used to calculate the link budget are the ones set by default in the simulator, and are presented in Table II.

#### TABLE I. DEFAULT SCENARIO SYSTEM AND MIMO PARAMETERS.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIMO configuration (Tx-Rx)</td>
<td>4x4</td>
</tr>
<tr>
<td>Antenna spacing (BS-MT)</td>
<td>$\lambda - \lambda$</td>
</tr>
<tr>
<td>Antenna feeding power</td>
<td>Dedicated</td>
</tr>
<tr>
<td>Detector</td>
<td>ML</td>
</tr>
<tr>
<td>System</td>
<td>HSPA+ with 16QAM (DL/UL)</td>
</tr>
<tr>
<td>BER target [%]</td>
<td>10</td>
</tr>
<tr>
<td>SNR target [dB]</td>
<td>15</td>
</tr>
<tr>
<td>Power control</td>
<td>Perfect</td>
</tr>
</tbody>
</table>

HSPA+ was considered as the default system, with the use of 16QAM for DL and UL, since it is the modulation for which one has more available information, thus, resulting in a more viable analysis. Despite the fact that only the MIMO 2x2 has been standardized in Release 7, for the default scenario the considered configuration is the 4x4 one, since SNR and antenna spacing variation effects are only considered for this configuration, as described in Subsections A.1 and A.2, respectively, and due to the fact that ZF and MMSE detectors are only defined for this configuration when considering 16QAM, thus allowing proper comparisons. Note that the SNR target used for these simulations is 15 dB, guaranteeing that a considerable percentage of the signals for all MIMO configurations are detected. Underlying the values and options of the remaining default parameters, is the idea of a best case scenario, i.e., a system operating with uncorrelated signals, making use of the best available detector, with a perfect channel knowledge, and with the same power dedicated to each antenna as for a SISO system.

### TABLE II. DEFAULT VALUES IN THE LINK BUDGET CALCULATION.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Default value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Default value</td>
</tr>
<tr>
<td>TX power [dBm]</td>
<td>44.7</td>
</tr>
<tr>
<td>Antenna gain [dB]</td>
<td>17</td>
</tr>
<tr>
<td>User losses [dB]</td>
<td>1</td>
</tr>
<tr>
<td>Cable losses [dB]</td>
<td>3</td>
</tr>
<tr>
<td>Standard deviation [dB]</td>
<td>Rayleigh</td>
</tr>
<tr>
<td>R99</td>
<td>10</td>
</tr>
<tr>
<td>HSDPA/HSPA+</td>
<td>25</td>
</tr>
<tr>
<td>R99</td>
<td>6</td>
</tr>
<tr>
<td>HSUPA/HSPA+</td>
<td>0</td>
</tr>
<tr>
<td>Frequency [MHz]</td>
<td>1927.8</td>
</tr>
<tr>
<td>Noise figure [dB]</td>
<td>8</td>
</tr>
<tr>
<td>DL</td>
<td>6</td>
</tr>
<tr>
<td>UL</td>
<td>6</td>
</tr>
<tr>
<td>Simulation interval [m]</td>
<td>Pico-cell</td>
</tr>
<tr>
<td>R99</td>
<td>10 - 60</td>
</tr>
<tr>
<td>HSUPA/HSPA+</td>
<td>Micro-cell</td>
</tr>
<tr>
<td>R99</td>
<td>60 - 600</td>
</tr>
</tbody>
</table>

#### B. Results

In this section, the main results are presented, with additional results being found in [10].

The throughput variation with distance in a pico-cell scenario for HSPA+ DL using 16QAM modulation is presented in Figure 1, regarding all the available MIMO configurations. For a matter of comparison, it seemed appropriate to perform simulations for HSPA+ with 64QAM, however, with the objective of avoiding more errors, due to the lack of results, the simulations were only performed for the 2x2 configuration, since it is the one for which one has a proper detector.

![Figure 1. DL Throughput vs. distance for different MIMO configurations applied to the default system in a pico-cell scenario.](image-url)
Within the pico-cell scenario, the throughput accomplished for HSPA+ 16QAM by the 2x2, 2x4 and 4x2 MIMO is about 13, 14.5 and 13.8 Mbps, presenting an approximately constant behavior, due to the value for the SISO system being also constant, Figure 1. However, for the 4x4 MIMO configuration, the situation is different, with the throughput increasing from about 20.5 to 29.5 Mbps in the 10 to 40 m region. This increment in throughput is coherent with the RMG model and can be explained by the increase in the number of MPCs and by the decorrelation among them, since the distance traveled by the signals is higher, as well as the probability of having more scatterers within this range, thus, resulting in higher RMG values. It should be pointed out that the reason why the throughput for the 4x2 configuration is slightly below the one for the 2x4 configuration is that, for the former, the detector presents higher BER for the same SNR, therefore, resulting in lower throughputs, or even in undetected signals, since the BER demands are more difficult to accomplish. As a consequence, and despite the throughputs being approximately of the same order, the 2x2 and 2x4 configurations are more reliable than the 4x2 one; however the 2x4 requires 4 antennas at the MT, which is quite a challenge for a small device. In what regards HSPA+ 64QAM, the throughput within the pico-cell scenario for the 2x2 configuration present an approximately constant value of 19.4 Mbps, due to the fact of the SISO throughput being also constant (about 12.7 Mbps). Although, if 4x4 is used on top of HSPA+ with 64QAM, the accomplished throughput is of about 43.8 Mbps [10].

One should notice that associated to each antenna configuration is a different detector performance, and as a consequence of this fact, there are also different detection percentages that will have some influence in the final throughput. Moreover, in this analysis, not only the antenna configuration is varied, but also the 64QAM modulation is analyzed for HSPA+ 2x2 MIMO system. With the objective of stressing out the throughput associated to each antenna configuration accounting for the dropped connections, one presents in Figure 2, the detection percentages that were used to calculate the final throughput by using (6).

![Figure 2. Average MIMO detection percentage for different antenna configurations.](image)

From Figure 2, it can be noticed that within the pico-cell, there are no connection flaws, hence, the final throughput for this cell type is the same as presented in Figure 1. For the micro-cell scenario, the final throughput is presented in Figure 3.

In Figure 3 one can observe that the throughput for the 4x4 configuration within the micro-cell scenario decreases from about 29.5 to about 17.5 Mbps. This decrease is explained by the decrease of the MPC signal strength (power), since each time a signal is reflected it loses part of his power, hence decreasing the RMG value due to less number of MPCs that reach the receiving antennas with sufficient SNR to provide high bit rates or even to be detected. However, within the micro-cell scenario, all the antenna configurations present throughput decreases. As expected, due to the observation of Figure 2, the highest decrease if for the 2x2 HSPA+ 64QAM system, presenting at the end of the cell less 1.7 Mbps. On the contrary, the lower decrease is for the 2x4 HSPA+ 16QAM system, which at the end of the cell has about less 0.4 Mbps. Regarding the 2x2 and 4x2 configurations, the throughput variation with distance presents a decrease within the whole cell, from 13 to 12.2 Mbps and from 13.8 to 12.5 Mbps, respectively.

![Figure 3. Final DL throughput in a micro-cell scenario for different antenna configurations.](image)

For a better understanding of the detection impact on the throughput of each MIMO configuration, the same analysis that has been performed for the DL was performed for the UL, i.e., (6) was used to calculate the final throughput, accounting for the detection percentages and the average simulated throughputs, with the results being depicted in Figure 4 and Figure 5 for the pico- and micro-cell scenarios, respectively.

![Figure 4. Final UL throughput in a pico-cell scenario for different antenna configurations.](image)

From Figure 4, it can be noticed that the throughput for the 4x4 configuration within the pico-cell scenario present a significant increase from 18 to 23 Mbps in the 10 to 30 m region of the cell, after which it decreases until the end of the cell to about 22 Mbps. For the 2x4 configuration there is a
slight throughput decrease from around 12.9 to 12.1 Mbps. Furthermore, it can be observed that the final throughputs for the 4x2 and 2x2 configurations, in a pico-cell scenario, decrease from 11.9 to 9.3 Mbps and from 11.1 to 9.4 Mbps, respectively, thus at the edge of the pico-cell the 2x2 configuration presents slight better performance than the 4x2 one. As one can observe from Figure 5, this better performance maintains within the micro-cell, due to the higher detection percentages that are associated to the 2x2 configuration.

Within the micro-cell scenario, the detection percentages are even more notable, since the higher the distance, the lower the average detection percentage, hence the lower the final throughput. From Figure 5 it is possible to observe that both SISO and MIMO throughputs present significant decreases and that after about 270 m the throughput for the 4x4 configuration start presenting an irregular behavior. The SISO throughput decreases from 7.6 to about 0.45 Mbps, and the 4x4 MIMO one decreases from 21.8 to around 1 Mbps. For the micro-cell scenario, the throughput associated to the 2x4 configuration, decreases from 12.1 to 3.8 Mbps, therefore, presenting better performance at the end of the cell than the default configuration. However, one can notice that this better performance is achieved at the distance of about 250 m. In what relates to the 2x2 configuration, the throughput decreases from 9.4 to about 1 Mbps, having similar performance related to the default scenario at the edge of the micro-cell. Being the most limitative configuration, the 4x2 configuration, presents a throughput decrease from 9.3 to 0.3 Mbps, therefore, having lower throughput values than SISO. Note that this situation is verified not only at the end of the cell, but also for all distances higher than around 350 m.

Figure 5. Final UL throughput in a micro-cell scenario for different antenna configurations.

The analyze of the effect of using split or dedicated antenna power fed is quite important, since power consumption is a very important issue for both, BS and MT. Regarding the BS, the power amplifier is an expensive feature, thus, the use of dedicated power would bring substantial cost increase to MIMO implementation, not to mention the electricity bill. In the MT side, one must attend for battery limitations, since more power consumption results in less autonomy, which is undesirable. It was expected that the use of split power among the different antennas would result in significantly lower throughputs, especially for the 4x4 situation, as a consequence of the lower achievable SNR. However, the simulation results, show that this decrease in throughput is not that expressive, being on average less than 0.2 Mbps. In what concerns detection percentages, within the pico-cell scenario, simulations show that it is indifferent to use one or the other option, with the fact of the low range of distances justifying the accomplishment of the SNR necessary to allow connectivity without problems, even with half or a quarter of the power used for SISO. A jointly analysis of the average simulated throughput with the detection percentages was performed, applying (6). The result of this analysis for DL is presented in Figure 6. As one can observe, the throughput differences are in fact more expressive if the detection percentages are taken into account, taking values of about 1.5 Mbps at the edge of the micro-cell for the 4x4 configuration. In what concerns the other two systems, these throughput differences are of about 0.3 and 1 Mbps for 2x2 16QAM and 64QAM, respectively.

The use of split antenna power fed in UL when using MIMO represents a capacity increase relative to SISO with no battery consumption increase, which is desirable. However, from the simulation results one can observe that, if split power is used for the 4x4 configuration, there is a significant throughput decrease, especially at the end of the micro-cell. In the [400:600] interval, this throughput decrease if of about 2.7 Mbps, and for the remaining intervals rounding 0.6 Mbps [10]. Concerning the 2x2 configuration, the throughput decrease is less notable, though the trend is similar to the 4x4 configuration, presenting within the [400:600] m interval a throughput decrease of about 0.5 Mbps. In the remaining intervals, for both configurations, the decrease related to the split power use, increases with distance due to the increase of detection percentages differences between the dedicated and split situations, with the use of split power fed in UL having significantly more impact in the detection percentage than in DL.

Moreover, for UL the difference in the average detection percentages can reach values of about 11 % for the 2x2 configuration and 22% for the 4x4 one, with these values being reached within the [60;100] m interval instead of the [400:600] m one, since in the former the MT power allows more often to accomplish the BER demands for higher distances. Similar to the DL a jointly analysis was performed by using (6), where an overall throughput decrease was verified, Figure 7. Despite this throughput decrease due to the detection percentages, regarding the results plotted in Figure 7, it can be noticed that the wider throughput variations are still for the 4x4 configuration, presenting within the [60;100] m interval, less 5.9 Mbps for the split situation than the dedicated
one. In what concerns the 2×2 configuration, the biggest difference is only felt within the [400;600] m interval, being of about 1.3 Mbps.

Figure 7. Final UL throughput for different types of antenna power fed.

Additional results for DL and UL, regarding the default scenario, as well as the results for the other analyzed scenarios, namely for the variation of some parameters (e.g. system, antenna spacing, type of detector, and the use of a Tower Mounted Amplifier (TMA) and/or reception diversity in UL), are presented in [10].

IV. CONCLUSIONS

This paper deals with the implementation of MIMO in UMTS/HSPA+, in terms of gain dependence on scenarios and other parameters (e.g. MIMO configurations and type of antenna power fed).

The study of different antenna configurations, namely 2×2, 2×4, 4×2 and 4×4, reveals that for the DL within the pico-cell scenario the 4×4 configuration, applied to HSPA+ with 16QAM, is the one capable of accomplishing higher throughputs, being the 2×2 the one that accomplishes the lower ones. For the 4×4 configuration, in DL, the throughput increase from 20.5 to 29.5 Mbps while in UL this increase is from 18 to 23 Mbps. Concerning the micro-cell scenario, the throughput decreases for both links, within the whole cell range. For the DL this decrease is from 29.5 to 17.5 Mbps, which is significantly smoother than the one presented for the UL, being from 21.8 to 1 Mbps. MIMO 2×2 on top of HSPA+ with 64QAM was also studied, leading to an approximately constant bit rate within the pico-cell scenario of about 19.4 Mbps. Contrary to the DL situation in the UL pico-cell scenario the throughputs do not present a constant behavior for the 2×2, 2×4 and 4×2 configurations, hence, a decrease is observed. Moreover, for the DL, within the micro-cell scenario, the detection percentages associated to the different MIMO configurations and to the 2×2 one for HSPA+ with 64QAM, have a major impact on the overall results. The use of 64QAM jointly with 2×2 MIMO is the more affected system, hence the throughput decreases within the whole cell from 19.4 to 17.7 Mbps. Concerning the 2×2 and 4×2 configurations for HSPA+ 16QAM, the throughput also decreases, though with a lower magnitude. The configuration that experiences the lower decrease is the 2×4 one, since it is the one that has the best BER vs. SNR performance. Despite the throughput decrease for 4×4, this is the configuration for which the higher throughputs can be achieved in DL, even higher than the ones achieved for the 2×2 one for HSPA+ with 64QAM. However, in UL the situation is quite different from the DL one, since for this link MT power limitations lead to much lower detection percentages. As a consequence of this fact, the configuration for which the higher throughputs are achieved for most of the micro-cell distances is the 2×4 one, presenting, at the edge of the micro-cell, a 2.8 Mbps throughput increase related to the use of 4×4. Although, this configuration does not have a better performance for all the distances, being the 4×4 configuration, the one that enables higher bit rates for distances up to 250 m.

The power amplifier being an expensive feature of the BS and MT battery autonomy one of the major concerns of the end users, the use of different antenna power fed solutions was also analyzed. The two considered options were the ‘dedicated’ power fed and the ‘split’ one. Regarding DL, the analyses were performed for the 2×2 and 4×4 configurations for HSPA+ with 16QAM and for the 2×2 for HSPA+ with 64QAM, with the use of split power fed, as expected, resulting in lower throughputs, these differences being, on average, of about 0.3, 1.5 and 1 Mbps, respectively, for distances from 400 to 600 m. In UL, the situation is quite different, once again due to MT limitations, which for the 4×4 configuration leads to a maximum throughput difference of 5.9 Mbps within a distance interval of 60 to 100 m. The maximum difference is experienced by 2×2 due to the use of split power fed being of 1.3 Mbps, though this difference is felt at higher distances than for the 4×4 case, since the power is only being divided by two, thus, enabling higher detection percentages up to higher distances. From these results, one can conclude that the use of split power fed in DL does not have a major impact on the accomplished throughput, however, for UL this is not true, the throughput decrease being, related to the use of 4×4 with split power, quite significant, i.e., up to about 22 % lower than the use of dedicated power.

REFERENCES


