

# Adaptive Modulation schemes for MIMO HSDPA

Javier R Fonollosa<sup>1</sup>, Markku Heikkilä<sup>2</sup>, Xavier Mestre<sup>1</sup>, Alba Pagès<sup>1</sup>, Adam Pollard<sup>3</sup>, Laurent Schumacher<sup>4</sup>,  
Lars Torsten Berger<sup>4</sup>, Ami Wiesel<sup>1</sup>, Juha Ylitalo<sup>5</sup>

<sup>1</sup>Universitat Politècnica de Catalunya,

<sup>2</sup>Nokia Mobile Phones

<sup>3</sup>Vodafone Group Research & Development

<sup>4</sup>Aalborg University

<sup>5</sup>Nokia Networks

[www.ist-imetra.org](http://www.ist-imetra.org)

## ABSTRACT

There is a growing interest in the standardisation of Multiple Input Multiple Output (MIMO) schemes for High Speed Downlink Packet Access (HSDPA) for future releases of UMTS. The I-METRA project, building on the legacy of METRA, has set up as one of its priorities to contribute to this standardisation effort by developing and evaluating pertinent transmission and reception schemes for this type of systems.

## I. INTRODUCTION

The concept of HSDPA has been recently standardised in 3GPP for UMTS [1]. It considers enhancements that can be applied to UTRA to provide very high-speed downlink packet access by means of a high-speed downlink shared channel (HS-DSCH). Among these enhancements, the I-METRA project is focused on MIMO antenna processing techniques which are necessarily also related to the evolution of other procedures, such as Adaptive Modulation and Coding (AMC) or Hybrid Automatic Repeat on Request (H-ARQ), in order to include *adaptive* MIMO techniques in the HS-DSCH structure.

Within the HSDPA concept, it is expected that modulation and coding are adapted to channel, traffic and user requirements. In this procedure, the user equipment (UE) should be able to estimate the channel state information and translate it into a metric, which is transmitted to its serving Node B within the DPCCH-HS channel (an uplink Dedicated Physical Control channel associated with HS-DSCH). It is required that this metric value can be mapped to the downlink channel FER. The Node B is continuously selecting the user to be served and its data rate based on a scheduling algorithm and on that feedback information received from all active users. The uplink DPCCH-HS also carries H-ARQ acknowledgements, which are used by the Node B to update the user traffic queues. The use of

AMC and H-ARQ procedures along with Fast Cell Selection and Stand-Alone DSCH [2] will provide up to 10.7Mbps of data rate. It is envisioned that the use of MIMO techniques on top of these other procedures will allow doubling this upper bound [3].

In the first stage of I-METRA<sup>1</sup>, project activities concentrate in two main issues. First of all, the analysis and development of space-time coding and beamforming techniques suitable for MIMO HSDPA and, secondly, the specification of link- and system-level simulations for evaluating these techniques under realistic scenarios.

## II. LINK AND SYSTEM LEVEL SIMULATIONS

According to 3GPP recommendations in [3], link-level simulations alone are not enough to conclude about the performance of a HSDPA system. Moreover it requires the use of system level simulations for algorithm comparison.

Consequently, the MIMO HSDPA simulations in I-METRA will be performed in two stages: link-level simulations and system-level simulations. Several look-up tables obtained in the link-level simulation stage should feed the system-level simulations. Those look-up tables, which mainly relate FER values to a given metric, will be computed for different Modulation and Coding (MC) schemes and different MIMO techniques. As described in this section, the MIMO singularity *on top of* the HSDPA adds some specific requirements to both the link- and system-level simulator.

### A. Link-level Simulator

The main objective of the HSDPA link-level simulations are to compute the FER for several scenarios, several MC schemes and different MIMO

---

<sup>1</sup> I-METRA started on the 1st of November 2001.

techniques. The additional complexity that MIMO link-level simulator demand with respect to the conventional case can be summarised in three aspects: (1) channel modelling, (2) definition of the metric and (3) HS-DSCH structure.

### A.1. Channel modelling

The I-METRA project will proceed with the MIMO channel model already developed in METRA, see [4] for more details. This model was filed in 3GPP in February 2001 [5] and after few months, major companies such as Nokia, Lucent, Siemens and Ericsson [6] endorsed the stochastic philosophy of METRA's MIMO model.

This model has the structure of a tapped delay line and its taps are matrices whose size depends on the number of active elements at the transmitting and receiving ends. As such, this model appears as a natural extension of well-accepted ITU profiles. This model is of stochastic nature. It manages to embed the full correlation information of the channel into two correlation matrices defined independently at both ends. A simple Kronecker product is performed to combine these matrices so as to achieve the full characterisation of the correlation properties of a given MIMO channel. The model in itself is able to address a wide variety of simulation environments. Indeed, the proposed model manages to account for the time dispersion, the fading and the spatial properties of MIMO channels, using a reduced set of parameters, namely the Power Delay Profile (PDP), the Power Angular Spectrum (PAS), including Angle of Arrival (AoA), Angle of Departure (AoD) and Azimuth Spread (AS) and the Power Doppler Spectrum (PDS).

I-METRA workpackage 2 is devoted to the development and maintenance of a platform suited for link-level simulations. Up to now, a package enabling to simulate MIMO channels as described by METRA's model has been developed in Matlab. The choice for Matlab has been motivated by the wish to perform link-level simulations relying on the matrix formalism described in [7]. The well-known performance limitations of Matlab when it comes to intensive Monte-Carlo simulations are expected to be addressed in a later optimisation phase.

This Matlab package uses as input a high-level description of the simulation environment, namely PDP, PAS, AoD, AoA, direction of movement, Doppler spectrum, etc. In an initialisation stage, it derives the correlation properties of ULAs placed at the transmitting and receiving ends of the communication links. This description of the correlation properties is then used to spatially correlate  $M \times N \times L$  vectors of fading samples which are later used, during the actual simulations, to populate the  $L$  matrix taps of the MIMO tapped delay line model. Figure 1 to Figure 3 show respectively the PDP, the Doppler spectrum and the

correlation coefficient of a 4x2 MIMO channel simulating 3GPP Case 4 of [8].

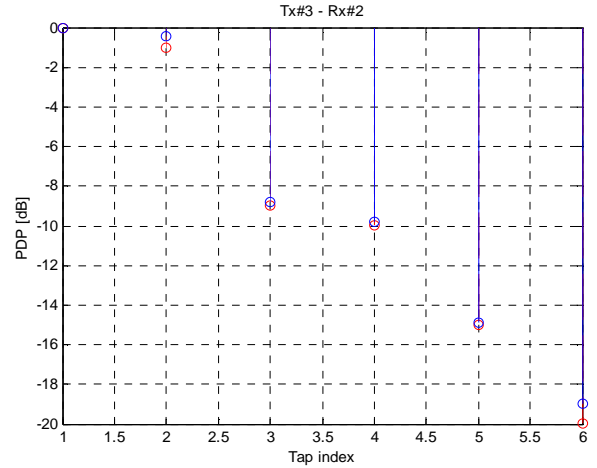


Figure 1. PDP of  $h_{32}$ , 3GPP Case 4 (ITU Pedestrian B, 6 paths).

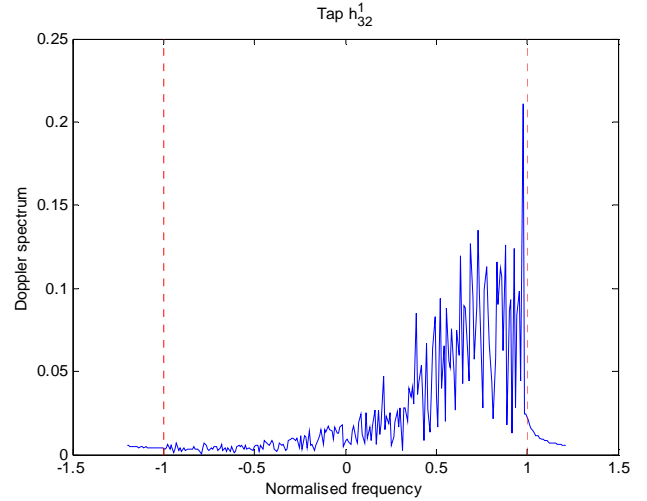


Figure 2. Doppler spectrum of  $h_{32}^1$ , 3GPP Case 4

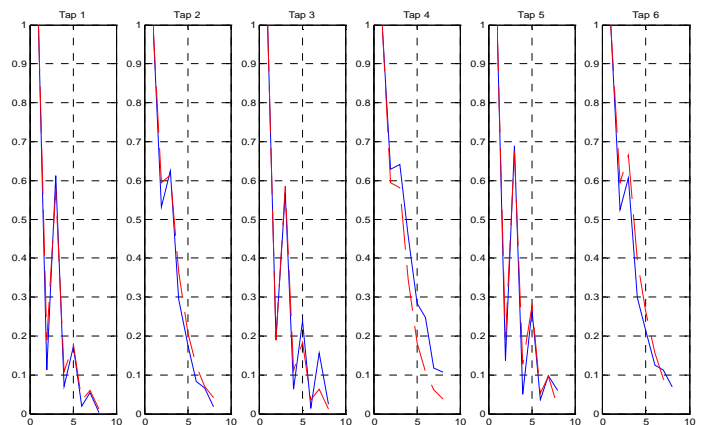


Figure 3. 1<sup>st</sup> row of the full 8x8 correlation matrix of a 4x2 MIMO model simulated according to 3GPP Case 4.

In Figure 1 and Figure 3, the red curve is the target definition, and the blue one is the achieved characteristic. One can see on Figure 3 the incidence of alternating AoA at the UE. In addition, the different

AoD at Node B for each tap generate slightly different correlation patterns between even taps on the one hand, odd taps on the other.

Thanks to the flexibility of the proposed stochastic model, its update with respect to the progress of 3GPP discussions is usually quite easy, as it is just a matter of some high-level parameter changes, like the AS or the AoA. However, the applicability of this model is not restricted to the 3GPP test cases. Whatever environment of interest might be simulated provided the corresponding description is fed to the package.

#### A.2. Channel metric and HS-DSCH structure

For a given data rate, the user performance in a Single Input Single Output (SISO) HSDPA channel, usually stated in terms of FER, is reliably predicted using an estimate of the C/I. Conversely, it is not clear which parameter is the C/I counterpart in a MIMO HSDPA channel. In order to deal with an HSDPA system able to adapt to channel propagation conditions, it is mandatory to define a metric function that maps the channel estimation to the FER on that channel. It is expected that this metric will be different for different MIMO techniques. Additionally, this metric should be simple enough to be transmitted to Node B within the uplink DPCCH-HS using up to 6 bits.

Another important aspect to take into account in the MIMO HSDPA simulator is the HS-DSCH channel structure defined in [1]. Concerning the complexity of the system, the study of MIMO techniques for HSDPA should evaluate up to what degree the HS-DSCH structure, which includes CRC, H-ARQ, interleaving and channel coding procedures, is affected.

#### B. System-level Simulations

System-level simulations are mandatory in order to include system attributes such as Fast Cell Selection, H-ARQ or Node B scheduling. System level simulations will take a similar format to that proposed in 3GPP for the evaluation of MIMO techniques for HSDPA [3]. These will take as input a range of link-level results that will be used in a look-up table – relevant factors may include modulation scheme, coding, redundancy, ratio of in-cell/out-of-cell interference (G-parameter). The referencing into the look-up table will depend on the chosen MIMO technique and the associated metric. The G-parameter is important as the interference situation will determine the modulation and coding (for example) chosen by the Node B and the distribution of this parameter will determine the availability of the higher data rates.

Figure 4 shows the distribution of the G-parameter and how it varies between macro-cell and micro-cell scenarios. These results have been obtained from simulations of realistic site deployments in a major city with traffic distributions derived from actual traffic

statistics. Full details of the simulation model used can be found in [9].

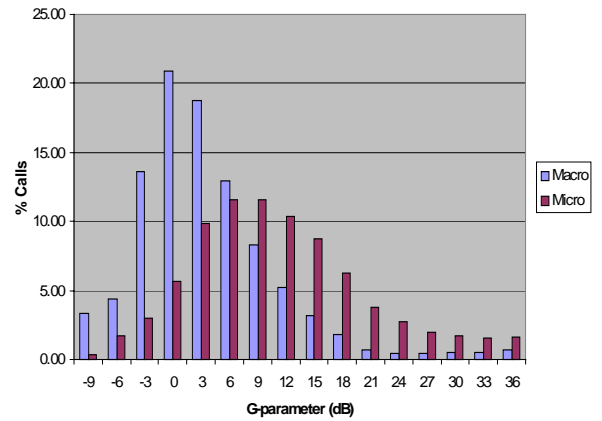


Figure 4. Distribution of G-parameter for realistic site deployment for macro- and micro-cells.

It can clearly be seen that higher G-parameters are achieved in micro-cells, which is due to the greater isolation of the coverage areas of the cells. These results can be used as a guide for the range of G-parameters that should be simulated at link-level to enable good interpolation when doing the mapping of link-level results in the system-level simulations.

### III. SPACE-TIME BLOCK CODING AND BEAMFORMING

The design of space-time transmit architectures has lately received much attention and a Space-Time block coding Transmit Diversity scheme (STTD) was included into the 3GPP UMTS FDD downlink specifications [13].

Using the I-METRA MIMO channel model, initial simulation results show that STTD is able to achieve the promised diversity order of 2 for uncorrelated frequency flat fading radio links (Figure 5, graph 1).

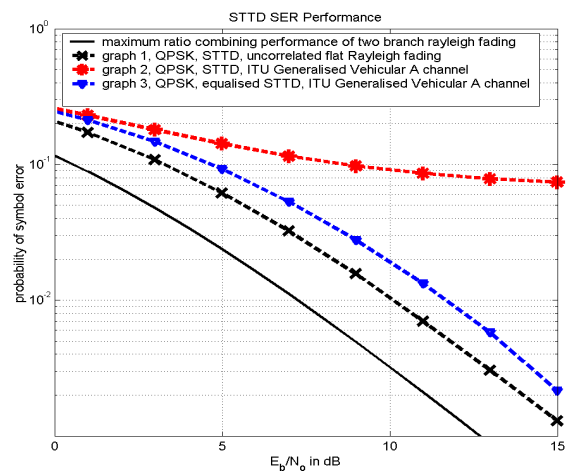


Figure 5: STTD Symbol Error Performance

The performance of STTD degrades significantly however in frequency selective environments (Figure 5, graph 2). This is due to the fact that the orthogonality between users, which in UMTS are served simultaneously on the same frequency but separated in the code domain, and the orthogonality between the employed space-time block codes is lost if the receiver uses standard RAKE reception.

Equalisation might be used to restore orthogonality. Under realistic channel conditions this will significantly enhance the performance of STTD. Nevertheless, equalisation is not straightforward when only a single receive antenna is employed [14] and a modification of the transmission scheme [15] was used to achieve the symbol error rate performance as shown in Figure 5, graph 3. Simulation parameters are given in Table 1:

	graph 1	graph 2	graph 3
tx scheme	STTD	STTD	modified STTD
rx scheme	RAKE	RAKE	minimum mean square error equaliser
channel	flat Rayleigh fading (case 1 in [8])	ITU Generalised Vehicular A, azimuth spread: 10 degree, angle of departure: 20 degree, antenna element spacing: 4 wavelength (case 3 in [8])	
number of transmit antennas	2		
number of receive antennas	1		
modulation scheme	QPSK		
spreading factor	16		
number of users	10		
channel estimation	ideal		

Table 1: Simulation Parameters.

Besides a combination of space-time block coding with equalisation, recent publications also proposed to combine space-time block coding with spatial filtering methodologies.

The so-called *linear dispersion codes* (LD), see [10], provide a new unifying framework to the actual space-time transmission process. They are defined as linear space-time codes that transmit  $Q$  complex symbols  $s_i = \alpha_i + j\beta_i$  using  $M$  antennas during  $T$  time instants according to a code matrix  $S$

$$S = \sum_{q=1}^Q (\alpha_q A_q + j\beta_q B_q)$$

completely determined by the pairs of complex matrices  $(A_q, B_q)$ . Orthogonal space-time codes are particular cases of LD codes. For example, the Alamouti code can be described using LD as:

$$A_1 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} B_1 = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} B_2 = \begin{bmatrix} 0 & 1 \\ 1 & 0 \end{bmatrix}$$

Additionally, LD codes can also represent BLAST architectures that do not include channel coding at each transmit branch. In this case  $Q=TM$  symbols using  $T$  time instants and  $M$  antennas are transmitted where:

$$A_{M(\tau-1)+m} = B_{M(\tau-1)+m} = \varphi_\tau \gamma_m^T$$

for  $m=1..M$  and  $\tau=1..T$  and  $\varphi_\tau, \gamma_m$  are  $T$ -dimensional and  $M$ -dimensional column vectors with ones in the  $\tau$  and  $m$  positions, respectively, and zeros elsewhere.

Assuming that channel state information is available at the receiver only, the code matrices are designed to maximise the MIMO capacity averaged over all the possible channel realisations. The overall transmit rate will depend on the number of symbols sent in parallel, the block length and the size of the symbols constellation, and the receiver can be implemented very effectively (linear receivers are viable). Therefore, the architecture allows for easy rate re-configurability in a MIMO architecture and, given the possibility of linear receivers, the channel performance metric seems easily computable. On the other hand, the approach is not optimal in the sense that no channel state information is used at the transmit side and furthermore the codes are optimised only for a particular channel statistics.

If the available channel state information is to be used at the transmit side, strategies combining space-time coding with spatial filtering have to be considered. An interesting example of this type of approach is the one presented in [11]. Assuming that  $S_k$  is a generic word of an orthogonal space-time block code (OSTBC), the authors propose to transmit  $\underline{S}_k = WS_k$ , where  $W$  is a space-time filter matrix. Figure 6 illustrates the combination of OSTBC and Beamforming. The filter is designed to minimise an upper bound to the pairwise codeword error probability at the receiver side. In order to consider the most general scenario, it is assumed that the transmitter has some information about the reliability of the channel estimation. Thus, the transmitter uses two different sources of information: the channel estimation itself, denoted by  $h'$ , and a measure of goodness of the estimation, given by the mean and correlation of the true channel  $h$  conditioned on the estimation  $h'$ :  $m_{h/h'}, R_{hh/h'}$ .

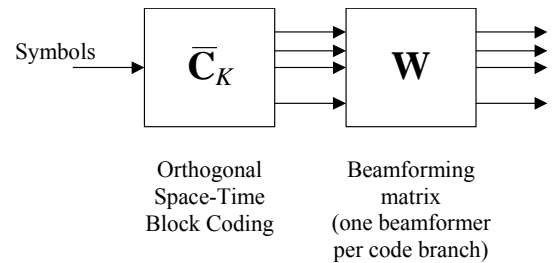


Figure 6. Combination of OSTBC and Beamforming proposed in [11]

The spatio-temporal filter is obtained solving a convex optimisation problem with a unique solution. It is shown in [11] that the architecture includes space-time block coding and beamforming as special cases. Classical beamforming is obtained when the transmitter has

perfect channel state information ( $\|R_{hh}/h\| \rightarrow 0$ ), whereas a pure OSTBC scheme is obtained when assuming that no channel state information is available at the transmitter. Thus, the main advantage of this approach is that it always outperforms both conventional spatial filter and OSTBC as standalone techniques. Furthermore, it allows for very simple architectures at the receiver side, because decoding can be performed with simple linear receivers followed by hard decisions. The main drawbacks of the technique are the need for feedback information and the relatively high computational demands at Node B. Note that a new beamformer must be calculated at each channel update, and a relatively complex optimisation procedure must be carried out every time. Moreover, the architecture is not very suitable from the rate re-configurability point of view, because a new beamformer matrix must be calculated every time the transmission rate is changed.

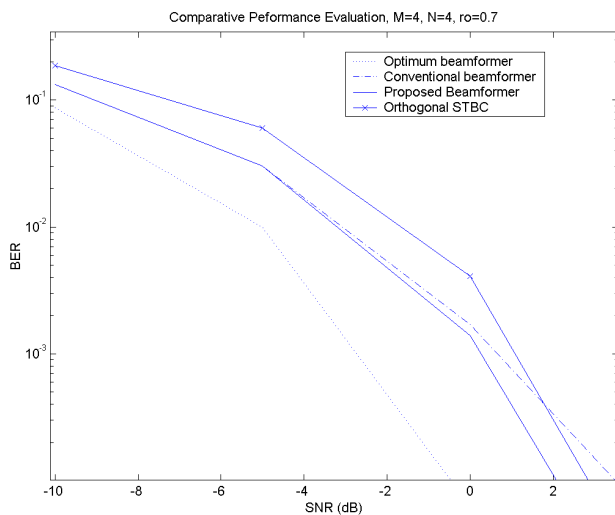


Figure 7. Performance of OSTBC combined with beamforming for a 4x4 case with  $\rho=0.7$

Figure 7 compares the performance in terms of BER of the conventional space time block coding and beamforming approaches versus the technique proposed in [11] for a 4x4 antenna configuration. The ideal beamformer is also plotted as a benchmark. Channel estimates at the receive side are assumed unbiased and characterised by correlation coefficient  $\rho$  of value 0.7 with the actual channel.

#### IV. CONCLUSIONS

This paper has outlined one of the main activities started within the I-METRA project related to the development and performance evaluation of MIMO techniques for HSDPA in future releases of UMTS. The MIMO

channel model inherited from METRA has been updated and is now fully compliant with the latest 3GPP specifications. In addition the evaluation methodology for link and system level simulations has been defined and several MIMO schemes introduced.

#### REFERENCES

- [1] 3GPP TR 25.858 V1.0.4, January 2002.
- [2] 3GPP TR 25.848 V4.0.0 (2001-03).
- [3] RAN WG1 #23, R1-02-0142. Lucent. MIMO system simulation methodology.
- [4] Schumacher, L., Pedersen K.I., Kermaol J.P. and Mogensen P.E., "A Link-Level MIMO Radio Channel Simulator for Evaluation of Combined Transmit/Receive Diversity Concepts within the METRA Project", IST Mobile Summit, Galway, Ireland, October 2000.
- [5] Nokia: 3GPP TSG R1-01-0260, "MIMO channel model for link-level simulations using correlated antennas".
- [6] Lucent, Nokia, Siemens, Ericsson: 3GPP TSG R1-01-1179, "A standardized set of MIMO radio propagation channels".
- [7] Heikkilä, M.J. et al., METRA Deliverable D3.2, "Review and Selection of Relevant Algorithms". Available at [www.ist-metra.org](http://www.ist-metra.org)
- [8] MIMO Rapporteur: 3GPP TSG R1-02-0141, "MIMO Conference Call Summary".
- [9] Tiirola E., et al., METRA Deliverable D4, "Performance Evaluation". Available at [www.ist-metra.org](http://www.ist-metra.org)
- [10] B. Hassibi and B.M. Hochwald, "High-rate codes that are linear in space and time", Submitted to IEEE Trans. Info. Theory, August 2000.
- [11] G. Jöngren, M. Skoglund and B. Ottersten, "Combining beamforming and orthogonal space-time block coding", to appear in IEEE Transactions on Information Theory.
- [12] Lucent: 3GPP TSG R1-01-0879, "Increasing MIMO throughput with per-antenna rate control".
- [13] 3GPP TS 25.211 V 3.3.0, "Physical channels and mapping of transport channels onto physical channels (FDD)", June 2000
- [14] Ling Li; Yu-Dong Yao; Hongbin Li, "Intersymbol/cochannel interference cancellation for transmit diversity systems in frequency selective fading channels", Vehicular Technology Conference, VTC 2001 Fall, IEEE VTS 54th, Volume: 2, Page(s): 678-682
- [15] L. T. Berger, L. Schumacher, "Modified Space-Time Transmission in DS-CDMA Downlink facilitating MISO Channel Equalisation", to appear in VTC 2002 Fall.