Evaluation of MIMO Transmission for HSUPA

Roman Maslennikov[1], Przemysław Czerepiński[2], Mikhail Shkerin[1],
Alexey Trushanin[1], Mikhail Shashanov[1], Vyacheslav Shumilov[1]
[1]Sitronics Labs, Nizhny Novgorod, Russia, maslennikov@sitronics-labs.com
[2]Nokia Siemens Networks, Research, Radio Systems, Wroclaw, Poland, przemyslaw.czerepinski@nsn.com

Abstract— **In this work, MIMO extensions to the existing HSUPA system are presented and evaluated. Three candidate MIMO enhancement architectures are proposed that differ with respect to the principles of code word mapping onto the two spatial streams for rank-2 transmission. The evaluation demonstrates MIMO throughput gains relative to SIMO ranging between 30% and 40%. The MIMO architecture with independent transmission of two code words over the two spatial channels is demonstrated to be the most effective because of its ability independently to adapt the data rate on each spatial channel to the instantaneous channel conditions. The gains are realized at high RoT values, indicating isolated small cells with low UE densities as the likely deployment scenario for HSUPA MIMO.**

Index Terms — WCDMA, HSUPA, MIMO

I. INTRODUCTION

The increasing demand for wireless broadband access motivates the continual enhancement of commercial radio network standards, such as the WCDMA-based UTRA (wideband code division multiple access, universal terrestrial radio access) developed by the 3GPP (3rd generation partnership project). The multiple input, multiple output (MIMO) antenna techniques play an important role in the enhancement process: the introduction of HSDPA (high speed downlink packet access) into the 5th release of UTRA [1] was followed by the addition of the MIMO capability in the downlink at release 7 [2]. Currently, MIMO enhancements for HSUPA (high speed uplink packet access) are researched by the 3GPP [3].

The goal of this paper is to describe and analyse the candidate HSUPA MIMO design choices, as well as describe the challenges posed by introducing MIMO solutions into an existing system. Our analysis indicates that MIMO link throughput gains of up to 40% are achievable under high RoT (rise over thermal) conditions, making UL MIMO applicable to scenarios of strong cell isolation. Among the challenges, we mention the difficulty of reconciling power based link adaptation with adaptive modulation and coding.

3GPP terminology is assumed in this paper. The mobile station is referred to as the UE (user equipment) and the base station as the Node B. The term MIMO refers to the spatial multiplexing transmission capability, rather than merely TX or RX diversity techniques.

The rest of the paper is organized as follows: section II describes HSUPA principles. Candidate MIMO enhancement options are provided in section III and evaluated in section IV. Conclusions are drawn in section V.

II. HSUPA PRINCIPLES

A. *Single TX Antenna HSUPA*

HSUPA was introduced into 3GPP UTRA at Release-6, around 2004 [4]. It is an extension of the 3GPP WCDMA system aimed at efficiently supporting packet traffic in the uplink. In line with the baseline WCDMA UL, single antenna transmission is assumed, with direct sequence CDMA at the chipping rate of 3.84 MHz. Turbo coding and Hybrid-Automatic Repeat reQuest (H-ARQ) is applied for error correction, together with the rate matching unit that allows varying the effective code rate for data transmission. QPSK and 16QAM are used for signal modulation.

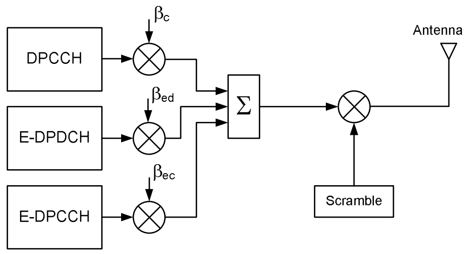

Figure 1. HSUPA physical channel structure for a single transmit antenna.

The physical channel structure of HSUPA is shown in Fig. 1. The DPCCH (dedicated physical control channel) pilot channel is used as a reference for channel estimation and transmit power control (TPC). The E-DPCCH (enhanced DPCCH) carries the HSUPA-related control information and can also be used as an additional reference for improved channel estimation. The E-DPDCH (enhanced dedicated physical data channel) is used for data transmission. All the channels are spread by orthogonal spreading codes. The relative physical channel powers are set by the β-coefficients and the total power level is controlled by the TPC loop. The signals from different UEs are non-orthogonal and non-correlated, due to the application of UE-specific long scrambling codes.

Two power control loops are used to control the block error rate (BLER) experienced by the transport blocks (TBs) originating from the UE. The outer loop power control (OLPC) adjusts the target signal-to-interference ratio (SIR) of the pilot channel, DPCCH. The E-DPDCH transmit power is set relative to the DPCCH level and the SIR changes of the DPCCH translate into changes of the E-DPDCH SIR. The inner loop power control (ILPC) adjusts the radiated power in the UE, so that the target SIR is met. This is achieved by estimating the SIR in the Node B receiver and issuing periodic ‘power up’ or ‘power down’ commands to the UE.

978-1-4673-0990-5/12/$31.00 ©2012 IEEE

With multiple UEs sharing the same carrier frequency, the system resource to be distributed by the Node B scheduler is the relative total received power level, measured at the Node B antenna (also known as the 'rise over thermal' or RoT budget). The role of the scheduler is to apportion the RoT to the associated UEs, in the form of transmission grants. A higher grant enables a higher data rate while consuming a larger proportion of the RoT.

Multiple receive antennas may be used at the NodeB, thus realizing a Single-Input-Multiple-Output (SIMO) antenna configuration. The conventional HSUPA system without multiple transmit antenna support will be referred to as a SIMO system throughout the remainder of the paper.

B. Closed Loop TX Diversity for HSUPA

HSUPA has been extended with the dual antenna transmission capability in the form of closed loop beamforming TX diversity (CL-BFTD) for 3GPP UTRA Release-11 [5]. The structure of the UL physical channels for the CL-BFTD is shown in Fig. 2.

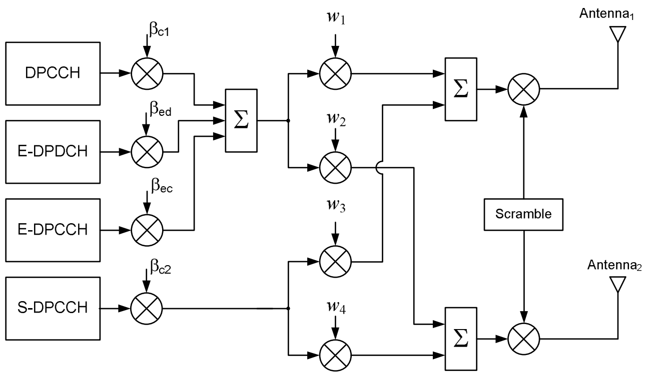

Figure 2. HSUPA physical channel structure for dual antenna CL-BFTD.

The DPCCH, E-DPCCH, and E-DPDCH are transmitted through the primary spatial channel formed by the weight vector $\mathbf{w_p} = [w_1; w_2]$ as shown in Fig. 2. The preferred weight vector $\mathbf{w_p}$ is recommended by the Node B to the UE at 2 ms intervals based on the DPCCH and the secondary pilot channel, S-DPCCH (precoded with the weight vector $\mathbf{w_s} = [w_3; w_4]$, orthogonal to $\mathbf{w_p}$). $\mathbf{w_p}$ is selected from a four-entry codebook such that the beamforming angle $\arg(w_1)$-$\arg(w_{2,k})$ is equal to $\pi jk/2+\pi j/4$, k=0,1,2,3. The vector $\mathbf{w_s}$ is implied by the orthogonality condition and does not need to be signalled [6].

CL-BFTD benefits from the array and diversity gains; a description of the gain mechanisms associated with CL-BFTD as well as the factors limiting the gains can be found in [7].

III. HSUPA MIMO ENHANCEMENTS

A. Design Objectives

The increasing need for mobile wireless data access has motivated the UL spatial multiplexing modes in LTE, and now also motivates the introduction of such schemes into HSPA. As in any existing system, backwards compatibility is an essential design goal for HSPA updates, in addition to the performance and complexity criteria.

While the details of the HSUPA MIMO design have not as yet been finalized in 3GPP, the extension of the CL-BFTD principles, described in the following, is a strong candidate that has been captured in the relevant technical report [3].

B. Physical Channel Structure

The MIMO mode extends the HSUPA signal structure by adding the secondary E-DPDCH (S-E-DPDCH) data and, potentially, the secondary E-DPCCH (S-E-DPCCH) control channels for data transmission over the secondary spatial stream. The physical channel structure for HSUPA MIMO is shown in Fig. 3. The transmit power levels are assumed equal between the primary and secondary physical channels (e.g., E-DPDCH and S-E-DPDCH).

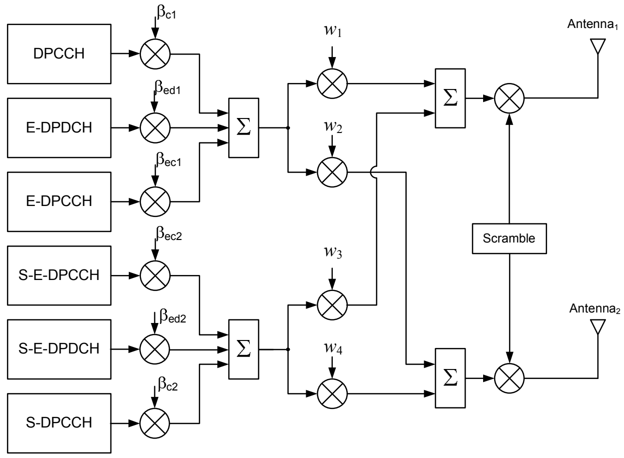

Figure 3. HSUPA physical channel structure for dual antenna MIMO.

The transmit antenna weight vector selection is done as for the CL-BFTD to maximize the DPCCH power received over the primary spatial stream. A single inner power control loop is used to keep the SIR of the primary DPCCH at the required level set by the OLPC.

C. MIMO Architecture Options

The MIMO system must include both the single- and dual stream modes and switch between them on a fast basis depending on the channel conditions. The single stream (rank-1) transmission can be realized by falling back to the CL-BFTD mode. In the case of the spatially multiplexed (rank-2) transmission, a number of design choices exist for transport channel processing, namely:

- *Option I – single TB rank-2 transmission*. A single, 'large' transport block (TB) undergoes transport processing and the result is mapped onto the E-DPDCH and S-E-DPDCH. The advantages of this architecture are simplicity and low control signalling overhead as long as the modulation, OVSF code allocation, systematic and parity bit mapping, and allocation are the same for both spatial channels.
- *Option II – dual TB rank-2 transmission*, independently over the spatial streams. Two TBs undergo transport processing independently. The primary TB is mapped onto the E-DPDCH while the secondary TB onto the S-E-DPDCH. The advantage

of this architecture is the flexibility to independently assign a different E-TFC (enhanced-transport format combination) to each spatial stream, i.e. to adapt the data rate of each stream to maximize the throughput, at the cost of a higher signalling overhead. Option II is well suited to the SIC (successive interference cancellation) receiver architecture due to the presence of two TBs, whose operating SINR points can be adjusted by the scheduler.

- *Option III – dual TB rank-2 transmission,* TBs interleaved between the two spatial channels. This can be viewed as a hybrid between options I and II above. Two TBs of the same size undergo transport processing independently, but the results are interleaved prior to being mapped onto the E-DPDCH and the S-E-DPDCH. In principle, SIC reception can be applied to Option III due to the presence of two TBs. However, the fact that both TBs share the same channel conditions and SINR operating point limits the achievable gains.

D. HSUPA MIMO Procedures

The gain mechanism of the MIMO transmission mode is its ability to, at maximum, double the network throughput. However, the maximum gain is rarely realized in practice due to the interference between the spatial streams (inter-stream interference).

The rank selection mechanism in the Node B decides whether the UE should make a rank-1 or rank-2 transmission based on a throughput maximization criterion under current or predicted channel conditions. In the case of rank-2 transmission, the transmission grant for both spatial streams is selected to fully utilize the UE RoT budget, in a similar manner as for conventional HSUPA and CL-BFTD. The transmit power is set to the same level for both the primary and secondary channels and, since the primary channel is power controlled, the conventional power-based rate selection mechanism can be used by the UE. For MIMO Option II, power-based rate selection is applied to the primary stream only. For the TB transmitted over the secondary stream, the scheduler selects the E-TFC based on the overall transmit grant level and the difference of the post-receiver SINR between the E-DPDCH and S-E-DPDCH, to guarantee the required BLER for the secondary stream. For MIMO Option II and III, the OLPC is driven only by the CRCs transmitted through the primary spatial stream.

IV. PERFORMANCE EVALUATION

A. Evaluation Assumptions

The traditional approach to link-level evaluation of HSUPA assumes fixing the transmitted data format (E-TFC) and collecting by simulation the transmit and receive power-related metrics (TX power or RX Ec/No). This approach can be used for CL-BFTD vs. SIMO evaluation. However, the traditional approach is not applicable for MIMO Option II, where fixing the E-TFC mapped onto the second spatial channel would counteract the link adaptation principle of the second E-TFC depending on the instantaneous channel conditions. To overcome this limitation and allow for a fair comparison of different transmission modes, an alternative simulation approach was proposed [8] where the RoT (or, equivalently, RX Ec/No) level is fixed by the scheduler and E-TFC(s) are selected adaptively depending on the instantaneous channel characteristics. Then the performance metric for different transmission modes is the link throughput at different RX Ec/No levels.

In order to perform the analysis in line with the above methodology, an E-TFC set with 11 entries and TB sizes ranging from 120 to 22995 bits was considered (corresponding to data rates between 60 and 11497 kbps). This set was applied for SIMO, CL-BFTD, and MIMO Options II and III. For MIMO Option I, the set was extended to include three E-TFCs with higher TB sizes so that the maximum TB size for MIMO Option I is two times larger than in the basic set, matching the doubled physical resource available for a single TB in MIMO Option I. All the E-TFCs were initially simulated in the AWGN channel to find the post-receiver SINR levels needed to operate each E-TFC at the target BLER of 10%. These values are further used for β-factor selection and are also known to the scheduler.

For MIMO Options I and III, the BLER performance depends on the post-receiver SINR levels in both spatial streams. In order to gain insight into the SINR operating point, BLER in the AWGN channel was measured as a function of two SINR values in the first and second spatial streams, respectively. Level lines for the BLER equal to 10% as a function of the two SINR arguments are plotted in Fig. 4 for MIMO Option III.

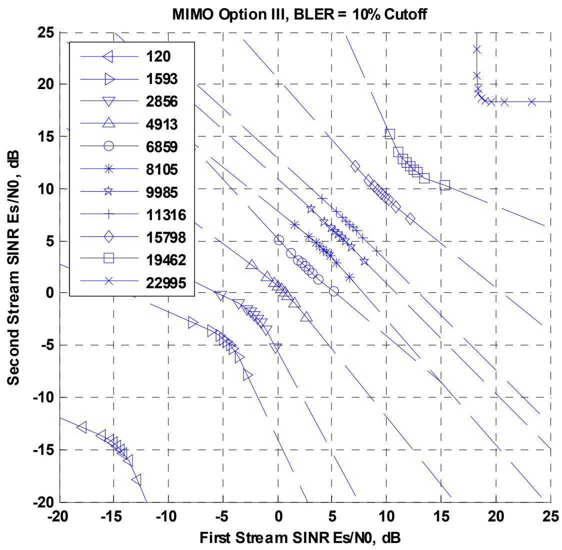

Figure 4. Level lines for BLER equal to 10% as a function of the per symbol SINR in the two spatial streams for MIMO Option III.

It may be seen from Fig. 4 that, for full utilization of the total received power over the two spatial streams, certain combinations of the post-receiver SINR values in the streams (shown by the level lines) are required and depend on the E-TFC. For the highest E-TFCs, which are needed to realize the MIMO gain, a small SINR loss in one stream must be compensated by much higher SINR increase in the other stream. Since the transmission power is the same for the two streams (adaptive power allocation is not considered because of complexity reasons), the received SINRs are a function of the propagation channel. Thus, a significant imbalance between the stream SINRs may lead to power-inefficient rank-2 transmission.

For MIMO Option I, the BLER performance is also a function of the two SINR values in the two spatial streams, however, it is not shown here due to limited space.

The linear equalizer operating at the minimum mean square error (MMSE) criterion and capable of inter-stream and inter-symbol interference suppression was assumed. The Pedestrian A and Vehicular A channel profiles [9] were assumed together with UE speeds of 3 km/h. The 1x2 (SIMO) and 2x2 (CL-BFTD and MIMO) antenna configuration is analyzed. Channel realizations between different transmit and receive antennas were assumed to be uncorrelated. MIMO transmission is always done using two spatial streams (rank-2). The adaptive rank performance can be approximately estimated as the supremum of the CL-BFTD and MIMO results. A detailed description of other simulation assumptions may be found in [10].

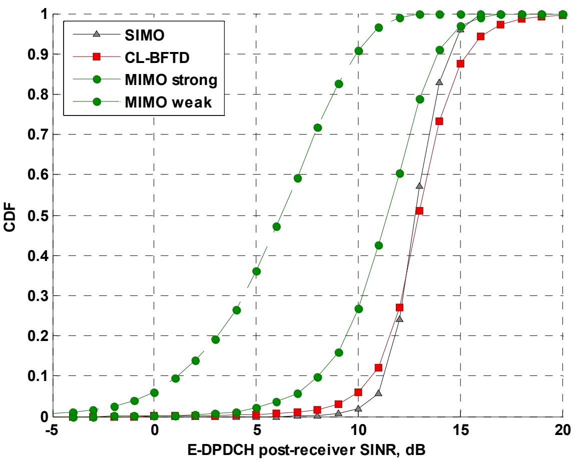

Figure 5. Post-receiver SINR distributions, PA3 channel.

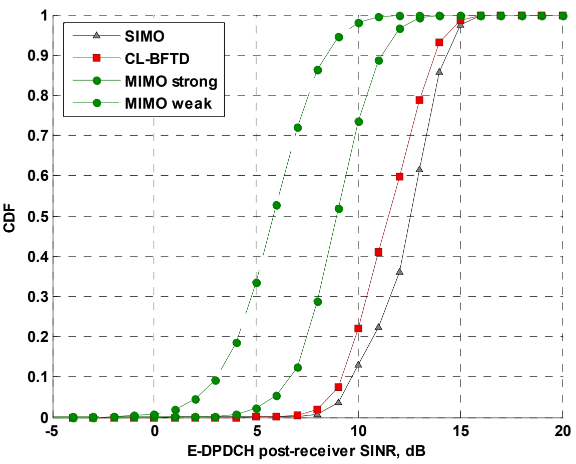

Figure 6. Post-receiver SINR distributions, VA3 channel.

B. Simulation Results

Fig. 5 and Fig. 6 show the post-receiver SINR distributions (at the LMMSE equalizer output) of the E-DPDCH channel for the SIMO, CL-BFTD, and MIMO transmission modes in the Pedestrian A 3 km/h (PA3) and Vehicular A 3 km/h (VA3) channels. The scheduler target RX Ec/No was equal to 15 dB. For the MIMO mode, post-receiver SINRs corresponding to both the primary (strong, E-DPDCH) and secondary (weak, S-E-DPDCH) spatial channel are shown.

Fig. 5 and Fig. 6 demonstrate that the post-receiver SINR levels for the SIMO and CL-BFTD are close in the PA3 channel and SIMO is up to 1 dB better in the VA3 channel: the CL-BFTD has the advantage of some multipath mitigation using beamforming but a disadvantage of additional interference from the S-DPCCH pilot. The MIMO primary (strong) spatial channel SINR is 1-2 dB below the CL-BFTD level for the PA3 channel and about 2.5 dB below in the VA3 due to higher-inter stream interference of MIMO rank-2 transmission. The secondary (weak) spatial channel of the MIMO mode is characterized by lower SINR, 5 dB (PA3) and 3 dB (VA3) below the primary stream SINR.

The simulated link throughputs for different transmission modes in the PA3 and VA3 channels, as a function of the target RX Ec/No, are plotted in Fig. 7 and Fig. 8, respectively. In the PA3 scenario, the performance of the SIMO, CL-BFTD, and MIMO Option II transmission modes is very close at the low RX Ec/No region of 0-10 dB. The MIMO Option I and III throughput for the same RX Ec/No region is about 1-1.5 Mbps lower. With the increase of RX Ec/No to 15-20 dB, the performance of the single stream SIMO and CL-BFTD modes saturates at the maximum E-TFC with SIMO providing about 5% higher throughput due to the S-DPCCH inter-stream interference degrading the CL-BFTD performance. The throughput of the MIMO modes for the high RX Ec/No region is not subject to the maximum E-TFC saturation constraint and continues to grow with the RX Ec/No increase leading to up to 37% gain of MIMO Option II relative to the SIMO performance for RX Ec/No equal to 20 dB. The gain of MIMO Options I and III is smaller (24-28% relative to SIMO at RX Ec/No of 20 dB) but is still significant.

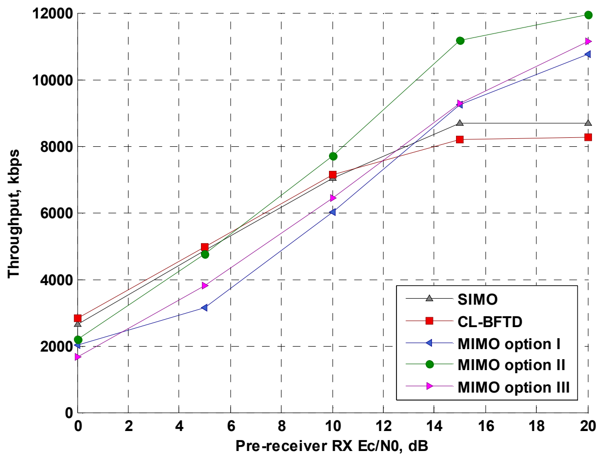

Figure 7. Link throughput vs. target RX Ec/No, PA3 channel.

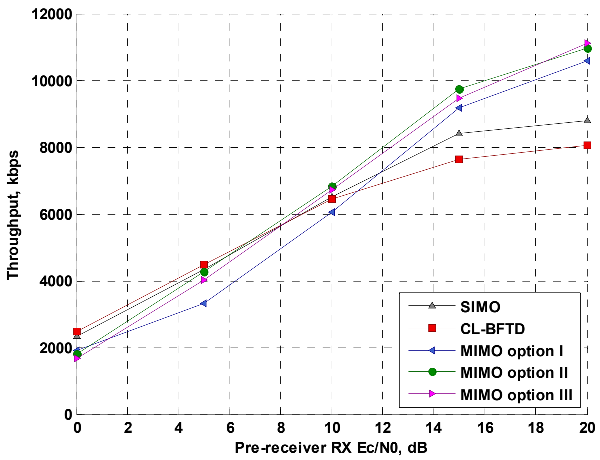

Figure 8. Link throughput vs. target RX Ec/No, VA3 channel.

The VA3 throughput results shown in Fig. 8 are in many aspects similar to the PA3 results provided by Fig. 7. The throughput gain of MIMO relative to SIMO is up to 29% (for MIMO Option II). The VA3 channel model has a richer multipath component than the PA3 model which, in combination with the uncorrelated antenna assumption, leads to a lower spatial channel singularity (i.e. a lower ratio of the signal powers received from the two spatial streams). As a consequence, the key distinction that may be observed from comparison of Fig. 7 and Fig. 8 is a smaller difference between different MIMO options, with almost no throughput gain provided by MIMO Option II over Option III and only 4-5% gain over Option I.

C. Discussion

The simulation results allow drawing some conclusions on HSUPA MIMO performance. Evidently, the throughput gains over SIMO and CL-BFTD are observed for the high RX Ec/No (RoT) region only. This implies that the inter-cell and intra-cell interference levels from other UEs should be very low or even absent. Hence, the high RoT requirement makes MIMO applicable to very low UE density or isolated indoor cell scenarios.

Simulation results reveal that MIMO Option II is able to outperform the other two MIMO architectures in terms of throughput by 10-15% in the channels with high spatial singularity (such as PA3) where the imbalance between the receive SINR on the primary and secondary beamformed channel is high. The reason for the observed gain of MIMO Option II is a more flexible E-TFC selection scheme allowing for better utilization of the transmitted power since, as described in Section IV-A, MIMO Options I and III require certain ratios of the SINR of the two spatial streams for optimal performance. The performance gain of MIMO Option II can justify the recommendation of this MIMO architecture for propagation channels with high spatial singularity.

At the same time, using MIMO transmission in the propagation environments where spatial channel singularity is low (as, for example, in the VA3 channel model) leads to approximately equal performance of all the MIMO options, making the selection of MIMO Option II as the best candidate less evident given the higher signalling requirement in comparison to MIMO Options I and III. However, taking into account the results from the two scenarios, MIMO Option II is recommended for application in practical systems.

V. CONCLUSION

In this work, MIMO extensions to the existing HSUPA system architecture were described and evaluated. The extensions were designed with both efficiency and commonality with CL BFTD in mind. Three candidate MIMO enhancement architectures were proposed with respect to the principles of code word (transport blocks) mapping onto the two spatial streams. MIMO Option I transmits a single TB over two spatial streams, MIMO Option II sends two TBs in parallel independently mapped on the two streams, and two TBs are also transmitted in the case of MIMO Option III but are interleaved between the spatial channels.

The link-level evaluation methodology with adaptive rate selection was adopted for this study. The simulation results were obtained for Pedestrian A and Vehicular A channel profiles with UEs moving at 3 km/h speed.

The simulation results have revealed that the throughput gains achievable for MIMO relative to SIMO are up to 37% for Pedestrian A and up to 29% for Vehicular A scenarios. The gains were obtained at high RoT values, making HSUPA MIMO best suited to isolated small cells with low UE densities. MIMO Option II was found to be the most effective architecture out of the considered ones because of its ability to adapt the data rates on each stream independently based on the instantaneous channel conditions. Since MIMO Option II is also well suited to the SIC receiver architecture, it is recommended for application in practical systems.

REFERENCES

[1] "Physical Layer Aspects of UTRA High Speed Downlink Packet Access", 3GPP TR 25.848.

[2] "Multiple Input Multiple Output (MIMO) antennae in UTRA", 3GPP TR 25.876

[3] "Technical report on UL MIMO", 3GPP TR 25.871.

[4] "Feasibility study for enhanced uplink for UTRA FDD", 3GPP TR 25.896.

[5] "New WI proposal: Uplink Transmit Diversity for HSPA", Document RP-101438, 3GPP TSG-RAN plenary meeting #50, Istanbul, Turkey, December 2010.

[6] 3GPP TS 25.214 "UTRA Physical Layer Procedures (FDD)", Rel-11.

[7] R. Maslennikov, A. Trushanin, M. Shkerin, M. Shashanov, P. Czerepinski, "Analysis of multiple antenna transmission for HSUPA", *Proc. 2nd Intern.worskhop on Recent Advances in Broadband Access Networks (RABAN) 2011,* Aug. 2011, Saint-Petersburg, Russia, 6 p.

[8] "Link link evaluation of UL MIMO using different link simulation methodologies", R1-110681, 3GPP TSG-RAN WG1 meeting #64, Taipei, Taiwan, Feb. 2011.

[9] Report ITU-R M.2135-1 "Guidelines for evaluation of radio interface technologies for IMT-Advanced", Dec. 2009.

[10] "Uplink MIMO link level evaluation", R1-112632, 3GPP TSG-RAN WG1 meeting #66, Athens, Greece, Aug. 2011.