Reconfigurable MIMO Downlink Air Interface and Radio Resource Management

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Abstract

This paper proposes a reconfigurable multiple-input multiple-output (MIMO) air interface design and advanced radio resource management (RRM) algorithms applicable to downlink orthogonal frequency-division multiple access (OFDMA) systems. A low complexity, adaptive and channel aware single/multi-user MIMO (SU/MU-MIMO) transmission solution is proposed based on the findings of the IST-2006-27187 SURFACE project. The presented cross-layer design covers the reconfigurable air interface and the main RRM mechanisms including MIMO adaptation, the Hybrid Automatic Repeat Request (HARQ) mechanism and a practical time-frequency packet scheduling. System-level performance analysis is presented for adaptive 2×2, 4×2, and 4×4 MIMO transmission schemes in 3GPP Micro Cell scenarios including the effects of limited and imperfect channel feedback from the terminals. We show that a loose cross-layer design provides a practical solution for operations with high-rate adaptive MIMO transmission schemes in the context of next-generation wireless communications systems.

1 Introduction

When facing the design of a new air interface for next-generation wireless communications systems, the fundamental ingredients are a wise combination of optimality with scalability and adaptivity. Multiple-input multiple-output (MIMO) orthogonal frequency-division multiple access (OFDMA) based transmission schemes have been and still are the focus of several cooperative research studies, e.g., SURFACE [1], MASCOT [2], and WINNER [3], since they can provide numerous degrees of freedom in order to achive those goals. Also within the standardisation context for the next generation of cellular systems, the support of various MIMO transmission modes is currently being approved by the 3GPP for UTRAN LTE [4, 5], and by IEEE for WiMAX [6], with first releases planned to be available by mid 2010-11. Furthermore, the investigations of advanced MIMO transmission schemes for operating bandwidths of up to 100 MHz are already on-going for IMT-Advanced compatible systems as part of the ITU-R standards [7].

Adding a multiuser (MU) component to MIMO OFDMA transmission schemes provides an attractive solution to support and meet the system performance targets in various deployment scenarios. However, most of the physical layer (PHY) and packet scheduling (PS) algorithms proposed so far in the open literature are quite involved, requiring in practice either a very large signaling overhead and/or exhaustive search algorithms in order to form the MU terminal pairs. Another important aspect which needs to be considered in practical MIMO systems is transmission mode adaptation and reconfigurability based on the available radio resources and the detected radio channel conditions of the served terminals. Ideally, in order to globally optimize system performance, this adaptation has to be performed on a per transmission time interval (TTI) basis, similar to the fast packet scheduling introduced for WCDMA/HSPA, and requires frequency domain optimization as for UTRAN LTE systems [4, 5]. Hence, this evolved MIMO air interface and system architecture poses new challenges and opportunities for radio resource management (RRM), whose essential role is to ensure that the radio resources are efficiently utilized taking advantage of the available optimization techniques, and to serve the users according to their quality of service (QoS) attributes.

This paper proposes and evaluates a MIMO air interface design and advanced radio resource management (RRM) algorithms for downlink (DL) OFDMA systems covering Hybrid Automatic Repeat Request (HARQ), fast link adaptation (LA), single-/multiuser (SU/MU) MIMO adaptation and practical time-frequency PS. The DL system with frequency-domain localized downlink transmission and reconfigurable PHY proposed in SURFACE [1, Deliverable 4.2] [8] and the multistream packet scheduling solutions described in [9] are adopted in this work. Their performance is evaluated through extensive multiuser system-level simulations in a typical micro cell scenario [1, 10], which take into account limitations due to practical system design aspects, including the channel estimation errors, channel quality indicator (CQI) imperfections and uplink feedback delays [11].

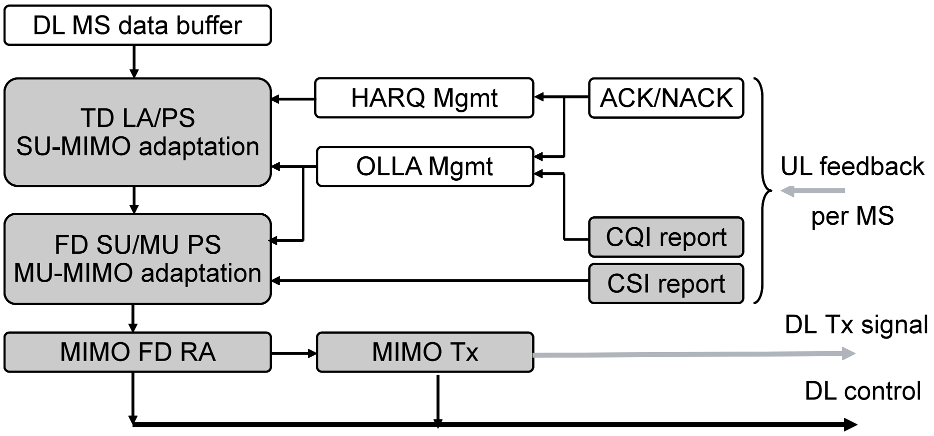

Figure 1: Block diagram of the downlink SU/MU-MIMO-aware RRM at the base station side. The blocks and feedback signaling analyzed in this paper are highlighted in gray.

The rest of the paper is structured as follows. Section 2 presents the proposed air interface and describes the main RRM blocks, their functionality and related modeling aspects. Section 3 covers the system-level performance evaluation. After presenting the the simulation assumptions, the results obtained for representative RRM settings in combination with several transmission schemes are discussed. The main conclusions from this study are summarized in Section 4.

2 System and Algorithm Considerations

2.1 RRM Framework

In advanced OFDMA systems with large operating bandwidths such as envisaged in SURFACE [1] and WINNER [3], and currently in standardisation for IMT-Advanced [7], a flexible data rate adaptation per sub-band is hard to achieve due mainly to signalling constraints, which increase the radio quality estimation errors. In this context, the design of RRM algorithms to ensure that the radio resources are efficiently utilized given the available channel state information (CSI), becomes a key step towards a new generation of wireless communication systems. In particular, performance studies of downlink OFDMA systems using a 20MHz bandwidth and single-input multiple-output (SIMO) transmission have shown that a time and frequency-domain packet scheduling (FDPS) algorithm can yield gains in both average system capacity and cell-edge data rates on the order of 35% to 40%. The FDPS performance, however, was also shown to depend significantly on the frequency-domain scheduling resolution as well as the accuracy of the CSI available at the base station (BS) via the feedback information from the mobile station (MS) [11, 12].

In this paper we present the SURFACE FDPS framework, which is designed to handle SU-MIMO LA/PS but additionally includes an PS/LA stage to accomodate MU-MIMO transmission schemes. Figure

1 shows the block diagram of the DL OFDM RRM functionalities analyzed and modeled in this paper, with emphasis on the MIMO-aware mechanisms. This RRM framework allows, independently for each of the served terminals, a two-fold MIMO adaptation: a 'traditional' SU-MIMO adaptation and the additional SU/MU reconfiguration, all based on the channel conditions and feedback information from the terminals.

The main system-level assumptions, according to the low-mobility (3 kmph) Micro Cell scenario selected in SURFACE, are summarized in Table 1 (see details in [1, Deliverables D2.1, D7.3, and D7.4]). Within a system bandwidth of 10 MHz, the minimum frequency-domain scheduling granularity is defined as one physical resource block (PRB) of 180 kHz and consists of a group of 12 consecutive OFDM sub-carriers. The minimum time-domain scheduling granularity is a transmission time interval (TTI) of 1 ms duration and contains of 14 OFDM symbols out of which 3 symbols are reserved for control channel data. Several PRBs can be allocated/scheduled simultaneously for the transmission to a terminal and the decision is performed dynamically on a per-TTI basis at the BS side. This setup is fully in accordance with the one envisioned for the next-generation wireless communications systems [4–6].

2.2 MIMO Transmission Schemes

To date, schemes operating close to the maximum achievable rates of MIMO downlink channels are largely derived within an information-theoretic context and rely on the dirty paper coding (DPC) technique. However, DPC is extremely computationally demanding and cannot be implemented in practice. There has been much research devoted to obtaining simpler schemes that mimic the DPC concept with lower complexity requirements, the most promising one being lattice coding. The simplest (one-dimensional) lattice encoder is Tomlinson Harashima precoding (THP), which is an appealing technique due to its low complexity and the fact that it is able to retain a large fraction of the gains promised by DPC. On the other hand, it has not been shown that DPC-like techniques are necessary for achieving most of the capacity. In practical cases when processing complexity must be mininized, we can resort to traditional linear techniques, i.e., precoding or beamforming. In our case, we focus on zero-forcing beamforming (ZFBF), which is known to exhibit low sensitivity to errors in the channel state knowledge.

Both ZFBF and THP are suitable transmissions techniques for MU transmission. However, when spatial multiplexing of multiple users is not feasible, e.g., due to ill-conditioning of the resulting aggregate channel matrix and/or non-optimal total served throughput, a SU MIMO technique may still be used to provide multiplexing and diversity gains for the two terminals. For this case, we consider a singular value decomposition (SVD) based precoding scheme that can establish several spatial streams, the number of which is denoted as transmission rank.

The precoding matrices $\mathbf{W}$ for the adopted MIMO transmission schemes are calculated both using delayed and incomplete or imperfect channel state information (CSI) feedback from the terminals (see Section 2.3 for details) as follows:

- *SVD-based Scheme*: $\mathbf{W} = \mathbf{V}\mathbf{R}$ where $\mathbf{H}_{\mathsf{csi}} = \mathbf{U}\mathbf{\Lambda}\mathbf{V}^{\dagger}$ is the SVD decomposition of the estimated average MIMO channel per group of consecutive PRBs, and $\mathbf{R}$ is a Hadamard rotation matrix used to equalize the SINR in case the selected transmission rank is higher than rank-1 [1, Deliverables D7.3 and D3].
- *ZFBF-based Scheme*: $\mathbf{W} = \mathbf{H}^{+}_{\mathsf{aggr}}$ is the Moore-Penrose pseudo-inverse of the aggregate MIMO precoding matrix built using the 2 strongest right singular vectors ($\mathbf{V}$ matrix) from the channels reported by the 2 selected terminals [1, Deliverables D7.3 and D4.2],
- *THP-based Scheme*: $\mathbf{W} = \mathbf{G}$ where $\mathbf{H}_{\mathsf{aggr}} = \mathbf{G}\mathbf{Q}$ is the LQ decomposition of the aggregate MIMO channel matrix built using the 2 strongest right singular vectors ($\mathbf{V}$ matrix) from the channels reported by the 2 selected terminals [1, Deliverables D7.3 and D4.2].

Within the SURFACE concept we assume, that the same modulation and coding scheme (MCS) and the same MIMO transmission rank is used on all PRBs allocated to a given terminal per TTI. Although this restriction certainly lowers the achievable system performance compared to a fully time-frequency MIMO adaptive case, it results in more practical transmission schemes and lower complexity RRM algorithms.

2.3 MIMO Feedback from Terminals

An efficient structure for the L1/L2 control signaling information is essential in order to maximize the throughput enhancement of downlink MIMO transmission. Feedback overhead, including precoding information as well as the channel quality indicator (CQI) and its granularity in the time and frequency domain, ACK/NACK, transmission rank, etc., should be aggressively minimized while keeping the system performances in the desired limits. Furthermore, the adopted MIMO transmission algorithms have also impact on the selection of the HARQ mechanism to be used and the resulting behavior [1, D4.2]. Hence, practical MIMO schemes should be carefully evaluated with LA and time-frequency domain PS schemes for optimal network performances. In terms of update/reporting rate, the CQI and H-ARQ information are potentially the most demanding (0.5msec - 20msec). The precoding information, on the contrary, can be reported at a lower rate (50msec) while the transmission rank can be updated at a very slow rate (100msec) in a semi-static way. Since the study and optimization of the terminal feedback reporting mechanism is out of the scope of this study, we adopt the 3GPP LTE Release 8 system-level assumptions, which have been used also for the first publicly available UTRAN Long Term Evolution (LTE) performance evaluations within the Next Generation Mobile Networks Operator Forum [13].

The minimum required feedback from the terminals in order for the BS to perform the proposed DL MIMO-aware RRM comprises (see Figure 1):

- *MIMO CQI* providing direct (e.g. SINR) or indirect (e.g. MCS) information on the average channel conditions estimated on individual or groups of PRBs,

- *MIMO rank* denoting the optimum number spatial streams to be used for next transmission,
- *MIMO CSI* as the $\mathbf{V}$ matrix from the SVD decomposition $\mathbf{H}_{\mathsf{csi}} = \mathbf{U}\mathbf{\Lambda}\mathbf{V}^{\dagger}$ of the estimated average MIMO channel per group of consecutive PRBs, and
- *HARQ information* indicating the reception status (ACKnowledged / Not ACKnowledged) of the transmitted data packets.

The first three items in the list above are determined by the MS using DL common pilot measurements and are transmitted to the BS in a quantized form [4,5,9,11]. The optimum channel rank is obtained based on the instantaneous channel conditions on all available PRBs. The CQI and CSI measures corresponding to the selected channel rank are estimated and feedback as average values for a group of consecutive PRBs. Here we assume that one CQI measure represents the average SINR estimate and the accuracy of the CQI feedback (dependent on several system design choices, such as time-frequency pilot distributions, channel estimation and advanced receiver algorithms) is modeled according to [9,11]. For implementation purposes, the frequency granularity (selectivity) and quantization procedure of the CQI-CSI can be further optimized based on the expected radio propagation conditions in order to minimize the required uplink overhead. Within the SURFACE concept, the CQI-CSI reports are calculated for each group of 2 consecutive PRBs (360 KHz) and are ready for use at the BS with a time-delay of 2 ms (2 TTI), including both the time it takes to send the reports and the time to decode them at the BS. A periodic reporting scheme with a period of 5 ms (5 TTI) is considered [1, Deliverables D4.2 and D5]. We further assume that the CQI-CSI reports are always received correctly at the serving BS.

The HARQ scheme and related feedback are described in [9,11] and due to adopted across-stream coding scheme, only one HARQ chain per terminal is needed to control the transmission in all MIMO transmission modes.

2.4 Link and Mode Adaptation

The optimized operation of the MIMO transmission schemes introduced in Section 2.2 requires, in addition to the classical LA (selection of the optimal MCS), a MIMO rank adaptation mechanism. In general, when closed-loop MIMO schemes are used, the MIMO rank selection procedure involves estimating the total achievable throughput with the adopted precoding schemes and each possible rank. In our case, the optimum transmission rank is selected at the terminal side based on the SVD decomposition of the average (over 2xPRB) estimated channel with the objective of maximizing the user throughput. The CQI estimated for this optimal channel rank is then feedback to the BS, and used in the LA/PS to configure the next transmission. Observe that the CSI feedback is needed at the BS to perform the correct stream orthogonalization based on the ZFBF or THP schemes.

Previous investigations with low mobility terminal scenarios have disclosed the influence on the overall system performance of the rate at which the MIMO adaptation is performed. In this study we adopt the quasi-dynamic MIMO scheme with adaptation only on the 1^{st} HARQ transmissions [9], as a tradeoff solution between the fast-adaptive (per TTI) and the slow-adaptive, e.g., geometry-factor based (per 5ms to 10 ms) schemes.

2.5 Packet Scheduling

A HARQ-aware time-frequency domain packet scheduling mechanism extended to operate with spatial-multiplexing MIMO schemes proposed previously in [9, 11, 12] is adopted in this study. The proportional fair (PF) scheduling metric is used in both the time and frequency domain PS.

The new degree of freedom in the PS is given by the possibility of scheduling in MU-MIMO mode a selected group of terminals. As described in Section 2.3, the terminals do not feedback any MU specific information to the serving BS, thus, the scheduling of MU-MIMO transmission is completely transparent for the terminals and decided solely based on their SU-MIMO specific CQI-CSI and HARQ feedback information available at the BS. There are three main steps in the MU-MIMO scheduling algorithm we propose:

- *Step 1:* Identify the candidate set of terminals to be potentially grouped for MU transmission, denoted as PotMU-MSSet.
- *Step 2:* Identify which frequency resources should/can be used for MU transmission and select the MU-MS pairs.
- *Step 3:* Select the final MU-MS pairs to be scheduled using the same PS algorithm as for SU-MIMO to be used for the final resource allocation.

In the literature there are several proposals how to implement and optimize the PS steps listed above. However, as mentioned in Section 2.2, here we aim for a more practical design solution, which can reuse most of the features of a previously developed time-frequency packet scheduler, e.g., [9, 11], in combination with more advanced schemes such as the ones envisioned for next-generation wireless communication systems. In following we outline our proposal for the PS algorithm.

For *Step 1*, keeping in mind that no specific MU feedback information is available from the terminals, the selection algorithm simply identifies the set of terminals with 1^{st} HARQ transmission and a given MIMO rank (only single stream, only multi stream, or any number of streams):

$$\mathsf{PotMU\text{-}MSSet} = \{\mathsf{MS}_k \text{ in 1stTx}\}_{k=1,\ldots,N} \cap \{\mathsf{MS}_k \text{ with Rank Tx}\}_{k=1,\ldots,N} \tag{1}$$

This algorithm is in-line with the adopted time granularity of the MIMO mode adaptation. As such, this step can be considered part of the time-domain PS. Furthermore, when only the rank-1 (single-stream) terminals are selected for instance, the algorithm avoids the additional rank adaptation at the BS, as both SU-MIMO and MU-MIMO transmission would be scheduled in rank-1 mode for these terminals.

Step 2 is part of the frequency-domain PS. A straightforward strategy for selecting the SU/MU-MIMO transmission mode is to maximize the total throughput on the scheduled PRBs, complementing the user throughput maximization rank selection criteria described in Section 2.4. All possible MU-MS pairs should ideally be verified on each PRB during this step. Nevertheless, this procedure can be highly computationally-demanding, depending on the maximum number of terminals allowed to be scheduled per TTI, N_{FDM}, as selected by the time-domain PS. For instance, when N_{FDM} ranges from 10 to 15, an exhaustive search could involve from 45 to 105 verifications. In order to reduce this computational complexity, the selected MU-MS pairs to be verified are only the ones in the 'top-2' on the considered PRB. The 'top-2' is found by ranking the terminals based on their reported CQI per 2×PRB (MaxCQI) as

$$\begin{aligned}\mathsf{MU\text{-}MS}_1 &= n = \arg\max_{k=1,\ldots,N}\{\mathsf{CQI}_k\}\\ \mathsf{MU\text{-}MS}_2 &= m = \arg\max_{k=1,\ldots,N,k\neq n}\{\mathsf{CQI}_k\}\end{aligned} \tag{2}$$

where CQI_k is the CQI feedback from the kth terminal for the current PRB. It is expected that the MaxCQI criterion provides good MU orthogonalization due to the similarly good channel conditions of the two terminals. The mechanism to select the MU-MS pairs uses additionally the estimated precoding vector orthogonality before the ZFBF or THP is applied.

For the final decision on the SU/MU-MIMO transmission mode, the user throughput estimation in MU-MIMO mode, $\mathsf{R}(\mathsf{MU\text{-}MS_k})$, is performed based on the CQI feedback information (the total transmit power per PRB is assumed to be the divided equally between the MU-MS pair) and compared to the SU-MIMO user throughput of the primary MS, $\mathsf{R}(\mathsf{SU\text{-}MS}_1)$:

$$\begin{aligned}&\texttt{IF}\quad \mathsf{R}(\mathsf{MU\text{-}MS}_1)+\mathsf{R}(\mathsf{MU\text{-}MS}_2) > \mathsf{R}(\mathsf{SU\text{-}MS}_1)\quad \texttt{THEN}\quad \text{use MU-MIMO}\\ &\texttt{ELSE}\quad \text{use SU-MIMO on the current PRB.}\end{aligned} \tag{3}$$

Furthermore, in order to account for the non-ideal MU orthogonalization, certain CQI degradation factor for each of the MS in the MU-MS pair is included when calculating $\mathsf{R}(\mathsf{MU\text{-}MS_k})$, depending on the used scheme, ZFBF or THP.

Step 3 requires the definition of a MU scheduling metric per PRB, denoted as $\mathsf{M_{MU}}$, similar to the SU-MIMO metric [9, 11], in order to make the final frequency-domain PS step un-aware of the MIMO transmission mode. For the frequency-domain PF scheduling mechanism adopted in this study, we have considered the following option for calculating $\mathsf{M_{MU}}$:

$$\mathsf{M_{MU}} = \frac{\mathsf{R}(\mathsf{MU\text{-}MS}_1)+\mathsf{R}(\mathsf{MU\text{-}MS}_2)}{\mathsf{T}(\mathsf{MU\text{-}MS}_1)+\mathsf{T}(\mathsf{MU\text{-}MS}_2)} \tag{4}$$

where $\mathsf{T}(\mathsf{MU\text{-}MS_k})$ is the average delivered total throughput in the past for the kth terminal.

Parameter	**Setting/Value**
Carrier frequency	2 GHz.
Transmission bandwidth	10 MHz.
Number of active sub-carriers	600.
Cellular scenario	SURFACE Micro Cell [1, 10].
Number of terminals per cell	5, 10, 20, 50.
Channel model	WINNER/3GPP SCME-D correlated [3].
Sub-frame duration	1 ms.
Sub-carriers per PRB	12 sub-carriers = 180 kHz.
Modulation schemes	QPSK, 16QAM, 64QAM.
Hybrid ARQ	6 SAW processes (time asynchronous and frequency adaptive).
Base station transmitter	2 and 4 omnidirectional antenna elements.
Terminal receiver	2 and 4 omnidirectional antenna elements. LMMSE per stream.
Terminal noise figure	9 dB.
Terminal velocity	3 kmph.
Traffic model	Infinite queue/buffer.
MIMO RRM	Time-frequency PF PS. Link adaptation: SU-SVD with different SER/BER target and terminal-side MIMO rank adaptation. SU/MU-MIMO adaptation: SURFACE FD algorithm. (more details in [1, Deliverable D6]).
CQI model	2×PRBs resolution. Includes measurement and quantizatiom errors, delays, and reporting period.
MIMO CSI feedback model	2xPRBs resolution.

Table 1: Downlink System-Level Simulation Parameters

3 System-Level Results and Discussions

3.1 General Simulation Settings and Assumptions

In order to evaluate the performance of the presented MIMO-aware RRM algorithms and transmission schemes, detailed multicell system-level simulations have been carried out in the SURFACE Micro Cell

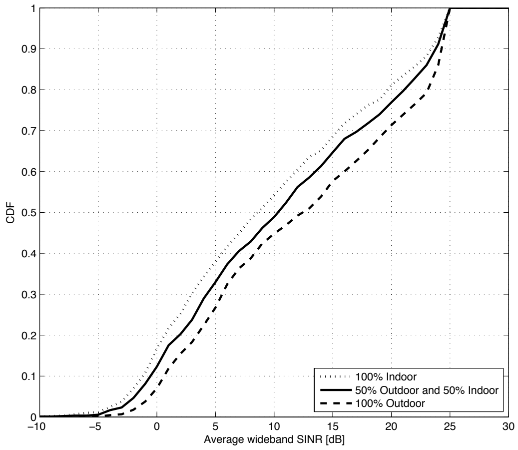

Figure 2: Distribution of the average downlink wideband SINR in the SURFACE Micro Cell scenario with different outdoor-to-indoor ratio for the user location.

scenario within a frequency reuse 1 network. Table 1 lists the main simulation parameters and assumptions. All terminals in a cell are assumed to be active, have low mobility (3 kmph) and utilize the same set of MIMO transmission modes. The interfering cells are assumed to operate at full load and the interference signal at the receiving terminal is calculated based on the assumption that it originates from a MIMO rank-1 transmissions with the same number of transmit antenna ports. The (self) interstream interference at the receiver is explicitly calculated at the output of the LMMSE receivers. The 3GPP SCM-D MIMO-correlated channel model has been used [3]. For the SURFACE Micro Cell system-level simulations a total of 19 BS are generated but only the center BS is simulated with full RRM functionality. The MSs are dropped uniformly distributed in the entire simulation area, and only the MSs connected to the center BS/site are kept and simulated with full RRM. The system-level results presented in this section are the most representative ones from the findings in the SURFACE project. Detailed description and further results can be found in [1, Deliverables D2.1, D5, D6, D7.4]. The corresponding link-level results have been presented in [8] [1, Deliverable D7.3].

For these results, the cell load is varied from 5 to 50 active users and, a maximum of 10 users are scheduled by the frequency-domain PS in each TTI. Based on the analysis of the proposed SURFACE fast LA algorithms [1, Deliverable D7.4], we have selected the BER LA scheme with BER target of 10% for all further studies [1][Deliverable D6], involving the SU- and MU-MIMO transmission schemes. This LA algorithm was found to fit best with the BLER target of 20% which was controlled by an outer loop LA based on the 1st HARQ transmission.

Figure 2 shows the distribution of the average wideband SINR in the SURFACE Micro Cell scenario with varying outdoor-to-indoor ratio for the user location. Due to lack of space, in this paper we present

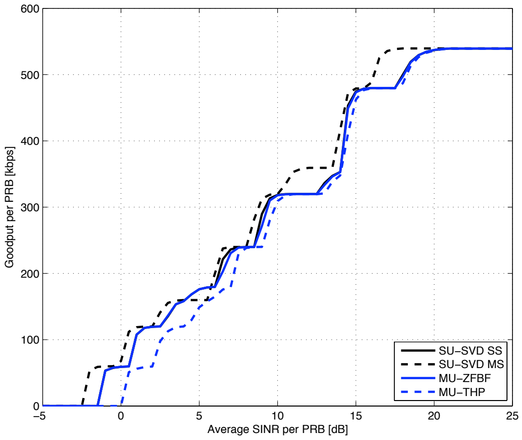

Figure 3: System-level goodput per PRB vs. SINR performance curves obtained for a BLER target of 20% and based on the link-level performance corresponding to the different MIMO transmission schemes.

only the results for the Micro-cell scenario with 50% outdoor and 50% indoor user location (further results can be found in [1, Deliverable D7.4]). In all SURFACE scenarios the maximum allowed receiver post-detection SINR is limited to +25 dB in order to include the effects of system imperfections and practical dynamic range of the transmit/receive RF components.

Figure 3 shows the goodput per PRB vs. SINR performance curves obtained for a BLER target of 20% and based on the link-level performance curves corresponding to the different SU/MU-MIMO transmission schemes. The single-stream (SS) SU-MIMO and the ZFBF-based MU-MIMO performance show similar performances. The multi-stream (MS) SU-MIMO performance is approximately 1dB better compared to the single-stream in the entire SINR range. The THP-based MU-MIMO performance results show approximately 1.5dB degradation at the cell-edge compared to the SU-MIMO case and this performance losses gradually decreases with increasing SINR and high SINR range both ZFBF and THP scheme yield the same performance. The latter result is direct consequence of the sensitivity of the THP-based precoding scheme on the quality of the channel state information and experienced SINR.

3.2 SU-MIMO Results

Figure 4 shows the main system performance results obtained for the reference 3GPP LTE Release 8 compliant 2×2 SU-MIMO transmission scheme and the SURFACE 2×2 SU-MIMO transmission schemes using the SURFACE BER LA algorithm with adaptive bit and power loading [1, Deliverable D6].

Comparing the SURFACE and the LTE performance in Figure 4 we can see that the SURFACE schemes perform best due to the better LA and precoding scheme (analog SVD). Due to the TD-FD PS, in the SURFACE results the average number of user scheduled per TTI can vary significantly depending not only

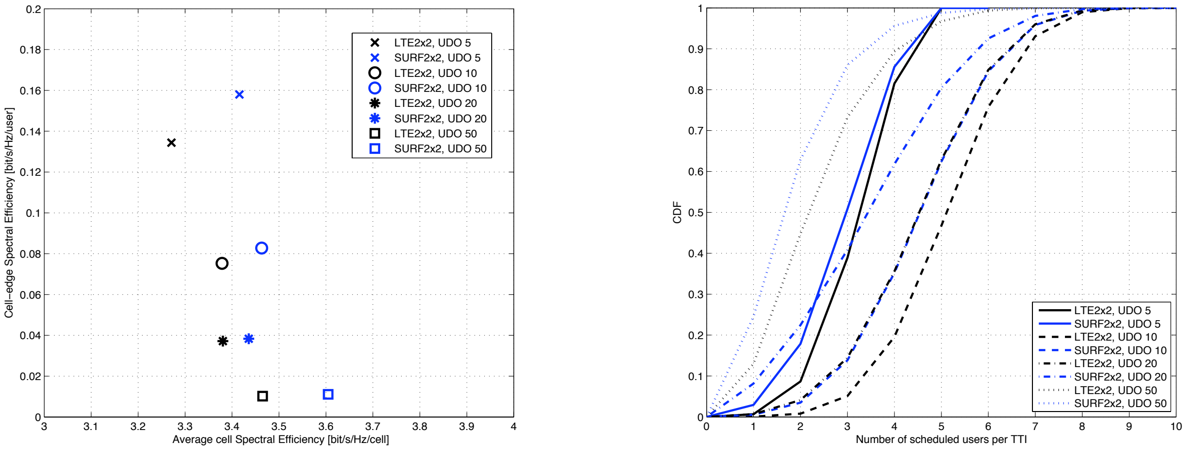

Figure 4: System performance results for the reference 3GPP LTE Release 8 2 × 2 SU-MIMO and the SURFACE 2 × 2 SU-MIMO transmission schemes with varying cell load: spectral efficiency (left) and number of scheduled users per TTI (right).

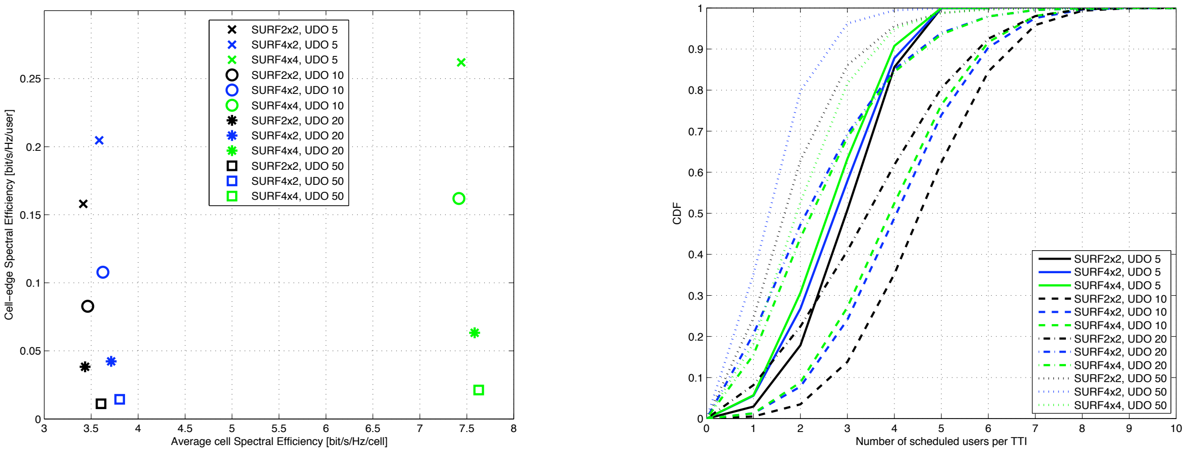

Figure 5: System performance results for the SURFACE 2 × 2, 4 × 2, and 4 × 4 SU-MIMO transmission schemes with varying cell load: spectral efficiency (left) and number of scheduled users per TTI (right).

on the cell load but also on the used target BER setting in the LA algorithm (the latter effect is not shown in the figure).

Figure 5 shows the comparison of the performance results between the SURFACE 2×2, 4×2, and 4×4 SU-MIMO transmission schemes when using the BER1 LA algorithm.

In average, over all MS and all simulated TTIs, the multi-stream transmission modes are used approximately 80% of the time for all transmission schemes. This is a direct consequence of the optimal rank

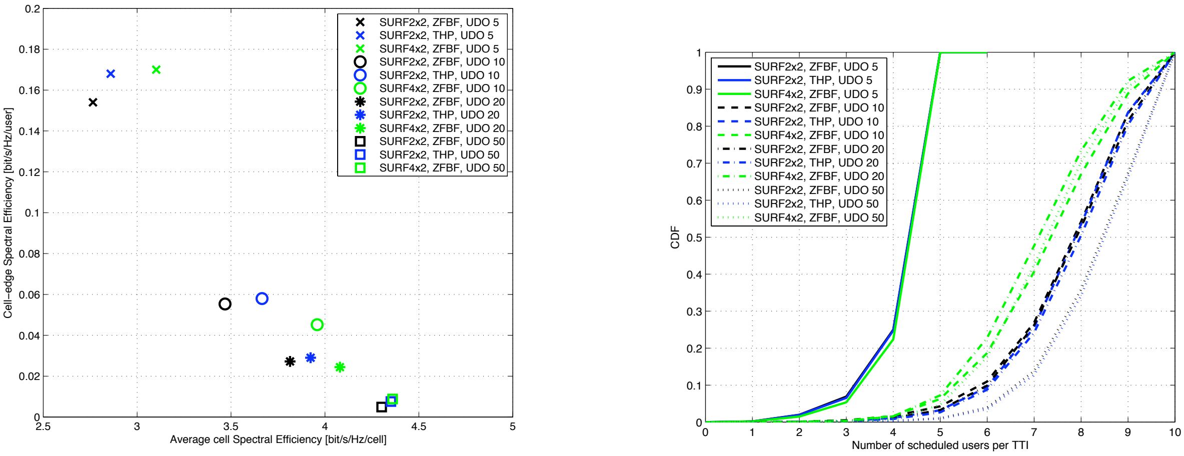

Figure 6: System performance results for the SURFACE 2 × 2, 4 × 2 MU-MIMO transmission schemes with varying cell load: spectral efficiency (left) and number of scheduled users per TTI (right).

selection and LA algorithms combined with the high average SINR conditions in the adopted Micro Cell scenario (see Figure 2).

3.2.1 ZFBF and THP MU-MIMO Results

The SURFACE ZFBF-based and THP-based transmission schemes (see Section 2.2) have been evaluated combined with the proposed MaxCQI MU scheduling algorithm (see Section 2.5).

Figure 6 shows the comparison of the performance results between the 2 × 2 and 4 × 2 MU-MIMO ZFBF-based and 2 × 2 MU-MIMO THP-based transmisison schemes. Comparing the gain of the 2 × 2 and 4 × 2 MU-MIMO schemes we can observe the same range of 10% to 15% improvement in the cell spectral efficiency. The cell-edge performance is only marginally impacted in high cell load conditions. Under the infinite queue/buffer traffic model assumption made in SURFACE, this gain comes mostly from being able to schedule an increased number of users per TTI and at the price of sacrificing the user fairness and reduced peak user throughputs [1, Deliverable D7.4]. For the finite queue/buffer traffic model case, the cell performance was, however, shown to be significantly lower while providing increased peak user throughputs with a low number of users scheduled per TTI [1, Deliverable D7.4].

Comparing the ZFBF-based and THP-based results in Figure 6, as expected, an overall better cell performance is obtained with the THP-based scheme. The cell-edge system performance is only slightly improved with the THP-based scheme and this is direct consequence of the algorithm used for preselecting the MU-MIMO MS, based on the MaxCQI criteria, which targets mostly the MS in cell-center conditions.

4 Conclusions

This paper has illustrated how advanced MU-MIMO schemes can be efficiently combined with practical packet scheduling to harness most of the potential gain of multiple antenna channels. The fast link adaptation scheme plays a critical role, and an adaptive bit and power loading scheme is desirable together with an ability to dynamically adapt between SU and MU modes. With the adopted SURFACE assumptions in the system design, it was shown that the proposed MU-MIMO transmission schemes are particularly beneficial in high-load scenarios with more than 10 active users per cell. Furthermore, the user traffic type has potentially a significant impact on the achievable system performance and the SU/MU-MIMO scheduling strategy has to be adapted to expected or detected type of traffic in the cell.

Acknowledgment

This work has been partly funded by the IST-2006-027187 FP6 STREP "Self Configurable Air Interface" (SURFACE) project.

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