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Authors:	H. Bölcskei, G. Matz, C.F. Mecklenbräuker, G. Taricco
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Abstract:

The project started on January 1, 2006. The research in WP1 focused on the design of space-time codes, MIMO receiver schemes, and MIMO subcarrier allocation strategies. A key result from WP1 are the newly developed multiuser space-time codes. WP2 focused mainly on the implementation of reduced-complexity receiver-side algorithms. A key result from WP2 is the VHDL implementation of tree-search algorithms as a reduced-complexity detection scheme. The research in WP3 focused mainly on the characterisation of multiuser capacity and quality-of-service regions, and ARQ concepts for relay networks equipped with multiple antenna arrays. A key result from WP3 is a new algorithm for the detection of neighbors in an ad hoc wireless network.

A liaison between the two FP6–IST projects SURFACE and MASCOT was established during June 2006. New partner Università della Calabria joined the consortium with effective date December 1, 2006.

Contents

Authors

Christoph F. Mecklenbräuker
ftw. Forschungszentrum Telekommunikation Wien
Tech Gate Vienna
Donau-City Str. 1
A–1220 Wien

tel.: +43 1 505 28 30 - 0
gsm.: +43 664 610 4924
fax.: +43 1 505 28 30 - 99
e-Mail: cfm@ftw.at

Gerald Matz
Vienna University of Technology
Wien, Austria

Helmut Bölcskei
Eidgenössische Technische Hochschule Zürich
Zürich, Switzerland

Giorgio Taricco
Politecnico di Torino
Torino, Italy.

Executive Summary

This deliverable reviews the first year of the MASCOT project.

- Research progress in WP1, WP2, and WP3.
- Dissemination activities during 2006.
- Consortium management.

Chapter 1

Research Progress

The progress in the workpackages was monitored by the WP leaders and reported to the co-ordinator on a quarterly basis. Here, we summarise the results of this monitoring activity during 2006.

1.1 Workpackage 1

This workpackage is lead by Prof. Gerald Matz, Vienna University of Technology (VUT).

Task 1.1

Partners having contributed to this task are NOK, FTW, and FhG-HHI.

Objectives: This task is concerned with adaptive modulation and scheduling and retransmission strategies for MU-MIMO systems taking into account spatiotemporal channel characteristics.

Progress: *Subcarrier allocation using linear programming (NOK).* One of the major problems in multi-user MIMO-OFDM systems is the design of frequency scheduling algorithms that take into account the spatial and spectral degrees of freedom of the individual user channels. Within MASCOT, novel subcarrier allocation schemes have been developed that are applicable for matrix-modulated high rate MIMO systems and for antenna selection MIMO schemes. Furthermore, scheduling algorithms for delay-differentiation have been developed. In terms of methodology, these scheduling techniques use linear programming methods, in particular special algorithms derived

for the assignment problem. These algorithms have many different uses in MIMO and non-MIMO systems.

QoS region and proportional fair scheduling (FhG-HHI). The maximum sum-capacity provides an important benchmark for the overall performance of multiuser MIMO systems. However, by aiming at the sum capacity, it can happen that users with bad channel conditions remain inactive, since this strategy favours the strong links. Such a behaviour is not always desirable. In particular, possible latency constraints require a certain degree of fairness.

Fairness means that the scheduler can assign the available resource among the communication links in a flexible and efficient way. A good tradeoff should be found between the overall system efficiency and fairness. The actual strategy should depend on the current channel state, but also on other criteria, like the data queue length etc. The inclusion of all these aspects typically results in complex problem formulations with many degrees of freedom. This is one of the reasons why MIMO scheduling is only partly understood up to date.

Hence, the first year of the project was partly devoted to a fundamental analysis of the quality-of-service (QoS) region (the set of achievable QoS tuples). Here, QoS stand for a certain choice of performance measure, which will be specified later (examples are capacity, MMSE, delay, BER, etc.). The problem of scheduling can be regarded as the search for a good tradeoff point on the boundary of the QoS achievable region. It was shown for certain types of interference functions and coupling scenarios, that proportional fair scheduling is a strictly convex optimization problem. This is exploited by a new algorithm, which combines utility optimization and adaptive transmitter optimization (e.g. beamforming).

Scheduling with noisy CSI (FTW). In another line of work, improvements of random user scheduling for the case where channel state information at the user side is noisy have been investigated. The case when the number of users is not high enough to use asymptotic techniques has received special attention. More specifically, a beam assignment algorithm has been proposed that is based on SINR channel quality indicators when users can receive either one or several beams simultaneously.

Deviations: The work has progressed according to the project schedule.

Deliverables: Deliverable D1.1.1, "Link layer adaptation and scheduling algorithms for MU-MIMO systems," was scheduled for and delivered by M12. This deliverable relates to milestone M1.1.1, "First versions of link layer adaptation and scheduling algorithms available" (M12).

Task 1.2

Partners having contributed to this task are ETHZ, FTW, NOK, UNICAL, and VUT.

Objectives: Task 1.2 is concerned with the design of space-time coding schemes for multiple-access channels (MACs) and for distributed MIMO systems and with analyzing the impact of various channel statistics (such as Rayleigh or Ricean fading) on the design of space-time codes.

Progress: *Space-time codes for Rayleigh fading MACs (ETHZ).* A significant body of results on space-time and space-frequency coding for single-user channels is available in the literature. In contrast, space-time/frequency coding for MACs seems largely unexplored. Building on the framework in Gallager, IEEE Trans. IT, 1985 for characterizing the dominant error event regions in single-antenna additive white Gaussian noise (AWGN) MACs, we derived rate-dependent space-time/frequency code design criteria for Rayleigh fading multiantenna MACs with perfect channel state information at the receiver. It was demonstrated that, depending on the transmission rate tuple, joint designs taking the presence of multiple users explicitly into account may be necessary. Our results furthermore allow to identify the rate regions where, for each user, employing codes designed for the single-user case is optimal. Finally, we showed that the number of receive antennas has a significant impact on the dominant error event regions and hence, plays an important role in the code design criteria. As a byproduct of our analysis, we found that the classical code design criteria (based on pairwise error probabilities) were recovered using a completely different approach aimed at minimizing the probability of encountering a bad effective channel realization.

Space-time codes for Ricean MIMO channels (ETHZ). For point-to-point Ricean fading multiantenna channels, we revealed the existence of a critical rate, below of which signaling with zero outage probability is possible, provided that the codes are designed appropriately. We were able to state closed-form expressions of the critical rate both for Gaussian codebooks and for codebooks with finite alphabets. For data rates below the critical rate, we presented the optimum code design criteria. In the high-SNR regime, we furthermore devised the optimum code design criteria for the case of data rates exceeding the critical rate and exhibited their resemblance to the classical space-time code design criteria. Finally, we characterized the entire diversity-multiplexing tradeoff curve of Ricean fading multiantenna point-to-point channels.

Golden codes and concatenated codes (FTW, NOK, UNICAL, and VUT). A concatenated coding scheme for a high rate 2×2 MIMO system over slow fading channels has been proposed, with the inner code a Golden code and the outer code a trellis code. Set partitioning of the Golden code is designed specifically to increase the minimum determinant. The branches of the outer trellis code are labeled with these partitions. Viterbi algorithm is applied for trellis decoding. In order to compute the branch metrics a lattice sphere decoder is used. The general framework for code optimization is given. The performance of the proposed concatenated scheme is evaluated by simulation. It is shown that the proposed scheme achieves significant performance gains over uncoded Golden code. The scheme is shown to be robust for both slow and fast block fading channels. Recently, the benefits of high rate algebraic and non-orthogonal STBCs for MIMO Systems have been investigated. Two high rate space-time coding constructions and layering techniques for MIMO systems have been considered, using the class of perfect and Golden space-time block codes, including the version that is included in IEEE 802.16e specification for a system with 2 Tx and 2 Rx antennas.

Asymptotics of quasi-orthogonal codes (FTW and VUT). In a different line of work, the asymptotic properties of quasi-orthogonal space-time codes have been investigated. While quasi-orthogonal space-time block codes in general do not achieve full diversity with linear reception, it was shown that full diversity order can be exploited asymptotically with a simple linear equalizer. This effect is demonstrated on the extended Alamouti code (also known as Jafarkhani Code).

Coded multiple access (ETHZ, FTW, and VUT). Implementation of multiple access in MIMO systems directly via coding without any spreading or orthogonal access was considered by FTW in collaboration with ETHZ and by VUT. Multi-user LDPC codes for low complexity iterative multiuser detection and decoding systems have been designed and a simulation and performance evaluation tool has been implemented and tested in Matlab and C. The LDPC code design is based on EXIT charts for the multiuser detector. Furthermore, interleave division multiple access using simple convolutional codes, random user-specific bit interleavers, and an iterative turbo-like receiver involving a computationally efficient multi-user MIMO detector has been shown to be a practically interesting and viable scheme to realize high-rate multi-user spatial multiplexing systems.

Deviations: The work has progressed according to the project schedule.

Deliverables: The milestone M1.2.1 entitled "First explicit multiuser space-time code constructions for uplink and downlink available" was scheduled for month 12. Code design criteria for multiuser space-time codes and corresponding explicit designs for the multiple-access channel have been reported by M. Gärtner and H. Bölcskei at ISIT 2006, Seattle, WA, July 2006.

Task 1.3

Within this task, considerable achievements have been obtained by partners ETHZ, FhG-HHI, FTW, Polito, UNICAL, and VUT.

Objectives: Task 1.3 is concerned with the development of efficient transceiver algorithms (e.g., channel estimation, synchronization, transmit precoding, data detection) for multiantenna channels, with an eye on VLSI implementation complexity.

Progress: *Data detection (ETHZ and VUT).* The extension of MIMO sphere decoding (SD) from the narrowband case to wideband systems based on orthogonal frequency division multiplexing (OFDM) requires the computation of a QR decomposition for each of the data-carrying OFDM tones. Since the number of data-carrying tones ranges from 48 (as in the IEEE 802.11a/g standards) to 6817 (as in DVB-T standard), the corresponding computational complexity will in general be significant. We proposed two algorithms for interpolation-based QR decomposition in MIMO-OFDM systems. An in-depth computational complexity analysis showed that the proposed algorithms, for sufficiently high number of data-carrying tones and small channel order, exhibit significantly smaller complexity than brute-force per-tone QR decomposition. We also undertook a hardware implementation of these algorithms to verify the findings of our high-level computational complexity analysis.

Instead of using binary decision outputs of the SD, we investigated the benefits of having the sphere decoder provide soft bit information. These state-of-the-art soft sphere detectors fall into two categories. On the one hand, optimal soft SD algorithms that entail superfluously large computational complexity. On the other hand, reduced-complexity soft SD solutions that sacrifice the optimality of the extracted soft bit information. Within this task, we have devised a novel soft sphere detector that achieves optimal soft outputs while exhibiting a substantially lower complexity than its state-of-the-art counterparts.

Low-complexity alternatives to (hard and soft) SD are of considerable

practical interest. Part of our work was motivated by the fact that the poor performance of low-complexity linear equalization schemes can be attributed to channel realizations with arbitrarily large condition number. In view of this fact, a simple MIMO receiver was proposed that uses a low-complexity equalizer for well-conditioned channels and ML detection (i.e., SD) for poorly conditioned channels, depending on a certain condition number threshold. We proved that this scheme is capable of achieving full receive diversity in a spatial multiplexing system. In a similar spirit, a two-stage receiver was proposed that consists of a partial channel equalizer followed by a mismatched ML receiver that ignores the noise correlation introduced by the equalizer. Numerical simulations and theoretical analyses revealed that this scheme has the potential to realize a continuous trade-off between complexity and diversity.

Linear multiuser receivers (Polito). We studied two types of receivers for the uplink of a CDMA-based MIMO multiuser system with frequency-nonselective Rayleigh fading: joint receivers, which address simultaneously both spatial and multiple-access interference; and separate receivers, addressing the two types of interference individually. This approach allows assessing the benefits of adding MIMO processing capabilities to existing multiuser single-input single-output systems. For both receiver types, we analyzed solutions based on linear (matched filter, decorrelator, minimum mean-square error) and maximum-likelihood receivers. For all the receivers considered, we provided closed-form expressions of the resulting pairwise error probabilities. Performance results are obtained in terms of frame-error rate, using an analytic approach based on large-system asymptotics (with number of users and antennas, spreading gain, etc. growing to infinity) and computer simulations.

Mismatched receivers (Polito and FTW). Two receiver structures for the separately-correlated Rician fading MIMO channel based on pilot symbol-aided channel estimation have been considered: 1) a mismatched receiver, which decodes the received signal by using a maximum-likelihood estimate of the MIMO channel matrix, assuming that the estimate is exact; 2) an optimum receiver, which does not estimate explicitly the channel matrix but jointly processes the received pilot and data samples assuming known channel distribution. The main focus is on the optimum receiver. First, the optimum detection algorithm for the separately correlated Rician fading MIMO channel is derived. Then, an iterative implementation suitable for trellis space-time decoding is proposed in order to reduce the algorithm complexity. Numerical results are presented for a 2×2 MIMO system with Rayleigh/Rice correlated/uncorrelated fading and a simple trellis space-time code. These results show that a substantial gain is available with the opti-

mum receiver either in terms of E_b/N_0 or system throughput (in both cases accounting for pilot-symbol rate reduction). These ideas have recently also been applied to a real MIMO channel based a set of measurements obtained over typical scenarios.

Channel Estimation (VUT). Reliable channel state information is at the heart of many transceiver algorithms. A novel approach to pilot-symbol assisted channel estimation based on irregular sampling techniques has been developed. This approach is specifically suited to multi-user systems employing OFDMA and yields accurate channel estimates with a very small number of pilots even in situations with strong time and frequency dispersion. Apart of its excellent performance the method is attractive for practical implementations due to its low computational complexity, which does not scale with the number of pilots.

MIMO Precoding (VUT). Vector perturbation has been identified as a promising alternative to dirty paper coding for the downlink of MIMO multi-user systems. Efficient approximations to vector perturbation involve lattice reduction techniques followed by sub-optimum precoding schemes (e.g., zero-forcing or Tomlinson-Harashima precoding). While lattice reduction is usually achieved via the LLL algorithm, we proposed a computationally significantly less expensive lattice reduction that is based on Brun's algorithm borrowed from algorithmic number theory. It was shown that in spite of its low complexity, the resulting scheme has the potential to exploit a large fraction of the available diversity. In view of this attractive performance and complexity, the algorithm has been selected for VLSI implementation in Tasks 2.1 and 2.2 of Workpackage 2.

MIMO Gaussian broadcast channel (FhG-HHI). We focused on linear transceiver design and take sum-rate and individual rate per user as our optimization performance measures. Specifically, we considered the following design goals: i) maximize the weighted sum-rate under a total power constraint; ii) minimize the total power under a sum-rate constraint; iii) maximize the minimum rate per user under a total power constraint; iv) minimize the total transmit power under individual rate per user constraint. With linear processing the above problems are non-convex, thus known algorithms cannot be applied. We proposed iterative algorithms, where the optimization of powers and transmit and receive filters is carried out in an alternating manner. Each iteration contains the optimization of uplink power, uplink receive filters and downlink receive filters in an alternating manner in virtual uplink and downlink channels. The essential step is the uplink power strategy. We showed that for each problem, the uplink power strategy can

be reformulated as a Geometric Programming (GP) problem, i.e, optimizing the sum-rate or rate per user is equivalent to optimizing the product of layer-MSEs of all users or of each user, respectively. This differs from the conventional approach to formulate a GP problem in terms of SINR, which involves a loss that can be compensated by our new approach. The proposed algorithms are proved to be convergent and outperform the existing linear schemes. Additionally, we show that this alternating optimization approach can be extended to non-linear processing as well with successive interference cancellation in the uplink and dirty paper precoding in the downlink.

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period. Milestone M1.3.1, entitled "First proposal of selected receiver algorithms available for investigation from hardware complexity point of view" was scheduled for M5. A number of algorithms have been selected for the assessment of hardware complexity, including (soft) sphere decoding, QR-interpolation for MIMO-OFDM, and lattice-reduction assisted MIMO precoding.

1.2 Workpackage 2

This workpackage is lead by Prof. Helmut Bölcskei, Eidgenössische Technische Hochschule Zürich (ETHZ).

Task 2.1

Objectives: Research efforts in Task 2.1 focus on assessing the complexity of algorithms and on obtaining a better understanding of the complexity-performance tradeoffs in MU- MIMO systems. This task also constitutes the interface between workpackage 2 and workpackages 1 and 3, where new algorithms for MU-MIMO are developed. Hence, it is an important goal of this task to define the interface between workpackages by providing researchers with guidelines that help in developing algorithms that are suitable for efficient VLSI implementation.

Progress: In this initial phase of the project we have extracted criteria and techniques for assessing algorithm complexity and for optimizing algorithms for hardware implementation. The result is a set of guidelines and examples from MU-MIMO communications that help researchers with a background

in signal processing to better assess the true silicon complexity of their algorithms and to facilitate the interface to researchers working on VLSI implementations. These results are reported in the deliverable D2.1.1.

Besides the identification of general guidelines for complexity evaluation and algorithm design, which are summarized in the corresponding report, we spent effort on the complexity evaluation of some key algorithms for MU-MIMO systems. In particular, we focused on analyzing the complexity-performance tradeoffs in tree- search algorithms with hard- and soft-decision outputs and we have analyzed complexity bottlenecks in the implementation of MIMO-OFDM systems which will constitute the basis for MU-MIMO systems. In addition to that, we considered an algorithm for lattice reduction proposed by D. Seethaler and G. Matz from TU Vienna.

Deviations: The work has progressed according to the project schedule.

Deliverables: By 31 December 2006, the deliverable D2.1.1 named "Algorithm assessment criteria for hardware implementation" is due. The deliverable D2.1.1 is delivered punctually. The corresponding document is an introduction for algorithm designers to the key aspects of implementing signal processing algorithms with a focus on algorithms for (MU) MIMO communications. To this end, it will describe complexity and performance measures, techniques for complexity reduction and a discussion on the tradeoffs to be made when implementing algorithms in VLSI. The theoretical part is complemented with examples from our research within MASCOT.

Task 2.2

Objectives: Task 2.2 is concerned with the development of low-complexity VLSI architectures for algorithms that are most relevant for the successful implementation of MU-MIMO systems and compilation of a library of VHDL reference designs.

Progress: So far, our efforts related to this task were focused on the design of low-complexity VLSI architectures for tree-search algorithms for MU-MIMO detection and on the optimization and reference-design implementation of a lattice reduction algorithm for ZF precoding. The architectures and algorithm optimizations developed for lattice- reduction-aided MU-MIMO precoding were based on an algorithm developed and proposed by D. Seethaler and G. Matz from the TU Vienna within the MASCOT project.

For the implementation of tree-search algorithms, we have analyzed a number of reference designs, including an implementation of the K-best algorithm and multiple circuits for fixed-complexity sphere decoding according to the algorithm described by Barbero and Thompson. We also proposed architectures and corresponding circuits for list sphere decoders. A particular emphasis will be on the implementation of soft- output sphere decoding based on the algorithms proposed by Studer et al. at the 2006 Asilomar conference.

In addition to that, we also presented a matrix-processing circuit, which may be used for MMSE-MIMO detection, for preequalization in MIMO systems, and for other MU- MIMO algorithms that require rank-one updates of a matrix inverse.

Future work will include the implementation of soft-output MIMO detection algorithms, the implementation of circuits for efficient singular-value decomposition and of circuits to support the estimation of channel capacity in order to enable rate- adaptation and MU scheduling.

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period. The developed circuits will contribute to the library reference designs.

Task 2.3

Objectives: Efforts in task 2.3 are targeted towards the extension of the ETHZ MIMO testbed to a MU-MIMO system to enable demonstration and performance assessment of MU- MIMO technology.

Progress: Work on this task was primarily concerned with the integration of the current RF- prototype to enable the implementation of multiple terminals at reasonable cost. To this end, we first developed, manufactured and tested a single-antenna RF interface. This interface was later extended to a MIMO RF interface for up to four antennas per terminal which is currently being tested. Initial test results indicate excellent performance.

With respect to baseband processing, we ported the original ETHZ MIMO testbed to a new proprietary platform. This platform provides more processing resources for new algorithms and additional processors for the implementation of the MAC layer. On this new platform, we started implementing a basic MAC layer and we conducted first experiments with bidirectional transmission. The developed basic MAC layer will serve as a basis for MU-MIMO extensions such as scheduling and rate adaptation algorithms.

The activities planned for the next 3-6 months comprise the completion of the basic MAC layer, the assembly of additional terminals, and the first demonstration of a basic multiuser setup. This setup will then serve as the basis for the implementation of MU-MIMO algorithms. Thereby, the most interesting candidate algorithms for a first MU-MIMO demonstration are algorithms for link-adaptation and scheduling developed in task 1.1, since this type of algorithms requires only moderate overhead for testbed integration. A decision on which of the algorithms to be demonstrated will be made in Q2/2007.

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period.

1.3 Workpackage 3

This workpackage is lead by Prof. Giorgio Taricco, Politecnico di Torino (PoliTo).

Task 3.1 (Partner: ETHZ)

Objectives: Task 3.1 is concerned with achievable information rates and performance tradeoffs. Before tackling the multiuser case, the fundamental tradeoffs of the point-to-point MIMO channel need to be investigated.

Progress: The diversity-multiplexing tradeoff characterizes the amount of diversity provided by the channel as a function of the multiplexing rate. Our work in this task established the diversity-multiplexing tradeoff curve of general time-frequency selective channels, and we presented a code design criterion that guarantees optimal performance.

We showed that this design criterion is tightly connected to the classical rank criterion. As an application of these results, we considered the performance of delay and phase diversity, and derived the conditions under which these schemes operate on the tradeoff curve. Finally, we proposed an optimal coding scheme based on linear precoding tailored to the channel scattering function.

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period.

Task 3.1 (Partners: FTW and PoliTo)

Objectives: Task 3.1 is concerned with achievable information rates and performance tradeoffs. Before tackling the multiuser case, the information rates of the point-to-point MIMO channel need to be investigated.

Progress: The information rate characterizes a point-to-point MIMO link by specifying the maximum rate at which data can be sent reliably (i.e., with arbitrarily small error probability) over the channel. Real MIMO channels are characterized by line-of-sight components and spatial correlation so that they can be modeled as separately- correlated Rician fading. Our work in this task focuses on the evaluation of the mutual information of a separately-correlated Rician fading channel in several conditions, with and without multiuser interference. Using an asymptotic technique borrowed from theoretical physics we obtained the following results:

- Mutual information of a single-user MIMO channel with separately-correlated Rician fading.
- Mutual information of a two-user MIMO channel with separately-correlated Rician fading (second user acting as interferer).
- Capacity of a two-user MIMO channel with separately-correlated Rician fading (second user acting as interferer).

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period.

Task 3.1 (Partner:FhG-HHI)

Objectives: Task 3.1 is concerned with achievable information rates and performance tradeoffs. This partners activity is concerned with the characterization of multiuser quality-of-service regions, by means of interference functions.

Progress: We study the quality-of-service (QoS) feasible region of a multiuser system, under the assumption that the QoS is a bijective function of the signal-to-interference ratio (SIR). The inverse function is assumed to be logconvex (e.g. log-SIR). We derive a necessary and sufficient condition for strict convexity of the QoS region. This property holds for the class of log-convex interference functions, which include linear interference functions

(resulting from single user receivers) and worst- case interference functions as special cases. Strict convexity is a desirable property, which ensures that optimization over the boundary of the region always leads to a unique global optimum. Moreover, we provide a necessary and sufficient condition for the strict convexity of a weighted cost/utility function, which is used in the context of resource allocation and scheduling.

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period.

Task 3.2 (Partner: NOKIA)

Objectives: Task 3.2 is concerned with the performance of mobile ad-hoc wireless networks (MANETs) equipped with multiple antenna arrays.

Progress: This activity focused on research on ARQ concepts for relay networks articulated as follows:

- Study of channel reallocation concepts using majorization theory.
- Development of a randomized relaying concept, with amplify and forward nodes ($M > 1$ sources, $M > 1$ relays, $N = 1$ receivers).
- Development a multi-channel relaying concept with subcarrier reassignment at the relay node. Reassignment is done based on inout or output channels. Main new results are the conditions under which channel pairing provides the optimal result, so that more complex assignment methods need not be used.
- Miscellaneous work in following FP6-IST Project WINNER work in this area, development of new relay ARQ schemes.
- Extension of the randomized relaying concept to the case with $N > 1$ receiver antennas.

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period.

Task 3.2 (Partner: FBM-UPF)

Objectives: Task 3.2 is concerned with the performance of mobile ad-hoc wireless networks (MANETs) equipped with multiple antenna arrays.

Progress: A new algorithm for the detection of neighbors in a wireless network has been developed and analyzed. This is based on multiuser detection concepts, which prevent the algorithm from collapsing when collisions among users are present. A large-system analysis has been initiated, to examine the performance of random-set-based multiuser detection techniques in the presence of a large number of users.

Deviations: The work has progressed according to the project schedule.

Deliverables: No deliverables were due during the reporting period.

Chapter 2

Dissemination activities

2.1 Web-site

A public web-site was established which announces events, tutorials, publications, deliverables, and achievements. It is accessible through the following URL:

http://www.ist-mascot.org

2.2 Press

The start of the MASCOT project was announced by FTW and VUT in press releases (January 2006). Details can be found in the MASCOT Dissemination and Exploitation Plan (Deliverable D4.2).

2.3 Publications

Details on the publication plans and policy can be found in MASCOT Deliverable D4.2. MASCOT's list of publications 2006 can be found in the MASCOT Activity Report for 2006.

2.3.1 Journals

MASCOT contributions have already been submitted to a number of important international journals during 2006:

- IEEE Journal on Selected Areas in Communications,
- IEEE Transactions on Information Theory,

- IEEE Communications Letters,
- European Transactions on Telecommunications.

2.3.2 Special sessions 2006

The following special sessions related to MASCOT topics were organised and held in 2006:

EUSIPCO 2006. A two part special session on multiuser MIMO communications, (Parts I and II), chair: Christoph Mecklenbräuker, Firenze, Italy.

Asilomar 2006. Special session on MIMO equalisation, chair: Christoph Mecklenbräuker, Pacific Grove (CA), USA.

Details on these special sessions can be found in MASCOT Deliverable D4.2.

2.3.3 Planning of special sessions 2007

- A joint MASCOT–SURFACE special session on "Optimization of wireless multiuser MIMO communication systems" is currently being planned for EUSIPCO 2007 (Poznan, Poland). The goal of this special session is to highlight optimization techniques for multi-user MIMO communications both in cellular networks and in ad-hoc mode. The following five contributions are planned: (Status 30 Nov 2006)

  1. Antonio Fasano and Sergio Barbarossa, "Information lossless space-time coding for multiple access systems". This is a contribution from FP6 IST project SURFACE.
  2. Daniele Angelosante, Ezio Biglieri, and Marco Lops, "Neighbor discovery in wireless networks: A multiuser-detection approach". This is a MASCOT contribution.
  3. Ari Hottinen and Tiina Heikkinen: "Delay-differentiated scheduling in a randomized MIMO relay-network". This is a MASCOT contribution.
  4. Gottfried Lechner, Andreas Burg: "Design of spatially multiplexed LDPC Codes for Multi-User Detection". This is a MASCOT contribution.
  5. Siddharth Naik, Holger Boche, Martin Schubert, Nikola Vucic: "Auction Based Resource Allocation for MU MIMO Systems". This is a MASCOT contribution.

- A special session is in preparation for SPAWC 2007, Helsinki.
- The two special sessions organised jointly by SURFACE and MASCOT which were proposed for ICASSP 2007 were rejected by the conference organisers.

2.3.4 Planning of WSA 2007 with full-week tutorial

FTW and VUT organise the ITG/IEEE Workshop on Smart Antennas (WSA 2007) in Vienna, Austria during the last week of February 2007. MASCOT Deliverable D4.3 is a *Full-week tutorial on MU-MIMO* and it is due in M13 (January 2007)[1].

We propose to delay the delivery of D4.3 by one month: This will enable organising the full-week tutorial on MU-MIMO in connection with WSA 2007 in Vienna. (In the week from February 26, 2007 to March 02, 2007).

Further, it is planned to organise the tutorial jointly with the FP6-IST project SURFACE. The liaison between MASCOT and SURFACE enables a co-ordinated planning of the tutorial's contents.

Tentative programme:

1. MIMO basics, multiplexing-diversity tradeoff
2. Capacity of wireless channels: ergodic capacity, outage capacity
3. Multiuser capacity and opportunistic communication
4. MIMO multiuser basics, multiple-access schemes, and multi-user space-time coding
5. Multi-User MIMO Sum-Rate Capacity Optimization Based on Iterative Water-Filling
6. Channel-aware multi-antenna multi-user relay networks
7. Information lossless space-time coding for multiple access systems
8. Algebraic tools for code design in MIMO systems
9. Resource allocation in OFDMA broadcast channels
10. Multi-user MIMO link and system performances for OFDMA cellular networks

[1] see Technical Annex [2], Section 7.5 on page 25.

11. Minimum BER Linear MIMO Transceiver Design
12. VLSI Implementation of MIMO systems
13. Using random-set theory for multiuser detection and neighbor discovery on wireless networks

List of Contributors

- Sergio Barbarossa, University of Rome "La Sapienza", Italy.
- Ezio Biglieri, FBM-UPF, Spain
- Helmut Bölcskei, ETHZ, Switzerland
- Andreas Burg, ETHZ, Switzerland
- Javier Fonollosa, Universitat Politecnica de Catalunya, Spain
- Ari Hottinen, NOKIA, Finland
- Gottfried Lechner, FTW, Austria
- Gerald Matz, VUT, Austria
- Christoph Mecklenbräuker, FTW, Austria
- Alba Pagés, Universitat Politecnica de Catalunya, Spain
- Martin Schubert, FhG–HHI, Germany
- Giorgio Taricco, PoliTo, Italy
- Emanuele Viterbo, UNICAL, Italy
- Jialai Weng, PoliTo, Italy

Further details on the tutorial will be available during the last quarter of 2006 at the WSA 2007 web-site www.ist-mascot.org/wsa2007 .

2.4 Standards

There were no specific inputs to standardisation during 2006. The use of the Golden space-time code in an IEEE 802.16 (WiMax) system with future MIMO-OFDM enhancements was benchmarked in a simulation study. This research was carried out jointly be the partners NOKIA, UNICAL, VUT, and FTW and submitted for publication to WSA 2007.

2.5 Exploitation activities

2.5.1 Intellectual Property Right management

The project partners established an IPR Policy Committee consisting of technical experts and legal experts in September, 2006[2]. This committee defines rules and guidelines for the reuse of existing knowledge (PEKH, Pre-Existing Know-How, Background) and the tracking of new knowledge generation (Knowledge, Foreground) in the project.

The IPRs generated by the project will be evaluated by the IPR Policy Committee for patent filing[3] or for exploitation. The actual patent filing itself will be performed by the partners involved. The ultimate goal of this activity is to build up and maintain a MASCOT IPR portfolio[4].

2.5.2 Licensing plan

A VHDL library of 4—6 selected MU-MIMO transceiver algorithms is developed within WP2. Under the lead of ETH Zurich, and subject to a mutually acceptable agreement with the other involved MASCOT partners, components from this library may be commercially licensed to the European industry[5]. The legal support of ETH Transfer, the technology transfer department of ETH Zurich, will then be solicited in questions relating to invention protection and exploitation, as well as preparation and negotiation of relevant contracts with potential industrial partners. Similar services will be provided by corresponding units at FhG-HHI, PoliTo, and VUT (see Table 2.1) on a per partner basis.

PoliTo has an office dealing with IPR management, also dealing with patents. There is a new regional technology transfer office, in which PoliTo participates, that acts as an industrial liaison office (ILO) for the three universities of Piemont. The target of this ILO is to provide a coordinated system for the management of IPR.

At VUT, the Technology Transfer Unit of the Department of External Relations (Außeninstitut) assists with the protection of IPR, filing of patents, and exploitation activities.

[2] see Technical Annex (Description of Work): [2], Section 6.2.2, page 19.

[3] Note: Some MASCOT partners may refuse to send invention reports to external bodies as a matter of policy.

[4] The MASCOT IPR portfolio is understood as a list of IPRs filed within MASCOT to be handled according to the MASCOT Consortium Agreement

[5] see Technical Annex [2], WP4 Summary, page 66.

1	FTW	internal responsible: Dr. C.F. Mecklenbräuker
2	NOKIA	internal
3	FhG-HHI	Dept. B9 – Patents and Licensing Dr. Michael Groß
4	PoliTo	regional technology transfer office for the three universities of Piemont.
5	VUT	Außeninstitut http://www.ai.tuwien.ac.at
6	ETHZ	ETH Transfer http://www.vpf.ethz.ch/transfer/index_EN
7	FBM-UPF	Business innovation & development responsible: Ms. Marta Ysern
8	UNICAL	to be defined

Table 2.1: Technology transfer institutions which will aid in exploitation, especially concerning the licensing of the VHDL reference designs.

Chapter 3

Consortium Management

3.1 Project Steering Committee

The current members of the project steering committee (PSC) are [2, 3]:

1. C.F. Mecklenbräuker (FTW)
2. A. Hottinen (NOK)
3. M. Schubert (FhG-HHI)
4. G. Taricco (PoliTo)
5. G. Matz (VUT)
6. H. Bölcskei (ETHZ),
7. E. Biglieri (FBM-UPF)
8. E. Viterbo (UNICAL), since December 1, 2006 (see [3] and below).

During 2006, the PSC convened four times:

- 1st PSC meeting, Vienna, January 19, 2006.
- 2nd PSC meeting, Phone Conference, April 20, 2006.
- 3rdPSC meeting, Firenze, September 7, 2006.
- 4th PSC meeting, Phone Conference, December 5, 2006.

Detailed PSC meeting minutes document the discussions during these meeting and the agreed decisions.

3.2 New partner Università della Calabria

Prof. Emanuele Viterbo changed his affiliation with effective date November 1, 2006. He was affiliated with Politecnico di Torino (PoliTo) until October 31, 2006. From November 1, 2006, he is a full professor at Università della Calabria (UNICAL). His research on algebraic space-time code constructions is an important part in the WP1 research plan. The MASCOT consortium would not be able to carry out the planned research on algebraic code constructions without Prof. Viterbo. As an example of the intense co-operation, we mention the joint research effort of Prof. Viterbo, NOKIA, VUT, and FTW in WP1 for evaluating the performance of the Golden space-time block code in a potential future MIMO-OFDM based WiMax extension. First results were submitted for publication to the Workshop on Smart Antennas 2007 (WSA 2007) in November 2006.

Therefore, the consortium agreed to invite UNICAL as the eighth partner into the project with the effective date of December 1, 2006. The planned effort at UNICAL is 10.5 person months and UNICAL's share of the budget equals approx. 100.000 EUR [1]. The description of work was updated to reflect these changes and submitted to Andrew Houghton (MASCOT's scientific offcer) for approval during Nov.-Dec. 2006 [3].

These changes are implemented in MASCOT Contract AMENDMENT 1.

3.3 Liaison between MASCOT and SURFACE

During June 2006, a liaison between the two FP6–IST projects SURFACE and MASCOT was established. Both projects participate in the Broadband Air Interfaces (BAI) cluster which is moderated by Sylvie Mayrargue (CEA–LETI) [1]. After the first BAI Cluster meeting in February 2006, it became clear that the SURFACE and MASCOT projects would mutually benefit from a closer cooperation than mere participation in the BAI Cluster would enable.

This liaison aims at coordinating the scientific scopes of both projects. It is believed by the participants that both projects will complement each other well because both projects attack challenges in multiuser MIMO communication systems (by theoretical investigations and numerical evaluation). Whereas SURFACE focusses on simulation and software tooling, MASCOT

[1] Details on this decision can be found in the meeting minutes of the 3rd project steering committee meeting, September 7, 2006 and the 4th project steering committee meeting, December 5, 2006.

implements VHDL reference designs and validates them on a hardware testbed.

Further, the liaison aims at a close cooperation on dissemination and exploitation. It is planned to organise joint workshops and tutorials with participation from both projects.

- The multi-user MIMO tutorial in connection with WSA 2007 is jointly organised by MASCOT and SURFACE.
- A joint special session is planned for EUSIPCO 2007, Poznan, Poland, with mixed contributions from MASCOT and SURFACE (session organiser: C.F. Mecklenbräuker).

3.4 Short Visits

- Christoph F. Mecklenbräuker (FTW) visited Helmut Bölcskei (ETHZ) on June 23, 2006 for discussing management issues relating to the testbed development in MASCOT WP2.
- Christoph F. Mecklenbräuker (FTW) visited NOKIA on September 14, 2006 for planning the joint research on WiMax (see Section 2.4). C.F. Mecklenbräuker gave an overview presentation over the MASCOT project for an internal audience of Nokia researchers at the premises of the Nokia Research Center.
- Erwin Riegler (FTW) visited PoliTo, Turin, Italy, October 9—16, 2006 for joint twork in WP3 with Giorgio Taricco.
- Dominik Seethaler (VUT) visited ETHZ from Nov. 1 to Dec. 31, 2006 in order to perform joint MASCOT research on the complexity and performance of efficient implementations of the sphere decoding algorithm.
- Ezio Biglieri (FBM-UPF): Two visits for MASCOT research to the Electrical Engineering Department of the University of California at Los Angeles (UCLA) took place, both in connection with MASCOT publications:
  - First ITA Workshop, February 2006, San Diego,
  - WPMC, September 2006, San Diego.
- Ari Hottinen (NOK) visited ETHZ two times during 2006 (two one day visits).

Bibliography

[1] Sylvie Mayrargue (Cluster Manager). Broadband Air Interfaces (BAI) cluster. http://bai.av.it.pt. 26

[2] Members of the MASCOT consortium. Multiple Access Space–Time Coding Testbed (MASCOT), Annex I (v. 2005-10-13), Description of Work, Contract no. 26905, October 13 2005. 21, 23, 25

[3] Members of the MASCOT consortium. Multiple Access Space–Time Coding Testbed (MASCOT), Annex I Amendment 1 (v. 2006-11-30), Description of Work, Contract no. 26905, November 30 2006. 25, 26

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