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DR2.2
First Report of the Activities on Feedback and Resolution of the Channel State

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Abstract:
This deliverable presents an overview of the activities pertaining to feedback and imperfect channel estimation and the interplay between the two in the form that is considered in NEWCOM++ WPR.2. We provide a description of the integration activities with other WPR from the network in addition to an up-to-date description of the three tasks of WPR.2 namely, Imperfect channel estimation (TR2.1), Point-to-point and Point-to-multipoint, Two-Way Channels (TR2.2), and Precoding Techniques for the MIMO Broadcast Channels (TR2.3). Cross-WPR Integration efforts with platform activities are also described. We include the initial planning for new joint research activities during the second year of NEWCOM++.

Keyword list: Channel Estimation, Unknown Channels, Feedback, MIMO Broadcast channels

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1 INTRODUCTION

WPR.2 aims to explore two crucial aspects in broadband wireless communications, namely the resolution of the channel state at the receiver and the use of feedback. These are related primarily since feedback of channel state information is becoming an integral part of modern wireless networks, both from the point-of-view of resource scheduling and advanced multi-antenna signal processing, and therefore the ability to resolve the channel at the transmitter is ultimately related to what can be estimated at the receiver.

This document presents the work carried out in 2009 in the context of WPR2 with a primary focus on the joint research activities covering at least two partners from the network. Integration with other activities in NEWCOM++ are provided in Section 2 along with a high-level description of WPR.2 tasks. Sections 3,4 and 5 respectively detail the activities carried out in 2009 in each of the three tasks as well as those which are planned in 2009-2010. Section 6 presents some conclusions.

1.1 Glossary

SNR	Signal to noise-ratio
DMT	Diversity-Multiplexing Tradeoff
FDD	Frequency-Division Duplex
TDD	Time-Division Duplex
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple-Access
LTE	Long-term Evolution of UMTS
UMTS	Universal Mobile Telephony System
CSI	Channel State Information
CSIT	Transmitter-end Channel State Information
CSIR	Receiver-end Channel State Information
MIMO	Multiple-Input Multiple-Output
MU-MIMO	Multiuser Multiple-Input Multiple-Output
BC	Broadcast Channel
MAC	Multiple-Access Channel
SISO	Single-Input Single-Output
BER	Bit Error-Rate
ZF	Zero-Forcing
MMSE	Minimum Mean-Squared Error
DFE	Decision Feedback Equalizer
DOF	Degrees of Freedom
BS	Basestation
MS	Mobile Station
OSTBC	Orthogonal Space-Time Block Code
LR	Likelihood Ratio
ML	Maximum-likelihood
ST	Space-time
MSE	Mean-squared Error
COSTBC	Complex Orthogonal Space-Time Block Code
MRC	Maximal Ratio Combining/Combiner

2 OVERVIEW OF WPR2 TASKS AND RESULTING JOINT ACTIVITIES

2.1 TR2.1 Imperfect channel estimation overview

TR2.1 considers the effects of the ability or not of a transmitter or receiver to acquire the channel knowledge. Channel estimation is the process by which the receiver resolves the channel state. It is well-known that as systems become more and more rich in terms of bandwidth and spatial processing (transmit antennas), which is what we are witnessing in the evolution of 3G networks and will surely continue in the future, the number of degrees of freedom to be estimated increases. This increase is approximately linear in both bandwidth and spatial dimensions for practical channel bandwidths. Moreover, due to the mobility of user terminals and objects in their vicinity, the channel does not remain constant for long periods of time (a few milliseconds suffice for the channel to have changed completely). This is particularly true in cellular networks where support for high-mobility is an ever-increasing feature. As a result of both these facts, resolution of all degrees of freedom characterizing the channel state is a difficult task.

Although it is well understood that channels are time-varying, a proper analysis of the resulting effects on system performance even for one-way communications is still incomplete. Significant headway has nonetheless been made in very recent years, both from the point-of-view of information-theoretic limits and error-rate characterization. More analytical work is required for broadband MIMO channels to put to rest the analytical treatment of channel state resolution. Furthermore, more refined practical techniques inspired from this analysis combining channel estimation and decoding are still active areas in the wireless communications research community.

2.2 TR2.2 Point-to-point and Point-to-multipoint, Two-Way Channels overview

A key feature of most modern radio systems is the fact that they allow for two-way communication. This allows for a sharing of the medium in both directions for both communication and low-layer signalling of channel quality indicators and decoding capacity indicators. This is the primary subject of TR2.2. In addition to studying the effect of imperfect channel knowledge at the receiving end we strive to study methods to encode it for the return channel as a function of the allocated bandwidth for feedback. Proper exploitation of incomplete feedback for both point-to-point two-way channels and multiuser/broadcast channels is still a very open area for research.

One set of joint activities within TR2.2 were carried out by EURECOM, CTTC and UPC and have already led to joint publications. Joint Work was initiated between EURECOM and Technion, no publications have resulted at this point.

2.3 TR2.3 Precoding Techniques for the MIMO Broadcast Channels overview

TR2.3 covers what is most likely the key practical problem in wireless communications today, namely precoding for the multi-antenna broadcast channel. This is a model for the downlink in a cellular network, where multiple-antennas (at least 4) will surely be used in evolving standards such as UMTS-LTE and 802.16m combined with feedback channels for channel state information and decoding capacity indicators. Based on existing theoretical research, which focuses on multi-antenna wireless broadcast channels, it is well understood now that precoding is fundamental in the strive to design modern wireless communications systems that will approach theoretical bounds. This subject has attracted recently a massive attention of researchers, and has also emerged in future wireless standards. While serious theoretical progress has been reported as of late, addressing a variety of state-of-the-art concepts, such as dirty-paper coding, the understanding of efficient robust approaches which cope with practical conditions is in its preliminary stage. One of the central aspects that calls for a deeper understanding is the impact of the accuracy of channel state information (CSI) on various communications strategies. Under ideal assumptions, recent theoretical developments do identify the optimal approaches. Once we deviate from ideal assumptions, it is unclear what constitutes the optimal strategy. Even within the restricted class of linear precoding techniques, such as zero-forcing, there is no clear understanding how to operate under these practical assumptions, and exhibiting robust features. The study focuses on precisely these aspects, which we believe have both theoretical and practical implications. The goal will focus on gaining analytical understanding of the optimal linear approaches under different models which reflect partial knowledge of the CSI parameters.

We consider further non linear robust precoding strategies relying on information theoretic insights and aimed at identifying robust techniques within the class of dirty-paper approaches, as well as more practical general vector perturbation methods. Finally, the precoding techniques are intimately linked with proper scheduling and required feedback information about CSI, which essentially touches also upon network aspects. Scheduling and CSI feedback demands cannot be interpreted as stand-alone entities, but rather as an inherent part of a unifying approach of robust precoding. We plan on conducting research to the end of understanding the basic role of the quality of CSI needed at transmitting ends, so as to provide the full promise of precoding, and primarily the superior multiplexing gain. This effort will include also an attempt to identify ultimate theoretical bounds on minimal demands of the feedback link that maintain optimal performance, in terms of multiplexing gain (degrees of freedom) as well as the gap to capacity. Comparison to actual robust pre-processing schemes is also planned, and is to be compared to the ultimate bounds.

Joint work was performed by CTTC and UPC in this task resulting in publications reported in Section 4. Joint work between EURECOM and Technion and EURECOM/CNIT-Torino was initiated, although neither have resulted in publications in 2009 or submissions.

2.4 WPR2 in NEWCOM++

The relationship between WPR2 and other NEWCOM++ activities is shown in Figure 1. These relationships are detailed in sections 2.4.1 and 2.4.2.

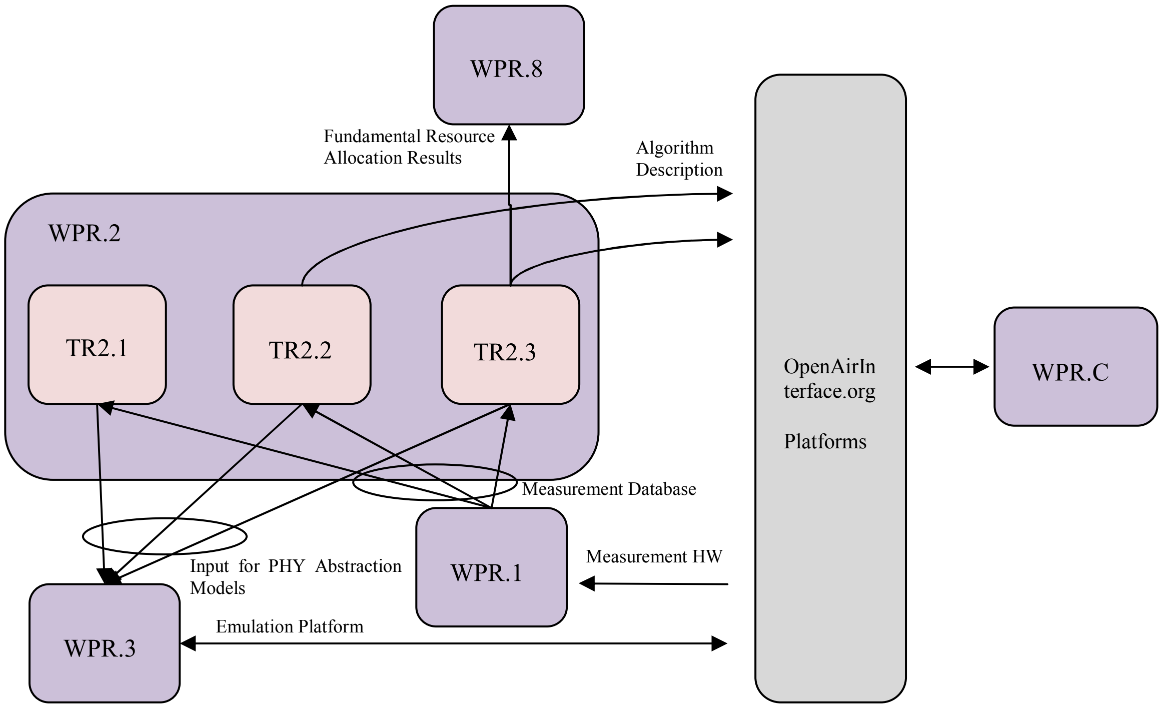

Figure 1: WPR.2 in NEWCOM++

2.4.1 Interactions with other WPRs

Here we provide a simple summary of the foreseen and ongoing interactions of WPR.2 with other WPRs.

WPR.1

The subject of WPR.1 is wireless channel modeling and measurement. Channel models are fundamental to accurate analysis of system performance and fundamental communication limits, whether the metric is link or system information rate or link error probability. As a result, there is a very strong relationship between WPR.1 and this workpackage, in the sense that channel modeling aspects will be used as input to analysis. An effective interaction has begun with WPR.1 activities in the sense that the measurement and modelling activity related to MU-MIMO channels have been used for joint-work in WPR.2 on empirical system performance analysis and feedback signalling design. This activity will surely continue. An explicit inter-WPR activity related to exploitation of reciprocity based on two-way auto-calibration in TDD systems will begin in 2009 (CNRS-EURECOM/FTW).

WPR.3

WPR.3 considers adaptive modulation and coding schemes and abstraction models for physical-layer processing. This work relies heavily on both feedback schemes based on channel quality indicators in order to adapt coded-modulation strategies dynamically. Here, WPR.2 can provide input regarding feedback protocols for next-generation wireless coding systems, primarily Hybrid-ARQ-based adaptive modulation and power-control strategies. In addition, information regarding the dimensioning of feedback channels and the granularity of the information used for feedback will be provided. The second important aspect of WPR.3 which can make use of the results of WPR.2 is physical-layer abstraction techniques. The latter requires accurate models for system performance, for instance error-rates of link. Here, WPR.2 will provide accurate characterizations of coded MIMO-OFDM channels under imperfect knowledge of channels at both ends of the communication link.

Concrete interaction has begun in the context of PHY abstraction models and integration with the OpenAirInterface.org [43] emulation platform in 2009 (CNRS-EURECOM/NKUA).

WPR.8

WPR.8 considers scheduling and adaptive radio resource assignment and can make use of the work here in a similar sense to WPR.3. The main difference is that system-wide (multi-user) results are pertinent as opposed to point-to-point link characterizations. This applies primarily to the WPR.2 work on MIMO broadcast techniques for single and multi-cell cellular systems.

No concrete interaction has begun.

WPR.C

WPR.C is dedicated to hardware platforms and real-time algorithm implementation. It was decided in 2008 that the third generation OpenAirInterface.org platform [43] will be one of the common platforms of WPR.C. As a result, algorithmic work carried out in WPR.2 could be ported to this platform since CNRS-EURECOM is the main developer of algorithms for this target. The joint-work of CNRS-EURECOM/CTTC/UPC in the context of feedback signalling mechanism would be a first target for this type of activity. In addition, the two-way firefly synchronization and distributed MIMO transmission have already been ported to the second generation OpenAirInterface.org platform.

This work establishes a clear link between WPR.2 and WPR.C.

2.4.2 *WPR2 Integration with Platforms*

Although the work package is dominated by studies of a fundamental nature, a very practical cross-WPR activity has also been added to create synergy with the measurement activities of WPR1 and highlight innovative ideas emanating from WPR.2 and to stimulate interaction with WPR.6. The target platform today for this cross-WPR experimental activity is the second-generation www.openairinterface.org platform. The evolution of the hardware component of this platform is part of the research activity in WPC. This algorithmic component of the WPR2 activity will hopefully lead to synergies with WPC in 2009-2010, and, in fact, this is already planned. Such an activity was not envisaged initially but turns out to be a noteworthy element of the work in WPR.2 done up until this point. Firstly, it was decided that a measurement test bench be setup for the purpose of feedback signaling dimensioning. It is planned to collect more two-way MIMO channel measurements using the OpenAirInterface platform provided by CNRS/EURECOM in order to study the effects of the channel on the feedback signaling in the context of both TR2.2 and TR2.3. The first results (to be published in 2009) consist on feedback quantization strategies using measured channels (CTTC/Eurecom/UPC). Two sites were used so far, Sophia Antipolis and Barcelona/Bellaterra in both indoor and outdoor TDD at 1.9 GHz (MIMO/OFDMA 5 MHz channels) scenarios. More such tests are planned at both sites in 2008-2009. Practical studies related to exploitation of channel reciprocity (TR2.2) will also be carried out, in addition to MU-MIMO coding strategies (TR2.2 and TR2.3). A team from FTW working in WPR.1 will likely be added to this activity to create a cross-WPR JRA.

Perhaps the most important benefit of this activity will be felt during the dissemination day in March 2009, where some aspects of these activities will be demonstrated. Other demonstration were performed in 2008, notably at the IEEE PIMRC conference in Cannes and at the 2009 NEWCOM++ Winter School on Flexible Radio in Aachen. It will allow for tangible demonstration of some innovative ideas emanating from WPR2 and other WPR making use of the activity.

The use of the real-time OpenAirInterface.org DSP platform for advanced offline empirical system analysis in addition to channel measurement and modelling (WPR1, EURE/FTW). In the context of WPR2 it is used to analyze two-way MU-MIMO signalling strategies and their resulting system performance (EURE/CTTC/UPC and EURE/FTW in 2009). This is not carried out on simulated or modelled channels, but, rather, on real mobile MIMO channel traces. Some of this system measurement work is planned to be used in the context of real-time system emulation as stimulus for PHY abstraction modules in collaboration with WPR.3(EURE/NKUA) in 2009.

3 TR2.1 ACTIVITIES IN 2008 AND ACTIVITIES PLANNED FOR 2009

3.1 Fundamental Limits of Non-Coherent MIMO Communications (CNRS-EURECOM)

In [17] the authors consider stationary time- and frequency-selective MIMO channels where channel knowledge either at the transmitter or at the receiver is assumed to be unavailable. They investigate the capacity behavior of these doubly selective channels as a function of one of the system parameters, the number of transmit antennas, and channel parameters such as delay spread, Doppler bandwidth and channel spread factor (the product of the previous two parameters). They further describe different capacity regimes at high values of signal to noise ratio (SNR) in which the dominant capacity term is log(SNR) or log(log(SNR)), depending upon the channel conditions (delay spread, Doppler Bandwidth and channel spread factor). For critically spread channels (channel spread factor of 1), it is widely believed that the dominant term of the high-SNR expansion of the capacity is log(log(SNR)) or in other words, the pre-log (the coefficient of log(SNR)) is zero. They provide a very simple scheme showing that for critically spread and mildly overspread channels a non-zero pre-log might exist under certain conditions. They specify these conditions in terms of the Doppler bandwidth and the delay spread. They reason that for nearly critically spread channels, MIMO systems exhibit the same degrees of freedom as that of a SISO system. At higher channel spread factor (overspread case), the log(SNR) term vanishes and a log(log(SNR)) term becomes the dominant capacity term. They specify the range of existence for both log(SNR) and log(log(SNR)) regimes and also provide simple bounds for the coefficient of the log(log(SNR)) term (the preloglog). Reference [18] also reports on related work.

In [19], the authors analyze a broadcast channel with no initial assumption of channel state information neither at the base station (BS) nor at the users' side. For the case when there is no possibility of feedback to the BS and the BS remains oblivious of the channel state information throughout the transmission, it is shown that the capacity region is bounded by the capacity of a point-to-point MISO link and hence the pre-log of the sum rate is $(1 - 1/T)$ for a block fading channel of coherence length T. When the BS is allowed to acquire channel knowledge, operating under time-division duplex (TDD) mode, the authors give a very simple scheme through which BS and all users get necessary channel state information and the high SNR sum rate shows significant multiplexing gain or degrees of freedom (DOF). See [20] for related work in the FDD case.

3.2 High-SNR Analysis of Frequency-Selective MIMO Channels (CNRS-EURECOM)

Since the introduction of the Diversity-Multiplexing Tradeoff (DMT) by Zheng and Tse for ML reception in frequency flat MIMO channels, some results have been obtained also for the DMT of frequency-selective MIMO channels and for the DMT of suboptimal receivers such as linear (LEs) and decision-feedback equalizers (DFEs) for frequency-selective SIMO channels or frequency-flat MIMO channels. In [16] we extend these results to the case of linear receivers for frequency-selective MIMO channels. We consider infinite length and FIR equalizers in standard single-carrier systems, and unconstrained equalizers in cyclic prefix systems. For linear equalizers, the diversity gain suffers significantly in the absence of any Channel State Information at the Transmitter (CSIT), since only a part of the receive spatial diversity gets exploited (the transmit spatial and frequency-selectivity diversities are lost). It is shown that some improvement can be obtained by varying the number of streams transmitted. However, the introduction of simple antenna subset selection CSIT is shown to provide for substantial boosts in the resulting DMT (partial recovery of transmit spatial diversity).

This work will be extended by the ongoing research activity with UCL-UGent in the form of an investigation of high-SNR BER behavior of MIMO spatial multiplexing with ZF or MMSE equalization, and comparison with outage probability.

3.3 BER Analysis for Pilot-Assisted Receivers (UCL-UGent, UCL-UGent/CNRS-EURECOM in 2009-2010)

The work of UCL-UGent considered in [1]-[3] addresses analytical performance of orthogonal space-time block-codes (OSTBCs). This has most often been carried out under the assumption of Rayleigh block fading, whereby the channel remains constant over one fading block, and changes independently from one block to another. The authors provide an analytical expression for the bit error-rate (BER) of OSTBCs in case of minimum mean-square error (MMSE) channel estimation.

This work is planned to be extended by joint studies with CNRS-EURECOM. The focus will be on the investigation of channel estimation errors on the BER performance of a MIMO system with precoding and analog feedback of channel state information. This will build upon the previous results and those of CNRS-EURECOM (See section 4.3). This work will provide input to both TR2.1 and TR2.2.

3.4 Performance of MIMO-OFDM Under Non-ideal Channel Estimation (FTW-TUWien/CNIT-Polito)

The joint activity reported in [21] focused on the performance analysis of an OFDM-MIMO system complying with the emerging standard IEEE 802.11n. The authors designed and studied a receiver for accounting for realistic channel estimation through the use of pilot symbols located in the frame positions indicated by the emerging standard IEEE 802.11n. They furthermore analyzed the error performance of this receiver, which is called optimum receiver, and compared it against the error performance of a genie receiver (corresponding to ideal channel estimation) and a mismatched receiver (using estimated channel state information in the ideal channel metric). The optimum receiver considered here was derived by maximizing the posterior probability of the received signal given the transmitted and pilot signals, after averaging out the effects of the channel matrix. The system is based on ideal knowledge of the channel distribution at the receiver even though no knowledge of the instantaneous channel state information is assumed. The channel state information (in terms of the channel matrix) is not actually extracted explicitly but rather it is accounted for implicitly by considering the knowledge of the pilot signals. The authors addressed the receiver complexity in two steps. First, they developed an iterative expression of the receiver metric, which can be used for decoding trellis codes. Then, they implemented a spectral approximation technique, which allows a substantial reduction of the receiver complexity without any noticeable degradation in the error performance. Finally, they provided numerical evidence on the effects of actual estimation of the channel state distribution at the receiver. Their results show that the estimation of these statistical parameters has little impact on the error performance and does not represent an issue for practical receiver implementation.

3.5 Universal Code Design for the MIMO channel (CNRS-EURECOM/FTW-TUWien)

The work reported in [6] presented new eigenvalue bounds, necessary conditions and existence results for approximately universal linear (lattice) codes that can be drawn from lattices of reduced dimension, and can thus yield a reduced decoding complexity. Currently, for the mxn MIMO channel, all known mxT approximately universal codes, except for the Alamouti code for m=2,n=1 draw from lattices of dimension equal to or larger than mT, irrespective of n. Motivated by the case where $n<m$, the work describes construction criteria for lattice codes that maintain their approximate universality even when they are drawn from lattices of reduced dimensionality.

This work was later extended in [7]. Currently, for the $m \times n$ MIMO channel, any explicitly constructed space-time (ST) design that achieve optimality with respect to the diversity multiplexing tradeoff (DMT) are known to do so only when decoded using maximum likelihood (ML) decoding, which may incur prohibitive decoding complexity. The authors prove that MMSE regularized lattice decoding, as well as the computationally efficient lattice reduction (LR) aided MMSE decoder, allows for efficient and DMT optimal decoding of any approximately universal lattice based code. The result identifies for the first time an explicitly constructed encoder and a computationally efficient decoder that achieve DMT optimality for all multiplexing gains and all channel dimensions. The results hold irrespective of the fading.

4 TR2.2 ACTIVITIES IN 2008 AND ACTIVITIES PLANNED FOR 2009-2010

4.1 Differential Feedback in MIMO Channels Based on Geodesic Curves (CTTC/UPC)

This joint research work has been focused on the design of feedback strategies for MIMO communications. In general, these feedback schemes are needed in scenarios where channel reciprocity does not hold and, therefore, a feedback channel with limited capacity has to be used to send the channel state information (CSI) from the receiver to the transmitter. In this sense, proper quantization procedures to be applied to the channel estimates have to be designed. Following this idea, some authors proposed previously Grassmannian packaging, which is the optimum non-differential quantization strategy for zero-mean Rayleigh MIMO channels with independent components and where the transmitter is constrained to apply a uniform power allocation through the transmission modes. It was shown that, under this constraint, the transmitter only needs to know which is the subspace spanned by the strongest right singular eigenvectors of the MIMO channel matrix **H**. Based on this, the quantization is applied over the Grassmannian manifold, i.e., the set of all the possible subspaces .

Other authors applied the same constraint but exploiting a differential quantization, which makes sense in scenarios where the channel is slowly varying and, therefore, the temporal correlation can be exploited to improve the quality of the quantization. The proposed technique consisted in defining geodesic curves over the Grassmannian manifold, i.e., curves whose all their points are within such manifold, and which connect pairs of points in this space (i.e., subspaces) with a minimum distance.

In more general cases where the power allocation is not constrained to be uniform, the optimum linear signalling scheme depends on the MIMO channel correlation matrix, i.e., $\mathbf{R}_H = \mathbf{H}^H \mathbf{H}$ for any proper quality criterion such as mutual information, mean square error (MSE), signal-to-noise ratio (SNR), bit error rate (BER), among others. Note that in this case, the design depends on the right singular vectors of the channel matrix (and not only on the subspace spanned by them) in addition to the eigenvalues. Taking this into account, now the quantization should be applied over the set of correlation-like matrices, i.e., Hermitian and positive definite matrices, instead of the Grassmannian manifold.

In this joint research work we have developed and proposed a differential quantization algorithm to be applied to the channel correlation matrix exploiting the intrinsic differential geometry of the set of positive definite matrices and using geodesic curves. More concretely, we have proposed an algorithm that, at each iteration, defines a set of orthogonal curves in the set and identifies a set of candidate points which are the quantization proposals. The selection of the point to be fed back depends on the cost function that can be related to the specific measure of performance for the system or can be the geodesic distance to the exact channel realization.

Simulations results have proved that the proposed differential quantization technique provided all the expected advantages when compared to other feedback mechanisms that quantize only the subspaces or do not exploit the differential philosophy.

The main objectives for the future are related to the following points:

- study of the statistical behaviour of the proposed differential quantization strategy
- study of the impact of having an imperfect feedback link with a certain error probability in the transmission
- extension of the differential philosophy to multi-user scenarios

4.2 Differential Feedback Strategies for MIMO Communication Channels using Measured Real-time Channel Databases (CNRS-EURECOM/CTTC/UPC)

In this joint research activity reported in we have studied the performance of a recently proposed differential feedback scheme for multi-input-multi-output (MIMO) communication systems using real channel measurement data. The work builds upon the study (CTTC/UPC) in [30] (Section 4.1), supplemented by the real-time MIMO measurement activity at EURECOM. This feedback algorithm is applied to the channel correlation matrix exploiting geodesic curves and the intrinsic geometry of positive definite Hermitian matrices. The performance of this and a conventional non-differential feedback scheme has been evaluated using real data and channel measurements obtained with the Eurecom MIMO OpenAirInterface platform based on measurements in Sophia Antipolis and Barcelona (Bellaterra). Additionally, the impact of the realistic assumption of having a delay in the feedback link has also been studied in terms of a loss of performance in the communication through several simulations.

The results of this study have shown that the differential feedback strategy performs much better than the non-differential strategies in real low mobility channels, while in high mobility channels the performance is similar. A delay in the feedback channel especially affects high mobility channels while having a negligible impact in the slow-varying cases.

In order to cope partially with the reduction of the system performance due to the feedback delay, a channel prediction technique based on the linear Wiener filter has been proposed and studied. According to it, the quantization for the feedback link is applied to the predicted channel instead of the current one. Simulations results show that this allows to improve the system performance only in some cases, such as for the situation corresponding to a channel generated according to an auto-regressive model. In the case of real channels, the prediction does not seem to provide significant gains in performance.

The research will be continued in 2009-2010 focussing on the following areas

- acquisition of new channel data in different scenarios and mobility conditions
- evaluation of the system performance using more feedback strategies
- modelling and evaluation of having errors in the feedback link
- adaptation of the feedback strategies and channel measurements to different physical layer specifications of different standards
- inclusion of selected feedback mechanisms in a real testbed under real implementation constraints

4.3 Use of Analog Feedback in Two-way Communication (CNRS-EURECOM, UCL-UGent)

The work in [8]-[11] proposes the use complex orthogonal space-time block coding (COSTBC) in analog transmission with application to channel feedback. The authors show that an equivalent complex orthogonal channel can be generated by COSTBC and then the matched filter bounds on the signal-to-noise ratio via multiple-input multiple-output channels are achieved by maximal ratio combining (MRC). Simulation results show that under the constraint of short delay, COSTBC-MRC analog schemes outperform spatial-multiplexing oriented analog schemes and uncoded random vector quantization schemes with respect to mean-squared errors (MSE).

This work is planned to be extended jointly with UCL-UGent in 2009-2010 in conjunction with their work described as in Section 3.1.

4.4 Uplink Sum-Rate Analysis of a Multicell System with Feedback (Technion)

The capacity region of a Multiple Access Channel can be increased by feedback to the sources, since feedback enables cooperative transmission. Focusing on a linear cellular system (as for a highway or a corridor), a novel transmission strategy is proposed in [36] that exploits feedback from the neighboring mobile stations (MSs). The strategy enables cooperative communications via “analog network coding” (i.e., broadcasting and interference cancellation via side information) to exchange signalling information among MSs. Numerical results show that the proposed technique provides gains over non-cooperative strategies in the low-signal-to-noise-ratio regime.

4.6 Compressed Sensing of Analog Signals (Technion)

The rapid developing area of compressed sensing suggests that a sparse vector lying in a high dimensional space can be accurately and efficiently recovered from only a small set of non adaptive linear measurements, under appropriate conditions on the measurement matrix. This mathematical problem, considered in [38][41][42] finds application in the design of channel feedback encoding, since the dimension of the channel response is typically far less than that of the signal space. The vector model has been extended both theoretically and practically to a finite set of sparse vectors sharing a common sparsity pattern. In this paper, the authors treat a broader framework in which the goal is to recover a possibly infinite set of jointly sparse vectors. Extending existing algorithms to this model is difficult due to the infinite structure of the sparse vector set. Instead, the authors prove that the entire infinite set of sparse vectors can be recovered by solving a single, reduced-size finite-dimensional problem, corresponding to recovery of a finite set of sparse vectors. The authors then show that the problem can be further reduced to the basic model of a single sparse vector by randomly combining the measurements. Our approach is exact for both countable and uncountable sets, as it does not rely on discretization or heuristic techniques. To efficiently find the single sparse vector produced by the last reduction step, the authors suggest an empirical boosting strategy that improves the recovery ability of any given suboptimal method for recovering a sparse vector. Numerical experiments on random data demonstrate that, when applied to infinite sets, our strategy outperforms discretization techniques in terms of both run time and empirical recovery rate. In the finite model, our boosting algorithm has fast run time and much higher recovery rate than known popular methods.

5 TR2.3 ACTIVITIES IN 2008 AND ACTIVITIES PLANNED FOR 2009

5.1 Empirical Study of MIMO Precoding Strategies Using Measured Channel Databases (CNRS-EURECOM)

The performance of precoding for MIMO broadcast channels is often assessed using simplified channel models, such as the i.i.d. model. The assumption of an i.i.d. channel is often justified using the argument that the users are spatially separated and thus the signals arriving at different users will be independent even in the presence of a line of sight (LOS) component. However, it turns out that this assumption is not always true [14].

Real channel measurements to study the performance of precoding for MIMO broadcast channels. The channel measurements were be obtained using Eurecom's MIMO OpenAirInterface Platform [13]. The EMOS can perform real-time channel measurements synchronously over multiple users moving at vehicular speed. The measured channels are stored to disk for offline analysis.

This work will be done in close cooperation with WPR1, where the main goal is the acquisition, the characterization and the modelling of the channel. See deliverable DR1.1 for a more detailed description of the hardware platform.

One of the conclusions in [14] is that there is a very large gap between full feedback and quantized feedback. One possible extension/improvement of the work is to exploit time and frequency correlation in the analysis. The final objective is to take into account the correlations of the channel in different domains to minimize the quantity of the feedback information, or, what is equivalent, to increase the quality of the channel information and, consequently, also of the global system performance, with a constraint over the maximum load in the feedback link (for example, using differential quantization strategies in channels with temporal correlation).

In order to validate the designs developed in this framework, it is proposed to use realistic and measured data from real channels to reduce the gap between the real performance and the one predicted by mathematical models that, in general, are not able to accommodate all the possible effects and non-ideal behaviour that may arise in a practical deployment.

This work will be continued jointly with CTTC/UPC in 2009 in relation to the feedback mechanisms studied in (Sections 4.1,4.2) with a particular focus on implementation of algorithms for the MIMO-Broadcast channel.

5.2 Robust MIMO-Broadcast Precoding and Feedback Signaling Based on Cross-Layer Performance Measures and Imperfect Channel Estimation

The problems arising from having an imperfect CSI are especially significant in the case of multi-antenna multi-user systems, basically due to the fact that the number of parameters that describe the channel is much higher than in the single-user or single-antenna configurations. The imperfections in such channel knowledge have an impact on the increase of the levels of inner multi-user interference. Besides, in the multi-user case, the qualities of the information coming from different users may be quite different and therefore, the system should be able to accommodate in the design this heterogeneous information. Consequently, in multi-user multi-antenna systems, the adoption of a proper design strategy able to cope with imperfect CSI is critical to obtain an acceptable performance in a practical deployment.

Concerning the multi-user broadcast MIMO channel, there are several possible transmission architectures, going from linear to non-linear schemes and with different capabilities of adaptation. Each of these schemes has a different computational complexity and requires a different degree of channel knowledge. Some examples are the linear beamforming design, the non-linear approach based on the spatial Tomlinson-Harashima precoding, and the multi-beam opportunistic beamforming scheme (see [22] and references therein). The channel information required for each case is different (for example, the adaptive linear scheme requires a complete channel estimation, whereas the opportunistic solutions require only some SNR values).

In all the previous cases, although the needed quantity of information is different, this information is expected to be imperfect, i.e., to have some error. For example, in the case of adaptive linear precoding, the channel response has to be estimated. In this estimation process some noise will appear. Besides, in some cases this estimation has to be quantized by the receiver before feeding back that information to the transmitter, including an additional quantization noise. In the opportunistic scheme the SNR values have also to be quantized.

Taking all this into account, the work in [22]-[29] focuses on the development of robust schemes and designs that are able to jointly fulfil the constraints derived not only from the complexity, but also from the channel imperfections. These solutions control the increased levels of multi-user interference due to the imperfections in the channel knowledge. The designs are directly related to the quality of the channel estimation, are based on cross-layer design criteria for the definition of proper feedback mechanisms. In other words, the work focuses on the interactions between the multi-user robust schemes and the joint-design of feedback mechanisms.

5.3 Distributed MIMO Systems with Oblivious Antennas (Technion)

A scenario in which a single source communicates with a single destination via a distributed MIMO transceiver is considered in [31]. The source operates each of the transmit antennas via finite-capacity links, and likewise the destination is connected to the receiving antennas through capacity-constrained channels. Targeting a nomadic communication scenario, in which the distributed MIMO transceiver is designed to serve different standards or services, transmitters and receivers are assumed to be oblivious to the encoding functions shared by source and destination. Adopting a Gaussian symmetric interference network as the channel model (as for regularly placed transmitters and receivers), achievable rates are investigated and compared with an upper bound. It is concluded that in certain asymptotic and non-asymptotic regimes obliviousness of transmitters and receivers does not cause any loss of optimality.

5.4 Large Random Hermitian Jacobi Matrices with Application to Wireless Communication (Technion)

In [32] the authors study the spectrum of certain large random Hermitian Jacobi matrices which find application in distributed antenna processing across several BS (distributed MU-MIMO MAC). In particular the authors are interested in an uplink cellular channel which models mobile users experiencing a soft-handoff situation under joint multicell decoding. Considering rather general fading statistics the authors provide a closed form expression for the per-cell sum-rate of this channel in high-SNR, when an intra-cell TDMA protocol is employed. Since the matrices of interest are tridiagonal, their eigenvectors can be considered as sequences with second order linear recurrence. Therefore, the problem is reduced to the study of the exponential growth of products of two by two matrices. For the case where K users are simultaneously active in each cell, the authors obtain a series of lower and upper bounds on the high-SNR power offset of the per-cell sum-rate, which are considerably tighter than previously known bounds.

5.5 Information-Theoretic Implications of Constrained Cooperation in Simple Cellular Networks (Technion)

Recent information theoretic results on cooperation in cellular systems are reviewed in [33], addressing both multicell processing (cooperation among base stations) and relaying (cooperation at the user level). Two central issues are addressed, namely, first multicell processing is studied with either limited capacity backhaul links to a central processor or only local (and finite-capacity) cooperation among neighboring cells. The role of codebook information, decoding delay and network planning (frequency reuse) are specifically highlighted along with the impact of different transmission/ reception strategies. Next, multicell processing is considered in the presence of cooperation at the user level, focusing on both out-of-band relaying via conferencing users and in-band relaying by means of dedicated relays. Nonfading and fading uplink and downlink channels adhering to simple Wyner-type, cellular system models are targeted.

5.6 Scaling Laws and Techniques in Decentralized Processing of Interfered Gaussian Channels (Technion)

In [34], the authors investigate the achievable communication rates and the corresponding upper bounds of distributed reception in the presence of an interferer. The scheme includes one transmitter which communicates to a remote destination via relays, which forward messages to the remote destination through lossless links with finite capacities. The relays receive the transmission along with some unknown interferer. We focus on two common setting for distributed reception wherein the scaling laws, where the power of the transmitter and the interferer are taken to infinity, are completely derived. Lattices are found to be beneficial here, and provide schemes used to characterize the scaling law.

5.7 Outer Bounds for Broadcast Channels (Technion)

Outer bounds on the capacity region of broadcast channels are reviewed and a new outer bound is presented in [35]. This work provides tighter outer bounds to the capacity region of the general broadcast channel. This is a long standing open problem in information theory. This work could have implications to more general broadcast channel models corresponding to particular downlink scenarios in cellular communications. More explicit links regarding the application in wireless networks will be sought in 2009.

5.9 Zero-Forcing Precoding and Generalized Inverses (Technion)

In [39], the authors consider the problem of linear zero-forcing precoding design and discuss its relation to the theory of generalized inverses in linear algebra. This work applies directly to precoding strategies for MU-MIMO downlink communications. Special attention is given to a specific generalized inverse known as the pseudo-inverse. The work begins with the standard design under the assumption of a total power constraint and proves that precoders based on the pseudo-inverse are optimal among the generalized inverses in this setting. Then, the authors proceed to examine individual per-antenna power constraints. In this case, the pseudo-inverse is not necessarily the optimal inverse. In fact, finding the optimal matrix is nontrivial and depends on the specific performance measure. The authors address two common criteria for multiuser scheduling, fairness and throughput, and show that the optimal generalized inverses may be found using standard convex optimization methods. The authors demonstrate the improved performance offered by their approach using computer simulations.

5.10 The Rembo Algorithm: Accelerated Recovery of Jointly Sparse Vectors (Technion)

The authors of [40] address the problem of recovering a sparse solution of a linear under-determined system. This is a mathematical problem which finds application in the design of MU-MIMO precoding strategies for the downlink in cellular systems. Two variants of this problem are studied in the literature. One is the case of a sparse vector with only a few non-zero entries, and the other is of a sparse matrix with few rows non-identically zero. In either scenario, the recovery is known to be a difficult combinatorial procedure. In this paper, the authors develop a method that transforms the recovery of a sparse matrix into the vector formulation. Our method is exact as it allows one to infer the sparse matrix from a single sparse solution vector. Once reduced to this basic form, known sub-optimal methods can be employed to approximate the solution. In order to further improve the performance, the authors derive a prototype algorithm, called ReMBo, which combines a boosting approach together with the reduction process. The boosting stage empirically improves the recovery rate of any given sub-optimal method. Numerical experiments demonstrate the superior performance of ReMBo-based methods in comparison with popular algorithms in terms of run time and empirical recovery rate when tested on random data.

6 CONCLUSIONS

This deliverable presented an overview of the activities pertaining to feedback and imperfect channel estimation and the interplay between the two in the form that were considered in NEWCOM++ WPR.2. Their relation stems from the fact that feedback of channel state information has become an integral part of modern wireless networks (UMTS-HSDPA, UMTS-LTE, 802.16m), both from the point-of-view of resource scheduling and advanced multi-antenna signal processing and therefore the ability to resolve the channel at the transmitter is ultimately related to what can be estimated at the receiver. Moreover, we strongly believe that the analysis of such systems should be considered in the two-way setting since bandwidth for feedback does not come without a price.

We provided the integration activities with other WPR from the network in addition to an up-to-date description of the three tasks of WPR.2 namely, Imperfect channel estimation (TR2.1), Point-to-point and Point-to-multipoint, Two-Way Channels (TR2.2), and Precoding Techniques for the MIMO Broadcast Channels (TR2.3). Cross-WPR Integration efforts with platform activities were also described. We included the initial planning for new joint research activities during the second year of NEWCOM++.

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