507325 NEWCOM

WPR1 Research Integration for Department 1
Analysis and Design of Algorithms for Signal Processing at Large in Wireless Systems
March 2005 – September 2006

Authors:
- Leading Editor: Phillip A. Regalia
- Contributing Authors: Department 1 partners

1. Introduction

The past decade has witnessed major advances in reliable communications, having a direct impact on the volume and quality of services offered in all wireless systems. Key to these advances are the signal processing subsystems on which wireless communications are built. Despite notable recent gains in coding theory, multi-access techniques, algorithm design, and processing efficiency, the ever increasing demand for higher data rates pushes current generation designs to their practical limits. To ensure that future systems will not be confined to permanent saturation, major co-operative research efforts into the fundamental capabilities and limitations of wireless systems must be pursued, addressing the present knowledge gaps in a number of arenas: information-theoretic capacity limits in time-varying multi-user channels, short packet code design for two-way communications, optimal resource allocation strategies under quality of service constraints, and increased mobility requirements, to name just a few. Although the basic signal processing techniques exploited in wireless systems have become increasingly mature and specialised over the past few decades, recent trends indicate that the joint optimisation of the various signal processing subsystems is a necessary ingredient in solutions that are to meet future demands in wireless communications.

2. Organization of the Joint Research Activities

Newcom provides a privileged opportunity to co-ordinate research efforts towards tackling the shortcomings exposed by today's knowledge gaps, whose solutions can only provide a bridge to introducing next-generation techniques consolidating reliability and high performance measures. The first deliverable submitted by Department 1 (DR 1.1, report on “Knowledge Gaps, Action Plan, and Partners’ Skills”) identified no fewer than 10 major knowledge gap areas that we have organized into four Supra Work Packages, which are detailed as follows:

Supra Work Package 1: Iterative Decoding and Receiver Design

The activity cluster groups three principal thrusts:
- Error correction coding for short block lengths;
- Joint (turbo) receiver optimisation;
- Multi-bit per Hertz coding.

Conventional turbo codes and low density parity-check codes offer impressive error correction capabilities for very long blocks, but such block lengths impose latency delays that prove unacceptable for two-way communications or other mobile applications. The error-correction capabilities for more modest block lengths are more nuanced: certain configurations work well in controlled laboratory conditions, but robustness issues once such codes are exposed to hostile real-world environments still present many open questions (cf. Deliverable 1.1). Thus the first thrust serves to extend the gains of high-performance codes to moderate block lengths, of greater interest in all mobile and interactive applications.

The second thrust seeks to extend the performance advantages of iterative decoding to interconnected receiver components, as has previously been evidenced by turbo equalisers, turbo synchronisers, turbo detectors, and so forth. Many of these schemes perform well in controlled laboratory conditions, but can give unpredictable behaviour when released in to the real world. This effort aims therefore to demystify the turbo principle which underlies iterative receiver design, aiming to interface theoretical analyses involving information-theoretic exchanges into sound engineering design principles for iterated receiver structures that should converge reliably to near-maximum-likelihood solutions.

The final thrust of this activity cluster seeks to overcome the traditional 1 bit/sec per Hertz of channel bandwidth that limits the data rate conventional communication systems since, at this rate, wireless communication channels will rapidly be saturated by the ever-growing number of wireless devices. A key component involves higher-order modulations in the mathematical setting of Galois fields, and the practical realisation of coding and decoding structures that offer rate adaptation and constellation changes in order to optimise the throughput versus error-rate trade-off. The results of this activity cluster should prove useful to Department 4 in the context of efficient turbo decoder realizations.

Supra Work Package 2: Signal Processing for MIMO Systems

This activity combines multi-user space-time coding, and in particular coding and signal design for OFDM and MIMO systems. Since the introduction of the Alamouti coding scheme, researchers have revised traditional shared and broadcast channels in order to deduce capacity regions and effective coding, co-operation, and sharing strategies among users which can approach extreme points in the identified capacity regions. Critical to these strategies are the code construction techniques, which will be developed in the context of OFDM applied to MIMO channels. The various design principles will be unified during this work, adopting the viewpoint that all space-time codes can be perceived in terms of fundamental compromises between spatial diversity, temporal diversity, and coding diversity. We anticipate interaction with Project C on the subject of resource allocation as the work progresses. Equally important in this direction is signal design at the physical layer, which impacts the peak-to-average power ratio, the ability to deduce channel state information, robust and scalable designs at transmitting and receiving and the exploitation of blind data acquisition. Critical to testing the validity of the techniques developed will be their practical verification using the MIMO channel models that Department 2 aims to measure and develop.

Supra Work Package 3: Advanced Signal Processing Algorithms and Mobility

Traditional wireless technologies are confronted with new challenges in meeting the ubiquity and mobility requirements of cellular systems. Hostile channel characteristics and limited bandwidths in wireless applications provide key barriers that future generation systems must cope with. Advanced signal processing methods, such as

- The expectation-maximisation (EM) algorithm;
- The SAGE algorithm;
- The Baum-Welch algorithm;
- Per-Survivor processing;
- Kalman filters and their extensions;
- Hidden Markov modelling;

- Sequential Monte Carlo filters;
- Stochastic approximation algorithms;
- Sphere decoding and convex relaxation techniques (semidefinite relaxation) for detection.

in collaboration with inexpensive and rapid computing power provide a promising avenue for overcoming the limitations of current technologies. Applications of advanced signal processing algorithms mentioned above include, but are not limited to, joint/blind/sequence detection, decoding, synchronisation, equalisation as well as channel estimation techniques employed in advanced wireless communication systems such as OFDM/OFDMA, Space-Time-Frequency Coding, MIMO, CDMA and with Multi User Detection, Time- and Frequency-Selective MIMO channels. Especially, the development of suitable algorithms for wireless multiple-access systems in non-stationary and interference-rich environments presents major challenges. While considerable previous work has addressed many aspects of this problem separately, e.g., single user-channel equalisation, interference suppression for multiple access channels and tracking of time varying channels, the problem of jointly combating these impairments in wireless channels has only recently become significant. On the other hand, the optimal solutions often present a prohibitively high computational complexity, impeding thus their implementation. The statistical tools offered by the advanced signal processing techniques above have provided a promising new route for the design of low complexity signal processing algorithms with performance approaching the theoretical optimum for fast and reliable communication in the highly severe and dynamic wireless environment.

Although over the past decade such methods have been successfully applied in a variety of communication contexts, many technical challenges remain in emerging applications, whose solutions will provide the bridge between the theoretical potential of such techniques and their practical utility.

Key knowledge gaps here concern:

i. Theoretical performance and convergence analyses of these algorithms;

ii. New efficient algorithms need to be worked out and developed for some of the problems mentioned above;

iii. Computational complexity problems of these algorithms when applied to on-line implementations of some algorithms running in the digital receivers must be handled;

iv. Implementation of these algorithms based on batch processing and sequential (adaptive) processing depending on how the data are processed and the inference is made has not been completely solved for some of the techniques mentioned above;

v. Some class of algorithms requires efficient generation of random samples from an arbitrary target probability distribution, known up to a normalising constant. So far two basic types of algorithms, the Metropolis algorithm and the Gibbs sampler have been widely used in diverse fields. But it is known that they are substantially complex and difficult to apply for on-line applications. There are gaps for devising new types of more efficient algorithms that can be effectively employed in wireless applications.

vi. Although the research on Sequential Monte Carlo signal processing has recently started, many optimal signal processing problems found in wireless communications, such as mitigation of various types of radio-frequency interference, tracking of fading channels, resolving multipath channels dispersion, space-time processing by multiple transmitter and receiver antennas, exploiting coded signal structures represent few problem waiting for to be solved under the powerful Monte Carlo signal processing framework.

Many of the scenarios under study find application in the design of Ad Hoc networks, for which we anticipate interactions with Department A. Similarly, much of the work on mobility tracking should integrate elements from Department 7 which include Quality and Service as it relates to mobility..

Supra Work Package 4: Large Scale, Large Band, and Asymptotic Systems

With increasing numbers of users sharing limited resources, and with the recent availability of wide band or ultra wide band portions of the spectrum, it is important to understand the complex dynamics of such "large-scale" systems. Increased numbers of users, antennas, and channel bandwidths normally translate into larger numbers of (potentially nonlinear) interactions, leading to more complicated and potentially intractable models. In such a context, basic parameter estimation problems are more difficult and new solutions need to be derived. As various system parameters such as the number of users, the available channel bandwidth, or the number of antennas of a MIMO system, become large, the system behaviour can, subject to certain technical assumptions, be shown to converge to a system described by few parameters. Such systems are more tractable analytically, which opens possibilities to improve estimation of the channel and certain performance measures, as well as to optimise load factors, frequency re-use, and power distribution profiles, and many more. It is also important to examine to what extent these asymptotic results scale down to moderately or heavily loaded systems. Topics of research in this direction will include the following subjects:

- *MIMO Systems*: Capacity analysis of MIMO Ricean channels with correlation for various types of models (Kronecker product model, virtual representation). Determining the asymptotic behaviour of the non-ergodic mutual information in order to cope with metrics such as outage rate. Output SINR for various types of receivers.
- *CDMA/MC-CDMA Systems*: Design of multi-user receivers. Performance analysis of CDMA/MC-CDMA for downlink and uplink systems with attention to frequency reuse factor. Extension of analysis to the multi-cell case. Implications on radio resource management methods for such systems. Investigation of synchronous and asynchronous downlinks and uplinks. Performance analysis of channel estimation algorithms.
- Finite size behaviour and convergence analysis: Study of deterministic approximations of the performance measures in the finite size regime. Convergence study of the performance measures toward their large system limits.

These items will involve interactions with Department 1, SWP2 "Signal Processing for MIMO Systems" and Department 2, WP2.1.3 "Analysis and Validation of MIMO Channel Models".

A parallel, but equally important consideration, is wide band system scalability of conventional modulation schemes such as CDMA or OFDM. Recent theoretical works show that large bandwidths over fading channels cannot be effectively utilised by systems that spread the signal power uniformly over time and frequency. Rather, peaky signalling schemes, which concentrate the signal power in both time and frequency, can attain channel capacity. What lies behind this phenomenon is that each signalling scheme requires a specific set of channel parameters to be estimated before successful detection can be carried out. Spread-spectrum systems, in particular CDMA, do not scale well when the bandwidth is increased, because channel estimates deteriorate as the bandwidth is increased. This casts doubts on the feasibility of wideband CDMA technology in meeting future wireless system requirements. There is need to study from a fundamental perspective the capacity and signalling problems related to next generation wireless systems to identify if present methods will encounter insurmountable scalability problems. Research in this direction will focus on the following subjects in ultra wide band (UWB) systems:

- *Capacity and achievable rates*: Estimating the UWB channel capacity, in particular, for the channel models specified by IEEE 802.15.3a group. Determining the achievable rates by various UWB signalling schemes, including OFDM, coded OFDM (COFDM), MIMO-OFDM, and pulse position modulation schemes. Implications of partial channel state information (CSI) at the transmitter. Investigation of time reversal signalling.

- *Interference Issues:* Effects of narrow-band interferers on wideband system performance. Co-existence with other wide band systems.

These items will involve interactions with Project B on ultra wide band systems.

3. Supra Work Package Descriptions and Partner Involvement

Total estimated person-month effort per partner in the next 18 months:

Workpackage number	WPR1	Start date of starting event:	T1
Work Package Leaders:	Phillip Regalia (GET – 17) and Luc Vandendorpe (UCL – 38)		

Activity Type:	Joint Research Activities

Participant id	NKUA	Technion	Bilkent	ISIK	UPC	CTTC	UPF
Person months	3.6	13.5	2.1	2.5	2.1	3.5	4.5
Participant id	UoP	Polito	STM	GET	Supelec	CNRS	FranceT
Person months	8.7	8.4	2.4	30	8.4	25	14
Participant id	Eurecom	Intracom	VUT		ETH	LNT-TUM	TUA
Person months	11.5	2	4		20	12	1.2
Participant id	UEN	DLR	CNIT	FTW		PUT	UGent
Person months	9	2	8	17		7	3
Participant id	UCL	ESA	AAU	Chalmers	LU	NTNU	UiB
Person months	4	1.5	1.5	1.5	1.5	5	4.5
Participant id	NERA	UoSo	UoE	KTH	UoY	ISMB	
Person months	1.5	4.8	8.7	1.5	1	2	

Details of individual work packages follows:

3.1 Supra Work Package 1:

Workpackage number	WPR1-SWP1	Start date or starting event:	T1

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Part id	FT (21)	VUT (24)	LNT-TUM (28)	TUA (29)	DLR (31)	CNIT (32)
Part id	FTW (34)	PUT (36)	UCL (38)	UGent (39)	AAU (41)	Chalmers (42)
Part id	LU (45)	UiB (49)	UoSo (51)	UoE (53)	UoY (61)	ESA (40)

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Objectives

The supra work package consists of the following parts with the corresponding objectives:

1. Error correction coding for modest block lengths

The overall objective is to reconcile conflicting constraints between decoding complexity, decoding delay, and low bit error rate, using the scientific methods as detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Theoretical bounds of bit error rates which encompass decoding delay constraints, finite (but potentially non-binary) alphabets, information theory adapted to linear codes and finite complexity decoding, and realistic channel conditions. This thrust is a clean break from traditional Shannon theory, which allows for potentially infinite length codes, arbitrarily large decoding complexities, and continuous amplitude signalling, over additive white Gaussian noise channels.
(T1 + 12).

Demonstrable: Practical development of rate-compatible codes, adaptive modulation dependent on time-varying channel conditions, refined tail-biting code structures, and extensions to Galois field alphabets for higher bit rates. The achieved performance levels will be gauged against the theoretical bounds to be obtained above. (T1 + 18)

2. Joint (turbo) Receiver Optimisation

The overall objective is to demystify the turbo principle so that interconnected receiver components can be reliably designed to exchange information and converge to near maximum likelihood solutions, thereby obviating the present-day dependence on black magic and divine intervention. The scientific methods that are to be used are detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Refinement of information geometry and extrinsic information interchange, aiming for analytic descriptions of convergent regions, domains of attractions, and sufficient prior information to trigger the turbo effect. (T1 + 18).

Demonstrable: Integration of all estimation phases for channel state information, carrier synchronisation, and multi-user loading profiles, into adaptive schemes for turbo synchronisation, turbo detection, and turbo multi-user decoding. Comparisons with maximum likelihood solutions will be carried out, with simplified structures offering minimal performance hits in exchange for vastly reduced processing complexity favoured. (T1 + 18)

3. Multi-bit per Hertz Coding

The overall objective is to develop practical, robust techniques for attaining signaling rates above 1 bit/second per Hertz of channel bandwidth, using the scientific methods detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Assessment of the performance limits of coset codes, multilevel codes, and bit-interleaved codes over Galois fields which transmit many bits per symbol, and the development of optimum bit mappings for high performance systems, for which conventional Gray mappings may prove suboptimal. (T1 + 12).

Demonstrable: Optimisation of Galois-field low density parity check and turbo codes, interleaved trellis coded modulation, and bit mapping by set partitioning techniques, aiming initially for 3 bit/s per Hertz data rates in reasonably adverse propagation environments, and hopefully higher rates in follow-on efforts. (T1 + 18).

Deliverables:

DR1-SWP1.1: Report on Analytic Milestones for Error Correction Coding, Turbo receiver optimization, and multi-bit per Hertz Coding (T1 + 12, T1 + 18).

Milestones:

Department 1 Workshops and Progress Review I (T1 + 6)
Department 1 Workshops and Progress Review II (T1 + 12)
Deliverable DR1-SWP1.1 (T1 + 18)

3.2 Supra Work Package 2:

Workpackage number	WPR1-SWP2	Start date or starting event:	T1

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Part id	NKUA (02)	Technion (05)	UPC (08)	CTTC (09)	CNRS (19)	FT (21)
Part id	Eurécom (22)	ETH (26)	UEN (30)	DLR (31)	CNIT (32)	FTW (34)
Part id	PUT (36)	NTNU (48)	UoSo (51)	KTH (58)	UoY (61)	VUT(24)
Part id	GET (17)	Supelec (18)	UU(44)	UCL(38)		

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Objectives

The supra work package consists of the following parts with the corresponding objectives:

1. *Multi-user Space-Time Coding*

The overall objective is to reconcile fundamental trade-offs between attainable capacity regions and user coding/allocation strategies which minimise user collision in time, frequency, and code spaces, in order to derive high-performance scheduling and detection algorithms, using the scientific methods that are detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Develop a unified framework for multi-access and broadcast channels in which the influence of user scheduling and multi-user detection can be related to attainable performance bounds. Autonomous and joint cooperative diversity and scheduling will be related to diversity techniques in assessing performance bounds. (T1 + 12).

Demonstrable: Emerging techniques exploiting soft interference cancellation, linear periodic time-varying filters, adaptive bit allocation and loading strategies, and cooperative optimisation, will be developed in the context of large area synchronized CDMA systems. (T1 + 18)

2. *Coding Design for OFDM and MIMO Systems*

The overall objective is to develop a unified framework in which the promise of improved channel capacity of multi-antenna systems correctly addresses unknown channel coefficients, variable loading factors, space, time, and frequency diversity, and multi-user interference, using the scientific methods that are detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Unified view of all space-time coding schemes, rendering transparent the various trade-offs in resource allocation, multi-user efficiency, carrier correlation, and relations to “dirty paper” coding techniques. (T1 + 12).

Demonstrable: Develop workable linear precoding schemes, adaptive codeword generation, resource allocation with and without feedback, and low complexity detection schemes. (T1 + 18)

3. Signal Design for OFDM and MIMO Systems

The overall objective is to pursue signal design aiming to reconcile all performance parameters related to multi-code frame allocation, multi-user capacity, Delay- and Doppler-diversity schemes for differentially modulated OFDM systems, peak-to-average power ratio, and pulse shape design, using the scientific methods detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Develop theoretical limits on performance versus peak-to-average power ratios, integrating the influence of pulse shape design, partial channel state information, and signal-to-noise ratio. Also Performance bounds for channel and carrier frequency offset estimation in the uplink of an MIMO-OFDMA system. Training sequence design for MIMO-OFDMA. Finally, capacity study and signal design in the uplink of an OFDMA system. (T1 + 12).

Demonstrable: Exploit adaptive beam forming, iterative decoding, channel estimation, pilot information, and non coherent detection, to develop robust OFDM processing algorithms functioning in multi-antenna systems and approaching theoretical performance limits developed in the analytic phases. (T1 + 18).

Deliverables:

DR1-SWP1.2: Report on Analytic Milestones for Multi-user space-time coding, coding design and signal design for OFDM and MIMO systems. (T1 + 12, T1 + 18).

Milestones:

Department 1 Workshops and Progress Review I (T1 + 6)
Department 1 Workshops and Progress Review II (T1 + 12)
Deliverable DR1-SWP1.2 (T1 + 18)

3.3 Supra Work Package 3:

Workpackage number	WPR1-SWP3	Start date or starting event:	T1

WP leaders	Erdal Panayirci (ISIK – 07)

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Part id	ETH (26)	LNT-TUM (28)	DLR (31)	UGent (37)	UCL (38)	AAU (41)
Part id	UoSo (51)	KTH (58)				

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Objectives

This supra work package consists of the following parts with the corresponding objectives:

1. Advanced Signal Processing Algorithms for Wireless Communications

The overall objective is to adapt high-performance and optimal statistical signal processing algorithms to combat imperfections in hostile communication environments, with complexity optimisation to render such algorithms suitable for real-time implementation on present-generation hardware, using the scientific methods that are detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Theoretical bounds on the complexity/performance trade-off inherent to advanced algorithms, including the EM, Baum-Welch, SAGE, Kalman and particle filter, hidden Markov model, sequential Monte Carlo, and stochastic approximation algorithms. (T1 + 18).

Demonstrable: Working optimised algorithms for parameter estimation, synchronisation, multi-user detection, diversity exploitation, equalisation, adaptive coding, and sphere decoding. (T1 + 18)

2. User Mobility Tracking and Hand-off Algorithms

As a validating application of the above techniques, the objective is understand the nonlinear dynamics which intervene in roaming, cell hand-off, and mobility tracking, in view of overcoming limitations of present-generation Kalman filter tracking approaches, and aiming for seamless, cost effective hand-off algorithms suitable for future generation systems, using the scientific methods that are detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Development of refined nonlinear dynamic models for user mobility, and the suitability of advanced Monte Carlo techniques in solving mobility tracking problems. (T1 + 12).

Demonstrable: Investigation and development of timing and angle estimation using smart antennas, location updating using fuzzy logic, wireless position parameterisations, and improved estimation of line of sight delays, with the aim of providing seamless hand-off algorithms for wireless local area

networks. (T1 + 18)

Deliverables:

DR1-SWP1.3.1: Report on User mobility tracking and hand-off algorithms. (T1 + 18).
DR1-SWP1.3.2: Report on Advanced Signal Processing algorithms for Wireless Communications. (T1 + 18).

Milestones:

Department 1 Workshops and Progress Review I (T1 + 6)
Department 1 Workshops and Progress Review II (T1 + 12)
Deliverable DR1-AC1.3.1 (T1 + 12)
Deliverable DR1-AC1.3.2 (T1 + 18)

3.4 Supra Work Package 4:

Workpackage number	WPR1-SWP4	Start date or starting event:	T1

WP leaders	Erdal Arikan (Bilkent – 06) and Ralf Müller (NTNU – 48)

Part id	Bilkent (06)	CTTC (09)	Supélec (18)	CNRS (19)	FT (21)	Eurécom (22)
Part id	VUT (24)	ETH (26)	TUA (29)	DLR (31)	FTW (34)	NTNU (48)
Part id	UoY (61)	NKUA (02)	Technion (05)			

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Objectives

The SWP consists of the following parts with the corresponding objectives:

1. Large-Scale Multi-user and Multi-antenna System Analysis

The overall objective is to adapt techniques from statistical physics and random matrix theory to gauge asymptotic performance regimes in systems having large numbers of users, large numbers of antennas and/or large number of cells. The aim is to devise signal processing strategies to cope with heavily loaded multi-access systems, and to design multi-access methods to improve spectral efficiency in cellular wide-band systems. Scientific methods that are detailed on a per-partner basis in Deliverable 1.1 will be applied. The tasks involve both analytic and demonstrable milestones:

Analytic: Application of random matrix theory to handle frequency selective, Ricean, synchronous and asynchronous channels, multi-user interference, and spectral loading factors. Performance analysis of channel estimation algorithms in the large system regime. (T1 + 18).

Demonstrable: Tutorial paper on analytic tools for large scale multi-user and multi-antenna systems. Preparation of a proposal to organize a doctoral school on the applications of random matrix theory in wireless communications. Development of multi-user detection algorithms adapted to up-link and down-link communications under heavy user load based on nonlinear iterative algorithms. Radio resource management methods for MC-CDMA will be evaluated. (T1 + 18)

2. Wide Band System Scalability

The global objective is to evaluate attainable capacity in wide-band systems and develop signaling schemes using the scientific methods that are detailed on a per-partner basis in Deliverable 1.1. The tasks involve both analytic and demonstrable milestones:

Analytic: Assessment of theoretically achievable rates in ultra wide-band systems of various candidate schemes proposed for normalization within the IEEE 820.15.3 Personal Area Network group, and their scalability with respect to bandwidth. In addition, achievable rates by time-reversal signaling will be studied. Effects of various types of interference on system performance will be studied. The influence of channel state information on system capacity will be assessed. (T1 + 18).

Demonstrable: Simulation packages in Matlab or IT++ will be developed and made available to the NEWCOM Software Library. (T1 + 18)

Deliverables:

DR1-SWP1.4.1: Report on Large Scale System Analysis. (T1 + 18).
DR1-SWP1.4.2: Report on Wideband System Scalability. (T1 + 18).

Milestones:

Department 1 Workshops and Progress Review I (T1 + 6)
Department 1 Workshops and Progress Review II (T1 + 12)
Deliverable DR1-SWP1.4.1 (T1 + 18)
Deliverable DR1-SWP1.4.2 (T1 + 18)