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ACE - Antenna Centre of Excellence

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Recommendations for the Deployment of Smart Antennas in Future Systems

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Executive Summary

In this deliverable, the joint research activities within the framework of ACE in the area of Context Aware Optimisation and Deployment Issues for Smart Antenna Networks are presented. The main objectives of joint research activities were to maximise integration among the ACE partners and spread the excellence through education and dissemination within the ACE community and to the European and international research community.

At the beginning of the ACE project the partners with expertise on these research themes were faced with the challenge to coordinate the existing knowledge and skills and come up with a common workplan for interaction, collaboration and dissemination of the knowledge at the European and global level. To this end the state-of-the-art was reviewed and knowledge gaps were identified. Based on the identified knowledge gaps, integration was achieved by organising joint research activities around two main tasks: 1) The design of robust techniques, which use side (contextual) information about the network status in order to optimise its performance at system level and 2) realistic performance evaluation of smart antenna systems through comparative studies of the trade-off among complexity, efficiency and cost for a number of promising techniques and architectures.

Along the lines of the above research themes the ACE partners have worked on spreading the excellence by organising short courses and supervising Masters and PhD projects in this area. Moreover, the research activities have been disseminated extensively on national, European and international level. Finally, two major dissemination/spreading the excellence events, one workshop and one special session at a conference, were successfully organised by ACE and attracted the interest of the European and international research community.

Table of contents

1 Introduction

Recent studies indicate that the overall system performance of Smart Antenna networks can be enhanced by taking into account higher layers of the OSI/ISO (Open Systems Interconnection model of the International Standards Organization) protocol stack. Smart Antenna techniques can be developed combining parameters in the physical, link (Medium Access Control - MAC, Data Link Control - DLC, scheduling, etc) and network layers (radio resource management, routing, transport, etc), that is, in a cross-layer fashion rather than attempting to optimize the designs in isolation of one another.

In this deliverable, the design of robust techniques, which use side (contextual) information about the network status in order to optimise its performance at system level, is being investigated. **Context aware MIMO network optimisation** will allow for enhanced performance and more intelligent applications based on the exploitation of another (fifth after time, frequency, code and space) source of diversity: network contextual information, such as traffic pattern tracking/prediction tracked data versus voice type of traffic etc.

Furthermore, the issues associated with the **deployment of Smart Antenna technologies in future wireless systems**, in terms of performance versus costs analysis for the operators and associated risks, are considered. Based on this type of analysis, technology roadmaps along with their associated risks can be concluded, which will enable appropriate technology intercept points to be determined, resulting in the development of technologies appropriate for each application area.

At the beginning of the project, several institutions in Europe performing first-rate research on these topics, were faced with the challenge to coordinate the expertise and skills in the area and come up with a common plan for interaction among researchers, directions of future research and dissemination of the knowledge and expertise at the European and global level.

The objective of the first part of the project has been to review the state-of-the-art and to identify the knowledge gaps. The identification of gaps has provided the grounds for drawing a specific action plan for interaction, collaboration and dissemination activities.

1.1 Progress towards objectives

Research Activities:

The research activities described in the deliverable have been structured around two tasks:

- **Context Aware Network Optimisation Strategies**: Design of robust techniques, which use side (contextual) information about the network status in order to optimise its performance at system level.
- **Smart Antenna Deployment in Future Systems**: The scope of this activity is to provide realistic performance evaluation of smart antenna systems. Comparative studies to provide the trade-off among complexity, efficiency and cost for a number of promising techniques and architectures will be carried out.

Integration Activities:

The integration activities carried out can be summarized as follows:

- **Identification of scientific and technical know-how.** An extensive review of the technical and scientific know-how of each partner has been carried out, in order to identify the potential ground for collaboration and the open knowledge gaps. The scientific and technical know-how was specified based on past collaborations in research projects, simulation platforms development and publications.

- **Identification of knowledge gaps**. Based on the review of state of the art and the identified know-how and research interests of the partners, the work has been structured around the two tasks as described above. For each task, identification of the most important/interesting knowledge gaps has been made and an action plan for future research collaboration and integration activities has been formulated.
- **Elaboration of an action plan for collaboration.**
  - UPRC and LUCENT collaborate on Context Aware Smart Antenna Network Optimization techniques. Joint conference publications have been presented and a journal publication is under preparation.
  - UPM, UPRC, KTH, IT and LUCENT are collaborating on evaluating network planning strategies for smart antenna systems.

These integration activities have been planned and monitored through several work package meetings and phone conferences. All partners are represented at the meetings and actively participate by giving technical presentations and being involved in the discussions. (The meeting minutes and partners presentation can be found on the VCE.)

Spreading the Excellence and Education Activities:

- PhD students in KTH, IT and UPM are currently focusing their research on Smart Antenna network optimisation and deployment issues.
- Short courses on smart antenna systems were taught by UPM professors.
- A course on future wireless systems featuring network optimization and smart antennas has been taught to UPRC students.
- A presentation by IT was made to the staff of Portugal Telecom Inovação on the activities carried out under the ACE framework.

Dissemination Activities:

The work developed under the umbrella of this work package has been submitted to and published in several journals, such as:

- IEE Electronics Letters
- IEE Proceedings in Communications
- IEEE Communications Magazine
- IEEE Wireless Communications Magazine

and international conferences, such as:

- IEEE Vehicular Technology Conference
- IEEE Sensor Array and Multichannel Signal Processing Workshop.
- IEEE PIMRC
- IEEE GLOBECOM
- WWRF meetings.

Moreover, ACE activities have been disseminated extensively on national and European level, including IST events, such as the IST concertation and clustering activities, the IST Mobile Summit.

Finally, two major dissemination/spreading the excellence activities were carried out:

- A special session on Cross-layer PHY-MAC/scheduling designs was organised at the IEEE PIMRC 2005 conference in Berlin (September 11 - 14, 2005). Moreover, two of the members of the Scientific Council participated in this conference as keynote speakers.

- An ACE workshop on Smart Antennas was organized at the IST Mobile Summit 2005, in Dresden (23 June 2005).

2 Joint Research Activities

2.1 Context Aware Smart Antenna Network Optimisation

Wireless communications, still standing at the forefront of the international research community interest, comprise a multiplicity of Radio Access Technology (RAT) standards. The most common include first cellular systems, such as GSM (Global System for Mobile communications) [19], GPRS (Generalized Packet Radio Service)[20], UMTS (Universal Mobile Telecommunications System) [21] and its evolutions, like High-Speed Downlink Packet access (HSDPA) [22]. Then there are shorter range systems, like BRAN (Broadband Radio Access Networks) [23], WLAN (Wireless Local Area Networks) [24] and even WMAN (Wireless Metropolitan Area Networks) and [25] finally, broadcasting systems like DVB (Digital Video Broadcasting) [26].

Moreover, the most recent trend in the communications landscape is the convergence of the set of identified RATs, towards a global system operating over a heterogeneous access infrastructure, namely the "*Beyond the 3rd Generation (B3G) wireless access infrastructure*", with the aim to offer seamless mobility in a cost effective manner. Major facilitator of the B3G vision is the evolution of adaptive (reconfigurable) networks [27]. Adaptive networks allow their segments to dynamically select and configure the set of the most appropriate RATs, in order to better handle service area region or time requirements.

In such a diversified context with time and place variant traffic conditions, there will be no exact separation between planning and management of networks, but innovative design and management mechanisms need to be defined, in order to guarantee for the best possible network operation. The work conducted during the first phase of ACE embraces the issue of B3G networks design and management, utilizing Smart Antennas technology, which is envisaged to incur significant benefits with respect to their operational characteristics.

For this purpose, the next section gives the motivation for this work, emphasizing on the state of the art on context aware network optimization and the manner in which it can prove beneficial for future systems. Then, the functionality for the design and management of wireless networks is described and formulated, along with indicative simulation results from its application in a real-time network

2.1.1 Smart Antenna Network Optimisation

Smart Antenna systems can improve the link quality, by combating the effects of multipath propagation or constructively exploiting the different paths, and increase capacity by mitigating interference and allowing the transmission of different data stream from different antennas. More specifically the benefits of Smart Antennas ([1],[28]) can be summarized in the provision of increased coverage, the increased spectral efficiency, the lower power requirements and cost, as well as the improved link quality/reliability.

The adoption of Smart Antenna techniques in future generation wireless systems as an inherent part of the system design and in a cost efficient fashion would require the consideration of critical parameters such as the variation of the propagation and traffic conditions and the transparent operation across different wireless systems and platforms. Reconfigurability in the form of adaptivity to the variation of these critical parameters has been studied in [1].

2.1.1.1 Performance Optimization Aspects

The overall system performance of a network employing smart antennas can be enhanced by finding ways to account for criteria associated with the upper layers in the OSI stack. For instance, resource management functions, such as scheduling, can benefit from smart antenna algorithms at the physical layer. This means that the smart antenna techniques are developed in close collaboration with designs at the physical, link (MAC, DLC, scheduling, etc) and network layers (radio resource management, routing, transport, etc), in a cross-layer fashion rather than attempting to optimize the designs of different layers functionalities in isolation of one another. Within the framework of cross layer optimization, user- and/or environment-related contextual information can be used to enhance Smart Antenna systems performance. More specifically, location-related information such as user position, velocity and orientation, surrounding propagation environment, interference parameters, traffic distribution, region-specific statistics and user profile data can be used to centrally optimize multiple antenna wireless networks, by making the best use of wireless resources, aiding user seamless experience and network reconfiguration across heterogeneous networks and for a variety of services and applications.

2.1.1.2 Design and Management Scenarios

Depending on the type of information exploited, two main scenarios will be considered in the optimization of Smart Antenna Systems:

- <u>Scenario 1 - Optimization based on network-related information</u>: Adaptation to traffic patterns is can be pursued by employing –for instance– fixed beam switching or adaptive beamforming in order to illuminate areas with the highest traffic density. Optimal transmission in this case is achieved by maximizing the transmitted power towards the wanted directions and minimizing the generated interference.
- <u>Scenario 2 - Optimization based on user-related information</u>: Information of the user location and the associated QoS can be exploited in order to optimize both multiple antenna transmission and multi-user scheduling.

2.1.2 ACE Partners Know-How and Identified Knowledge Gaps

The ACE partners bring into the network an impressive record on:

- Multiple antenna transceivers design
- Reconfigurability in transceiver design
- Multi-user scheduling
- System level analysis of multiple antenna systems
- Optimisation of wireless network based on cross layer information
- Optimisation of wireless networks employing a multiplicity of RAT standards

During the first phase of the work in ACE, the partners have investigated the state of the art and exchanged views on future directions of research in the framework of Smart Antenna network optimisation. The following knowledge gaps have been identified:

- Optimisation of Smart Antenna transceiver design that exploits contextual information
- Context aware smart antenna network optimisation

Theoretical analysis, algorithm design, system level and cross layer optimisation strategies have not yet been addressed in the context of the above-identified problems. It was felt among the ACE partners that these are promising areas to direct joint research objectives.

In the following sections work performed under the ACE joint research activities attempting to address the above identified knowledge gaps is presented and the outcome and the future actions – to be taken under the framework of ACE2 – are discussed.

2.1.3 Context Aware Smart Antenna Systems – Network Design, Management and Optimization

The adoption of Smart Antenna techniques in future wireless systems is expected to have a significant impact on the efficient use of the spectrum, the minimization of the cost of establishing new wireless networks, on the optimization of the service quality provided by wireless networks and the realization of transparent operation across multi-technology wireless networks.

To be used efficiently, Smart Antennas features need to be considered by their incorporation into the process of designing and managing a reconfigurable network. To this point, the impact of utilizing Smart Antennas is multi-fold. One of the most important aspects to be considered is the spatial behaviour of the mobile radio propagation channel, i.e. where from and how the signal arrives at the base station/user terminal. An appropriate deployment of Smart Antennas would require consideration of (i) the location of the base stations, (ii) antenna characteristics, such as height and tilt, (iii) the number, size and arrangement of antenna elements, (iv) the user terminal distribution and traffic characteristics and (v) the algorithms used for network optimization.

It is expected that Smart Antennas in the form of reconfigurable multiple antenna transceivers can be used in a multi-RAT environment in order to improve the overall system's capacity allowing for higher data rates and larger number of users served per base station, thus increasing revenues of network providers (NPs), as well as providing a higher utility to customers. Furthermore, link quality can be improved without increasing signal power and thereby increasing interference.

Based on these objectives, the next section presents the methodology for the design and management of a reconfigurable network utilizing Smart Antennas.

2.1.4 Design and Management of Reconfigurable Networks

2.1.4.1 Problem Statement

The motivation for this work lies in the anticipation of a situation where an NP faces a situation requiring reconfiguration, within their administrative domain. The assumption is that there are reconfigurable multiple antenna transceivers within the service area. As an initial assumption, the Smart Antenna feature will provide the capability of reconfiguration for each transceiver with respect to tilt and beamforming options. Other multiple antenna transceiver reconfigurability functionalities are envisioned to be integrated in future network design and management studies that will be assessed during the second phase of ACE.

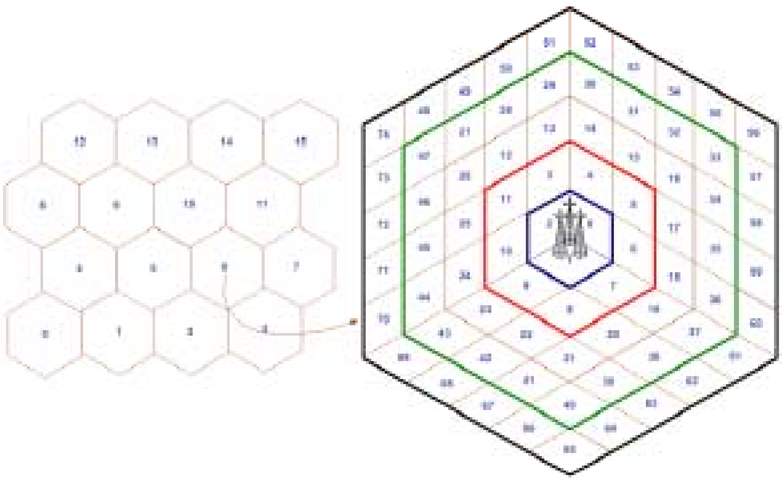

Figure 1: Typical Service Area layout and structure

The situation arising requires reallocation of RATs to the transceivers of the "target" region, as well as reconfiguration of resources for each RAT. The basic problem of (re)configuring resources has been extensively addressed with respect to different application cases; examples include TDMA (Time Division

Multiple Access), CDMA (Code Division Multiple Access), as well as B3G systems. The RAT selection problem, however, has so far not been addressed and constitutes an active research issue. In the context of this study, the whole problem is approached jointly and thus aims to determine new possible configurations (RATs-Frequencies-Transceivers, Demand and QoS Allocation problem - “RFTD-A”), i.e. its solution aims at new assignments of RATs to transceivers, spectrum (frequencies) to RATs/transceivers, new configurations to transceivers, and finally demand to QoS levels and to transceivers/RATs.

2.1.4.2 RFTD-A High Level Description

The RFTD-A problem can be generally described with its input and expected (objective) output, as depicted in
Figure 2.

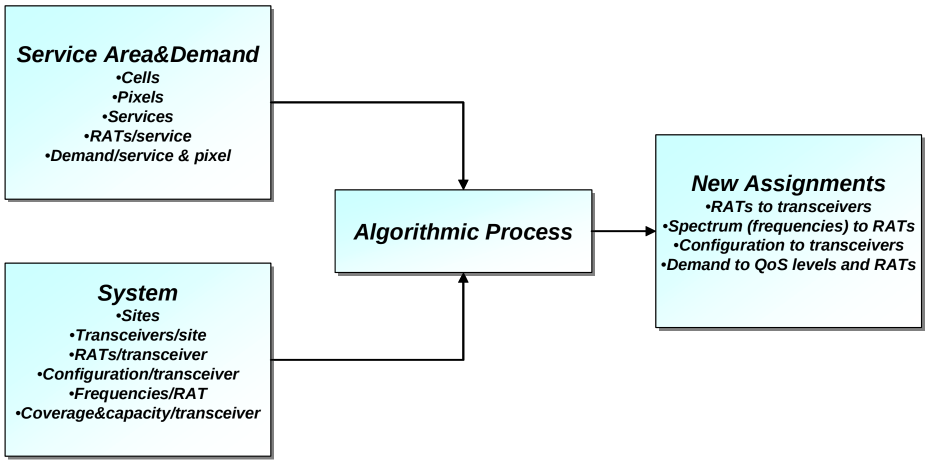

Figure 2: RFTD-A Functional Description

The input provides information on the service area and demand, as well as on the system:

The service area is divided into a number of cells. Each cell is further divided in a set of pixels. Of interest are again the applications (services) offered in the service area, the quality levels through which each service can be offered, the RATs through which each service can be offered and the demand per service and pixel. Additional requirements are the utility volume and resource consumption, when a service is offered at a QoS level, through a certain RAT.

System items to be taken into account include:

- the set of sites that cover the region of the service area that faces the need for reconfiguration, and their locations (pixels);
- the set of transceivers per site;
- the set of RATs that can be used per transceiver;
- the set of possible operating frequencies for each RAT;
- the coverage and anticipated capacity, when a RAT is used by a transceiver and operates in a certain frequency, taking into account intra- and inter-RAT interference.
- the transceiver configuration, i.e. the number of antenna elements, their tilt, their size and arrangement, as well as the beamforming capabilities, for each transceiver.

The (objective) output of the RFTD-A problem is the aforementioned determination of new configurations. These allocations (i.e. new assignments of RATs to transceivers, frequencies to RATs/transceivers, configuration to transceivers, and demand to QoS levels and to transceivers/ RATs) should optimize a utility-based objective function, which is associated with the resulting QoS levels. All allocations should respect the relevant system constraints, i.e. the overall demand in the service area should be satisfied. Additionally, applications should be assigned to acceptable QoS levels, and permissible RATs assigned to individual transceivers. The allocations of RATs to transceivers, as well as tilt and beamforming parameters (transceiver configuration) should provide adequate capacity and coverage levels.

2.1.4.3 Optimisation Methodology

The optimisation methodology involves the investigation of all possible allocations of frequencies to RATs, RATs to transceivers as well as tilt and beamforming parameters to transceivers, within the whole service area, considering as acceptable only those that satisfy the co-channel and adjacent channel interference constraints. Acceptable configurations constitute sub-problems that should be solved in parallel. Each of these sub-problems aims at allocating the demand to transceivers. For this purpose, the transceivers are initially providing the lowest acceptable QoS levels, while in subsequent reconfigurations these levels are gradually augmented in a greedy fashion. Finally, the method selects the 'best' combination of frequencies to RATs, RATs to transceivers, tilt and beamforming parameters to transceivers, demand to RATs/transceivers and applications to QoS levels, which maximizes the objective function.

2.1.4.4 Simulation Platform

In order to validate our algorithms for context aware network optimization with the use of smart antennas, we recruit the NS-2 simulator, after integrating the appropriate UMTS and WLAN extensions (see

Figure 3) and adapting the respective source code to this simulation's specific needs, in order to achieve a fine integration between the available RATs, namely UMTS and WLAN. The simulator consists of the mobile nodes and the base stations (Node-B – RNC, Access Points) that can be seen as a gateway between wireless and wired domains. Base Stations are composed of smart antennas with certain number of elements that can be properly configured in terms of selecting the appropriate RATs or adapting (in general) to the time and space varying environmental requirements.

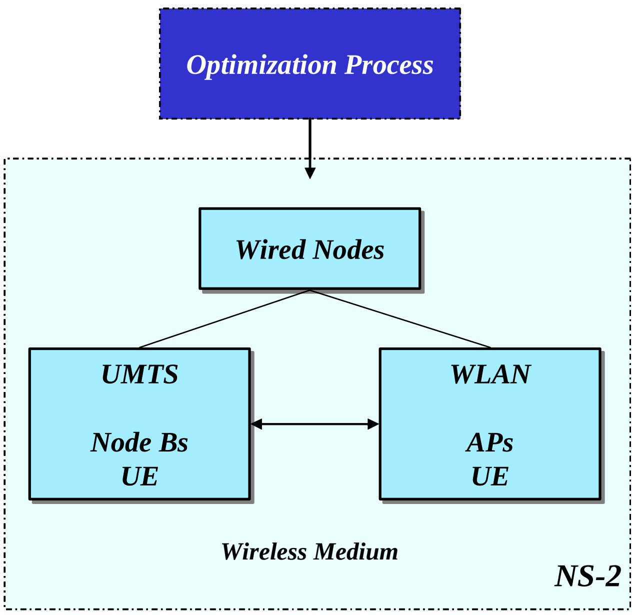

Figure 3: Simulation Platform

The simulations use the Okumura – Hata propagation model for UMTS and the Two-Ray ground model for WLAN, in order to predict the received signal power of each packet. While the above path loss models are used to predict the mean received power at a certain distance, the impact of shadowing, which reflects the variation of the received power at a certain distance, is also taken into consideration and described by a log-normal random variable.

2.1.5 Outcome of Joint Research and Future Actions

The main outcome of the joint research performed during the first phase of ACE in the framework of Context Aware Network Optimisation Utilizing Smart Antennas can be summarised as follows:

- The efficient integration of expertise of the partners on Context Aware Network Optimisation and Smart Antennas
- The evolution and specification of an existing simulation tool to include new feature for Smart Antenna Network Optimisation
- The identification of a workplan in terms of new context aware algorithms, test cases to be assessed and simulation plans (currently on going activity)
- The publication of joint conference papers, contributions to IST, WWRF and preparation of journal paper.

In the context of ACE2, more joint research activities will be carried out in the field of context aware network optimization, so as to encompass a number of smart antennas characteristics and a number of contextual information parameters.

The use of user- and/or environment-related contextual information to enhance Smart Antenna systems performance will be addressed in a generic optimisation framework where location-related information such as user position, velocity and orientation, surrounding propagation environment, interference parameters, traffic distribution, region-specific statistics and user profile data will be used to centrally optimize multiple antenna wireless networks, by making the best use of wireless resources, aiding user seamless experience and network re-configurability across heterogeneous networks and for a variety of services and applications.

The network optimisation simulation tool will incorporate the following sets of parameters.

1. Propagation channel-related parameters:

- Channel State Information (CSI)
- CSI reliability
- Channel correlation
- MIMO channel rank
- MIMO channel capacity

2. User profile related parameters:

- Signal to Noise and Interference Ratio (SINR)
- Packet Error Rate
- User Location
- Velocity (speed, velocity vector)
- Delay-related parameters (waiting time)
- User profile (preferred network options, services and applications)

3. Network-related parameters:

- Traffic data
- Cell of interest and neighbouring cell load
- Region specific statistics

4. Transceiver options:

- Fixed beam selection
- Adaptive beamforming (dynamic for clusters of users or per user)
- Space-time coding with Linear Precoding
- Spatial mutliplexing

The objective of the studies in ACE2 will be to assess the performance gains of Smart Antenna network with context aware optimisation functionalities in a number of scenarios, as defined by the above sets of parameters and furthermore, to understand and evaluate the overhead signalling and underlying complexity involved.

2.2 Deployment of Smart Antennas in Future Systems

The application of advanced smart antenna processing techniques in future systems will impose stringent demands upon both base station and terminal implementations, and this increased functionality will also be expected to be achieved at low cost. It is therefore important that the viability of the proposed smart antenna processing techniques is addressed in terms of software and hardware complexity requirements.

At the base station of particular importance is the development of improved antenna structures (possibly employing MEMS technology, e.g., micro-switches, or left-handed materials), improved cabling structures, and efficient low cost RF/DSP architectures.

At the terminal the application of Smart Antenna techniques can have a significant impact, not only in terms of system performance but also in terms of cost and the terminal's physical size. It is therefore important to examine the viability of such terminals, which are likely to be both multi-mode and multi-band in nature, and available in a wide variety of forms. Particular areas that need to be examined are: efficient MIMO/diversity antenna system designs, small low power RF structures, use of RF combining techniques and viable low power digital signal processing implementations. Terminal cost requirements may lead to use of non-perfect RF/analogue components and DSP algorithms for compensating should be investigated.

The above implementation issues are explored within ACE within work packages 2.2-2 and 2.2-3.

The objective herein is to understand, assess and eventually come up with recommendations on the deployment of Smart Antenna systems in terms of:

- Realistic performance evaluation
- Deployment and integration of Smart Antennas in existing networks or networks under development
- Deployment of Smart Antennas in next generation networks
- Financial impact and cost analysis.

2.2.1 ACE Partners Know-How and Identified Knowledge Gaps

The ACE partners bring into the network expertise in the areas of:

- Link level performance evaluation of reconfigurable multiple antenna transceivers [1]
- Performance of a number of access technologies [2]-[5]
- Multi-user scheduling [6]
- System level analysis of multiple antenna systems [7],[8]
- Critical issues and parameters for the design of a new air interface [9]

During the first phase of the work in ACE, the partners have investigated the state of the art and exchanged views on future directions of research in the framework of Smart Antenna Deployment Issues. Although a large amount of research effort has been dedicated to the evaluation of the relative merits of different Smart Antenna techniques, the assessment of the system level performance and the understanding of the underlying complexity and implementation issues, several open issues and knowledge gaps have been identified associated with:

1. The performance evaluation based on realistic channel, interference and traffic models;
2. The constraints and requirements for the integration of Smart Antennas into existing networks (or networks under development), as those arise from backward compatibility and complexity limitations;

3. The requirements and provision of features/functionalities for the incorporation of Smart Antennas in future system design, especially taking into account overhead signalling and the introduction of new technologies (e.g. multi-hop or ad hoc connectivity);
4. The fact that, although performance evaluations for different scenarios and antenna configurations provide some insight on the performance versus cost trade off, a rigorous approach to understand the financial impact and cost implications and eventually persuade the operators to adopt Smart Antennas has only been addressed in a fragmental fashion.

In the following sections work performed under the ACE joint research activities attempting to address the above identified knowledge gaps is presented and the outcome and future actions – to be taken under the framework of ACE2 – are discussed.

2.2.2 Deployment and integration of Smart Antennas in existing networks or networks under development

2.2.2.1 Definition of a link-to-system level interface for adaptive antennas

The research performed in this framework aims at the definition of a realistic link-to-system level interface that allows the evaluation of the smart antenna impact on a cellular network.

In the near future, an enormous increase in traffic will be experienced in mobile communication networks due to the introduction of new high bit rate data and multimedia services. Smart antenna systems are recognized as one of the most promising technologies for allocating the capacity demand when employed instead of conventional sector antennas. Network operators need to estimate the actual performance gain that can be achieved with a smart antenna system.

In the case of CDMA based systems, smart antennas provide a number of advantages and benefits. In CDMA systems such as UMTS, all the users transmit simultaneously using the same frequency band and time slot. Therefore, the co-channel interference increases as the number of users increases and the capacity of the system decreases. Thanks to the spatial filtering capabilities of smart antennas, these systems are particularly advantageous for interference-limited networks WCDMA, the FDD mode of UMTS.

Despite the advantages achieved in terms of coverage extension and capacity increase, the deployment of smart antenna systems is not a reality. During the last decades, smart antennas have been widely studied from a signal processing perspective, and a number of beamforming algorithms, channel estimation techniques and receiver structures have been proposed. The performance achieved with a smart antenna system is usually obtained through extensive link-level simulations that test the proposed algorithm in scenarios that rarely appear in practical cellular deployments.

The main difficulty that appears in the evaluation of a smart antenna scheme at the system level is that, in contrast to conventional sector antennas, the radiation pattern is not known a priori. Moreover, it depends on a number of variables: beamforming algorithm, spatial user distribution, requested service and features of the propagation channel. Therefore, the calculation of performance gains in terms of the signal-to-interference plus noise ratio (SINR) is not straightforward at the system level.

Traditionally, the introduction of smart antennas in system level simulations is based on unrealistic hypotheses, especially incorrect in the case of adaptive antennas. Other researchers have approximated the smart antenna pattern with a step function, without taking into account the dynamic nature of the beamforming process. In some other works, the antenna array pattern is approximated by a fixed pulse function and analytical results for the outage probability in a CDMA system are obtained with spatially white noise; this way, the performance achieved by an adaptive antenna system in a mixed service scenario is not evaluated. In other analyses, either smart antennas are modelled as spatial filters with fixed predefined antenna diagrams such as the flat-topped pattern or it is assumed that the gain provided by the smart antenna as compared to a sector antenna can be approximated by the number of elements of the antenna array. Finally, it is worth mentioning that existing system level studies make use of multibeam antennas or, in case adaptive antennas are included, the beamforming vector is assumed to be known a priori without any calculation.

The performance of a network scenario with many base stations is evaluated by means of a simulator which combines both link and system level aspects. The complexity of such a simulator (in terms of memory requirements and processing time) including both simulation levels from the transmitted waveforms and impulse responses of the propagation channel to the radio resource managements algorithms in the multitier network would be far too high. Either we should include some simplifying hypothesis in the simulation process or the simulation time along with the required hardware would be unaffordable.

As a solution, the use of separate link and system level simulators is preferred. This approach reduces the complexity of a unique simulator while maintaining realistic system-level performance figures starting from link-level result, but an appropriate definition for the link-to-system interface is required to export link level results to the system level.

Link-level analysis follows a Monte Carlo simulation approach to study the performance of single radio links, including signal processing algorithms, such as channel estimation methods, demodulation techniques and beamforming algorithms. Therefore, detailed and accurate representations for the signal and the radio propagation channel are required. As the signal processing techniques operate on the samples of the signal, the temporal resolution of link level simulations is very high, with a sampling rate higher than the chip rate for CDMA systems. The number of users is kept below some limit determined by the computational load of the simulation, and all of them are distributed within one sector. Intercell interference is modelled by Gaussian noise.

Link-level performance results are usually given in terms of the bit error rate and the frame error rate for a given transmitter and receiver structures and propagation environment. However, in order to study the performance obtained with smart antenna systems, SINR values are to be provided. Moreover, we take the SINR increase compared to a sector antenna (ΔSINR) as the key parameter to quantify the improvement achieved with a smart antenna.

On the other hand, system-level simulations aim at evaluating radio resource management procedures such as power control, handover, call admission and congestion control, packet scheduling, etc. Therefore, the simulator does not require details of the transmission chain at the chip or bit level, but the simulated real time will be of the order of some tens of seconds. A complete system-level simulator should include a multi cell network deployment, different cell types (macro, micro or pico cells), traffic models, quality of service parameters, user mobility, etc. Typical system-level results are cell capacity, throughput per cell, cell loading, and best server maps. If smart antennas are included in the simulation, other parameters such as the range extension or transmit power reduction are also of interest.

From the above paragraphs, it is clear that separate link and system level simulations are required. The next step is then the definition of an appropriate interface between both simulation levels. The interface should define an adequate format to export the link-level information to the system-level simulator while maintaining the reliability of the radio link results.

Traditionally, the results obtained at link level are reported in the system level simulator in the form of look-up tables (LUTs). These tables relate a set of initial conditions (mean carrier-to-interference ratio level, channel coding parameters, terminal speed, cell type) with a quality metric (number of erroneous bits, block error rate). However, if smart antennas are included in the radio link simulations, other input parameters should be taken into account: beamforming algorithm, spatial distribution, service type, and any other variables having an impact on the performance provided by the smart antenna system.

In the context of adaptive antennas, the antenna pattern cannot be used to characterize the coverage or interference rejection performance due to the iterative nature of the beamforming techniques, which are based on the dynamic reconfiguration of the antenna diagram. For that reason, in our analysis we consider the ΔSINR information obtained via extensive link-level simulations as the most relevant parameter to characterize the performance of a smart antenna system.

On the other hand, average ΔSINR values are not enough to fully characterize the performance gain achieved with adaptive antennas as these results present a great variance which depends on a number of parameters: spatial user distribution, service profile and beamforming algorithm.

Therefore, the LUT must contain the complete statistical characterization of the ΔSINR gain. As the most appropriate format, we propose the use of cumulative distribution functions (CDFs) of the ΔSINR for each specific scenario, so that there will be a different CDF for each spatial user distribution, requestedf service, and beamforming scheme.

The corresponding CDFs are used in the system simulator to generate the actual ΔSINR gains via the inverse transform method. The procedure is applied for uplink and downlink. As shown in Figure 4, we use the inverse transform method to the corresponding CDF to extract the ΔSINR gains to be used in the system simulator for transmit power calculations and interference analysis.

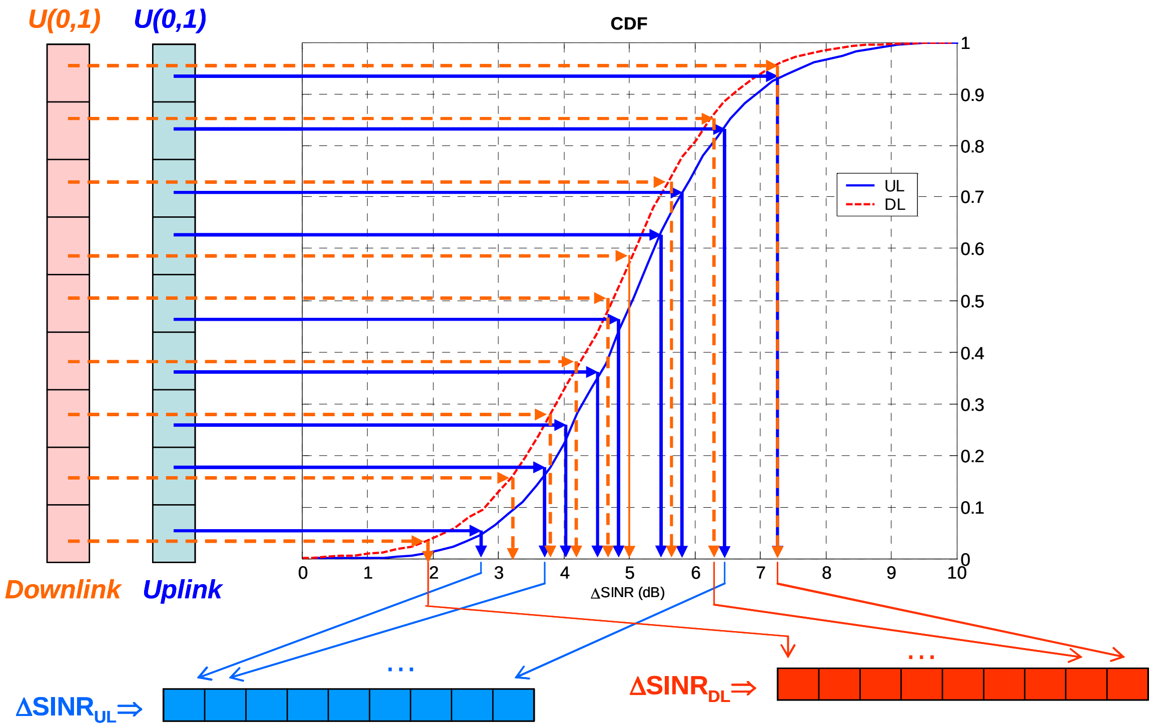

Figure 4: Use of CDFs in the system level simulator to generate the actual ΔSINR

Consequently, the next three steps must be fulfilled to define the link-to-system level interface: 1) characterize and model the scenario (spatial user distribution, service profiles, spatio-temporal channel model) and beamforming algorithm; 2) execute extensive Monte Carlo link-level simulations to obtain the ΔSINR gain for every user in the scenario, and 3) compute the CDF for the ΔSINR for each algorithm and service profile pair in uplink and downlink directions.

The most important result of this research activity is the definition of a technique to include smart antennas in network simulators. Moreover, a number of statistical distributions have been provided to characterize the statistical behaviour of different smart antenna schemes.

Future activities will focus on the search of new performance that can be used to define the interface, such as BER, antenna gain, etc. Furthermore, a number of statistical distributions for different scenarios will be provided to be used in network simulators as a first step in the network planning process with smart antennas.

2.2.2.2 Methodology for the evaluation of smart antenna systems on the capacity of UMTS networks

The research performed in this task aims at the definition of a methodology for the introduction of smart antenna systems in network simulators and therefore obtain some figures of capacity increase.

The proposed methodology considers the next steps:

- Characterize and model the scenario (spatial user distribution, service profiles, spatio-temporal channel model);
- Select a number of beamforming algorithms (adaptive antennas, switched-beam antennas);
- Execute extensive Monte Carlo link-level simulations to obtain the ΔSINR gain for every user in the scenario;
- Compute the CDF for the ΔSINR for each algorithm and service profile pair in uplink and downlink directions;
- Import the link level results using the inverse transform method to the system level simulator;
- Perform network simulation including different smart antenna schemes;
- Collect the results (capacity increase, transmit power reduction, number of users in outage, etc.) and
- Post-process the results (cellular maps with load factor, throughput, intercell interference level, histograms, etc.)

The simulations performed in this research work are based on the definition of a link-to-system level interface performed under the framework of the ACE network activities. This interface considers the statistical behaviour of a smart antenna in the link level and 'translates' it at the system level in a simple and accurate way through cumulative distribution functions (CDFs) as discussed in the previous section.

We have considered a scenario with a mix of speech (12.2 kbit/s) and data services, including low bit rate (LBR, 64 kbit/s) and high bit rate (HBR, 144 kbit/s) users. In the simulations, users are uniformly spatially distributed in the service area.

Figure 5 illustrates the throughput increase results for a cellular network with 19 base station sites and 57 sectors. As it can be seen, using a smart adaptive antenna under the control of LMS (Least Mean Square) the throughput per cell is increased by an average factor of 2.3.

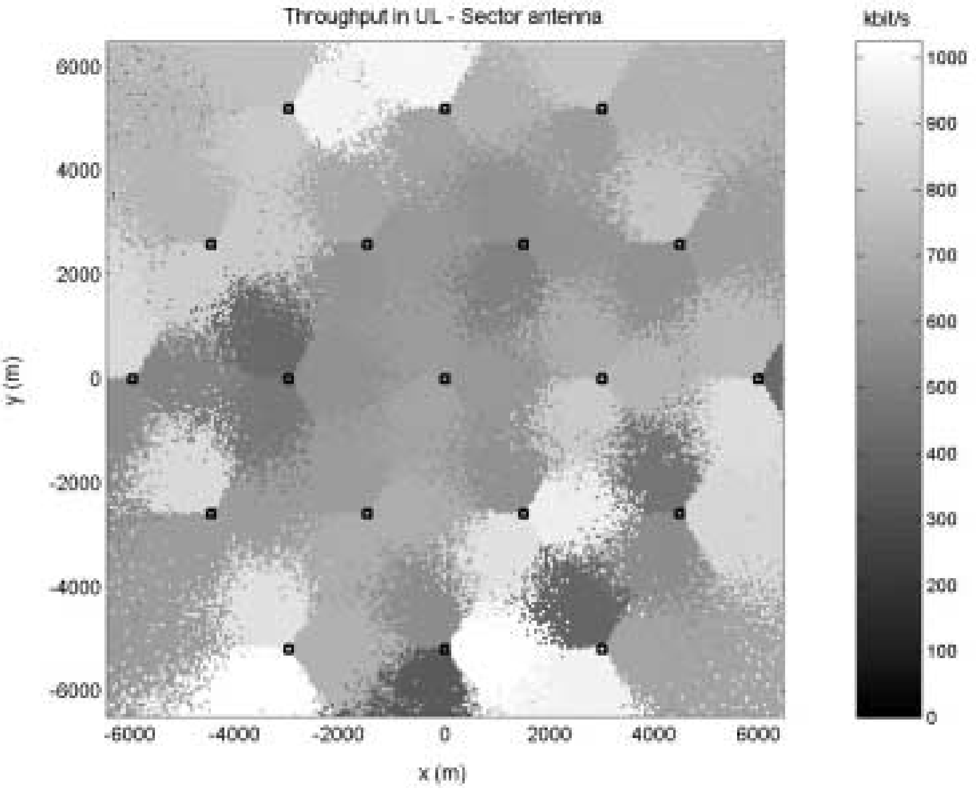

Figure 5: Throughput foe sector antennas

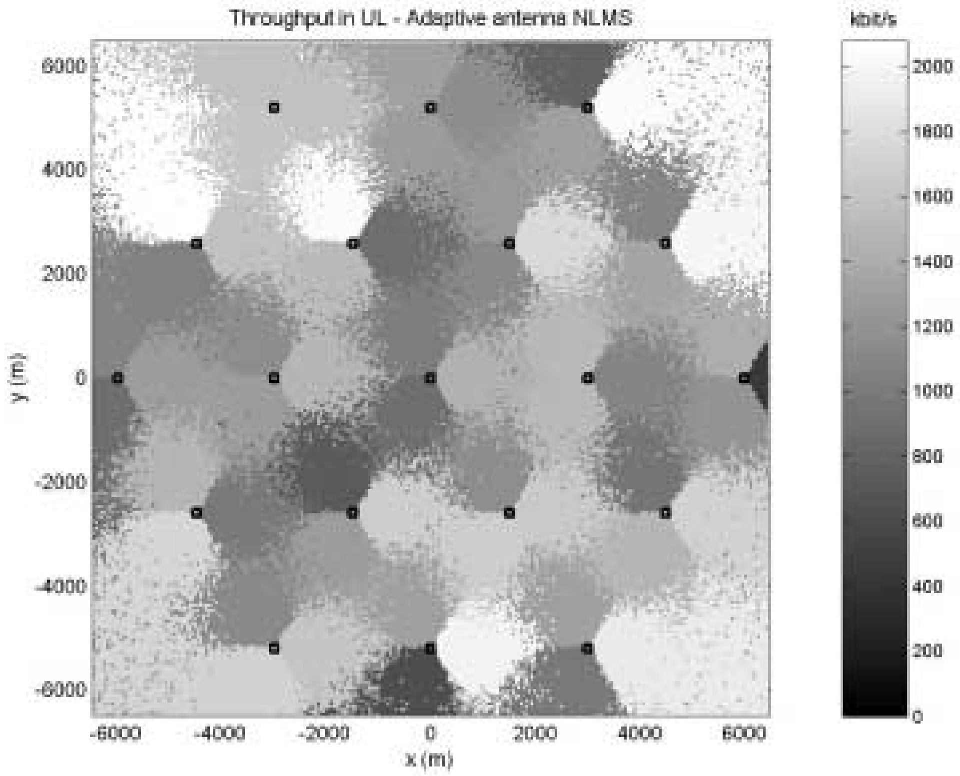

Figure 6: Throughput for adaptive antennas

This methodology allows the network operator to estimate the capacity increase achieved with different smart antenna schemes. Therefore, the network operator can use these results to introduce smart antenna systems in the initial dimensioning stage of the network planning process. Depending on the results, the operator can select the most appropriate smart antenna system for any deployment scenario optimising the trade-off between performance and complexity or cost.

Future work will focus on the realization of system level simulations using this methodology, and the utilisation of the final results to provide a reference technique to evaluate business models for a cellular network operator using smart antenna systems.

2.2.3 Financial Impact Analysis of the Deployment of Smart Antenna Techniques

A key output of this area of study is an understanding of the base technologies that are required to make the future use of Smart Antennas viable. The financial impact of the deployment of Smart Antenna technologies in future wireless systems has been studied in [11] for the cases of CDMA2000 in the United States and UMTS in Europe. The results of this study showed that "smart antenna techniques are key in securing the financial viability of the operator's business, while at the same time allowing for unit price elasticity and positive net present value. They are hence crucial for operators that want to create demand for high data usage and/or gain high market share". Based on this type of analysis, technology roadmaps along with their associated risks can be concluded, which will enable appropriate technology intercept points to be determined, resulting in the development of technologies appropriate for each application area.

2.2.3.1 MIMO Mobile Relays – Cost Analysis

The mobile relay concept is introduced and analysed in [12]. The main idea of the MIMO relay concept is that the path from the base station to the user equipment is split into two. The intermediate station is a unit we call a mobile relay. In the communication link between the base stations and the relays, each mobile relay acts as a mobile station in a classical cellular system - only that it is physically large so that it can carry multiple antennas, a large battery and high processing capabilities. In the link between the mobile relays and the user equipment, the relay acts an access point using some form of short-range wireless technology. The mobile relays are intended to be user operated - and would need only one button - on/off. The users would place them wherever they need coverage such as in a living room, in a car, or at the location of an outdoor restaurant, see Figure 7. The relays can be moved to any place that is covered by a cellular base station. The relays should probably be privately owned and may be sold as a part of a subscription. One important remark is that the user equipments would be charged for the link from the mobile relay to the base station. Since there should be much fewer mobile relays than user equipments it is believed that they could also be allowed to be more expensive than the user equipment.

In order to investigate the economy of the proposed concept a downlink simulation was performed where the capacity of the base-station to mobile relay link were investigated, taking into account both interference and receiver noise. Two different approaches were analyzed in this respect: "smart" and "opportunistic". In the former case the base-stations perform beamforming based on the long-term channel covariance matrix of the desired and interfering users. In the "opportunistic" scheme the beamforming is random and the mobile relays measure the channel and feedbacks the SNR experienced on the random base-station beams. The base-stations then schedule users based on this feedback. In both cases and OFDM modulation with 128 sub-carriers in a 3.84MHz bandwidth is used. The receiver performs a per-sub-carrier MMSE combiner with coefficient updates every 0.123ms, thereby achieving efficient interference suppression. The system was simulated on the 3GPP SCM channel model using the suburban settings. In this environment the "smart" approach achieved the best performance (maybe because this propagation model exhibits a small angular-spread). With a performance requirement (per relay) of 2.0Mbit/s or better with 90% probability and 11.0Mbit/s with 50% probability, the "smart" system employing four base-station antennas (per sector) and eight mobile-relay antennas could host 6.4 time more relays per base-station, than if HSDPA with single-antenna had been used for the base-station to relay part.

To investigate the cost of the proposed solution, the cost of the base-stations and mobile-relays were estimated based on some open sources. It was further assumed that the number of relays per user equipment is six (which means that the cost of each relay will be split on six user equipments), and the probability of a user equipment being used is 1% during a busy hour. With these assumptions, the cost per-user was minimized by varying the number of base-station and relay-antennas. The minimum cost was found using four base-station antennas (per sector) and eight mobile-relay antennas. The cost was found to be 4.1 times less than if HSDPA (single-antenna) technology had been used for the base-station to relay link.

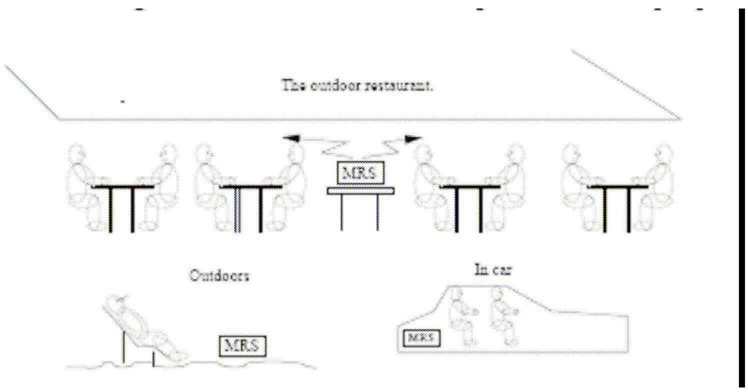

Figure 7: Illustration of mobile-relay station usages.

2.2.4 Outcome of Joint Research and Future Actions

The main outcome of the joint research performed during the first phase of ACE in the framework of the Deployment of Smart Antennas in Future Systems can be summarised as follows:

- Identification of the requirements and critical parameter for the integration of Smart Antennas into existing networks (or networks under development), as those arise from backward compatibility and complexity limitations;
- Definition of the methodology to estimate the capacity increase achieved with different smart antenna schemes that will facilitate the introduction of smart antennas in the initial dimensioning stage of the network planning process. The operator should then be able to select the most appropriate smart antenna technique for a given deployment scenario.
- An approach to assess the financial impact and cost implications of the introduction of Smart Antennas in existing and future networks.

In the context of ACE2, the partners plan to continue the above-described activities. In an effort to formalise their approach for the assessment of different Smart Antenna techniques, they aim at utilising a common network planning simulation platform in order to evaluate performance trade-offs for different scenarios under identical assumptions and simulator implementation constraints.

3 Integration Activities

Integration among the partners of ACE working in the area of Context Aware Smart Antenna Network Optimisation and Smart Antenna Deployment Issues has been achieved in various aspects:

- Exchange of views on the state of the art
- Sharing of expertise on specific research items
- Assessment of the state of the art and identification of knowledge gaps along with an approach to address them based on partners individual expertise
- Sharing of simulation data
- Planning to perform simulations with the use of a common platform
- Examples of the impact on teaching, and Master/PhD research agenda:
    - One PhD student will investigate antenna designs to be used within antenna selection, based on the ACE work within this area.
    - Speakers from ACE will be invited to lecture in our seminar series course for Masters students (www.s3.kth.se/signal/edu/s3_seminar/).
    - Teaching material and student feedback from the short course "MIMO Communication Systems and Antennas" is used to develop the internal course "smart antenna implementation" (www.s3.kth.se/signal/grad/smart_impl/).
    - One PhD student will be analysing channel capacity based on measurements collected jointly KTH and UPM.
- The members of the Scientific Council played an important role in the integration carried out within ACE, as explained in the following section.

3.1 Interaction with the members of the Scientific Council

The involvement of the Members of the Scientific Council, especially the ones specialising in Signal Processing and Smart Antennas (Prof A. Paulraj and Dr J. Winters), in the integration of ACE has been instrumental in:

- Supervising the research directions
- Observing the dissemination activities
- Participating in the ACE Special Session at PIMRC 2005 and interacting with the ACE researchers
- Giving keynote presentation at the PIMRC Plenary sponsored by ACE:
    - "Smart Antenna Techniques and Application to Ad Hoc Networks" by Dr. J. Winters, Motia Inc.
    - "OFDMA, MIMO, OS and IM– Key Ingredients for Mobile Broadband") by Prof. A Paulraj
- Most importantly, giving advice on future research directions, which are valuable for the organisation of the research activities in ACE 2. Their suggestions include the following topics:
    - MIMO for IEEE 802.16e and 802.11n standards
    - Cooperative MIMO and SDMA concepts
    - Low complexity MIMO receivers design

4 Spreading the Excellence and Dissemination

4.1 Organisation of a New Course on Smart Antenna Systems

Theme: Smart Antennas for Communications Systems (code MC05)

Lecturers (UPM): Ramón Martínez (coord.), Laura García, F.J. García-Madrid, Leandro de Haro, Miguel Calvo, Manuel Sierra-Pérez

Dates and duration: Fall 2005, March 29 to April 11, 2005 (20 hours)

Description: This is a new course for students of Telecommunication Engineering in their last year. The course is oriented to students specializing on Communication Systems. The contents of the course are structured in 9 lessons, including a practical class for the evaluation of beamforming algorithms based on simulation programs developed and tested by the lecturers. Moreover, all of the lecturers actively participate in the activities of ACE network. The modules of the course are:

1.- Introduction

2.- Smart antennas and basic architectures

3.- Signal model and spatio-temporal channel models

4.- Smart antennas based on beamforming

5.- Space-time coding

6.- Transmission and reception architectures

7.- Lab session: evaluation of beamforming algorithms

8.- Implementation aspects

9.- Network planning and new services with smart antennas

Outcome and future actions: The course was attended by 15 students. Lecturers prepared a large amount of material including slides (delivered to the students by e-mail), journal and conference papers, software, etc. As future actions, we plan to give similar lectures in the following years (the subject has been recently approved for the Fall 2006 semester), with content updates according to the new technology developments.

4.2 Participation in the ACE Course on Antennas for New Systems of Mobile Communications

Theme: Antennas for new systems of mobile communications

Lecturers (UPM): Manuel Sierra-Pérez, Ramón Martínez

Dates and duration: 14-17 September 2005, (Gandía, Spain)

Description: The course will feature lectures on the different configurations for Base Stations, including the state of the art of the actual systems, and the new concepts including multibeam systems, adaptive arrays, digital processing array and optical beamforming networks. Lecturers from UPM have participated in the ACE Course on "Antennas for new systems of mobile communications" in the areas of antennas for base stations and smart antennas. The course was oriented to students (Masters, PhD) and also for professional people working in the area of base station antenna systems. The lessons include theoretical aspects, implementation aspects, advanced antenna systems for base stations (multibeam and adaptive arrays), and finally a lesson on deployment and systems aspects related to smart antennas. The contents of the course were organised around the following list of themes:

- Antennas for Base Stations and Smart Antennas
- State of the art
- Multibeam systems
- Adaptive arrays
- Digital Signal Processing: Hardware implementation

More information on the course can be found in the Antennas VCE website (Education) and in the following URL: http://www.ursi2005.upv.es/WorkShop2.html.

Outcome and future actions: The material and slides prepared for this course was given to the students. People from many countries attended the course. The course was held in parallel with the Spanish URSI Symposium. This course will be organised again in the coming years (ACE2) and will include the participation of lecturers from UPM working on smart antennas.

4.3 Dissemination

The following list includes representative samples of the ACE dissemination activities in the area of Context Aware Smart Antenna Network Optimisation and Smart Antenna Deployment Issues:

Paper Title: **Design and Management of Reconfigurable Networks: Smart Antennas Utilization**

Authors: G. Dimitrakopoulos (UPRC), A. Alexiou (LUCENT), P. Demestichas (UPRC)

Conference: WWRF14, San Diego, USA, July 7^{th}-8^{th}, 2005.

Abstract: Wireless communications witness the continuous emergence of revolutionary applications, aligned with the ever-increasing user demands. Additionally, the coexistence of a multiplicity of Radio Access Technologies (RATs) standards has set the scene for a convergence towards a global wireless infrastructure, namely the "B3G wireless access infrastructure", with the aim to support a seamless operation in diverse contexts, in a cost effective manner. As a facilitator for this convergence, adaptive networks have become an indispensable part of international research effort. However, in order to guarantee for the commercial success of future systems, novel mechanisms need to be discovered, for supporting their operation in diverse environments, where fluctuations in the demand pattern impose a continuous optimization process. To this effect, this paper considers the possibility of utilizing Smart Antennas so as not only to improve networks' performance, but also to control/reduce their deployment and operational cost. The relevant problem is described and formulated, while indicative results from the application of the method in a real-time network are also contained.

Outcome and future actions: The aim of this paper was to present the concept, set the ground and formulate the problem definition of the Context Aware Smart Antenna System Optimisation. These new innovative concepts were discussed among the participants of the forum. The objective is to investigate the algorithms and assess the performance gains via simulation results in order to identify the constraints and trade offs involved. The researchers are in the process of carrying out simulations and will present the results in future conferences and journal papers.

Paper Title: **Methodology for the evaluation of smart antenna systems on the capacity of UMTS networks** (in Spanish)

Authors (UPM): Ramón Martínez Rodríguez-Osorio, Leandro de Haro Ariet, and Miguel Calvo Ramón

Conference: XXV Jornadas de Telecom I+D (Madrid, November 22-24, 2005)

Abstract: In the near future, an enormous increase in traffic will be experienced in mobile communication networks due to the introduction of new high bit rate data and multimedia services. Smart antenna systems are recognized as one of the most promising technologies for allocating the capacity demand when employed instead of conventional sector antennas. Network operators need to estimate the actual performance gain that can be achieved with a smart antenna system. This paper presents a technique to introduce smart adaptive antenna schemes in system level simulations based on the statistical performance gain computed in link-level simulations. Results in a typical WCDMA deployment scenario quantify throughput increases with smart antennas of up to 87 % over conventional sector antennas.

Outcome and future actions: The aim of the work is to present a new technique to introduce smart antenna systems on cellular networks. In such a way, cellular operators may estimate the impact of advanced antenna systems on the network parameters (blocking probability, transmit power, capacity, throughput, etc.) and the benefits obtained from the use of smart antennas. This is a first step for the deployment of smart antennas in cellular networks.

Paper Title: **Definition of a link-to-system level interface for adaptive antennas** (in Spanish)

Authors (UPM): Ramón Martínez Rodríguez-Osorio, Leandro de Haro Ariet, and Miguel Calvo Ramón

Conference: XX Simposio Nacional de la URSI 2005 (Gandía, Spain, September 14-16, 2005)

Abstract: The introduction of smart antenna systems on a system simulator to estimate their impact on the network is essential for the operators before the deployment of such systems. However, this is mot an easy task due to the statistical behaviour associated to the operation and performance of smart adaptive antenna systems. In this paper, we propose a definition for a link-to-system level interface based on the link level simulation results such as statistical gain, statistical level of interference reduction, etc.

Outcome and future actions: Future actions following up this contribution will be the implementation of a system level simulator including smart antennas, which can produce results and methodology for cellular dimensioning and network planning.

Presentation of ACE activities to Portugal Telecom (by IT)

A presentation of IT activities on wireless communications was made to the staff of Portugal Telecom Inovação in September 2004. The objectives and activities carried out under the ACE framework were presented by was made.

Outcome and future actions: One of the major long-term objectives of the studies of Smart Antenna Deployment Issues is to understand the underlying trade offs and constraints and re-direct research to realistic investigation and provide advice to the operator, service providers, research fora and standardisation bodies. The ACE partners plan to continue and enhance their activities towards this direction during the second phase of ACE.

5 Conclusions

The main outcome of the joint research, integration and dissemination performed during the first phase of ACE in the framework of Context Aware Network Optimisation Utilizing Smart Antennas and the Deployment of Smart Antennas in Future Systems can be summarised as follows:

- Efficient integration of expertise of the partners;
- Evolution and specification of existing simulation tools to include new feature for Smart Antenna Network Optimisation and the identification of a workplan in terms of new algorithms, test cases to be assessed and simulation plans (currently on going activity);
- Identification of the requirements and critical parameter for the integration of Smart Antennas into existing networks (or networks under development);
- Definition of the methodology to estimate the capacity increase achieved with different smart antenna schemes that will facilitate the introduction of smart antennas in the initial dimensioning stage of the network planning process;
- Definition of an approach to assess the financial impact and cost implications of the introduction of Smart Antennas in existing and future networks;
- Impact on teaching, and Master/PhD research agenda
- Organisation of short courses, and
- Publication of joint conference papers, contributions to IST, WWRF and preparation of journal paper.

In the context of ACE2, more joint research activities will be carried out in the field of context aware network optimization, so as to integrate a number of smart antennas characteristics and a number of contextual information parameters. The objective of the studies in ACE2 will be to assess the performance gains of Smart Antenna network with context aware optimisation functionalities in a number of scenarios and furthermore, to understand and evaluate the overhead signalling and underlying complexity involved. Moreover, in the framework of the Deployment of Smart Antennas in Future Systems the aim within ACE2 will be to utilise a common network planning simulation platform in order to evaluate performance trade offs for different scenarios under identical assumptions and simulator implementation constraints.

Within the framework of ACE2 and building upon the achievements of ACE, the partners plan to enhance the education and dissemination activities also leveraging on the valuable guidance of the members of the Scientific Council.

6 References by members of ACE

[1] A. Alexiou, M. Haardt, "Smart Antenna Technologies for Future Wireless Systems: Trends and Challenges", IEEE Communication Magazine, vol.42, No. 9, pp. 90-97, September 2004.

[2] R. Martínez, L. de Haro, M. Calvo, "Application of Smart Antennas to the Cancellation of Measured Impulsive Noise Interference in W-CDMA Environments", 62nd IEEE Vehicular Technology Conference (VTC2005-Fall), Dallas, TX, USA, September 2005.

[3] R. Martínez Rodríguez-Osorio, L. de Haro Ariet, M. Calvo Ramón, M. García Sánchez, "Performance evaluation of W-CDMA in actual impulsive noise scenario and using adaptive antennas", IEE Proceedings Communications, vol. 151, pp. 589-594, December 2004.

[4] R. Martínez, L. de Haro, M. Calvo, "Statistical Characterization of the Performance of Smart Antenna Systems in W-CDMA Mixed-Services Scenarios", 60th IEEE Vehicular Technology Conference (VTC2004-Fall), Los Angeles, CA, USA, September 2004.

[5] R. Martínez Rodríguez-Osorio, L. de Haro Ariet, M. Calvo Ramón, "Statistical characterisation of adaptive antenna performance in WCDMA scenarios", Electronics Letters, vol. 40, 22nd July 2004.

[6] D. Avidor, J. Ling and C. Papadias, "Jointly Opportunistic Beamforming and Scheduling (JOBS) for Downlink Packet Access", IEEE International Conference on Communications, Paris, France, June 2004.

[7] IST-FITNESS project

[8] K. Peppas, A. Alexiou, F. Lazarakis, T. Al-Gizawi, D. Axiotis, "Performance Evaluation at the System Level of Reconfigurable Space-Time Coding Techniques for HSDPA", EURASIP Journal on Applied Signal Processing, vol. 2005, No. 11, pp. 1656-1667, July 2005.

[9] A. Alexiou, et.al, "Duplexing, Resource Allocation and Inter-Cell Coordination-Design Recommendations for Next Generation Systems", Wireless Communications and Mobile Computing magazine, Wiley, vol. 5, p.77-93, 2005.

[10] G.Dimitrakopoulos, A.Alexiou, P.Demestichas, "Design and Management of Reconfigurable Networks: Smart Antennas Utilization", in Proc. WWRF14, San Diego, USA, July 7th-8th, 2005.

[11] D. Avidor, D. Furman, J. Ling, C. Papadias, "On the Financial Impact of Capacity-Enhancing Technologies to Wireless Operators", IEEE Wireless Communications, Vol. 10, Issue 4, pp. 62-65, August 2003

[12] M. Bengtsson, D. Svedman, P. Zetterberg, "Comparison and Cost Analysis of Smart and Opportunistic MIMO OFDM Schemes", Submitted to ICC2006.

[13] Evolution in wireless systems management concepts: from composite radio to reconfigurability P.Demestichas, G. Vivier, K.El-Khazen, M. Theologou, IEEE Communications Magazine, Vol. 42, No. 5, pp. 90-98, May 2004.

[14] G.Dimitrakopoulos, D.Bourse, K.ElKhazen, P.Demestichas, A.Saatsakis, J.Luo, "Planning Reconfigurable Network Segments: Motivation, Benefits for Operators and Manufacturers, and Strategies", in Proc. IEEE PIMRC 2005, Berlin, September 2005.

[15] G. Dimitrakopoulos, P. Demestichas, A. Alexiou, "Design and Management of High Speed, Wireless Access, B3G Networks, Utilizing Smart Antennas", submitted to VTC 2006.

[16] G. Dimitrakopoulos, P. Demestichas, A. Alexiou, "Design of Context Aware, Reconfigurable, High Speed, Wireless Access Systems", ACE Workshop, IST Summit 2005.

[17] R. Martínez Rodríguez-Osorio, L. de Haro Ariet, and M. Calvo Ramón, “Definition of a link-to-system level interface for adaptive antennas (in Spanish)”, XX Simposio Nacional de la URSI 2005, Gandía, Spain, September 14-16, 2005.

[18] R. Martínez Rodríguez-Osorio, L. de Haro Ariet, and M. Calvo Ramón, “Methodology for the evaluation of smart antenna systems on the capacity of UMTS networks (in Spanish), XXV Jornadas de Telecom I+D, Madrid, November 22-24, 2005.

7 Other References

[19] M. Mouly, M.-B. Pautet, “The GSM system for mobile communications”, published by the authors, Palaiseau, France, 1992.

[20] R. Kalden, I. Meirick, M. Meyer, “Wireless Internet access based on GPRS”, IEEE Personal Commun., Vol. 7 No. 2, April 2000.

[21] 3rd Generation Partnership Project (3GPP) Web Site, www.3gpp.org.

[22] 3GPP TR 25.858 V1.0.4, January 2002.

[23] U. Varshney, R. Vetter, “Emerging mobile and broadband wireless networks”, Communications of the ACM, Vol. 43, No. 6, June 2000

[24] Institute of Electrical and Electronics Engineers (IEEE) 802 standards, Web site, www.ieee802.org, 2004

[25] IEEE Standard for Local and Metropolitan Area Networks-Part16: Air Interface for Fixed BroadbandWireless Access Systems

[26] Digital Video Broadcasting (DVB) Web site, www.dvb.org, Jan. 2002.

[27] End to End Reconfigurability (E2R), IST-2003-507995E2R

[28] A. Paulraj, R. Nabar, and D. Gore, “Introduction to Space-Time Wireless Communications,” Cambridge University Press, 2003

8 Terminology

B3G	Beyond 3rd Generation
CDF	Cumulative Density Function
CDMA	Code Division Multiple Access
FDD	Frequency Division Duplex
GSM	Global System for Mobile communications
HSDPA	High Speed Downlink Packet Access
MIMO	Multiple Input Multiple Output
MMSE	Minimum Mean Square Error
NP	Network Provider
OFDM	Orthogonal Frequency Division Muliplexing
QoS	Quality of Service
RAT	Radio Access Technology
RFTD-A	RATs-Frequencies-Transceivers, Demand and QoS Allocation problem
SINR	Signal to Interference and Noise Ratio
SNR	Signal to Noise Ratio
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband CDMA
WLAN	Wireless Local Access Network