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CODIV

D6.5

Final Test Results and Performance Analysis

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Abstract:

The scope of this deliverable is to present test results of the cooperative techniques implemented into WiMax and LTE platforms. Furthermore we analyze the performance of the aforementioned techniques in accordance the conformance and interoperability testing procedures adopted by 4G standardization bodies and versus corresponding theoretical bounds.

Keyword list:

Cooperative diversity, radio network deployment, relay element, relaying-able terminal

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Abbreviations

Acronyms	Meaning
3GPP	3rd Generation Partnership Project
AC	Alternating Current
ACLR	Adjacent Channel Leakage Ratio
ADC	Analog to Digital Converter
ARQ	Automatic Repeat Request
ATP	Acceptance Test Procedure
Att	Attenuator
AWGN	Additive White Gaussian Noise
BIT	Build In Test
BER	Bit Error Rate
BLER	Block Error Rate
BS	Base Station
BR	An RfNode fulfilling the B-Role
BW	Bandwidth
CCM	Control and Communication Module
CID	Connection Identifier
CIR	Committed Rate
CP	Cyclic Prefix
CPE	Customer Premises Equipment (See UT)
CPLD	Complex Programmable Logic Device
CRC	Cyclic Redundancy Check
CTC	Convolution Turbo Code
CS	Convergence Sub-layer
DAC	Digital to Analog Converter
DC	Direct Current
Demo	Demonstration
DL	Downlink
DPR	Dual Port Ram
ETSI	European Telecommunications Standards Institute
EVM	Error Vector Magnitude
FFT	Fast Fourier Transform
FCC	Federal Communications Commission.
FDD	Frequency Division Duplexing
FPGA	Field-Programmable Gate Arrays
GDB	Global Database
GPS	Global Positioning System
GPIO	General Purpose Input Output
GUI	Graphic User Interface
HDL	Hardware Descriptive Language

Acronyms	Meaning
HIM	Human Interface Module
HO	Handover
HW	Hardware
IF	Intermediate Frequency
IO	Input Output
IP	Internet Protocol
IPC	Inter Processor Communication
ISE	Integrated Software Environment
LTE	Long Term Evolution
LOS	Line Of Sight
MAC	Medium Access Control Layer
MIB	Management Information Base
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MN	Mesh Node
MCS	Modulation Coding Scheme
MRC	Maximal Ratio Combining
OFDMA	Orthogonal Frequency Division Multiple Access
P-SCH	Primary Synchronization Channel
PA	Power Amplifier
PC	Personal Computer
PCMCIA	Personal Computer Memory Card International Association
PER	Packet Error Rate
PHY	Physical Layer
PUSC	Partially Usage of Sub channels
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RAM	Random Access Memory
RB	Resource Block
RFIC	Radio Frequency Integrated Circuit
RFM	Radio Frontend Module
RS	Reference Signal
RTT	Round Trip Time
SC-FDMA	Single Carrier Frequency Division Multiple Access
SFBC	Space-Frequency Block Coding
SIMO	Single Input Multiple Output
S-SCH	Secondary Synchronization Channel
SoC	System on Chip
S/N	Signal to Noise Ratio
SNR	Signal to Noise Ratio

Acronyms	Meaning
SPM	Signal Processing Module
SW	Software
TDD	Time Division Duplexing
TBD	To Be Defined
TTA	Telecommunications Technology Association
TX	Transmitter
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
UGS	Unsolicited Grant Service
UL	Uplink
UT	User Terminal
Veh-A	Vehicular –A channel model as defined in Wimax forum
VSA	Vector Signal Analyzer
VSG	Vector Signal Generator
WPS	WiMesh Product Specification
ZIF	Zero Insertion Force

1 Introduction

1.1 Scope

In [COD1] a detailed description of the concepts and objectives was given. At the technical level the main objectives of CODIV project encompass:

- Development and validation of approaches allowing for integration of cooperative diversity with other types of diversity schemes,
- Evaluation of the implications of the incorporation of capabilities based on the cooperation between different network entities upon the existing wireless architecture and system models
- Proof of concept for the investigated technologies.

In the framework of WP6 the proof of concept is restricted to assessment of implementation feasibility of cooperative schemes and algorithms developed in WP3 and WP4 into existing 4G prototypes. The performance analysis of the cooperative algorithms at the system and network levels is carried out within the framework of WP5.

From the beginning of the CODIV project, it was decided to develop, within WP6, two different demonstration platforms: WiMAX platform endowed with a number of relaying and cooperative capabilities and a LTE platform supporting several Multi-User MIMO schemes. Preliminary prototype design, specifications and some testing results of the basic features were presented in [D6.2][TID1]. Furthermore [D6.4] included main characteristics and building blocks of the final test bed platform as well as test results performed in order to assure proper functioning of the demonstration prototypes. In addition D6.4 describes the work carried out in test bed platforms in the course of implementation of the CoDIV algorithms and test results for several basic modes of operation. At the moment both demonstration platforms are fully operational and support all the relaying and multi-user algorithms as defined in D6.4. Both platforms are ready to the final demo in which the performance and benefits of the aforementioned techniques will be exhibited in different scenarios and for a wide range of SNR regimes.

The primary objective of this deliverable's is to present all details regarding the performance and test results of the CoDiv cooperative/relay and multi-user techniques. The performance of these techniques will be analyzed and the achieved benefits will be assessed under the test conditions and procedures defined by the relevant documents of the 4G standardization committees.

1.2 Objectives

This deliverable's objectives are:

- To present performance curves and test results of the implemented relay techniques in different scenarios and for wide range of bitrates
- To analyze the test results and assess the benefits achieved through comparison with the requirements defined by the conformance testing documents issued by 4G standardization bodies. .
- To elaborate on scenarios of the final demonstration, namely techniques to be presented, setup, main parameters and expected performance.

2 CoDiv Demonstration Prototypes

2.1 WiMax Platform

2.1.1 General Description and Setup of the WiMax Platform

Runcom has developed from scratch a novel system which enables relaying in WiMax. Demonstration prototype of Runcom consists of four system elements, constituting a Decode and Forward WiMax relay chain. It is composed of four network entities: the first one acting as a BS, two acting as relay terminals and the last element acts as a UT as shown in Figure 1. The whole system is mostly based on the IEEE802.16e standard while several IEEE 802.16j concepts have been adopted to enable relay functionalities.

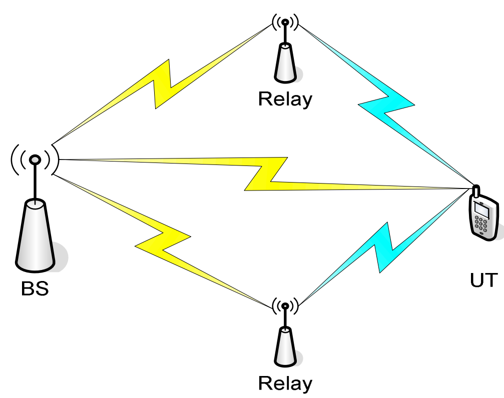

Figure 1: General Setup of the WiMAX Demonstration Platform

Each demonstration prototype include a rich set of features and capabilities as required by WiMax profile, Rel. 1.5 for BS and UT and supports four relaying algorithms developed within CoDiv project framework. In addition the WiMax prototypes comply with the requirements of the WiMax Forum Mobile RCT. It is noteworthy, though, that the system does not fully comply with the IEEE802.16e standard due to compromise needed to be done in order to enable incorporation of various relaying capabilities and future CODIV algorithms. The following cooperative features were implemented in the demonstration platform within the scope of the CoDiv project:

- Cooperative Maximal Ratio Combining (MRC)
- Cooperative Space-Frequency Block Coding (SFBC) scheme
- Cooperative Handover (HO) Mechanism: Radio Resource Management and Relay Activation
- Cooperative Automatic Repeat Request (ARQ) Mechanism
- Novel CINR Computation Algorithm

These schemes will be exhibited at the final review of the CoDiv project under a wide range of scenarios.

Each demonstration prototype (platform) consists of two similar RNA200 UT SoC entities: one implements the BS entity and UT entity, connected through a Dual Port Ram (DPR) interface and several additional synchronize/control lines The first RNA200 entity supports the full WiMax functionality of a UT; the second RNA200 has been modified to operate as a BS. The UT unit is connected to the host through PCMCIA interface and to the GPS inputs.

2.2 LTE Platform

At first it is important to remind that the two demonstrators developed inside CODIV to prove part of the algorithms investigated in the project, have different purposes. As was already explained in the correction for LTE platform of last WP6 deliverable [D6.4c], while WiMax prototype has the purpose to demonstrate the main cooperative technique proposed in CODIV based on relaying technical approach (dedicated relays and able-relaying terminal), the LTE prototype deals with the demonstration of some particular PHY algorithms investigated in the project (synchronization and channel estimation strategies) as well as the multi-user MIMO implementation where the cooperative dimension is in the decision of BS to select the best users. Therefore, LTE demonstrator in CODIV is complementary to WiMax prototype and for this reason the resources devoted to the development of the LTE platform were significant lower than in the case of WiMax platform. Note also that the design and development of the LTE demonstrator has been produced during the life of the project and some additional problems to the implementation of particular PHY algorithms proposed for CODIV in WP3, were reported in [D6.3] giving rise to important delay in the tune up of this platform. In any case at the moment all the problems of the LTE platform have been solved and thanks to the extension of the project, the correct operation of the platform as well as the demonstration of some of the physical algorithms proposed and investigated in the project has been achieved.

2.2.1 General Description of LTE prototype

TID has developed a real time MIMO (Multiple Input - Multiple Output) lab test-bed for the 3rd Generation Partnership Project (3GPP) Long-Term-Evolution (LTE) system. From a general perspective, the aim of LTE prototype has been to develop an experimentation platform that can help in the design, evaluation and rapid prototyping of techniques for the future MIMO-LTE systems. The prototype is based on a SDR (Software Defined Radio) platform using Xilinx FPGAs and includes a completely new design for the RF front end module. The intended test-bed use includes developing hardware algorithm implementation, on account of this the entire digital signal processing is achieved in real-time. The platform works in frequency division duplex (FDD) mode using the UMTS frequency extension band VII (see Table 1).

Table 1: LTE FDD frequency band allocations used in LTE platform

Band number	Band description / name	UL (MHz)	DL (MHz)
VII	IMT extension	2500-2570	2620-2690

In the first deliverables of WP6 ([D6.2] and [D6.3]), the preliminary test-bed, configuration and testing metrics for LTE demonstrator in the context of CODIV were described and explained. Besides, several internal informative notes have been produced during the project to describe the block diagram and main modules for interacting with the LTE demonstrator [TID1], as well as to specify the link level simulation chain associated to this platform [TID2], and the PHY algorithms developed in CODIV (implemented and tested in the link level simulator developed in C++ by TID) to be finally included in LTE demonstrator [TID3]. Also, it is important to note that in the correction to last deliverable of WP6 [D6.4c] produced and delivered to the Commission in July of 2010 after the implementation of LTE platform was finished and the final test bed was defined, the test bed configuration proposed for final testing of the platform and some results for final testing of the LTE demonstrator were presented. Therefore, the interested readers in knowing the details of the architecture and block diagram of the different elements integrating the LTE platform as well as the definition of the test beds and testing procedures to verify and evaluate the CODIV algorithms implemented in this platform, are recommended to review all the documents mentioned above.

Anyway in summary, the LTE demonstrator is composed by one base station and two user terminals, all the equipments with two antenna ports. Note that due to important limitations in the FPGAs of the signal processing module to process LTE signals of 20 MHz of bandwidth including the encoder and mainly decoder functions, the equipments of the demonstrator have been implemented with only two transceivers. Figure 2 shows schematically the basic components of the LTE demonstrator developed inside CODIV project. The control and configuration of the platform are performed through the Ethernet or serial port RS-232 included in the BS and UTs of the prototype. For example one of the possibilities is to establish from any personal computer a Telnet session to connect to the PXA microcontroller inside the Control and Communications Module (CCM) of the LTE equipment (BS or UT), so that the different scripts developed and implemented as automatic procedures for the configuration and control of the equipment can be executed. Theses procedures include the load of programs for each of the FPGAs in terms of the function of the equipment, the configuration of the RF parameters (transmission and reception frequencies, value of the different attenuators, power amplifier on/off), and some basic parameters related to the LTE signal processing such as modulation, number of physical resource blocks and transmission mode. Just the main goal for LTE platform in this deliverable is to demonstrate, evaluate and check against simulation results, the different transmission modes developed an implemented during the project, in a real radio environment. The multiple input multiple output schemes implemented in the LTE platform and which results and correspondent analysis are included in this deliverable, are the following:

- SIMO 1x2 or receive diversity.
- MISO 2x1 or transmit diversity.
- MIMO 2x2 with receive and transmit diversities.
- Spatial Multiplexing (SM) MIMO 2x2.
- Multi user MIMO 2x2.

After the configuration of the equipments of the LTE platform is completed and the radio transmission and reception are initiated, some programs (also through the Telnet session) can be executed in order to know on the one hand the error rate (BER and BLER before and after decoding) and the estimated signal to noise ratio, and on the other hand to change some parameters of the equipment such as the value of the transmission and reception attenuators, and the PA on/off.

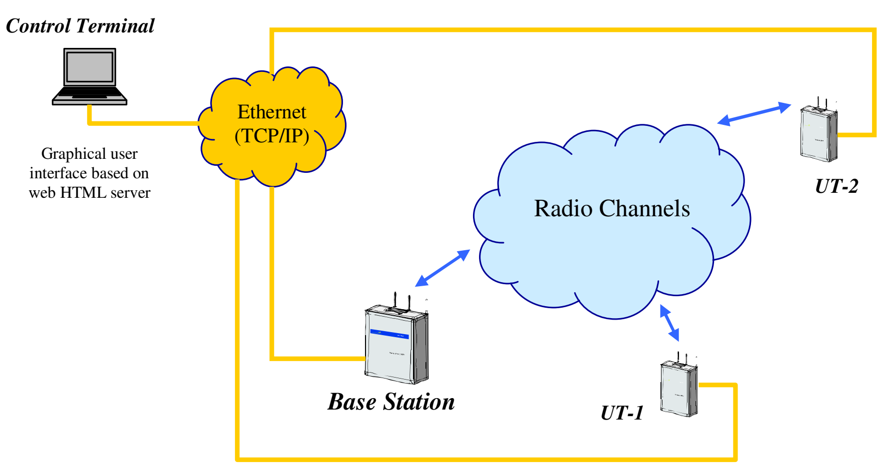

Figure 2: General configuration of LTE demonstrator platform

As was explained in previous deliverables ([D6.3] and [D6.4c]) the equipments of LTE platform (BS and UTs) have been built-up with the same architecture and since finally there was not time in the project to implement the UL transmission scheme proposed in 3GPP for LTE (SC-FDMA), the only difference between the BS and the UTs has been the programming of the frequencies and therefore the position of the duplexer in the RF module so that the transmission in the BS corresponds to DL band whereas in the UT is the UL band, but using in both cases the DL transmission scheme (OFDMA). Figure 3 illustrates the common architecture used in the equipments of the LTE platform showing the role and main features of the three modules which form the equipment: Control and Communication Module (CCM), Signal Processing Module (SPM) and Radio Frontend Module (RFM). Also it is showed the different interfaces between modules as well as the two ports (Ethernet and RS-232) available for programming and control purposes of the different parts of the equipment as was explained above. The three modules along with the power supplies (AC/DC and DC/DC included in an additional tray) are inserted in a 19" rack. The SPM is in charge of the baseband digital processing and the interface with the radio modules through ADCs and DACs. This module was based on seven FPGAs Virtex 4 of Xilinx, and it is capable of controlling up to 2 RF transceivers. The link with the CCM is made by a 32 bit parallel ARM type bus. The CCM is built around a PXA family microprocessor and provides an interface to a host PC via Ethernet or RS-232 connection. This core runs custom software based on LINUX embedded that provides access to and from the host PC for controlling the test-bed. The RFM have been designed exclusively for LTE standard and it is based in a super heterodyne transceiver with a selected IF baseband of 69.12 MHZ.

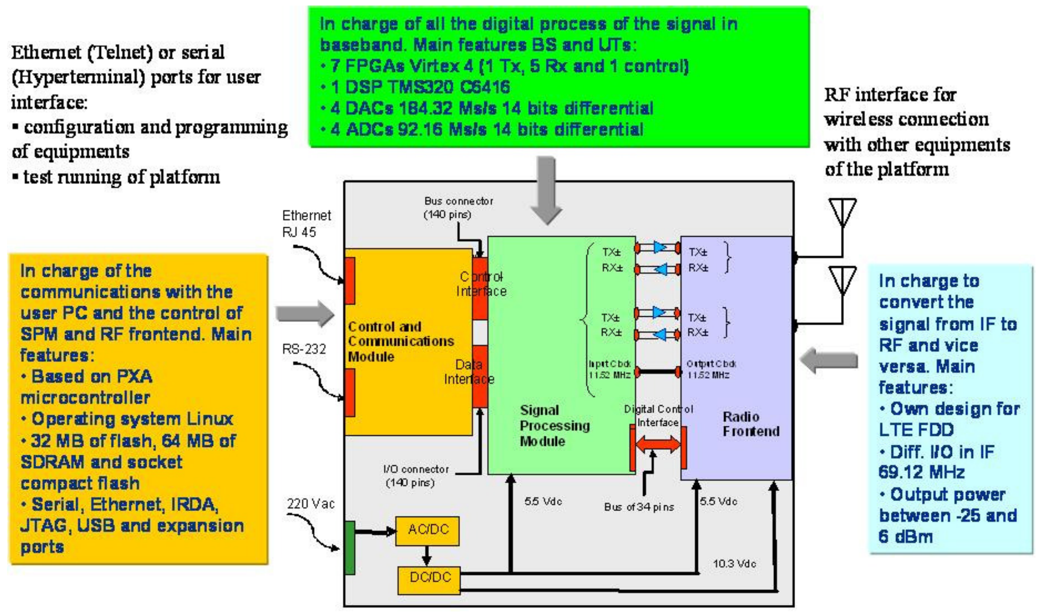

Figure 3: General view of SDR architecture used in the equipments of LTE platform

The overall development of code for LTE test bed with MIMO capabilities has been completed in two phases as Figure 4 shows. In the first phase the work was focused to optimize the design and implementation of PHY algorithms inside FPGAs of Xilinx (Virtex 4) as described by the technical specifications of the 3GPP regarding physical channel and modulation for the LTE standard [TS 36.211] as well as multiplexing and channel coding for this standard described in [TS 36.212]. In this phase, the standard procedures described for LTE in frequency division duplex (FDD) mode were implemented, as well custom-made procedures for the receiver side in order to complete the physical layer TX-RX chain. The own simulation tools of Xilinx (ISE and ModelSim) were employed in this phase to optimize the design and procedures and also to validate the hardware implementation HDL code by comparing traces data drawn up for similar HDL functions. In the second phase the different modules made out from the first phase were translated into HDL code. The process included behavioural simulation to compare with the results of similar functions in the C++ simulator, implementation into FPGA logic blocks, user constraints definitions, place and route with Xilinx tools and real time simulation [Vir08], and drawn up data traces in real-time using the test-bed platform.

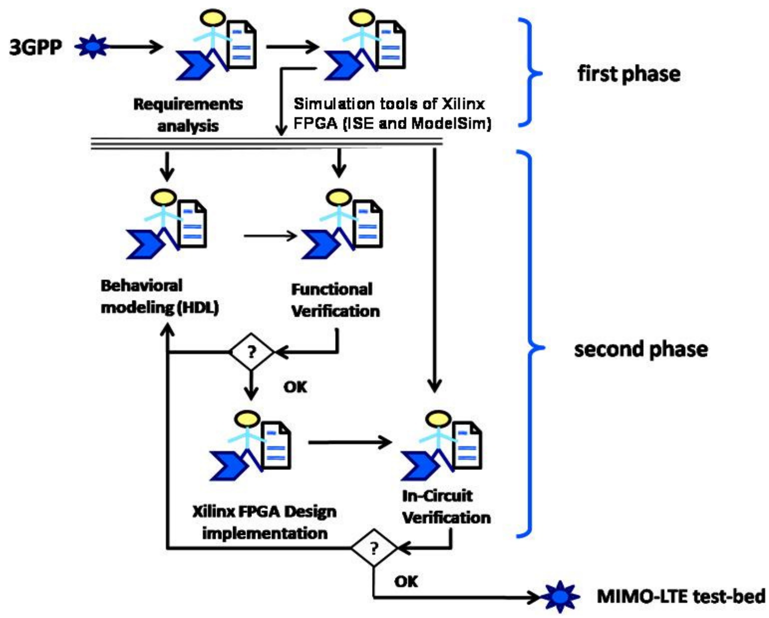

Figure 4: Workflow of the code development for LTE platform

3 Description of the Implemented Techniques

In this subsection a brief description of the cooperative algorithms implemented on the WiMax and LTE prototypes will be given. More detailed explanation of the implemented functionalities, demonstration scenario and system configuration can be found in [D6.4].

3.1 WiMax Prototype: Description of the Implemented Techniques

3.1.1 MRC Technique for Relaying Networks

The key feature to be demonstrated in this scenario is the ability of the destination node (called receiver or UT hereafter) to decode signals transmitted by two relays. This scheme enhances the performance of the reception at the receiver by offering additional degree of diversity (sometimes dubbed cooperative or relaying diversity). First the information stream (live video) is transmitted from the source node (referred to as BS hereafter) towards the relays. Afterwards the relays terminals transmit the information stream to the UT. The UT combines the signals transmitted by the relays. Since both transmitted signals carry the same information delivered through different wireless channels, the optimal detection method for the decoding of the received signal is so-called MRC technique. Note that the due to the fact that the receiver is endowed with a single receive antenna, the relays cannot utilize the same time-frequency resources for the transmission. Therefore the signals will be transmitted over different frequency resources (but over same time slot). It should be mentioned that the same MCS is transmitted over the BS->Relay1, BS->Relay2 and Relay1,2->UT links.

The main phases of the cooperative MRC demo can be summarized as follows:

a) The BS transmits the data stream (video) towards the relays