Project No: **IST-27675 STP**

Project Acronym: **FIREWORKS**

Project Title: **FlexIble RElay Wireless OFDM-based netwoRKS**

Publishable Final Activity Report (PFAR)

Instrument: **Specific Targeted Research or Innovation Project (STREP)**
Thematic Priority: **IST 2.4.5 "Mobile and Wireless Systems beyond 3G"**

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Project coordinator organization name : *INTRACOM Telecom*

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1 Project execution

1.1 Summary description of project objectives

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FIREWORKS project aims to enhance OFDM(A)-based WMAN/WLAN technologies with novel concepts such as Mesh network architecture, flexible Relay-based deployment and co-operative communications with a final objective to design - validate a next generation Broadband Wireless Access (BWA) prototype. The advantage of the FIREWORKS BWA system is its ability for *fast, scalable* and *cost-effective* network deployment under highly diverse terrain environments with considerably increased *coverage* and *capacity* capabilities. The FIREWORKS system is based on enhancements on IEEE 802.16e and 802.11s Standards.

FIREWORKS aim comprises the utilization of novel network architectural elements (relays stations) jointly with a range of novel communication concepts that span from the PHY to Networking layer. The core system operation is based on the optimisation of the cross PHY-MAC and Radio Resource Management (RRM) functions through the novel prism of mesh architecture that is using relays. An additional target is the PHY enhancement with cooperative communication and Advanced Antenna Systems (AAS).

There are mainly two major issues investigated within the FIREWORKS framework in the PHY and MAC layers:

- *Design of advanced cooperative MTMR techniques:* Dynamic MTMR techniques, hybrids of MIMO and beam-forming techniques, that efficiently adapt to various radio and network variations while the spectrum efficiency and system performance are maintained balanced, are exploited to achieve a required data rate control and maximize the sum-capacity of several multi user links. Cooperative MTMR techniques provide and additional degree of freedom.
- *Enhanced MAC Layer:* The MAC Layer must be flexible to functionalities for both ad-hoc and mesh network, supporting advanced MTMR techniques and maintain a backward compatibility to pre-existing standard.

Beside these research directions PHY-MAC cross layer methodology is tackled in FIREWORKS.

The final goal of FIREWORKS is through a judicious prototype validation activity to provide sufficient insight for the evaluation of the economic viability of the relay based network concept and exploring also its environmental impact and its social acceptance.

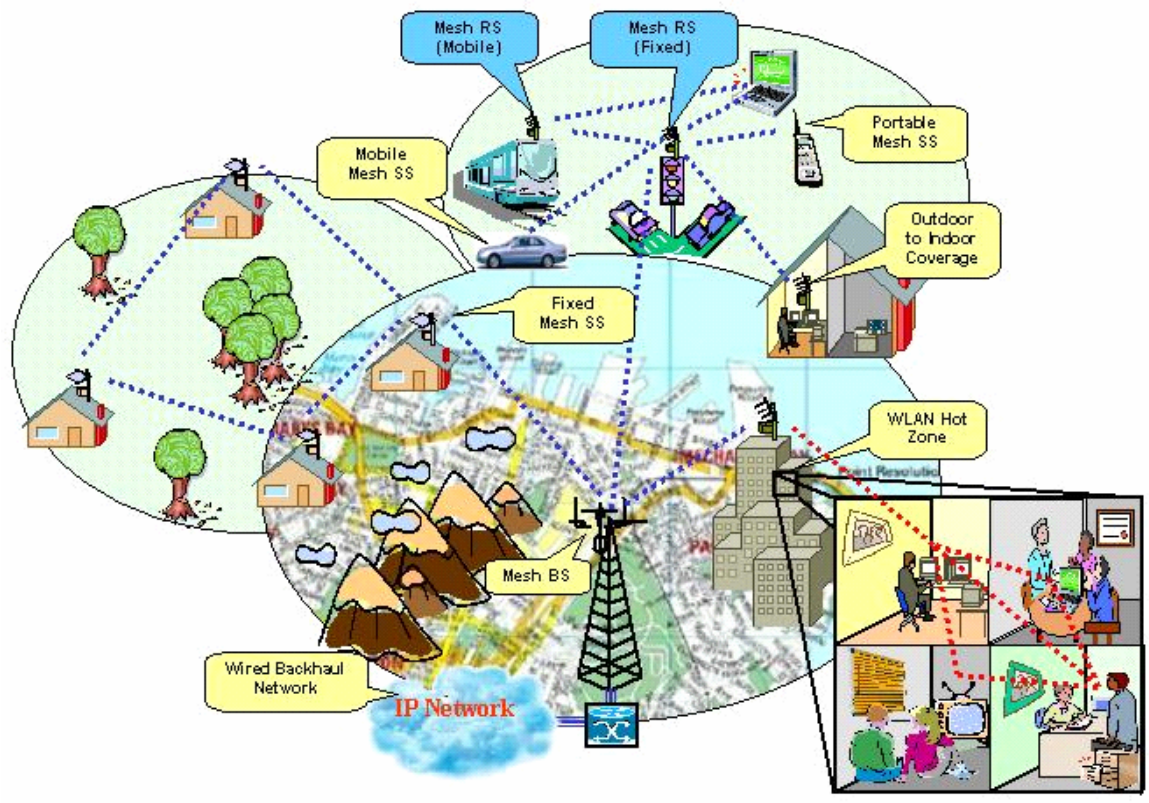

Figure 1 –FIREWORKS Deployment Overview

The main objectives of FIREWORKS are detailed hereafter:

1. To establish the project management and technical structures, the relationships with EC and the appropriate procedures that will ensure the progress according to the technical and contractual obligations.
2. To specify operational scenarios, service provisioning and system requirements as well as techno-economics assessments of the feasibility of such a wireless system able to contribute towards the vision of *"Optimally Connected Anywhere, Anytime"* at a European, as well as a worldwide level.
3. To investigate wireless deployment concepts based on relaying and search for the methods of relaying that achieve the maximum possible capacity improvement in comparison with conventional deployment scenarios, both in highly shadowed (urban) and wide-area (rural) scenarios. Outdoor-to-indoor scenario based on relaying with the same or different frequency bands used indoors and outdoors will be contemplated.
4. To study deployment concepts of hybrid WMAN and WLAN Mesh networks, that might coexist with the target being their cooperation in license-exempt spectrum and their jointly optimised capacity deployment and operation. In this way, *"...different terrestrial access levels and technologies are combined to complement each other in an optimum way for different service requirements and radio environments*", which is a major target of "Mobile and Wireless Systems beyond 3G" IST Strategic Objective in Call 4.
5. To design advanced radio resource management (RRM) algorithms for relaying, including cooperative communication, ad-hoc association and disassociation of nodes by also addressing the impact of these developed techniques on the higher layer routing algorithms.
6. To define and develop novel distributed MAC protocols for Mesh networks that exploits efficiently relaying features, Advanced Antenna techniques and cooperative communication.

7. To optimise decision rules and schemes for cross-layer interaction in FIREWORKS MAC and PHY layer. This set of methods target to improve the service quality (BER, delay tolerance) with respect to complexity and processing power according to the various propagation conditions, the user terminal specifications (power and size) and the geographical positions of the cooperative relays.
8. To separate, order and analyse the criteria and tradeoffs among MAC and PHY methods and/or schemes, based on the capacity, complexity, flexibility and robustness of the system. Such criteria could be the quantity and quality of Channel State Information knowledge at the transmitter and/or receiver, the complexity level of implementation and the degree of cooperation between MAC and PHY.
9. To design a MTMR Advanced Antenna System (AAS) that includes selected and optimal diversity exploitation MTMR techniques (like space-time trellis & block coding), interference managing MTMR schemes (such as joint detection, spatial multiplexing) and adaptive arrays MTMR methods (for instance beamforming) in a transparent manner.
10. To realize a distributed MTMR system that exploits and extends MTMR concepts through cooperation of relay nodes. The resulting MTMR system uses cooperation among MTMR nodes to achieve a higher degree of configuration and scaling which conducts to a superior flexibility and robustness of the services provided to the end users.
11. To establish appropriate System and Link level simulators, define a benchmarking framework and evaluate the performance of the techniques and schemes of the MTMR cooperative system.
12. To validate the FIREWORKS System, PHY and MAC concepts via the Real Time Advanced Antenna Radio Emulation Environment (RTAARE Environment).
13. To evaluate the economic viability of the relay based network concept and also explore its environmental impact and its social acceptance.
14. To monitor, participate and potentially contribute in the relevant WMAN and WLAN existing or emerging standardisation bodies and Working Groups.
15. To promote dissemination of project results in the relevant international forums, workshops and conferences, and IST dissemination activities.

The OFDM technique had been initially selected based on the know-how of the consortium and especially on the pre-existing demonstrator characteristics used as initial platforms for the FIREWORKS prototype. However, the selection of the OFDMA space as the only research area by the main standardization body targeted for dissemination and contribution by the consortium, i.e. IEEE 802.16j, led the FIREWORKS consortium to decide to target OFDMA based systems. All partners have adjusted their work, methodology and tools to support OFDMA schemes. As expected, there was no noticeable deviation of the workplan of either the partners or the consortium as a whole.

1.2 Contractors involved

The FIREWORKS consortium consists of eight partners with complimentary competence and expertise to achieve the goals of a promising undertaking like FIREWORKS. The participants in the consortium represent a significant part of south-eastern and central Europe that now includes new members or have established core business in the general Europe, middle East and Africa (EMEA) geographic region whose topology strongly favours the deployment of Mesh Broadband Wireless Access networks, and thus are seen as holding a great stake in the eventual market success of the technology. The sectoral integration of the consortium comprises a good balance of telecom operators, Telecom Manufacturers, as well as independent Research Centres and Academic Research Institutions. The contractors involved in FIREWORKS are: *INTRACOM TELECOM SOLUTIONS S.A. (GR), MOTOROLA Labs (FR), Commissariat à l'Énergie Àtomique – LETI (FR), RWTH Aachen University (DE), University of Surrey (UK), Technical University of Catalonia (ES), Czech Technical University (CZ), Wind Telecomunicazioni SPA (IT).*

1.3 Work performed and end results

The first outcome in FIREWORKS has been to identify a common framework for inter-workpackage communication and a common ground for simulations. This has been achieved with the definition of the terminology, 5 target scenarios, 5 prototype scenarios, 5 traffic models, and 11 assessment criteria. Specifically, types of devices were clarified (Multihop BS, RS, SS, Enhanced Mesh AP) and the associated deployment and prototyping scenarios (Rural, City centre, Office, etc) with associated simulation parameters (e.g. typical cell sizes, devices powers, etc) were described.

Using the scenario specifications, the system requirements of the various devices (e.g. standard compliance), the expected performance requirements and the regulatory constraints (bandwidth, mobility) are drawn. The defined requirements are based on a checklist provided by the EU IDABC program divided in the following FIREWORKS categories: system capability requirements (performance, cost, QoS…), system architecture requirements (functional requirements, node characteristics …) and operational characteristics requirements (system management at installation and maintenance, regulatory).

From simulations, a business case analysis of the FIREWORKS relay-based system has been completed. Initially, the market and service assumptions for the business case have been established including the identification of the market segments (Broadband Wireless Access for Residential and SOHO, SMEs) along with their associated demographics (e.g. densities in urban, sub-urban and rural areas). A common set of assumptions case has been established on traffic (service penetration rate, activity factors, and generated traffic), device characteristics (transmit powers, number of antennas, topology, etc…) and, in particular, on the key technical features of the FIREWORKS system (OFDMA, multi-hop, cooperation, SDMA). They have been integrated to the financial and network simulation tools in order to complete the business case. A breakdown of CAPEX and OPEX has been completed. It was observed that relaying is cost-efficient only in coverage-limited scenarios where the CAPEX in rural deployments or during the early stages of urban deployments is reduced.

From the first activity of the conceptual study of the project, an analysis of the impact of the relay position on the capacity and coverage of cellular multihop networks has been completed. The evaluation of cooperative relaying protocols in different propagation environments shows that large BS-RS capacity required to achieve significant throughput gain with cooperative relaying (e.g., LOS links, dedicated channel) while complex cooperative protocol seem to provide the best performance. The study of frequency- and time-domain forwarding in relaying systems served to identify the appropriate length of TDD guard time and the DL-UL, Tx-Rx synchronization issues. From the comparison, larger mutual capacity (in bps/Hz) is observed for FDD-based protocols. Additionally, the capacity increase due to SDMA in cellular WiMAX networks has been evaluated for the development of strategies to use SDMA in multihop deployments. Also, the impact of mobile subscriber stations in multihop deployment has been studied. Similarly, the impact of channel state knowledge at the relay station for cooperative amplify-and-forward protocols has been evaluated. Finally, a comparative study of different cooperative protocols, based on Decode-and-Forward, Amplify-and-Forward and Compress-and-Forward has been completed.

Development, implementation and performance evaluation of a combined TD-/SDMA Medium Access Strategies to Support Relay-Enhanced Broadband Cells has been carried out. A mechanism for interference reduction by means of space-time sectorization and other approaches of cooperation across base stations and/or relay stations has been developed. Novel algorithms such as Integrated Sub-carrier, Bit and Power Allocation algorithm and an Integrated Radio Resource Allocation algorithm for OFDMA relaying systems have been studied and evaluated. Several radio resource allocation techniques based on capacity of cooperative relaying protocols for a multiuser setup have been investigated such as RRM techniques for D&F TDMA, RRM techniques for D&F TDMA/OFDMA and Spatial-reuse cooperative multiuser access (A&F). The multihop subframe concept with SDD operation of sub cells and several grouping strategies for a Hierarchical SDMA/TDMA scheduling process have been analysed. Also, the development and evaluation of concepts for: optimum positioning of fixed relays, RRM in OFDMA, AF with spatial reuse, and RRM

for multihop AMC-OFDMA under PUSC/FUSC has been completed. Finally, handover algorithms in multihop developments have lead to the definition of means to optimize handover.

In FIREWORKS, coexistence mechanisms for enabling an operation of IEEE 802.16 in spectrum shared with 802.11(a) have been developed following the development, implementation and evaluation of the Hot Zone concept for a hybrid MAN-LAN network. An analysis of the WiMAX/WiFi MAC overhead, range, and capacities has been completed.

Also, a link level simulator for the evaluation of cooperative relaying has been produced. System level simulators for higher layer protocol optimization, MAC-PHY cross-layer issues and relaying functionality, and hybrid LAN MAN systems have been implemented while a MATLAB framework for mobility issues investigations in multihop deployments has been established.

After a literature review on existing concepts, such as HiperLAN/2, IEEE 802.16 standards and Task Group IEEE 802.16j, a MAC sub-frame concept compatible with PMP MAC layer that can support multihop communication has been designed and proposed. Potential extension of the MAC frame concepts towards SDMA have been studied and evaluated. Both centralized and semi-distributed approached were considered. The MAC based cooperative communication scheme was developed and evaluated including adequate frame structures, forwarding techniques and standard procedures supporting similar strategies such as MDHO. A way of implementing each protocol within each frame, by means of STC, ARQ and H-ARQ standard capabilities, has also been described. The impact of cooperative transmission in the MAC layer of 802.16-e standard has been studied and more specifically the required IE's to inform the involved stations have been identified. A relaying concept has been designed, proposed and evaluated utilizing true sectoring capabilities from the RS point of view. MAC management messages exchanging procedure during handover for the relay-based FIREWORKS system were studied and analyzed. These messages extend those in 802.11s, 802.16-2004 and 802.16e involved in network entry, node association and handover procedure. Their additional overhead has also been investigated. Finally, requirements of the MAC SAP and PHY SAP have been evaluated for the novel relaying and cooperative schemes.

From the above mentioned studies, the separation of the MAC layer to upper/lower or alternatively to RLC/lower in order to form a list of required MAC functionalities to be addressed in relay-enhanced systems has been concluded. Following the outcomes from the baseband research, the specifications of a comprehensive MAC/PHY interface capable to support the newly introduced techniques and functionality of FIREWORKS have been deduced. In the MAC Common Part Sub-Layer, the following specifications were provided:

- Relay station discovery and optimum handover station selection.
- Various handover techniques assuming relay communication.
- Multi-sectoring relay concept.
- MAC based cooperative communication.
- Frame structures to support sub-frame relay concepts assuming either OFDM or OFDMA transmission technology. This includes and appropriate modifications of MAP messages and IEs fields.
- Frame structure and specific message fields and IEs supporting cooperative techniques following the sub-frame concept.
- Support possible 802.16 and 802.11 coexistence by performing minimum modifications.
- For the CS-MAC interfacing, specifications were provided for connection creation, characteristics' modification and termination.

Within the system level simulators developed, multihop and cooperative features compliant with 802.16e specs for OFDMA, based on the recommendations and the RRM methods for PUCS/FUSC were implemented. A Space Time forwarding concept and sophisticated UL-scheduling strategies both allowing spatial reuse evaluation have been integrated in the simulators. The performance, efficiency

and overhead evaluation of several proposed techniques, extensions and algorithms such as specialized handover procedures have also been evaluated. To end with, the final specification for the FIREWORKS system is extracted from the above evaluation

The first outcome of the baseband investigation is a state of the art review on available MIMO channel models and in order to provide guidelines on possible use of the channel model in FIREWORKS identified MIMO and relay propagation scenarios. Evaluation of space-time golden codes for IEEE 802.11n, review of SDMA techniques and description of implementing Obele algorithms as a promising SDMA technique for a generic OFDM system and a comprehensive review of multi-user and joint detection techniques for different possible multi-user MIMO transmission-reception configurations are some of the initial results obtained at the beginning of the project.

More analytically, the main initial technical outcomes are:

- The adoption of MIMO channel models to be used in FIREWORKS identified MIMO and relay propagation scenarios.
- The performance evaluation of bidirectional beam forming is done in the context of IEEE 802.11n for uplink and downlink transmissions.
- A generic SISO list sphere detector to be used for detection of linear dispersion codes (LDC) with arbitrary constellation.
- The evaluation and comparison of different space-time codes including Golden code and other algebraic codes with different ML, MMSE, and sphere detectors for WiMAX RS-SS link under FIREWORKS Car scenario.
- The performance evaluation of Obele algorithm as a promising SDMA technique for WiMAX system under realistic conditions and imperfect channel knowledge.
- Final performance results on the application of multi-user and joint detection techniques for different possible multi-user MIMO transmission-reception configurations of WiMAX system.
- Performance modelling and mobility analysis of the Dynamic Band Allocation (DBA) for WiMAX AMC sub-carrier mapping.
- A generic performance modelling approach to estimate overall performance of a multi-hop route with the optional engagement of (H)ARQ process.
- The description of control and measurement parameters to implement a MAC/PHY interface supporting Advanced Antenna System (AAS).

For the modified and enhanced techniques on the use of cooperative and relay transmission techniques for FIREWORKS mesh/relay scenarios, the consortium produced results for multiple and single relay cooperative transmission including AF/DF, distributed STBC with AF/DF, distributed turbo code, CF with Slepian-Wolf based LDPC compression and a low complexity multiple antenna quantise & forward (QF). Average DL/UL capacity calculation for CF cooperative relaying and performance results for adaptation of cooperative transmissions such as selective relaying, hybrid ARQ and selective relaying with hybrid ARQ are also provided.

The main technical outcomes are:

- A new adaptive hybrid AF scheme attaining the best performance between direct and cooperative AF transmissions and reduction in relay's transmitted power.
- Three enhanced DF schemes: (i) Soft DF (SDF) extended to higher order MQAM modulations, (ii) DF with indirect route equivalent SNR combining (EDF), and (iii) DF with relay reliability (RDF). All the proposed enhanced DF schemes achieve significant gain with respect to original DF.
- A novel low complexity transmit-cooperative scheme based on layered higher order modulation and LDPC based compression. An iterative detection scheme to be used for the proposed transmit cooperation scheme.

- Extension of cooperative DF scheme to multi user case in uplink and comprehensive performance evaluation of the proposed scheme for WiMAX system.
- Precoding scheme for MIMO cooperative DF with transmitter channel knowledge.
- Comprehensive description, performance analysis, and information theoretic treatment of a generic cooperative MIMO BICM scheme exploiting enhanced RDF scheme.
- Extension of EESM performance modelling for cooperative DF scheme under all possible transmission/reception protocols.
- Efficient MCS selection procedure for cooperative DF schemes based on throughput and PER performance obtained through extended EESM performance model.
- A novel quantisation algorithm based on the achievable rate for cooperative CF scheme. A combination of CF cooperative relaying and uplink SDMA is proposed and its performance is evaluated.

The performance results and evaluations that took place in FIREWORKS were possible with development of several Link Level Simulators dedicated to the evaluation of the novel PHY algorithms. In addition, a link performance modelling using exponential effective SNR mapping (EESM) for single and multi-hop relaying supporting MCS has been performed.

Initially, in the prototyping activity of the project, simple and relevant scenarios for implementation have been extracted. The composition of the FIREWORKS prototype is refined and the requirements of the elements compositing the demonstrator are defined. The hardware platform capable to meet the conditions required for the demonstration of the selected FIREWORKS features is selected.

Then, the PHY algorithm planned for implementation is defined and analytically described. The algorithm is selected after a hardware complexity analysis concerning the implementation feasibility. Then, detailed specifications at the block level of the functionality of the PHY prototype are deduced. Finally, the PHY blocks needed for the STBC process for the final prototype composed of 2 antenna elements at both ends of the transmission chain are developed.

Similarly, the minimum specifications to assure simple relaying and cooperative scenarios have been established. The development of the MAC functionality as well as the corresponding MAC-PHY interface has been produced.

Meanwhile, based on a state of the art analysis, a guideline has been proposed to specify the form factor (or the maximum gain) of the antenna. Depending of the link between the source and the destination (LOS, NLOS), the size (or the maximum gain) of the antenna at the relay station can be reduced without decreasing strongly the performances. Simulations have been performed in such a way: evaluate the degradation on the link budget versus the antenna patterns and distributions of incoming waves. From the developed simulation chain including RF modelling, several simulations have been done in order to estimate the degradation in term of BER in the transmission between a source and a destination through a relay using AF or DF techniques in simple relaying and cooperative scenarios.

Lastly, the final configuration to interconnect the node boards (MBS, MRS and MSS) has been decided after a full analysis of the capabilities of the newly acquired custom hardware solution for the development of the FIREWORKS prototype. The design (schematics), development and testing of an adapter board to interconnect all boards of the demonstrator (nodes and RTAARE) has been concluded. The specifications, development, testing and validation of the RTAARE environment for the FIREWORKS prototype has been concluded following three distinct implementation steps. Appropriate channel impulse responses for the real-time channel emulator (RTAARE) have been generate offline on MATLAB and converted for implementation in the hardware board. The integration of the prototype has been successfully carried out including a cross-validation procedure with a MATLAB simulation platform. Three distinct integration stages have been concluded adding extra features to the platform. A Graphical User Interface (GUI) for the demonstration of the prototype

features has been developed. Finally, a performance evaluation and general conclusions on the prototyping activity have been drawn.

More analytically, the FIREWORKS project includes the development of a prototype platform of the target system in order to evaluate the complexity and validate the implementation of the algorithms investigated within the framework of the project. Based on selected demonstration scenarios, the objective of the FIREWORKS prototype is to provide a proof-of-concept of the relaying and cooperative communication schemes.

To this end, a system composed of three nodes has been selected for implementation. The nodes of the prototype are one Multihop Base Station (MBS), one Multihop Relay Station (MRS) and one Multihop Subscriber Station (MSS). These nodes are connected through a RTAARE (Real-Time Advanced Antenna Radio Emulation) Environment in charge to provide a realistic emulation of the propagation conditions between the nodes of the FIREWORKS prototype system. The RTAARE entity is a central entity that provides control over the entire demonstration system. In the same time, the real-time capabilities ensure an accurate validation of the algorithms and techniques implemented.

The FIREWORKS prototype is composed of six boards in total. One board is used for the MBS entity, one board for the MSS entity and two boards are used for the MRS entity. At the MRS, data is bridged from the receiver side (Rx board) to the transmitter side (Tx board) via Ethernet creating a "virtual" real-time pipeline between the two boards. The RTAARE modules are integrated on a commercial FPGA board. The sixth board is a custom board designed to create a connection interface compatible with the different boards.

The four system boards are connected via Ethernet to a host workstation used for the management and control of the platform. The management PC runs an appropriate custom Graphical User Interface (GUI) for the control and observation of the functionalities supported by all network elements of the prototype.

The FIREWORKS prototype is included of two additional workstations connected via Ethernet, one to the source board (MBS) and one to the destination board (MSS). These stations are used for the provision of source and sink entities to the system for the generation of various data flows and for end-to-end evaluation.

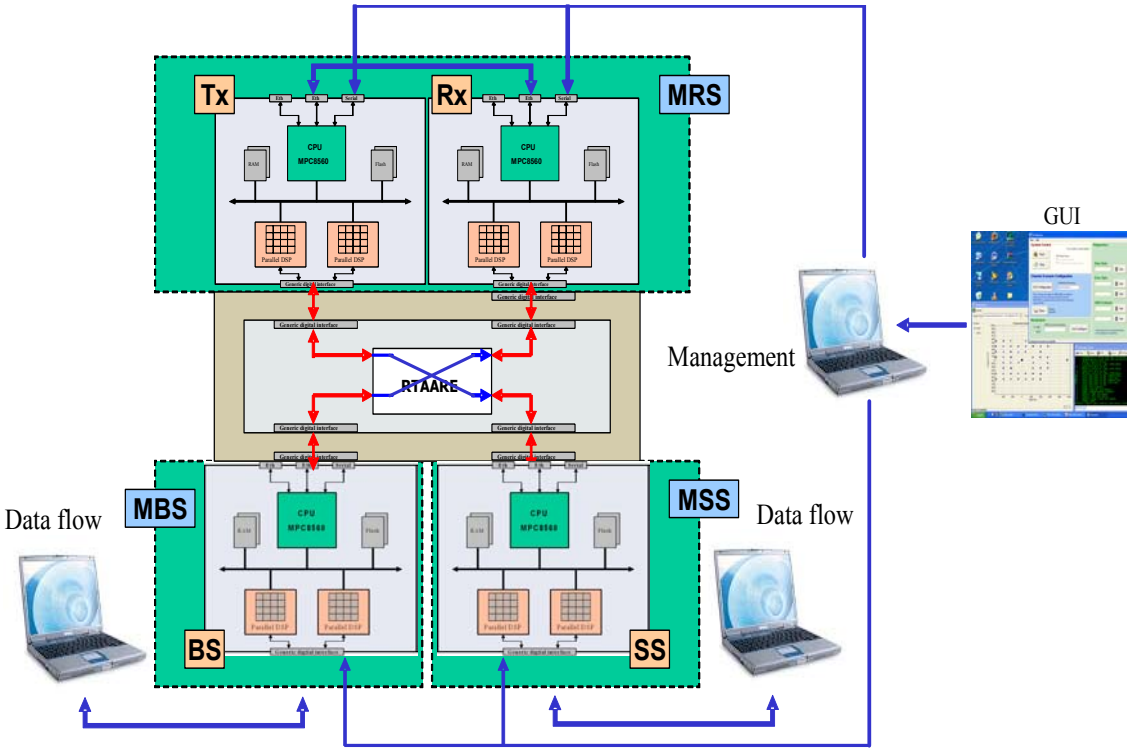

Figure 2: Block diagram of the FIREWORKS prototype platform

The FIREWORKS demonstrator has been displayed at the ICT Mobile Summit held in Stockholm, Sweden on June 10-12, 2008.

In order to consolidate the various outcomes of the project, the FIREWORKS consortium considered of great importance for future exploitation opportunities to carry out an analytical description of the IPR portfolio that covers the ideas and activities investigated in FIREWORKS. The novel concepts and innovations considered for the FIREWORKS target system are analysed. The IPR portfolio analysis targets to identify the IPR blocks and assess the valuable knowledge acquired by the consortium in order to identify expected impact to existing and future standards and projects.

Also, interaction with other project has been carried out through presentations in respective plenary meetings of the projects. Two presentations on behalf of SURFACE project and one on behalf of WIP project have been held in FIREWORKS plenary meetings. FIREWORKS presented parts of its achievements at one of WIP's plenary meetings.

In FIREWORKS, 7 articles, 59 conference publications and 2 book chapters have been issued. Furthermore, 4 contributions to the novel IEEE 802.16j relay task group on Mobile Multihop Relay standardization body have been provided. Two patents have also been filed.

1.4 Impact on industry or research sector

The impact of flexible relays in wireless OFDM/OFDMA-based networks concerns the WMAN and WLAN standards, the industry sector, telecom operators and users. For telecom operators, FIREWORKS expects to reduce investment risks, to offer higher scalability to customer expansion and to maintain requested provision of profitable services. FIREWORKS end-users will enjoy ubiquitous access independently from the equipment nature or the communication environment. FIREWORKS impacts can be categorized as follows:

- *Efficient radio and spectrum exploitation:* By using Advance Antenna techniques in combination with relay based concept, single links and overall system capacities will be improved leading to a reduce radio exposure and an enhanced radio coverage.
- *Economical and multifaceted network topology:* The ad-hoc nature of a mesh network incorporating cooperative concept results to a reduced network failure probability, self-organization functionality and low infrastructure costs; while integrating the relaying functionality in a multi-service BWA MAC layer the coverage region is extended.

In FIREWORKS, the conceptual studies related to the integration of relays in wireless broadband networks and, the investigations of advanced baseband cooperative techniques and novel MAC protocols have been intentionally placed within a standardized framework. With this approach, it has been possible to investigate the effects and changes needed to support and implement features from the FIREWORKS system to a standard non-relay-based WMAN architecture. Hence, for example, the studies on hybrid WMAN and WLAN networks could be potentially exploited for future dimensioning WiMAX cells under Wi-Fi hotspots.

The effective impact of the work in FIREWORKS is reflected via the contributions to the emerging standardization body IEEE 802.16j relay task group on Mobile Multihop Relay and via the patent applications related to the work produced in FIREWORKS.

Besides that, the prototyping activity of the project gave to the consortium an initial insight of the modification needed to support advanced techniques of the FIREWORKS system within a common hardware platform capable to support standardized features. Additionally, the FIREWORKS business model analysis offers to the industrial community and telecom operators a concrete idea of the financial benefits and costs of the development, deployment and maintenance of a relay-based system and more particularly of the FIREWORKS system. The IPR portfolio analysis carried out at the end of the project serves the consortium to identify the major IPR blocks and possible impacts of the project in terms of technical achievements, industrial competitiveness and social acceptance.

Finally, for the academic sector, the completion of Master thesis and PhD dissertations around cutting-edge technologies is an essential way for the acquisition of valuable know-how that could influence the academic community. More generally, acquiring expertise through the development of complex simulation platforms and the implementation of advanced techniques and protocols is a beneficial consequence of the work carried out in FIREWORKS that might lead to future exploitation by universities, research centres and industries.

2 Dissemination and use

2.1 Achievable Compress-and-Forward rates in MIMO (as described in 4D3)

Result description

The result consists in a means to quickly compute the potential throughput gains brought by compress-and-forward relaying in MIMO-OFDM systems. It was published at ICC 2007 conference. The expertise acquired on this topic will support the derivation of a techno-economical assessment of fixed relays and Base Stations cooperation via a constrained backhaul in the uplink.

Key descriptors: Broadband technologies, communication engineering technology, future and emerging technologies, systems analysis and models development and wireless systems, radio technology

Possible market applications

Research and development

Stage of development

Scientific and/or Technical knowledge (Basic research)

Collaboration sought or offered

Further research or development

Intellectual property rights granted or published

Copyrights registered

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2.2 Cooperative Downlink Beamforming (as described in 4D3)

Result description

The result consists in source and relay pre-coder optimization techniques for cooperative beamforming in the downlink. It allowed us to have a first evaluation of the gains that can be achieved by exploiting Channel State Information in cooperative networks. This work will be continued in FP7 project ROCKET.

Key descriptors: Broadband technologies, future and emerging technologies, systems analysis and models development, telecommunication engineering/technology and wireless systems, radio technology

Possible market applications

Manufacture of radio, television and communication equipment and apparatus
Post and telecommunications
Computer and related activities
Research and development

Stage of development

Scientific and/or Technical knowledge (Basic research)

Collaboration sought or offered

Further research or development

Intellectual property rights granted or published

Copyrights registered

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2.3 Multi-Antenna decoder apparatus for Matrix-A /STC-2

Result description

The result implements maximum ratio combining functionality for a multi antenna receiver capable of decoding STC-2/Matrix-A signalling. This module is appropriate for a two-antenna receiver and supports both one- and two-antenna (Matrix A) transmitters. For single-antenna transmission it performs maximum ratio combining of the two received signals, based on the two Rx antenna channel estimates, while for two-antenna transmission it also performs Alamouti decoding, in addition to the maximum ratio combining. The result is a stream of compensated QAM symbols. It is compatible with multicarrier modulation schemes, such as OFDM and OFDMA.

Key descriptors: Broadband technologies, design, design engineering; future and emerging technologies, telecommunication engineering/technology and wireless systems, radio technology

Possible market applications

Manufacture of radio, television and communication equipment and apparatus
Post and telecommunications
Computer and related activities
Research and development

Stage of development

Experimental development stage (laboratory prototype)

Collaboration sought or offered

Further research or development

Intellectual property rights granted or published

Secret know-how

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2.4 LLR combiner for Cooperative decoding

Result description

The result implements the Log-Likelihood Ratio (LLR) combining of successive transmissions. The functionality can be incorporated into future multi-hop MBS/MRS and MBS/MRS/MSS Co-operative relay scenarios. In cooperative relaying the signal received from MBS and the signal received from the MRS are combined at the destination MSS. In such a system enhanced spectral efficiency and mitigation of path loss and shadowing is achieved. The design involves the definition of a suitable MAC frame supporting relaying and Cooperation as well as a radio resource manager. The main advantage of the cooperative schemes, with respect to simple relaying is that cooperation effectively forms a virtual MIMO system that increases the capacity without increasing the number of antennas at the receiver. We have implemented protocol-I of Cooperative relaying. Nodes implement a structure similar to the transparent mode of 802.16j. Recombination of the frame packets is performed at the MSS.

Key descriptors: Broadband technologies, design, design engineering; future and emerging technologies, telecommunication engineering/technology and wireless systems, radio technology

Possible market applications

Manufacture of radio, television and communication equipment and apparatus
Post and telecommunications
Computer and related activities
Research and development

Stage of development

Experimental development stage (laboratory prototype)

Collaboration sought or offered

Further research or development

Intellectual property rights granted or published

Secret know-how

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2.5 Cooperative Channel Emulator

Result description

The goal of this cooperative channel emulator is to allow three stations (base station, relay and subscriber) to communicate within MIMO channels (2 antennas per station). This channel emulator has been designed in order to support cooperative techniques (two transmitters in the same time-slot). In this purpose, the channel emulator simulates air interface but also RF impairments. The channel emulator takes into account multipath aspects and an additive white Gaussian noise. The noise power is controllable in order to adjust a desired SNR. It can emulate different scenarios (cooperative or simple relaying transmission in a slow time varying, urban or rural propagation environment). The channel emulator has been developed in VHDL code and has been implemented on a FPGA. Its operation is controlled via specific commands from a Graphical User Interface (GUI). Scenarios can be assigned dynamically by changing the set of channel parameters through the GUI. An important asset of this channel emulator is its flexible implementation, i.e. parameters and scenarios can be very easily modified according to the needs of the system-under-test.

Key descriptors: Digital Systems, digital representation, Electronics, electronic engineering, Future and emerging technologies, Telecommunication engineering/technology and Wireless systems, radio technology

Possible market applications

Manufacture of radio, television and communication equipment and apparatus
Post and telecommunications
Computer and related activities
Research and development

Stage of development

Experimental development stage (laboratory prototype)

Collaboration sought or offered

Further research or development

Intellectual property rights granted or published

Partnership / other contractual agreement(s)

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2.6 Generic simulation environment: Open Source Wireless Network Simulator – openWNS

Result description

The Wireless Network Simulator (WNS) is a sophisticated framework for event driven, stochastic system level simulations. Its highly modular nature allows for performance evaluation of various wireless systems such as IEEE 802.16, IEEE 802.11, Universal Mobile Telecommunications System (UMTS), and the WINNER Protocol Stack (WinProSt). It has been developed at ComNets and contains a wide range of modules to analyze cellular mobile radio networks at almost any level of detail for the purpose of research development and standardization activity. The WNS provides modules for the following layers:

1. Multimedia load generator, e.g. voice, video, and web browsing
2. Transport Layer, e.g., Transmission Control Protocol (TCP) and User Datagram Protocol (UDP)
3. Network Layer, Internet Protocol (IP)
4. Radio Access Technology including Logical Link Control (LLC), Radio Link Control (RLC), and Medium Access Control (MAC)
5. Interference Calculation including smart antennas and characteristics of the PHY layer

To enable the fast and reliable development of new modules, WNS provides a set of support libraries e.g. for design implementation and for measurements. A simulator finally consists of one or more modules being loaded at runtime by the runtime environment. As mentioned above, each module has a specific task and roughly fits into one of the five categories.

Key descriptors: Communication engineering/technology, Electrical engineering/technology, Simulation, simulation engineering and Wireless systems, radio technology

Possible market applications

Manufacture of radio, television and communication equipment and apparatus
Research and experimental development on natural sciences and engineering

Stage of development

Software code

Collaboration sought or offered

Further research or development

A tool is provided for the evaluation of wireless communication system with the opportunity of fast implementation of new systems (close to emulation). Further, the service of support for the tool (for self developing partners) or the service of performance evaluations of wireless networks can be offered. New technologies and their necessary extensions can be efficiently investigated in conventional or arising standards of wireless networks by the means of the simulator.

Collaborator details

External partners from academy, industry and standardization domains are appreciated. Ones with involvement in R&D of next-generation wireless network (e.g. IMT-advanced systems) can provide valuable feedback to necessary extensions of the framework in order to let it support future key technologies such as relaying, cooperative communication, coordination or coexistence. Further expertise in topics such as system-level, link-level simulations can provide important remarks to further improve the usability of the software tool (for instance in terms of implementation effort, reliability and reuse of the code).

Intellectual property rights granted or published

Partnership / other contractual agreement(s)

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