PROJECT FINAL REPORT

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1 Final publishable summary report

1.1 Project objectives

The goals of FREEDOM (www.ict-freedom.eu/) are to investigate the technical challenges resulting from the deployment of femtocell networks within an environment populated by cellular users and to propose innovative algorithms to handle interference properly and achieve the potential advantages of the new technology. The possible massive deployment of owner-operated home base stations makes a centralized radio resource management hard to achieve. To tackle this concern, in FREEDOM a special attention is devoted to develop decentralized resource management techniques, with possible interaction among nearby femto access points (FAPs) to improve the overall system efficiency. The interaction among FAPs occurs over the (ADSL) wired backhaul and, since the ADSL line has variable QoS, alternative forms of interactions are envisaged, spanning from coordination, where only control signals are exchanged, to cooperation, where information data are exchanged as well. Interference management and seamless connectivity through the identification of appropriate handover techniques are some of the key developments in the projects. A system level simulator and an experimental testbed are developed and used to validate the project results.

1.2 Description of the work

In the recent years there has been an increasing demand for mobile traffic due to the large nomadic population and the type of applications to be employed. This has motivated that the near-future 4G networks must enhance their efficiency in terms of spectrum, energy and cost. The solution addressed in this project is the use of femtocells and it is also considered by several mobile operators (e.g. T-Mobile Europe, TELECOM-Italy and Vodafone in Europe; NTT DoCoMo and Softbank in Japan; O2/Telefonica, Sprint, AT&T Mobility and Verizon in the US; and Chunghwa in Taiwan) and different standards, such as IEEE 802.16m and LTE-Advanced.

Currently, femtocells and macrocells are seen as isolated networks, competing for the resources available in the common spectrum band, at the cost of injecting interference to the whole system. FREEDOM project faces key technical and industrial concerns about the foreseen mid-term massive deployment of femtocells by adopting a new approach based on cooperative/coordination paradigms, enabled by the quality-limited ISP backhaul link. The project does not disregard the approach of isolated networks because it is met when there is not enough backhaul link connecting femtocells and macrocells. In order to guarantee a strong focus and efficiency, FREEDOM focuses on:

- Advanced interference-aware cooperative PHY techniques,
- Improvement of the control plane procedures for seamless connectivity, and
- System-level evaluation and hardware demonstrator of the proposed femto-based network architecture.

FREEDOM is organized in six technical work-packages (WP), as described below, aimed at solving as many research challenges, plus a management WP.

WP2: The goals of this WP are to identify the scenarios of interest, establish requirements and performance metrics, to ensure that the project offsprings are consistent with reference organizations (e.g. IETF, 3GPP/LTE-A, Femto Forum), and disseminate the results.

WP3: WP3 is primarily concentrated on Physical Layer (PHY) issues. Its goals are: 1) to examine decentralized strategies for radio resource management; 2) to evaluate the spectral/energy efficiency improvement resulting from local coordination of femto access points (FAP), through the backhaul (wired) link; 3) to explore the gain obtainable through cooperation, based on the exchange of data among FAPs;

WP4: The goals of WP4 are: 1) to design advanced handover procedures for coordinated macro/femtocells; 2) to design a fast handover and a fast admission processes by passive scanning based on user's location; 3) To design advanced procedures for routing, power control and scheduling and propose fast cell identification methods.

WP5: The goals of WP5 are: 1) to evaluate the algorithms of WP3/WP4 at system level, under planning strategies.

WP6: The goals of WP6 are: 1) to develop a prototype hardware platform realizing the selected techniques and analyze performance; 2) to provide a reduced-scale testbed and conduct proof-of-concept test allowing a standalone or limited number of femtocells to be integrated with xDSL access network.

1.3 Contacts and website

All information generated within the project is timely updated at www.ict-freedom.eu.

The FREEDOM consortium consists of eight partners with complimentary competence and expertise to achieve the goals of a promising undertaking like FREEDOM. The sectorial 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 FREEDOM are: Universitat Politècnica de Catalunya (UPC), Università di Roma La Sapienza (INFO), Dune S.R.L, (DUN), Commissariat a l'Energie Atomique et aux Energies Alternatives (CEA), Czech Technical University in Prague (CTU), Sequans (SEQ), Siradel (SIR), Telkom (TELK). Contact details can be found in the table below.

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1.4 Project results and achievements

This section provides a comprehensive description of the project results and conclusions and their potential impact and use1. These are grouped per workpackage and per-activity on each workpackage, matching the research roadmap described in section 1.2. In all cases the techniques proposed assumed some baseline specifications based on the LTE and/or WiMAX standards, and required modifications are identified and developed in the deliverable associated to the activity.

1.4.1 WP2. Requirements and dissemination

Even though FREEDOM is a STREP project, with short duration and focused objectives, FREEDOM has had a significant impact, with more than 15 journal publications, about 40 conference papers, 4 standard contributions to 3GPP, 4 patents. Direct impact on product has been seen, with 5 products being improved thanks to project outcomes. At last, the project supported 7 masters students and 3 PhD.

This impact is the result of several aspects. Among them, the project was able to keep a close link with trend and standard, in order to steer the technical activities in line with the overall market and context evolution. This was the goal of the activity 2A1: to define appropriate scenarios and requirement for the technical work to be undergone. Moreover, the project has spent specific effort for dissemination, captured in task 2A2. At last, the project has a dedicated task related to business model, bridging the technical work with business related aspects.

Activity 2A1: Scenarios and requirements

Femto-cells are foreseen to become a key enabler of capacity and coverage improvement for next generation cellular systems (IMT.ADV) and could become in addition the bridge between in-home entertainment systems and mobile communication systems. However, a massive deployment of femto-cells raises numerous technical problems that need in-depth analysis. The basic requirements and assumptions for this analysis are described in the first report generated by Freedom project: D2.1

In D2.1, a clear list of scenarios, requirements and assumptions that could be shared by the partners during the whole duration of the project was provided. These scenarios and assumptions are derived from two main sources: The first source is from operator business scenarios and models; the second source is obviously the already huge contributions from standardisation bodies and femtocells related fora. From these scenarios, requirements were derived and we defined as exhaustively as possible systems assumptions to ensure common simulation assumptions within the project.

Activity 2A2: Dissemination

To focus the dissemination effort on meaningful actions, in M2.2 milestones the project has defined the strategies of FREEDOM project with respect to dissemination standardisation and IPR. It started with an overview of the bodies of interest for the FREEDOM project, highlighting the most appropriate ways for dissemination. Then, during the whole duration of the project, the outcomes of the work were widely disseminated and promoted both at academic level (through conference, publications on peer-reviewed journals, organization of a winter school, invited talks etc.) and industrial level (standardization, patents, internal company promotion).

It is worth noticing that despite the lack of partner in the consortium having a large footprint in the standardisation area (typically a large manufacturer), the project successfully achieved to presents its results in 3GPP-LTE standardisation meetings. In particular, the results obtained with decentralized strategies, with possible local coordination among femto access points, have been seriously considered and is becoming a study item within RAN3 group, as an alternative to the already foreseen centralized

[1] For a detailed description of the dissemination, IPR generation and standardization activities please refer to deliverable D2.3 – Market opportunity, business model and technology implementation-dissemination plan.

strategies. Also, the advanced use of relay transmission strategies was warmly received in the RAN1 meeting in Athens, in August 2011.

Activity 2A3: Business model

The activity related to business models was divided into two phases during the project. An initial analysis of the business trend was done at the project start, and reported in D2.1. This phase allowed the project to focus on most important technical aspects, driven by the market view. A value chain was presented in this report and most important targets (small office and home deployment) were identified.

At the end of the project, this initial business model was revisited in D2.3, especially to capture the benefit of the project innovation. A specific focus has been given on financial aspects of femtocell deployment in particular region based on the scenario resulted from technical WPs. The business model simulation presents two scenarios: operator push or customer pull. Both scenarios show that the FREEDOM technology is feasible to deploy, with positive net present value within 10 years of project.

Impact of project results

- Definition of detailed scenarios for the deployment of femtocells. These scenarios have been used throughout the project and can be used by subsequent projects and/or operators for business planning.
- The contributions of the project have been brough to one meeting of 3GPP-LTE RAN1 and three meetings of 3GPP-LTE RAN3 in 2011 and 2012 (see section 2A2). The impact has been significant in the definition of the scenarios and the adoption of SON strategies for small-cells activities, as can be checked in the reports of the attendance.
- Activities on cell search and multiuser MIMO access are being implemented by SEQ. Some other activities have generated patents (see section 2B1).
- The project has produced a considerable number of publications in quality journals and conferences (see section 2A1).

1.4.2 WP3. Advanced PHY-techniques for femto-based networks

The technical outcomes that follow correspond to the activities in WP3, where we have looked into different channel models and interference power models. In particular, decentralized algorithms for interference management and resource allocation have been investigated. Alternative strategies have been identified and analyzed, depending on the utilization and quality of the backhaul link connecting the FAPs: a purely *competitive* approach, when there is not any message exchange; a *coordinated* approach, when control messages are exchanged; a *cooperative* approach, when there is full exchange of control and data plane information among FAPs. Furthermore, the following relevant issues have been investigated:

1. Scanning of neighboring BSs
2. Improving the spectral efficiency by user-pairing in the uplink
3. Effect of time-misalignment and carrier frequency offsets in cooperative techniques.

A description of the major results is reported next.

Activity 3A1: Identification of the interference (SEQ-INFO)

This activity digged in the modeling of the received interfering power and the wireless propagation channels in scenarios specifically related to the FAP deployment. These models have been further considered in the development of decentralized interference management algorithms based on a competitive approach. The major technical achievements are:

Interference and channel modeling

- The indoor-to-outdoor path-loss has been modeled using a large set of measurements collected in urban environment at frequency 2.1 GHz. Two models have been proposed: a) analytical formulas (useful for link-level and system-level simulations) and b) ray-tracing based model providing deterministic path-loss predictions (useful for precise radio analysis or radio planning tasks). Some results of those models in terms of predicted received power in Figure 1. (SIR)

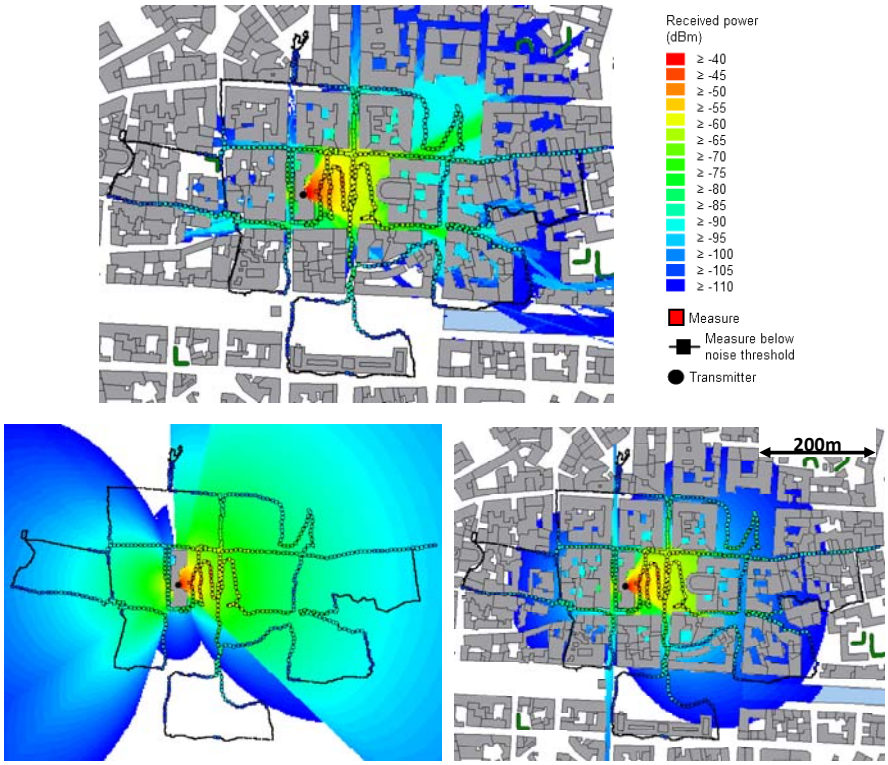

Figure 1. Top) Received-power predicted from the enhanced site-specific model, for Close To Window transmitter in the ground-floor in dense urban environment. Bottom-left) Received-power predicted from the 3GPP model. Bottom-right) Received-power predicted from the FREEDOM model.

- The human activity impact on the wireless indoor channels has been studied and introduced in the wireless stochastic channel model by means of a time-variant component. (SIR)
- Closed-form expression modeling the interfering power has been derived taking into account the random location of active FAPs and the time misalignment between non-colocated transmitters in OFDMA context. While in the first case, the position properties of the nodes are taken into account, the second case models the interference as a Poisson Point Process in space and frequency to deal with the inter-carrier interference generated by propagation delays that exceed the cyclic-prefix duration. (CEA)

Decentralized interference management

- Distributed mechanisms for spatial frequency reuse have been analyzed. They are based on a competitive approach where each user tries to optimize its own utility function (either maximize individual bitrate, subject to a maximum available power, or minimize the transmit power guaranteeing a minimum target rate). It has been shown that a purely decentralized mechanism maximizing the sum-rate is able to provide an interference free cannel assignment, with high probability, provided that the number of carriers needed to avoid conflicts among neighbors respect the inequality $N>2\times\log(n)+1$, under the assumption of a uniform spatial distribution of users of n terminals/m^2. (INFO)

- Assuming that all terminals may not have the same priority (for instance the macro users should not be interfered by FAPs transmissions), we have derived a distributed mechanism to cope with the maximization of the rate. Before transmitting, the channels must be sensed in order to check their occupancy state by macro BS (MBS) transmissions. This approach requires the introduction of appropriate detection thresholds over each channel. We have proposed an algorithm that jointly optimizes detection thresholds and vector power allocation across a set of sub-channels, in order to maximize the throughput. The results show a significant improvement of overall capacity with respect to the case where detection and power allocation are considered separately. (INFO)
- We have modeled the macro-user activity as a discrete time homogeneous Markov chain under the assumption of the channel sensing can be performed on a time scale larger than that of the macro-cell channel occupation dynamics. We propose algorithms to maximize the average rate, conditioned to the observation of the interference activity over each channel and based on the estimation of the activity probabilities, and to minimize the transmitted power for a given average target rate. (INFO)

System functionalities

- Taking into account a dense femtocell deployment, an algorithm for fast network entry (*fast scanning*) has been proposed and evaluated showing a considerable reduction in acquisition time when compared to conventional approaches. This algorithm scans neighboring cells in order to anticipate radio link failure and trigger handover before loosing the connection. (SEQ)
- To improve the spectral efficiency when multiple users are transmitting to the same destination (uplink transmission), we have implemented the MIMO collaborative spatial multiplexing (CSM) where transmitters (UEs) are paired so that they can transmit simultaneously. We have studied how packet error rate (PER) is affected when UEs employ different modulation and coding schemes (MCSs) and how they are affected by different frequency offsets. See for example Figure 2 where we see the effect on the two layers when the MCS is different. Here, the frequency error is introduced only to the layer with MCS of 64QAM 5/6. However, it affects the other layer with lower MCS remarkably. For a frequency error of 90 Hz on the second layer, the degradation on the other layer exceeds 4 dB for PER of 10^{-2} (SEQ)

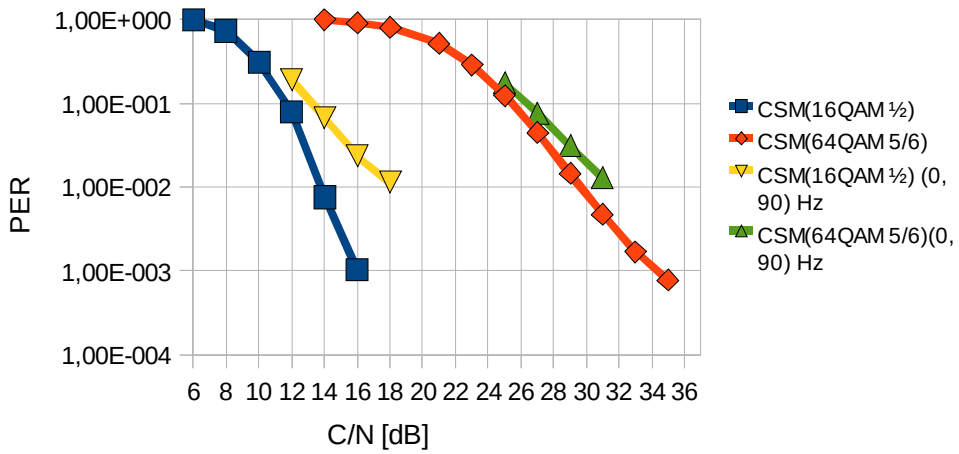

Figure 2. Effect of frequency offset on the MCS pair (16QAM 1/2, 64QAM 5/6) with 13 dB offset. ITU Pedestrian-B channel.

Activity 3A2: Interference coordination (led by UPC)

In contrast to activity 3A1, where transmitters work in a competitive way, in this task we have proposed decentralized algorithms that exchange messages at control-plane level through the backhaul link. Those messages, named pricing in the sequel, account for the sensitivity of the objective function considered at each source as a function of the received interference. They also convey information about the priority of the served users and how the different constraints (target rate, max sum-rate, ..) are met. The technical achievements are the following:

Decentralized coordinated radio resource management

Algorithms have been devised for two criteria (which may be associated to different traffic requirements) assuming a limited bandwidth backhaul link, for the general MIMO configuration:

- Minimization of the total system transmitted power still guaranteeing a minimum per-user target rate, by allocating transmitted power and MIMO precoders. (INFO, UPC)
- Assuming a scenario where FAPs are serving multiple UEs in orthogonal frequency division multiple access (OFDMA) , we have proposed an algorithm to optimize the weighted sum rate of the users, by allocating power, frequency bands and MIMO precoders. Results confirm that the cooperative pricing-based techniques are able to take into account the QoS (in terms of user priorities) of the different neighboring users. (UPC)
- A pricing-based algorithm has been designed in order to optimize the modulation and code selection (MCS) and the bandwidth selection in LTE-A. This algorithm faces the practical constrains imposed in the LTE-A, such as that there is no power control in the downlink or that there is not a detailed signal-to-noise plus interference ratio (SNIR) reporting. The algorithm reports the cost of the neighbouring transmissions in terms of MCS degradation. Figure 3 presents the maximum MCS for the worst 20% of user equipments (UEs) as a function of the average number of active FAPs in our scenario. In case of harmful interference Macro-UEs usually are not able to operate (MCS becomes 0). Nevertheless, the proposed algorithm allows serving those MUEs with a reasonable good performance. Likewise, the MCS attained by Femto-UEs is almost doubled when there are 10-25 active FAPs.

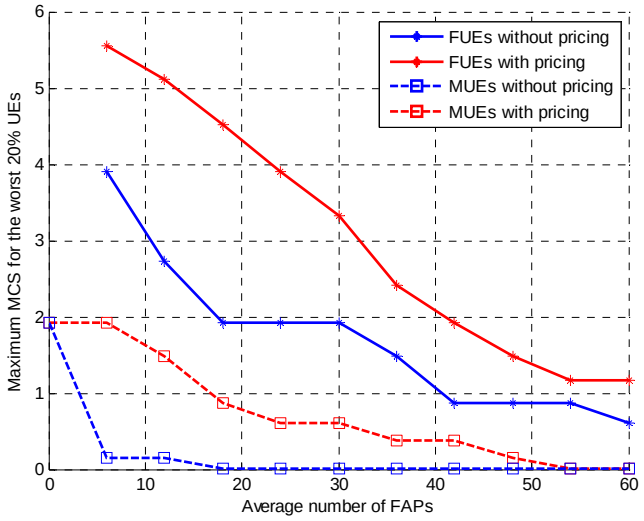

Figure 3. Maximum MCS for the worst 20% UEs as a function of the average number of FAPs.

- Decentralized algorithms have been modified to account for sources of randomness in the scenario. For example, the coordinated approach of the algorithm devised in activity 3A1, where the sources sense the channel before transmitting, is enhanced by exploiting

coordinated channel sensing over neighboring nodes. Likewise, the algorithm proposed in 3A1 taking into account (estimating) the macro-user activity has been improved by the exchange of control-plane messages (see the benefits in Figure 4). Finally, one of the major critical issues about the exchange of data through the backhaul is that this link is a best effort link. Hence, some packets might be received with excessive (unpredictable) delay. To cope with this shortcoming, we adopted a simple mechanism that simply drops packets that are not received within a maximum delay. Then, we analyzed the problem of loss of some control messages (affected by a large delays) due to random failures of the backhaul link, and the effects of quantization of pricing information, and we have proposed a robust stochastic pricing algorithm that converges (almost surely) to the right solution. The only price paid for the randomness of packet delivery is that the convergence process slows down as a function of the random link failures and quantization noise. (INFO)

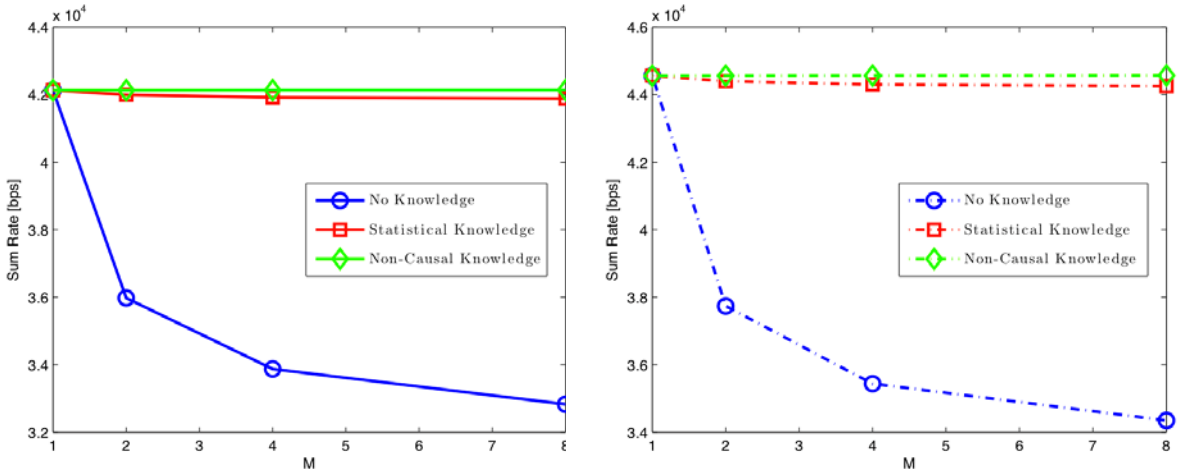

Figure 4. Sum rate of 10 FAPs vs. number of time slots for the maximum expected rate game. Left) without pricing, Right) with pricing.

Centralized radio resource management

- To benchmark the performance of decentralized strategies, we have compared them to a centralized approach based on Genetic Optimization, under the assumption that a central processor unit is able to collect all channel states of users and FAPs in the system. It is based on time averages and it is designed to be resilient to fast fluctuations of propagations conditions. (DUNE, INFO)

  Since the global utility function (sum-rate) is non convex, the solution attained by both the decentralized and centralized approaches is not necessarily globally optimal. To this regard, Figure 5 compares the performance of the decentralized and centralized approaches. The decentralized algorithm considered here is the iterative water-filling algorithm based on statistical inference of the probability of resource block occupation by the macro BS, that we call Statistical Inference Driven Iterative Water Filling Algorithm (SIDIWFA) and has been developed in this activity. We have considered three scenarios for the test: 1) a completely silent MBS, 2) a MBS whose traffic saturates the whole bandwidth, and 3) a case in which about a half of the frequency resource blocks are used while the other half is idle.

  The chosen performance metric is the per-FAP average (achievable) rate, measured in bits per OFDM symbol interval. It is interesting to remark that the results obtained with the decentralized approach are even better than in the centralized case. This happens because the genetic algorithm is a very general purpose algorithm that requires many iterations to converge. Conversely, our decentralized algorithm is perfectly matched to the problem at hand. For each user, the solution is found in closed form. This is why, in numerical terms,

under a finite number of iterations, our (dedicated) decentralized scheme does not loose with respect to the general purpose GA (it is worth recalling that the iterative water filling runs in a very few iterations).

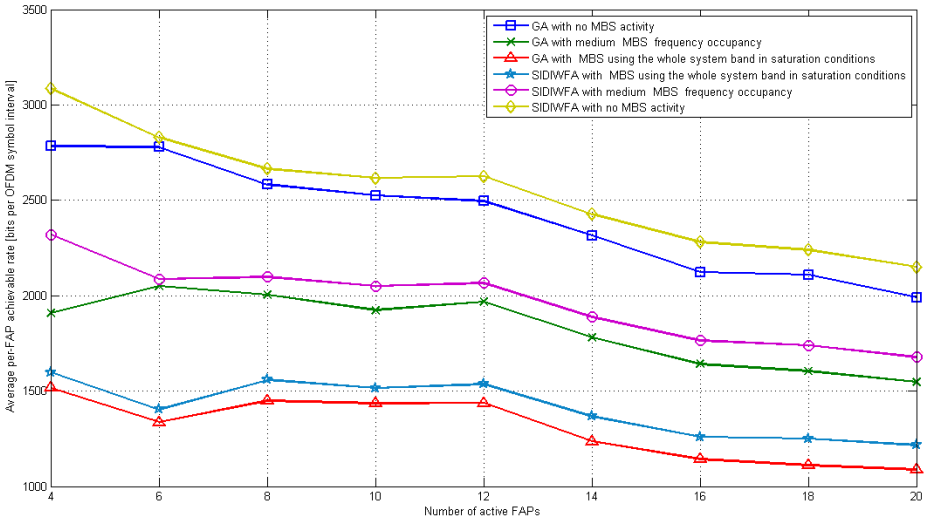

Figure 5. Comparison of averate bitrate achieved per FAP when using centralized (GA) or decentralized (SIDIWFA) resource allocation, as a function of the number of active FAPs in the area

Activity 3A3: Femto-network cooperative schemes (led by CEA)

In this activity is assumed that FAPs and macro BS can exploit a high-quality backhaul to exchange control and data plane messages, and implement cooperative transmission techniques whereby transmission rate can be increased. Techniques can be grouped . The main technical achievements are:

Cooperation without CSIT

- Cooperation is affected by time misalignments between signals transmitted by different FAPs involved in cooperation, due to different propagation delays. Consequently, the equivalent channel observed at the receiver exhibits a longer channel impulse response that affects the inter-carrier interference if it is longer than the cyclic prefix length. In this regard, we have obtained a set of possible distances between a macro BS and FAP to carry out the cooperation without generating additional interference. (CEA)
- Carrier frequency offset is related to the different oscillators distributed among devices. This effect is also responsible for generating inter-carrier interference in the base-band signals. We have evaluate the performance in the downlink cooperative beamforming technique and proposed a method to compensate for that error. In Figure 6 we present the link capacity for a cooperative beamforming scheme where one macro base station and one FAP cooperate together in order to send a downlink stream to one user equipment. Each device (FAP, MBS and UE) is equipped with two antennas. The carrier frequency is set to 2GHz and the OFDMA parameters are those corresponding to a 20MHz bandwidth LTE system. We assume the carrier offset between the UE and the MBS is perfectly compensated, and only carrier offset with respect to the FAP oscillator is considered. One can see that with a carrier offset of 0.05ppm, a very little degradation is observed with respect to the ideal case of perfectly synchronized oscillators (in the FAP and in the MBS). With a higher value of carrier offset value (0.35ppm and 0.25 ppm), a significant degradation is observed, mainly in high SNR regimes. (CEA)

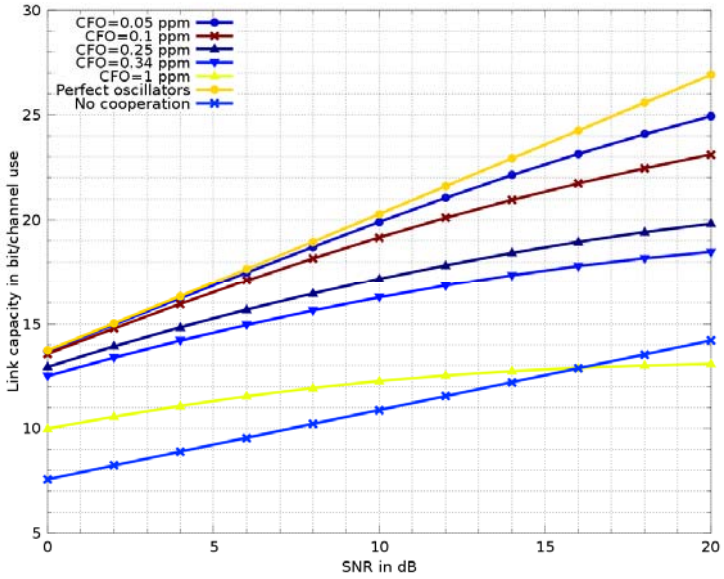

Figure 6. Capacity of cooperative beamforming scheme by taking into account CFO errors between transmitters

- Most known cooperative techniques assume that, when multiple nodes cooperate, they should have the same packets to be transmitted simultaneously. However, the backhaul link connecting these nodes (for example a macro BS and a FAP) might present random delays, in addition to delay randomness associated to different propagation channels. Hence in some situation the packet to be transmitted is not simultaneously present at all the cooperative nodes. In this respect, two solutions have been proposed:
  - Design appropriate cooperative space-time codes taking into account those random delays (delay-tolerant space time codes). Likewise, flexible decoding schemes based on sub-codewords decoding windows have been proposed to reduce the complexity at the UE side. (CEA)
  - For delay-critical applications, such as VoIP, we proposed a cooperative downlink scheme that allows reducing the average transmit power from a set of FAPs, while satisfying QoS constraints in terms of uncoded BER and delay. Alternatively, operating at a prescribed outage probability in terms of "instantaneous" (per packet) BER, and with a given overall transmit power, the proposed scheme allows to reduce the playout-buffer delay Δ_p, thus yielding a better user experience. Figure 7 shows these two possible gains. If a packet is not present at all the cooperating FAPs at the due time, only those FAPs that have it, transmit it. The proposed scheme is based on a receiver design capable to recover the message when at least one cooperative node has transmitted it. We observe that, with this design, there is no need for the (occasionally) non-cooperating FAP to inform the receiver. (UDSDRLS)

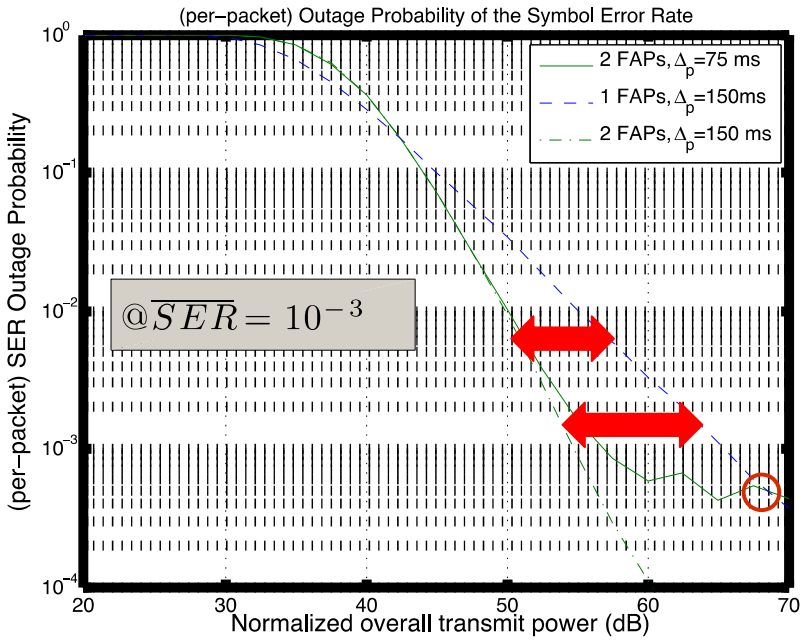

Figure 7. Performace gains of the cooperative scheme for delay-critical applications.

Cooperation with CSIT

- The MIMO *X* channel describes a multi-user cooperative scenario where two sources transmit messages to two destinations. In contrast to conventional cooperative MIMO (also named network MIMO or CoMP-JP), in this scenario each source generates independent messages to each destination and each destination receives independent messages from both sources. The MIMO X channel has the advantage of being less sensitive to timing and phase mismatch between cooperative transmitters. We have derived the linear MIMO precoders based on the combination of null-steering beams and the interference alignment concept that are able to maximize the number of transmitted streams per message at high SNR, a result not previously known in the information theory community. Likewise, for the low-medium SNR regime we have proposed an MMSE (minimum mean square error)-based algorithm to obtain the precoders.

  As a function of the channel gains and message's priorities, the algorithm provides the precoders of the limit cases of the MIMO X channel: MIMO BC (broadcast) if there is only one source active, MIMO MAC (multiple access) if there only one destination active, MIMO IC (interference) if each source only sends one message to one destination or the MIMO parallel point-to-point, if the cross channels are null. Figure 8 depicts the sum-rate of the MIMO X channel as a function of the SNR when sources are equipped with M_1=5, M_2=6 antennas, while destinations have N_1=8 and N_2=7, respectively. In all cases, the algorithm provides MIMO precoders that get the degrees of freedom (DoF) or slope of the capacity at high SNR for different configurations. (UPC)

- Although the MIMO *X* channel subsumes the MIMO IC channel, we have explored under what channel configuration the full benefits of the MIMO *X* disappear compared with the MIMO-IC. When the ratio between the cross and direct channels is less than 7.5 dB, each source tends to transmit to one destination. In such a case, we can employ the techniques based on the pricing studied in 3A2. On the other hand, in the low-medium SNR we have observed that the MIMO-*X* transmitter design can get a slightly loss in terms of sum-rate than Network-MIMO (around 10%), but at the cost of much less required backhaul (around 55%), because Network MIMO needs to have knowledge of all the messages to be transmitted by the cooperating sources. (UPC)

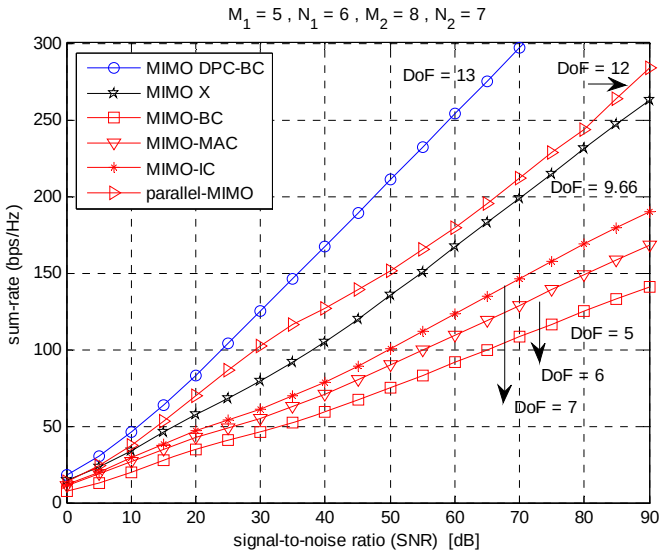

Figure 8. Average sum-rate vs SNR for the DPC-BC (DoF=13), MIMO *X* (DoF=9.66), MIMO-BC (DoF=5), MIMO-MAC (DoF=6), MIMO-IC (DoF=7) and dual-MIMO channel (DoF=12) with M_1= 5, N_1=8, M_2=6, N_2=7

Impact of project results

- The different system functionalities investigated in activity 3A1 have been implemented in WP6 (SEQ)
- Activities on propagation modeling gave SIRADEL the opportunity to develop new features in its two leading software products, in particular to adapt them to the femto- and small-cell wireless market. Besides, advanced features on channel modeling are available in new prototypes to be used mainly as simulation tools for expertise.(SIR)
- A set of cellular scenarios considering a corporate femtocell deployment with realistic channel models have been generated. Some of the techniques developed in activity 3A2 have been evaluated in that configuration (SIR, UPC)
- Some of the decentralized algorithms envisioned in activity 3A2 have been adapted/re-designed considering current LTE standard constraints. We have identified which parts of the LTE standard could be improved thanks to the decentralized approach. Three contributions to LTE-A RAN3 meetings #73, #74 and #75 (in Athens, San Francisco and Dresden respectively) have been submitted. (UPC)
- One patent application has been developed for the fast scanning algorithm (SEQ)
- Two patent applications have been developed for an algorithm to maximize the rate or minimize the power under interference power constraints (UPC).
- One patent application is in process for an innovative algorithm to enhance the uplink transmission by means of cooperation of macro-BS and FAPs at the receiver side (CEA).

1.4.3 WP4. Improved control layer for RRM and mobility support

The research activities performed in WP4 produced the following results, organized in tasks.

Activity 4A1: Handover for seamless connectivity

The activity 4A1 is focused on control procedures for mobility support in networks with femtocells. Three aspects of user's mobility are addressed: i) hard handover, ii) Fast Cell Selection (FCS), and iii) vertical handover.

For hard handover, four different procedures are designed. The first approach extends common methods for elimination of redundant handovers by adaptation of actual value (hysteresis, timer, window size) of the particular method. The adaptation is based on the received signal level with consideration of interference. The results show that the proposed modification is profitable for hysteresis margin and for handover delay timer. Both techniques reach a throughput gain of several percents compared to conventional techniques. At the same time, the same performance in elimination of redundant handovers as in case of the conventional handover is ensured.

The second enhancement of hard handover utilizes Estimation of Throughput Gain (ETG) reached by performing handover to the FAP. The gain is estimated based on the signal level evolution and observed mean time spent by User's Equipments (UEs) connected to the potential target FAP. The handover is performed only if the estimated gain exceeds a predefined threshold value. The ETG algorithm is more complex compared to the conventional or adaptive techniques. Nonetheless, at the cost of increased algorithm complexity, the efficiency in elimination of handovers is twice the efficiency reached by conventional techniques. At the same time, the utilization of ETG provides even a slight increase of the observed throughput.

The third hard handover proposal, named beacon-assisted handover, consists in introducing external beacon devices to be installed at appropriate places in femtocell premises, in order to improve femto to macro handover seamlessness. This solution requires equipping of UEs with an additional hardware (e.g., RFID tag or RFID reader) or with enabled Bluetooth at UEs. This simple solution eliminates most redundant handovers to FAPs. However, it implies additional hardware requirements on UEs.

The fact that FAPs can provide cheaper connections than macrocell is considered in the last proposed hard handover algorithm, where the handover decision is based on the connection cost. This approach enables to prioritize connections to FAPs rather than to MBSs and thus it prolongs the time spent by UEs connected to FAPs rather than MBSs. As the results demonstrate, the proposed scheme reduces the outage probability and simultaneously increases the time spent by users connected to FAPs if the FAPs provide lower cost of connection. Using the proposed algorithm, an operator can provide benefits to users that are willing to offload operators' network.

The second main topic addressed in this activity deals with FCS mechanism. The FCS derived from common CDMA soft handover is adapted to OFDMA femtocell networks. The system architecture for FCS in OFDMA systems is described. The results show a decrease in packet losses by implementing FCS in OFDMA networks with femtocells. For further improvement of the performance, a novel procedure for active set management considering specific aspects of FAPs, such as low coverage radius or limited backbone capacity is proposed. This procedure outperforms all compared competitive techniques in terms of throughput for indoor as well as outdoor users. The gain compared to conventional active set management is in order of tens of percents depending on amount of traffic offered by users (see Figure 9).

Besides throughput gain, management overhead is reduced to roughly a half with respect to the common algorithms. Slight improvement is observed also for users' satisfaction regarding the achieved throughput and a delay. As the simulations show, the most efficient active set always contains a MBS. For indoor users, the closest FAP deployed in the same house should be included as well. The amount of FAPs included in active set together with the MBS for outdoor users depends on mutual distance between the UE and neighbouring FAPs. Further, the number of FAPs slightly varies with offered traffic level. In average, roughly between 1.3 and 1.5 FAPs are included in active set of outdoor UE if this UE.

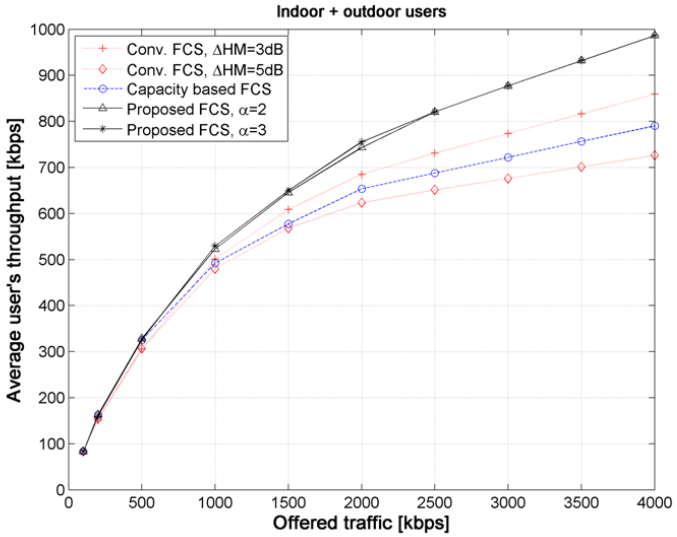

Figure 9. Average throughput of users for conventional and proposed algorithm of active set management for FCS

Last, inter-RAT between LTE and UMTS is analyzed and the objective is to make proper decision between both technologies to minimize amount of vertical handovers, to minimize degradation of quality of service and to maximize system throughput. To accomplish that, three handover decision strategies are proposed and their performance is compared with the conventional handover decision algorithm. While the first proposed strategy makes vertical handover decision according to signal quality, the other two strategies initiate vertical handover specifically according to users' requirements. The first proposed strategy is the best choice for users preferring low amount of interruptions (typically, users using voice services) as it is able to eliminate the vertical and horizontal handovers most effectively. On the contrary, the third proposed decision strategy is most appropriate for users having high requirements on throughput since system throughput is maximized and at the same time, the amount of observed handovers is notable reduced.

Activity 4A2: MAC control procedures for femtocell and performance evaluation

The activity 4A2 focuses on radio resource management in networks exploiting femtocells. The objective is to propose efficient control procedures to address key problems relating to femtocells' implementation.

First, an efficient path selection procedure enabling two users connected to the same FAP to communicate with each other is defined. The novel routing scheme manages data transmissions directly between the two users instead of a two-hop communication for users in close proximity. Whether direct transmission is feasible or not is evaluated at the femtocell using Radio Resource Cost metric.

It is demonstrated that our proposal outperforms conventional routing approaches both in terms of throughput (see Figure 10) and packet delays experienced by users. The throughput achieved by our proposal is always higher than the throughput delivered by conventional schemes. A throughput gain is mostly influenced by the ratio of indoor/outdoor traffic and by the FAP's location within the house. The higher amount of indoor traffic leads to the higher throughput gain. The FAP located closer to the middle of the house achieves lower throughput than the FAP located at the edge of the house. Packet delays experienced by UEs in UL are significantly lower for our proposal than packet delays generated by the conventional routing scheme. If the proposal is implemented, UL packet delays are negatively influenced only by the FAP's position. Finally, the performance of the proposal is less degraded for higher PER than the performance of the conventional scheme.

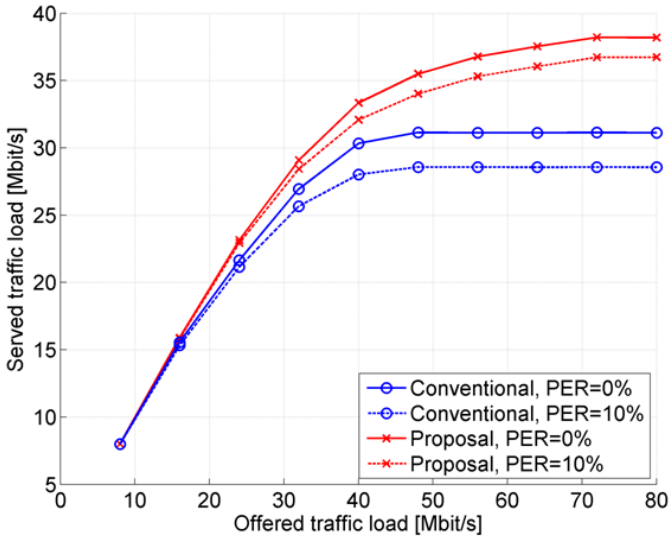

Figure 10. Served traffic by conventional data routing and by proposed path selection with direct communication between closed users

The second topic addressed in 4A2 is focused on power control procedure. The new proposed algorithm dynamically adapts the transmitting power of femtocells according to current traffic load and signal quality between the user equipments and the femtocells in order to fully utilize radio resources allocated to the FAP. The advantage of the proposed scheme is in providing high quality of service level to the femtocell users while interference to users attached to macro base station is minimized. The results achieved by our power control method are always better as long as the generated traffic is at light or medium levels and sufficient amount of radio resources is allocated to the FAP. Nonetheless, if the length of adaption interval is optimized, the proposed approach performs better at all traffic loads if sufficient amount of radio resources is allocated to the FAP while it still enables the coverage of all users in the house. The benefit of the proposed power control could be seen also in reduction of FAP's power consumption. The minor drawback of the proposed power control algorithm could be seen in a slight increase of the number of mobility events with extension of adaptation interval length. This issue is addressed by further optimization of the algorithm as we select appropriate target frame utilization. The results show that the proposed adaptation algorithm outperforms the former one using longer adaptation periods, so that signaling overhead can be reduced.

The next topic is the implementation of Multimedia Broadcast and Multicast Services (MBMS). MBMS has been evaluated for networks with and without femtocells and for Single Frequency Network (SFN), Point-to-Point (P2P) and Point-to-Multipoint (P2M). Based on the results, it can be concluded that SFN shows the best performance compared to the other two techniques in femtocell's based MBMS as well as in MBMS without femtocells. This can be achieved for SFN because the timing synchronization and shared resources used in this mode can efficiently transmit the data to all users. In addition, results also show that MBMS implementation in femtocells networks outperforms the implementation of MBMS in MBS.

Since the deployment of FAPs causes problems in physical layer identification due to limited number of the Physical Cell Identifier (PCI), a novel structuring of PCI has been proposed. The basic idea is to enhance the PCI structure by a new identifier called FAP cluster identifier where a FAP cluster is comprised of set of neighboring FAPs. The FAP cluster identifier can be specified either as an extension or as a sub-identifier of current PCI structure. The advantage of the proposed structure is that it makes possible to dynamically adjust the range of used PCIs according to the femtocell density in the area of a given macrocell, i.e., the range of PCI can be updated in time and it is independent from macrocell to macrocell. As to the PCI selection itself, a decentralized method using radio

environment scanning combined with a central network entity storing available FAP positions seems to be the most appropriate approach.

A further problem is the authorization of a user who is accessing a closed femtocell at which the user is not included in closed subscriber group (CSG) list. Two situations of such authorization are investigated. First, the authorization procedure of so-called visiting users to CSG FAPs is proposed. Conventionally, the user, which is not included in the CSG list, cannot access the CSG FAP. Two options are proposed of a control procedure to enable temporary access of the visiting user to the CSG FAP if this access is approved by a FAP subscriber. Both options differ to each other in a band used for management communication. The first one, in-band, is performed via the radio access technology (e.g., LTE or LTE-A) while the second one, out-of-band, requires additional technology (e.g., Bluetooth). For the out-of-band communication, appropriate technology must be enabled on visiting UE equipment and the UE of the FAP subscriber. On the other hand, it introduces no additional overhead on communication channels. Second, the procedure how to inform even the CSG FAP and accept an emergency call is proposed. The control procedure includes messages already defined by 3GPP. However, those messages are ordered in a specific way to allow access to the CSG FAP in the case of emergency.

To support measurements and information exchange required by the coordination algorithms developed in WP3, control procedures have been specified and new information elements have been defined. Additional requirements for the precoder design due to the coordination are: the measurement and reporting of the interference sensitivity and the cross-channels with dominant interferers by the UEs, and the forwarding of cost values by FAPs/MBS that will be used to calculate the pricing matrix. The performance degradation due to quantization of the information exchanged between FAPs (and MBS) with a limit number of bits compared to the ideal case of having infinite bits available is evaluated. Quantization implies some loss with respect to perfect information exchange. However, even if a low number of bits per cost value is employed, this degradation is low enough to consider valid the conclusions obtained in D3.2.

Two ways of scheduling are addressed 4A2. The first one, timer based interference mitigation, is developed to significantly reduce downlink femto to macro interference, when both tiers share the same spectrum, and when closed mode is assumed for femtocell access. This technique is based on avoiding the use of frequencies that produce high interference. The evaluations prove that the proposed algorithm reduces interference and thus it improves network performance in term of packet losses. The results show also that such improvement is not achieved at the expense of opportunistic scheduling efficiency. The second scheduling is called Backhaul Aware Scheduling (BAS). This study is driven by the limitation of backhaul capacity (e.g., bottleneck or congestion) caused by other traffic (e.g., IPTV or Internet access), which affects the performance of FAPs in serving requested traffic from femtocell users. The admission control is incorporated with the scheduling method to treat all kind of traffic served by FAP. With BAS, the FAP can decide whether the backhaul capacity is enough to support existing session. The simulation results show that with BAS, the performance of the FAP can be improved especially for peak backhaul conditions.

The optimal scheduling strategy in each cell depends on the power allocations used by the other FAPs. Hence, to compute the globally optimal power allocation for all the FAPs, a centralized control that solves this problem is required. The non-cooperative solutions based on distributed algorithms that do not require any coordination among different FAPs is proposed. Such a solution is suitable when the backhaul link is not available or its quality is not good enough to guarantee a reliable exchange of information. The system design is formulated within the game theory framework. After investigating the conditions for the existence and uniqueness of Nash equilibrium, we proposed a simple iterative scheme to reach that Nash equilibrium, which takes the form of a waterfilling-like solution, where the power/bit allocation varies dynamically, depending on the queue and channel states jointly. The decentralized scheduling technique guarantees the queue stability, provided that the arrival rates are compatible with the transmission rates, without the need to know the arrival rates.

Impact of project results

- Reduction of the number of redundant handovers and thus reduction of the management overhead. If less handover is performed, the handover interruption is reduced.
- Increased QoS perceived by the users during delay sensitive services (e.g., VoIP, video conferences, etc). The same objectives are achieved also by the proposal on vertical handover, where the reduction of the interruption is even higher due to longer interruption in case of the vertical handover.
- Additional increase of QoS is ensured by introduction of FCS in networks with femtocells since the interruption is nearly eliminated. Conversely, the solution for offloading macrocells by postponing handover until the FAP is no longer able to serve the UE is achieved in in the proposed connection cost based handover. This algorithm reduces the cost of communication and it enables to optimize expenditure on the side of users as well as operators.
- 4 publications in journals (1 published and 3 submitted), 5 conference papers (4 published and 1 submitted), a published book chapter, one PhD and one master thesis. (Activity 4A1)
- Efficient utilization of radio resources achieved by the new path selection algorithm that reduces load transferred via FAP for proximate users.
- Higher efficiency in utilization of spectrum is observed. The MBMS is also a potential solution for lowering a load of MBSs if FAPs are deployed.
    - Minimization of interference of FAP to MBSs or to other FAPs in its neighborhood through the proposed power control procedure and allocation of power among subcarriers.
    - Reduction of interference due to higher interval required for reporting of system parameters.
- From the networks perspective, the novel structure of PCI eliminates confusions and collisions of PCIs in the networks if FAPs are deployed densely. The user can benefit from algorithms developed for temporary access to CSG FAPs. The visiting UE access is designed to provide short time access to the CSG FAP. It lowers requirements on user's capabilities and knowledge on how to configure the FAP.
- Increase of efficiency in the case of emergency. The situation when the user would not be admitted by a CSG FAP in case of emergency is eliminated.
- 2 publications in journals (1 published and 1 submitted), 5 published conference papers, and two master theses. (Activity 4A2)

1.4.4 WP5. System level benefits of the femto-based network

The main goal of WP5 is to merge the most relevant techniques deployed in the previous WP's in a system level simulator, as well as evaluating the complementarities of relay-based and femto-based deployments. Some of the results in this activity are fed as technical inputs to the business case study. The activities are organized in the following tasks.

Activity 5A1: Comparison of relay-based and femto-based networks

This activity aims at comparing the performance of centralized and decentralized RRM techniques for femto deployments, developed in WP3, activity 3A2. The distributed strategy has also been applied to a hybrid deployment where relays and femtos are providing indoor/outdoor service in hotspot areas, evaluating tradeoffs and complementarities between both technologies.

A second tier network constituted by an ensemble of femtocells gives rise to an activity which has been simulated by implementing a dynamic system simulator resembling all aspects of transmission of

a data packet, from application level, towards coding over the radio link and delivery to the final destination.

Considering a deployment of MUEs, FUEs and FAPs, the system takes into account all interference relations among users and their mutual impact, analyzing the time evolution of the system metrics over a given amount of time. The proposed scenarios resemble the suburban homogeneous deployment, the corporate urban and, to some extent, the residential dense urban scenario. A wide variation of parameters has been implemented to describe both the structure of single buildings (e.g. number of floors, width, length, shape, streets in between), and the deployment of the single transmitters (e.g. MUEs indoor, outdoor, FAPs deep/light indoor).

The study evaluated the impact of a deep penetration of femtocells in a network in terms of improvement of overall performances, leading to a twofold result:

- the amount of sustainable traffic load in a cell benefits from the MBS offload;
- the overall quality of the traffic benefits from a significant reduction of interference, expressed in terms of reduced outage percentage.

The results of the dynamic simulator show how indoor users (particularly for the LTE frequencies) are strongly benefited by a dense deployment of FAPs. As a byproduct of the simulations, an evaluation of the possible transmission power adopted by the FAPs/FUEs equipment has shown how a significant reduction of transmission power, from a maximum of 20 dBm to a minimum of 10 dBm, implies a modest reduction of average capacity and outage, both of order of a few percent. Indeed, indoor users spend less energy and the signal loss is compensated by an average lower interference.

Some aspects of interference management algorithms have been considered in terms of their resilience to some topics relevant at a system level point of view, such as the choice of the time frame and synchronization of subframes among FAPs and for FAPs with the MBS.

Even though in-band relay-based transmissions cannot compete with FAP-based transmissions (due to the proximity between transmitters and receivers as well as the loss of spectral efficiency due to half-duplex relaying) the system can still benefit from deploying RSs to enhance service to those users which are not attached to any FAP without increasing MBSs density. To achieve these benefits, advanced MIMO access schemes based on CoMP are defined for BS-RS link (first hop in downlink transmission), which provides significantly better downlink spectral efficiency and coverage than conventional CoMP BS-based schemes.

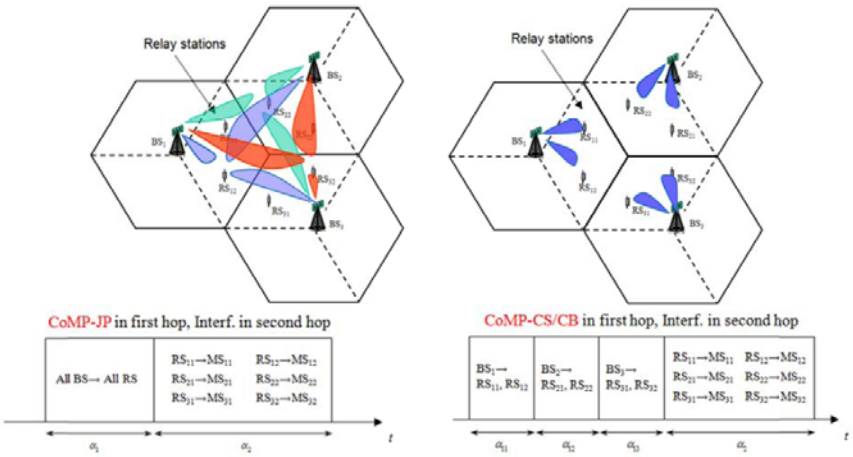

Figure 11. Examples access modes considered in the first hop for Coordinate multi-point (CoMP): left, CoMP-JP (Joint Processing); right, CoMP-CS/CB (Coordinated Scheduling/Beamforming).

To evaluate the potential complementarities between FAP-based networks and RS-based networks, several users are deployed in a corporate hotspot scenario. A fraction of the users are linked to their own relevant FAP (depending on the FAP density) while others are served by the MBS, either by direct BS transmission or by relay-assisted transmission. Simulation results are taken when the number of active FAPs in the cell increases, so as to evaluate from which value of FAP density a deployment of RS is no longer useful.

In order to control the interference between both networks, orthogonal sub-frames in TDD mode of LTE are assumed for RS-assisted transmissions and FAP-based transmissions. The number of sub-frames assigned to each network is optimized following two different criteria: the first is to have a fixed relation between spectral efficiency per user on each network; the second is to have a fixed relation between the transmission time allocated per user on each network. Both criteria depend on a design parameter giving the operator one degree of flexibility to balance the resources towards relay users or FUEs.

Simulation results show that deploying relays significantly improves the outage rate and the coverage in hotspot scenarios at low density of FAPs. In addition, it is also observed that RS-based deployments can complement FAP-based deployments to improve the system cellular spectral efficiency and outage rate for low density of FAP.

Activity 5A2: Network planning for the interference management

This activity addresses the impact of network planning for interference management by evaluating both the radio coverage and the cell performance when a set of MUEs and FUEs are present. Such issues are merged in the dynamic simulator, which includes transmission events and traffic flows in the network, as well as the optimization strategies designed in WP3, activity 3A2.

The developed system simulator is based on algorithms managing the transmission events related to the time slots assignment in the LTE subframe, taking into account also data packets generated by applications running on mobile terminals and their encoding in the Packet Resource Block (PRB) structure by the RRM scheduler. The packet flow module, complemented with the transmission system dynamics, tracks the information data passing through the cell and the impact on all transmitters. A measurement of the QoS and traffic load has finally been put in relation to the energy needed to run a set of applications on UEs mobile terminals.

The simulator has been tested in a set of cases of interest, which can be summarized as follows:

- Impact of clustering on optimization methods at system level, managing a possibly high number of users;
- Inclusion of a set of realistic environments produced by SIR (with geographic deployments of buildings and users) and evaluating the resulting performance metrics;
- Mobility of users and temporal changes in the environment around transmitters;
- Evaluation of system performance for different partitions of the overall band between femto and macro-users: equipartition of band between MBS and femto network, considering a fixed spectrum allocation for the MBS and varying that of the second tier, or fixing the band usage of the femto network and increasing the other;
- Inclusion of Genetic Optimization (GO) for power assignment of FUEs/FAPs to mitigate indoor interference;
- Assessment of the MBS offload when routing traffic of a set of UE's indoor through FAPs instead of routing it through the macro network.

A part of activity 5A2 was devoted to the development of a simulation chain for the evaluation of the macro+femto LTE coverage performance, which is composed of: large-scale FAP deployments in synthetic and realistic geographical environments; prediction of 3D path-loss maps (indoor and

outdoor); prediction of LTE downlink coverage (signal-to-interference maps and spectral efficiency maps); and, finally, estimate of the delivered throughput and network capacity. Such simulation tools support both the open and closed-access modes, and provide performance statistics for both FAP subscribers and non-FAP subscribers.

Coverage simulations are conducted in a large number of scenarios to investigate FAP deployments in urban corporate and suburban residential environments, in the presence or absence of co-channel macro coverage. The impact of a FAP deployment is analyzed at different scales: in FAP proximity, within the deployment floor, within the deployment building, in surrounding streets, or within a whole macro cell. Some properties of FAP deployment (density, location within the building and transmit power) and of FAP traffic are also investigated. A part of urban corporate simulations relies on real geographical map data and site-specific path-loss predictions, thus leading to realistic results.
Coverage simulations provide outcomes towards the engineering rules elaborated in activity 6A2 and towards the 2A3 business model analysis.

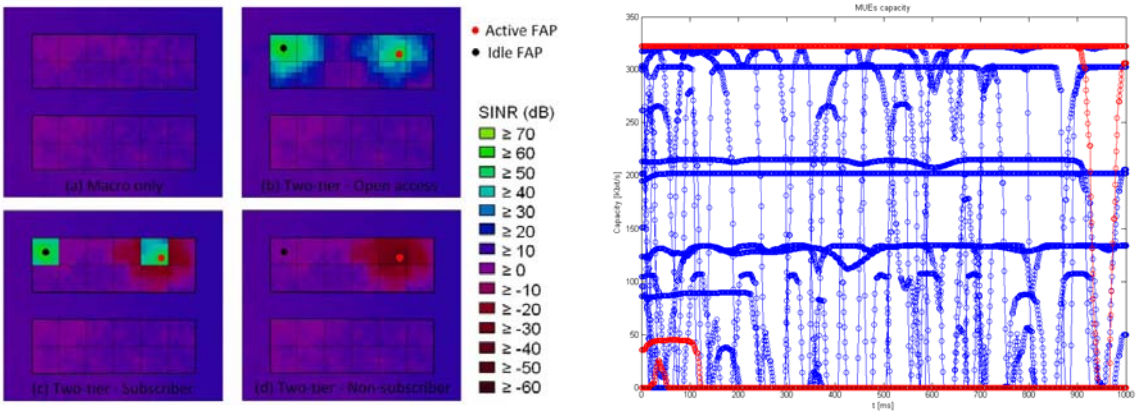

Figure 12. Left: Map of SINR for users in open or closed access mode; right, temporal variation of MUEs capacities, red (MUEs indoor) and blue (MUEs outdoor).

Network management can be improved by designing and evaluating clustering methods in order to run faster management algorithms on selected sets of users. Power and/or band assignment shows to be much more efficient when evaluating the impact of fast metric measurements. Indeed, optimization algorithms show far less complexity when run in parallel on sets of few units (less than 20) with respect to considering the network as a whole. Different cluster topologies and possible implementations of Genetic Optimization at system level have been implemented both for transmission events and network data flow.

Adaptive resource allocation algorithms, initially proposed in D3.2 and based on macro-users interference activity have been evaluated, also using alternative pricing mechanisms to allocate power in the joint time-frequency plane. Considering the scheduling of the resource allocation algorithms on the LTE frame structure, the data-rate loss due to the time elapse needed to let the iterative method to converge was properly taken into account for the max-rate game. The knowledge (estimate) of interference statistical parameters, if properly exploited, yields a rate very similar to the ideal case assuming non-causal knowledge of the macro-users activity.

The metrics measuring system performances have also been tested for different combinations of variable band allocations, which could be of interest for a Mobile Network Operator (MNO), including a temporal variation of the environment and of users' positions.

Activity 5A3: Routing optimization and security mechanisms for IP backbone

This activity addresses the proposal of strategies for optimized routing and adapted security support in the Internet Protocol (IP) backbone. These two topics are the keys to optimize in the same time

bandwidth consumption through header downsizing (adapted security support) and data latency through path lengths reduction (routing optimization).

The end-to-end IP network architecture and its standard procedures have been related to the current 3GPP specifications of the core network and also to WiMAX network architecture. Once highlighted where the IP links are and how IP communications operate, the interconnection of femtocells (FAPs) to those architectures has been considered to find a candidate end-to-end IP architecture. Both 3GPP and WiMAX specifications support the IPsec and define data communications using various routing protocols such as GTP, Mobile IPv6, Proxy Mobile IPv6, to name a few. A first result is the explanation of why standard operation relying on Proxy Mobile leads to sub-optimal routing when users are close to each other and why the use of IPsec is not optimized for voice communications.
A further task has been to analyze the system challenges and drawbacks of existing solutions and standards. Indeed, routing management protocols are sub-optimal and for secure transport methods, the usage of IPsec is not an optimal solution for securing a delay sensitive content such as voice. A NAT (Network Address Translation, a functionality used in the majority of today home networks running IPv4, which is an obstacle for IPsec as well) must be solved by additional encapsulation, resulting in bigger overhead.

A strategy to support routing optimization in the IP backbone is addressed in an environment where users can switch from macrocells to FAPs in a seamless way, and their communications are generally routed with respect to a routing management protocol. The protocol of interest is PMIPv6 because it does not require any action and knowledge from end-user equipment. However, the generic architecture of PMIPv6 supposes that all communications are routed through a central entity, the Local Mobility Anchor (LMA), which may be far from FAPs; although some PMIPv6 routing optimization proposals exist in the literature, such optimization have been extended for a better flexibility. The solution proposed enables route optimization between users by bypassing the LMA while ensuring flexibility to support the operator's service policy.

A solution to support adapted security mechanisms has also been proposed. Data/voice packets are encapsulated in an encrypted tunnel between a FAP and a core network. Voice packets are generally short. Such kind of security support is, by nature, sub-optimal as data packet headers take a significant part of the entire packet, resulting in an inefficient use of the bandwidth. On the other hand, SRTP is considered as a more efficient approach for such kind of situation, is optimized for voice traffic and it is compatible with combination of multiple flows to cope with the header size. The development of the integration of SRTP to support secure communications in the IP backbone has been addressed on this activity.

Finally, the joint key exchange mechanism for TLS and DTLS protocol has been described in view of the increase of overall efficiency when replacing the IPsec protocol suite by TLS and DTLS ones. The TLS protocol is used as an IPsec replacement for remote administration and support from mobile operator's network while DTLS protocol is used for securing the voice streams with less overhead and delay than IPsec.

Impact of project results

- Provision of a dynamic system simulator LTE-compliant to reproduce transmission events and data flows, different traffic types, variability and traffic scheduler. This provides a tool to assess at system level:
    - Benefits/properties of a femto-deployment with MUEs and for varying FAP penetration values;
    - Cell performances by clustered configurations for interference management and mitigation;
    - Comparison of centralized algorithms, including mobility, human activity and realistic deployments;

- MBS traffic offload by the femto-network has been evaluated for different scenario deployments.

- Definition of advanced strategies for relay-assisted transmissions in the downlink, by combining CoMP among neighboring BS in the first hop, exhibiting large performance gains as compared to conventional relaying. Relevant to operators and vendors.
- Evaluation of complementarity between relay-based and femto-based transmission in a hot-spot corporate scenario with a high density of femtos and users, assuming relay-based CoMP (Coordinated Multipoint) transmission, showing its effectiveness when density of femto-cells is low. Relevant to operators and vendors.
- Evaluation at system level and adaptation to realistic scenarios of some distributed or centralized algorithms developed in WP3 at system level.
- Development of a system for the whole simulation of LTE coverage and femto-based interference, from scenarios to path-loss grid predictions at different positions for the simulation of multi-floor coverage grids, gaining the analysis of coverage, interference, spectral efficiency and throughput statistics.
- Achievement of macro+femto downlink LTE coverage module, addressing both the open- and closed-access modes, with point-to-point channel realizations and point-to-area path-loss predictions, including a tool for SISO to MIMO extrapolation.
- Development of a model for time-variant channel predictions (related to human activity) with a basic indoor mobility model.
- Specification of the routing optimization solution to get rid of the mandatory LMA anchor point in the core network while maintaining control over the communication path and over data processing (e.g. data filtering, charging, legal interception).
- Optimization of the Femtocell IP backbone security mechanism by replacing the original IPsec with the SRTP transport level protocol to secure a voice data stream, with less overhead generated.
- Integration of both TLS and DTLS protocols into a joint TLS and DTLS handshake mechanism.

1.4.5 WP6. System demonstrator

WP6 aims at putting in practice the concept developed in the other work-packages, developing a hardware prototype and a small-scale testbed.

Activity 6A1: Hardware Feasibility Study and Prototyping

The first task of this WP has been to prepare the prototyping by first identifying techniques that could be implemented in the short time frame (and limited effort) of FREEDOM project. The techniques were listed in M611 and in M612.

Three techniques were finally identified, prototyped and tested in a demonstrator testbed: fast scanning and UL collaborative MIMO schemes from WP3, and routing optimization from WP5. More specifically, two schemes from WP3 where brought to prototype: fast scanning (implemented in a terminal device) and UL collaborative MIMO scheme (prototyped in a femto-like BS). Additionally, one technique from WP5 is demonstrated, related to routing optimization in context of mobility management (PMIPv6). Figure 13 illustrates the testbed configuration for demonstration of optimized routing and fast scanning prototypes. Prototyping and demonstrator testbed are reported in D61.

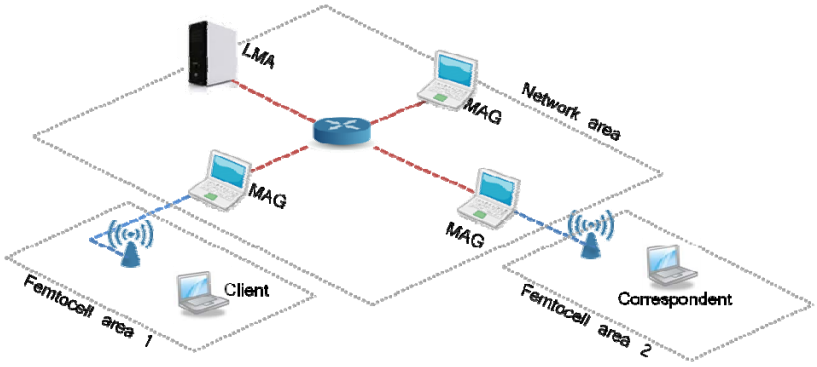

Figure 13. Architecture of testbed to demonstrate new prototypes

Fast scanning is a technique discussed in D31. This feature is designed for improving the speed of the environment scanning (primarily by a mobile but could be applied as well by a FAP to quickly sense its environment). Fast Scanning is a MS feature that consists of scanning for a suitable BS and to connect as fast as possible, when not connected to the network. This feature is designed to speed up network entry and handover, and also to minimize battery consumption. This feature has been introduced in Sequans MS software roadmap and has thus been subject to extensive validation and non-regression tests in the lab. Beyond tests in the lab, the fast scanning feature has been tested in the field (in Korea where the network deployment conditions were the closest compared to a dense femto deployment). The mobile had to scan 57 channels. Without fast scanning, it took 34s to scan all the possible channels, i.e. 596ms per channel. With fast scanning feature, it took 1.92s, i.e. 34ms per channel. The fast scanning feature brought a gain on real device of about 17 times.

UL-CSM (UL Collaborative Spatial Multiplexing) is a technique specified in the WiMAX standard although not widely implemented because of the numerous challenges it rises. This technique has been described in D31. The UL-CSM has been introduced in the Sequans base station prototype software. For that purpose, various tests were defined to validate the proper behavior of the base station and check if this new feature does not degrades the overall performance of the FAP. The implementation required small modifications to the firmware at the terminal side (to modify pilot insertion in the regular chunk) but significant modifications at the BS side. Actually, a new equalizer had to be implemented, memory should be added, BS has to support higher throughput and thus CPU load. Due to the constraint of the existing platform, it was not granted that UL-CSM would actually bring a gain at system level. Nevertheless, the prototype showed satisfying results, demonstrating increase in the overall UL throughput.

Routing optimization has been developed on the basis of specific PMIPv6 extensions, in order to improve inter gateway mobility in the context of current 3GPP LTE architecture. However, its potential will be generalized to other mobility scenarios when flat architectures will be considered. Though prototyping for routing optimization has been done in the context of WiMAX, it has been specified in such a way that it remains compatible with 3GPP LTE and LTE advanced architectures.

PMIPv6 has been implemented from scratch using C programming language. It represents more than 10,000 lines of code. All required functions to manage mobile nodes mobility have been implemented. The testbed has still to be extended to improve the support of specific features such as the policy profile and the access authentication service. On top of this implementation, the routing optimization has been developed following the specification proposed in WP5. The PMIPv6 data structures have been extended to support the new features and procedures. Finally, two new signaling messages have been specified and implemented.

Activity 6A2: Integration and proof of concept

A small-scale 3GPP compliant test bed was developed. The testbed consists of 3-5 FAPs connected to FAP-GW and 3G core networks. The testbed are located in TELKOM RDC premises and TELKOMSEL testbed Indonesia, allowing partners to observe the characteristics of interference, handover, backhaul and basic 3G service performance. This tested has been used as observational environment in order to provide input to business model (WP2) and technical WPs including WP3, WP5 and deliverable D6.2.2. Two documents have been delivered namely D6.2.1 about Trial Report and D6.2.2 providing refined engineering rules for femtocell deployment.

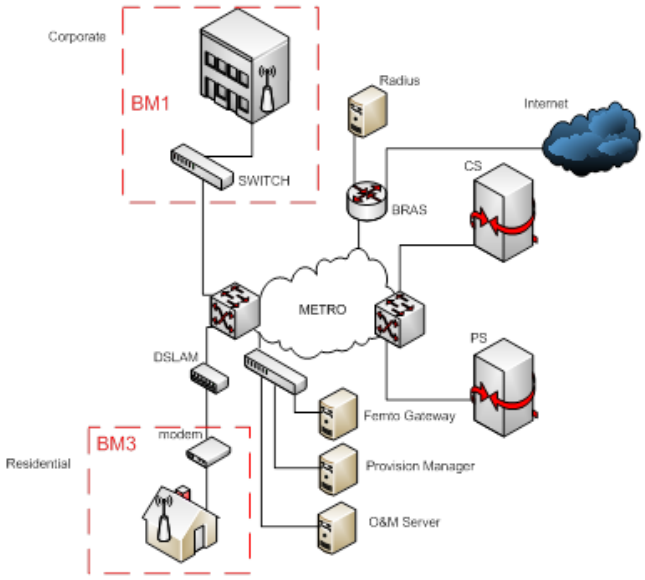

Figure 14. Testbed configuration to support corporate and residential scenarios

The decision of developing 3G-based femtocell testbed is based on the following reasons:

- Developed FAP prototypes are WiMAX based in one hand, and on the other hand TELKOM does not have any commercial Mobile WiMAX networks. Therefore the integration of WiMAX FAP with the WiMAX macrocell & core network is not possible.
- According to RFI outcomes as part of 6A1 activity and reported in D622, most vendors will have LTE Femtocell prototypes for trial in 2012 (3 out of 4 vendors), the earliest plan will be in Q4 2011. In addition, most vendors prefer to start developing HeNB in 2.6 GHz unless there is significant demand in other spectrum band. Even though TELKOM has conducted LTE trial, it used 2.1 GHz band. The fact that LTE FAP will be available after FREEDOM period, it was not possible to have LTE FAP in TELKOM network.
  According to RFI & JVM activities conducted in 6A1 and reported in D622, the most mature FAP products are 3G femtocell systems. TELKOM has installed a 3G FAP system testbed operating at 2.1GHz to conduct trial as part of 6A2 activity.

Based on observations made in the trials, relevant engineering rules for femtocell deployments are derived.

Firstly, measurement of the radio coverage and interference has been conducted in the TELKOM testbed, i.e. for the urban corporate environment defined in FREEDOM business model 1 (BM1). A specific measurement methodology has been elaborated for investigating the impact of single-FAP and multi-FAPs deployments; inter-FAP distance; outdoor leakage; closed- and open-access modes; and visibility condition (LOS, NLOS, inter-floor). This impact was measured on the useful signal level, interference level and signal-to-interference statistics; FAP coverage radius; macro deadzone radius; FAP-to-macro handover distance; DL and UL throughput. The results give clear and valuable insight

into the coverage provided by a 3G corporate FAP deployment (from FAP coverage radius) and into the FAP-based interference levels (e.g. characterized by the deadzone radius). Detailed results are reported in deliverable D6.2.1 while the main conclusions have been reformulated for derivation of engineering rules.

The proposed recommendations and rules are expected to help the engineers in the following tasks: design of a femto-based network; installation and parameterization of femto base-stations; simulation of the network coverage performance; control of the network coverage quality. Rules on FAP coverage radius and interference levels have been extracted from analysis of the 3G measurements collected in activity 6A2 , but have been completed with LTE simulation analysis carried out in WP5 (D52 deliverable). These rules mainly apply for macro-femtocell (two-tier) co-channel networks but partly as well for femto-only networks.

Another engineering rule is related to backhaul. Backhaul plays an important role in femtocell deployment since it utilizes existing broadband connection in customer side. DSL backhaul model is derived in order to address different qualities of backhaul. The model has been used by technical WPs in elaboration of RRM, scheduling and system level simulation which taking into account the backhaul quality. Several steps to engineer femtocell backhaul are proposed. Firstly, the bandwidth requirement of backhaul is derived based on the measurement. Bandwidth estimation is done based on mix traffic of basic femtocell service including voice, video, http and ftp traffic. This will guide engineers to predict bandwidth requirement for femtocell both for residential and enterprise. Secondly based on measurement result reported in (D621), the effect of background traffic in xDSL modem and corporate internet link will affect the femtocell performance. Increasing the bandwidth may cope with the performance degradation but with the cost of adding more bandwidth for customer. Thirdly, based on the fact that femtocells use DiffServ mechanism, there is a way to ensure E2E QoS by transfer of the DSCP value from access, backbone and mobile core network. Based on DSCP marking mechanism the network will give prioritization and treat the service flow according to its QoS requirement.

The last engineering rules are related to the handover observation. Optimum settings of hysteresis margin (HM) and handover delay timer (HDT) are recommended for mobility management. It is shown that the right value setting of HM and HDT can reduce the number of redundant handovers that would be performed by FUE when moving from a FAP to another FAP. At the same time, the percentage of handover failure rate is maintained to zero, due to stability of handover decision when the FUE already firmly handed to the target cell. According to the measurement, 4dB HM and 640ms HDT are recommended. This setting will decrease the redundant handover and improve handover successful ratio. However this recommendation must be further exercised in the real femtocell deployment to cope with different environments and femtocell densities.

Impact of project results

- Impact of fast scanning algorithm (SEQ).
  - Speed up of the network entry and the handover process of a user terminal when facing numerous cells to scan, which is to become a typical case in dense (femto) deployment. Although the development has been done in WiMAX context (and integrated in SEQ official product roadmap), it provided a good know-how that is naturally integrated in the development of LTE terminal chipset.
  - Filing of a patent application. (SEQ)
- Impact of the development of the uplink collaborative spatial multiplexing access scheme: porting in SEQ Compact Base Station, thus improving the company offer in terms of pico/femto cell components. (SEQ)
- PMIPv6 protocol implementation: CEA also would like to exploit results from FREEDOM related to the optimal routing solution. By leveraging a complete prototyping of this

innovative solution, CEA expects to influence IETF standardization related to PMIPv6 protocol extensions, and to involve partners in view of porting such solutions into concrete solutions.

- A two-tier femto-macro network has been characterized in terms of interference, coverage gain, capacity gain and mobility aspects. This characterization can be referred by a mobile operator who plans to deploy 3G femtocells. This will guide the operator to carefully plan the deployment effort and further elaborate any available mitigation schemes from manufacturers in the real deployment. In addition to the backhaul quality model, it will allow researcher to understand xDSL backhaul characteristics for the future study of femtocell performance and RRM which take into account backhaul quality condition.

- Recommendation about femtocell bandwidth requirement for both residential and enterprise femtocell: will give insight to xDSL provider, mobile operator and prospective customer to consider the backhaul subscription scheme in order to accommodate the femtocell minimum performance requirement.

2 Use and dissemination of foreground

Section A (public)

List of all scientific (peer reviewed) publications relating to the foreground of the project

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	Downlink Coordinated RRM in Cellular Networks with Partial CSI	Eduard Calvo, Olga Muñoz, Josep Vidal, Adrian Agustin	IEEE Transactions on Signal Processing	vol 30, no. 3, March 2012 (monthly)	IEEE		2012			NO
2	A Bio-Inspired Swarming Algorithm for Decentralized Access in Cognitive Radio	Paolo Di Lorenzo, Sergio Barbarossa	IEEE Transactions on Signal Processing	Vol 29, no. 4, Dec. 2011 (monthly)	IEEE		2011	6160 - 6174		NO
3	Decentralized Resource Assignment in Cognitive Networks Based on Swarming Mechanisms Over Random Graphs	Paolo Di Lorenzo, Sergio Barbarossa, Ali Sayed	IEEE Transactions on Signal Processing	monthly	IEEE		2012 (accepted for publication)			NO
4	Distributed Sum-Rate Maximization in Femtocell Networks with Random Graph and Quantized Communications	Paolo Di Lorenzo, Marco Omilipo, Sergio Barbarossa	IEEE Transactions on Signal Processing	monthly	IEEE		submitted			NO

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

5	Joint optimization of sensing and radio resource allocation in collaborative femtocell networks,	Sergio Barbarossa, Stefania Sardellitti	IEEE Transactions on Signal Processing	monthly	IEEE		to be submitted			NO
6	A Survey of Physical Layer Signaling Overhead in LTEAdvanced	Pavel Mach, Zdenek Becvar	IEEE Communication Magazine	Bi-monthly	IEEE		submitted			NO
7	Efficient Data Transmission within the Femtocells	Pavel Mach, Zdenek Becvar	IEEE/ACM Transaction on Networking	monthly	IEEE/ACM		submitted			NO
8	Estimation of Throughput Gain for Handover Decision in Femtocells	Zdenek Becvar, Pavel Mach	Mobile Information Systems	4 issues per year	IOS Press		submitted			NO
9	QoS-guaranteed Power Control Mechanism Based on the Frame Utilization for Femtocells	Pavel Mach, Zdenek Becvar	EURASIP *Journal on Wireless Communications and Networking,*	monthly	EURASIP		2011			Yes
10	Optimal resource allocation in fetmocell networks based on Markov modeling of interferers' activity	Stefania Sardellitti, Alessandro Carfagna, Sergio Barbarossa	EURASIP Journal On Wireless Communication and Networking - Special Issue on Femtocells in 4G Systems	monthly	EURASIP		submitted			Yes
11	Fast Cell Selection with Efficient Active Set Management in OFDMA Networks with Femtocells	Zdenek Becvar, Pierre Roux, Pavel Mach	EURASIP Journal on Wireless Communications and Networking		EURASIP		submitted			
12	Decentralized Weighted Sum Rate Maximization in MIMO-OFDMA Femtocell Networks	Adrian Agustin, Josep Vidal, Olga Muñoz	EURASIP Journal on Wireless Comm. and Networking - Special Issue on Recent Advances in Optimization Techniques in Wireless Communications	monthly	EURASIP		submitted			Yes

13	Handover Procedure and Decision Strategy in LTE-based Femtocell Network	Ardian Ulvan, Robert Bestak, Melvi Ulvan	Telecommunication System		Springer		2012 (accepted for publication)			
14	Vertical Handover Decision in Heterogeneous Wireless Networks with Femtocells	Pavel Mach, Zdenek Becvar	European Transactions on Telecommunications	8/year	Wiley-Blackwell		submitted			
15	Femtocélulas	Guillaume Vivier, Mohamed Kamoun, Zdenek Becvar, Enrico de Marinis, Yves Lostanlen, Anggoro Widiawan,	RTI: Redes, Telecom e Instalaçoes	No. 130				pp. 42 - 53		

In addition to the journal publications listed in Template A1, partners involved in the FREEDOM consortium produced two book chapters (BC) and a number of peer-reviewed conference papers (CP):

Book Chapters:

BC1. Adrian Agustin, Josep Vidal, Olga Muñoz, Savo Glisic, "Relay-Assisted Wireless Networks", chapter in *Advanced Wireless Communications and Internet*, 3rd Edition, John Wiley & Sons (edited by Savo G. Glisic) New York, USA, May 2011, pp. 585 - 682.

BC2. H. Hariyanto, R. Wulansari, Adit Kurniawan, Hendrawan, "Femtocell Performance over non-SLA xDSL Access Network", chapter in *Mobile Networks*, InTech Open Science, 2012, ISBN 979-953-307-568-5

BC3. Zdenek Becvar, Pavel Mach, Michal Vondra, "Handover procedure in femtocells", chapter in *Femtocell Communications and Technologies: Business Opportunities and Deployment Challenges*, edited by Rashid A. Saeed, Bharat S. Chaudhari, and Rania A. Mokhtar.

Conference Publications:

CP1. Z. Becvar, P. Mach, "Adaptive Hysteresis Margin for Handover in Femtocell Networks", *International Conference on Wireless and Mobile Communications (ICWMC 2010)*, Valencia, Spain, September 2010.

CP2. P. Mach, Z. Becvar, "Dynamic Power Control Mechanism for Femtocells Based on the Frame Utilization", *International Conference on Wireless and Mobile Communications (ICWMC 2010)*, Valencia, Spain, September 2010.

CP3. H. Hariyanto, "Finding New Drivers for Femtocell Deployment", *The 9th Meeting of the APT Wireless Forum*, Doc. No. AWF-9/INP-69, Seoul, September 2010.

CP4. G. Vivier, M. Kamoun, Z. Becvar, E. de Marinis, Y. Lostanlen, A. Widiawan, "Femtocells for next-G Wireless Systems: the FREEDOM approach", *Future Network & Mobile Summit 2010*, Florence, June 2010.

CP5. S. Barbarossa, S. Sardellitti, A. Carfagna, P. Vecchiarelli, "Decentralized Interference Management in Femtocells: A Game-Theoretic Approach", *IEEE International Conference on Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2010)*, Cannes, June 2010.

CP6. Lamhot Simamora, Patricia Gaspersz, Hadi Hariyanto, F.X Ari Wibowo , "The Femtocell Business Opportunity & Model in Indonesia Market", *Femtocell Symposium,* Beijing, September 2010.

CP7. G.Imponente, E. de Marinis, S. Ponnekhanti, "Femtocell clustering and system optimization by generic algorithm", *FuNEMS 2011*, Warsaw, June 2011.

CP8. Ulvan, R. Bestak, M. Ulvan, "Handover Scenario and Procedure in LTE-based Femtocell Networks", *The Fourth International Conference on Mobile Ubiquitous Computing, Systems, Services and Technologies (UBICOMM 2010)*, Florence, Italy, 2010.

CP9. Z. Becvar, P. Mach, "Adaptive Techniques for Elimination of Redundant Handovers in Femtocells", *Int. Conference on Networking (ICN 2011)*, Netherlands, January 2011.

CP10. P. Di Lorenzo, S. Barbarossa, "Distributed Resource Allocation in Cognitive Radio Systems Based on Social Foraging Swarms", *IEEE SPAWC 2010 (Best Paper Award)*, Marrakech, 2010

CP11. P. Di Lorenzo, S. Barbarossa, "Bio-Inspired Swarming Models for Decentralized Radio Access Incorporating Random Links and Quantized Communications", *IEEE Int. Conf. on Acoustics, Speech and Signal Processing, ICASSP 2011*, Prague, Czech Republic, May 2011.

CP12. A. Agustin, J. Vidal, O. Muñoz, J.R. Fonollosa, "Decentralized Weighted Sum Rate Maximization in MIMO-OFDMA Femtocell Networks", IEEE Global Communications Conference, Second GlobeCom Workshop on Femtocell Networks, Houston, USA, December 2011, pp. 1 - 5.

CP13. O. Muñoz-Medina, J. Vidal, A. Agustín, A. Pascual-Iserte, Sergio Barbarossa, "Distributed Interference Pricing for MinPower Games in MIMO Femtocell Systems", IEEE Global Communications Conference, Second GlobeCom Workshop on Femtocell Networks, Houston, USA, December 2011.

CP14. Z. Becvar, P. Mach, "On Enhancement of Handover Decision in Femtocells", IFIP Wireless Days 2011, Niagara Falls, Canada, October 2011.

CP15. P. Mach, Z. Becvar, "Efficient Routing of Data for Femtocells", IFIP Wireless Days 2011, Niagara Falls, Canada, October 2011.

CP16. T. Vanek, M. Rohlik, "Perspective Security Procedure for Femtocell Backbone", IEEE ICUMT 2011, Budapest, Hungary, October 2011.

CP17. P. Mach, Z. Becvar, "Optimization of Power Control Algorithm for Femtocells Based on Frame Utilization", IEEE PIMRC 2011, Toronto, Canada, September 2011, pp. 187 - 191.

CP18. A. Agustín, J. Vidal, S. Lagén, E. Valera, "Network MIMO for downlink in-band relay transmissions with relaying phases of fixed duration", European Conference on Signal Processing, EUSIPCO, Barcelona, Spain, August 2011.

CP19. A. Agustin, J. Vidal, "Weighted Sum Rate Maximization for the MIMO X Channel through MMSE Precoding", IEEE Intl. Symposium on Information Theory (ISIT-2011) , August 2011.

CP20. F. X. A. Wibowo, A. A. P. Bangun, A. Kurniawan, Hendrawan, "Multimedia Broadcast Multicast Service over Single Frequency Network (MBSFN) in LTE based Femtocell", 2011 International Conference on Electrical Engineering and Informatics, Bandung, Indonesia, July 2011.

CP21. O. Muñoz-Medina, A. Pascual-Iserte, P. Baquero, J. Vidal, "Preemption and QoS Management Algorithms for Coordinated and Uncoordinated Base Stations", SPAWC 2011, IEEE International Workshop on Signal Processing Advances in Wireless Communications, San Francisco, USA, June 2011.

CP22. A. Agustin, J. Vidal, O. Muñoz, "Interference Pricing for Self-organisation in OFDMA Femtocell Networks", European Workshop on Broadband Femtocell Networks - Future Network and Mobile Summit (FuNeMS-2011), Warsaw, Poland, June 2011.

CP23. F.X. Ari Wibowo, A. A. P. Bangun, "Study on Transmission Bearer Mechanisms for e-MBMS in LTE based Femtocells", European Workshop on Broadband Femtocell Networks - Future Network & Mobile Summit 2011, Warsaw, Poland, June 2011.

CP24. A. Agustin, J. Vidal, "Improved Interference Alignment Precoding for the MIMO X channel", IEEE Intl. Conference on Communications (ICC2011), Kyoto, Japan, June 2011.

CP25. J. Vidal, A. Agustin, S. Lagen, E. Valera, O. Muñoz, A. Garcia Armada, M. Sanchez Fernandez, "Network-MIMO Backhauling for QoS-constrained Relay Transmissions", Int. Conference on Acoustics, Speech and Signal Processing, 2011, Prague, Czech Republic, May 2011.

CP26. F.X. Ari Wibowo, "Seeking for Femtocell Drivers", Femtocell Asia 2011, Singapore, Singapore, April 2011.

CP27. I. Ouled Ali, M. Kamoun, "Power assignment strategies for FDD femto-cell networks", ICC 2011, Kyoto, Japan, June 2011.

CP28. Z. Becvar, P. Mach, "Adaptive Techniques for Elimination of Redundant Handovers in Femtocells", International Conference on Networks 2011, Netherlands.

CP29. S. Barbarossa et Al., "Optimal Radio Access in Femtocell Networks based on Markov Modeling of Interferers' Activity", ICASSP 2011, Prague, Czech Republic.

CP30. G.Imponente, E. de Marinis, "Femtocell system optimization by genetic algorithm in clustered scenarios", European Workshop on Broadband Femtocell Networks - Future Network and Mobile Summit (FuNeMS-2011), Warsaw, Poland, June 2011.

CP31. Y Corre, M. Brau, Y. Lostanlen, "Femtocell wireless time-variant stochastic channel modelling related to indoor human activity", IEEE PIMRC 2011 (International Symposium on Personal, Indoor and Mobile Radio Communications), Toronto, Canada.

CP32. Y. Corre, J. Stephan, Y. Lostanlen, "Indoor-to-outdoor path-loss models for Femtocell predictions", IEEE PIMRC 2011 (International Symposium on Personal, Indoor and Mobile Radio Communications), Toronto, Canada.

CP33. Hadi Hariyanto, Karina W. Noviyanti, A K. Widiawan, A. Kurniawan, Hendrawan, "Backhaul-aware Scheduling for WiMAX Femtocell with Limited Backhaul Capacity", IEEE Regional 10 TENCON International Conference International Conference, in Bali, Indonesia, 22 – 24 November 2011.

CP34. F.X. Ari Wibowo, Arya A. P. Bangun, A. Kurniawan, Hendrawan, "Transmission Scheme Mechanism in Femtocell based eMBMS: A Review", The 6th International Conference on Telecommunication Systems, Services, and Application (TSSA) 2011, Denpasar, Bali, Indonesia, 20-21 October 2011.

CP35. Michal Vondra, Zdenek Becvar, "Connection Cost Based Handover Decision for Offloading Macrocells by Femtocells", 10th International Conference on Wired/Wireless Internet Communications, WWIC 2012.

CP36. S. Barbarossa and S. Sardellitti, “Joint optimization of sensing and radio resource allocation in collaborative femtocell networks,” invited paper submitted to Third International Workshop on Cognitive Information Processing, CIP 2012.

TEMPLATE A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	Type of activities[4]	Main leader	Title	Date	Place	Type of audience[5]	Size of audience	Countries addressed
1	Workshop		European Workshop on Broadband Femtocell Networks	June 2011	Warsaw, Poland	Scientific community	50-100 persons	European Countries
2	Journal Special Issue		Eurasip Journal on Wireless Communications and Networking: Special Issue on Femtocell Networks	Summer 2012		Scientific community	All the scientific community	All
3	Press releases		11 press releases check http://www.ict-freedom.eu/index.php?option=com_spcom&Itemid=89	2010	www	Civil society	National audience	Spain
4	Lessons cycle		The Joint BeFemto & Freedom WinterSchool (http://femtoschool.cttc.es/)	Feb 2012	Barcelona	Scientific community	All the scientific community	All
5	Radio broadcast		2 radio broadcasts on ComRadio,	Spring 2011	Barcelona	Civil society	Local radio audience (Barcelona city)	Spain
6	TV broadcast		1 TV broadcast on the news in TV3, coverage in Catalonia region	Spring 2011	Barcelona	Civil society	Local TV audience (Catalonia region)	Spain

* Furhter details on the press releases, radio and TV broadcasts can be found online at http://www.ict-freedom.eu/index.php?option=com_spcom&Itemid=89.

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias ('multiple choices' is possible.

PhD and Master Theses

- Sandra Lagén, "Access Modes based on Coordinated Multipoint for Relay Transmissions in 4G Systems", Universitat Politècnica de Catalunya, Advisor/s: Adrian Agustin, Josep Vidal.
- Marc Torrellas, "Beamforming Coordination Techniques in OFDM Multihop Cellular Networks", Universitat Politècnica de Catalunya, Advisor/s: Adrian Agustin, Josep Vidal.
- Bretislav Jancik, "Handover in Femtocells", Czech Technical University in Prague, Czech Republic. Advisor/s: Zdenek Becvar.
- Jan Oppolzer, "Assignment of Femtocell Identifiers", Czech Technical University in Prague, Czech Republic. Advisor/s: Robert Bestak.
- Marek Sedlacek, "Identification of Femtocells", Czech Technical University in Prague, Czech Republic. Advisor/s: Robert Bestak.
- Pasquale Vecchiarelli: "Strategie di accesso decentralizzate per reti cognitive" (Decentralized access strategies for cognitive networks), advisor: Sergio Barbarossa, April 2010.
- Paolo di Lorenzo, "Bio-Inspired Dynamic Radio Access in Cognitive Networks based on Social Foraging Swarms", Master Thesis, University of Rome "La Sapienza," advisor: Sergio Barbaorssa, 2012.

Ongoing Doctoral Theses:

- Matej Rohlik, "Broadcast security in future mobile networks", Czech Technical University in Prague, Czech Republic. Advisor/s: Tomas Vanek, expected defense: 2012/2013.
- Michal Vondra, "Radio Resource Management in Femtocell Networks", Czech Technical University in Prague, Czech Republic. Advisor/s: Zdenek Becvar, expected defense: 2014.
- Alessandro Carfagna, "Distributed resource allocation in femtocell networks based on Markov Modeling of interferers", Ph. D. Thesis, University of Rome "La Sapienza," advisor: Sergio Barbaorssa, to be defended in March 2013.

Clustering activities:

The FREEDOM consortium has been very active within the research community and the 7th FP circles. The following activities were endeavoured:

- FREEDOM has participated in the two concertation meetings organised by the Programme in Brussels.
- FREEDOM representatives have been actively present in RAS cluster meetings and conf calls.
- FREEDOM was represented at the TPC in the ICT Future Networks and Mobile Summit 2011.

- FREEDOM co-organised with the BeFemto project the European Workshop on Broadband Femtocell Networks, during the ICT Future Networks and Mobile Summit 2011. Four papers were presented there.

Jointly with the project BeFEMTO:

- Organisation of the European Workshop on Broadbadn Femtocell Networks, co-located with FuNeMS 2011, on 14th June 2011, with the lively participation of some 50 attendants. During the workshop 15 papers were presented, representing up to 6 national and EC research projects. Two keynote talks were given by Prof. Simon Saunders (FemtoForum) and Rupert Baines (Picochip), followed by a round table. (http://www.futurenetworksummit.eu/2011/default.asp?page=relevents)

- UPC made a connection between the workshop and a special issue of EURASIP Journal on Wireless Communications and Networking (current impact factor of 0.81), whose editorial work will be in charge of Josep Vidal, Sergio Barbarossa and two members of BeFemto: Thierry Lestable and Stefan Kaiser. 26 papers were submitted which are in review. The expected publication date is Summer 2012.

- A winter school on held in Barcelona in Feb 2012. The Winter School co-organized by BeFemto and Freedom Projects took place at the Castelldefels premises of CTTC, Barcelona (Spain). The workshop was attended by 50 physical attendees and 20 remote live-video attendees, which could and did ask questions per Twitter and stayed for virtually the entire week. Furthermore, the Winter School had presentations well balanced from industry and academia. The sessions included a poster presentation.

Contributions to standardization bodies:

The consortium has been active in providing inputs to standardization bodies, six proposals were presented at RAN meetings:

1. R3-120087 3GPP, "Autonomous operational carrier selection: gain, X2 overhead and other aspects", by UPC, WG3 #75, Dresden, Feb 2012 (activities from 3A2 and 4A2)
2. R3-120284 3GPP, "Motivation and relevance of autonomous operational carrier selection", by Nokia Siemens Networks, Alcatel-Lucent, Orange, Potevio and UPC, WG3 #75, Dresden, Feb 2012 (activities from 3A2 and 4A2)
3. R3-112801 3GPP, "Text proposal for carrier-based ICIC TR on use cases for Macro - SC HeNB scenario" by UPC, WG3 #74, San Francisco, Nov 2011 (activities from 3A2)
4. R3-112953 3GPP, "Text proposal for carrier-based ICIC TR on use cases for Macro - SC HeNB scenario", by UPC and Telefonica, WG3 #74, San Francisco, Nov 2011 (activities from 3A2 and 4A2)
5. R3-112752 3GPP, "Proposal for DL interference coordination in Macro - SC HeNB scenario" by UPC, WG3 #74, San Francisco, Nov 2011 (activities from 3A2 and 4A2)
6. R1-112096 3GPP, "Proposal of a CoMP study focused on relay-based networks" by UPC, WG1 #66, Athens, Aug 2011(activities from 5A1)

Section B (Confidential[6] or public: confidential information to be marked clearly)
Part B1

List of application for patents, trademarks, registered designs

TEMPLATE B1: LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights[7]:	Confidential Click on YES/NO	Foreseen embargo date	Application reference(s) (e.g. EP123456)	Subject or title of application	Applicant (s) (as on the application)
Patents	YES		EPO 10192086.6	**Cell search method for a downlink channel of an OFDMA transmission system**	Joséphine Hus, Fabien Buda
Patents	YES		France INPI (Institut National de la Propriété Industrielle) No. 1153022	**Method and Apparatus for the optimization of the routing of data in a network** This invention relates to a method for optimizing the routing of data between two nodes in a telecommunication network of an operator. This method includes a step consisting in re-routing the data via at least one intermediate server between the two nodes, where the server can apply to the data at least one specific treatment predefined by the operator.	Michael Bos, Christophe Janneteau, Alexandru Petrescu
Patents	YES		P201131913U SPTO (United States) and OEPM (Spain)	**Methods and systems for decentralized managing of neighboring femtocells** This invention relates to the field of communication. More specifically, the invention relates to methods and systems for decentralized managing of neighboring femtocells, including the self-configuration of transmission parameters and the adjusting of interference requirement constraints in a femtocell network.	Javier Rodríguez, Adrián Agustín, Olga Muñoz, Josep Vidal

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

[7] A drop down list allows choosing the type of IP rights: Patents, Trademarks, Registered designs, Utility models, Others.

Part B2 : Exploitation of foreground.

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	**Decentralized resource allocation algorithms with pricing** Resources (transmit precoders, power allocation, resource block assignment) are optimized to maximize the weighted sum-rate of the system or minimize the transmit power subject to a target rate.	NO		Interference-aware radio resource management based on multiple user, multi-carrier transmission with limited backhaul quality	Telecom Industry		Journal or conference publication(s)	UPC, USDRLS
Exploitation of R&D results via standards	**LTE-A adapted pricing mechanisms** Pricing-baed algorithms have been adapted to the LTE-A, which imposes certain constrains about the information exchanged over nodes.	NO		Interference-aware radio resource management based on multiple user, multi-carrier transmission with limited backhaul quality	Telecom Industry		Journal or conference publication(s) Contributions to LTE-A RAN3	UPC
Commercial exploitation of R&D results	**Rate Max or Power Min under Interference-power constraints**	YES		Interference management, Multi-carrier transmission, Control-plane messages	Telecom Industry		Patent application filed to the USPO and Spanish Patent Office	UPC

[19] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[9] A drop down list allows choosing the type sector (NACE nomenclature) : http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	**Femtocell MIMO-X Transmission** A pair of nodes cooperate for transmitting data to two users. However, each source sends independent messages to both destinations and each destination receives independent messages from both destinations	NO		Interference-aware radio resource management based on multiple user, multi-carrier transmission with high backhaul quality	Telecom Industry		Journal or conference publication(s)	UPC
Exploitation of R&D results via standards	**Joint Processing Cooperative Multipoint (JP-CoMP) with half-duplex relays** Assuming a scenario with multiple BSs, where each sector presents multiple RSs, we design the duration of each phase of the communication and the precoders of BSs.	NO		CoMP-JP in multi-user transmissions with the use of relays	Telecom Industry		Journal or conference publication(s) Contribution to LTE-A RAN1	UPC
General advancement of knowledge	**Distributed allocation strategies based on PHY level activity characterization of the interferers** These techniques extend the popular distributed iterative water filling algorithms to the application in the joint time-frequency domain.	NO		The project provided first results in the application of the techniques. How to apply these techniques including more realistic elements, e.g. in the traffic carachterization of the interferers is a research field to explore.	Telecom Industry		Journal or conference publication(s)	UDSDRLS

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	The results achieved during the project pave the way to further advances,							
General advancement of knowledge	**Coordinated jont channel sensing and distributed transmission scheduling.** FAPs/FUEs track the activity of the interference (i.e. MBS) and exchange the measures over nearby FAPs. Using that set of measures, each FAP is able to allocate the resources in a smart way when the detection and channel access parameters are jointly done.	NO		Distributed algorithms for channel sensing and TX scheduling in the case of highly dense networks, can be developed based on these ideas, under a variaety of assumptions and scenarios. In such situations, the benefit of avoiding a central unit coordinating users over a wide area is evident.	Telecom Industry		Journal or conference publication(s)	UDSDRLS
General advancement of knowledge	**Cooperative downlink for delay-critical applications** Development of a transmission protocol and a receiver design able to implement cooperation in the downlink from multiple antennas without requiring real-time signalling, but coordination only at the beginning of a packet flow originated from a delay critical application.	NO		Extension to the multi-user case. Analysis and evaluation of the proposed technique in conjunction with other protocols for guaranteeing a given QoS on a delay critical application (e.g., VoIP)	Telecom Industry		Journal or conference publication(s)	UDSDRLS
General advancement	**Stochastic pricing for Distributed resource**	NO		Extension of the proposed techniques to	Telecom Industry		Journal or conference	UDSDRLS

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
of knowledge	**allocation in the presence of link failures and quantized communicaitons** Resorting to stochastic omptimization, it has been possible to develop a technique suitable to cope with problems like the quantized nature of the signalling communications requried by distributed pricing algorithms and the possible failure of the inter-node radio links.			different scenarios and/or adaptation to be employed in conjunction with other techniques.			publication(s)	
Commercial exploitation of R&D results	**Fast scanning** A method to accelerate the acquisition of the list of available channels when entering a mobile network**.**	YES		Fast scanning can be used in mobile terminal	Telecom Industry		1 patent pending	SEQ
General advancement of knowledge	Enhanced indoor-to-outdoor path-loss and channel modelling	NO	-	Enhancement of SIRADEL propagation models	Radio network planning	2012	Conference publications	SIR
General advancement of knowledge	Heterogeneous network coverage simulation tools	NO	-	Enhancement of SIRADEL simulation platform	Radio network planning	2012	Conference publications	SIR
General advancement of knowledge	Analysis of femto deployment simulations and measures + derived engineering rules	NO	-	Enhancement of SIRADEL expertise in radio network deployment	Radio network planning	2012	-	SIR
Commercial exploitation of	Opimized routing solution for femtocell attached terminals.	YES		Optimized routing in femtocells networks	Telecom Industry	Unknown	Patent application has been filed at the INPI (French	CEA (owner)

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
R&D results							institute for intellectual property)	
General advancement of knowledge	**Estimation of throughput gain for handover decision** UEs monitor the signal level and reports is back to the network. The network then estimates gain in UE's throughput if the UE would perform handover to the FAP instead of staying connected to a MBS. The handover is performed if the estimated gain exceeds a threshold.	NO		Handover decision for UEs moving from a macrocell to a femtocell.	Telecom Industry		Journal or conference publication(s)	CTU
General advancement of knowledge	**Adaptive hysteresis for handover decision** Hysteresis considered in common handover decision is dynamically adjusted according to the relative position of a UE and all cells in its neighborhood.	NO		Handover decision algorithm for all scenarios with femtocells	Telecom Industry		Journal or conference publication(s)	CTU
General advancement of knowledge	**Connection cost-based handover decision** Handover decision is	NO		Handover among macrocells and femtocells	Telecom Industry		Journal or conference publication(s)	CTU

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	modified to prolong a time spent by UEs under the FAPs coverage instead of being attached to a macrocell if a connection via femtocell is of a lower cost than connection via macrocell.							
General advancement of knowledge	**Management of active set for Fast Cell Selection (FCS)** Individual cells (FAPs and MBSs) are added/deleted to/from active set of each UE according to overall amount of consumed radio resources to maximize network throughput. Also, FAPs backbone quality is considered as a parameter for active set management.	NO		Algortihm for selection of cells included in active set if FCS is supported.	Telecom Industry		Journal or conference publication(s)	CTU
General advancement of knowledge	**Three way of vertical handover decision** Algorithms minimize amount of vertical handovers to minimize degradation of quality of service and to maximize system throughput. The handover is initiated primarily according to signal quality (for the first algorithm). In case of the	NO		Handover decision considering QoS metrics for handover between different versions of standards.	Telecom Industry		Journal or conference publication(s)	CTU

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	second and third strategy, the decision is primarily done according to the serving and target stations load and UE's QoS requirements.							
General advancement of knowledge	**Physical Cell Identification (PCI) for dense deployment of FAPs** PCI structure is enhanced by a new identifier called FAP cluster identifier where a FAP cluster is comprised of set of neighboring FAPs. The FAP cluster identifier can be specified either as an extension or as a sub-identifier of current PCI structure. As to the PCI selection itself, a decentralized method using radio environment scanning combined with a central network entity storing available FAP positions are the most appropriate approach.	NO		Increase in a number of PCI for avoiding confusion and colisions cells' identification at physical layer.	Telecom Industry		Journal or conference publication(s)	CTU
General advancement of knowledge	**Access of non-CSG users to closed FAPs** The new control procedure enables temporary access of the visiting user to the closed FAP if this access is	NO		Control procedure and messages for enabling temporary access of user's not included in CSG list of a FAP in case of visiting users and in emergency	Telecom Industry		Journal or conference publication(s)	CTU

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	approved by a FAP subscriber. Two types of management information exchange are distinguished: in-band and out-of-band. Further, new control procedures for emergency calls in scenario with closed access femtocells include present messages of several procedures and combine them into one procedure.			situations.				
General advancement of knowledge	**Path selection for direct communication between two users** If two users connected to the same femtocell communicate with each other, data are sent directly instead of two hop communication. This way, the radio resources allocated to the femtocells are more efficiently utilized. Whether direct transmission is feasible or not is evaluated at the femtocell using Radio Resource Cost metric	NO		Path selection procedure enabling two users connected to the same FAP communicate directly with each other without data transmission via the FAP.	Telecom Industry		Journal or conference publication(s)	CTU
General advancement of knowledge	**QoS guaranteeing power control based on traffic load** Dynamic power control	NO		Control procedure for management of direct communication of users' in mutual vicinity.	Telecom Industry		Journal or conference publication(s)	CTU

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	algorithm dynamically adapts the transmitting power of FAPs according to current traffic load and signal quality between the user equipments and the femtocells in order to fully utilize radio resources allocated to the FAP.							
General advancement of knowledge	**Replacement of IPsec by protocols generating less overhead** The handshake process has been modified by using a new message referred to as HandshakeRequest. This mechanism enables to build up a new DTLS connection by using the existing TLS tunnel.	NO		Integration of both TLS and DTLS protocols into a joint TLS and DTLS handshake.	Telecom Industry		Journal or conference publication(s)	CTU
General advancement of knowledge	**Joint key exchange mechanism for TLS and DTLS protocol** Modification of flow of management message for joint TLS and DTLS handshake process by a new message referred to as HandshakeRequest. This mechanism enables to build up a new DTLS connection by using the existing TLS tunnel.	NO		Exchange of management messages for TLS and DTLS to security of FAP's backbone communication.	Telecom Industry		Journal or conference publication(s)	CTU

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
General advancement of knowledge	**Backhaul aware scheduling** Development of backhaul aware scheduling and admission control which take into account backhaul load condition in order to maximize the femtocell performance under non-SLA (best effort) based backhaul network.			Extension of the techniques which has backhaul awareness in femtocell product	Telecom Industry		Journal or conference publication(s)	TELKOM
General advancement of knowledge	**xDSL backhaul and corporate LAN characterization as femtocell backhaul** Observation done to obtain xDSL characteristics under FTTE/FTTC/FTTB configuration, Femtocell minimum bandwidth requirement. Observing femtocell performance under non-SLA network	NO		Engineering rules for femtocell deployment mainly for 3G deployment	Telecom Industry		Journal or conference publication(s) or book chapter	TELKOM
General advancement of knowledge	**Interference Characterization of 3G femtocell network** Observation result related to the impact of single-FAP and multi-FAPs deployments; inter-FAP distance; outdoor leakage; closed- and open-access	NO		Engineering rules for femtocell deployment mainly for 3G deployment: The results give clear and valuable insight into the coverage provided by a 3G corporate FAP	Telecom Industry			SIRADEL, TELKOM

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
	modes; and visibility condition (LOS, NLOS, inter-floor). This impact was measured on the useful signal level, interference level and signal-to-interference statistics; FAP coverage radius; macro deadzone radius; FAP-to-macro handover distance; DL and UL throughput.			deployment (from FAP coverage radius) and into the FAP-based interference levels (e.g. characterized by the deadzone radius).				
General advancement of knowledge	**Femtocel based e-MBMS Simulation** Developing simulation for e-MBMS (enhanced Multimedia Broadcast and Multicast Services) in Femtocell networks in order to exercise its performance of delivering multimedia traffic compared to its implementation in Macro Base Stations.	NO		Potentially new method in delivering multimedia services towards LTE implementation.	Telecom Industry		Journal or conference publication(s)	TELKOM
General advancement of knowledge	**Genetic Optimization algorithm for power and band allocation.** System simulator for data traffic flow and scheduler in the LTE network. Simulator of transmission events to analyse network interference.	NO		LTE compliant traffic system simulator	Telecom Industry		Journal or conference publication(s)	DUN

Type of Exploitable Foreground[8]	Description of exploitable foreground	Confidential Click on YES/NO	Foreseen embargo date	Exploitable product(s) or measure(s)	Sector(s) of application[9]	Timetable, commercial or any other use	Patents or other IPR exploitation (licences)	Owner & Other Beneficiary(s) involved
Commercial exploitation of R&D results	Opimized routing solution for femtocell attached terminals.	YES		Routing optimized femtocells	Telecom Industry		Patent application has been filed at the INPI (French institute for intellectual property)	CEA (owner)
General advancement of knowledge	Sub-optimal decoding for delay tolerant space time codes, in femto assisted cellular networks.	NO		Modified femtocells and terminals	Telecom Industry			CEA
General advancement of knowledge	Location based power assignment for femto-overlaid networks	NO		Planning tool	Telecom Industry			CEA

3 Report on societal implications

A General Information *(completed automatically when **Grant Agreement number** is entered.*

Grant Agreement Number:	ICT-248891
Title of Project:	**FREEDOM:** Femtocell-based network enhancement by interference management and coordination of information for seamless connectivity
Name and Title of Coordinator:	Josep Vidal Associate Professor at Universitat Politècnica de Catalunya

B Ethics

1. Did you have ethicists or others with specific experience of ethical issues involved in the project?	O **X**	**Yes** **No**

2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
INFORMED CONSENT	
• Did the project involve children?	NO
• Did the project involve patients or persons not able to give consent?	NO
• Did the project involve adult healthy volunteers?	NO
• Did the project involve Human Genetic Material?	NO
• Did the project involve Human biological samples?	NO
• Did the project involve Human data collection?	NO
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	NO
• Did the project involve Human Foetal Tissue / Cells?	NO
• Did the project involve Human Embryonic Stem Cells?	NO
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)	NO
• Did the project involve tracking the location or observation of people?	NO
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	NO
• Were those animals transgenic small laboratory animals?	NO
• Were those animals transgenic farm animals?	NO
• Were those animals cloning farm animals?	NO
• Were those animals non-human primates?	NO
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Use of local resources (genetic, animal, plant etc)	NO
• Benefit to local community (capacity building ie access to healthcare, education etc)	NO
DUAL USE	
• Research having potential military / terrorist application	NO

C Workforce Statistics

3 Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	**Number of Women**	**Number of Men**
Scientific Coordinator		1
Work package leader		5
Experienced researcher (i.e. PhD holders)	7	31

PhD Students	5	14
Other	3	1

4 How many additional researchers (in companies and universities) were recruited specifically for this project?	
Of which, indicate the number of men:	1
Of which, indicate the number of women:	1

D Gender Aspects

5	**Did you carry out specific Gender Equality Actions under the project** ?	○ X	Yes No

6 Which of the following actions did you carry out and how effective were they?

	Not at all effective				**Very effective**
❑ Design and implement an equal opportunity policy	○	○	○	○	○
❑ Set targets to achieve a gender balance in the workforce	○	○	○	○	○
❑ Organise conferences and workshops on gender	○	○	○	○	○
❑ Actions to improve work-life balance	○	○	○	○	○

○ Other:

7 Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

X No

E Synergies with Science Education

8 Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

X Yes, some of the scientific progress achieved in FREEDOM has been brought to PhD courses. Dissemination has been done to undergrad students through seminars.

○ No

9 Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

X Yes- please specify: The FREEDOM project website, www.ict-freedom.eu

○ No

F Interdisciplinarity

10 Which disciplines (see list below) are involved in your project?

X Main discipline[10]: 2.2

X Associated discipline[10]: 1.1

○ Associated discipline[10]:

G Engaging with Civil society and policy makers

11a	**Did your project engage with societal actors beyond the research community?** *(if 'No', go to Question 14)*	X ○	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)?

X No

○ Yes- in determining what research should be performed

[10] Insert number from list below (Frascati Manual)

○	Yes - in implementing the research	
○	Yes, in communicating /disseminating / using the results of the project	
11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ X	Yes No

12 Did you engage with government / public bodies or policy makers (including international organisations)

○	No
X	Yes - in framing the research agenda
○	Yes - in implementing the research agenda
X	Yes, in communicating /disseminating / using the results of the project

13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers?

X Yes – as a **primary** objective (please indicate areas below- multiple answers possible)
Information Society
Competition

X Yes – as a **secondary** objective (please indicate areas below - multiple answer possible)
Research and Innovation

○ No

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	X
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
		Foreign and Security Policy		Space	
Education, Training, Youth		Fraud		Taxation	
Employment and Social Affairs		Humanitarian aid		Transport	

13c If Yes, at which level?

○	Local / regional levels
X	National level
X	European level
○	International level

H Use and dissemination

14 How many Articles were published/accepted for publication in peer-reviewed journals?	**6 (+9 submitted)**
To how many of these is open access[11] provided?	**1**
How many of these are published in open access journals?	**1**
How many of these are published in open repositories?	
To how many of these is open access not provided?	**14**
Please check all applicable reasons for not providing open access:	
X publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other: ……	

15 How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		**3**
16 Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	
	Registered design	**3**
	Other	
17 How many spin-off companies were created / are planned as a direct result of the project?		**0**
Indicate the approximate number of additional jobs in these companies:		

18 Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

X	Increase in employment, or	X	In small & medium-sized enterprises
❑	Safeguard employment, or	X	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
❑	Difficult to estimate / not possible to quantify	❑	

19 For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	❑

[11] Open Access is defined as free of charge access for anyone via the internet.

I Media and Communication to the general public

20 As part of the project, were any of the beneficiaries professionals in communication or media relations?

○ Yes X No

21 As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

X Yes ○ No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

X	Press Release	❑	Coverage in specialist press
❑	Media briefing	X	Coverage in general (non-specialist) press
❑	TV coverage / report	X	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
X	Brochures /posters / flyers	X	Website for the general public / internet
❑	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

X	Language of the coordinator	X	English
❑	Other language(s)		

***Question F-10*:** Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES

1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]

1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)

1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)

1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY

2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES

3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES
5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES
6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group] .