SHARING

SELF-ORGANIZED HETEROGENEOUS ADVANCED RADIO NETWORKS GENERATION

D7.1 (Tasks 7.1/7.2)

Selection of scenarios for proof of concept testbeds and recommendations on key building blocks for implementation

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Editor(s)	Raymond Knopp (EUR)
Author(s)	Raymond Knopp (EUR), Yolanda Fernandez (TTI), Adrian Sanchez (TTI), Sylvie Mayrargue (CEA), Engin Zeydan (AVEA)
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Abstract:

This deliverable specifies the proof-of-concepts demonstrators that will be developed in the context of the SHARING project. More specifically it specifies the scenarios as well as the building blocks for each of the PoCs. The scenarios are a subset of those defined in D2.2 and IR5.1 which are chosen based on maximal impact and feasibility for demonstration purposes.

Keywords: Scenarios for Experimental Validation, Overview of Platform Building Blocks

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EXECUTIVE SUMMARY

This document aims to set the scene for the work in WP7 which entails the selection of target scenarios and implementation of proof-of-concept (PoC) platforms to highlight major innovations in the SHARING project.

We describe the concrete use-case scenarios that are currently considered for experimental validation. The specific networking topologies (i.e. number and nature of nodes) are described along with the concepts (e.g. distributed MIMO, agile RF, joint RRM, etc.). The performance evaluation methodology to be used during experimentation is detailed. The primary scenarios at this point are:

- Evolved Multimedia Broadcast Multicast Service (eMBMS) relays for coverage extension of eMBMS multicast-broadcast servicesDevice-to-device (D2D) communications for content delivery reusing uplink resources
- Cooperative Multipoint (CoMP) transmission coupled with interference rejection in User Equipment (UE) and Multiuser-MIMO (MU-MIMO)
- Advanced RF architectures in support of Carrier Aggregation (CA)
- WIFI Offloading

We also provide preliminary descriptions of the technologies used to build the PoC demonstrators. We specify the required modifications to existing hardware and software along with addressing the integration methodology.

1 INTRODUCTION

This document aims to set the scene for the work in WP7 which entails selection target scenarios and implementation of proof-of-concept (PoC) platforms to highlight major innovations in the SHARING project.

Section 2 describes concrete use-case scenarios that are currently considered for experimental validation. The specific networking topologies (i.e. number and nature of nodes) are described along with the concepts (e.g. distributed MIMO, agile RF, joint RRM, etc.). The performance evaluation methodology to be used during experimentation is detailed. The primary scenarios at this point are:

- eMBMS relays for coverage extension of eMBMS multicast-broadcast services (WP5)
- Device-to-device (D2D) communications for content delivery reusing uplink resources
- Cooperative Multipoint (CoMP) transmission coupled with interference rejection in User Equipment (UE) and Multiuser-MIMO (MU-MIMO)
- Advanced RF architectures in support of Carrier Aggregation (CA)
- WIFI Offloading

Section 3 provides preliminary descriptions of the technologies used to build the PoC demonstrators. It specifies the required modifications to existing hardware and software along with addressing the integration methodology.

2 DEFINITION OF USE CASES FOR EXPERIMENTAL VALIDATION

Here we describe concrete use case scenarios currently considered for experimental validation. The specific networking topologies (i.e. number and nature of nodes) are described along with the concepts (e.g. distributed MIMO, agile RF, joint RRM, etc.). The performance evaluation methodology to be used during experimentation is detailed.

2.1 Use-case 1: Relaying and D2D

2.1.1 eMBMS relaying

The first WP5 scenario pertains to multi-relaying in the context of multicast/broadcast applications using eMBMS (Enhanced Multimedia Broadcast Multicast Service). The key bottleneck in such multicast/broadcast applications is providing a high-level of QoS (Quality of Service) to all users in the coverage area, while keeping spectral-efficiency as high as possible. The latter is to provide multicast/broadcast services on common carriers with unicast services with minimal impact on the throughput of unicast bearers. To this end, we propose the use of low-cost eMBMS relays for coverage holes in hot-spot areas. We note that for multicast/broadcast bearers, the spectral-efficiency guarantees are much more important than for unicast bearers, since for the latter the service degrades gracefully due to adaptive modulation and coding. In the multicast scenario the minimal service (spectral-efficiency) users would dominate the overall cell spectral-efficiency

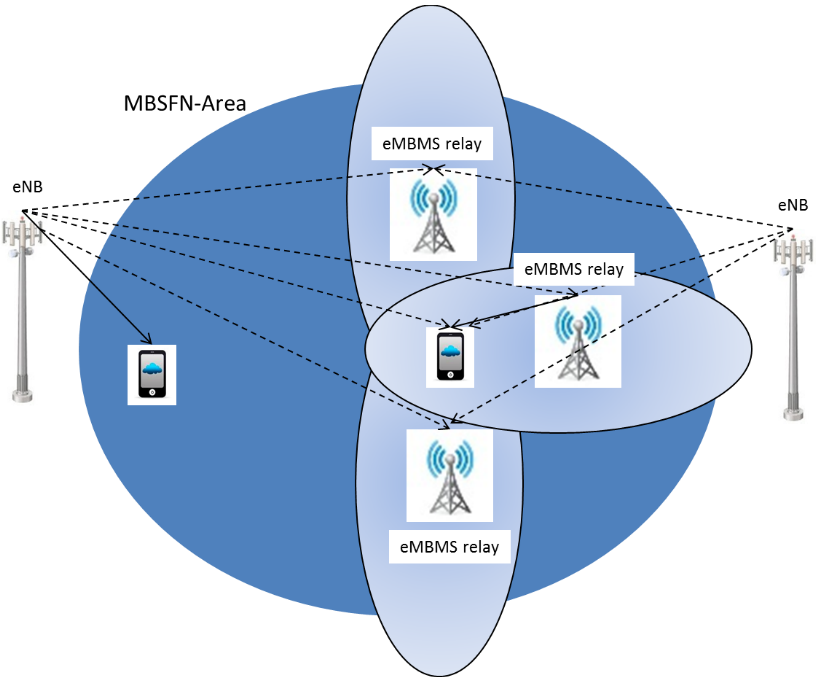

Figure 1: eMBMS Relaying

The considered scenario is depicted in Figure 1 where we show the coverage zone of two eNB from the same so-called MBSFN-area1 and three relays for improving service in a coverage hole. The terminals in the vicinity of the relays can potentially receive the same flow from both the main eNB and the relays, although not in the same subframes. However, due to the presence of the relays, the target would be to use a very high spectral-efficiency/MCS (Modulation and Coding Set) which would be impossible without the help of a relay. The position of the relays would be chosen to allow decoding and

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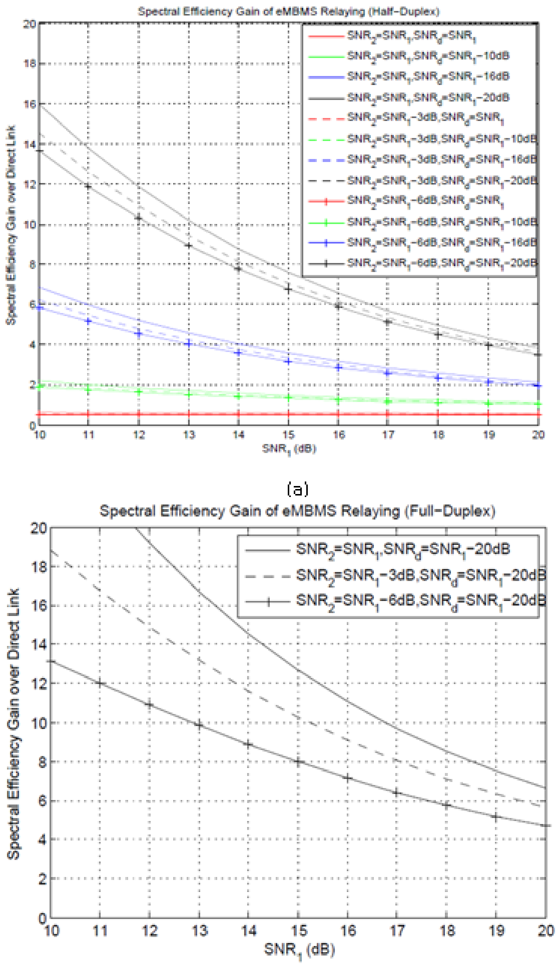
[1] A geographic zone covered with a common broadcast waveform/content from several synchronized eNBs

regeneration of the signal (i.e. decode-and-forward relaying) for terminals in their vicinity in a two-hop, half-duplex, fashion. The transmission could be in two different time slots on a common carrier, or two completely different carriers.

From the terminal’s perspective the benefit of digital signal regeneration and natural signal-level combining of the eMBMS waveform in the second-hop should be high-enough to outweigh the fact that transmission occurs in a half-duplex mode. If the cost of relays can be increased, the combination of self-interference cancellation and proper antenna deployment would allow for full-duplex operation and would consequently remove any loss in spectral efficiency.

In the case of full-duplex we only consider the case of a weak direct-link in the coverage hole since there is no channel separation between the incoming and outgoing links at the relay and consequently interference between new primary transmissions and relayed versions of previous transmissions would be unavoidable. This could be overcome with interference cancellation in the terminal, but this is not considered in this simple analysis. Moreover, full-duplex would also require directional antennas in the coverage hold in order to cause interference in the remainder of the MBSFN-Area. We can conclude than in both cases, significant spectral-efficiency improvement (8-10 times) can be obtained by judicious deployment of relays for coverage holes, without penalizing the users with good coverage, or dropping the overall spectral efficiency of the multicast/broadcast service. The result of a simulation of such relaying in terms of spectral efficiency is shown in Figure 2a for half-duplex operation and Figure 2b for full-duplex operation.



(a)

(b)

Figure 2: Spectral Efficiency with eMBMS Relaying, (a) Half-duplex, (b) Full-duplex

The scenario corresponding to this analysis is given in Figure 3, where SNR1 corresponds to the worst-case aggregate signal-to-noise ratio (SNR) between the MBSFN-Area primary transmitters and the relays, SNRd corresponds to the direct-link signal-to-noise ratio at the receivers in the coverage hole and SNR2 is the aggregate signal-to-noise ratio from the relays at the receiver in coverage hole.

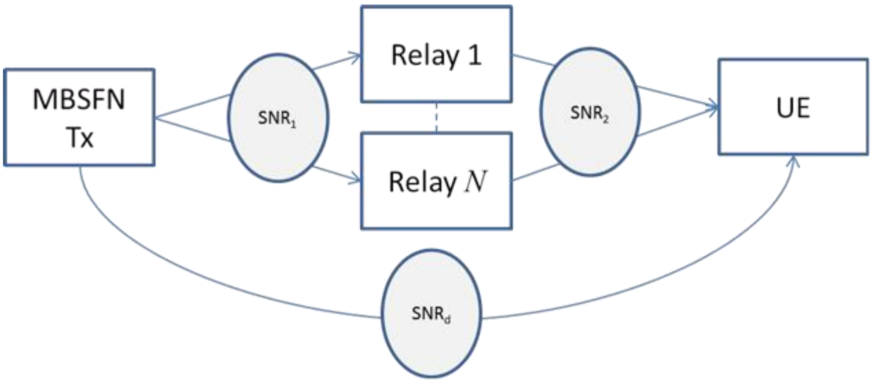


Figure 3: Relaying Scenario for Simple Analysis

The goal of this activity is to validate the feasibility of deployment of simple eMBMS relays (half-duplex) in order to achieve gains outlined above.

2.1.2 D2D communications for content distribution

In the second WP5 scenario shown in Figure 4, we consider usage of D2D links firstly to aid in the distribution of content by coverage extension due to the proximity between devices. In order to minimize overhead will a large number of relaying devices, we will assume that they transmit in a collaborative random-access fashion.

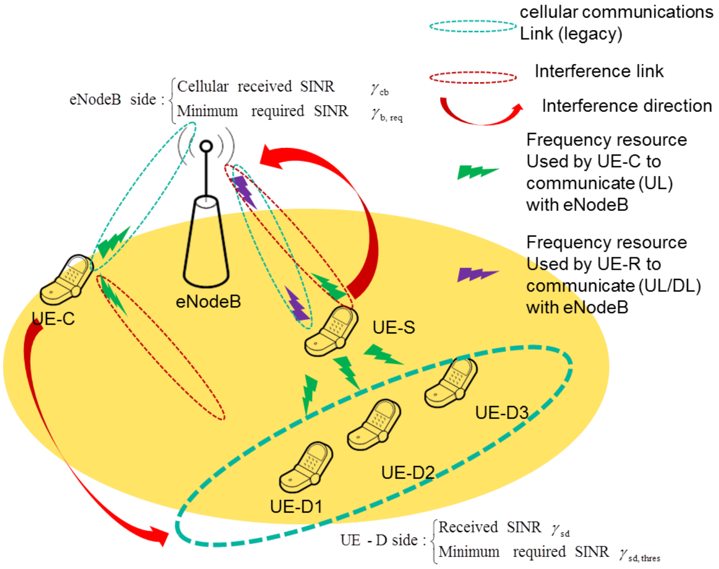


Figure 4: D2D communications reusing legacy LTE cellular Uplink resource: broadcast scenario

The second usage of D2D links is to allow end-devices with cached content to exchange this content under the control of the local base stations either to aid in interference management of the overall network or due to the absence of the particular content in the local cache of the base stations. This communication would primarily be used to hide the content distribution in the background noise of the network and is made possible solely because of the combination of the proximity of the nodes and their capacity to store content with the macroscopic vision of base stations with respect to the nodes in their cells. We could consider both scheduled access for D2D or random-access as a function of the number of nodes that are helping the eNB to deliver content.

2.1.3 Evaluation Criteria

In order to assess the improvement brought about through collaborative relaying in the two scenarios we will evaluate the practical spectral efficiency improvement with and without the relays. Specifically, in the case of the eMBMS relaying we will determine the achievable MCS (modulation and coding set) for the deployment area for a different number of relays. In the case of the D2D scenario, we will assess the increase in spectral-efficiency through the reuse of the uplink carrier, as a function of the performance degradation at the eNB seen by the service a "victim" UE which is scheduled in parallel to D2D links.

2.2 Use-case 2: CoMP

Coordinated MultiPoint (CoMP) aims at improving the Quality of Service of users at cell edge. Among the different types of CoMP defined in [3], Joint Processing-Joint Transmission (JT) has been selected for study in WP3 T3.1, and for implementation in WP7. It is nevertheless clear that the price to pay to obtain improved quality at cell edge with this scheme is a loss of resource in the set of cooperative eNBs considered as a whole, since the same resource block is used in each eNB to serve a single user. Therefore, in order to compensate for this resource loss, it is necessary to complement JT CoMP with MU-MIMO. MU-MIMO Transmission Mode 5 (TM5), i.e. codebook-based closed loop spatial multiplexing with one layer dedicated for one UE, will be considered.

2.2.1 Use case scenarios for experimental validation

Combined CoMP and MU-MIMO is a promising technology but many practical obstacles arise when it comes to practice. Among these hurdles is the minimization of the feedback signalling rate, from UEs to eNBs. In order to contain this rate, the LTE standard [TS36.211] provides for the use of a reduced set of precomputed codewords. Unfortunately the very poor resolution of these codewords gives rise to interference at the co-scheduled receivers. In this context, scenarios will be designed in the aim to prove experimentally that interference rejection receivers can make the best use of the diversity introduced by TM5 of 3GPP LTE.

2.2.1.1 Scenario 1

This scenario is described by Figure 5. It is intended to prove the efficiency of interference rejection receivers in a basic configuration, where no CoMP is used. The eNB is equipped with two or four transmit antennas. Only the receiver of interest, UE0, will be implemented; it is equipped with one or two antennas. At the eNB, precoder w_0 is used for UE0 and an orthogonal precoder w_1 is used for UE1. The precoders will be chosen in the 3GPP codebook. Interference Rejection (IR) algorithms are implemented at UE0.

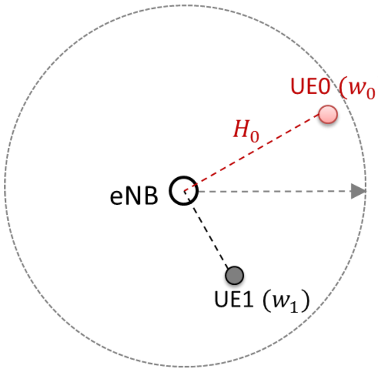


Figure 5:. Scenario 1. MU-MIMO, No CoMP.

In a first step, IR algorithms will be assessed with maximum information available at the UE side. UE0 will then have full knowledge of the interfering precoder, of its channel H_0 and of the interfering constellation.

In a second step, the robustness of the IR algorithms at UE0 will be assessed by making more realistic assumptions, such as imperfect channel estimation and unknown interfering constellation.

2.2.1.2 *Scenario 2*

This scenario is described by Figure 6. Compared to scenario 1, CoMP has been introduced. The eNBs are equipped with two or four transmit antennas. Only the receiver of interest, UE0, will be implemented; it is equipped with one or two antennas. At eNB1, precoder $w_{1,0}$ is used for UE0 and an orthogonal precoder w_1 is used for UE1. At eNB2, precoder $w_{2,0}$ is used for UE0 and an orthogonal precoder w_2 is used for UE2. The precoders will be chosen in the 3GPP codebook. Interference Rejection (IR) algorithms are implemented at UE0. In this scenario, the interference comes from both precoders of UE1 and UE2.

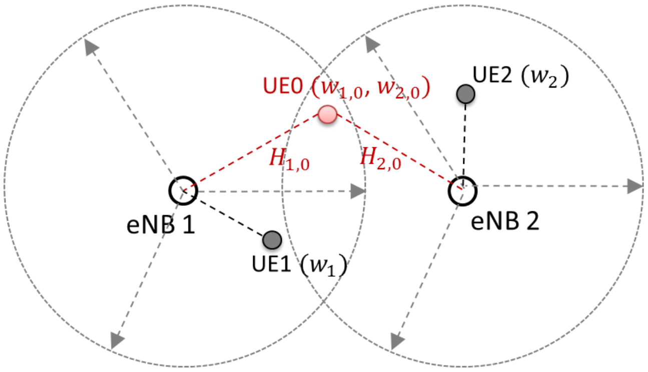


Figure 6. Scenario 2. MU-MIMO CoMP.

In the same way than for scenario 1, the evaluation of the performance of the receiver will be done in two steps: first with maximum information available at the receiver and then with more realistic assumptions.

2.2.2 Performance evaluation methodology

The receiver performance will be assessed thanks to BER and PER measurements. Several parameters that may impact the performance will be varied, namely

- Level of knowledge of the channel(s)
- Knowledge or not of interfering precoder(s)

Knowledge or not of the interfering constellation(s)

2.3 Use-case 3: Carrier Aggregation

This section describes the use cases where a reconfigurable RF front-end supporting carrier aggregation (CA) appears as a suitable solution. Using CA, the available bandwidth could be extended up to 100 MHz by aggregating up to five component carriers (CC) with 20 MHz maximum bandwidth. Therefore reconfigurable and flexible bandwidth hardware is appropriated to adapt to different scenarios where there is certain variability in traffic demand.

In Deliverable D2.2 [2], various potential CA deployment scenarios were presented. At this point, some of them have been selected for experimental validation in WP7. Nevertheless, the experimental validation will be placed in a lab environment.

First of all, there are two different types of CA: intra-band CA and inter-band CA. Intra-band CA is defined to support up to five CCs in the same band, while inter-band CA uses different bands. Moreover, there are two types of intra-band CA: contiguous or non-contiguous. Intra-band contiguous CA is performed when CCs are put together and intra-band non-contiguous CA is performed when CCs are separated into the same band.

For experimental validation, LTE band 7 has been selected to implement intra-band CA, and LTE band 7 and LTE band 20 to implement inter-band CA.

For intra-band CA, possible deployment scenarios are depicted in Figure 7: CA deployment scenario improving throughput in a) nearly the same coverage or b) cell edge

. Two different cells can be considered F1 and F2, which can also represent a CC. Each cell could be associated to a CC and the coverage area which provides user service. If they are co-located and overlaid, they will provide nearly the same coverage improving throughput in this same area (Figure 7: CA deployment scenario improving throughput in a) nearly the same coverage or b) cell edge

). Up to five CCs or cells could be added to improve throughput. Another scenario could be when F1 and F2 are co-located, but F2 is directed to the cell boundaries of F1 so that cell edge throughput is increased as shown in Figure 7: CA deployment scenario improving throughput in a) nearly the same coverage or b) cell edge

b. It is expected that F1 and F2 cells of the same eNB will be aggregated where coverage overlaps. For both scenarios, a reconfigurable RF front-end supporting intra-band CA fits well. In this scenario, F1 and F2 are of the same band.

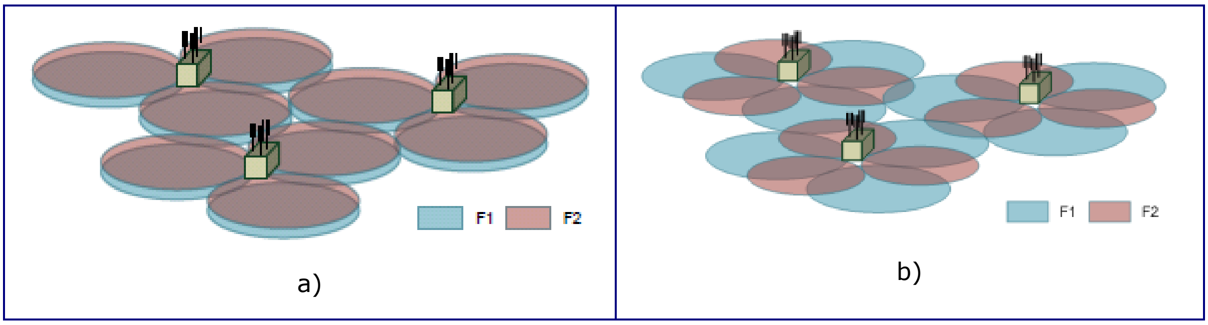


Figure 7: CA deployment scenario improving throughput in a) nearly the same coverage or b) cell edge

For inter-band CA, a possible deployment scenario is presented in Figure 8. F1 and F2 cells are co-located, but F2 provides smaller coverage due to larger path loss. In this likely scenario, F1 and F2 are of different bands and F2 is higher than F1. The aggregation is performed in F2 coverage area where both overlap.

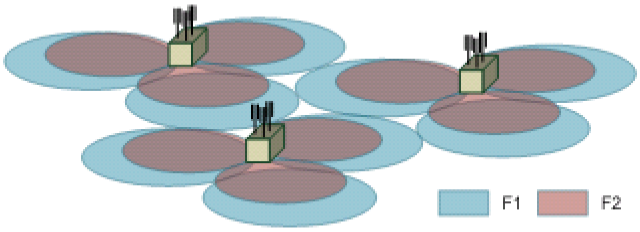


Figure 8: CA deployment scenario improving throughput with smaller coverage due to larger path loss in F2

Envisioning these deployment scenarios, some use cases will be presented. The scope of this study is focused on femto cells, which could be deployed in public areas such as airports, train stations or shopping centres, and in private areas such as enterprises. All mentioned use cases are indoor networked and they can provide open access in public areas or closed access in private areas.

In public areas such as airports, there are a variable number of travellers depending on the time and the airport zones. Sometimes planes are delayed for different reasons and the impatience of travellers might be compensated by a femto cell network. Thankfully this network can offer wireless access to enjoy during the waiting time, improving the user experience at the airport. Furthermore, travellers could download their boarding pass to access to the plane at the same time. A reconfigurable hardware is an appropriate solution to adapt to the different situations which can appear.

Another use case could be a private area like an enterprise. The needs may change as a function of time, as example when there are invited partners or customers in the meeting rooms, they will require connectivity support. A reconfigurable RF front-end supporting CA can be a solution to complement the current fixed network with a wireless solution based on a femto cell network in order to meet the needs of the guests. Moreover, this solution offers many advantages both for installation and maintenance. Additionally, femto cell solutions are non-costly.

The main objective is to develop a reconfigurable and flexible bandwidth RF front-end supporting intra-band CA and inter-band CA to adapt throughput to traffic demand, and at the same time achieve energy savings. In WP3, a reconfigurable HPA will be studied to adapt the RF output power level according to the number of CCs in CA mode. A unique HPA is proposed for each frequency band modifying its operating points to adjust to traffic demand associated to the number of CCs. The main target of this study will be to reach energy savings through hardware reconfigurability.

2.4 Use-case 4: Cellular Offloading

Cellular offloading scenario aims at developing efficient techniques for offloading data of AVEA 3G customers into TTNET Wi-Fi infrastructure whenever there is Wi-Fi coverage. Seamless offloading between 3G and Wi-Fi infrastructure is to be performed by EAP-SIM protocol. User usage scenarios include roaming and messaging realization in Wi-Fi infrastructure so that optimization of the appropriate technology selection by optimizing mobile network operator's objective function can be performed. For this mobile network operators are using their information and incentive to perform network-wide optimization in terms of, e.g., many parameters such as delay, channel utilization, the load at the access network or the backhaul, etc.

In this scenario, users equipped with multiple radio devices of different technologies (e.g., Wi-Fi APs and HSPA) can be selected to best access network under the control of a single operator. The objective is to ensure the best connectivity of the user in such a scenario. The decision for access technology selection will consider all the data coming from both network and user equipment and the decision should be in a timely manner.

In summary, we pursue the following objectives:

1) Increased network capacity
2) Decreased the OPEX/CAPEX costs
3) Achieve better QoE for the users

General structure:

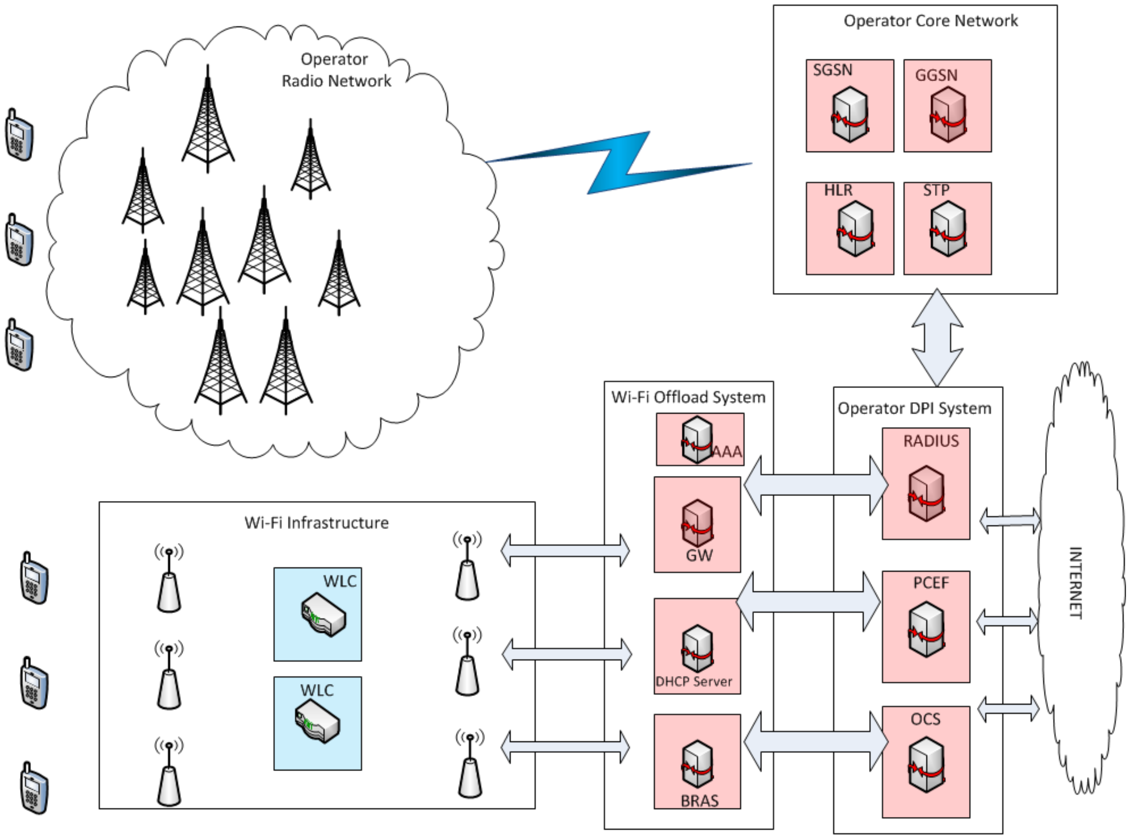


Figure 9: General Architecture

Figure 9 shows the general architecture of Wi-Fi offloading solution integrated with a mobile operator’s infrastructure. The scenario can be characterized by existence of a number of overlapping heterogeneous networks that can be used by the terminal device as potential connection points. As can be seen coverage is provided by heterogeneous networks (3G and Wi-Fi). This creates the need for joint coordination and optimization which may happen in three ways: (i) user initiated, (ii) network initiated and (iii) collaborative.

In user initiated mode, this operation can be implemented easily within mobile network. In network assisted mode, this operation is assisted by mobile network operator since the decisions it can take aims at global objectives. In collaborative approaches, the best decision on the network selection will be not only based on user requirements but also from the point of network perspective. Collaborative techniques exploit the network-terminal cooperation.

2.4.1 Roaming

Roaming is handover of a mobile network user into same or different network controller device in a secure and reliable way with possibly minimum delay. There are different roaming conditions such as roaming between access points that are attached to same network controller devices or between access points that are attached to different network controller devices.

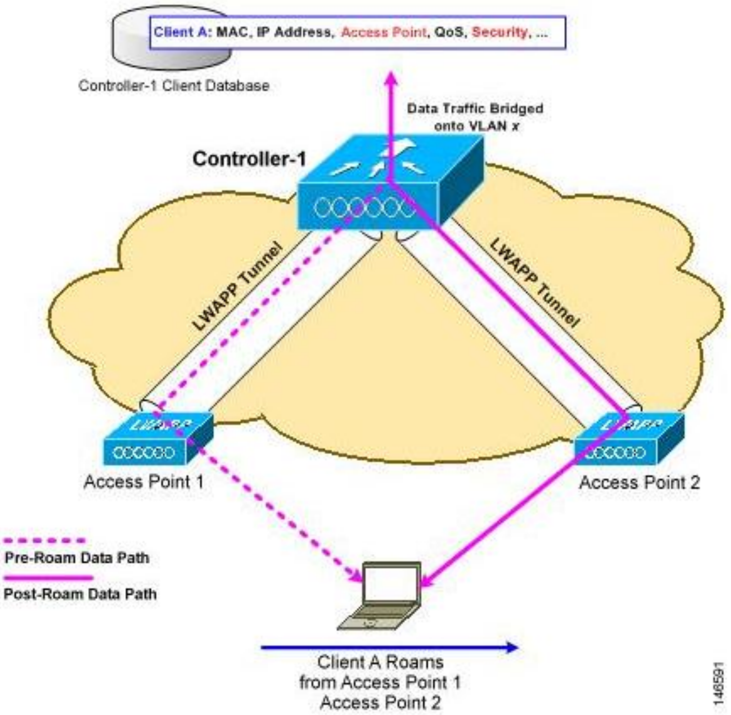


Figure 10: Roaming scenario between access points that are connected to same Network Controller Devices [6]

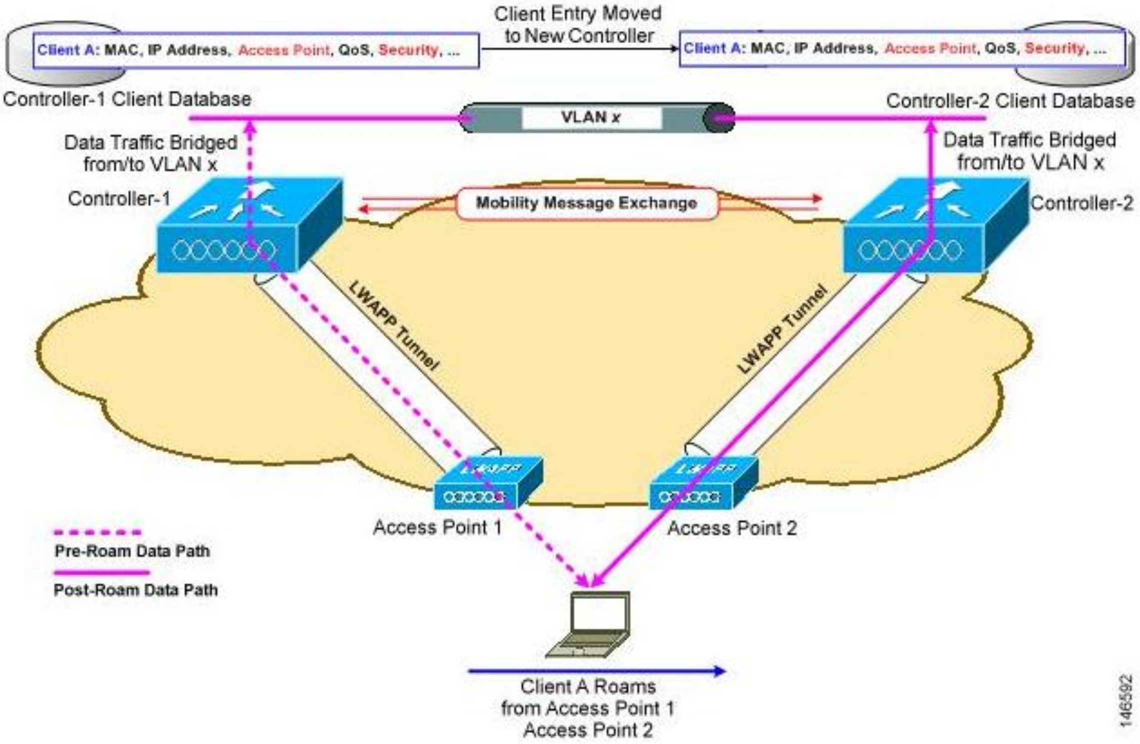


Figure 11: Roaming scenario between access points that are connected to different network Controller Devices[6]

2.4.2 Mobility Group

Mobility Group is a protocol that is developed in order to group mobile users who are connected into a specific network controller device in a similar manner so that management and seamless roaming can be enabled more easily. Using mobility group, user information sharing between access points connected to the same mobility group network controller devices can be done dynamically.

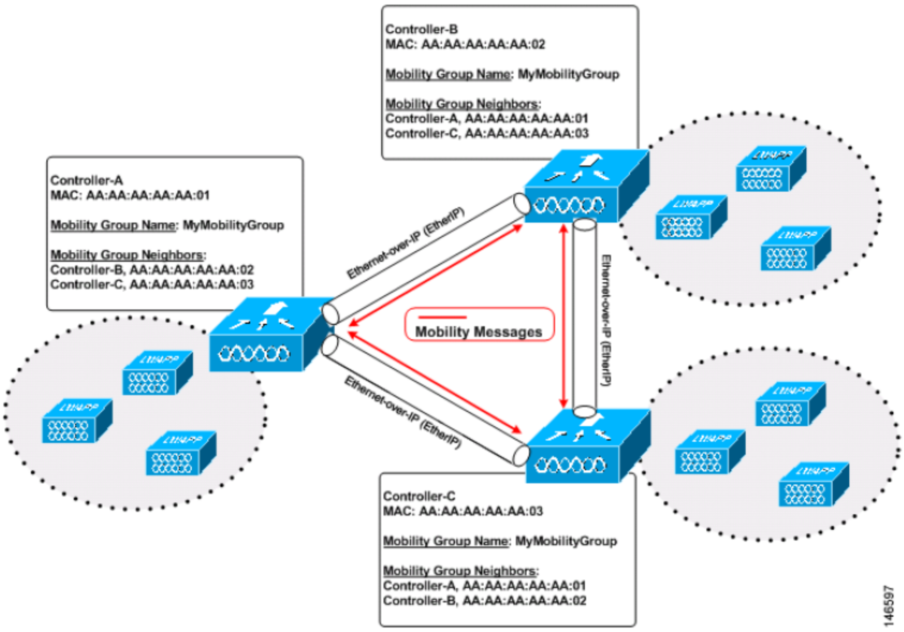


Figure 12: Mobility Group[6]

2.4.3 WLC parameters

Idle Timeout: A global parameter in WLC. If there is not any packet transfer at the end of idle timeout duration, user is unregistered from WLC.

Session Timeout: A parameter adjusted in WLC per SSID. This parameter is included in Radius packets. At the end of the session timeout, user is again authenticated and some interim packets can be sent.

User ScenariosUser scenarios are determined especially focusing on two categories of users: static and mobile users.

In static scenarios, users are assumed to be located in a specific location with no movement.

In mobile scenarios, the condition where the user is pedestrian or moving by changing the locations is considered. Mobile users can be moving between different access points. The scenarios are constructed based on the access point's connection conditions into infrastructure. Messages in Radius packet can be of interest for further analysis.

User scenarios that are expected to be foreseen in the real-world conditions are described in the following subsections.

2.4.4 Static scenarios

User is connected to a SSID. Since the user is static, the user is always connected to same access network controller through the same access point. User is connected to same Wi-Fi infrastructure for a specific duration of time. User can be connected to another SSID for ending the current session.

The operation and observed messages between the infrastructure and user equipment should be investigated for all user equipment types. Standard packets and any additional packets related to access and accounting requests during login is to be investigated for this scenario. If parameter such as session timeout duration is set, update and request packets for both accounting and access should also be investigated. After connection with Wi-Fi has been stopped by the user, idle timeout duration packages such as account stop, etc. will also be important.

2.4.5 Idle scenarios

After the mobile device is connected to Wi-Fi, the device behavior characteristics can be investigated through the received packets such as Radius. In this scenario, users shut down the Wi-Fi connection for a moment. If this shut down period exceeds the idle timeout duration, the user session is terminated by WLC with the appropriate packets such as accounting-stop. Note that the behavior of every device will differ for different phone types.

2.4.6 Mobile scenarios

2.4.6.1 Scenario 1: Same WLC, Same MG

After the user is connected to a SSID, the aim of this scenario is to observe messaging between the device and the infrastructure when the user is moving from access point to the next under the same network controller device under same mobility groups. After the handover is performed, the user can be disconnected from the network by selecting another SSID.

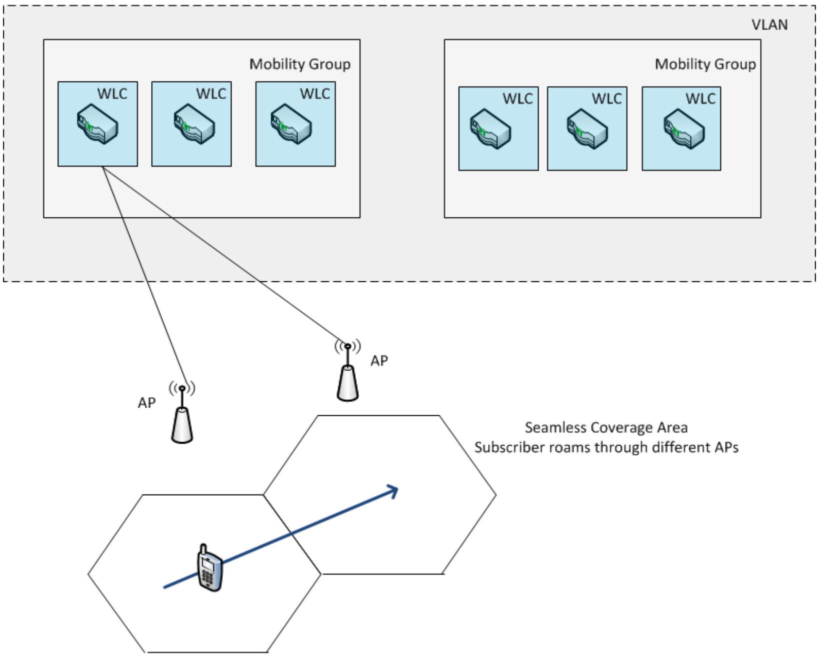


Figure 13: Mobile Scenario 1: Same WLC, Same MG

2.4.6.2 Scenario 2: Different WLC, Same MG

After the user is connected to a SSID, the aim of this scenario is to observe messaging between the device and the infrastructure when the user is moving from one access point to the next under the different network controller device under the same mobility group. After the handover is performed, the user can be disconnected from the network by selecting another SSID.

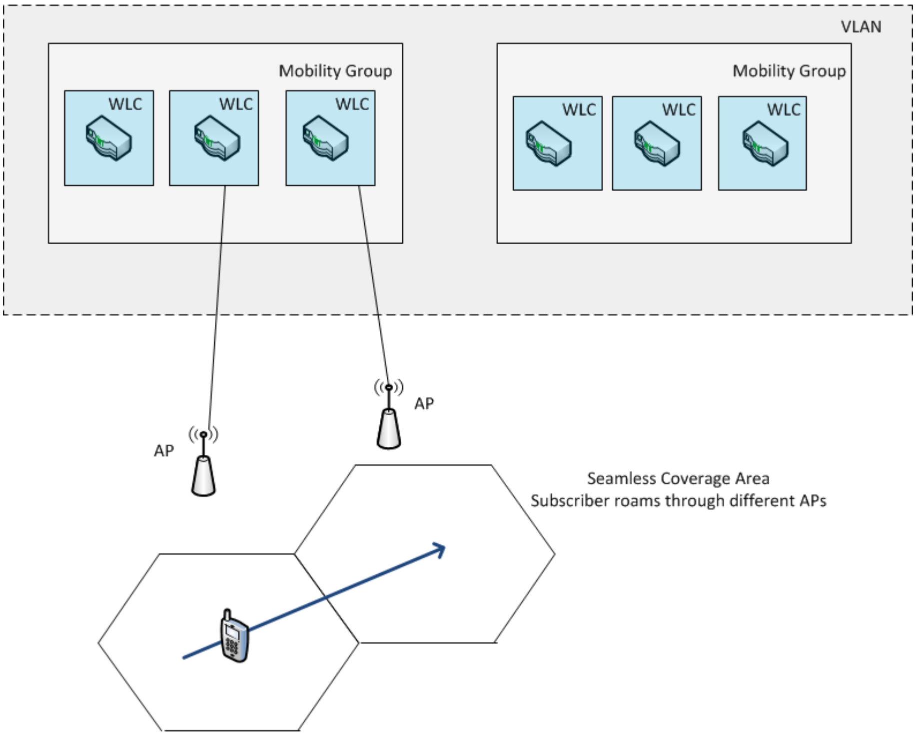


Figure 14: Mobile Scenario 2: Different WLC, same MG

2.4.6.3 *Scenario 3: Different WLC, Different MG*

After the user is connected to a SSID, the aim of this scenario is to observe messaging between the device and the infrastructure when the user is moving from one access point to the next under the different network controller device under a different mobility groups. After the handover is performed, the user can be disconnected from the network by selecting another SSID.

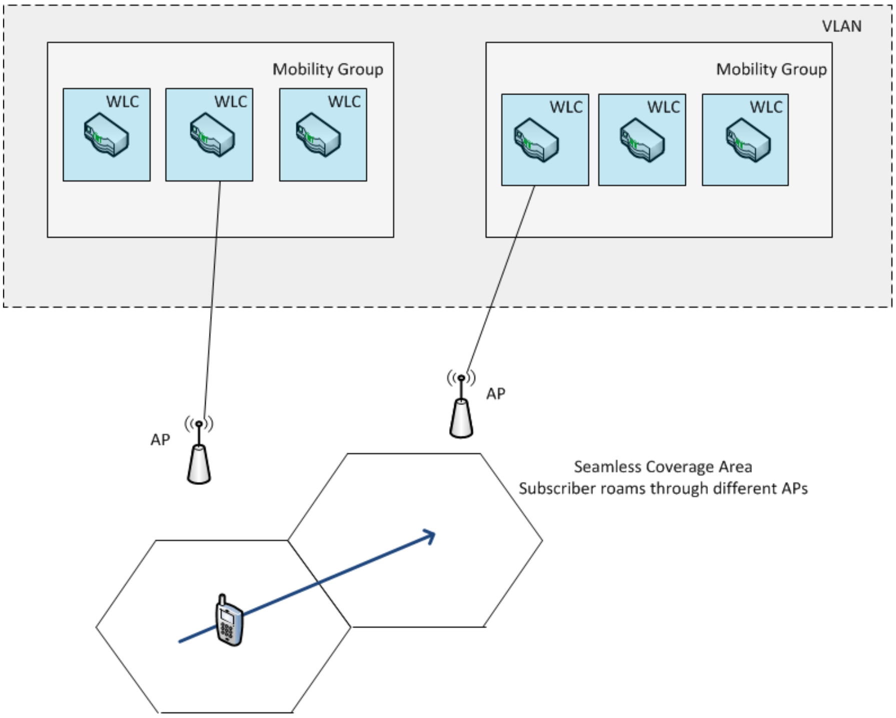


Figure 15: Mobile Scenario 3: Different WLC, Different MG

3 SPECIFICATION OF REQUIRED BUILDING BLOCKS FOR PROOF-OF-CONCEPT DEMONSTRATION

This section provides preliminary descriptions of the technologies used to build the PoC demonstrators. It specifies the required modifications to existing hardware and software along with addressing the integration methodology.

3.1 HW/SW Extensions to OpenAirInterface.org in Support of Relaying and D2D

3.1.1 Overview of OpenAirInterface.org Software

OpenAirInterface.org (OAI) is an open-source platform (GNU GPL v3) for experimentation in wireless systems primarily targeting cellular technologies (LTE/LTE-Advanced and beyond) and rapidly-deployable mesh/ad-hoc networks. It has been funded predominantly by collaborative projects under the 6th and 7th EU framework programmes and to a lesser extent by the French ANR programmes. The platform comprises both hardware and software components and can be used for simulation/emulation as well as real-time experimentation on both custom RF equipment and standard equipment from National Instruments/Ettus. It comprises the entire protocol stack from the physical to the networking layer starting from Rel-8 LTE. The current software can interoperate with commercial LTE terminals and can be interconnected with closed-source EPC (Enhanced Packet Core) solutions from third-parties (e.g. OpenEPC from Fraunhofer or the LTEBOX development from Alcatel-Lucent). The objective of this platform is to provide methods for protocol validation, performance evaluation and pre-deployment system test.

OAI is currently hosted and maintained by EURECOM. It will become a foundation (French Association) in the fall of 2014 and will seek funding from members, in the spirit of foundations offering support for open-source software such as OpenStack, APACHE and ANDROID. The current major industrial users of OAI for collaborative projects are Agilent, China Mobile, IBM, Alcatel-Lucent, Thales, and Orange. One of the main objectives is to provide an open-source reference implementation which follows the 3GPP standardization process starting from Rel-12 and the evolutionary path towards 5G.

OAI can be executed on standard x86-based RF platforms using either custom EURECOM hardware (see Section 3.1.2) or standard laboratory equipment from National Instruments/Ettus (USRP B200/B210/X300/X310). It has also been ported to some industrial platforms using commercial remote radio-head (RRH) equipment.

3.1.2 Extensions

3.1.2.1 eMBMS additions

OAI currently supports Rel-10 eMBMS transmission and reception. Small modifications in the scheduling entity to allow for decode-and-forward relaying would need to be configured in the D-eNB (specifically to allow overlay transmissions from the relays). This would be accomplished by configuring relays as both UE (to receive eMBMS transmission from the D-eNB) and eNBs themselves in order to jointly relay the eMBMS to their vicinity.

3.1.2.2 D2D additions

OAI currently does not support D2D. The adopted method to experiment with techniques proposed in the context of WP5 is to reuse the eMBMS waveform for D2D in the second hop. The primary link (eNB to UE) would be unicast Rel-8 transmission. D2D UEs would act as local caches for their vicinity and would use eMBMS transmission (multicast) to relay to nearby nodes either in a random-access fashion on the uplink carrier, or scheduled on the uplink carrier by the eNB. Both scheduling policies will be implemented and tested on the live network.

3.1.3 Experimental Testbed

In order to test the eMBMS collaborative relaying and D2D concepts, EURECOM is in the process of deploying a small-scale 4-5 node network at its premises which corresponds to the scenarios in Figures 3 and 4. The mock network comprises 1 primary eNB, 2 rapidly-deployable nodes configured either as eMBMS relays (Section 2.1.1 scenario) or D2D-enabled UEs (Section 2.1.2 scenario) and 1 or 2 terminals (UEs). Photographs of the equipment are shown in Figure 16. The relays and user terminals are embedded in vehicles in order to experiment with different locations for their deployment. All equipment is based on the ExpressMIMO2 SDR platform using either exclusively eMBMS carriers (Section 2.1.1 scenario) or both unicast and eMBMS carriers (Section 2.1.2 scenario). For more information regarding the platform specifications and RF hardware components, see [1]. The experiments can be carried out using any of the following configurations, and potentially a combination of two

- 5 MHz carrier LTE Band 33 (1.9 GHz TDD)
- 20 MHz carrier LTE Band 7 (2.6 GHz FDD)
- 20 MHz carrier LTE Bands 42,43 (3.5 GHz TDD)

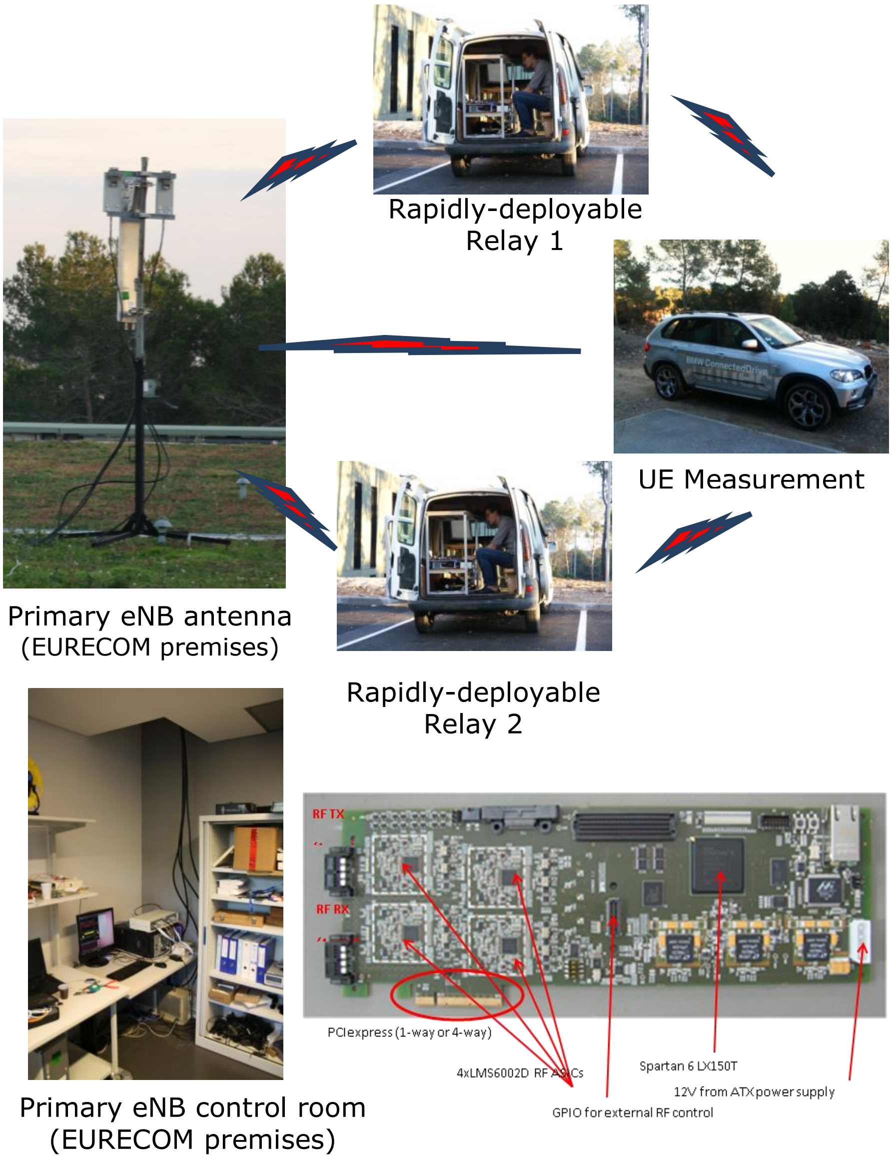


Figure 16 : Relaying and D2D Testbed Components

Both the eNB and relays are equipped with 1W high-linearity power amplifiers used in conjunction with ExpressMIMO2.

The map of the primary eNB's vicinity is shown in Figure 17 along with one option for relay deployment which is currently being tested to cover the area where service from the primary eNB is degraded (identified in the figure as a coverage hole.) The objective is to show the benefit of using the proposed relaying strategy for high-spectral efficiency coverage extension in these areas. Although not shown in Figure 16, there are other areas where relays can be deployed, in particular to cover a small commercial zone towards the northeast. In general, this experiment should be seen simply as a proof-of-concept of the relaying technique since in a true deployment, the location of the primary eNB would be more appropriately chosen, and more importantly, it would be elevated to a much higher level.

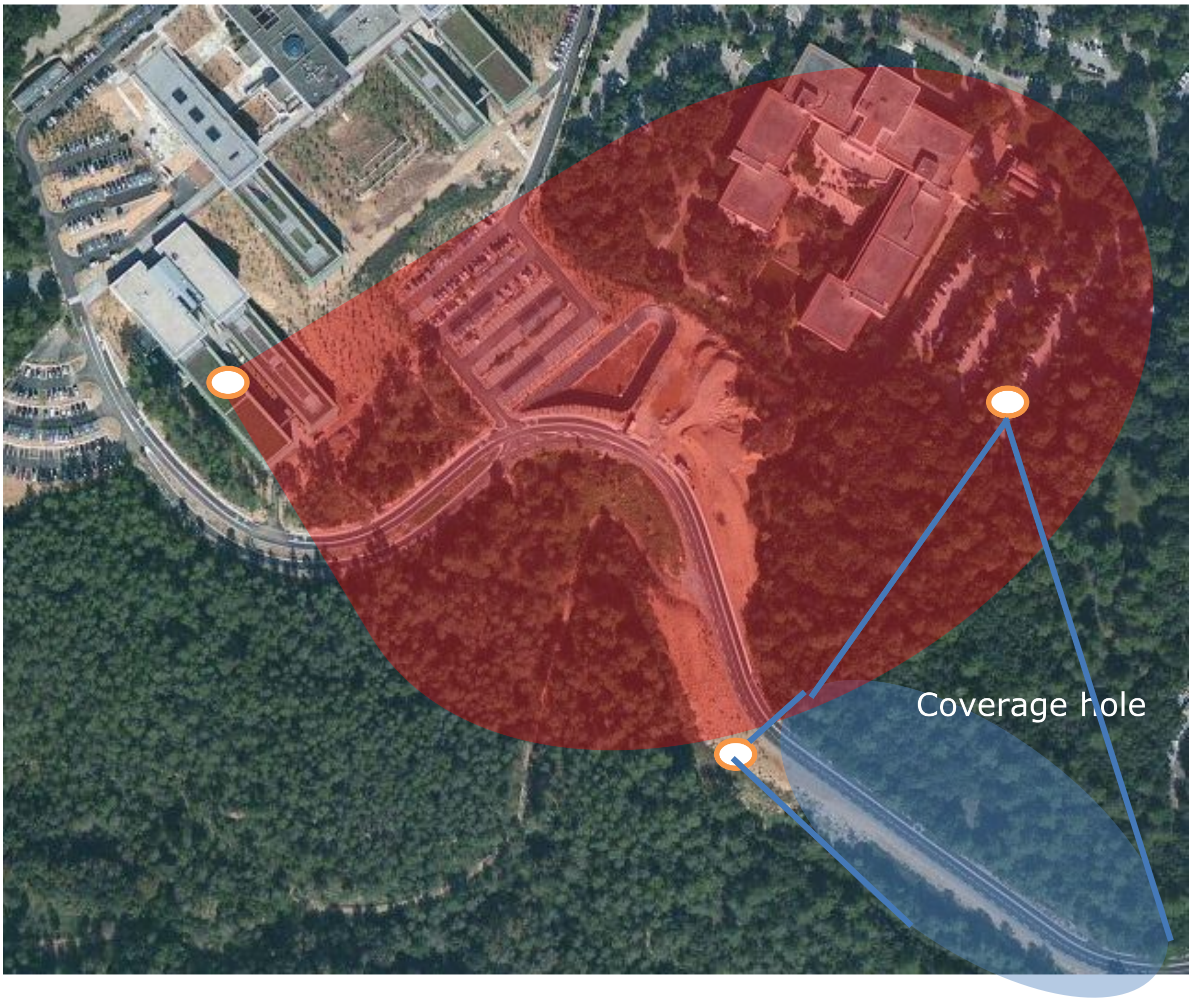


Figure 17: Relaying + D2D Testbed Deployment Area

3.2 HW/SW Developments for CoMP

The purpose of this PoC is to understand the architecture and the potential limitations the proposed CoMP implementation will face. This demonstrator will therefore focus on scenario use-case 2, MU-MIMO CoMP, to implement and evaluate in terms of both complexity and performance the muti-user MIMO interference cancellation scheme at the mobile side.

A real-time hardware in the loop demonstrator will validate the CoMP concept, combining multi-user MIMO at the base stations with an interference cancellation scheme at the mobile side. The main objective will be to evaluate implementation of these innovative algorithms on the mobile side, while base station signals will be generated by simulation tools. Criteria for evaluation include hardware performance and implementation complexity.

The main architecture of the CoMP PoC will be composed of two elements connected by a fast data link (type ethernet as shown in Figure 18):

- A Personal Computer: to emulate the enodeB and the channel model considered by the scenarios of the PoC
- An FPGA/ARM based FPGA platform: to emulate the baseband hardware of the user equipment

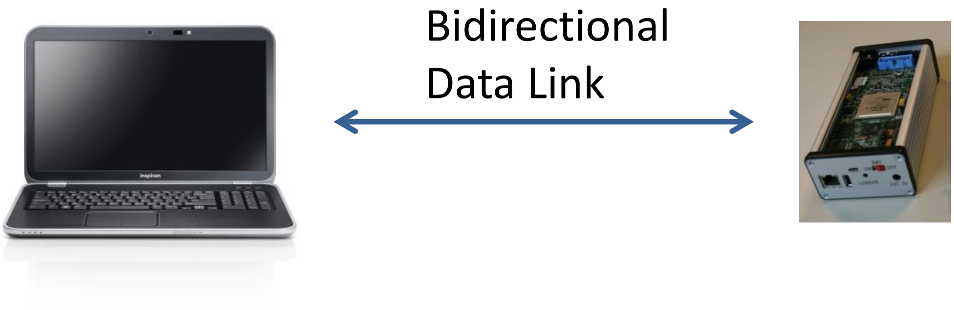


Figure 18 Hardware elements considered for MU-MIMO CoMP

The hardware platform used to implement the user equipment side of the PoC is based on a Kintex-7 Xilinx FPGA build on a dedicated baseband board. Its main components are a Kintex7-325T Xilinx FPGA, a Cortex-A8 ARM microprocessor associated with a TMS320C64 DSP in DM3730 component, with many interfaces possibilities.

The main components of the Baseband board are:

- 1 FPGA Xilinx XC7K325T-1FFG676C (326080 Logic cells / 840 DSP (25x18 multiplier) / 445 Blocks RAM 36Kb)
- 1 ARM microcontroller DM3730CBP100 (cortex A-8 at 1GHz + DSP TMS320C64x)
- 1 package on package memory module MT29C4G48MAZAPAKQ-5 IT (= 4 Gbits Nand Flash + 2 Gbits LPDDR SDRAM)
- 1 TPS65950 integrated power management (DC/DC converters, battery charger, USB OTG interface, audio CODEC…)
- 2 dual ADC AD9643 14 bits / 250 MHz
- 1 quad DAC AD9148 16 bits / 1 GHz (with 3 interpolators, NCO and integrated digital mixer)
- 1 microSD card (compact flash) for ARM programming
- External interfaces:
    - 2 Samtec QSE-020 connectors for daughter board plug-in
    - 2 Picoblade Connectors (12 pins) towards a black/white camera and a color camera
    - 1 miniHDMI Connector (19 pins) towards an infrared camera
    - 1 USB interface High-speed OTG
    - 1 Ethernet interface 10/100 Mbps
    - 1 dual RS232 Transceiver MAX3380E
    - 1 WLAN 802.11 Bluetooth interface using a TiWi-R2 module
    - 2 Jack Audio connectors connected to the onboard audio CODEC (TPS65950)
    - 1 Samtec SFMC-117 connector for interface to a LeopardBoard (camera)

- ○ 1 HDMI connector connected to the onboard graphics controller TFP410 (video HD output)

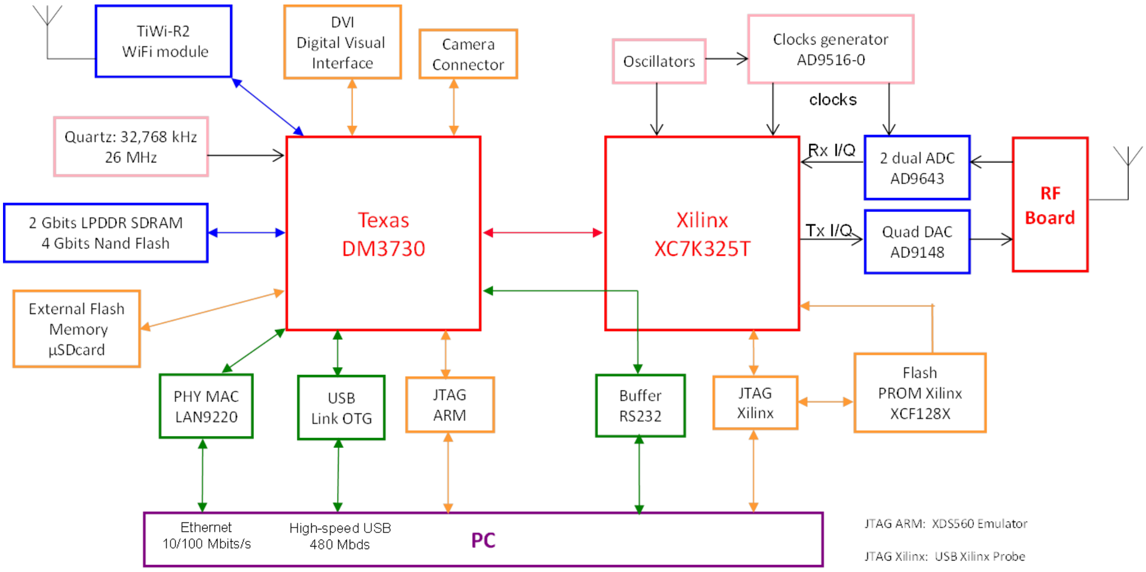


Figure 19 CoMP Main baseband board architecture

The baseband computing engine for the CoMP demonstrator is depicted in Figure 19 and Figure **20**.

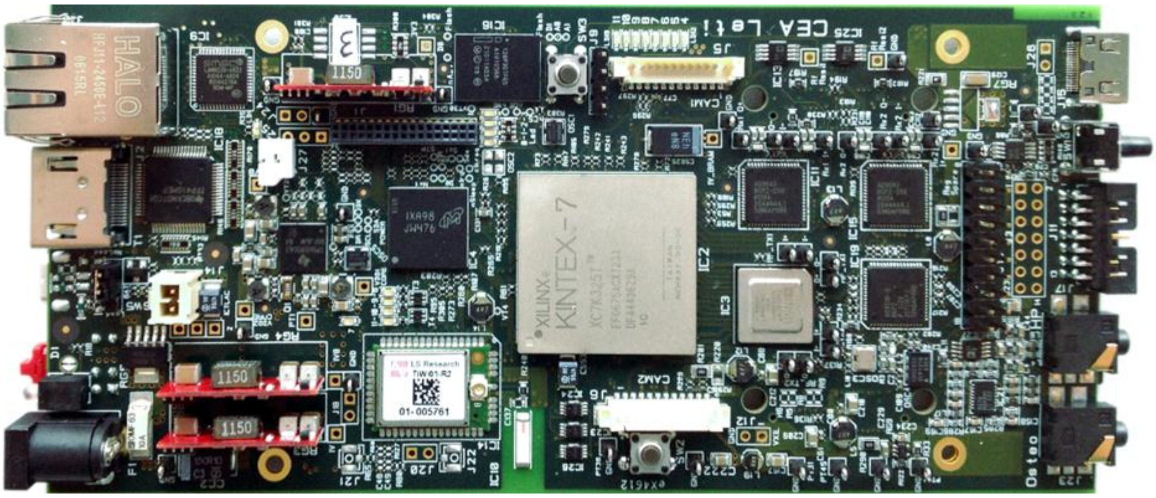


Figure 20 Main baseband board considered for the CoMP PoC

Data transfer between the Personal Computer emulating the eNB and the channel will be done using one of the possible network interface (Ethernet, USB or WiFi). The dataflow illustrated in Figure 21will be considered for the PoC.

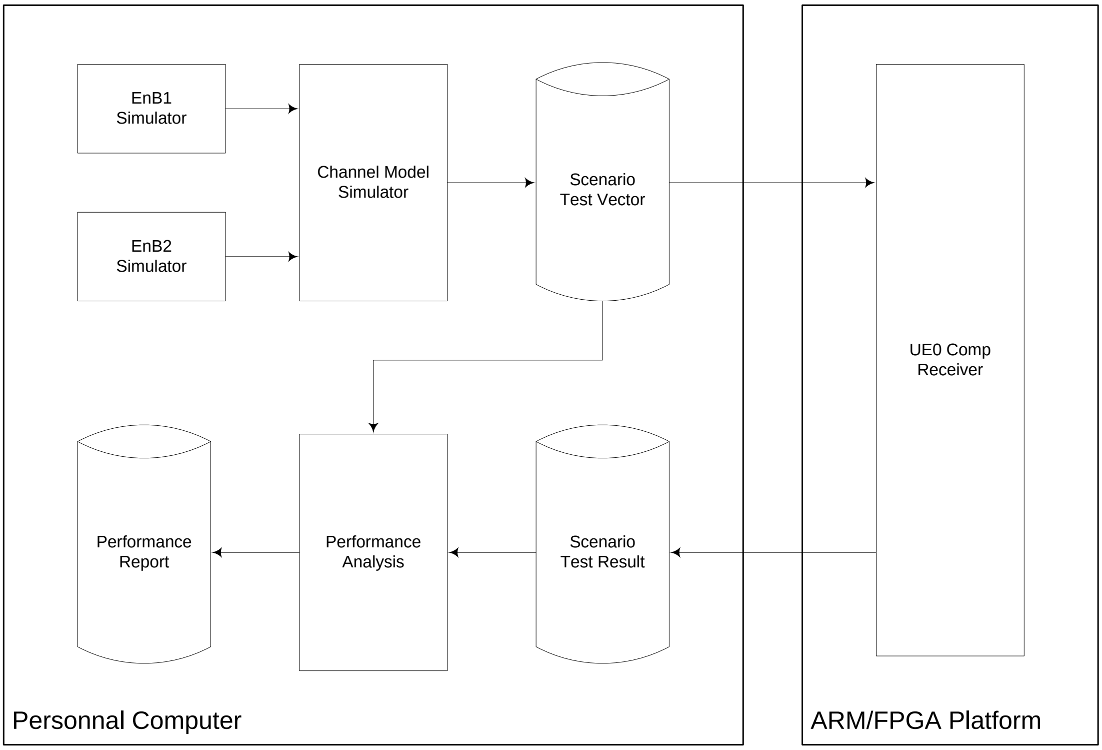


Figure 21 Proposed CoMP PoC dataflow

A list of CoMP scenarios for which the hardware implementation of the receiver algorithm should be tested will be proposed.

For every considered scenario, a test vector will be generated by the Personal Computer and stored into a file. The file will then be transfered to the ARM/FPGA platform and sent to the FPGA emulating the baseband algorithms under evaluation. Once processed, the results will then be forwarded to the Personal Computer via the network interface of the baseband ARM/FPGA board. Results will be analyzed and performance will finally be reported using key performance indicators validating the tested algorithm. This could include BER or PER parameters.

3.3 Reconfigurable RF development for Carrier Aggregation

The scope of this PoC demonstrator is focused on the transmitter of a femto cell BS supporting intra-band CA and inter-band CA, adding some reconfigurability features to the HPA in order to provide energy savings. Due to lab equipment constraints, the demonstrator will be limited to a maximum of three CCs instead of five CCs (see Figure 22).

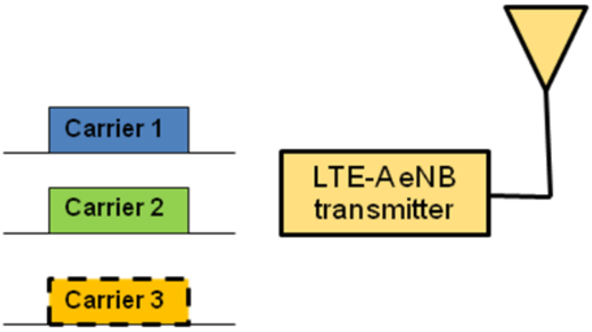


Figure 22: Scope of the PoC demonstrator on CA

As it was previously mentioned, LTE band 7 has been selected to implement intra-band CA for experimental validation, and LTE band 7 and LTE band 20 to implement inter-band CA. Figure 23 presents some possible CA configurations that will be probed based on the exposed premises.

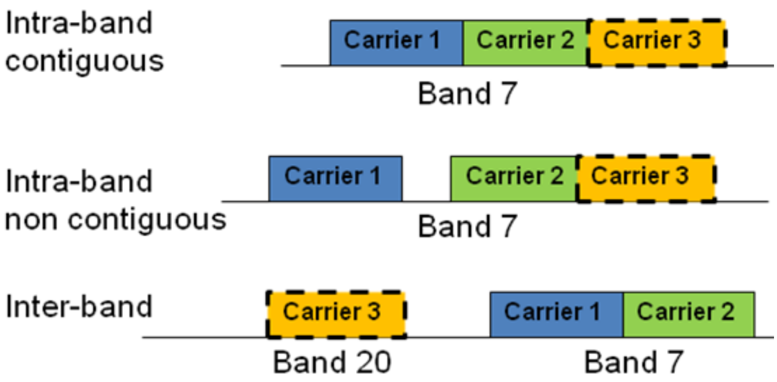


Figure 23: Possible CA configurations for PoC demonstration

3GPP standard has proposed different TX architectures to implement CA [3]. Figure 24 presents an architecture which supports intra-band contiguous and non-contiguous CA. For a femto cell, a unique RF PA is very likely to work with a combination of various CCs. In this architecture, the PA is not optimized according to the number of CCs which will be the target of the study.

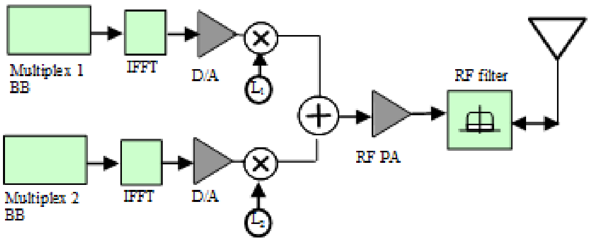


Figure 24: TX architecture for intra-band contiguous and noncontiguous CA

Figure 25 shows an architecture to support intra-band CA and inter-band CA. In this architecture, a different PA is defined for each frequency band. In general wideband PAs present worse characteristics than narrowband PAs, especially when output power level increases. Therefore a dedicated PA is usually implemented for each frequency band.

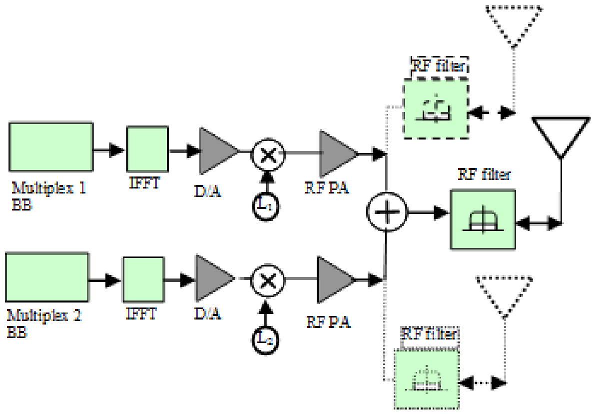


Figure 25: TX architecture for intra-band contiguous and non contiguous CA and inter-band CA

The proposed reconfigurable TX architecture in Figure 26 combines previous architectures adding some features such as reconfigurability in PA according to the number of CCs, and ON/OFF feature to deactivate the inter-band CA PA when it is not required (intra-band case).

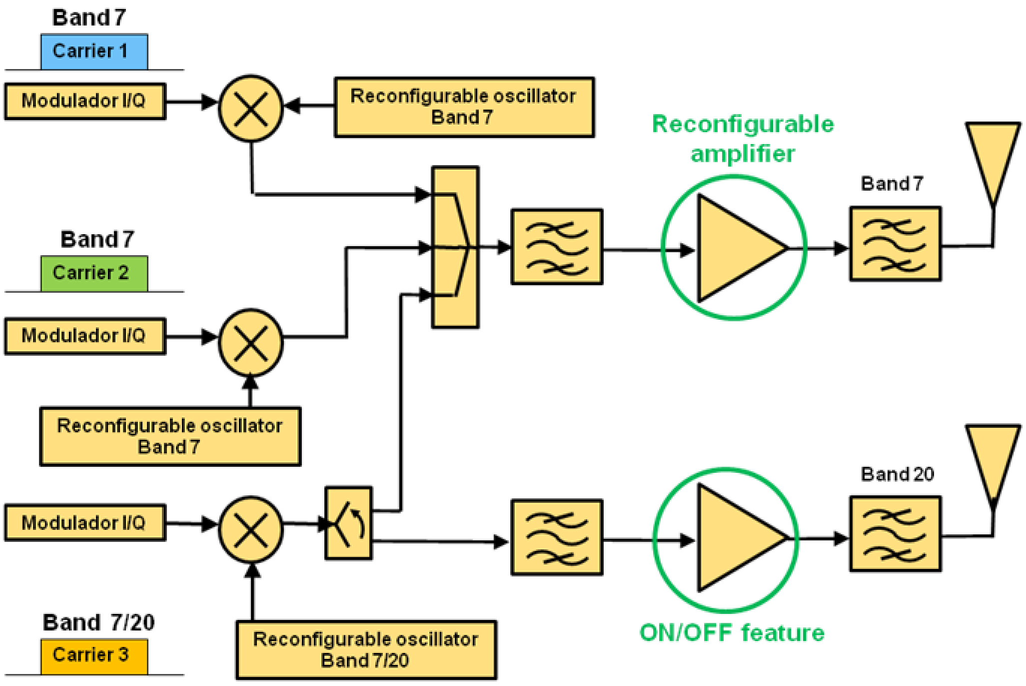


Figure 26: Proposed reconfigurable TX architecture for CA

The PoC demonstrator will test up to three CCs. For intra-band CA, a reconfigurable amplifier will work in band 7, adapting its characteristics concerning the number of CCs. Furthermore, depending on intra-band contiguous or intra-band non-contiguous CA mode different intermodulation performances will be analysed. The purpose of the reconfigurable amplifier will be to fit all these different configurations.

Additionally, the demonstrator will also operate in inter-band CA using another PA for band 20, being able to turn it off when inter-band CA mode is not selected. The transition times to perform ON/OFF feature will be analysed as well.

Antenna

In order to be compatible with all the possible CA configurations, the antenna structure should cover the whole band 7 and one channel (Tx+Rx) of the band 20 simultaneously. It should also cover the whole band 20 non simultaneously. Band 7 and band 20 will have two different RF interfaces, therefore, a two ports antenna strucutre is required. This allows the design of disctinct radiating structures whose co-integration in a compact volume will be demonstrated.

For antenna miniaturisation purpose, it has been decided to design a frequency agile antenna for the band 20 and a non agile antenna for the band 7. Agility allows miniturization for the band 20 antenna (narrow instantaneous bandwidth) whereas the band 7 antenna won't be miniaturized. Because of their respective working wavelength (band 20 : λ=379mm ; band 7 λ=120mm), the size of the band 20 antenna would be around 3 times the size of the band 7 antenna if no miniturization work is done for the band 20 antenna. Antenna miniaturisation effort is done at low frequency (band 20) in acordance with narrow instantaneous bandwidth.

The FEMTO Cell BS antennae wil be designed inside a maximum volume of 100 x 100 x 30 mm^3.

The two antennae should have a radiation pattern with the maximum radiation towards the normal direction of the larger section (100 x 100 mm^2) in the upper hemisphere (Z^+). Linear polarisation is firstly investigated during feasability phasis. A -10dB impedance bandwidth (reference impedance 50Ω) has been chosen as a requirement for both band 7 and band 20.

Band 7 antenna

A classical solution for this antenna is to design a Patch antenna. The resonant dimensions of such an antenna are about λ/2 which fits within the allowed volume with a relatively low profile. Patch antennae have a radiation pattern that fulfill the requirements (maximum gain towards the normal direction of the ground plane).

A patch has been designed (figure 7) so that it covers the whole band 7 with a -10dB impedance bandwidth (figure 8).

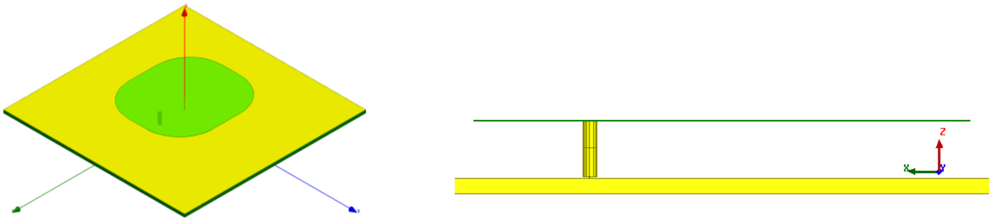


Figure 27 : 3D views of the patch antenna

The patch is 51.5*46mm² and is 6mm above the PCB.

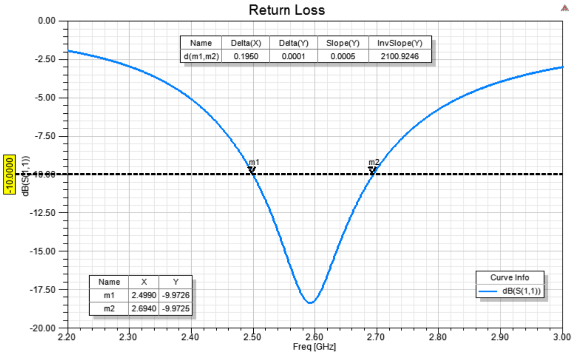


Figure 28 : Return loss of the patch antenna between 2.2 and 3 GHz

The Simulation shows a directional radiation pattern with maximum gain of 8.9dBi towards the Z^+ direction (figure 9).

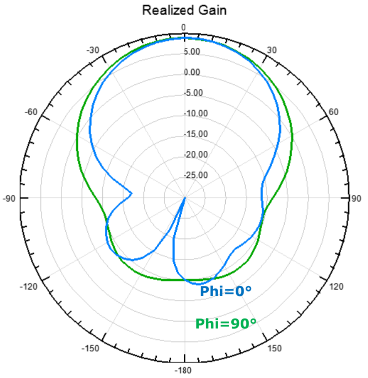


Figure 29 : Realized gain (dB)

Band 20 antenna

A T-slotted Planar Inverted F Antenna (PIFA) has been studied (figure 10) for the design of compact dual narrow band antenna. This antenna covers with a -10dB impedance matching bandwidth simultaneoulsly two narrow bands of almost 10MHz (figure 11) which correspond to the Tx and the Rx sub-channel of the same band 20 channel. The two narrow bands configuration is used to obtain compact antenna dimensions. A solution to shift the two narrow bands in accordance with used channel has been tested by simulation. The frequency agile solution allows to switch from one channel to another and thus to cover the whole band 20 without enlarging the antenna strucutre to widen the operating band. The agility is brought through two tunable capacitors placed inside the T-slot. They are placed so that each frequency can be controled independently (fine tuning of each frequency possible). Also, their location within the slot controls the frequency shift sensibility and windows. It is planned to use Digital Tunable Capacitors (DTC).

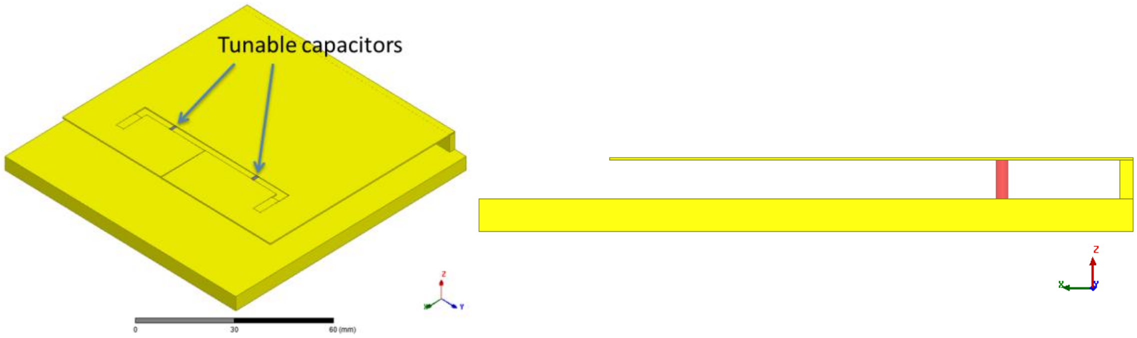
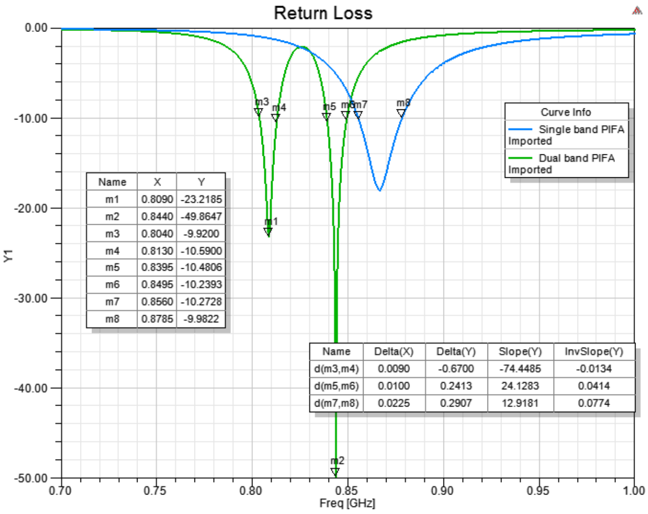


Figure 30 : 3D views of the T-slotted PIFA

The PIFA roof is 90.5*80mm² and is 6mm above the PCB.



Name	X	Y
m1	0.8090	-23.2185
m2	0.8440	-49.8647
m3	0.8040	-9.9200
m4	0.8130	-10.5900
m5	0.8395	-10.4806
m6	0.8495	-10.2393
m7	0.8560	-10.2728
m8	0.8785	-9.9822

Name	Delta(X)	Delta(Y)	Slope(Y)	InvSlope(Y)
d(m3,m4)	0.0090	-0.6700	-74.4485	-0.0134
d(m5,m6)	0.0100	0.2413	24.1283	0.0414
d(m7,m8)	0.0225	0.2907	12.9181	0.0774

Figure 31 : Return loss of the T-slotted PIFA and a simple PIFA between 0.7 and 1 GHz

For the same volume, a single band non agile PIFA antenna would only cover a 22,5MHz Bandwidth while the proposed frequency agile antenna will cover a 81MHz band (figure 11).

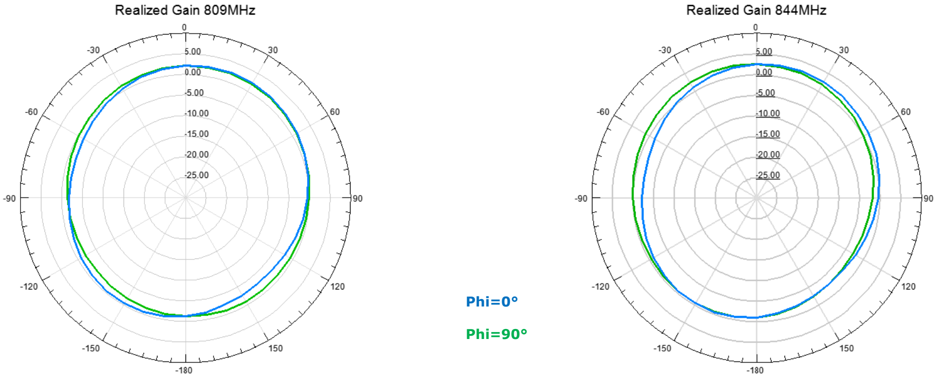


Figure 32 : Realized gain (dB)

The Simulation shows a directional radiation with maximum gain of 2.8dBi in the upper hemisphere (figure 12) close to the Z^+ axis.

Combined antenna solution

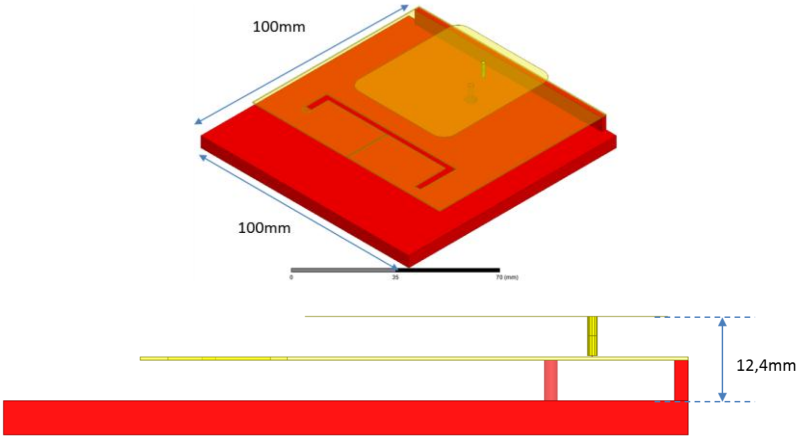


Figure 33 : 3D views of the combined solution

Specific investigations has been done to combine the two antenna solutions together over the same ground plane. To avoid a high coupling between the two antenna ports, the patch has been placed on top of the PIFA away from the PIFA roof slot (figure 13). With this optimized configuration a maximum coupling of -15dB has been reached (figure 14), which seems acceptable for the front end module. Also, with this configuration, both antenna keep their respective caracteristics (impedance, radiation...) though a frequency tuning has been necessary.

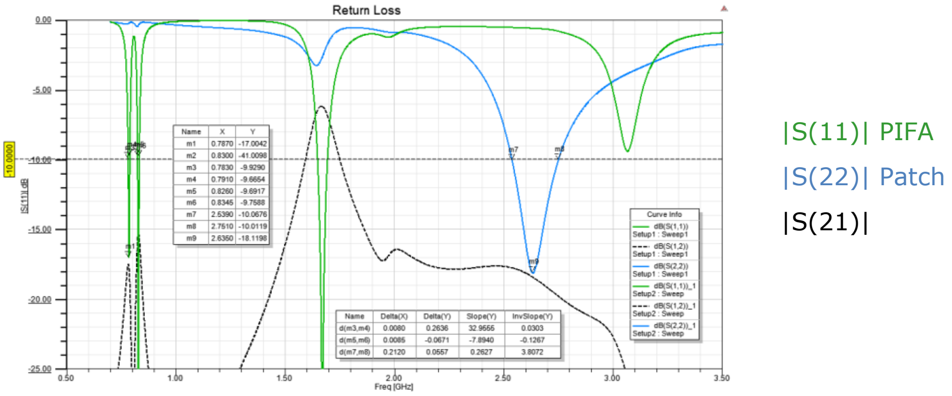


Figure 34 : Return loss of the combined solution

3.4 Multi-RAT Testbed Development

Some of the key requirements of Wi-Fi offload testbed development solutions are described in the following subsections.

3.4.1 Some of the Actors and their roles

Core Network (CN): The core network architecture of UMTS is deployed on top of the GPRS architecture. There are two different domains: i) the Circuit Switching (CS) domain and ii) Packet Switching (PS) domain. Circuit switching is composed of the Mobile Switching Center (MSC), the Visitor Locator Register (VLR) and the gateway MSC. Regarding packet switching, it offers backwards compatibility with GPRS; it is composed of the Serving GPRS Support Node (SGSN) and the Gateway GPRS Support Node (GGSN).

User Equipment (UE): The UE is the mobile radio terminal used by the subscriber to access the UTRAN. This can be a mobile phone, a Personal Digital Assistant (PDA) or any type of radio communication device. The UE is connected to the node B (BS), and it is usually identified by the Subscriber Identity Module (SIM).

Node B: It provides communication to the radio cells. Node B is the radio transceiver unit, and it connects the UE via Wide-band Code Division Multiple Access (WCDMA); the node B also provides TDD and FDD.

UMTS Terrestrial Radio Access Network (UTRAN): It is composed of the Node B and by the Radio Network Controller (RNC). UTRAN manages the access to the radio mobility and resource allocation. The RNC builds the logical connection between the User Equipment (UE) and the CN. UTRAN uses internal and external interfaces in order to connect the different infrastructure and user-terminal elements, namely the so-called Uu, Iub and Iur links.

The PCRF is the part of the network architecture that aggregates information to and from the network, operational support systems, and other sources (such as portals) in real time, supporting the creation of rules and then automatically making policy decisions for each subscriber active on the network. Such a network might offer multiple services, QoS and QoE levels, and charging rules. PCRF can provide a network agnostic solution (wire line and wireless) and can also enable multi-dimensional approach which helps in creating a lucrative and innovative platform for operators. PCRF can also be integrated with different platforms like billing, rating, charging, and subscriber database or can also be deployed as a standalone entity.

Media Independent Information Service (MIIS) Server provides the discovery and distribution of network information within a geographic area. Also, an MIIS server needs to control WAG and GGSN so that access network availability for each user will be efficiently handled.

WAG provides tight and loose coupling architecture for heterogeneous networks as it connects AR (Access Router) with GGSN. It provides security tunnel between the UE and the gateway that supports the Internet Key Exchange version 2 (IKEv2) protocol for negotiating inside the Wi-Fi infrastructure. Tunnel encapsulation and decapsulation, route selection and forwarding, PDP context action and deactivation and obtaining a subscribers's static IP address from 3GPP AAA server are some of its functionalities.

RADIUS Server provides support for EAP-SIM/AKA authentication base on the authentication data from HLR. It can also support functionalities for terminate session of WLAN UEs, provide attach status, of WLAN UEs, and support getting subscriber authentication data and subscription data from HLR.

3.4.2 Key requirements for Wi-Fi Offload TestBed Development

3.4.2.1 Tight coupling between the existing 3G/WiFi EPC Core

The main requirement is tight coupling of cellular and WiFi access networks with single core. The illustration in Figure 35 suggests that WLAN technology is employed as a new radio access technology within the cellular system. In this architecture testbed, regardless of the access technology, there would only be one common cellular core network [5]. All the functionalities such as seamless authentication of subscribers to Wi-Fi hotspots and smart offloading between cellular core network and Wi-Fi hotspots are achieved with minimal interruption from the users.
Tight-coupling needs to be implemented in between core network and WiFi RAN along with a PCEF node support for GGSN.

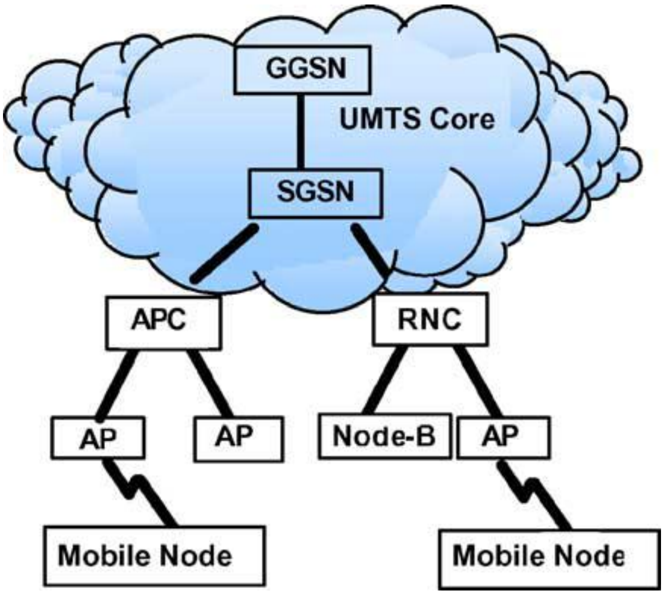


Figure 35- Tight Coupling

3.4.2.2 *Seamless authentication of users with EAP-SIM supported devices*

Authentication of users by SIM data with EAP-SIM supported devices is another requirement for testbed- developments. EAP-based authentication uses EAP and IEEE 802.1x to provide Layer 2 authentication for subscribers accessing the network with EAP-capable devices. For actual authentication, multiple credentials can be used, depending on the capability of the device.

Devices with SIM cards encapsulate the SIM application information exchange into the EAP message, and these are proxied by the AAA server to the home-location register (HLR) for authentication.

EAP-SIM (RFC 4186) or EAP-Authentication and Key Agreement (EAP-AKA; RFC 4187) standards are used for the encapsulation, depending on the type of SIM card used and the HLR capabilities. Obviously, this method requires interconnection between the AAA server and the HLR or home-subscriber server (HSS) [4]. Figure 36 shows a regular EAP call flow.

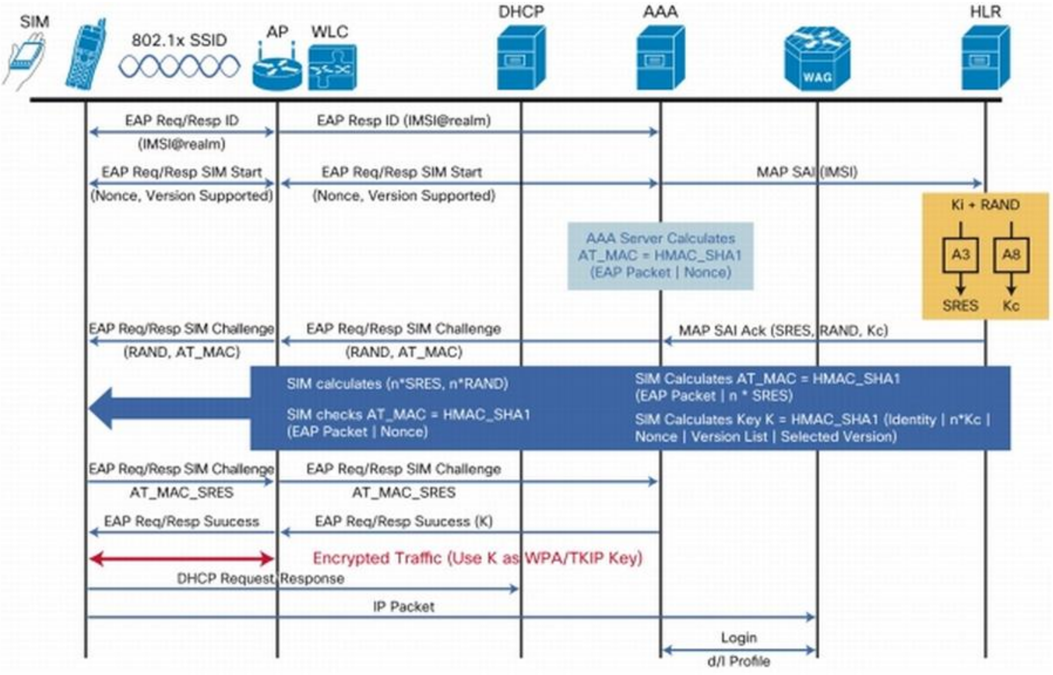


Figure 36 - EAP Call Flow [5]

3.4.2.3 *Wi-Fi offloading software installed on devices*

The software installed on user device will ensure that in mobile scenarios where there are multiple handovers of a user, handling IP mobility for each change of attachment can be performed accordingly.

3.4.3 Test Environment and Topology

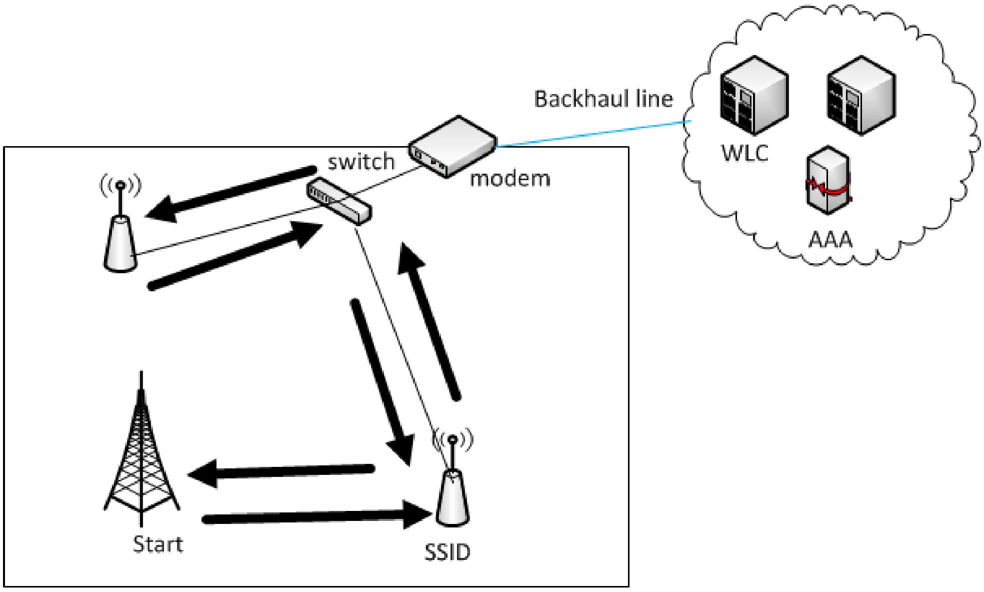


Figure 37: The setup of access points and the plan of the test environment and its connection to center system

In Figure 37, in the topology for test environment, by performing an inter-Radio Access Technology (RAT) handover, a user is detached from its serving 3G NodeB and it becomes associated to a Wi-Fi AP. The user is roaming through different networks seamlessly, i.e. without losing its active connections so that in the case of connection to a network with different wireless access technology, the soft handover is realized.

Furthermore, the mobile node roams through the different intra networks without losing its active connections, i.e. seamless, so that soft hand-over is realized also in the case of association to a network with a different wireless access technology.

4 CONCLUSION

This document aimed to set the scene for the work in WP7 which entails selection target scenarios and implementation of proof-of-concept (PoC) platforms to highlight major innovations in the SHARING project.

We described the concrete use-case scenarios that are currently considered for experimental validation. The specific networking topologies (i.e. number and nature of nodes) are described along with the concepts (e.g. distributed MIMO, agile RF, joint RRM, etc.). The performance evaluation methodology to be used during experimentation is detailed. The primary scenarios at this point are

- eMBMS relays for coverage extension of eMBMS multicast-broadcast services (WP5)
- Device-to-device (D2D) communications for content delivery reusing uplink resources
- Cooperative Multipoing (CoMP) transmission coupled with interference rejection in User Equipment (UE) and Multiuser-MIMO (MU-MIMO)
- Advanced RF architectures in support of Carrier Aggregation (CA)
- WIFI Offloading

We also provided preliminary descriptions of the technologies used to build the PoC demonstrators. We specified the required modifications to existing hardware and software along with addressing the integration methodology.

5 List of Abbreviations, Acronyms, and Definitions

3G	Third Generation
3GPP	Third Generation Partnership Program
AAA	Authentication, Authorization, and Accounting
AKA	Authentication and Key Agreement
AP	Access Point
BER	Bit-Error Rate
BS	Base station
CA	Carrier aggregation
CAPEX	Capital Expenditure
CC	Component carrier
CN	Core Network
CoMP	Cooperative Multipoint
CS	Circuit Switching
D2D	Device-to-device
EAP-SIM	Extensible Authentication Protocol for GSM Subscriber Identity Module
eMBMS	Enhanced Multimedia Broadcast Multicast Service
eNB	Enhanced Node B
EPC	Enhanced Packet Core
FDD	Frequency Division Duplex
FPGA	Field Programmable Gate Array
GGSN	GPRS Gateway Support Node
GPL	GNU Public License
GPRS	General Packet Radio Service
HLR	Home Location Register
HPA	High Power Amplifier
HSPA	High Speed Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol
LTE	Long-term Evolution

MBSFN	Multicast Broadcast Single-Frequency Network
MCS	Modulation and Coding Set
MG	Mobility Group
MIIS	Media Independent Information Service
MIMO	Multiple-Input Multiple-Output
MSC	Mobile Switching Center
MU-MIMO	Multiuser Multiple-Input Multiple-Output
OPEX	Operational Expenditure
PA	Power amplifier
PCEF	Policy and Charging Enforcement Function
PCRF	Policy and Charging Rule Function
PDA	Portable Digital Assistant
PDP	Packet Data Protocol
PER	Packet error rate
PoC	Proof of Concept
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio frequency
RNC	Radio Network Controller
RRM	Radio Resource Management
SGSN	Serving GPRS Support Node
SIM	Subscriber Identity Module
SSID	Service Set Identification
TDD	Time Division Duplex
TM5	Transmission Mode 5
TTNET	Turk Telecom Network
TX	Transmitter
UE	User Equipment
UMTS	Universal Mobile Telecommunication System
USRP	Universal Software Radio Peripheral

UTRAN	UMTS Terrestrial Radio Access Network
VLAN	Virtual Local Area Network
VLR	Visitor Location Register
WAG	Wireless Application Gateway
WCDMA	Wideband Code Division Multiple-Access
WLAN	Wireless Local Area Network
WLC	Wireless Local Area Network Controller

6 References

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