

Specific Targeted Research Projects

SOLDER

Spectrum OverLay through aggregation
of heterogeneous DispERsed Bands

FP7 Contract Number: 619687



WP2 – Application Scenarios, Use Cases and Requirements

D2.2

Component-level requirements for scenarios and use cases

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Abstract

Workpackage (WP) 2 deals with the use cases, scenarios, and requirements of the SOLDER project. The first deliverable in this WP, D2.1, gave an overview of the state-of-the-art of aggregation technologies in wireless communication technologies as well as an initial definition of the application scenarios and use cases considered in the SOLDER project. In this deliverable, D2.2, we review all the scenarios and for each scenario describe the high-level architecture of the proposed solution identifying functional components and their interfaces. We further specify the requirements of the different components and their interfaces. There will be a final deliverable, D2.3, that will focus on the system-level requirements with the overall SOLDER system protocol and functionality architecture.

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Executive Summary

Spectrum for wireless communication is scarce and fragmented, and the rules for its use are very heterogeneous. Most of the spectrum is licensed to a specific operator or service, for example for cellular communication systems like GSM, UMTS and LTE. There is also unlicensed spectrum, most notably the industrial, scientifically and medical (ISM) bands, which are open to all users and all services as long as some “fair use” is guaranteed and technical constraints such as a maximum transmission power are adhered to. Recently, there has also been a strong interest in the use of TV white spaces (TVWS) for mobile communication. These refer to channels within TV bands that are locally unused, typically due to the switching of TV broadcast from analogue to digital. Some countries, most notably the United States and the United Kingdom have made use of TVWS “license-exempt”, as long as the devices are certified as communicating directly with a geolocation database, implementing the channel/power usage instructions sent from the geolocation database, take into account security considerations, and comply with requirements such as achieving their stated or given spectrum mask, among others.

Future, data-hungry mobile communication systems will need to make use of all possible parts of the spectrum – relying on only one frequency band will not be an optimal solution. For example, a terminal connected to a licensed LTE network may experience network congestion, while other parts of the spectrum are temporarily underutilized. Switching completely to another band and/or radio technology might only provide a short-lived remedy, until the primary user claims back its spectrum. Therefore, aggregation of multiple bands and radio access technologies is of high importance.

The main objective of SOLDER is to develop tools and methods for the aggregation of such heterogeneous bands. This report follows up on D2.1, where we have described the state of the art and the different scenarios considered in the SOLDER project. In this report, we specify for each scenario the high-level architecture of the proposed solution, identifying functional components and their interfaces. We further specify the requirements of the different components and their interfaces.

In summary, there are 9 scenarios. All of the scenarios have in common that they use LTE as a state-of-the-art baseline technology as the main vehicle of carrier aggregation technology. The first three scenarios focus on traditional carrier aggregation as defined by 3GPP LTE Release 10 in homogeneous and heterogeneous networks as well as in the case where spectrum of multiple operators can be aggregated. In these scenarios, we are planning to develop PHY/MAC and RRM functions and algorithms (within WP3) as well as to demonstrate the proof-of-concept (within WP4). The next three scenarios focus on the aggregation of LTE in licensed spectrum with a carrier in either unlicensed spectrum or TVWS. The main idea is to use one carrier as an anchor point to the system for control information and basic services while another (opportunistic) carrier could be used for broadband, delay tolerant services. The aggregation of licensed LTE spectrum with LTE in unlicensed spectrum has recently also gained attention within 3GPP, where a study item called LTE-U is being prepared for release 13. In SOLDER we are planning to produce simulation studies as well as a proof-of-concept for these scenarios.

Last but not least, we consider a scenario of a 5G communication system employing a new waveform, called filter bank multi carrier (FBMC). This new waveform has the advantage of lower peak-to-average power ratio (PAPR) as well as adjacent carrier leakage (ACLR). Further it does not have as stringent requirements on synchronization as OFDMA used in LTE. We also study the possible aggregation of this new 5G carrier with existing LTE and HSPA carriers, as a multi-RAT CA scenario, through simulation as well as through proof-of-concept.

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1. Introduction

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2. LTE (Licensed) + LTE (Licensed) – Homogeneous deployment

This scenario addresses the “regular” carrier aggregation case as the most likely scenario to be deployed by network operator and opened for commercial operation. In order to motivate the choice of such scenario, let’s first have a look on the spectrum available for main operators in the US. Indeed, the US is one country with a highly developed LTE network (together with Japan or Korea; European countries are quite late with respect to 4G deployment). The following figures are extracted from [1] and depict in a coloured manner the width of the spectrum each operator own for LTE, on a per band basis. This is for downlink direction.

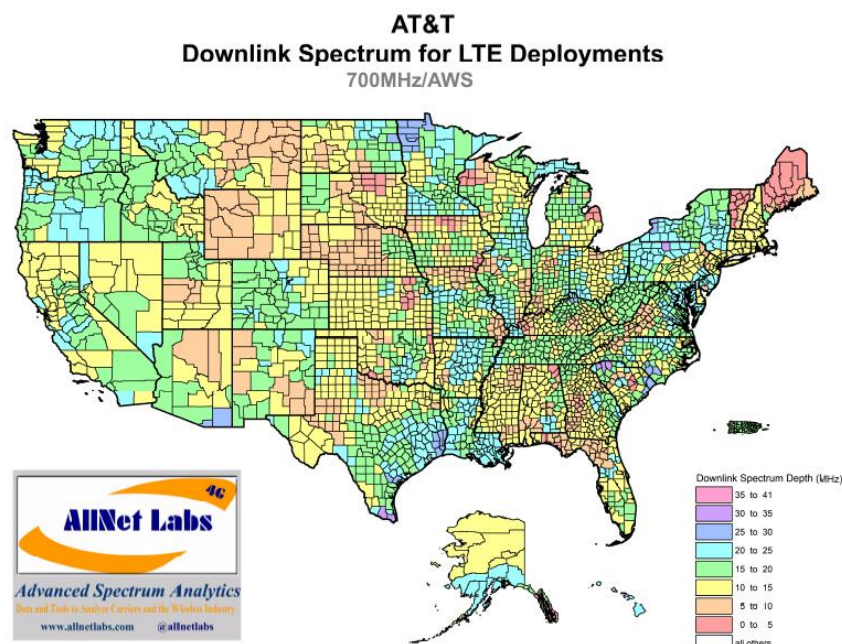


Figure 1 : AT&T spectrum

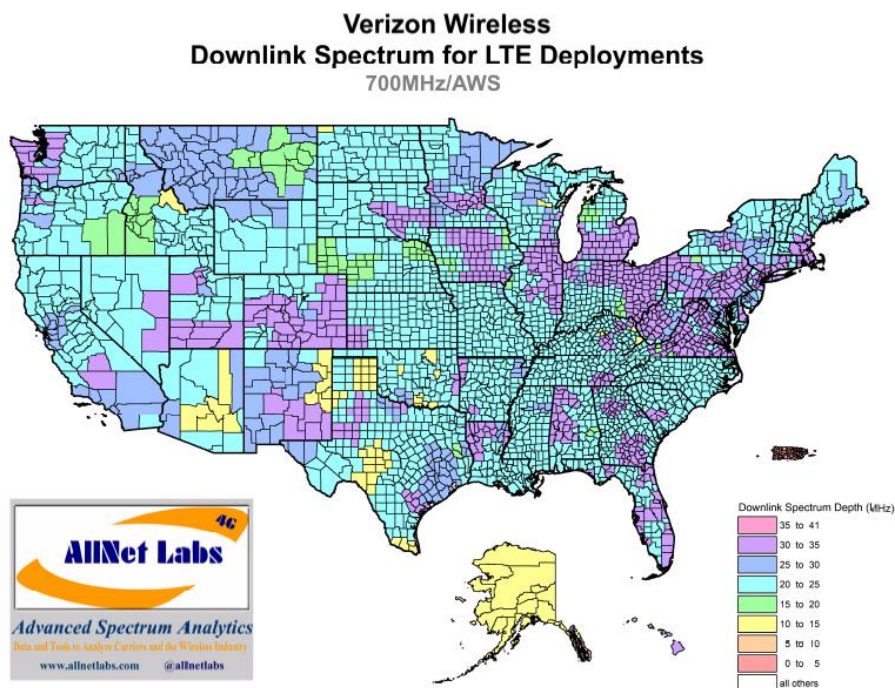


Figure 2 : Verizon spectrum

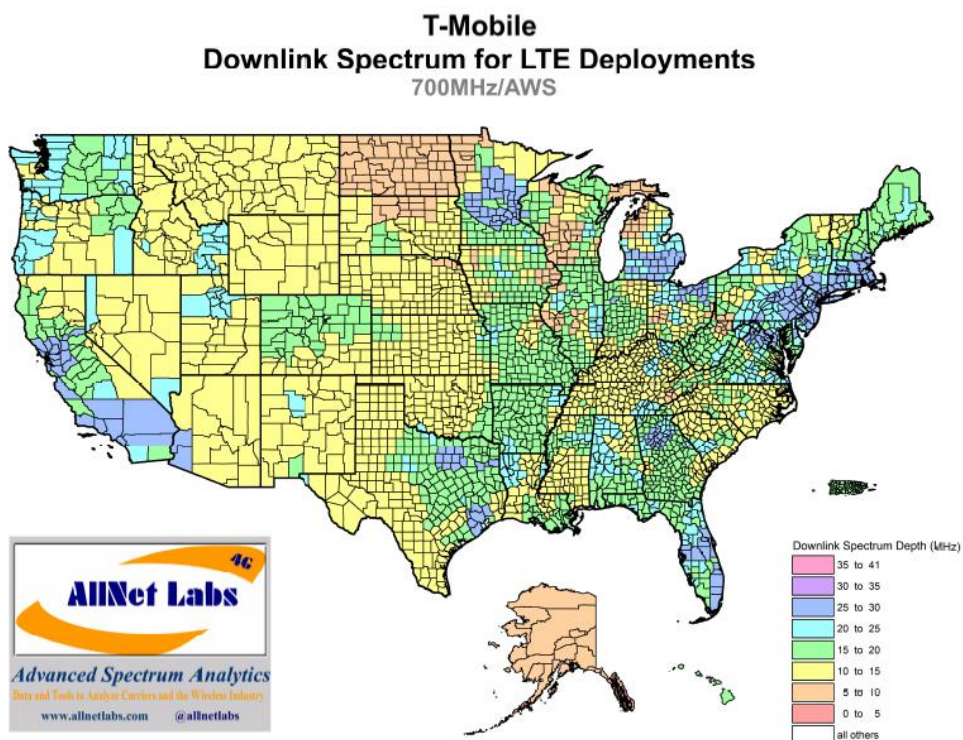


Figure 3 : T-Mobile spectrum

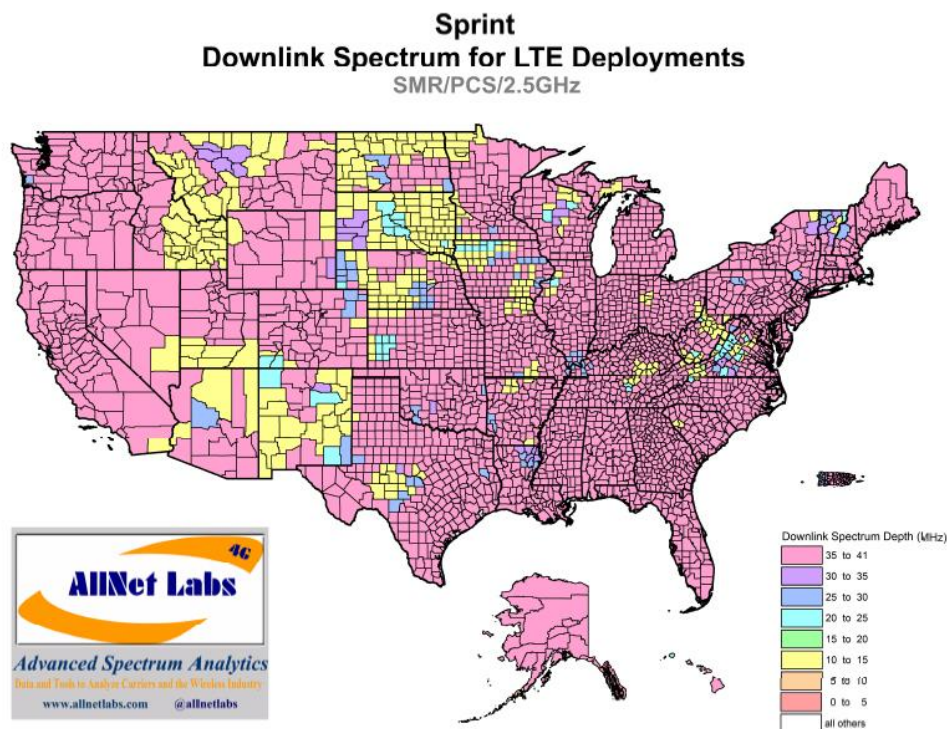


Figure 4 : Sprint spectrum

As we can see in Figure 1 to Figure 4, there is no nation-wide scenario: the spectrum was acquired on a per-city or per-state basis, and each operator has to inherit from the past situation. Considering AT&T or T-Mobile cases, we could see that the map is dominated by orange, yellow green colors: these two operators have spectrum with limited bandwidth, more often 10 MHz, sometimes, 20MHz. Conversely, Sprint owns large blocks of spectrum with for most of cases, more than 30MHz bandwidth. Bearing in mind that the bandwidth could be directly linked with the peak data rate, and that peak data rate is often used as a commercial argument for operators to compete with each other, one could expect that AT&T, T-Mobile and Verizon will consider in a soon future the deployment of carrier aggregation. Moreover, in the bands where they could get large spectrum, the operators have fragmented allocation. For instance in Band 2 Verizon has more than 1/3 of their spectrum made of 2 blocs inherited from PCS, each block being 5, 10 or 15 MHz.

The spectrum fragmentation and the commercial competition pressure are two arguments in favor of a rapid deployment of carrier aggregation. The most likely band to be considered are:

- In FDD: band 2, band 4, band 5, band 13, band 17 (AT&T, Verizon and TMO)
- In TDD: band 41 and band 42 (Sprint)

In Europe, following a similar analysis, the most likely scenario for carrier aggregation will involve the band 3, 7 and 20 (FDD).

Based on this analysis, we decided to down-select the scenario in SOLDER to consider (following market likelihood) inter-band case with band 4 and band 13. This is a typical scenario, involving a low band (band 13, with limited bandwidth 10MHz) and a high band (band 4, with possibly a bandwidth up to 20MHz). The low band could be used for coverage purpose while the high band could be used for capacity.

An issue of paramount importance is how to efficiently manage available radio resources in case of Carrier Aggregation (CA). A process of scheduling, interference and power

management becomes rather complex with increasing number of combined carriers. Thus, a joint and robust Radio Resource Management (RRM) approach is desired. It should ensure fairness among users and simultaneously maximize system performance. Several factors need to be taken into account prior to the ultimate resource assignment. First of all, radio conditions must be evaluated. It is usually conducted via an analysis of Reference Signal Received Power (RSRP) estimated by the UE. This straightforward measure might be insufficient in complicated networks incorporating CA techniques, though. Therefore, additional factors are included as well. Besides RSRP, a comprehensive scheduling algorithm is expected to consider instantaneous load on each of Component Carriers (CC). It could be implemented in various ways – either by evaluating interference level on each CC or by simple user count. It is worth to mention that optimally load should be distributed equally among all CCs and this is one of the goals scheduling algorithm need to strive for. As proposed in [16] such technique can be put into practice by allocating to the UE a subset of carriers (CCs) which fulfills the following formula:

$$S = \arg \max \left\{ \frac{\text{Throughput gain}}{\text{Load_balance}} \right\} \quad (1)$$

where “S” denotes a certain subset of carriers, “Throughput gain” is calculated in compliance with Shannon equation, whereas “Load balance” reflects the number of UEs allocated in each CC after assignment has been made.

The CC with the highest RSRP level is chosen as a Primary CC (PCC). This algorithm can evolve into a more sophisticated version which takes into account also mobility aspects. For example – rapidly moving users can be scheduled on lower frequency band (i.e. band having better propagation characteristics). Furthermore, ultra-fast subscribers can be scheduled in “semi-persistent” way in order to reduce signaling utilization. Another direction of enhancements could be to introduce a fully dynamic scheduling approach with respect to component carrier selection. Traditional mechanisms assume that a subset of carriers is chosen once - when RRC Connection is established. A more efficient and flexible attitude incorporates a periodical review of all possible CCs a mobile operator has available. If a carrier that is not within a chosen subset offers better transmission opportunities (in terms of throughput, load, system performance, etc.) then RRC Reconfiguration should be executed and CCs should be swapped (a modification of pre-defined CC subset is executed). Nevertheless, this technique substantially increases system complexity and requires additional signaling to evaluate traffic conditions on all carriers that are regarded as potential members of CC subset. A central managing entity is the most obvious architectural solution to coordinate the process of dynamic CC distribution among mobile users. Such administering module need to gather measurements from all frequency bands within the system, take appropriate decision and communicate it towards affected UE. Whole process must occur in the blink of an eye. Figure 5 depicts a rough idea of such central managing block which evaluates various factors. A similar approach has been presented in [18].

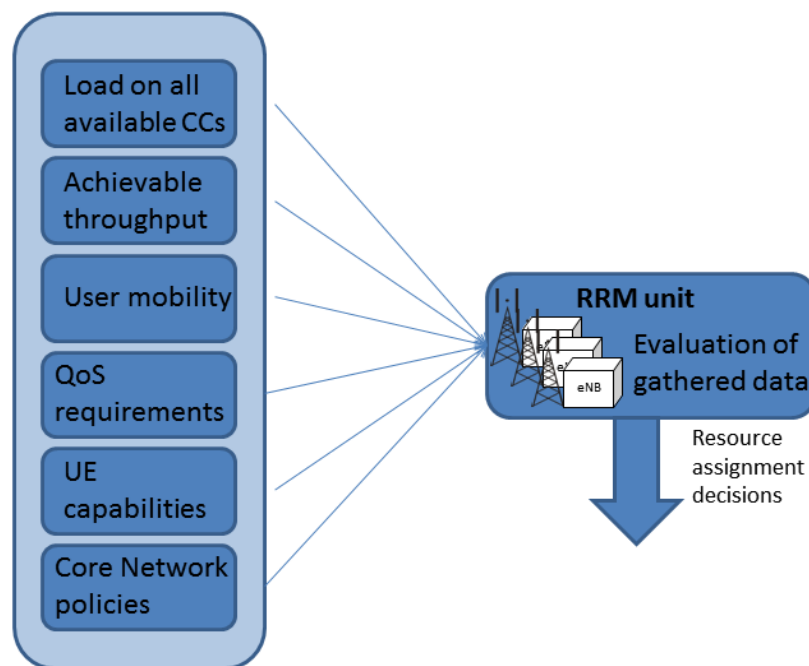


Figure 5: Central managing unit and its input data

Another key aspect that cannot be neglected with respect to RRM for Carrier Aggregation is the flow of control information. The joint usage of at least two carriers implies signaling overhead which has to be curbed. The most evident consequence of CA usage is the necessity to provide Channel State Information (CSI) separately for each CC. It results in increased data volume that is transmitted over PUCCH for PCC. This important procedure is not subject to any major simplifications as CQI/CSI is an inherent feedback component for each active data channel. The next big challenge associated with Carrier Aggregation is the procedure of Secondary Component Carrier (SCC) activation and deactivation. Resources on SCC are not available immediately after establishing an RRC Connection via Primary CC. Currently it takes at least 8 ms (i.e. 8 subframes) to complete RRC Connection Reconfiguration and involve SCC in scheduling decisions. It provides an opportunity for research on how to shorten this period in order to offer end-user additional carrier quicker than in 3GPP Release 10. For example - it can be considered to include SCC already into RRC Connection Setup if it is known a priori certain UE would need extra frequency resources. Another issue with reference to SCC activation and deactivation that needs to be addressed is how to efficiently configure related timers. 3GPP Release 10 introduced "sCellDeactivationTimer-r10" to trigger SCC deactivation. It will be accomplished when "sCellDeactivationTimer-r10" expires. Thus, it is of vital importance to configure this timer properly in order to avoid unnecessary RRC Reconfiguration procedures. A problem becomes non-trivial if we take into account that up to four Secondary CCs can be established. Ultimately, it might be considered to aggregate "ordinary" carrier with Lean carrier – a new concept expected to be introduced within 3GPP Release 12 content [17]. Lean carrier has minimum control channel overhead and can be used to enhance spectral efficiency. PCC will be responsible for all control plane processing whereas the existence of Lean Carrier will boost achievable data rates.

2.1 High level architecture

The high level architecture of the LTE-LTE carrier aggregation scenario is the default LTE architecture as defined by 3GPP. The figures in the following are extracted from [2]. Figure 6 depicts the user and control plane architecture. Carrier aggregation will affect mostly the

PHY and MAC layer on the user plane, involving some new messages at the RLC and RRC control plane.

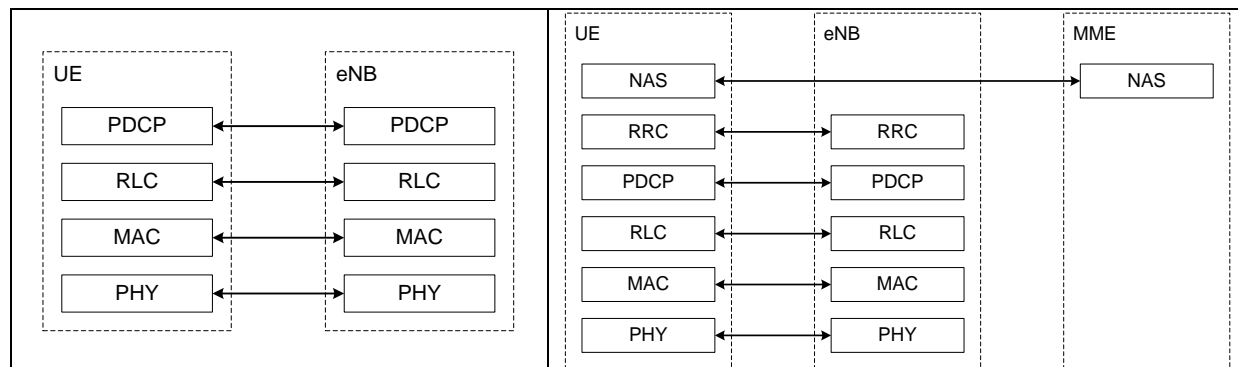


Figure 6 : User and control plane protocol architecture

When CA is used, the split and merge between carriers is uniquely done at the MAC layer. Each carrier has its own HARQ entity, as depicted by the Figure 7 and Figure 8 respectively for the DL and the UL.

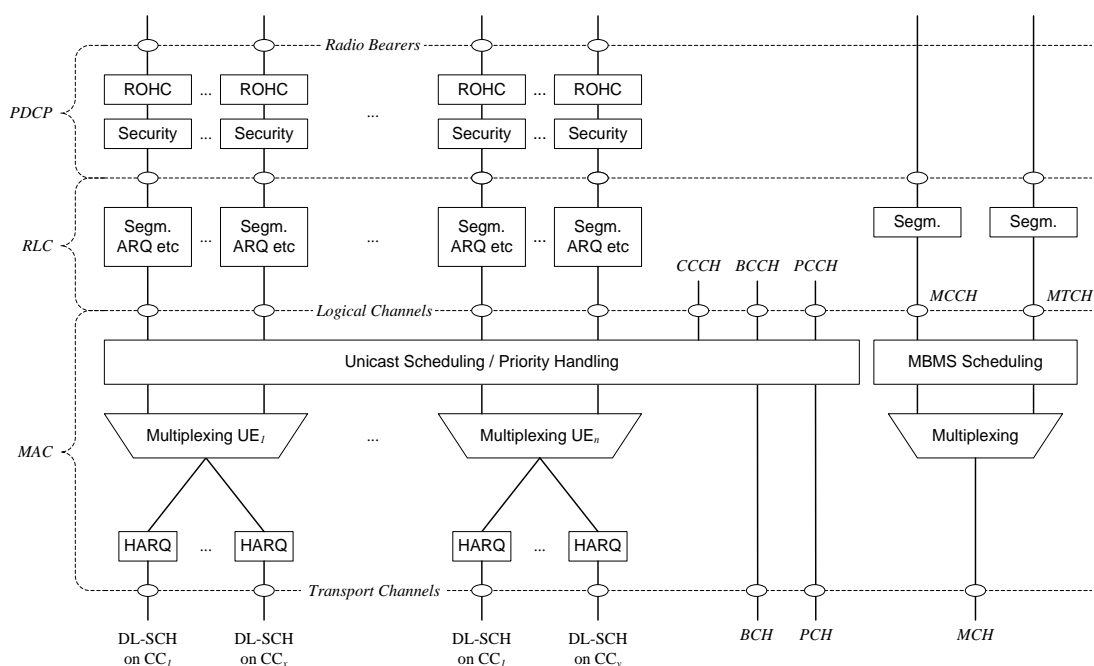


Figure 7 : Layer 2 structure for DL with Carrier aggregation

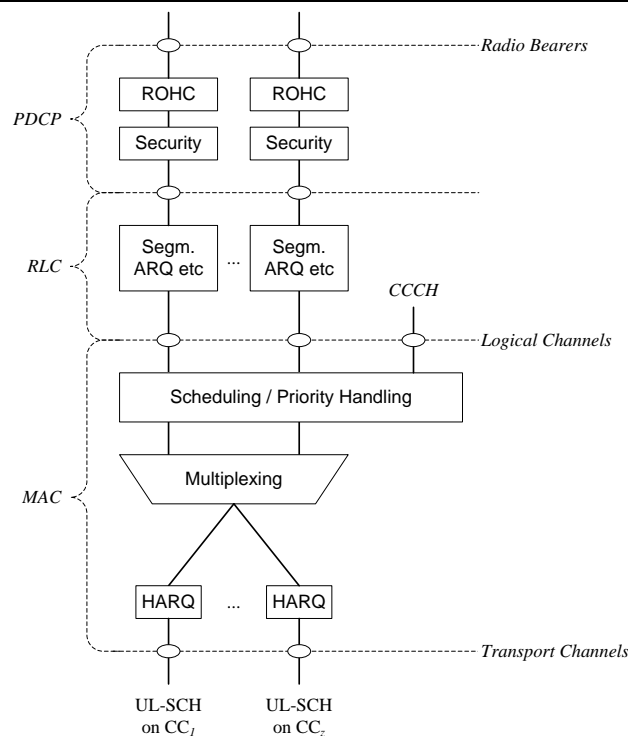


Figure 8 : Layer 2 structure for UL with CA

At the RRC layer, a user equipment operating carrier aggregation has only one RRC connection with the network. The cell having this connection is referred to the Primary Cell (PCell); the other serving cells are the Secondary Cells. The addition, removal and modification of the set of PCell and SCell (e.g. in case of mobility and handover is made thanks to RRC messages) is carried out. A more dynamic scheme is defined at the MAC layer to activate/deactivate the use of SCell when configured. Depending on the capability of the UE, UL and DL SCell could be defined. The number of SCell for DL and UL could be different, assuming that there are more DL SCells than UL SCells.

2.2 Component level requirements

In order to address the scenario described in the previous paragraph, the SOLDER project will work both from the terminal side and the network side.

Requirements are in short to support the CA as defined by the 3GPP, with a primary focus on the following case:

- 2 DL Component Carrier, one in low band (e.g. B13), one in High band (e.g; Band 4)
- 1 UL Component Carrier
- Colocated base station and overlaid coverage
- Modification of the PHY, MAC, RLC and RRC layers to support CA operation

High-level Requirements with respect to Radio Resource Management (RRM):

- An effective method of conveying increased volume of control/feedback information must be found. Each CC requires its own ACK/NACK confirmations as well as CQI and such information cannot be omitted. As a result, PUCCH for Primary CC is overloaded with additional control data.
- Additional carriers configuration should be completed in 8 ms (8 subframes) - according to 3GPP. Current implementation requires RRC Reconfiguration procedure in order to establish SCC. Perhaps it can be already involved in RRC Connection Setup if it is known a priori supplementary frequency resources would be necessary

- Secondary CC should be deactivated by “sCellDeactivationTimer-r10” timer expiry. A carefully chosen value must be assigned to this timer in order to avoid excessive signaling due to RRC Reconfiguration messages related to Cell activation and deactivation.
- Frequency measurements need to be collected periodically in order to support the concept of dynamic resource assignment. Such measurements should be sent over X2 interface (between base stations) or with the participation of Core Network (via S1 interface)
- User mobility should be tracked and MAC layer is expected to take such information into account while choosing a relevant scheduling approach. One of the ways to monitor mobility is to observe the tendency of RSRP on a certain carrier measured by the UE.

Detailed Requirements with respect to Radio Resource Management (RRM):

- RRM mechanism should be able to ensure load balancing and efficient scheduling across multiple carriers (i.e. PCC + 1-4 SCCs)
- RRM should handle intra-band and inter-band Carrier Aggregation
- A central RRM unit (in most cases: located within a eNB) shall take into account various input data before making resource assignment decisions. Among the context information which should be evaluated prior to resource allocation are: load on CCs, SNIR values, achievable throughput, QoS requirements, UE capabilities, Core Network/operators policies, etc.
- Dynamic RRM approach is highly desirable. A set of Component Carriers should not be fixed and given once per RRC Connection. Conversely, it has to be revised frequently and reallocated if necessary.

3. LTE (Licensed) + LTE (Licensed) – Different operators

3.1 High level architecture

Two LTE base stations with different operators are deployed covering the same area. Multi-hop routing employing optionally both D2D and infrastructure-based communications links, with the possibility of spectrum aggregation over both systems, is investigated. Hence, users can aggregate both operators' bands for their transmissions, where the use and aggregation of another operator's resources might be done through a concept such as Licensed Shared Access (LSA) [3].

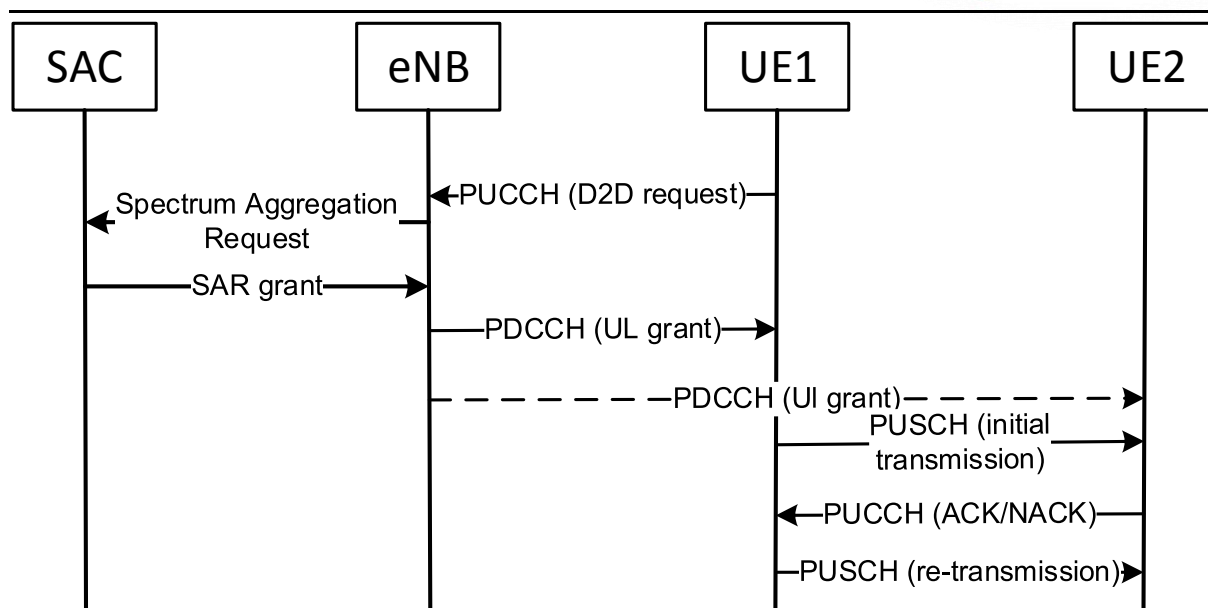


Figure 9: Resource allocation and data transmission procedure for D2D communications with involving spectrum aggregation in two licensed LTE system

In this case, since the D2D communication use the licensed LTE bands, the operators should consider the resource allocation and interference management in order to avoid the interference causing to normal LTE users. A centralized resource allocation mode is involved, where the eNB has the full control over the resources allocated to each D2D users. Just as shown in Figure 9, the UE1 would ask an allocated resource from eNB before the D2D communication established. The spectrum aggregation control (SAC) is responsible for control the whole spectrum aggregation process in two licensed LTE systems.

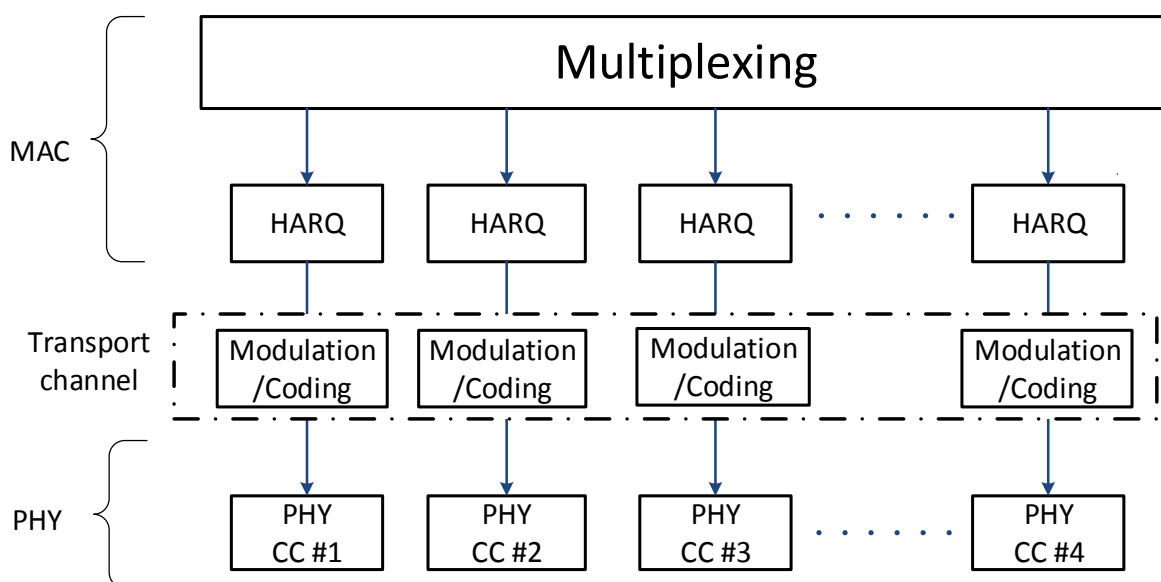


Figure 10: MAC and PHY layer architecture for spectrum aggregation

Figure 10 depicts the MAC and PHY layer for spectrum aggregation in licensed LTE system. The data streams are aggregated at the MAC layer [4], the set of data packets is divided in to several parts for different spectrum bands, and transmitted by different carriers on the PHY layer. The transport channel provides the interface between MAC and Physical layer which is

also separate for each CC. Notice that the transport blocks sent on different CCs can be transmitted with independent modulation and coding schemes.

3.2 Component level requirements

On the PHY layer, Rate Adaptation OFDM radio access is involved for transmission [5]. This technique is depicted in Figure 11. Unlike traditional OFDM technique, RA-OFDM uses different coding and modulation schemes for different sub-bands, based on their frequency diversity. For frequency diversity, different sub-bands have very different SNRs even for a single sender-receiver pair. According to the individual SNR, the optimal bitrate for each sub-band can be calculated, so that the total network performance such as throughput, QoS requirements can be improved.

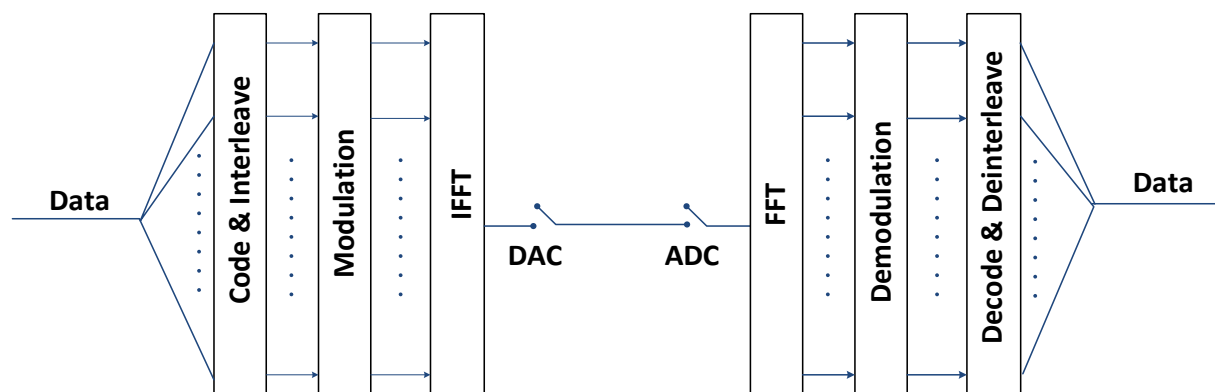


Figure 11: Rate Adaptation OFDM architecture

A hybrid aggregation technique is proposed to select the best set of resources for transmission. As shown in Figure 12. In hybrid spectrum aggregation, all aggregation techniques (intra-band contiguous aggregation, intra-band non-contiguous aggregation, and inter-band contiguous and non-contiguous aggregation) are combined together with a novel spectrum selection algorithm. Therefore, the best set of spectrum bands is selected for aggregation based on this approach.

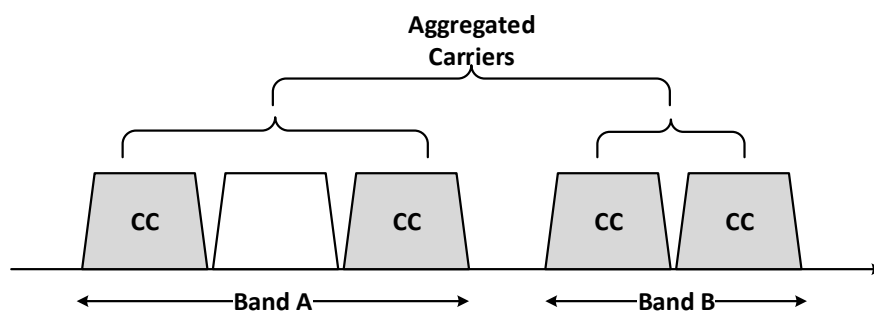


Figure 12: The Hybrid Spectrum aggregation technique

Key component-level requirements for this scenario are summarized as follows:

- The LTE base station is able to allocate LTE spectrum bands for D2D communication.
- Devices must be able to adjust their transmission power based on the current channel quality and traffic load in order to avoid interference to conventional LTE users.

- Devices and radio network components must be able to concurrently transmit and receive on two or more sets of licensed LTE spectrum resources.
 - These resources might optionally be either inter-band contiguous, inter-band non-contiguous, or intra-band contiguous or non-contiguous, or optionally a combination of the above where more than two sets of licensed LTE resources are being aggregated.
- Devices and radio network components preferably have a relatively wide-band capability to be able to aggregate resources of different operators, covering different contiguous or non-contiguous bands. This has implications for, e.g., the need for a very high sampling rate.
 - Devices and radio network components might alternatively have multiple radio chains that are able to be used concurrently to aggregate resources of different operators in the different bands.
- Devices and radio network components must be capable of an OFDM PHY compliant with LTE, and preferably RA-OFDM.
- Devices and radio network components should be capable of producing well-defined CCs, that interfere minimally with adjacent CCs. This is particularly necessary given the case depicted on the left of Figure 11, for example, where CCs are aggregated either side of a CC that is not accessed by the communication link.
- Devices must preferably be compliant with D2D communications capabilities, as defined in LTE Release 12 [6].
- The MAC layer should be able to split or combine the data streams coming from or going to higher layers, and map the sub-divided data to different CCs at the PHY layer for aggregation purposes.
 - A MAC functionality that decides which CCs to aggregate, from which systems, must be present, having interfaces and capabilities at each end of the communication link. This functionality must be aware of aspects such as reliability and QoS of the CCs from the different systems, and higher-layer traffic requirements, and must implement algorithms and/or heuristics for deciding on the component carriers to map to and aggregate based on this.

4. LTE (Licensed) + LTE (Licensed) – HetNet deployment

Radio Resource Management (RRM) for Carrier Aggregation (CA) is a complex issue – even in case of Homogeneous deployment. It becomes a significantly more challenging problem when Heterogeneous system is considered. Efficient scheduling and resource control in the environment comprising various types of cells (i.e. pico, femto, macro) is a key aspect to ensure high overall system performance. The most striking difference between macro and pico cell is the output power imbalance. Typical macro cell's Tx power is equal to 43 dBm (i.e. 20W) or 46 dBm (40W) whereas pico cell usually does not have more than 30 dBm (i.e. 1W) of Tx power available. If we go further and add various antenna gains the results will differ even more (EIRP of 60 dBm for macro versus 35 dBm for pico, according to the study given in [19]). If RSRP- based cell selection criteria is used in such network then the majority of UEs will be handled by macro cell which has incomparably larger coverage. To avoid such scenario a technique called Cell Range Extension (CRE) is introduced. The concept is straightforward – add a positive bias to pico cell RSRP measured by the UE. As a result – more mobile terminals will be served by pico cell which could lead to optimal load balancing. A significant question to be answered is how to adjust bias value to guarantee efficient traffic distribution among involved cells.

An important factor which has an impact on Heterogeneous Network's performance and resource assignment procedures is a type of frequency deployment. There are two main approaches:

- Co-channel deployment
- Dedicated carrier deployment

A clear benefit from co-channel deployment is the full usage of available system bandwidth. However, it comes at a price. Interference coordination becomes a serious problem to be tackled. On the other hand, dedicated carrier deployment does not require interference mitigation but the spectrum utilization is far from optimal. As proposed in [19] - co-channel deployment is recommended to operators having not much spectrum available whilst dedicated carrier solution might be used by those with large chunk of bandwidth (i.e. greater than 20 MHz). When Inter-Site Carrier Aggregation is taken into consideration a robust resource management information exchange must be implemented. It is due to the fact, CA occurs between cells originating from separate base stations. It is usually assumed that macro cell is connected with pico cell via high-capacity and low-latency fiber [19]. This ensures a reliable and fast information exchange between engaged eNBs. In general macro cell plays the role of Primary Component Carrier (PCC) and is responsible for the majority of baseband processing. Secondary Component Carrier is established via pico cell which provides an opportunity to achieve high data rates. Scheduling is handled by PCC and a simple extension of well-known Proportional Fair (PF) approach can be used. A joint PF algorithm takes into account data scheduled in the past for a certain UE over all available CCs. Such attitude boosts system fairness and maintains a desired level of load balancing.

The system briefly described above is based on central management approach. Macro cell serves as a PCC and all resource assignment decisions are communicated via X2 interface towards SCCs (i.e. pico cells). An alternative proposal assumes distributed coordination of radio resources. In [20] author presents a solution called Autonomous Component Carrier Selection (ACCS). Each eNB (pico, femto or macro cell) gathers information about the surroundings via "sensing". Component Carrier is selected in a way that ensures minimum level of interferences for neighbouring nodes. The concept is depicted in Figure 13.

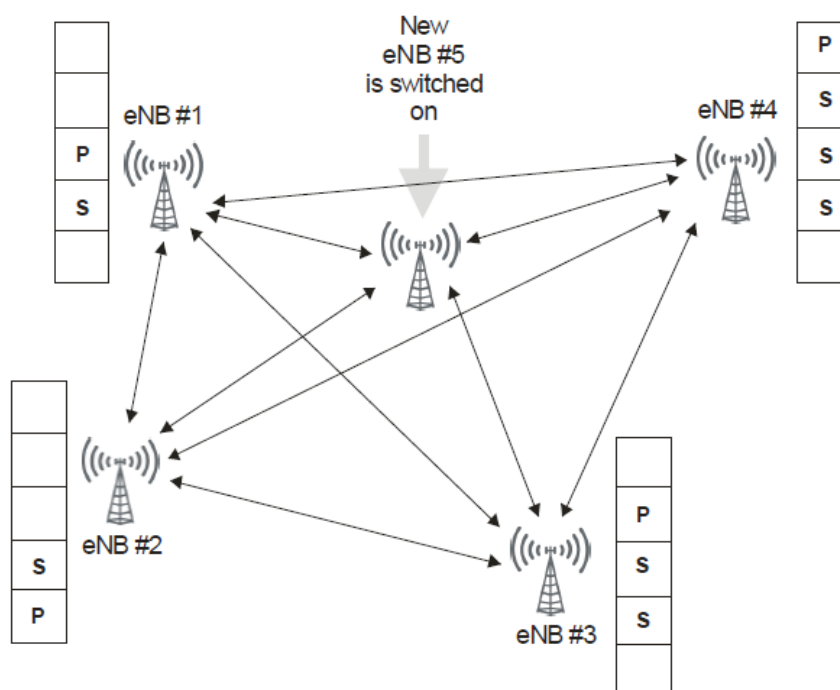


Figure 13: Autonomous CC Selection

Each eNB is entitled to have one Primary CC (denoted as “P”). The configuration of additional CCs (i.e. SCCs, denoted as “S”) can be executed provided that it does not result in excessive interference level in surrounding cells. This scheme is scalable and should operate without central managing decisions. Furthermore, it should provide robustness against “greedy” base stations intending to allocate CCs regardless of harmful impact it may have on the closest environment. To achieve this goal each eNB stores a Background Interference Matrix (BIM) which contains C/I (Carrier to Interference ratio) measurements for each CC. Based on the data kept in those matrices the ultimate CC selection is executed.

Carrier Aggregation including small cells inherently means the distance between the UE and the base station is relatively short. Thus, it is justified to assume propagation conditions are favourable and usually a Line-Of-Sight (LOS) exists. Due to such beneficial circumstances a usage of higher modulation for Downlink (DL) can be considered. 256 QAM would increase spectral efficiency and achievable data rates in pico cell. It can be especially effective if the UE is in “low-mobility mode”. This enhancement can be implemented in conjunction with already known Cross carrier scheduling. PCC will offer its PDCCH to inform the UE about allocations on both PCC and SCC whereas SCC will be used exclusively for data transmission. Such solution yields decreased interference level and boosts downlink throughput in pico cell.

4.1 High level architecture

The high level architecture for eNB and UE of this scenario are the same as in the homogeneous deployment scenario (cf Section 2) with the addition that in a heterogeneous network the X2 interface between eNBs is used to exchange information between RMs (see Figure 14).

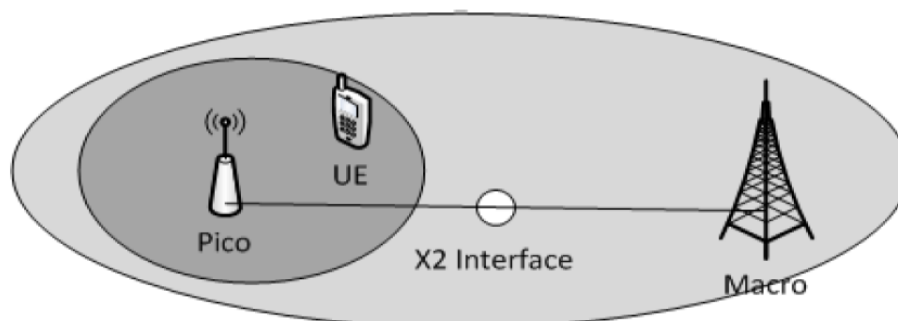


Figure 14: LTE HetNet with X2 interface [36]

4.2 Component level requirements

4.2.1 MIMO Link Adaptation with CA over HetNets

The HetNet BSs of macro-/pico-cells will exploit the benefits of MIMO technique and the more advantageous combination of MIMO link adaptation (LA). MIMO techniques used in LTE can be categorized as follows: space-frequency block coding (SFBC), frequency-switched transmit diversity (FSTD), and cyclic delay diversity (CDD). LA refers to the concept of dynamically adjusting the transmit parameters, such as the modulation order and coding rate according to the near-instantaneous channel conditions. The adaptive modulation and coding (AMC) capabilities of the transmitter in MIMO LA schemes is really a challenging issue since AMC is sensitive to channels measurements errors and delays. In practice, in an (N_r, N_t) -element MIMO system, the receiver estimates the channel state information (CSI) and decides upon the optimum transmit mode, which is then send back to the transmitter through a low-rate feedback channel; actually, the UE feeds back the eNodeB with three

indicators namely: channel quality indicator (CQI), precoding matrix indicator (PMI) and rate indicator (RI). CQI reported by UE to eNodeB indicates modulation and coding schemes to eNodeB; PMI send by UE to eNodeB indicates to eNodeB which precoding matrix should be used for downlink transmission; finally, UE indicates to eNodeB, the number of layers that should be used for downlink transmission to the UE with RI. LA techniques designed for MIMO can be classified as: a) Adaptive Modulation (AM), b) Transmit Precoding (TP), c) Antenna Selection (AS) and d) Hybrid Adaptation (HA).

The corresponding component requirements for the particular HetNet application scenario are defined as follows:

- An assessment of how the most interesting of the current MIMO LA techniques affects the behavior of intra-band or non-contiguous and inter-band CA per Component Carrier (CC) i.e., performance assessment at the transmitter and/or receiver.
- MIMO LA algorithm per CC.
- Reliable channel estimation techniques per CC and how delayed or partial feedback affects AMC at the eNodeB given the current channel state.
- Channel measurements per cell and CC in conjunction with feedback reporting will be incorporated to the LA scheme.
- Important Link Quality Metrics (LQMs) such as Precoding Matrix Indicator (PMI), Rank Indicator (RI) and Channel Quality Indicator (CQI) in different HetNet scenarios where LA is applied.

MIMO LA with CA over HetNets will be developed considering the following component parameters:

- UE equipped with one, two or four antennas.
- 4x4, 4x2, 2x2 or 2x1 MIMO OFDM DL transmissions,
- EPA, EVA, ITU channel models, which takes into consideration the slow fading parameters (i.e., propagation parameters).
- Two 10MHz frequency bands 882MHz (*belonging in LTE-A band 5*) and 2.14GHz (*belonging in LTE-A band 1*) i.e., inter-band NC CA.

A detailed design of the RF front end to support the MIMO LA application over HetNets with CA is depicted in Figure 15.

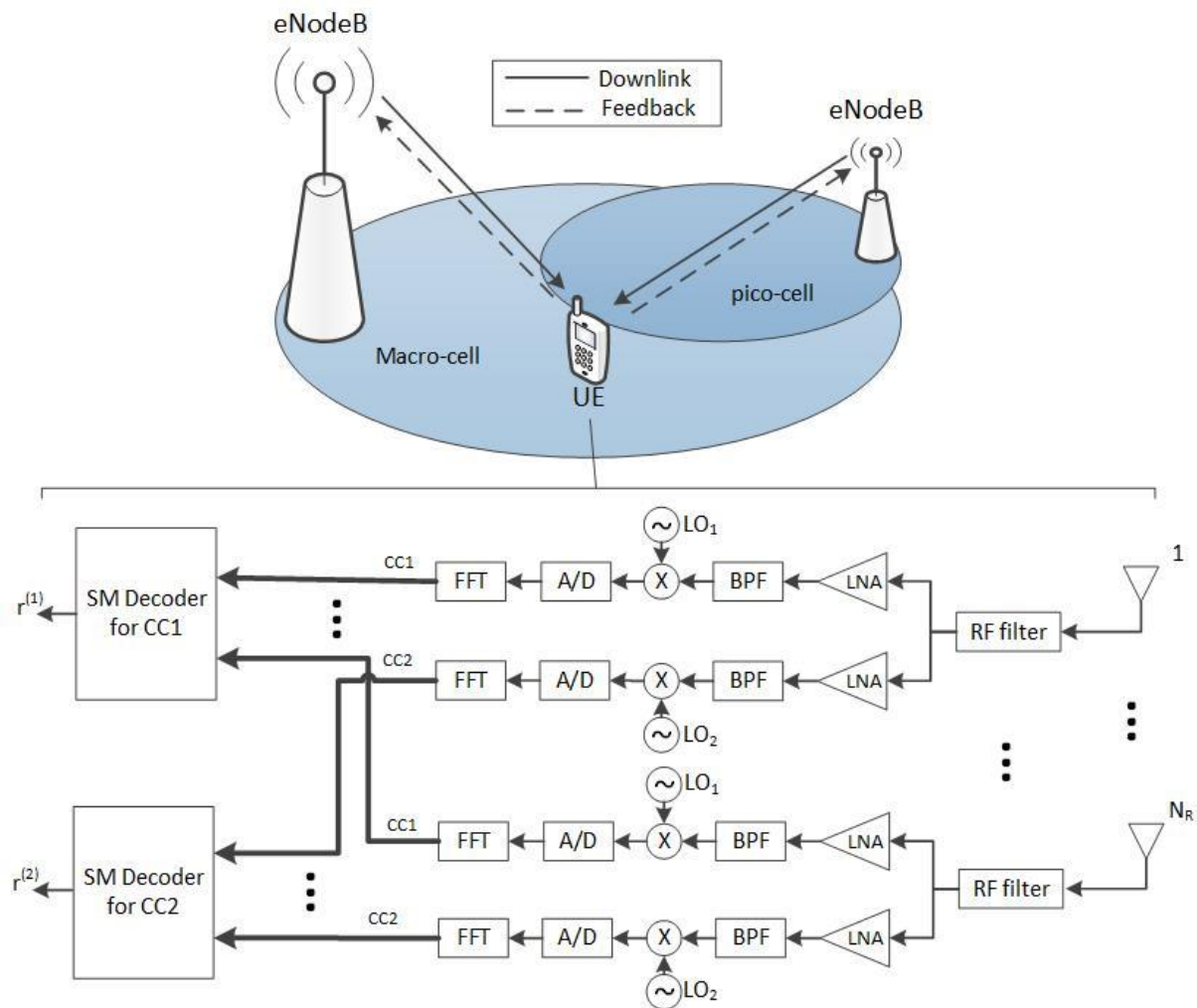


Figure 15: MIMO LA with CA and the required components at RF front end

4.2.2 TDD+FDD carrier aggregation

One of the most promising aspects in LTE CA is the aggregation of FDD and TDD CCs standardized in Release 12. The earliest LTE relied on frequency division duplexing (FDD-LTE), but there is interest in deploying the time division duplex variant of LTE (TDD-LTE) due to spectrum scarcity. The joint operation of TDD and FDD offers a set of remarkable advances such as flexible interference coordination, reduce large control information latency, efficient load balancing between TDD and FDD systems etc. More, TDD spectrum could be used to supplement FDD spectrum to provide additional throughput and capacity on the downlink. Conversely, FDD spectrum, which is generally at lower frequencies than TDD spectrum, could be used to achieve greater range on a TDD uplink, which is often the limiting factor for TDD coverage. However, the aggregation of TDD and FDD CCs is a really challenging problem since there are a lot of differences in control signaling and subframe timing [21].

In order the UE to be able to work under the TDD+FDD CA, the following RF component requirements need to be specified:

- receive simultaneously FDD and TDD carriers supporting DL CA;
- transmit simultaneously on FDD and TDD supporting UL CA;

- transmit and receive simultaneously on FDD and TDD supporting full duplex CA.

To be more specific, 3GPP has defined 10 frequency bands for TDD-LTE and 23 for FDD-LTE. The TDD-LTE frequency bands currently attracting the most interest are 2.6 GHz and 2.3 GHz, while the recently ratified 3.4-3.8 GHz bands are also likely to play an important role [22].

In LTE Release 12, two deployment scenarios have been proposed [23]:

- a) Co-Located FDD and TDD carriers* where FDD and TDD carriers are used at the same eNodeB. In this scenario macro eNodeB serves FDD, TDD and the joint FDD+TDD UEs.
- b) Non Co-Located FDD and TDD carriers* where FDD and TDD carriers used at different eNodeBs. . In this scenario macro eNodeB serves FDD UEs, pico eNodeB TDD UEs and joint FDD+TDD UEs are served by both eNodeB's simultaneously.

In SOLDER, a practical LTE-A scenario with non-contiguous (NC) joint FDD/TDD carrier aggregation (CA) in a HetNet will be investigated and developed. A HetNet deployment is considered which includes the following FDD and TDD band aggregations:

- 1 3GPP-based LTE-FDD macro eNode base station at 800MHz (20MHz spectrum bandwidth) + 1 3GPP-based LTE-TDD pico eNode base station at 2600 MHz (20MHz spectrum bandwidth)
- 1 3GPP-based LTE-FDD macro eNode base station at 1800 MHz (20MHz spectrum bandwidth) + 1 3GPP-based LTE-TDD pico eNode base station at 2600MHz (20MHz spectrum bandwidth)
- 1 3GPP-based LTE-FDD macro eNode base station at 800MHz (20MHz spectrum bandwidth) +1 3GPP-based LTE-FDD macro eNode base station at 1800 MHz (20MHz spectrum bandwidth) + 1 3GPP-based LTE-TDD pico eNode base station at 2600MHz (20MHz spectrum bandwidth)
- 1 3GPP-based LTE-FDD macro eNode base station at 800MHz (20MHz spectrum bandwidth) +1 3GPP-based LTE-FDD macro eNode base station at 1800 MHz (20MHz spectrum bandwidth) + 2 3GPP-based LTE-TDD pico eNode base station at 2600MHz (20MHz spectrum bandwidth each)

These are some of the requirements from Rx/Tx point of view, on the base band side, there are several issues due to the difference between FDD-LTE and TD-LTE subframes in the DL and UL. For example, in FDD mode every DL subframe can be associated with an UL subframe, while in TDD, the number of DL/UL subframes are different and such an association is not possible. To this end, TDD/FDD CA requires the design of a combined control signaling format and subframe timing [23]. A derived design requirement from this challenge is the aggregating of the DL subframes and the UL subframes of the TDD carrier with the FDD UL carrier. Another important issue it that the coverage with of TDD UL is not that robust as in FDD mode due to the fact that the UL transmission is not continuous. This should be taken into account when one of the TDD+FDD modes will be considered either as primary CC (pCC) or secondary CC (sCC) in conjunction with the fact that the interference emitted by the FDD mode is less than in TDD mode. Furthermore, scenarios can be expanded and combine their low-frequency FDD bands such as 850 MHz and 900 MHz with high-frequency TDD bands such as 2300 MHz and 2600 MHz. Also, different pathloss exponents are assumed for each HetBand to capture the large variation in propagation associated with each HetBands carrier frequency. Thereby, timing and frame adjustment is required for the efficient CA between TDD and FDD CCs as depicted in Figure 16.

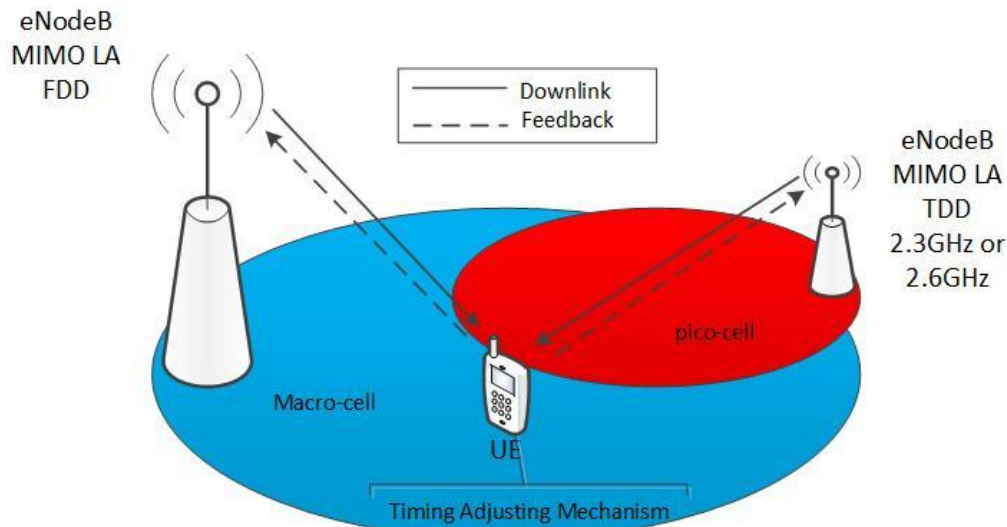


Figure 16: Timing and frame adjustment mechanisms for TDD+FDD CA with MIMO LA

The component requirements at the base band side for the TDD+FDD CA can be summarized as follows:

- New enhanced inter-cell interference coordination (eICIC) algorithms for advanced received with TDD+FDD CA capabilities;
- Enhanced uplink and downlink HARQ timing and frame adjustment mechanisms.

4.2.3 D2D communications

The case for licensed LTE – licensed LTE aggregation involving D2D optionally combined with infrastructure-based links, discussed in Section 3 might also be applied to aggregation involving HetNets. In fact, the assumption of LSA as one likely means for access to another operator's spectrum is in line with small-cell deployments, which are often seen as a key context in which LSA might be used. The requirements on the systems being aggregated are broadly similar in this case to those already discussed in Section 3, noting that it is assumed for this particular purpose that the small-cells and macro-cells will be using different operators' spectrum, thereby simplifying the scenario.

4.2.4 Radio Resource Management

High-level requirements:

- RRM mechanism must take into account different characteristics of cells constituting a Heterogeneous environment. Particularly important is to beware of completely distinct output power between macro- and pico cell which has a direct impact on the coverage and interference management
- RRM for a scenario with one large macro cell and at least one pico cell will be investigated. Pico cells will be mainly used to offload the macro cell.
- RRM mechanism should handle both co-channel and dedicated carrier deployment
- RRM must be implemented as a centralized solution or in a dispersed way (i.e. each eNB, regardless of the type, is actively engaged in Radio Resource Management. No central coordination is necessary.)
- Usually a macro cell would play the role of PCC (responsible for signaling of each CC) whereas pico cell will be used to boost the data rate. The latter can be facilitated for example by introducing a higher modulation scheme in downlink

- RRM for inter-site Carrier Aggregation should be also considered. It requires additional signaling on X2 interface to coordinate such transmission between involved nodes.

Requirements with respect to Radio Resource Management (RRM):

- Scheduling mechanism should be able to differentiate between pico and macro cell in terms of propagation conditions. A positive bias should be added to pico cell RSRP level observed by the UE (CRE technique)
- PDCCH for PCC should be utilized to convey allocation information for both PCC and SCC (Cross-carrier scheduling).
- Achievable throughput in pico cell can be boosted in case of low-mobility users and the existence of Line-of-Sight. In such circumstances, RRM algorithm should decide to use higher order modulation (e.g. 256 QAM).
- A Secondary CC can be implemented as a “Lean carrier”. Almost entire signaling will be handled by PCC (usually a macro cell) whereas pico cell (i.e. Lean carrier) can be fully exploited for data transmission
- A robust mechanism of RRM coordination over X2 interface for inter-site Carrier Aggregation is necessary
- In case of distributed resource management approach each eNB should be able to sense its surroundings and build “Background Interference Matrix”. A decision which carrier to choose as PCC and SCC is made based on the data stored in such matrices.

5. LTE (Licensed) + LTE (Unlicensed) – LTE-U

Considering that the unlicensed spectrum assigned to users is much bigger than the licensed spectrum (700MHz-3.6GHz) and also the benefits of LTE, it is apparently that the use of LTE in unlicensed spectrum (LTE-U or Licensed-Assisted Access) will improve significantly the usage of unlicensed spectrum (e.g. higher Tx efficiency, higher coverage, lower overhead etc). Therefore, the LTE-A users will benefit further by using CA technique to increase significantly DL and UL data rates [24][25][26][27]. LTE-U is targeted in 2.4GHz and 5GHz bands to effectively enhanced network capacity. Both bands are standardized today for the unlicensed WiFi. Nevertheless, 2.4GHz is very crowded and thus 5G-Hz remains a good alternative option to deploy unlicensed LTE. More, 5GHz band has potentially up to 500MHz available spectrum and thus a better co-existence between LTE-unlicensed and WiFi users is achieved. Also, since many unused channels exist in 5GHz band, the interference is minimized.

The scenarios for LTE-U CA appeared recently in the telecom industry are the followings:

- Micro/Pico cell with co-located licensed and unlicensed users (highest priority use case);
- Macro-cell with co-located or intersite unlicensed micro-/pico-cell;
- Macro-cell with co-located licensed and unlicensed.

In SOLDER project, our study in LTE-U CA will be focused on A and/or B scenarios with A being the use case of highest priority [24]. Considering the A deployment scenario, a micro-/pico-cell deployment where licensed and unlicensed spectrum is accessed from the same eNodeB building upon the existing CA framework is considered. More specifically, a Heterogenous Radio Access Technology (h-RAT) deployment is considered which includes a micro-/ pico-cell eNodeB operating in licensed and unlicensed spectrum under 3GPP LTE-A standards. Also, different path-loss exponents are assumed for each band to capture the large variation in propagation associated with each CC (primary or secondary). Moreover,

the overall fading environment is modeled under practical LTE-A channel models, such as Extended Pedestrian A model (EPA) and/or Extended Vehicular A model (EVA), and/or Extended Typical Urban model (ETU).

Components requirements for the particular h-RATs application scenario are specified as follows:

- Co-existence with WiFi (and to a smaller extent BlueTooth) as incumbent technologies in the 5.8 GHz band. LTE-U should develop and enforce a “**Robust Co-Existence Mechanism**” (RCM) such that its introduction doesn't negatively impact these existing services in unlicensed bands: interference issues of LTE-U UEs with WiFi UEs e.g. smart selection of CCs in secondary CCs to avoiding interference among LTE-U and WiFi users
- Inter-modulation interference between unlicensed and licensed bands: Since LTE-U operated in a secondary cell is controlled by the primary cell, the band combination to be aggregated should be chosen to avoid strong inter-modulation interference between each other, especially in-device interference for the given unlicensed band. This is likely to happen due cross-band emissions issues between 5GHz band and IMT cellular. The mitigation of inter-modulation interference can be achieved in MAC layer by using the most common methods such as: dynamic frequency selection (DFS), transmission power control (TPC), and time sharing (TS).
- Aggregation with licensed spectrum (DL only): a) Signaling and critical data to be carried over the licensed spectrum; b) Common channels to be sent over the unlicensed spectrum to support synchronization, RRM measurement, etc. Therefore, a jointly optimization for resource allocation for both licensed and unlicensed bands is necessary to maximize the sum of the total throughput [28].
- As conventional receivers with channel estimation based on the interfered Cell-specific Reference Symbol (CRSSs) fail to work properly, advanced interference mitigation schemes for user equipment (UE) are adopted, such as: the received-power dependent interference cancellation (IC), and the decision-directed channel estimation and IC-assisted channel estimation.

A micro-/pico architecture with an eNodeB that can serve both LTE and LTE-U UEs will be developed, wherein the LTE-U CA will be investigated considering the following parameters¹:

- UE equipped with one, two or four antennas.
- 4x4, 4x4, 4x2, 2x2 or 2x1 MIMO OFDM DL transmissions,
- EPA, EVA, ITU channel models, which takes into consideration the slow fading parameters (i.e., propagation parameters).
- LTE-A: 20MHz frequency band at 882MHz (*belonging in LTE-A band 5*) and 2.14GHz (*belonging in LTE-A band 1*)
- LTE-U: 20MHz at 5.15-5.35GHz (Band A) and/or 5.47-5.725GHz (Band B) and/or 5.725-5.850GHz (Band C) unlicensed band.

¹ Note, that the above co-located scenario can be further extended to inter-site network where macro-/micro-/pico-cells cover different areas assuming a higher speed backhaul between macro node and micro-/pico-cell.

6. LTE (Licensed) + LTE (TVWS)

6.1 High level architecture

For licensed LTE - TVWS LTE aggregation, one LTE cellular network base station with a single operator is assumed, and a TVWS LTE base station also assumed, whose coverage coincides with the licensed LTE base station. These two base stations may, in practice, be combined into the same element. Aggregation may also be performed over D2D links between devices.

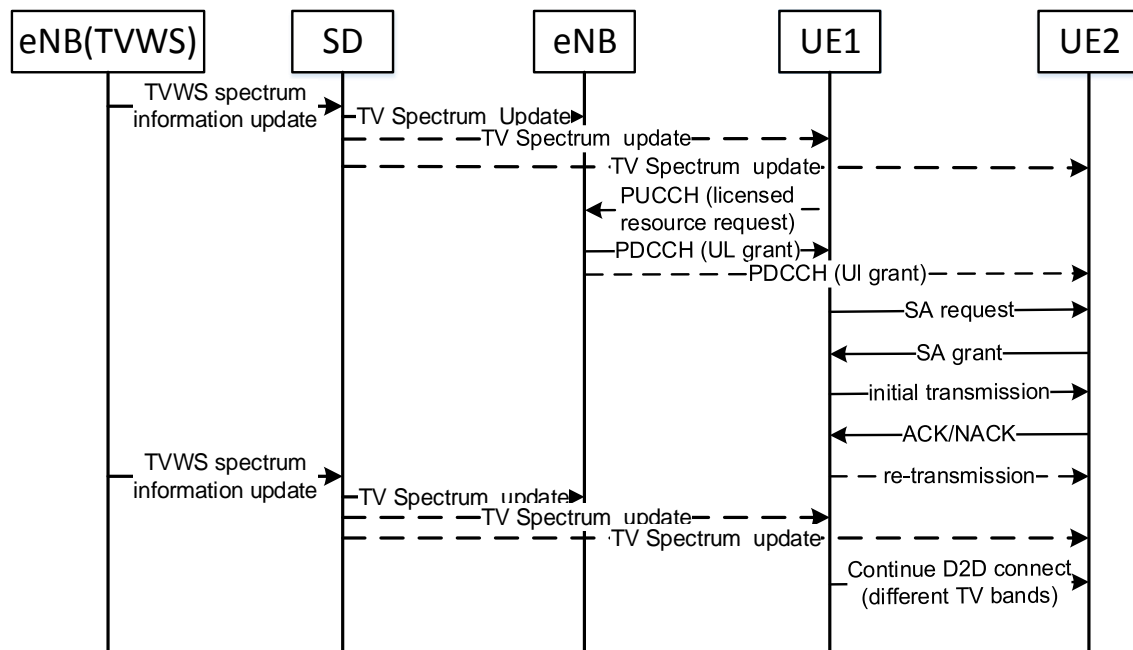


Figure 17: Resource allocation and data transmission procedure for D2D communications with involving spectrum aggregation between licensed LTE and TVWS

Similarly in two licensed LTEs, in Figure 17, the eNB provides a centralized resource allocation for D2D devices in licensed LTE network, which would provide a licensed LTE band for UE1 and UE2. However in TVWS LTE, the eNB (TVWS) would update the TVWS spectrum utilization information of primary TV services to Spectrum Database (SD) periodically. The Spectrum database is responsible for sharing the TVWS spectrum usage information to base stations and D2D users. The D2D user will aggregate the licensed LTE bands with TVWS bands based on the received spectrum usage information.

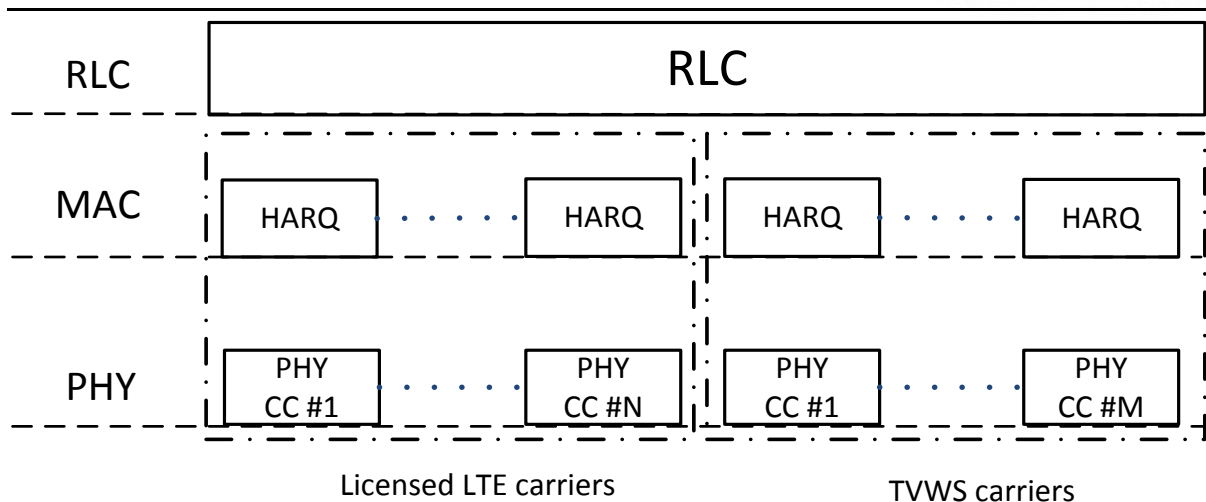


Figure 18: MAC and PHY layer architecture for spectrum aggregation in licensed LTE and LTE (TVWS)

The MAC and PHY layer architecture of spectrum aggregation between licensed LTE and LTE (TVWS) is similar with the one between two licensed LTE, as shown in Figure 18. The data streams are again aggregated at the MAC layer and the data packets are divided in to several parts for different spectrum bands, and transmitted by different carriers at the PHY layer. Both MAC and PHY layers should be compatible with transmitting data on licensed LTE bands and TVWS bands.

6.2 Component level requirements

On the PHY layer, the Rate Adaptation OFDM technique is involved for spectrum aggregation between licensed LTE bands and TWVS bands [5]. The RA-OFDM must be compatible with working on both licensed LTE and TVWS bands.

Key component-level requirements for this scenario are summarized as follows:

- Devices and radio network components must be able to concurrently transmit and receive on licensed LTE and TVWS LTE resources.
 - These resources might optionally be either inter-band contiguous, inter-band non-contiguous, or intra-band contiguous or non-contiguous, or optionally a combination of the above where more than two systems and resource sets are being aggregated.
- Devices and radio network components preferably have a relatively wide-band capability to be able to aggregate the resources in licensed LTE and TVWS LTE – these resources might be adjacent based on higher-frequency TVWS opportunities and LTE 700/800, for example, although it is noted that there are still some regulatory challenges in implementing such a scenario. Such a capability has implications for, e.g., a very high sampling rate being necessary.
 - Devices and radio network components can alternatively have multiple radio chains that are able to be used concurrently to aggregate TVWS LTE and licensed LTE resources.
- Devices must be capable of an RA-OFDM PHY compliant with both LTE bands and TVWS bands.
- Devices and radio network equipment must communicate with a spectrum database on the TVWS LTE side, in order to obtain information on channel usage opportunities in TVWS. Devices and radio network components must be generally compliant with TVWS regulations [7]-[15].

- Devices should preferably be compliant with D2D communications capabilities, as defined in LTE Release 12 [6]. On the TVWS LTE side, devices and networks should also preferably be capable of D2D communications.
- The MAC layer should be able to split or combine the data streams coming from or going to higher layers, and map the sub-divided data to different CCs at the PHY layer on the LTE side and different LTE carriers in TVWS on the TVWS LTE side, for aggregation purposes.
 - A MAC functionality that decides which licensed CCs and TVWS LTE carriers to aggregate, from which systems, must be present, having interfaces and capabilities at each end of the communication link. This functionality must be aware of aspects such as reliability and QoS of the CCs on the licensed LTE side, and on the TVWS LTE side must be aware of the characteristics of the TVWS that might affect QoS, such as communication uncertainty due to competing systems accessing the TVWS, uncertainty in authorized transmit power levels, and other aspects. It must also implement algorithms and/or heuristics for deciding on the resources and spectrum opportunities to map to and aggregate.

7. LTE (Licensed) + WiFi (Unlicensed)

This use-case/application scenario has been defined in D2.1, Section 3.2.2.4 and is quickly recalled here.

7.1 Scenarios and uses cases

The application scenario for the aggregation of WiFi and LTE are small cells with a high number of users and limited spectrum availability in the licensed band. In scenario 1 we consider a single-tier network of small cells, where each cell supports aggregation of LTE and WiFi. Users can aggregate LTE and WiFi carriers, but only originating from one eNB, called integrated LTE + WiFi (ILW) eNB (single flow carrier aggregation). In scenario 2 we consider a two-tier network, with LTE macro cells and WiFi small cells. Here users can aggregate carriers from both tiers simultaneously. In both cases LTE is used as a primary component carrier (PCC) and WiFi as a secondary component carrier (SCC). We will firstly consider the option of using the SCC for downlink (DL) only and secondly for both DL and UL. We will further consider 3 types of user: users that support LTE only; users supporting WiFi only; and users supporting LTE+WiFi aggregation. We will study benefits of aggregation in terms of throughput when both networks are highly loaded.

Figure 19 shows the two scenarios as well as the reference scenario (Scenario 0), where users can connect to either LTE or WiFi, but not to both.

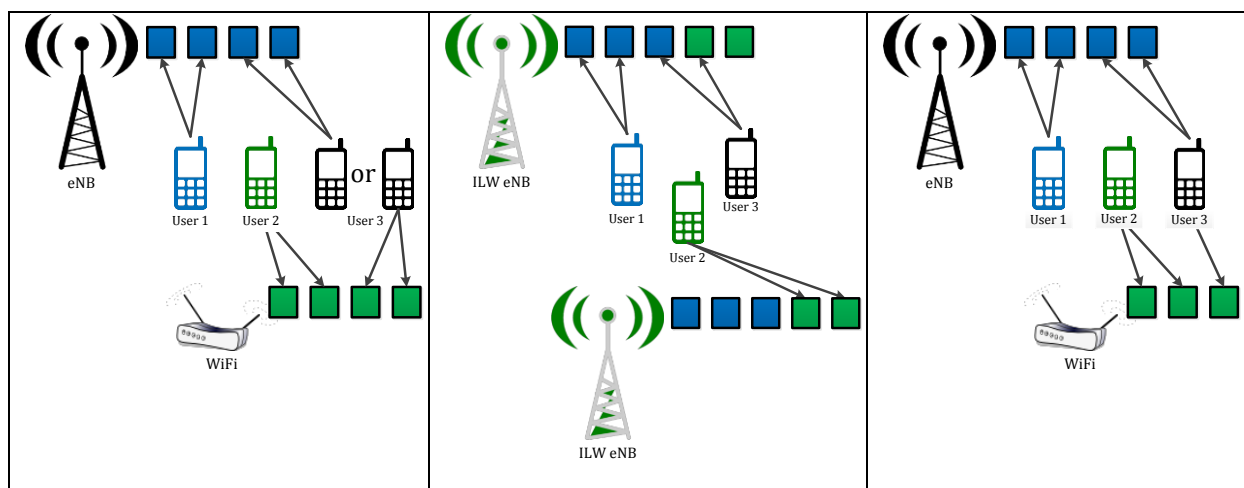


Figure 19: LTE + WiFi aggregation scenarios

7.2 High level architecture

Two different aggregation options will be studied. The first one is depicted in Figure 20 and shows aggregation at layer 3 (IP). The second one is depicted in Figure 21 and shows aggregation on layer 2 (MAC).

7.2.1 Option 1: Aggregation at Layer 3

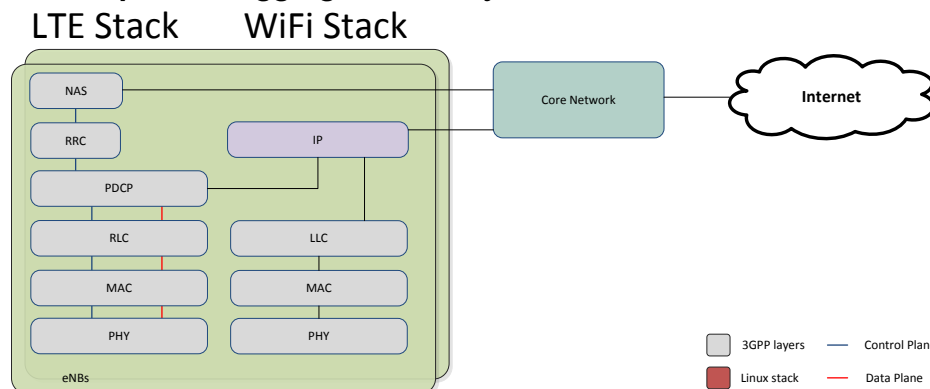


Figure 20: Aggregation of LTE and WiFi at Layer 3 (IP)

7.2.2 Option 2: Aggregation at Layer 2

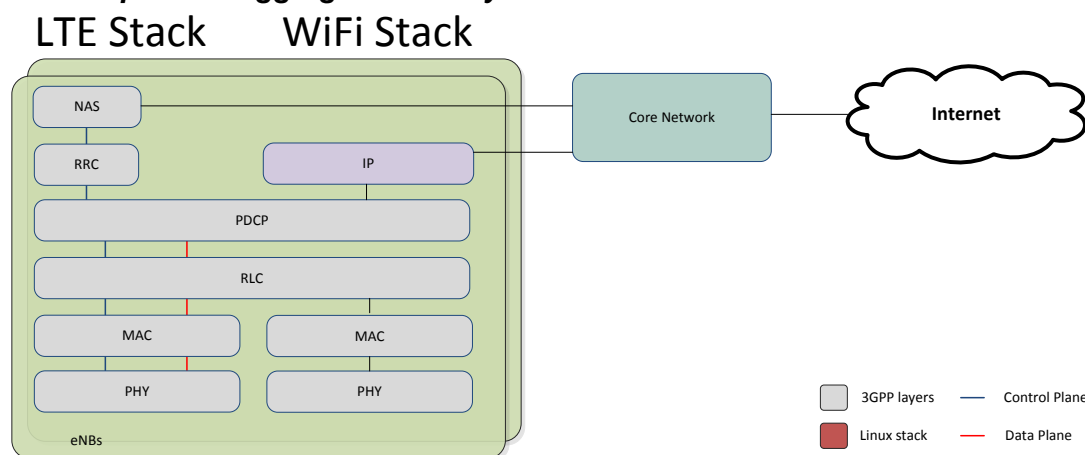


Figure 21: Aggregation of LTE and WiFi at Layer 2 (MAC)

7.3 Component level requirements

The requirements are divided in three groups: one for the simulation studies, one for the proof-of-concept, and one common group.

7.3.1 Common requirements

RRM strategies

For each of the two blocks, strategies for load balancing of multiple carriers shall be developed. The load balancing of multiple carriers is happening either at the IP layer (option 1) or at MAC layer (option 2) and therefore shall take the constraints associated to each layer into account.

RRM Measurements based on 802.21 MIHF

A set of measurements common to LTE and WiFi (using 802.21 MIHF) that can be used by RRM strategies defined above shall be defined.

7.3.2 Simulation studies requirements

Abstraction model for LTE and WiFi

This block is common to both options. The block shall provide an abstraction of the performance of the physical layer of both LTE and WiFi.

Input parameters:

- Code block size,
- Modulation and coding scheme,
- Resource block allocation,
- Channel state (SINR per subcarrier)

Output parameters

- Average block error rate

Scheduler model for LTE and WiFi

This block is applicable to both options. The block shall provide an abstraction of the multi-user scheduler of a single-carrier LTE/WiFi system

Input Parameters

- Number of users
- Users' buffer status
- Users' channel status
- PHY Abstraction model

Output Parameters

- Cell throughput
- Average user throughput
- Average user delay

7.3.3 Simulator requirements

A simulator that implements both scenarios and both options shall be developed.

The following list provide a non-exhaustive list of the input parameters:

- Number of users and traffic type of each user;
- User capabilities (LTE, WiFi, LTE+WiFi);
- Basic geometry and propagation conditions of the scenario.

The simulator shall be able to provide the following results:

- System, Cell and user throughput.

7.3.4 Proof-of-concept requirements

WiFi protocol stack

A 802.11n Wifi software PHY for the OpenAirInterface ExpressMIMO2 target shall be developed. It shall support single layer transmission and a 20MHz bandwidth.

LTE protocol stack

The OpenAirInterface LTE Rel. 10 protocol stack shall be used for the PoC. The carrier aggregation mechanism shall be extended according to Option 2 to include the Wifi protocol stack above.

The implementation shall follow as much as possible the developments on LTE-U in 3GPP LTE release 13.

8. Wifi (UnLicensed) + LTE (TVWS)

8.1 High level architecture

For TVWS LTE - unlicensed WiFi aggregation, LTE provided in TVWS is aggregated with deployed conventional WiFi system capabilities. Again, both D2D and infrastructure-based communication may be aggregated.

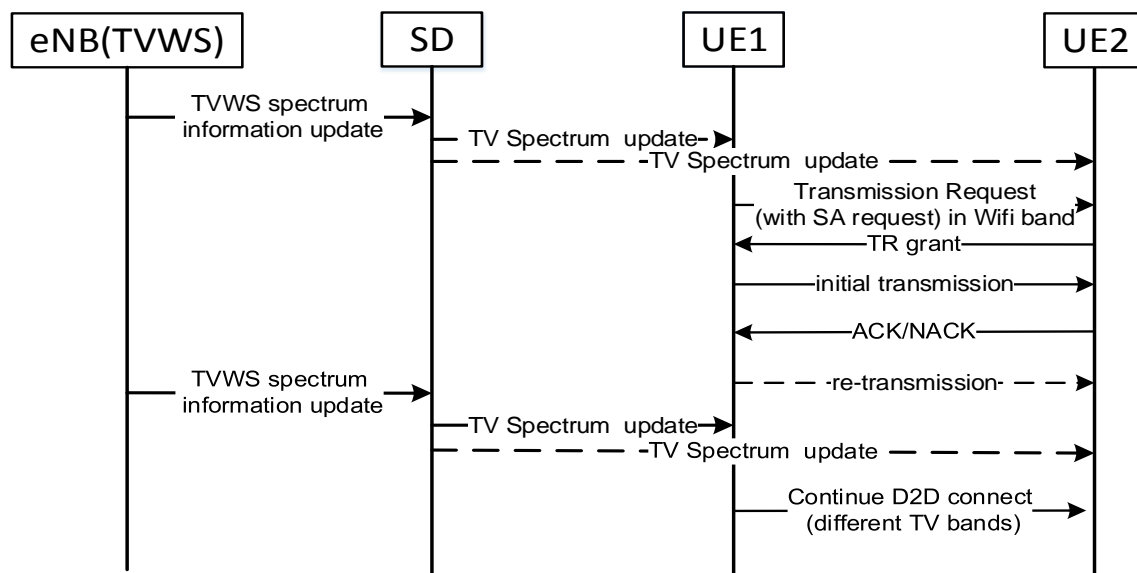


Figure 22: Resource allocation and data transmission procedure for D2D communications with involving spectrum aggregation between unlicensed WiFi and TVWS

For unlicensed WiFi and TVWS LTE aggregation, the D2D devices are compatible with both WiFi and LTE (TVWS), which means they can transmit data on either WiFi or TVWS bands even no spectrum aggregation happening. In TVWS LTE, the eNB (TVWS) would update the TVWS spectrum utilization information of primary TV services to Spectrum Database (SD) periodically. The Spectrum database is responsible for sharing the TVWS spectrum usage information to D2D devices. As shown in Figure 22. The D2D user can aggregate the unlicensed WiFi bands with TVWS bands based on the received spectrum usage information.

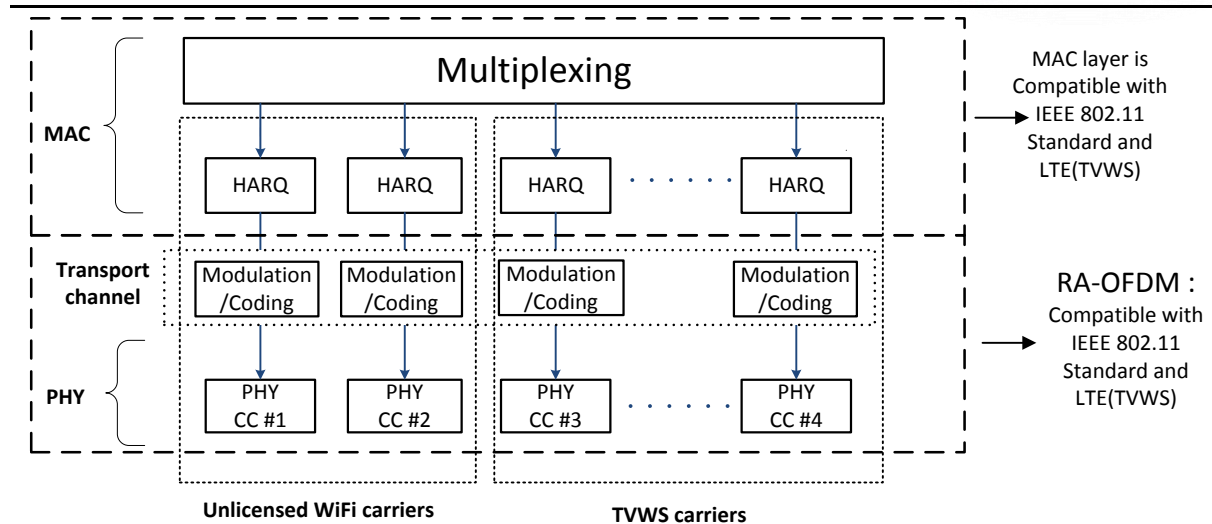


Figure 23: MAC and PHY layer architecture for spectrum aggregation in unlicensed WiFi and LTE (TVWS)

The MAC layer and PHY layer in this case must be compatible with WiFi and LTE (TVWS), as shown in Figure 23. The data streams are again aggregated at the MAC layer and the data packets are divided in to several parts for different spectrum bands, and transmitted by different carriers at the PHY layer.

8.2 Component level requirements

On PHY layer, the Rate Adaptation OFDM technique is involved for spectrum aggregation between unlicensed WiFi and LTE (TVWS) [2]. The RA-OFDM must be compatible with working on both unlicensed WiFi and TVWS bands.

Key component-level requirements for this scenario are summarized as follows:

- Devices and radio network components must be able to concurrently transmit and receive on TVWS LTE and unlicensed (e.g., ISM) WiFi resources.
 - These resources might optionally be either inter-band contiguous, inter-band non-contiguous, intra-band contiguous or non-contiguous, or optionally a combination of the above where more than two systems and resource sets are being aggregated.
- Devices and radio network components must be capable of an RA_OFDM PHY. The PHY layer must be compliant with LTE on the TVWS LTE side, and WiFi on the unlicensed WiFi side.
- Devices and radio network components should be capable of producing carriers on the TVWS LTE side that meet spectrum mask requirements in the regulations for TVWS. On the unlicensed WiFi side, the spectrum mask capabilities must be compliant with relevant regulations for unlicensed bands.
- Devices and radio network equipment must communicate with a spectrum database on the TVWS LTE side, in order to obtain information on channel usage opportunities in TVWS. Devices and radio network components must be generally compliant with TVWS regulations [7]-[15].
- Devices must preferably be compliant with ad-hoc communication capabilities on the unlicensed WiFi side, as defined in IEEE 802.11.
- Devices should preferably be capable of D2D communications capabilities on the TVWS LTE side.

- The MAC layer should be able to split or combine the data streams coming from or going to higher layers, and map the sub-divided data to different carriers at the PHY layer for the TVWS LTE side, and access opportunities on the unlicensed WiFi side, for aggregation purposes.
 - A MAC functionality that decides which CCs and resources to aggregate, from which systems, must be present, having interfaces and capabilities at each end of the communication link. This functionality must be aware of aspects such as reliability and QoS of the TVWS LTE side, and must be aware of the characteristics TVWS that might affect QoS, such as uncertainty in allowed powers, or interference uncertainty due to competing systems in TVWS. On the unlicensed WiFi side, it must be aware of the characteristics of the WiFi that might affect QoS, such as delay uncertainty due to the channel back-off mechanism. It must also implement algorithms and/or heuristics for deciding on the resource opportunities to map to on the TVWS LTE and unlicensed WiFi sides.

9. 5G waveform (Licensed) + 5G waveform (Licensed)

The use-case/application scenario referring to the use of a “5G waveform” has been defined in section 3.2.1.1 of D2.1. In this scenario, we are addressing a carrier aggregation of two or possibly more LTE carriers, operating intra-band, contiguously or non-contiguously, using the same duplex method. The aggregation is performed at the PHY layer thanks to the consideration of an alternative waveform (with regards to LTE-Advanced) called filter bank multicarrier (FBMC). In this scenario, two (or more) component carriers are directly occupied by the same PHY layer. PHY layer carrier aggregation shall be very efficient when the spectrum availability is highly fragmented. By “efficient”, we mean that the interferences generated outside the available spectrum are extremely low. Association of FBMC with PAPR reduction and digital predistortion (DPD) algorithms is expected to reach this goal.

9.1 High level architecture

In this scenario, the carrier aggregation is directly done at the PHY layer since PHY is considered as the multiplexer layer. The multiplexed component carriers, which belongs to the same band (intra-band) and are contiguous or non-contiguous, are multiplexed thanks to a FBMC modulation (Figure 24). Note that upper layers (MAC and RLC) shall comply with this PHY layer carrier aggregation, nevertheless the goal of the FBMC studies in SOLDER is to propose solutions in order to ensure that the radiated signal in space at the transmitted antenna has excellent spectrum properties and generates negligible interferences. For these reasons and for this scenario, the impact on upper layers is out of the scope of SOLDER.

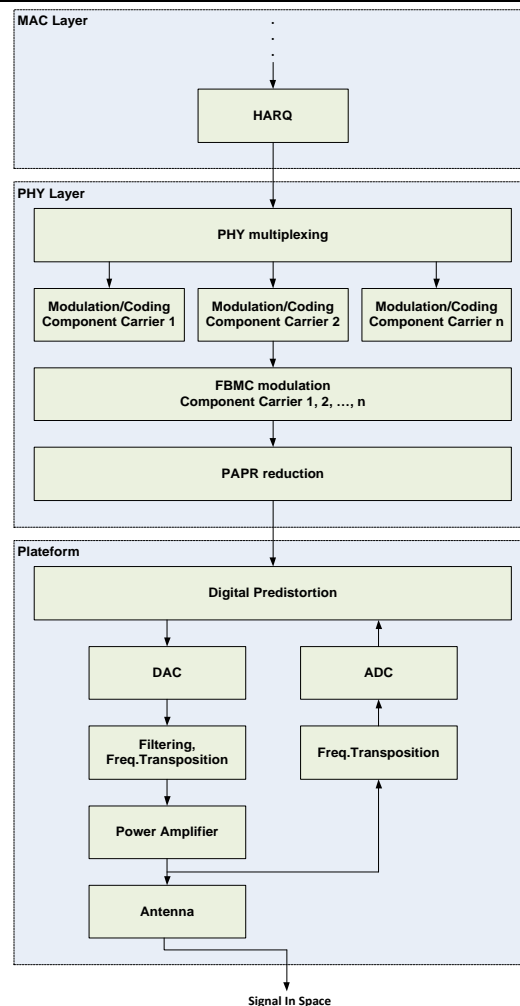


Figure 24: PHY layer and platform architecture for “5G waveform” carrier aggregation

9.2 Component level requirements

In order to address the “5G waveform” scenario, we will work on both terminal and base station sides. The key component-level requirements are summarized as follows:

- Platform requirements
 - The transmitter part of the platform shall be capable to host a digital predistortion processing
 - The platform shall be capable to digitalize an image of the signal at the power amplifier output. In general, the bandwidth of the digitalized signal shall be at least 5 times the bandwidth of the signal to be transmitted.
 - The platform shall be capable to transmit a pre-distorted signal with a single radiofrequency path, and more specifically with a single power amplifier.
- PHY layer requirements
 - The PHY layer shall be capable to split the data streams coming from MAC layer and map the subdivided data to different component carriers with the same PHY access. The considered component carrier aggregation is intra band, contiguous or non-contiguous, preferably in the UHF band.
 - The PHY layer shall be capable to control the peak power distribution (PAPR) of the signal to be transmitted to the front-end to a predefined and deterministic value.

10. 3G+4G+5G

10.1 High level architecture

The coordination of various radio access technologies (RATs) such as LTE/UMTS/GSM/CDMA/WLAN is a very challenging issue for mobile operators. The joint operation of LTE/HSPA requires seamless LTE/HSPA resource management for seamless multi-RAT operation [29][30][31]. A multi-RAT CA scenario may include adjacent carriers and/or non-adjacent carriers. Non-adjacent carriers may or may not belong to the same frequency band, which means that multi-RAT CA may be intra-band (all RATs in same band) or inter-band (at least 2 RATs/carriers in different bands). Non-limiting examples of other multi-RAT CA scenarios are: 1) LTE and CDMA2000, 2) LTE and GSM, 3) LTE, HSPA, and GSM, etc. In SOLDER project, we consider a h-RAT deployment scenario consisting of a macro LTE eNodeB and a HSPA micro-pico cell operating under 3GPP LTE-A standards. Also, different pathloss exponents are assumed for each band to capture the large variation in propagation associated with each CC (primary or secondary).

10.2 Component level requirements

Component requirements for the multi-RAT CA application scenario, wherein 3G technology with 4G technology can be aggregation (i.e. h-RAT scenario), are considered as follows:

- Synchronization for the efficient medium access control: multiple timing issues in multi-CCs environment for synchronization of UL transmissions in the multi-RAT CA. Also, efficient multiple timing advance algorithms so UEs will be able to independently advance or delay their transmission to each CC in order to compensate for the propagation delay.
- Control signaling will be considered for multi-RAT carrier aggregation. In order to support CA in the DL, HARQ feedback (ACK/NACK) i.e., multiple ACK or NACK signals, associated with multiple downlink CCs must be transmitted from a UE using the physical uplink control channel (PUCCH). Therefore, optimum structures for PUCCH could be investigated to achieve better ACK/NACK performance and/or methods to avoid PUCCH collisions [32][33]. More, the use of one control channel (i.e., HS-DPCCH or PUCCH) may be used to send feedback information (e.g., ACK/NACK, CQI, etc.) related to both RAT systems (HSPA and LTE). Apart from reducing BS complexity because only one control channel needs to be demodulated, using one control channel has a number of advantages such as: reduce signaling overheads, eliminate control channel bottleneck, and reduce UE power backoff in HSPA [34]. In this way, a cross-layer optimization will be provided [35].

An LTE-HSPA CA as an h-RAT application scenario will be supported considering a macro BS and a micro or a pico BS. This aggregation scenario will be investigated considering the following parameters:

- UE equipped with one, two or four antennas.
- 4x4, 4x4, 4x2, 2x2 or 2x1 MIMO OFDM DL transmissions,
- EPA, EVA, ITU channel models, which takes into consideration the slow fading parameters (i.e., propagation parameters) in LTE eNodeB.
- Macro LTE-A eNodeB: 10MHz frequency band at 2.6GHz
- Pico HSPA NodeB: 5MHz at 2100MHz.

11. Conclusions

This document has presented the component level requirements of the 9 scenarios that will be applied to prove the SOLDER concept of aggregating heterogeneous bands efficiently, i.e., adapting all layers to such new cognition-aware environments through incorporating

technologies such as opportunistic spectrum usage (e.g., TV White Spaces), and better awareness of communication/link opportunities. These requirements will lead to more detailed specifications in D2.3, which will govern the work to be carried out in the workpackages 3 and 4.

List of Acronyms

Acronym	Meaning
3GPP	3 rd Generation Partnership Project
4G	4 th Generation
ABS	Almost Blank Subframes
AP	Access Point
BER	Bit Error Rate
BS	Base Station
CA	Carrier Aggregation
CC	Component Carrier
CIF	Carrier Indicator Field
CSI	Channel State Information
CoMP	Coordinated MultiPoint
CQI	Channel Quality Indicator
CR	Cognitive Radio
D2D	Device-to-Device
DSM	Dynamic Spectrum Management
DL	DownLink
HetNet	Heterogeneous Network
EAP-SIM	Extensible Authentication Protocol Subscriber Identity Module
eICIC	Evolved Intercell Interference Coordination
eNB	Evolved node B
E-UTRA	Evolved UMTS Terrestrial Radio Access
FBMC	Filter Bank MultiCarrier
FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FFT	Fast Fourier Transform
HARQ	Hybrid Automatic Repeat Request
HSPA	High Speed Packet Access
IFFT	Inverse FFT
IP	Internet Protocol
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
LPN	Low Power Node
MAC	Media Access Control
MAI	Multiple Access Interference
MIMO	Multiple Input Multiple Output
MIH	Media Independent Handover
MT	Mobile Terminal
MU	Multi-User
NC-OFDM	Non Contiguous Orthogonal Frequency division multiplexing
MBB	Mobile BroadBand
NC	Non-Contiguous
NAS	Non-Access Stratum
Ofcom	Office of Communications
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PA	Power Amplifier
PAPR	Peak-to-Average Power Ratio
PCC	Primary Component Carrier

PCell	Primary Cell
PDSCH	Physical Downlink Shared Channel
PHY	Physical Layer
PUSCH	Physical Uplink Shared Channel
PU	Primary User
RRC	Radio Resource Control
RAN	Radio Access Network
RAT	Radio Access Technology
RF	Radio Frequency
RRH	Remote Radio Head
RRM	Radio Resource Management
RSRP	Reference Signal Received Power
SAW	Surface Acoustic Wave
SAP	Service Access Point
SCC	Secondary Component Carrier
SCell	Secondary Cell
SINR	Signal-to-Interference-Plus-Noise Ratio (SINR)
SME	Spectrum Management Entity
SU	Secondary User
TA	Timing Advance
TDM	Time Division Multiplexing
TDD	Time Division Duplex
TVWS	TV White Space
UCI	User Control Information
UE	User Equipment
UL	UpLink
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WWAN	Wireless Wide Area Network

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