MiWEBA

Millimetre-**W**ave **E**volution for **B**ackhaul and **A**ccess

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D3.1: Separation of data and control plane

Deliverable 3.1: Design of mm-Wave Access Links and Integration into Cellular Network Infrastructure

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Abstract

This deliverable investigates the separation of user and control plane in the architecture proposed in the MiWEBA project. Starting from the analysis of control plane in mobile access networks, it discusses special requirements for the control plane in millimeter-wave scenarios with separation, then, it investigates the logical localization of network control functionalities. It finally examines with more details the functional separation architectures proposed in 3GPP and the new context management functionalities required by the proposed architecture.

Keywords

mm-wave radio link, overlay HETNET, control plane and user plane separation, functionality logical localization,

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Abbreviations

Acronym	Description
BS	Base Station
C-plane	Control plane
eGTP	Evolved GPRS Tunneling Protocol
eNB	enhanced NodeB
E-RAB	EUTRAN Radio access bearers
EPS	Evolved Packet System
EU	European Union
GLB	Green Link Budget
HetNet	Heterogeneous network
HO	Handover
JP	Japan
MME	Mobility Management Entity
NAS	Non-Access Stratum
P-GW	PDN Gateway
PDN	Packet Data Network
RAT	Radio Access Technology
RRC	Radio Resource Control
S-GW	Serving Gateway
U-plane	User plane
UE	User Equipment

Executive Summary

One of the key components of the new architecture proposed in the MiWEBA project is the data and control plane separation. The UE possesses two wireless interfaces, one for the legacy connection to the macro cell and one for the connection to a millimeter-wave link. In general the UE is connected to the small cell via the millimeter-wave link when necessary. At the same time the UE, is attached to the macro BS via the legacy communication link. On each physical connection control and/or user data can be transported. Thus, when the UE is connected on both, the legacy and the millimeter-wave interface, two control and two data connections exist. Despite UE double connectivity and control-/user-plane split, control functionalities should not be entirely relegated to one wireless interface. There are some control functions, like channel estimation and beamforming tracking, that must be carried out on the millimeter-wave link. Other functions, instead, can be partially or totally moved to the legacy 4G connection.

In this report we investigate the special requirements for the control plane with respect to millimeter-wave specific characteristics and we discuss the resulting options for the logical localization of network functionalities. For that purpose, we first investigate control plane signaling traffic in mobile access network in order to understand which are the main functions involved and the relationship among the players of signaling procedures.

The analysis of special requirements for the control plane starts from considering the changes needed in the legacy network functions due to the new split architecture, then, the specific properties of millimeter-wave frequency bands are explained, together with existing 60 GHz indoor communication standards. This allows to properly discussing the logical localization of control functionalities.

A final part provides more details on three important aspects related to control and user plane separation: first, functional separation architectures proposed in 3GPP and their critical issues with respect to MiWEBA architecture; second, the new context management functionalities for resource allocation required by the architecture proposed in the MiWEBA project; third, the multiple interface management combined with control-/user-plane split.

1 Introduction

The millimeter-wave overlay system architecture with split user and control planes is shown in Figure 1.1-1. A macro base station provides coverage to all mobile terminals within its coverage area. Millimeter-wave small cell base stations are placed within the area of the macro base station and provide a smaller area of coverage with a millimeter-wave access link. The small cell base stations are connected to the macro base station via a high capacity backhaul. They can be in an active or inactive state, depending on the presence of users within their coverage area. The user terminal possesses two wireless interfaces, one for the legacy connection to the macro cell (e.g. LTE) and one for the connection to a millimeter-wave link. In general the UE is connected to the small cell via the millimeter-wave link when necessary. At the same time the UE is attached to the macro BS via the legacy communication link. On each physical connection control and/or user data can be transported. Thus, when the UE is connected on both, the legacy and the millimeter-wave interface, two control and two data connections exist. One of each to the macro cell and one to the small cell

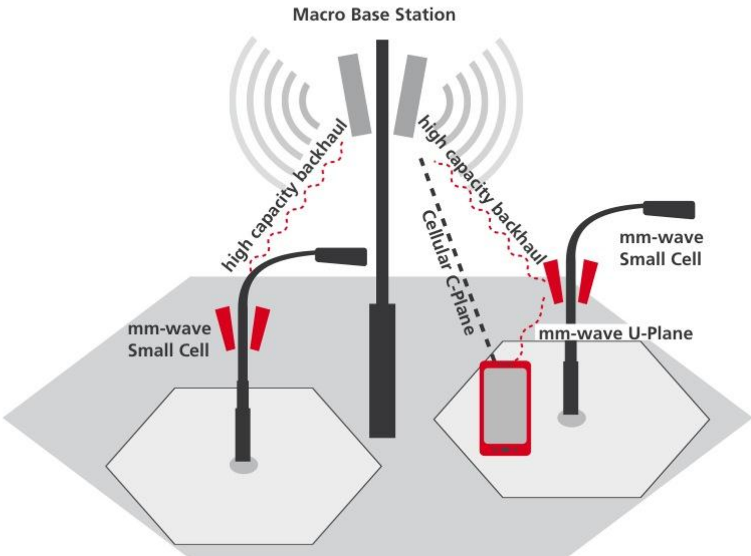

Figure 1.1-1 Reference C-/U-plane split scenario

1.1 Role of the control and data split in the MiWEBA architecture

As introduced in the previous section the concept envisioned for the overlay of millimeter-wave small cells foresees a split of the control and data connection of the UE to the access network. Through this the UE can keep a main control-plane connection active, typically within a long-range macro cell, and activate user-plane connections to different base stations which provide the best data traffic bearers according to both user and network status. Different connection configurations can be possible in order to adapt to different network and traffic layouts, they are explained in *Deliverable D.1.2* [1] . User-plane connections can be established with both macro cells and small cells leaving room for the development of optimized resource allocation algorithms.

Despite UE double connectivity and control-/user-plane split, control functionalities should not be entirely relegated to one wireless interface. There are some control functions, like channel estimation and beamforming tracking, that must be carried out on the millimeter-wave link. Other functions, instead, can be partially or totally moved to the legacy 4G connection. While in *Deliverable D.1.2* [1] we showcased design options for the new architecture, in this report we investigate the special requirements for the control plane with respect to millimeter-wave specific characteristics and we discuss the resulting options for the logical localization of network functionalities.

1.2 Structure of the document

In Section 2 we first investigate control plane signaling traffic in mobile access network by providing a description of message exchange during the main LTE procedures. In Section 3 we analyze special requirements for the control plane in millimeter-wave scenario with separation and discuss the logical localization of control functionalities. In Section 4 provide more details on three important aspects: 1) functional separation architectures proposed in 3GPP and their critical issues with respect to MiWEBA architecture, 2) the new context management functionalities for resource allocation required by the proposed architecture, 3) the multiple interface management combined with control-/user-plane split.

2 Analysis of C-plane and signaling traffic in mobile access

In this section we focus on the main signaling procedures involved in mobile network operations. We analyze the signaling message exchange in LTE networks as thay can be assumed to be the conventional network technology in the next years. The goal of this analysis is twofold: 1) representing a reference for the extended control protocol to be discussed in *Deliverable D.3.2* and 2) providing a support to identify the basic control functions in the split architecture, whose requirements for mm-wave cells are discussed in the next sections.

We showcase the following network procedures: UE Attach, data call initiation, data call release and intra-RAT handover. The analysis has been carried out by considering 3GPP recommendations: TS 29.274 "*Tunnelling Protocol for Control plane (eGTP-C)*" [2], TS 36.413 "*S1 Application Protocol (S1AP)*" [3], TS 24.301 "*Non-Access-Stratum (NAS) protocol*" [4], TS 36.331 "*Radio Resource Control (RRC): Protocol specification*" [5], TS 36.423 "*X2 Application Protocol (X2AP)*" [6].

2.1.1 UE Attach

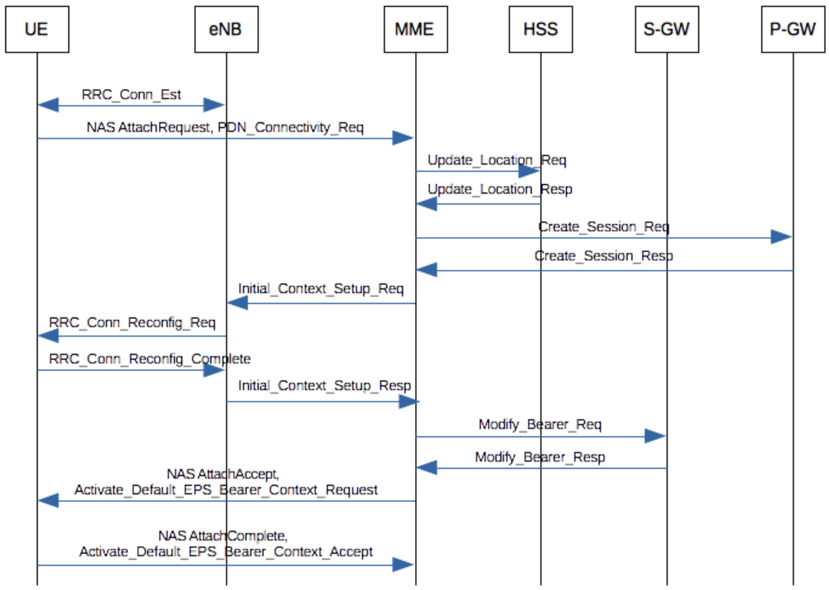

Figure 1.2-1 UE attach procedure.

The message exchange is shown in Figure 1.2-1. The flow proceeds as follows:

- **UE->eNB:** UE establishes the RRC Connection with the eNB.
- **eNB->MME:** The eNB establishes the S1 logical connection with the MME for this UE (the UE sends the ATTACH REQUEST message together with a PDN CONNECTIVITY REQUEST for the PDN (IP) connectivity on the established RRC Connection).

- **MME->HSS:** The MME update the HSS with the location of the UE using the Update_Location_Request message (*using the Diameter protocol*). It also requests the subscriber profile from the HSS using this message.
- **HSS->MME:** The HSS updates its database with the current location of the UE and sends the subscriber profile information to the MME in the Update_Location_Response message.
- **MME->S-GW:** The MME now establishes an eGTP User Tunnel to establish the default bearer at the S-GW. It sends a Create_Session_Request (*eGTP-C protocol*) to the S-GW.
- **S-GW->MME:** The S-GW creates the default bearer for this UE and requests the P-GW **(MME->P-GW)** to create a bearer for this UE between the S-GW and the P-GW to provide end-to-end bearer connectivity. The P-GW then creates the bearer and allocates an IP Address for the UE. The S-GW responds with a Create_Session_Response to MME.
- **MME->eNB:** The MME now has to establish the bearer between the eNB and S-GW. It sends the Initial_Context_Setup_Request (*S1AP*) to the eNB to create a context for this UE, which includes the bearer context and the security context.
- **eNB->UE:** The eNB reconfigures the resources to the UE by sending an RRC_Connection_Reconfig_Request to the UE (in this message, the eNB piggy-backs the Activate Default EPS Bearer Context Request NAS message to the UE).
- **UE->eNB:** The UE updates its RRC connection configuration and responds back with an RRC_Connection_Reconfig_Complete message.
- **eNB->MME:** The eNB sends the Initial_Context_Setup_Response to the MME.
- **MME->S-GW:** The MME sends the Modify_Bearer_Request (*eGTP-C*) to the S-GW to update the eNB Tunnel Id for the default bearer.
- **S-GW->MME:** The S-GW responds with a Modify Bearer Response to the MME.
- **MME<->UE:** The MME now sends the Attach_Accept and Activate_Default_Bearer_Context_Request NAS message to the UE. The UE piggy-backs the Activate Default EPS bearer context Accept NAS message to the MME.Data

2.1.2 Call Initiation

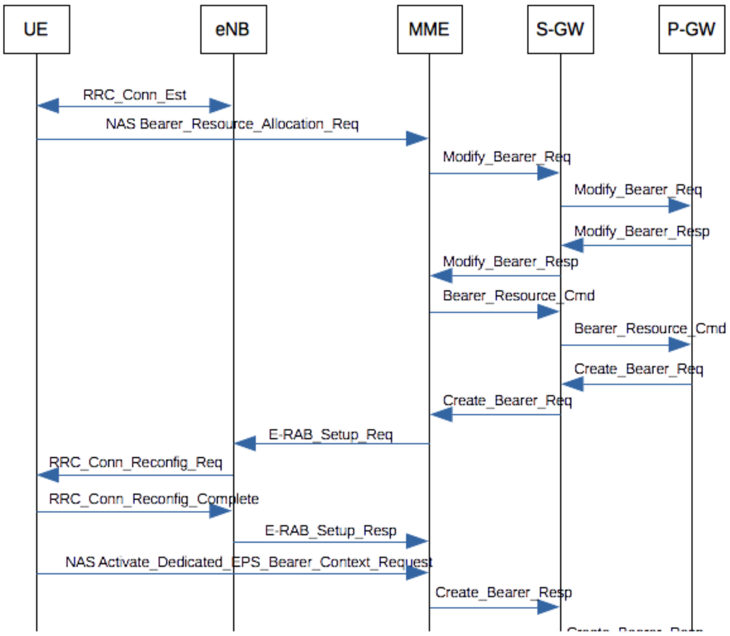

Figure 1.2-2 Data call initiation.

The message exchange is shown in Figure 1.2-2. The flow proceeds as follows:

- **UE->eNB:** UE establishes the RRC Connection with the eNB.
- **UE<->MME:** The UE sends NAS Messages (e.g. Service_Request) to the MME and requests (dedicated) bearer resources by including the Bearer_Resource_Allocation_Request. The eNB establishes the S1 logical connection with the MME for this UE. (the UE may also send the Bearer_ResourceAllocation Req to the MME as a standalone message at a later point in time as well).
- **MME->S-GW:** The MME initiates the activation of default bearer with the S-GW& P-GW by initiating the Modify_Bearer_Req message (*eGTP-C*) towards the S-GW.
- **S-GW->P-GW:** The S-GW activates the required resources and forwards the request to the P-GW.
- **P-GW->S-GW:** The P-GW activates required resources (the IP Address is allocated during the 'attach procedure' not now). It responds back with the Modify_Bearer_Response to the S-GW.
- **S-GW->MME:** S-GW forwards the response to the MME.
- **MME->S-GW:** MME now initiates the Dedicated Bearer establishment by sending the Bearer_Resource_Cmd (*eGTP-C*) to the S-GW.
- **S-GW->P-GW:** The S-GW forwards the command to the P-GW.
- **P-GW->S-GW:** The P-GW responds with a Create_Bearer_Request to the S-GW after allocating the dedicated bearer resource.

- **S-GW->MME:** The S-GW forwards the request to the MME.
- **MME->eNB:** The The MME sends the E-RAB_Setup_Request to the eNB to allocate the bearer between the eNB and the S-GW; it piggy-backs the NAS Activate_Dedicated_EPS_Bearer_Context_Req to the UE.
- **eNB<->UE:** The eNB allocates the resources for the Radio bearers using an RRC_Connection_Reconfig message to the UE. The eNB includes the received NAS message in it.
- **eNB->MME:** Radio bearers are established between the eNB and the UE by now (the eNB sends the E-RAB_Setup_Response to the MME).
- **UE<->MME:** The UE sends the NAS message (Activate Dedicated EPS Bearer Context Accept) to the MME via the eNB.
- **MME->S-GW:** The MME sends a Bearer_Response to the S-GW to complete the Dedicated Bearer Activation.

2.1.3 Data Call Release

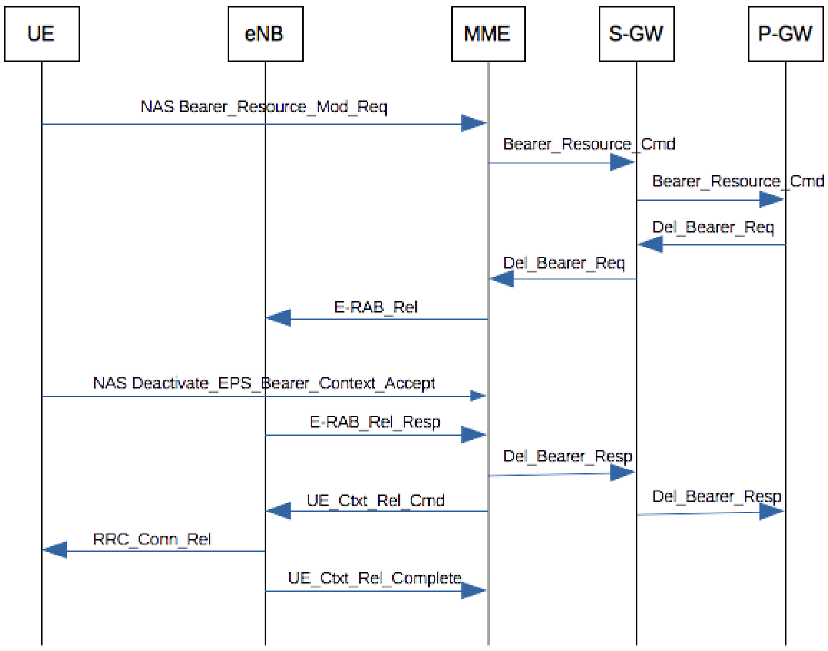

Figure 1.2-3 Data call release.

The message exchange is shown in Figure 1.2-3. The flow proceeds as follows:

- **UE ->MME:** The UE triggers a resource modification by sending the Bearer Resource Modification Req message to the MME, which can then take care of releasing the dedicated bearer with the SGW and PGW.
- **MME -> S-GW:** MME now initiates an EPS bearer context deactivation procedure by sending the Bearer_Resource_Cmd (*eGTP-C*) to the S-GW.

- **S-GW -> P-GW:** The S-GW processes the command and forwards it to the P-GW.
- **P-GW -> S-GW:** The P-GW initiates the Delete_Bearer_Request to the S-GW to clear the requested bearer resources.
- **S-GW -> MME:** The S-GW forwards the request to the MME.
- **MME -> eNB:** The MME initiates the E-RAB Release Command to the eNB to clear the bearer resources.
- **UE -> MME:** UE clears bearer resources and sends a Deactivate EPS Bearer Context Accept to the MME.
- **eNB -> MME:** The eNB sends the E-RAB Release Response to the MME.
- **MME -> S-GW:** The MME sends the Delete Bearer Response to the S-GW.
- **S-GW -> P-GW:** The S-GW forwards the command to the P-GW after clearing the bearer resources, which, in turn, deletes the bearer resources.
- **MME ->eNB:** After the release of the last UE resource, MME releases the context associated with this UE by sending a Context Release Command.
- **eNB -> UE:** The eNodeB clears the radio resources allocated to this UE by sending the RRC Connection Release message to the UE.
- **eNB -> MME:** The eNodeB sends the UE Context Release Complete message to the MME.

2.1.4 Intra-RAT Handover

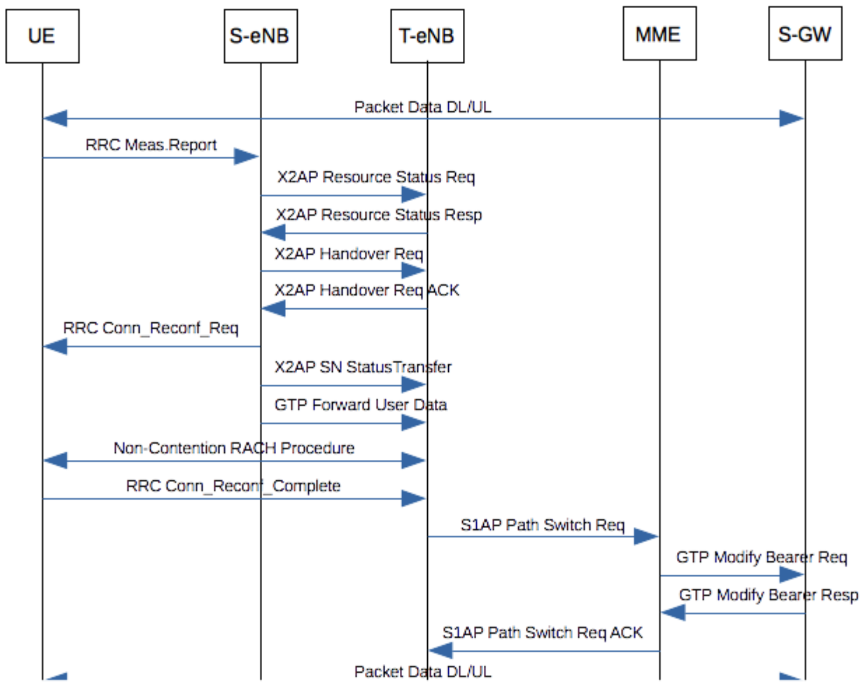

Figure 1.2-4 X2 intra-RAT Handover

eNB monitors UE radio resource quality via RRC Measurement Report messages periodically sent by UE. Whenever handover algorithm indicates the need of handover, source eNB triggers the handover procedure. In case interface X2 is

implemented, source eNB and target eNB can directly interact via X2AP protocol. The message exchange is shown in Figure 1.2-4. The flow proceeds as follows:

- **S-eNB -> T-eNB:** S-eNB sends to neighboring T-eNB a Resource Status Request message to initiate the requested measurement according to the parameters given in the message. Typically, this message is used to gather information on the load of T-eNB.
- **T-eNB -> S-eNB:** T-eNB sends to neighboring S-eNB a Resource Status Response message to indicate that the requested measurement, for all or for a subset of the measurement objects included in the measurement is successfully initiated.
- **S-eNB -> T-eNB:** The S-eNB sends a Handover Request message to the T-eNB passing information about UE context and RB context to prepare the handover.
- **T-eNB -> S-eNB:** The T-eNB checks for resource availability and, if available, reserves the resources and sends back the Handover Request Acknowledge message.
- **S-eNB -> UE:** The S-eNB sends Connection Reconfiguration Request message to UE in order to perform the handover.
- **S-eNB -> T-eNB:** S-eNB sends a Status Transfer message to T-eNB to transfer the uplink/downlink PDCP SN and HFN status during a handover.
- **S-eNB -> T-eNB:** S-eNB forwards downlink user data to T-eNB.
- **UE -> T-eNB:** UE tries to access the T-eNB cell using the non-contention-based Random Access Procedure. If it succeeds in accessing the target cell, it sends the Connection Reconfiguration Complete to the T-eNB.
- **T-eNB -> MME:** The T-eNB sends a Path Switch Request message to the MME to inform it that the UE has changed cells.
- **MME -> S-GW:** The MME sends a Modify Bearer Request message to the S-GW.
- **S-GW -> MME**: The S-GW sends downlink packets to the T-eNB using the newly received addresses and replies with the Modify Bearer Response message to the MME
- **MME -> T-eNB:** The MME responds to the T-eNB with a Path Switch Request Ack message to notify the completion of the handover.
- **T-eNB -> S-eNB:** The T-eNB requests the S-eNB to release the resources using the Context Release message.

If X2 interface is not implemented, the message exchange is shown in Figure 1.2-5.

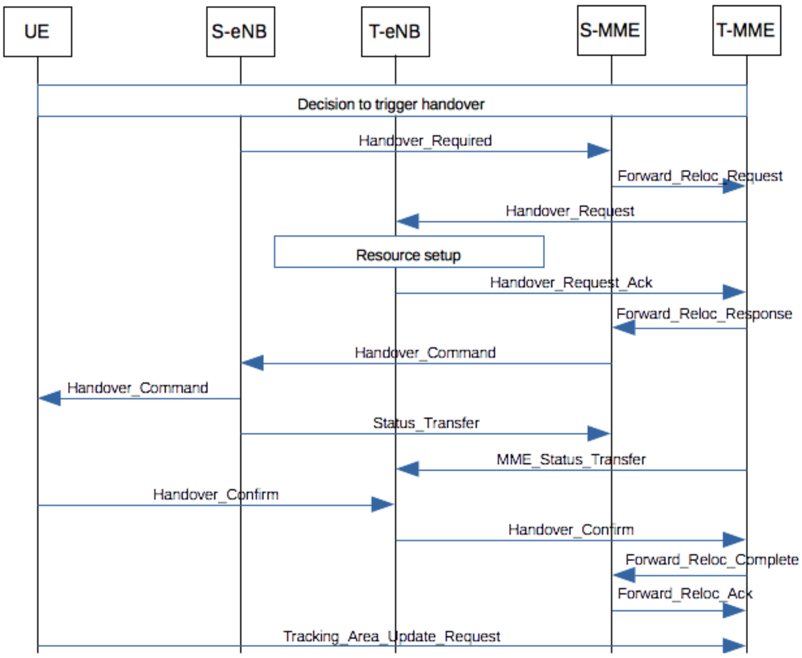

Figure 1.2-5 Intra-RAT Handover

2.1.5 Identification of network functions

The signaling message exchanges described in this section highlight the four main network control functions that need to be investigated in the mm-wave C-/U-plane split scenario:

- Service Access and Paging: how UE can ask for a new session to be set up, both UE-originated and network-originated.
- Resource Selection and Activation: once the UE's request has been received, the best set of resources to serve the request must be found among the available network resources.
- Context Management: the proper selection of network resources can be better carried out if a precise and complete knowledge about user and network context is available.
- Session and Mobility Management: mm-wave cells are characterized by limited coverage, therefore the management of the mobile connections is of utmost importance.

In addition, there are other functionalities, which are part of the above main control functions, which deserve a special attention in the mm-wave scenario:

- Cell discovery: this is an important issue since a mm-wave base station must point its directional antenna to a UE, and vice versa, in order to let UE detect the cell and establish a session.
- Location Update: since UE may have multiple simultaneously active connections, it is important to define which connected base station is in charge of managing location updates.

- Beamforming tracking: the beamforming tracking is crucial for mm-wave connectivity as links continuously change. Updates of beamforming vectors have to be delivered over one of the active connections.

The following sections discuss these functionalities within the MiWEBA framework.

3 Analysis of C-plane requirements for mm-wave cells

3.1 Basic control functions in the split architecture

The C-\U-plane separation requires the modification of the way of dealing with basic functionalities of the network architectures opening the way to new challenges and opportunities. In the following we analyze the behavior of the main four control functions in the new split scenario: Service Access and Paging, Resource Selection and Activation, Context Management, Session and Mobility Management.

The Service Access and Paging function is the one that requires the fewest modifications, as it is mainly a pure signaling function. The only difference introduced by the C-\U-plane split with respect to legacy 4G systems is that the base station the UE connects to for access and paging services may not be the same used to establish a radio bearer for data communication.

In legacy systems, Resource Selection and Activation is in charge of selecting and allocating the radio resources necessary to serve a user request at the base station where the request has been addressed. Resource selection procedures are a key component of the new architecture to provide a high-rate data connection to a wide set of users. In order to do that, these procedures must have a network-global perspective and take into account not only the context information on the service request, but also the status of the network and their devices. Indeed, UEs that a mm-wave base station is already serving may impact on the ability of efficiently serving new UEs.

Generally speaking, even the selection and (if required) activation of a mm-wave base station able to serve a user request given the context information discussed above may be a difficult task. Unfortunately, optimizing this decision process is much more complicated. The identification of an optimization objective is not easy as well, due to the obvious tradeoff between energy cost and performance and the number of constraints involved for quality of service requirements, terminal capability limitations, technologies of base stations in range, and available radio resources.

Traditional signaling mechanisms adopted by current cellular technologies interact with user terminals to get information on the service requests and with the network elements necessary to provide the service. At the radio interface, the user terminal issues service requests to the same base station that then allocates the resources to serve the requests. Differently, the C-plane infrastructure of the new architecture needs to get more information from the users due to the possible separation of the signaling base station that receives user requests and the base station of the data network that then allocates resources. This richer information is required in order to characterize what can be called the “context” of a service request. The context is the key element that allows the signaling network to activate appropriate resource selection algorithms for the data network.

A first and fundamental information to be included in the context is the user terminal location with respect to the access points or base stations that can potentially serve its request. This is obviously not necessary in traditional systems since the base station

that gets the service request is the same that serves it. The location service used for estimating user terminal position can be part of the functionalities provided by the new signaling network or be provided by external systems. Several localization systems can be also used in parallel in order to obtained the best possible estimation to be used by the mobile network when necessary, according to scenario (e.g. outdoor or indoor) and services supported by the terminal (e.g. satellite positioning).

Position information may not be sufficient to identify the most appropriate base station since the quality of the radio channel among user terminal and closest base station may be poor due to obstacles and propagation impairments. It is therefore necessary to map appropriately the location information to estimations of the quality of radio channels with base stations in the visited area. The system can use for example measurements provided by the terminals during active data sessions, which can be stored together with positions and then used for future requests. When some of the access devices of the data network are active, a beaconing mechanism like those commonly implemented by current wireless technologies can be adopted to complement position estimations and enrich context information.

Not only the location of user terminal at the moment of the service request, but also its estimated mobility can be an important element to characterize the context. Information on user mobility can help to identify the base station to activate, avoiding for instance to select a cell that with high probability will be quickly left by the terminal during its movement. During data session, mobility estimation is crucial to select and activate the available base stations to which the session needs to be handed off following the user trajectory within the coverage areas.

In addition to location and channel quality, other information that can help the resource selection process of the new architecture, such as terminal capabilities (supported data network technologies, transmission rates, power, etc.) and user profile (service level agreed with the provider, required quality of service, preferences on different access options, user category, etc.).

The C-\U-plane split is particularly suitable for managing heterogeneous wireless technologies as it reverses the classical approach to network selection. Since the access to communication service is mediate, it is no longer the user terminal that selects the access point, but this is basically delegated to the network. This allows a more flexible and intelligent management of traffic with the set of technologies and radio resources available through algorithms that are able to take into account the status of the whole system. The design of these new algorithms is an interesting technical challenge since several issues can be considered including specific resource management policies of mobile operators. Mobility management among different data networks during active communication sessions is also an important aspect of the problem with, however, the advantage of the new system architecture to be in full control of resource selection.

The whole set of these advantages, however, has the cost of requiring higher coordination for orchestrating base station services and increasing the complexity of the system.

3.2 C-plane requirements for mm-wave channel

This section investigates the specific properties of the millimeter-wave frequency bands and their implications for the user/control plane split architecture. Based on a review of existing standards for 60 GHz indoor communication the choices and challenges for the split plane design are investigated.

3.2.1 Specific properties of millimeter-wave frequency bands

The millimeter-wave band between 30 and 300 GHz recently received increasing interest for new communication standards to overcome the shortage of spectrum [7]. The increase in carrier frequency however leads to a higher pathloss. In free-space conditions the Friis equation shows that the received signal power is inversely proportional to the carrier frequency.

Several measurement campaigns of outdoor millimeter-wave channels were reported recently [8] [9] [10] [11]. The time dynamic behavior of the link and especially of the spatial multipath components is important for the design and parameterization of the beam forming algorithms in the millimeter-wave band. An analysis of channel measurements performed at 60 GHz in a busy urban outdoor access scenario shows that the different multipath components arriving at the receiver can be grouped into different classes, according to their availability over time [12]. Figure 3.2-1 shows the behavior of the omnidirectional channel impulse response for static transmitter and receiver locations on a busy urban street over a time of 50 seconds (see [10] [11] [12] for more details). Multipath components with a path loss of less than 120 dB are shown in blue. This threshold represents the maximum allowable path loss for communication and depends on the system implementation (e.g. antenna gain, noise figure, transmit power, modulation). It was chosen arbitrarily here. The distance between transmitter and receiver was 25 meters, which can be clearly seen by the constant path of the unblocked line of sight component at around 80 ns delay. Other multipath components at higher delays are caused by reflecting objects, such as the ground, surrounding buildings, street furniture, cars, etc. It can be seen that some exist throughout the measurement and are only interrupted while others only appear for a short period of time. In order to counter the higher path loss compared to sub 6 GHz communication systems, millimeter-wave communication systems have to use directional antennas with high gain. To support mobile devices in outdoor environments the direction of the beam will need to adapt to the changing radio channel very fast, thus making electronic beam forming or beam steering, such as beam forming arrays necessary.

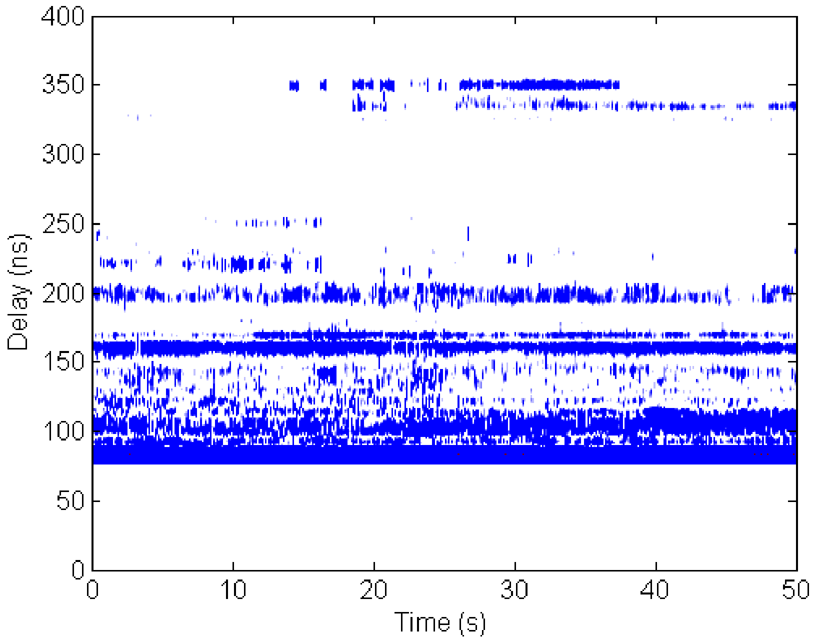

Figure 3.2-1: Time evolution of 60 GHz outdoor channel impulse response

A thorough statistical analysis of this multipath component behavior over time is still open work. When assuming a blocked line of sight however, there are still a number of candidate multipath components that could be used to establish a directional link between the transmitter and the receiver, assuming that different multipath components stem from different spatial directions. The frequent interruption of some multipath components however indicates that a frequent switching between spatial directions might be necessary for a stable connection.
In cases when all multipath components between the transmitter and the receiver are too weak to support a communication link, the connection would have to fall back to the legacy connection.

3.2.2 Existing 60 GHz indoor communication standards

A number of standards were defined during the last few years for very high data rate indoor communication at 60 GHz. The standards ECMA-387 and IEEE 802.15.3c were published in 2009 but no products were released so far based on them. The standard IEEE 802.11ad was published in December 2012, based on a standard that was previously developed by the WiGig Alliance [13]. This part of the IEEE 802.11 standard also recently got part of the Wi-Fi Alliance.

The rest of this section focuses on IEEE 802.11ad as it is the most recent standard and due to it being part of a family of sub 6 GHz transmission protocols. Nevertheless all three standards share some basic concepts, such as channel bandwidth, channelization and directional transmission with beamforming antennas.

3.2.2.1 Overall topology

The standard IEEE 802.11ad builds on top of the other IEEE 802.11 WPAN standards and introduces the extension to 60 GHz. In this extension one of the participating stations of a network or an access point (AP) takes the role of the PCP

(personal basic service set control point) and provides basic timing information to all stations nearby.

The radio transmissions are organized in so called beacon intervals, shown in Figure 3.2-2. Within a beacon interval there is a beacon header interval (BHI) and a data transfer interval (DTI). In the BHI one or multiple beacon signals (BTI) are transmitted by the PCP, some basic beamforming training (A-BFT) can be performed and announcements can be transmitted (ATI). The DTI consists of a contention-based access period (CBAP) and a contention free service period (SP).

While the stations can compete for access during the CBAP, the PCP schedules the transmissions according to the demand during the SP. Special care is taken to reduce interference that might occur through neighboring PBSS.

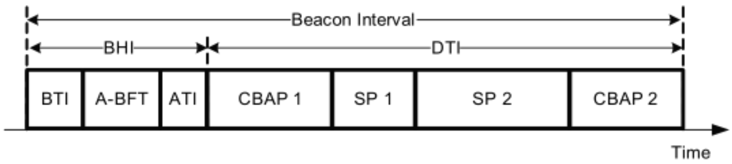

Figure 3.2-2: An IEEE 802.11ad beacon interval (BI) structure

3.2.2.2 Beacon and discovery

The beacon signal is transmitted by the PCP during the beacon transmission interval, as previously shown. During this interval the PCP can transmit multiple beacon signals in different spatial directions. As information on the spatial transmission is included in the beacon this is also the first step for the beamforming training.

3.2.2.3 Beamforming support

For any pair of communicating stations there is a total of 4 beamforming vectors that needs to be trained: transmit and receive vectors for each station. When the hardware supports reciprocity by using the same antenna array for transmission and reception and calibrated phase shifters, only one vector has to be trained per station.

The beamforming training is performed at the setup of a communication link and consists of the two phases sector-level sweep (SLS) and beam refinement protocol (BRP). A beam tracking protocol is used to update the beamforming vectors in an established link.

All protocols are based on the selection of the best performing beamforming vector out of a selection of candidates, for example from a code book. Multiple transmit beamforming vectors are applied sequentially and receiver feedback highlights the best one. This beamforming technique was developed for indoor environments and its applicability to outdoor environments with much larger distances and possibly higher time variance remains an open issue.

3.2.2.4 Fast session transfer

Fast session transfer (FST) allows transferring a session from one physical channel to another channel (i.e. frequency band). A session is the state information that is kept in a pair of stations that have an established direct physical link. The FST allows the stations e.g. to switch to the 2.4 GHz band when reaching the limits of coverage at 60

GHz. Each station can initialize or request the fast session transfer and it completes when both stations have established a connection in the new band.
From its design this approach is independent of the concrete implementation of the physical channels and does not rely on dedicated stable control channel. Such a channel however, as it is available in the split plane concept, could be used to improve the seamless transfer between the different channels or bands.

3.2.2.5 Frame format

The frame format is shown in Figure 3.2-3. A frame consists of a preamble, a header, the data payload and optional beamforming tracking (TRN) fields. The preamble is composed of a short training field (STF) and the channel estimation (CE) sequence. Both of these fields use special concatenations of Golay sequences. The short training field is used for AGC training, frequency offset estimation, synchronization and determines the type of frame (e.g. control frame, OFDM frame, single carrier frame). The channel estimation sequence is designed in a way that allows efficient calculation of the channel impulse response.

The header contains various fields, depending on the type of the frame. Fields can be the definition of the modulation and coding scheme (MCS) of the payload symbols, the number of payload bits, beamforming tracking requests, etc.

The optional beamforming tracking fields are inserted upon request and can be transmitted for receiver (R) or transmitter (T) tracking.

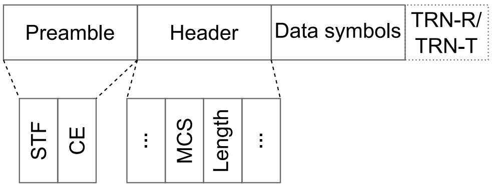

Figure 3.2-3: IEEE 802.11ad frame format

3.2.2.6 Applicability to outdoor access

The general topology of IEEE 802.11ad is similar to what would be needed for an evolution of wireless radio networks with millimeter-wave overlay cells. These small cells might advertise their existence with beacon signals and will coordinate the communication. They will also have to take care of beamforming training and tracking, which might become even more challenging in dynamic outdoor environments, compared to the indoor environments targeted by IEEE 802.11ad.
The fast session transfer is a building block that is also needed for outdoor access. Its implementation in IEEE 802.11ad however relies on a stable link in the old band. This might be problematic when this link gets suddenly lost. By relying on a separate, more stable control plane the reliability of the fast session transfer could be increased.
The frame format and the physical layer (PHY) (not described here in detail) could form a basis for a millimeter-wave outdoor access system. The challenges of initial synchronization, channel estimation, etc. are well addressed for wide bandwidth channels. Regular beam tracking is also included, though this might need to be extended.

3.2.3 Split plane concept

As described earlier, the concept envisioned for the overlay of millimeter-wave small cells foresees a split of the control and data connection of the UE to the access network. Through this the UE can keep a main control-plane connection active, typically within a long-range macro cell, and activate user-plane connections to different base stations which provide the best data traffic bearers according to both user and network status. Different connection configurations can be possible in order to adapt to different network and traffic layouts [1]. User-plane connections can be established with both macro cells and small cells leaving room for the development of optimized resource allocation algorithms. In this scenario two types of mobility can be identified, a so-called small-scale mobility, where the UE moves within the coverage of a single control-plane macro cell and performs user-plane handovers through small cells, while traditional mobility occurs when the UE crosses macro cell boundaries.

3.2.3.1 Time dynamic behavior

Two aspects of time dynamic behavior that might have a great impact on the design of the split plane concept are worth mentioning. One is the behavior of a UE with respect to the coverage area of a small cell and the other is the implications of the kind of traffic that is requested by the UE.

UE behavior

Several possible behaviors of the UE with respect to its position within the macro cell can be identified: entering a small cell, staying or moving within a small cell, exiting a small cell. Even the type of mobility is important: very fast users with irregular trajectory can be difficult to serve with millimeter- wave small cells, while users with predictable trajectory can be served by properly allocating resources in advance.

Traffic model

The traffic model or type of traffic has a great impact on the way the control functionality should behave. While traffic with fully buffered maximum demand simply requires a continuous high speed data connection two other cases are more challenging. One would be sporadic or regular high data traffic demand with gaps between transmissions (Figure 3.2-4, left) and the other would be low or medium rate continuous traffic (Figure 3.2-4, right).

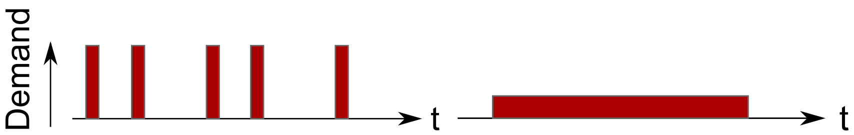

Figure 3.2-4: Traffic models (left: sporadic, right: constant)

In the case of intermitted traffic the decision has to be made whether the connection between the UE and the millimeter-wave small cell should remain active. When it is kept active the beamforming vectors have to be updated, even though the link is unused. In the case of low or medium rate traffic the decision has to be made whether the millimeter-wave or the legacy wireless connection should be used. For these decisions a number of factors, such as total traffic demand, link quality, and power

consumption of components or links have to be taken into account. Also the delay tolerance of the requested service is an important factor, it may or may not allow buffering techniques to help network reconfigurations.

3.2.4 Logical localization of control functionality

Despite UE double connectivity and control-/user-plane split, control functionalities should not be entirely relegated to one wireless interface. There are some control functions, like channel estimation and beamforming tracking, that must be carried out on the millimeter-wave link. Other functions, instead, can be partially or totally moved to the legacy 4G connection. Generally speaking, 4G connection is more avaialable, has higher reliability and requires fewer handovers than the millimeter connection, therefore, it can be used for exchanging information not directly related to the use of millimeter-wave resources, but rather, to critical network management functions, like session setup, location update and context acquisition. In addition, control functionalities, having no strict bandwidth requirements, can waste millimeter-wave resources, which are better suited for high-rates and would be less efficiently utilized.
We can divide the control plane in two sub-planes: macro cell control plane (on legacy 4G connection) and small cell control plane (on millimeter-wave link). We discuss the control function allocation on each sub-plane in the following paragraphs.

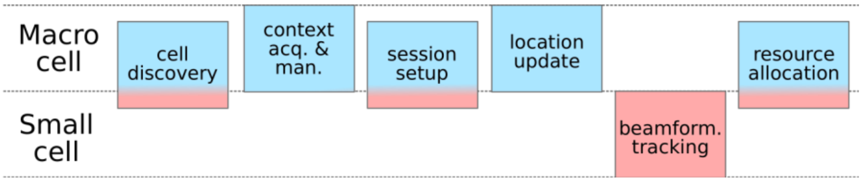

Figure 3.2-5: Control functionality and possible localization on control plane

Cell discovery

The UEs discovery and attachment to a macro cell base station is made as usual. The discovery of millimeter-wave small cell base stations does not necessarily have to be performed continuously but only when needed or requested. Discovering available small cells becomes more complicated with the increased path loss in the millimeter-wave bands. This requires either omnidirectional modes with low data rates and signal processing gain (e.g. spreading sequences) or directional antenna patterns with a certain gain. The support of a separated control-plane connection established with a macro cell becomes crucial to provide information for a fast discovery. The information can go from a minimal list of millimeter-wave small cell positions to a smart antenna configuration suggestion to connect to the best small cell.

Context acquisition and management

In order to make smart choices for cell discovery the system must rely on a rich context about UE and network status. The network collects information on UE position, antenna configurations, related channel quality and builds a context database that is used to predict the performance experienced by future UE requests at the same position. This information, together with UE type, capabilities, and traffic

requirements, is conveyed to the resource allocation engine through the macro cell connection, which is more reliable.

Session setup

The session setup discussed here is the process of starting a communication between the UE and the access network on request by either entity. When the UE is in idle state it is connected to the legacy macro base station. It is assumed that the UE is not connected to a millimeter-wave link when idle, in order to reduce the energy consumption. This reduces both UE power consumption and network power consumption. Indeed, due to control-/user-plane separation, millimeter-wave base stations, which are typically deployed in large number and are mainly used to provide high-rate traffic bearers, can be switched off when no data session is active.

When the session is initiated by a request from the macro base station, the macro cellular control plane has to be used to alert the UE. Then the UE and the appropriate small cell have to initiate the directional millimeter-wave connection. This could be performed solely on the millimeter-wave control plane or with support on the macro cellular control plane. Such support context information could be for example position information of the UE, physical locations of small cells within the macro cell area, timing information, etc.

Once a millimeter-wave link is established, further control information can be transferred on either of both control planes.

Location update

As described above, the expected directionality of the millimeter-wave links requires a new kind of mobility support on the link or beam level. This is discussed as beamforming tracking. The traditional understanding of mobility, i.e. a UEs attachment to a certain macro base station or area, will undoubted remain on the legacy control plane, due to the much higher robustness of the link.

Beamforming tracking

The beamforming tracking is a crucial part of the millimeter-wave connectivity. As discussed in section 3.2.1 the directional millimeter-wave link continuously changes and updates of beamforming vectors have to be performed frequently. Such information is needed on both ends of the millimeter-wave link. This functionality will therefore undoubtedly be located at the small cell control plane.

Resource allocation

The resource allocation describes how and when the UE and the small cell should access the millimeter-wave channel. Depending on the granularity of the channel access and due to the increased complexity with directional communication this can generate a noteworthy amount of traffic. Taking IEEE 802.11ad as an example the small cell polls the UEs for their demand to communicate and allocates time slots. However, the use of macro cell control plane allows orchestrating the operation of surrounding millimeter-wave small cells. This, on one hand, facilitates the wireless medium access of millimeter-wave devices, on the other hand, allows to fine tuning available resources enable scenarios where UEs receive multiple streams from different millimeter-wave base stations and, vice versa, a millimeter-wave base station simultaneously communicates with multiple UEs. In addition, interference

coordination techniques can further improve the wireless resource exploitation. The following scenario can be envisioned: medium access and high-level connection management are carried out through macro cell control plane, while small cell control plane is involved in local millimeter-wave resource allocation and adaptation.

4 Functional separation of C-plane and U-plane

4.1 Functional separation approach

In this section, we first introduce the architecture for C-plane and U-plane (C/U) splitting discussed in 3rd Generation Partnership Project (3GPP) as the first step to realize C/U plane splitting scheme for the mm-Wave Overlay HetNets. Then, we describe the enhancement required for MiWEBA architecture.

In the standardization for Long-Term Evolution (LTE)-Advanced in 3GPP, numerous technologies for a study item named “small cell enhancement (SCE)” have been studied to improve system performances in HetNet environments [14]. The C/U plane splitting scheme is one of the most important technologies of SCE that can offer UEs C-plane data via MeNB (Master eNB) and U-plane data via MeNB and SeNB (Secondary eNB) as shown in Fig. 4.1-1. In the typical case, MeNB and SeNB are LTE macro eNB and LTE small eNB, respectively. Owing to the scheme, both stable and high throughput communication will be realized.

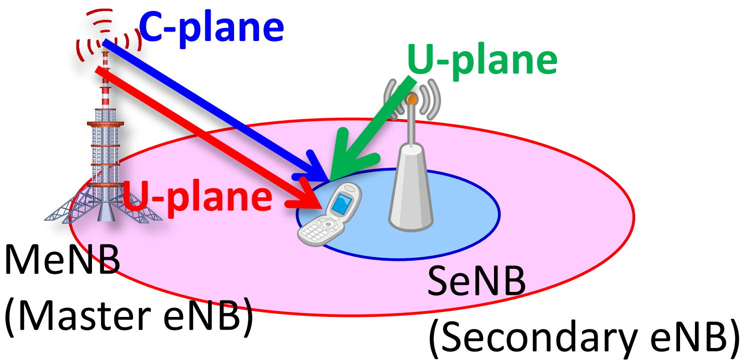

Figure 4.1-1 Overview of C/U-plane splitting

Figure 4.1-2 shows the architectures for C/U-plane splitting. There are two options and the important thing is that, for both options, C-plane is offered by only MeNB. In the first option, S-GW (Serving Gateway) flow splitting, U-plane data is split at S-GW to MeNB and SeNB. That is, in this option, U-plane data can be directly transported to SeNB. On the other hand, in MeNB bearer splitting, all U-plane data is transported from S-GW to MeNB, and then U-plane data is split at MeNB.

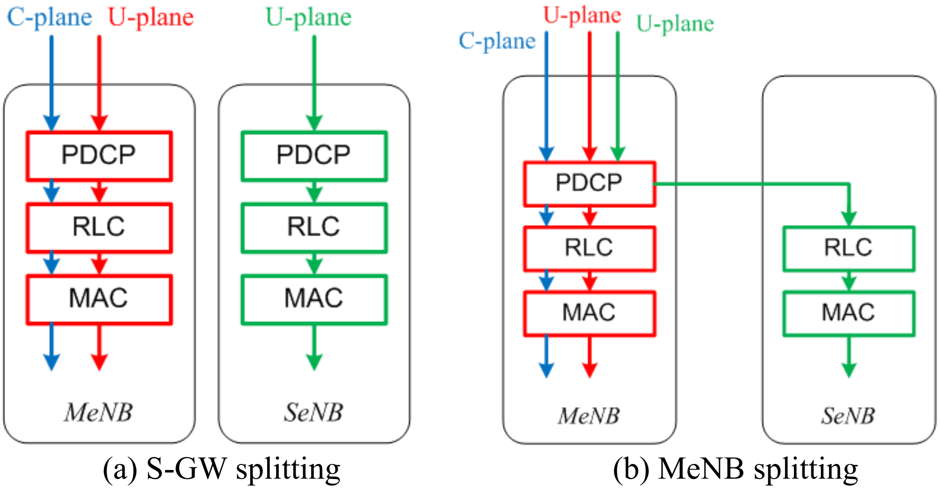

Figure 4.1-2 Architectures for C/U-plane splitting in 3GPP

As mentioned above, if the C/U-plane splitting scheme is introduced, C-plane data is always served by MeNB that usually offers wide coverage area. Therefore, stable communication will be realized. To verify the stativity, we evaluate the number of C-plane HOs (handovers) with and without the C/U-plane splitting scheme trough the computer simulation. The simulation conditions are listed in Table 4.1-1.

TABLE 4.1-1 SIMULATION PARAMETERS

Parameter	Macro cell	Small cell
Number of Cells	57	0, 5, 10, 20 per cell
Cell Layout	Hexagonal (ISD: 500 m)	random drop
Carrier Frequency [GHz]	2.0	3.5
BS Tx Power [dBm]	43	30
BS/UE Height	25 m / 1.5 m	10 m / 1.5 m
Anttena Pattern	Sector	Omni
Path Loss [dB] (*d* in [m])	128.1+37.6*log10(*d*)	147+37.6*log10(*d*)
Shadowing	log normal distribution with decorrelation distance: 50m standard deviation: 8dB for Macro Cell, 10dB for Small Cell	
Fast Fading	Typical Urban 6path	
UE mobility	30 km/h random walk	
Handover Parameters	Intra-freq: RSRP-based A3 events Inter-freq: RSRQ-based A3 events A3 offset: 0 dB, Ocn, Ocs: 0 dB, Hysteresis: 3 dB, Time to Trigger: 128 ms	

Figure 4.1-3 shows the results. It is found that when more than 10 small cells are deployed in a macro cell, the number of HOs can be reduced to about 1/2 by introducing the C/U-plane splitting scheme. Without frequent C-plane HO, the mobility management of UEs becomes easier and stable communication will be realized.

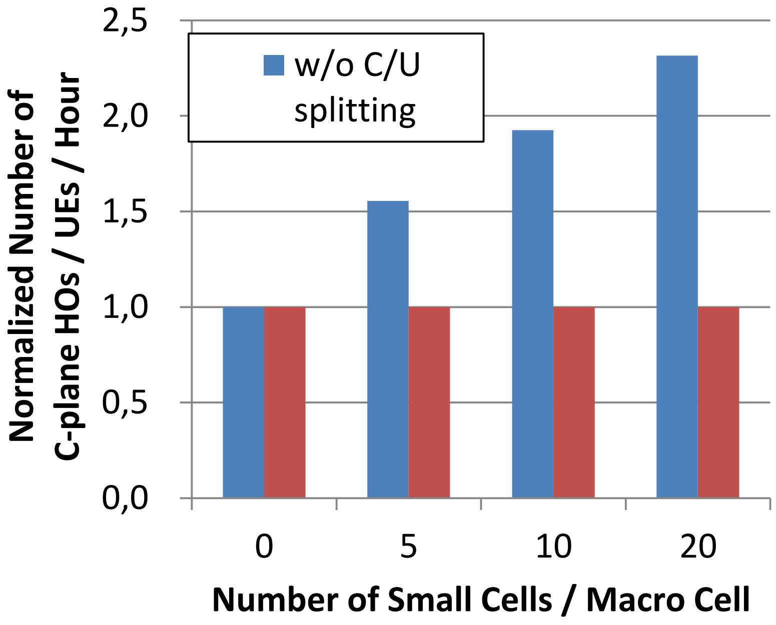

Figure 4.1-3 Number of C-plane HOs with and without C/U-plane splitting scheme

Generally, the concept of C/U-plane splitting scheme is independent of carrier frequencies, but the architecture shown in Fig. 4.1-2 is specific to 3GPP LTE systems. Therefore, we need to enhance the architecture so that can apply to the MiWEBA HetNets by introducing more flexibility and multiple design choices. Moreover, extended network functionalities are required to deal with millimeter wave C/U-plane split as described in Section 3. Since MiWEBA HetNets may consist of several radio access technologies (RATs), one of the approaches to enhance the architecture is the develop of translators or interpreters between LTE and other RATs for the control signals in C/U-plane splitting scheme. The enhancement of conventional LTE C/U-plane splitting scheme is being studied in Task 3.1 and the outputs will be presented in Deliverable 3.2 “Extension of control plane.”

4.2 Context management functions in the split architecture

Traditional signaling mechanisms adopted by 4G cellular technologies interact with user terminals to get information on the service requests and with the network elements necessary to provide the service. At the radio interface, the user terminal issues service requests to the same base station that then allocates the resources to serve the requests. Differently, the C-/U-plane split needs to get more information from the users due to the physical separation of the base station that receives user requests and the base station that allocates resources. Indeed, this base station cannot directly collect information about communication settings, but it must rely on information gathered from the mobile terminal, from other base stations or from past requests from the same location.

Richer information is required in order to characterize what can be called the “context” of a service request. Indeed, context acquisition is more difficult than in traditional cellular technologies. Moreover, the quality and the expressivity of the obtained context are much more critical due to C-/U-plane separation. The context is

the key element that allows the network to activate appropriate resource selection algorithms for the establishing U-plane connections. The choices, thus the efficiency, of these algorithms strongly depend on how the real context is carefully described.

Position is an essential piece of context information, we assume it is available through an external positioning system at the moment of data session request and is accurate. Obviously, position information alone is not sufficient for the selection of the communication resources necessary for setting up data session requested by the user. The minimum additional information required is the best server that is the base station (for both 4G and millimeter-wave technologies) with the best propagation conditions with respect to the user position. In addition to position and best server information, richer information on coverage of other base stations and radio channel quality can be also considered. Given a target radio channel quality (in terms for example of minimum SNR or minimum data rate), we assume that the list of data base stations that can serve a mobile terminal in a given position is known as well as their respective potential “quality”. The quality associated at each potential serving base station can be initially estimated by using channel propagation models and refined at run time by the smart management of past measurements at the same positions.

In addition to user terminal position, the information on the network status is particularly useful for the selection of the data base station and its radio resources. Information on network status basically includes operation modes of base stations, active or sleeping, and amount of radio resources available for new data sessions. In addition, for directive antennas, the set of possible configurations and the currently used directions can help in finding the best serving candidate that allows better exploitation of radio resources.

Finally, the characteristics of the data session requested and the profile of the user are considered. The capabilities of the terminal, its type of mobility and the traffic requests by its running applications can be used to implement sophisticated resource allocation algorithms.

4.3 Multiple Interface Management combined with C/U plane separation

Multiple Interface Management dealing with Multi-Technology HetNets architectures will be integrated in C/U plane separation functional modules for 5G mm-wave overlay architectures. This research item will be addressed in the MiWEBA project considering extended C/U plane separation schemes using green CQI metrics [15] [16] to dynamically select the air interface and transmission mode for C- and U-plane transports.

First architectures resorting from the ICT FP7 OMEGA project dealing with Multiple Interface Management for the Home Networking [17] have been designed that are based on the link availability between two nodes and best path selection processing in relay node architectures. The ICT-FP7 OMEGA project considers an additional layer (L2.5) managing different air interfaces using new control plane functionalities (Figure 4.3-1).

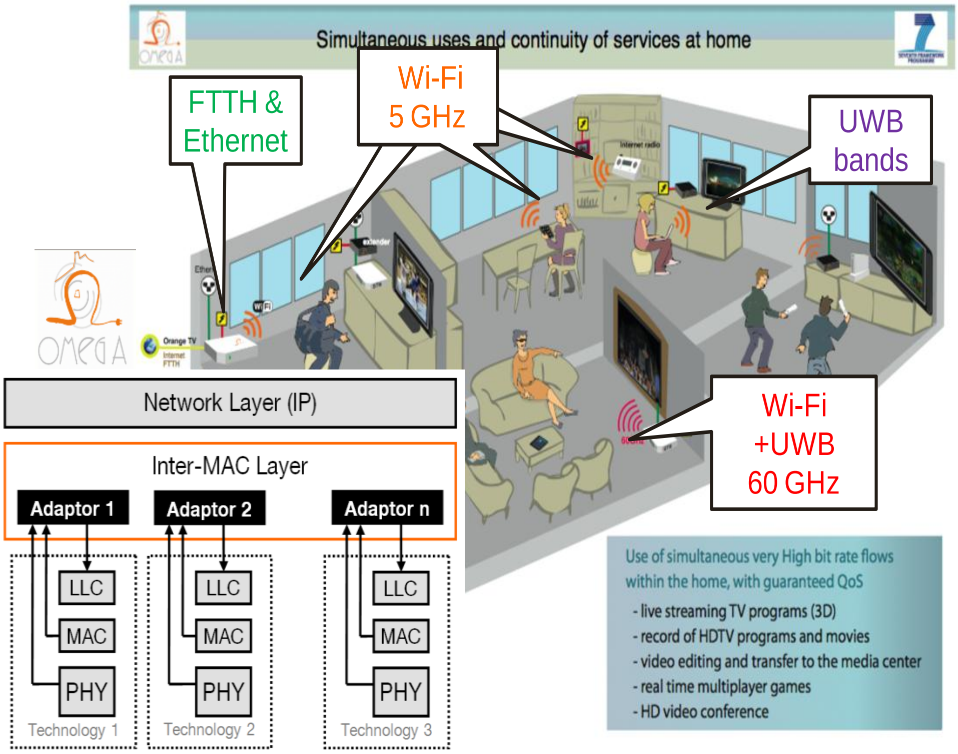

Figure 4.3-1: The Multiple Interface Management using L2.5 layer in the ICT OMEGA project

In the MiWEBA project, the Green Link Budget (GLB) CQI metric designed in the MiWEBA WP2/WP3 to perform Multi-Techno Link Adaptation processing [16] [15], will be used to emulate different air interfaces for C- and U-plane transports respectively, considering transmit power minimization, radio coverage targets and QoS. The implementation will potentially utilize the OMEGA C-/U-plane architecture for AI switching in a reduced latency scheme; other architectures are under progress for optimization and backward compatibility issues. A first analysis has been carried out to identify Control Plane signaling fields able to integrate the GLB metric as illustrated on the Figure 4.3-2.

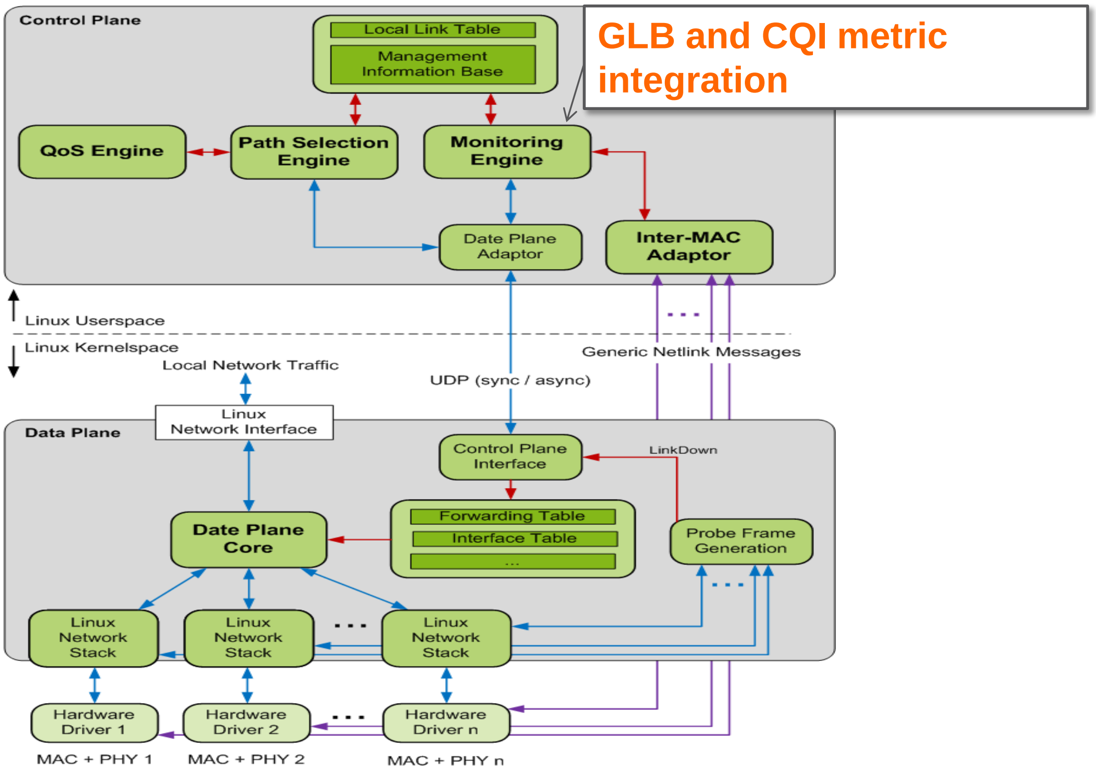

Figure 4.3-2: The GLB metric integration in the Control Plane architecture using a L2.5 layer

The further step of the work will be based on C-/U-plane architectures harmonization between MiWEBA partners and the GLB metric integration in such architectures, to appropriately select the air interface for C- and U-plane transports respectively.

5 Conclusions

The introduction of the millimeter-wave frequency bands into future generations of mobile radio networks requires new architectural approaches and opens a new design space. In this deliverable we investigated the specific requirements of these high frequencies in the context of outdoor access systems. We investigated the design options for a split plane concept where data and control traffic can be transported on different physical interfaces (i.e. frequency bands). While the localization of some functionality (e.g. location update, beamforming tracking) in such architecture is very clear, the other functionality still offers a large design space. The exploration of the design space and the choice of a solution within this space rely on the knowledge of the whole system, from the physical propagation channel to the network architecture and type of traffic model. In the further investigations we will refine the design choices for data and control plane separation in order to reflect the results of different activities in MiWEBA project into the final design.

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