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Multi-Connectivity Functional Architectures in 5G

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***Abstract*—Future mobile networks need to fulfill stringent requirements on data rates, reliability, and availability. In order to satisfy these requirements, heterogeneous radio access technologies and deployments need to be used. To make efficient use of these technologies, multi-connectivity has been proposed to connect to multiple different technologies simultaneously. In this paper, we discuss different options to connect to multiple radio access points. Each of these options is further detailed, novel functionality required for multi-connectivity is introduced, and expected benefits are explained.**

***Keywords*—Multi-Connectivity, multi-RAT, functional architecture, network function virtualization, HetNet, C-RAN.**

I. INTRODUCTION

One of the key objectives for mobile networks is to provide an excellent end-user experience to satisfy the ever-growing demand on data rates which is roughly doubling every year. But the need for more capacity is just one driver for mobile networks to evolve towards 5G. In fact, 5G networks are envisioned to be unified platforms for all types of spectrum and bands, from low bands below 6GHz to emerging higher bands such as above 30GHz (mmW).

Multi-Connectivity of single user terminals to multiple radio access points is a 5G key enabler in order to satisfy the demanding requirements of 5G mobile networks. Multi-Connectivity supports simultaneous connectivity and aggregation across different technologies such as 5G, 4G (e.g. 3GPP LTE [1]), and unlicensed technologies such as IEEE 802.11 (Wi-Fi) [2]. In addition, it may connect to multiple network layers such as macro and small cells and multiple radio access technology (RAT) layers such as below 6GHz and mmWave. The latter example particularly results in improving the capacity as well as the reliability. In addition, multi-access 5G core networks will ensure mobile operators can continue to leverage today's investments. To accomplish this, 5G systems will need to support end-to-end network architectures and protocols that seamlessly combine multiple RATs and network layers together into a single virtual radio access network (RAN).

In this paper, we present three specific architecture options which allow for integrating multi-connectivity into 5G networks. We highlight changes applied to 3GPP LTE as well as novel functionality which has not yet been considered by 3GPP LTE. In Section II, we provide an overview of the individual architecture options before detailing them in Sections III, IV, and V. The paper concludes in Section VI.

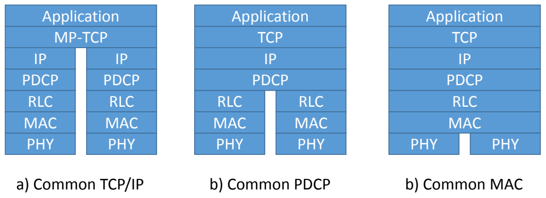

Fig. 1. Overview of the three considered architecture options

II. MULTI-CONNECTIVITY FUNCTIONAL APPROACHES

Fig. 1 shows the considered multi-connectivity architectures that are further detailed in the following sections. The first option a) refers to using multiple IP addresses for one terminal and thereby exploiting multi-path gains; the second option b) refers to using a common Packet Data Convergence Protocol (PDCP) layer, and the third option c) refers to using a common Medium Access Control (MAC) layer across different RATs. The main difference of these three options is the level of integration between different RATs which is determined by their commonalities in terms of required capabilities. Furthermore, a higher integration also imposes stronger constraints on the coordination of different RATs, particularly in terms of latency. Furthermore, for each layer different functions are affected or need to be introduced, in particular

PDCP	Existing functions such as data transfer, routing, and reordering would need to be modified. Novel functionality for service-flow mapping, flow-control, anchoring, or user/control-split may be needed.
RLC	Mainly buffering, reordering, duplicate detection, re-assembly, and re-segmentation would need to be modified.
MAC	Mainly link adaptation would be modified. Novel functions would be required for inter-RAT scheduling, common priority handling, uplink coordination, and radio network identities.

In the following sections, we explain the different options and their impact on existing as well as perspective mobile network architectures.

III. COMMON TCP/IP SOLUTION

Multi-homing, multi-path and multi-connectivity mechanisms can take advantage of a single network node with multiple network interfaces and configure the network node with multiple routing addresses (IP addresses). These mechanisms can assist the network to increase the reliability, gain, throughput and goodput, reduce the fault tolerance and eliminate the single point of failure. Multi-homing mechanism are divided into two types: Asymmetric multi-homing and symmetric multi-homing. Asymmetric multi-homing is the case where one of the two end-points does not support multi-homing but is able to transmit or receive from single application address (port number) with multiple routing addresses. Symmetric multi-homing is the case where the two end points do support multi-homing, and are able to transmit and receive from a single application address (port number) with multiple routing addresses at both ends. Multi-Path mechanisms provide the ability to simultaneously use multiple paths between nodes, and create multiple TCP/IP sessions.

Stream Control Transmission Protocol (SCTP) [3] supports multi-homing for providing network fault tolerance, network load sharing and multiple path capabilities for transmitting user messages. Multi-Path Transmission Control Protocol (MPTCP) [4] is an extension of TCP that allows a client to establish multiple links over different network interfaces to the same network destination. It also provides multiple TCP flows across disjoint paths.

A key aspect of multi-homing, multipath and multi-connectivity is dealing with the range and variabilities of performances that can be exhibited over the different available link/connectivity options. Efficiency can be significantly reduced by the need to cope with the fluctuations in capability over different links, and to direct packets accordingly among the links (i.e., decide on and dynamically vary which packets should be sent on which links). One loose analogy to the issues experienced here is, for example, apparent in multi-part download managers. Download managers may wast a significant amount of time by waiting for packets on a remaining given block to arrive. If those packets were sent again on a new connection, the download would be completed almost immediately. Moreover, such an issue is very apparent if multicast and particularly broadcast solutions are employed. In this case, limited feedback on the success of packets at receivers may be available. Hence, multicast/broadcast packet retransmissions due to lost packets may not be useful at a large proportion of receivers.

In such cases, a means is needed of transmitting packets that are guaranteed to be always useful at receivers, no matter which packet is sent. A solution to this can be the implementation of a rate-less fountain coding solution at packet-level on a download file, such as RaptorQ coding [5]. Coded packets can be created almost unlimitedly on-the-fly and sent over the links as needed. This maximises the utilization efficiency on each link because each packet would be useful to reconstruct the download. Furthermore, the success of decoding is very high (one chance in a million of failure) if only two more coded symbols (or packets) than the number of symbols in the download is received, i.e., very low transmission overhead. Such RaptorQ coding can be easily implemented as a sub-layer of the transport layer or application layer, residing between the conventional transport (e.g., TCP) and application (e.g., HTTP).

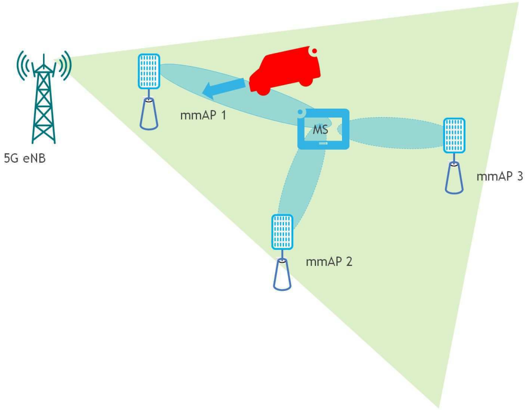

Fig. 2. Redundant coverage for mmW base stations shown here as mmAP

IV. COMMON PDCP SOLUTION

A. Multi-RAT Support (mmW)

We envision a key role of mmW technology in the development of 5G access networks [6]. Future deployments of mmW access points (mmAPs) in 5G access networks will ensure the delivery of high data rates to the user equipments (UEs). However, it is challenging to provide highly reliable and uninterrupted data transfer to the UEs using the mmW technology (especially for the mobile UEs).

The urban-micro mmW channel, as considered for our architecture, is characterized by a low number of possible paths (LOS and NLOS) between base station and UE, from which in most cases probably only one path will be used for transmission with high gain, narrow half-power beam width antenna beams. This makes transmission quality sensitive to blocking effects caused by sudden user movement or obstacles entering the transmission path, leading to poor reliability. Therefore, to minimize interruption times or ideally even to avoid interruptions and to guarantee reliability, we propose:

a) The mmAP deployments must be supported by the low-band 5G coverage.
b) Redundant coverage of mmAPs should be provisioned for the UEs.

For this purpose, we foresee that multi-connectivity will be an essential or rather a fundamental feature in 5G-access networks. Moreover, a UE must be able to detect and receive multiple mmAPs to ensure the possibility of multi-connectivity, link monitoring and fast selection. To provide redundant coverage, multiple mmAPs are placed within the low-band 5G coverage area, building a ”serving cluster”, so that the UEs are within transmission range of each mmAP of the cluster (see Figure 2). It is assumed that a UE is served by at least one of the mmAPs out of the serving cluster at a time (in the example mmAP1). If the connection to the serving mmAP is blocked by an obstacle, the UE possibly will be instructed to connect to another base station mmAP serving the area from another direction, so that the transmission is no longer affected by the obstacle, i.e. there is no interruption in the data transfer (e.g. mmAP2 or mmAP3 can take over). It is assumed that such a cluster of mmAPs is within the coverage area of a 5G eNB, and the mmAPs are using the same high carrier frequency and bandwidth. However, for full flexibility, the mmAPs in a cluster may belong to different eNBs. This requires an efficient multi-connectivity based architecture of 5G access network that will support intelligent radio resource management, data forwarding and data buffering for services requiring mmW transmission.

In line with these requirements, we now introduce and discuss efficient methods for mmAP detection, cluster configuration, required functionalities, protocol mechanisms and the architecture solution to enable reliable high rate data transmission with mmW technology.

Detection of mmAPs and configuration of clusters: In LTE, neighbour cell detection by the UEs is based on common reference signals (pilots). However, common pilots for mmW detection will drastically reduce the coverage of the mmW access point [7]. We propose that precoded pilots should be used for mmAP detection by the UEs. In addition to that, for a mmAP cluster, pilot transmission patterns need to be coordinated and communicated to the UEs. For this purpose, initial access schemes supported by low-band 5G nodes are required to be specified for mmAP systems supporting high gain beam forming antenna configurations. We propose a two step scheme where in the first step a certain degree of information about UE location within low-band coverage area is provided to mmAP. In addition to that, low band 5G configures the UE with a precoded pilot structure of mmAP. As a second step, the mmAP can transmit long range narrow beams using precoded pilots which can be efficiently detected by the UE. In the case of clusters, coordinated pilot transmission by the mmAPS in the cluster supported by the low-band 5G will enable the UE to measure the mmAPs in the cluster. In case of mobility, new mmAPs can be configured and the cluster can be updated. For these requirements, a low band 5G node should control the UE, i.e. new RRC functionality or new RRC protocol elements:

- Definition of a mmW cluster (possible mmW access points for each UE) by the 5G node and configuration of this cluster towards the UE.
- Definition of time, frequency of precoded pilots: info to mmW APs and UEs
- Update of mmW clusters in case of UE mobility.
- UE measurement configuration and UE measurement evaluation for mmW.
- UE Centric ID given by low-band 5G node, also valid inside the cluster.

Architechture Option supporting mmW Data: LTE dual connectivity is mainly designed for non-ideal backhaul using X2 interfaces [8]. Therefore, using dual connectivity option 3C (split within PDCP layer) all data is processed and stored within the MeNB (macro cell). The 5G node supporting multiple mmAPs (as shown in Figure 2) would require large storage capacity and many high speed links to the mmAPs. In this case, the dual connectivity architecture will not be efficient. Therefore, we propose that within the 5G access network, the data storage and forwarding functionality should be revisited. Especially, a PDCP storage and traffic steering functionality should be defined which forwards the data to the serving mmAP or serving cluster. However, the configuration of clusters and mmAPs can still be controlled by the 5G control node. This will efficiently manage the data transfer during handover between mmAPs and 5G control nodes.

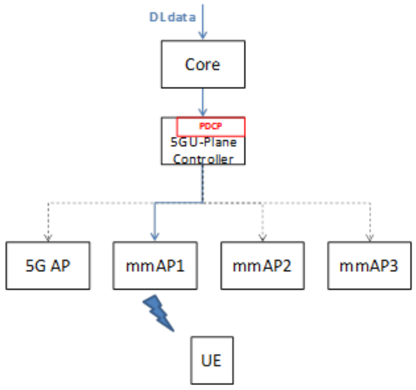

Fig. 3. Proposed architecture solution for low band supported mmW 5G access network including 5G U-Plane Controller

In Figure 3, we propose the architecture option with a 5G user plane controller functionality. From the support of the low-band 5G node, the 5G user plane controller distributes the mmW data to mmAPs. In case a UE is moving outside the mmW cluster and can no longer be served by the any mmAP, the low-band 5G node can still be used as fall-back solution for the continuous transmission but with lower data rate.

A further option supporting mmW data forwarding is to use geolocation functionalities. Here, the mmAPs and UEs might be precisely or approximately geolocated, and the 5G user-plane controller use that geolocation to map mmAPs to UEs based on their known positions-perhaps even using advanced localized propagation knowledge to assess the likely propagation loss between them. Such a possibility can be realized through the geolocation information being returned to the 5G user-plane controller via the fall-back 5G low-band. One option is to scan for a pilot signal of the mmAP and to use that to associate with the mmAP. By contrast, geolocation can also be used predictively: geolocation and patterns in geolocation (e.g., movement along a highway-perhaps linked to applications such as navigation), can determine with a high probability exactly when a user might be within coverage of particular mmAPs in the future. This might be done, e.g., in view of resource usage optimization, and might additionally take advantage of, e.g., traffic elasticity for transfers such as non-urgent background downloads.

B. User- and Control-Plane Evolution

Despite the advantages of dual connectivity in terms of throughput increase, the underlying LTE architecture is not suitable for supporting multi-connectivity as a means to address the requirements set for 5G. The main shortcomings are twofold: a) An increased signaling overhead is associated with frequent mobility events within HetNet deployments; b) Ultra-reliable applications cannot be supported. Next, we elaborate on the above shortcomings, and provide a solution aimed to address the above points.

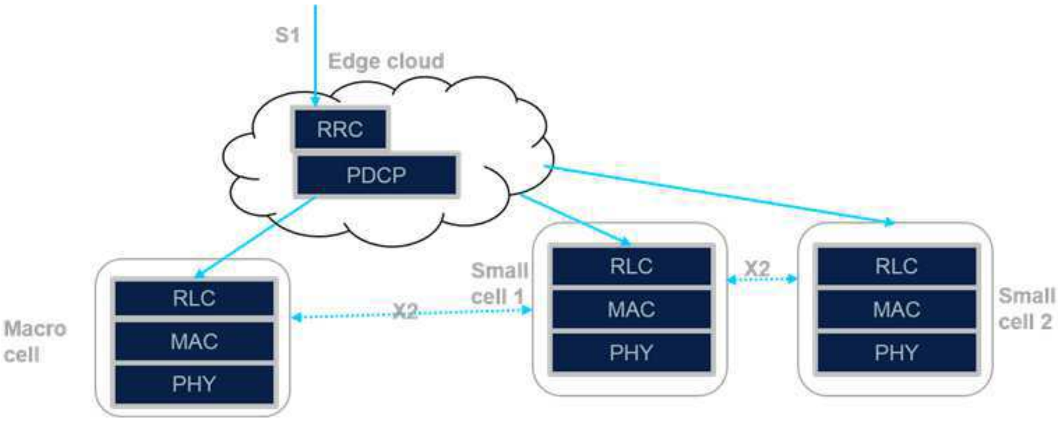

Fig. 4. Moving RRC (c-plane) and PDCP (u/c-plane) to the cloud

Signaling overhead due to mobility: 5G network topologies are anticipated to deploy several clusters of 5G small cells, the coverage area of which overlapping with that of a (either 5G or legacy LTE) macro cell [9]. Although not clearly defined yet, the number of 5G small cells within one cluster is expected to be large (i.e., some 10s of small cells per cluster), owing to their limited coverage area. The limited coverage area of small cells is associated with an increased occurrence of mobility events (such as handovers, cell measurements, etc), particularly for fast moving UEs. The frequent occurrence of mobility events entails a huge signaling overhead to the RAN, involving a set of control signals associated with handover commands which are exchanged between eNBs. Additionally, the current RAN architecture allows that the frequent mobility events affect the core network as well. This is because each time a handover is triggered by the RAN the core network has to switch the transmission path accordingly.

Support of Ultra-high reliability: Dual connectivity in LTE standards focuses on increasing the throughput by establishing dual bearer connection to the UE. In some cases, bearer split is also supported, in the sense that the UE is able to split its bearer connection to two eNBs, aggregating thus its throughput. Nonetheless, in LTE standards no care was taken for addressing ultra-reliability scenarios (i.e., scenarios where high reliability is more critical than high throughput), since there was no such requirement in LTE. Ultra-reliable applications involve the duplication of one or more bearers across multiple eNBs, exploiting thus the concept of diversity. On the basis of the LTE RAN architecture, a bearer duplication would involve new features which would also increase the complexity of the corresponding deployment.

The proposed architecture involves the use of an edge cloud, where the RRC (control) and the PDCP layer will be located. The remaining protocol stacks will remain on the eNB site, as shown in Figure 4. With respect to the multi-connectivity-related shortcomings of the LTE architecture, the proposed architecture offers the following anticipated advantages:

a) The frequent mobility between the small cells is hidden to the core network. This is because from the core network's perspective no path switch occurs each time a handover between two small cells takes place. In addition, the RRC layer where such the mobility of the UE is anchored remains the same. This results in a considerably lower signaling overhead.
b) Data duplication across cells is facilitated: The PDCP layer in the RAN cloud would be responsible for duplicating the data across multiple cells. Such feature can be more easily supported with the introduction of the edge cloud, resulting in much lower burden compared to duplication from the core network.

C. Inter-RAT Connectivity

Inter-RAT multi-connectivity is a feature that enables the UE to simultaneously connect to more than one Radio Access Technology (RAT). A multi-connectivity approach is proposed in LTE Release 12, with the launch of dual connectivity. Dual connectivity allows the UE to connect to multiple base stations that operate on different frequencies. The base stations are connected via x2 interface, hence enabling direct flow of packets through split bearer. The dual connectivity approach enhances reliability of data flow, however it does not address the scenario of two base stations belonging to different RATs. As LTE is a widely accepted and heavily deployed technology, the transition from LTE to 5G is critical, and will take some time. Therefore, it is of extreme importance to consider backward compatibility of 5G with previous standards like LTE and UMTS. As shown in Figure 5, the UE is connected to multiple RATs. The radio access network control functions for all the RATs are implemented in the edge cloud. These functions along with the interworking function provide integration of multiple RATs. Since the interworking of LTE with previous standards is not tightly coupled, a significant delay is introduced [10]. Therefore, similar mechanisms cannot be adopted for the interworking of 5G with previous standards, due to ultra-low latency and high reliability requirements of 5G services.

To provide a tight integration between multiple RATs, we propose interface x_n between 5G base stations and LTE enodeB as shown in Figure 6. The introduction of this new interface will enable direct communication between LTE and 5G base stations, reducing signalling overhead by using a common control plane for both RATs, while simultaneously exploiting control plane diversity. According

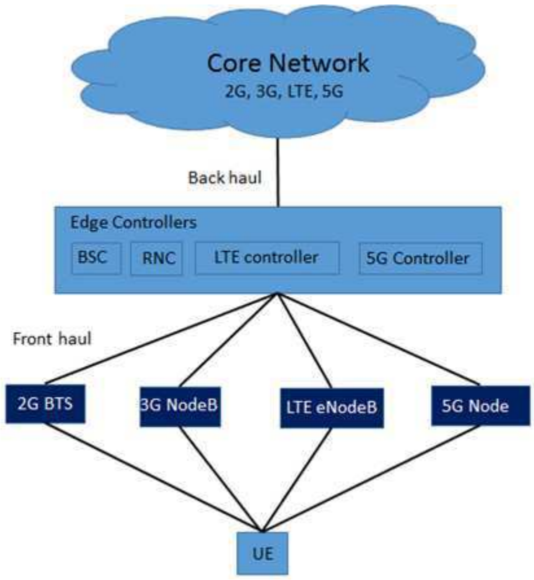

Fig. 5. RAT Multi-Connectivity to UE

to recent research [11], tight integration between LTE and 5G can be provided by using common protocol layers across RATs. Also, it is important to consider previous standards (2G and 3G) along with the tight integration of evolved LTE-5G RATs. As shown in Figure 6, the higher protocol layers are common across LTE and 5G, but not with 2G/3G RAT. As the use of same common protocol approach between 2G/3G and 5G, will lead to high cost in comparison to achievable gains. The integration of 2G/3G and LTE is already state of the art, and it is carried via interworking function [12]. We propose moving the LTE-(2G/3G) interworking function into the edge cloud, and enhancing its functionalities to incorporate the interworking with tightly integrated LTE-5G. The interworking function will run in parallel with inter-RAT mobility anchor functions located in the edge cloud. Moving the anchor point close to the edge will provide low latency handovers between multiple RATs.

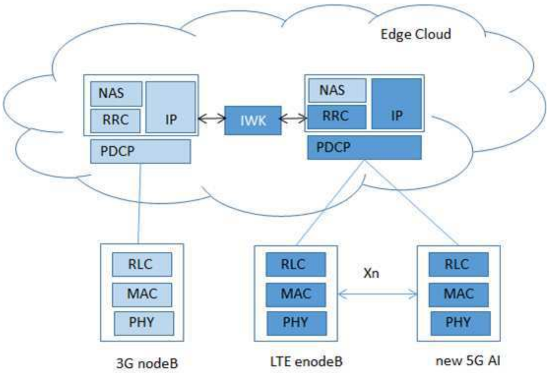

Fig. 6. Integration of multiple RAT in Edge cloud

In this section we identify the required functionality for integration of LTE-5G at RRC and PDCP layer. The integration of RRC and PDCP is much more feasible as the functions are asynchronous with respect to transmission time interval (TTI) [11]. LTE and 5G are assumed to have common control plane and user plane. As proposed in [11], the integration can be carried out in two operating modes: diversity mode and reliability mode. The signalling/data flow in reliability mode is carried out via multiple RATs, increasing the reliability, and no inter RAT handover is required. However, in diversity mode, signalling is carried through either one of the RATs. Therefore, handover procedures are required, and initiated if the user moves into a cell that belongs to a different RAT. We also propose dynamic selection of operating modes by RRC, depending on the QoS requirements from the UE. Reliability mode is selected if the UE requests very high data rate services like online gaming, video streaming etc. On the other hand, the diversity mode can be selected, if the fairness among the UEs is required in case of sudden increase in demand from large number of users. The data is then transmitted through either one of RAT, instead of duplicating it over multiple RATs, to serve a large number of users. To provide close integration of RATs, we follow the architecture shown in the Figure 6. We identify new functionalities that are required to provide inter RAT multi-connectivity and are given as following:

- *RAT selection:* the function enables selection of RAT depending on the measurement report from UE and QoS requirements. RAT selection function selects either one or multiple RATs, to provide data flow and signalling to a single UE. The RAT selection function operates closely with QoS and Inter RAT Traffic management function.
- *Operating Mode selection:* This function selects operating mode, either reliability mode or diversity mode. Different modes can be selected for control plane and user plane. For instance, control plane operates on diversity mode, allowing signalling through a single RAT, while user plane can operate in reliability mode, allowing data flow via multiple RATs, and vice versa.
- *Inter RAT Traffic Management:* The traffic management function operates on the network layer. It manages the network load across different RATs and provide inputs to the RAT selection function.
- *Control and Data flow routing:* The function is responsible for the routing of data packets and control packets if reliability mode is selected. Duplicate packets are routed through multiple RAT, increasing the throughput, or different data packets are routed through different RATs to satisfy low delay requirements.
- *PDCP Sequence number synchronization:* The common PDCP layer across multiple RATs requires additional functionality to synchronize sequence number of PDUs across multiple RATs. The sequence number of the PDUs needs to be adapted, with the addition/release of RATs connected to the UE.
- *Multi RAT support for RRC and NAS:* Additional functions like connection establishment, modification, and release for multiple RATs, service flow mapping to RBs for multiple RATs, etc. are required.

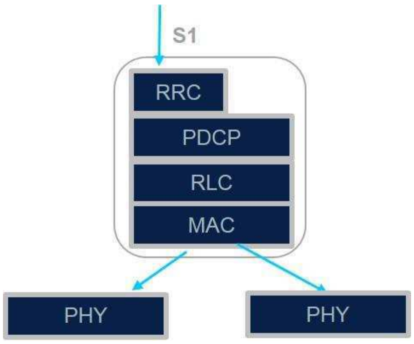

Fig. 7. The common MAC approach.

Additional functionalities like Inter RAT mobility management, resource scheduling and interference cancellation are also necessary to achieve inter RAT coordination gains.

V. COMMON MAC SOLUTION

For scenarios where the multiple legs of the multi-connectivity connection originate from the same physical site, the common Medium Access Control (MAC) case is envisioned. Common MAC refers to the case where the multi-connectivity legs share the PDCP, RLC and MAC layers of the protocol stack, in a way similar to carrier aggregation [13]. An illustration of this idea is provided in Figure 7.

The main benefit of using the common MAC approach instead of the common PDCP is the faster switching between the legs. Particularly for mmW frequencies, where abrupt channel variations are anticipated, the common MAC approach is more robust than the common PDCP approach, since the switching occurs at a lower layer in the protocol stack. On the other hand, however, the common MAC approach is limited to the collocated scenarios. That is, the common layers of the protocol stack must be located at the same physical location, while only the Physical layer is separated in different remote radio heads. In fact, it is the delay caused by the backhaul connection between different sites which renders the separation of the MAC layers impractical for multi-connectivity implementations. The reason is that the packet segmentation carried out in the RLC layer must be able to follow the link adaptation messages coming from the MAC layer, and this is achieved only via a low-latency connection.

Nonetheless, it is worth pointing out that the common MAC approach does not necessarily contradict the common PDCP approach, but can rather be used on top of it. In such case, the common PDCP layer would be located in the cloud while the RLC and MAC layers in the RAN site. To put it in another way, the network perception of the cloud-based PDCP layer is independent of whether the common MAC approach is employed.

VI. CONCLUSIONS

This paper introduced and discussed three options for multi-connectivity in 5G mobile networks. We detailed required functionalities, benefits, as well as challenges for an implementation of multi-connectivity. In a 5G mobile network, possibly all three options may find their place depending on the environment and requirements, i. e., the 5G mobile network architecture must support a variety of multi-connectivity option and utilize always the one which suits best. Our future work will apply the introduce multi-connectivity options to 5G mobile nework models in order to quantitatively evaluate their benefits.

VII. ACKNOWLEDGMENT

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