Converged Access/Metro Infastructures for 5G services

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Abstract: This paper focuses on Converged Access/Metro Infrastructures for 5G services proposing the novel "Dis-Aggregated RAN" architecture adopting "disaggregation" of hardware and software components across wireless, optical and compute/storage domains. The proposed approach is theoretically evaluated.
OCIS codes: (060.4254) Networks, combinatorial network design; (060.4256) Networks, network optimization.

1. Introduction

The explosive growth of mobile internet traffic introduces the need to transform the traditional closed, static and inelastic network infrastructures into open, scalable and elastic ecosystems that can support a large variety of dynamically varying applications and services. In these environments, a heterogeneous set of air interfaces (i.e. 3G, 4G, Wi-Fi) is integrated with high-capacity wired network domains to provide ubiquitous access to a large pool of end-devices. At the same time, to further enhance spectral efficiency and throughput, small cells can be deployed either adopting the traditional Distributed Radio Access Network (D-RAN) paradigm, where Base Band Units (BBUs) and radio units are co-located or the more recently proposed concept of Cloud Radio Access Network (C-RAN). In C-RAN remote units (RUs), are connected to the Central Unit (CU) where the BBU pool is located through high bandwidth transport links known as fronthaul (FH). Through its pooling and coordination gains, this approach can address the limitations of D-RAN at the cost of increased transport bandwidth requirements, low latency and strict synchronization constraints.

Recognizing the benefits of the C-RAN architecture and the associated challenges, equipment vendors try to address the intensive bandwidth requirements of FH networks through a variety of solutions and techniques. These include, expansion of mobile FH solutions adopting more effective wireless technologies, development of new versatile Wavelength Division Multiplexing (WDM) optical network platforms combining both active and passive optical elements [1] and, introduction of alternative architectures that can be used to relax the stringent FH requirements of C-RAN, while maintaining its pooling and coordination gains. These alterantive architectures rely on concepts such as the flexible split options (Fig. 1b) [2]- [3].

The introduction of flexible splits allows dividing processing functions between the CU and the RUs. Through this approach, a set of processing functions can be performed at the RUs deploying local dedicated compute resources and the remaining functions can be performed centrally, through shared compute resources. The required flexibility can be provided by programmable digital hardware, able to support flexible reconfiguration of hardware-accelerated (HWA) and software-realized baseband functions, which can be partitioned at different levels to serve different Key Performance Indicators (KPIs). The shared "*pool of resources*" required to support this type of activities alleviates the need of owning hardware as it can be hosted either at publicly available micro-Data Centers (DCs)– or at remote regional and central large-scale DCs.

This alternative RAN approach introduces the need to develop new technology solutions both at the transport network segment for the interconnection of the RUs with the BBUs and at the DCs for the processing of BBU functions. For the transport network segment, we consider a multi-technology solution comprising point-to-point microwave links and elastic optical network technologies. Optical technologies offer improved energy efficiency, capacity and deterministic performance compared to wireless solutions but suffer significant deployment and installation costs which increase proportionally to the range of coverage. On the other hand, microwave links can be easily installed almost everywhere offering significant benefits in terms of flexibility and upgradability. Given the significant role that these technologies are expected to play in future 5G systems, this study aims to identify the optimal deployment strategies for both mm-Wave and optical fiber transport solutions considering a set of parameters including, RU and optical metro node locations , capital cost for each technology (fixed costs associated with installation of nodes and links), and operational expenditure (capacity-dependent costs) associated with the power consumption levels of each technology domain.

For the DC segment, we rely on the recently proposed concept of "*disaggregation of resources*" [4] to decouple HW and SW components and create a common "*pool of resources*" that can be independently selected and allocated on demand adopting the notion of service chaining. Through on-demand selection and allocation of these resources, any service and functional split option can be provisioned. In this study we assume that the processing resource pool comprises a mix of general purpose processors (GPPs) (i.e. x86 CPUs, GPUs) and specific purpose processors (SPPs) (i.e., ASICS. FPGAs) to support BBU processing. These resources are hosted at regional or mobile edge DCs and are adopted to process in a parallel manner the various FH functions. In general, these functions can be mapped to GPPs or SPPs adopting either the *pipelining* or *parallel* processing mode. In the former, each processing unit handles a specific function adopting 1:1 mapping, whereas in the latter the same function is distributed across multiple processing units (1:N).

To identify the optimal mix of transport network technologies (optical/wireless) and processing modules that are required to support any functional split option in a cost and energy efficient manner, a two-stage optimization framework is proposed. In the first stage, a multi-objective optimization scheme focusing on the transport network segment is proposed that tries to jointly minimize: (a) the CAPEX of the converged 5G network infrastructure through the identification of the optimal mix of wireless and optical transport network technologies and, (b) the operational expenditure in terms of power consumption by identifying of the optimal functional splits as well as optimal BBU placement [5] subject to a set of constraints including the tight FH delay requirements. The output of the first stage optimization problem is given as input to the second-stage optimization problem. This focuses on the DC network segment, aiming at identifying the optimal processing modules where the remaining parts of the FH service need to be allocated.

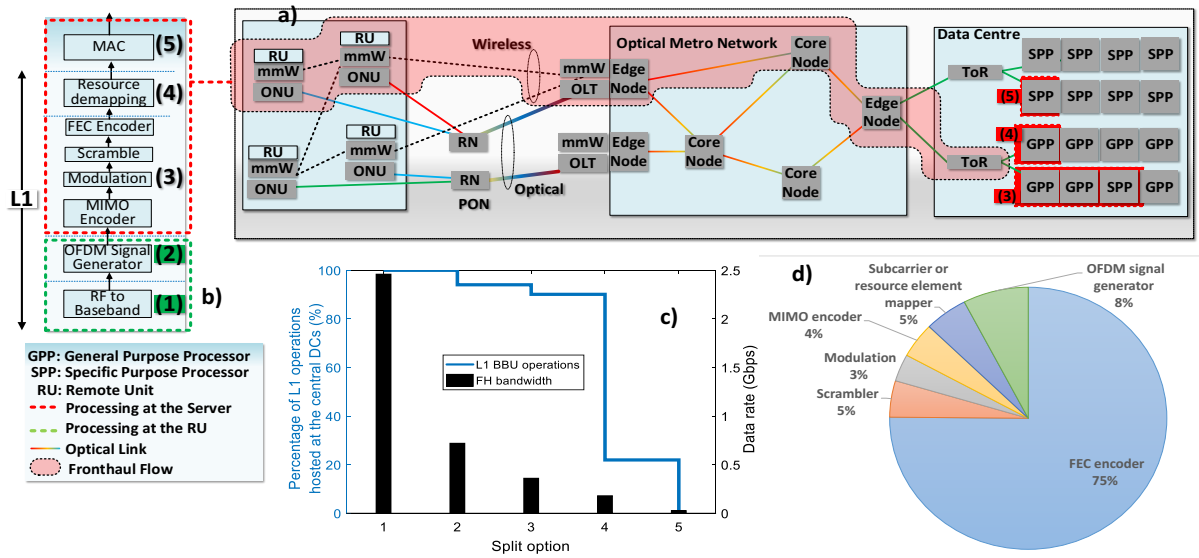

Figure 1: a) Multi-technology network infrastructure, b) BBU processing chain and functional split [3]-[4], c) Transport Network and L1 processing requirements per functional split option, d) Processing requirements per BBU function.

2. Network Description and Problem definition

We consider a multi-technology network infrastructure deploying a set of optical and wireless network technologies to interconnect the RUs with the compute resources Figure 1 (a). Backhauling of the RUs can be provided either through a set of microwave links or through WDM-PON. In addition, an active optical metro solution is considered aggregating traffic demands generated at the RUs, to provide the necessary capacity for the interconnection of more remote compute resources. A key architectural issue associated with this type of infrastructure is the placement of BBUs with respect to the RUs. Recognizing the stringent delay and synchronization requirements of existing FH protocol implementations, the concept of functional split processing is also considered. As illustrated in Figure 1 (b) the range of "split options", spans between the "traditional distributed RAN" case where "all processing is performed locally at the AP" to the "fully-centralized C-RAN" case where "all processing is allocated to a CU". All other options allow allocating some processing functions at the RU, while the remaining processing functions are performed remotely at the CU.

To this end, we propose a two-stage optimization problem as described above. The *first stage* problem focuses on the joint optimization of converged 5G infrastructures in terms of CAPEX and OPEX. To minimize CAPEX, initially, the *network design* problem is formulated aiming at identifying the optimal transport network technologies that can be used in support of the operation of the RUs. Once the network design problem has been formulated a second problem linked to the *operation design* is provided. To keep the analysis tractable, it is assumed that the optical metro network (location of the optical nodes, fibers and RUs) is kept fixed, thus, the topology design problem is limited to the transport network interconnecting RUs with the aggregation network. The first stage problem is divided into two-subproblems: *(a) Sub-problem 1.1 (SP1.1): Transport Network design.* This subproblem aims at minimizing the total cost for installing and operating the transport network capacity from the RUs to the edge nodes. Two options are considered, the first assumes that RUs are interconnected to the metro/optical network using mmWave links while the second relies on the deployment of PONs. For the equipment and installation costs of both technologies (i.e. mmWave tower, optical equipment, fiber trenching costs, etc.), the values reported in [6] have been adopted assuming linear fiber installation costs increase with distance, whereas for microwave links these costs remain almost constant as they primarily depend on initial tower set-up costs. Despite the initial high installation cost of optical technologies their daily operational costs are lower compared to mmWave due to their much lower power consumption. *(b) Sub-problem 1.2: Operations optimization.* The second sub-problem tries

to identify the optimal split option and the location of the DCs where the BBUs are processed so that the total power consumption of the resulting network infrastructure is minimized. The capacity network and processing requirements of each split option are taken into account in the analysis.

The *second stage-problem* identifies the optimal processing modules where the remaining parts of the FH service have to be allocated (Figure 1a)). Once FH data reach a DC hosting the candidate pool of resources, a path interconnecting the edge DC node with the GPP/SPP modules that will process the remaining FH functions is established. The order of FH functions processing is defined employing the concept of Service Chaining (SC). We assume that each function forming the FH SC can be processed either at a single or multiple processing units (see e.g., Figure 1 (a) where function 3 can be distributed to multiple GPPs/SPPs whereas functions 4 and 5 are hosted at a single processing unit). The decision to parallelize a function depends on its speedup factor measuring how much faster a function can be executed when processed in parallel by multiple processing units. The objective of the second stage problem is to identify the optimal degree of parallelization of each function and the server where each function is hosted to minimize power consumption at the CUs.

3. Numerical Results

The proposed optimization scheme is evaluated using the optical network topology of the Bristol is Open city infrastructure covering a 10x10 km^2 area over which 50 RUs are uniformly distributed. End-users served by the RUs generate demands according to real measurements. In the numerical results, it has been assumed that OPEX is associated with the power consumption and has been converted to monetary values by multiplying with 0.02r.u/ kWh. Our results in Figure 2 a) show that when RUs are fully backhauled through microwave technologies the total CAPEX and OPEX is high due to the relatively high-power consumption levels of mm-Wave links, but the increase of WDM-PON penetration reduces the total cost due to its energy efficient operation. However, exceeding a specific number of RUs backhauled by WDM-PON, leads to an increase of the total CAPEX and OPEX due to the significant fiber optical trenching costs. The impact of the WDM-PON penetration of the resulting split option is shown in Figure 2 b). Figure 2 b) illustrates that for low values of WDM-PON penetration, high values of split options (light CPRI flows) are preferable as the operational cost for transporting heavy CPRI flows over microwave is high. On the other hand, an increase in the penetration of WDM-PON results to an increase of the transport network capacity of the converged network infrastructure allowing the selection of bandwidth demanding split options (e.g., split options 1 and 2). Finally, the impact of the BBU function parallelization on the total power consumption of the converged network in shown in Figure 2 c). As can be seen for high volume of traffic demands, the parallel processing approach (according to which multiple SPPs/GPPs process in a parallel fashion the BBU functions) outperform the pipeline case (where each function is assigned to a specific SPP/GPP). Parallelization of BBU functions results to lower BBU processing times. Smaller processing times at CUs counterbalance the increase of FH transmission delays, thus enabling higher degree of consolidation. At the same time, the disaggregated RAN approach exhibits lower network power consumption compared to the traditional D-RAN approach.

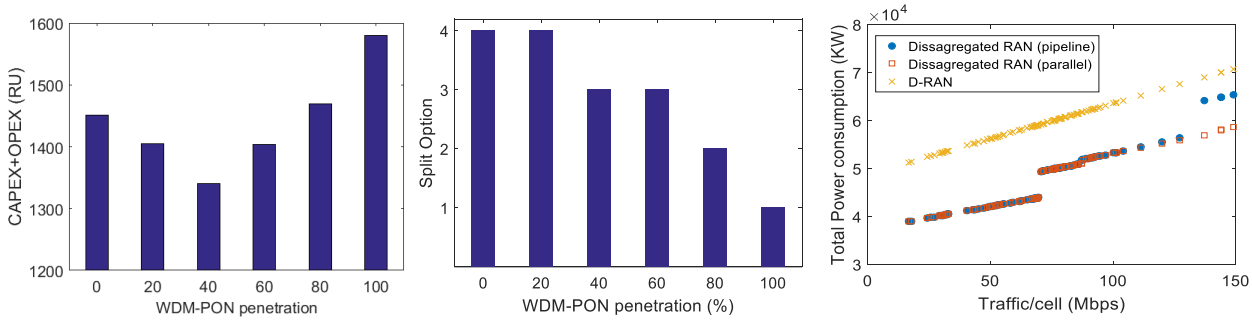

Figure 2: a) Total operational cost as a function of the percentage of RUs relying on WDM-PON transport, b) Split option as a function of WDM-PON penetration. b) Impact of processing parallelization on split option, and c) power consumption

Acknowledgments

This work has been supported by the EU Horizon 2020 project 5G-PICTURE.

4. References

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