Optimal Function Split via Joint Optimization of Power Consumption and Bandwidth in V-RAN

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Abstract— **Cloud radio access network (CRAN) has been a promising architecture in reducing the power consumption and to increase the capacity and performance in comparison with the traditional RAN networks. The traditional CRAN separates the digital unit (DU) from radio unit (RU), while most of the processing is performed in the DUs. However, the fronthaul links cannot afford to meet stringent delay and bandwidth constraints in similar systems. Thus, network function virtualization (NFV) has been very promising to relax the processing in the DUs and ease to dynamically shift the power consumption and processing whenever the need for the relaxation. This paper studies a Dual sites processing based in the central and edge sites in virtualized Radio Access Network (H-VRAN) and it recommends the amount of processing in the dual sites for the functional splits proposed by ETSI. This leads to ease of management and flexibility of the operation and increase the processing/ power efficiency. Moreover, we identified the amount of power consumed in both sites at different percentages of functional splits to compromise the tradeoff between the midhaul bandwidth and power consumed in the network. Furthermore, Joint optimization of the power consumption and midhaul bandwidth is performed to validate and recommend the optimal split function.**

Keywords—Hetrogenous CRAN; Network Virtualization NFV; Function Splits, Joint Optimization.

I. INTRODUCTION

ETSI has extensively work on network function virtualization (NFV) and it presented 9 use cases in small world virtualization functional split release to explore the virtualization opportunities within wireless core [1-3] including NFV infrastructure as a service, virtual network function as a service, virtual network platform as a service, virtualization of mobile core network and IMS, virtualization of mobile base station, virtualization of home environment, virtualization of CDNs and fixed access network functions virtualization. In particular, use case # 6, virtualization of mobile core network is expected to be interested in the research direction of small cell virtualization as it might provide lower footprint and energy consumption, allow dynamic resource allocation and load balancing and move at least a part of the processing of the base station to standard servers, storages and switches. In addition, it will be satisfactory to apply use case #6 in cloud RAN architecture (C-RAN) which can provide faster load balancing and easier interference management between cells.

The key challenge in the virtualization is to what extent a base station virtualization can be applied to relax the amount of processing and its benefits for indoor coverage and cost for urban and rural areas.

New Generation Mobile Network (NGMN) has been investigating to decompose eNB into two different nodes with different terminology [4]. In addition to, ETSI presented a terminology to split the cell functions between central and remote cells. The functions in both cells are virtualized as virtualized network function (VNF) and physical network function (PNF), respectively [5]. Several functional splits have been proposed in the literature to split some of the functional processing in the VNF and PNF to relax the bandwidth between them which is called a midhaul links.

Literature has been proposing new enhancements in the network function virtualization (NFV) as it is one of the main promising development in the fifth generation (5G). Only few references that discussed a dual processing based on their work. The work in [6] solve a cost function of power consumption and bandwidth of a dual sites using IBM ILOG CPLEX, but they did not solve the joint optimization problem which inspires us to extend their work. Also, the derived the processing delay for the same model and their effect on the function splits in [7]. In addition to, a Techo-econmic study to design a low cost heterogeneous radio access network (H-CRAN) is discussed in [8].

The main contribution in this paper is to verify the work in [6] by fitting and compare the bandwidth curves with the ones obtained from [2] and [3]. Then, we study and derive the separation of data processing between the two sites based on the physical functional splits developed and approved by ETSI [1-3]. This leads to ease of management and flexibility of the operation and increase the processing/ power efficiency. Moreover, we identified the amount of power consumed in both sides (CS and RS) at different percentages of functional splits to compromise the tradeoff between the midhaul bandwidth and power consumed in the network. Furthermore, Joint optimization of the power consumption and midhaul bandwidth is performed to validate and recommend the optimal split function. Network with such a specifications will enable the door to let same hardware to be used in multiple services yet to be secured and isolated. Moreover, it will facilitate the operation of removing and adding new services when needed and the flexibility of dynamically shifted the processing power from the heavily loaded servers.

This paper is organized as follows; section II discusses the network model and the function splits used in the literature, section III addresses the Joint optimization problem of the consumed power and midhaul bandwidth. The simulation results are discussed in section IV. Section V concludes the work in this paper.

II. NETWORK MODEL

A. Network Architecture

The network model shown in Fig. 1 is a hybrid virtualized radio access network (V-RAN) architecture that has a dual-site processing instead of the single site in traditional heterogeneous cloud radio access network (H-CRAN). The network is considered as three-layer architecture. The first layer shows the central cloud site (CS) which provisioned the second layer of edge cloud remote sites (RS) as an aggregation point. The third layer is the cell layer of RUs which is designed to densify the coverage of the UEs. A group of UEs are connected to Radio Unit (RU) and a group of RUs are connected to RS and so on. This three layers' architecture creates what is called midhaul link between the CS and RS. The link between the cell and RS is about few hundreds meter so the free space optical (FSO), and mmWave transmission technologies are suitable. Where these links can provide high speed connections.

The processing takes place in either the CS or the RS. The users or cells data can be processed by using digital-processing units (DUs) either in CS and RS according to the function split. Thus the computational resources can be virtually processed at edge cloud or at the centralized cloud. While the processing in the RS consumes more power, it requires less transmission capacity. The tradeoff of this network is whether to perform most of the processing (centralize) at RS to save bandwidth on expense of the power, or to make the most of processing at CS to save the power on expense of the bandwidth.

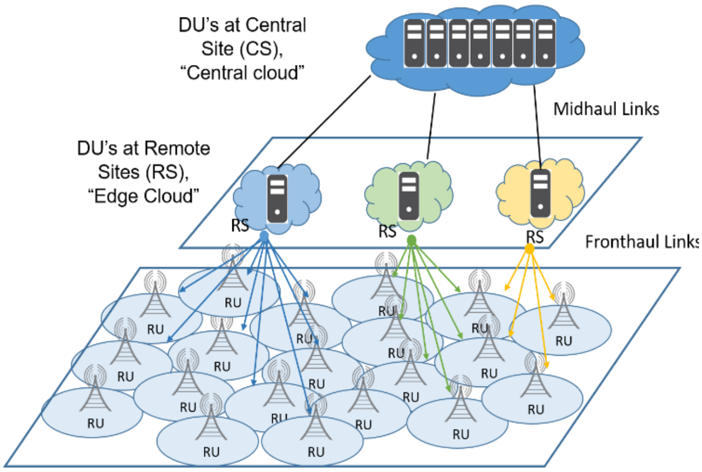

Fig. 1: Hybrid-VRAN architecture

B. Function Splits

According to 3GPP standard and ETSI, there are eight function split [1-5]. On the other hand, VRANs with dual sites have been presented in the standards in order to reduce the overhead computation that is expected to be implemented in RRHS which enable a functional split in the physical layer [3]. Thus, five function splits in the physical layer have presented in [3,4] to investigate its effect against centralization. The baseband processing for a cell includes *m* Cell-Processing (CP) and *n* User-Processing (UP) functions. CPs are performed in the physical layer for processing signals from the cell where the UEs signals are multiplexed. It performs serial-to-parallel conversion (or common public radio interface (CPRI) encoding), removing cyclic prefix, fast Fourier transform, and finally resource damping etc. While, UPs are processed on per UEs basis, equalization, inverse discrete Fourier transform, quadrature amplitude modulation, antenna damping, multi-antenna processing, forward error correction, turbo decoding, and other Layer2 and Layer3 functions are performed in this basis.

Fig. 2 illustrates an assumption of the implementation of processing chain where some of the processing occur at the RS (lower layer) and other in the CS (Upper Layer). Each function split incurs a different power and transmission rate. Moreover, the number of CPs and UPs are determined after the function split is decided based on the service required. In case of processing happen in CP, large requirements of bandwidth to transmit partially processed signals. Users served by multiple resources, the resources have to be at the same DU. In case the split happens in UP, cell's signals are processed in larger scale, thus less midhaul bandwidth will be required.

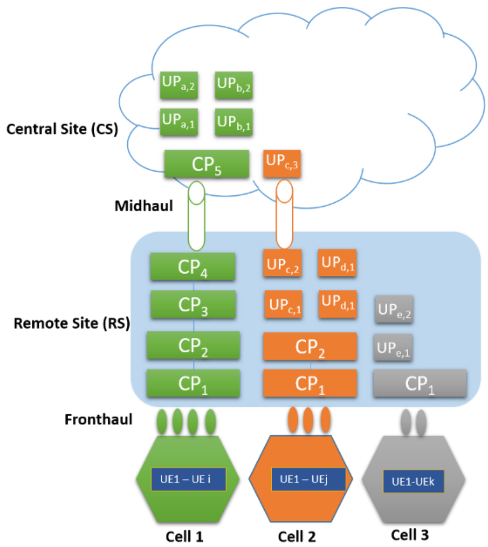

Fig. 2: H-VRAN model with the function split

III. JOINT OPTIMIZATION OF CONSUMED POWER AND BANDWIDH

This section concerns with the following; 1) identifying the equivalent physical splits to a specific amount of processing in CS and RS and compares it to the standard and interpolates the percentages in between these points. 2) Studying the power consumption behavior in both sites CS and RS with respect to different percentage of function splits. And 3) Jointly optimization of the total power consumption in the network and midhaul bandwidth between the two sites with respect to different percentage of function splits. We introduced a joint optimization problem in Eq.1 which aims to find the optimal percentage of function split in CS and RS and the optimal weights to the normalized power and midhaul bandwidth.

$$(\mathrm{FSP}_{RS}\,^*, \mathrm{FSP}_{CS}\,^*, \alpha\,^*) = \arg\ min\ \alpha\ P_T + (1-\alpha)\ B_{MH} \qquad (1)$$

The optimization problem is performed with optimal weights α between the normalized total consumed power P_T and normalized midhaul between the two sites B_{MH} where $\alpha \in [0\ 1]$. The Total power Consumption is the summation of the power consumed in both sites CS and RS. P_{LC} is the power consumed in the power line, g is the number of active wavelength in the midhaul, and multiplication of both is considering the fixed consumption in the CS and P_{ONU} is the power consumed in optical network unit is the fixed consumption in RS. While, P_{CS}, P_{RS}, P_{CS}^{DU} and P_{RS}^{DU} are the power consumption of the DU housing and the consumption towards the processing in CS and RS. l and e_r are the number of active users in CS and RS under consumption that each user will take only 1 DU. μ_l and μ_{er} are a binary indicator to show the existence of the working DUs.

$$P_{CS} = g\, P_{LC} + (P_{CS} + \lceil l\,(1 - FS_{RS})\rceil . P_{CS}^{DU})\mu_l \quad (2)$$

$$P_{RS} = \sum_{r\in R}(P_{ONU} + (P_{RS} + \lceil\, e_r\; FS_{RS}\rceil . P_{RS}^{DU})\; \mu_{er}) \quad (3)$$

$$P_T = P_{CS} + P_{RS} \quad (4)$$

This is a test indicator that checks of to ensure whether the constrain is satisfied or not.

$$\mathbb{I}(a = b) = \begin{cases} 1, & if\ a = b \\ 0, & if\ a \neq b \end{cases} \quad (5)$$

The midhaul bandwidth is obtained as the follows; where $G_c(q_c)$ and $J_i(P_i)$ are the pre calculated mapping from the CP and UP to the required midhaul bandwidth which is factor of number of resource blocks (RB).

$$B_{MH} = \sum_{w\in W}\sum_{r\in R}\mathbb{I}(w_{r=}w).\sum_{c\in C_r}(G_c(q_c) + \sum_{i\in I_c} J_i(P_i)\,) \quad (6)$$

where, P_i is the percentage of UP of UE_i and q_c is the percentage of function split of CP in Cell C. The joint optimization is performed with the following constraints:

- To maintain that only one function split occur either at CP or at UP,

$$\mathbb{I}(p_i < |F_{UP}|) + \mathbb{I}(q_c < |F_{UP}|) = 1 \quad (7)$$

- To ensure that both CPs and UPs resources for same users have to be using the same DU.

$$(p_i < |F_{UP}|) \rightarrow (m_i = x_c) \quad (8)$$

$$(q_c < |F_{CP}|) \rightarrow (n_i = y_c) \quad (9)$$

- To constrains ensure that the number of CPs and UPs accommodated for the required service in RS and CS are less than the DU's capacity for CP and RS in RS and CS, respectively.

$$\sum_{c\in c_r} H_{CP}^{RS}(q_c).\mathbb{I}(x_c = d) \leq L_{CP}^{RS} \quad (10)$$

$$\sum_{c\in c_o} H_{CP}^{CS}(q_c).\mathbb{I}(y_c = d) \leq L_{CP}^{CS} \quad (11)$$

$$\sum_{i\in I_r} H_{UP}^{RS}(p_i).\mathbb{I}(m_i = d) \leq L_{UP}^{RS} \quad (12)$$

$$\sum_{i\in I_o} H_{UP}^{CS}(p_i).\mathbb{I}(n_i = d) \leq L_{UP}^{CS} \quad (13)$$

- To make sure that the required capacity is less than the available capacity.

$$\sum_{r\in R}\mathbb{I}(w_{r=}w).\sum_{c\in C_r}(G_c(q_c) + \sum_{i\in I_c} J_i(P_i)\,) \leq \mathrm{K} \quad (14)$$

Algorithm 1 shows the procedures that are used in this work. The algorithm evaluates the system performance with different values of function split and combine them till it satisfy one of the two constraints of the max iterations or best fitting values and return back the optimal values that lead to the fittest values.

Algorithm1: Genetic Algorithm for H-VRAN
1: Set Parameters
2: Generate initial population
3: **while** (I< MaxIterations) and (Fitness<MaxFitness)
4: Select fitter individuals
5: Recombine individuals
6: Mutate individuals
7: Evaluate the fitness of modified individuals
8: **End**
9: Decode individuals with best fitness
10: Return best fitness

IV. Simulation and Analysis

This section concerns with presenting the numerical and simulation results discussed in the theoretical analysis section. The system parameters are used in the simulation is presented in Table I.

TABLE 1: SYSTEM PARAMETERS FOR POWER CONSUMPTION

Description	***Symbol***	***Value***
Number of active Wavelength in Midhaul	g	*6*
Power Consumption for line card	P_{LC}	*20*
Power Consumption for housing DUs in CS	P_{CS}	*500*
Number of Active DUs in CS	l	*5*
Power Consumption of the DUs in CS	P_{CS}^{DU}	*100*
Binary Indicator of active DUs in CS	μ_l	*1/0*
Number of RS	R	*6*
Power Consumption for Optical Network Unit	P_{ONU}	*5*
Power Consumption for housing DUs in RS	P_{RS}	*150*
Binary Indicator of active DUs in RS	μ_{er}	*1/0*
Number of Active DUs in RS	e_r	*7*
Power Consumption of the DUs in CS	P_{RS}^{DU}	*20*
Percentage of the Function Split of RS	FS_{RS}	*0→1*

A. Bandwidth Analysis

The downlink (DL) midhaul bandwidth is calculated as in Fig. 3 with the same behavior in [6] but with only one RRH to compare the performance with the bandwidth obtained in the standard in [3]. We plotted the bandwidth with the percentage of function split at RS in Fig. 4 in comparison to the obtained BW from the standard in [3] considering the bandwidth obtained at specific splits and specific percentages of function split. Mathematical interpolation is used to provide the performance to the points that have no specific percentages of function split in the standard.

B. Power Consumption Analysis

While increasing the percentage of function split in the RS, the power consumed in the CS decreases as more processing has to be done in the RS as illustrated in Fig. 5. Moreover, we observed the amount of power consumed in both sides at the discussed functional splits in standard in [3].

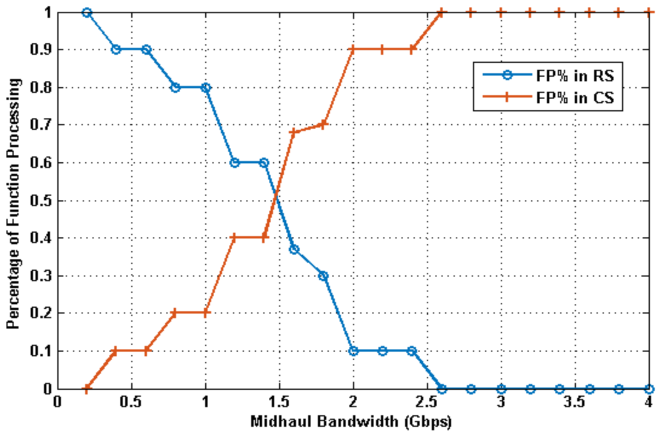

Fig. 3 Percentage of function split Vs Midhaul BW

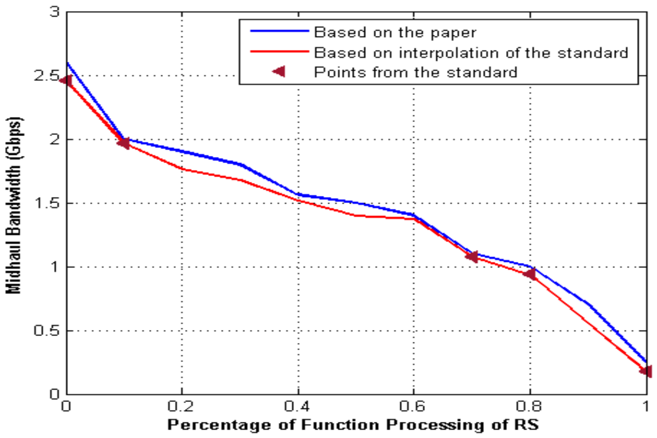

Fig. 4 Percentage of Function split Vs Midhaul BW

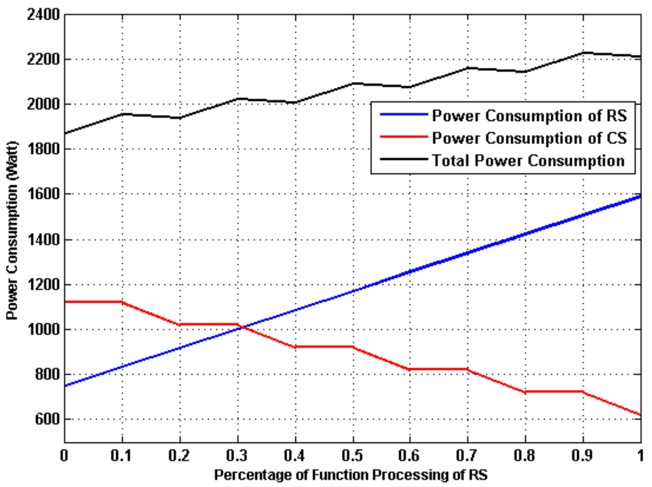

Fig. 5 Percentage of function split Vs Power Consumption

C. Joint Optimization

To validate our recommended functional split, we jointly optimized the power consumed in both sites and the midhaul bandwidth. The Optimization problem is solved to identify the optimal percentage of the functional split and optimal weights of the power and bandwidth. The problem is considered as a nonlinear problem which is solved using MATLAB Genetic Algorithm (GA-OPTIM tool).

Fig. 6 illustrates the number of RSs vs proposed performance metric. The brow diamond curve shows the effect of the normalized total power consumption with the increase of RSs which is approximately a linear behavior. The blue star-shaped curve shows the normalized midhaul BW with the increase of the RSs. The purple circle is equally weights of the midhaul BW and Power consumption in the cost function. The performance metric has its lowest values at RS = 2 and 5. The green, squared shaped is the cost function with 3 arguments in the optimization problem; FS_{RS}, FS_{CS} and α. The curve shows a lower performance when we the weight parameters is varied.

TABLE II. OBSERVED POWER CONSUMPTION IN CS AND RS WITH EACH FUNCTION SPLIT

Split Fun.	*FS of RS (%)*	*BW (Mbps)*	*CS Power (W)*	*RS Power (W)*	*Total Power (W)*
I	*100%*	*173*	*620*	*1590*	*2200*
II	*80%*	*933*	*720*	*1422*	*2142*
III	*70%*	*1075*	*820*	*1338*	*2158*
IIIb	*10%*	*1966*	*1120*	*834*	*1954*
IV	*0%*	*2457.6*	*1120*	*750*	*1870*

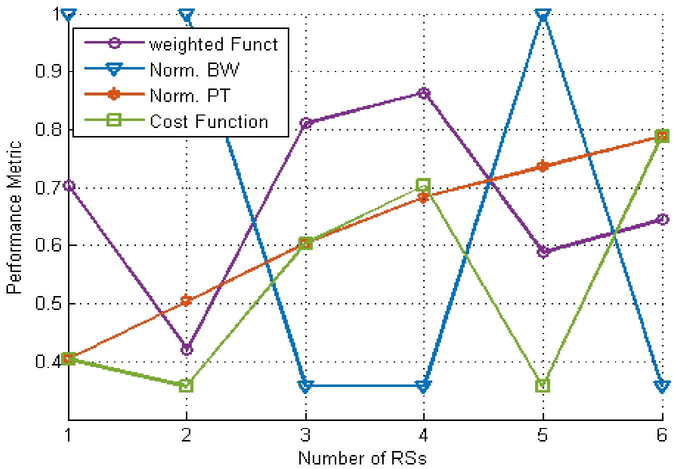

Fig. 6 Number RSs vs Performance Metric

Table III shows the optimal percentages of function split in all cases previously discussed. At RS=1,3,4, 100 Split of RS or Split I is very recommended, however the this may lead to high power consumption as the optimization problem found the optimal value at zero weight of the total power which represent the ideal case and by considering the effect of the power consumption, it might degrade the performance of the system linearly. At Rs=2 and 5, the zero weight of the bandwidth is obtained as it has a very high value of the performance metric.

TABLE III: OBSERVED OPTIMAL PERCENTAGE OF FUNCTION SPLITS IN RS FOR NORMALIZED POWER, NORMALIZED BANDWIDTH AND PERFORMANCE METRIC.

#RS	Optimal FS_RS* (Norm. PT)	Optimal FS_RS* (Norm. BW)	Optimal FS_RS* (equal weights)	Optimal FS_RS* (Cost Function)	
					α*
1	0.8	0.9	0.9	0.8	0
2	0.8	1	1	1	1
3	0.8	1	0.9	0.8	0
4	0	1	0.9	0.8	0
5	0	1	1	1	1
6	0	1	1	0	0

V. CONCLUSION

ETSI has been encouraging of making dual sites for processing CS and RS which puts us on a tradeoff of whether to perform most of the processing (centralize) at RS to save bandwidth on expense of the power, or to make the most of processing at CS to save the power on expense of the bandwidth. The processing is performed using CPs and UPs resources after the function split is decided. This paper recommends the amount of processing in the dual sites for the functional splits proposed by ETSI. This leads to ease of management and flexibility of the operation and increase the power efficiency. Moreover, we identified the amount of power consumed in both sites at different percentages of functional splits to compromise the tradeoff between the midhaul bandwidth and power consumed in the network. Furthermore, Joint optimization of the power consumption and midhaul bandwidth is performed validate and recommend the optimal split function.

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