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Optimum Functional Splits for Optimizing Energy Consumption in V-RAN

TAWFIK ISMAIL[1,2], (Senior Member, IEEE), AND HAITHAM H. M. MAHMOUD[3], (Member, IEEE)

[1]National Institute of Laser Enhanced Sciences, Cairo University, Giza 12613, Egypt
[2]Wireless Intelligent Networks Center (WINC), Nile University, Giza 12677, Egypt
[3]School of Engineering, Birmingham City University, Birmingham B5 5JU, U.K.

Corresponding author: Tawfik Ismail (tismail@cu.du.eg)

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ABSTRACT A virtualized radio access network (V-RAN) is considered one of the key research points in the development of 5G and the interception of machine learning algorithms in the Telecom industry. Recent technological advancements in Network Function Virtualization (NFV) and Software Defined Radio (SDR) are the main blocks towards V-RAN that have enabled the virtualization of dual-site processing instead of all BBU processing as in the traditional RAN. As a result, several types of research discussed the trade-off between power and bandwidth consumption in V-RAN. Processing at remote locations instead of BBU reduces mid-haul bandwidth at the expense of power consumption and vice versa. As a result, the integration of NFV and SDR in V-RAN facilitates dynamic power consumption and processing whenever relaxation is needed. This paper studies several functional splits proposed by ETSI in the NFV of the dual-site network. In addition, network performance is analyzed in terms of data rate, power consumption, and energy efficiency (EE) optimization. Furthermore, the combined optimization of power consumption and mid-haul bandwidth are investigated, and optimal operating parameters are recommended for similar network operators. Thus, regulators/operators can adjust their networks with these parameters to achieve the best performance. Additionally, the UEs switching scheme is introduced to sleep some RRHs in low-density traffic to lessen power consumption.

INDEX TERMS V-RAN, C-RAN, NFV, functional splits, energy consumption.

I. INTRODUCTION

Network Function Virtualization (NFV) is an initiative to virtualize traditional network services using dedicated functions such as load balancing, routing, dynamic resource allocation, etc., which are performed on virtual machines (VMs). In contrast, NFV is listed and presented in a small world virtualization functional split release supported by ETSI. This release aims to explore the virtualization opportunities within the wireless core used to reduce energy consumption, reduce footprints, and facilitate dynamic resource allocation and load balancing in similar networks [1]. NFV integration in Virtualized Radio Access Networks (V-RAN) has been optimized to maintain optimal energy consumption, load balancing, and easier cell interference management based on the nature of the load. This reduces processing at the Remote Radio Head (RRH) by moving part of the processing to standard servers, storage, and switches. These servers, storage, and switches are referred to as Remote Sites (RS). Several communities have discussed the fact of splitting the processing of currently evolved node B (eNB), including the New Generation Mobile Network (NGMN) [2]–[4]. ETSI has considered the two layers of processing of central and remote sites where the center is considered to be served at base stations and remote cells for physical locations of servers, storages, and switches [5], [6].

Literature investigated RAN based on cloud or virtualization in the following works. Tran *et al.* [7] and Zhou *et al.* [8] discussed the Energy Efficiency (EE) of C-RAN using non-orthogonal multiple access (NOMA) modulation schemes. Also, Tran *et al.* proposed an iterative algorithm to determine the maximal number of cells supported in different environments. On the other hand, Zhou *et al.* discussed the open research issues to enable heterogeneous

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C-RAN. Moreover, many related works considered solving optimization problems [9]–[12]. Peng *et al.* [9] proposed a joint optimization for EE resource allocation between resource block and transmit power in heterogeneous C-RAN. Zhao *et al.* [10] formulated an optimization problem considering sub-channel allocation to RRH and multicast groups to improve network throughput. Chughtai *et al.* [11] formulated an optimization problem between efficient power and resource allocation to enhance EE. Albabasi *et al.* [12] proposed the cost and energy efficient methodology, including operational expenditures, to immigrate from traditional RAN to C-RAN.

The processing is being split into Virtualized Network Function (VNF) and Physical Network Function (PNF). Consequently, a midhaul channel is initiated. Several works considered dual-site architecture as follows. Alabbasi *et al.* [13] investigated processing delay in the same dual-site processing, and they highlighted the minimum delay at a specific functional split decision. Wang *et al.* [14] discussed several enabling technologies such as; software-defined radio (SDR) and coordinated multipoint (CoMP) transmission/reception to exploit virtualized base stations per cell/ per user basis in different functional splits in V-RAN. Alabbasi and Wang *et al.* [15] discussed the optimal processing functional split by studying the interplay between energy efficiency and midhaul bandwidth in the same dual-site processing. Moreover, their work in [16] has solved a cost function of power consumption and bandwidth using IBM ILOG CPLEX, but they did not solve the joint optimization problem, which inspires us to extend their work. Therefore, this motivated us to work on dual-site processing, in addition to the recommendation to work on the same model from ETSI [1], small cell community, 3GPP and NGMN [4].

Other recent studies solve a joint optimization of the splits and routing path to support the multi-access edge computing (MEC) services such as FluidRAN by Garcia-Saavedra *et al.* [17] and LayBack by Shantharama *et al.* [18]. Both systems found substantial multiplexing gains in the bandwidth and compute processing context. This will likely reduce network costs and energy consumption. Garcia-Saavedra *et al.* solved the optimization problem to minimize the operational costs with satisfying o the MEC requirements on three operational scenarios; (i) pure C-RAN, (ii) FluidRAN on distributed RAN (D-RAN), and (iii) MEC. On the other hand, Shantharama *et al.* proposed an architecture based on software-defined network (SDN) wherein several functional splits are considered in the MEC nodes through NFV protocols. They found out that the revenue rate is increased by 25% for the non-uniform calls and functional computations on resource sharing.

However, a few works considered the virtualization in the dual sites of C-RAN, but solving the optimization problem of the power consumption and midhaul bandwidth still requires further studies. This study will provide recommendations with the adequate function split for different use-cases.

Another work by Shantharama *et al.* [19] surveyed the hardware-accelerated platforms and infrastructure for virtualization comprehensively. This survey categorized them into enabling technologies and research studies on hardware accelerations for CPU, memory, interconnects (between CPU and memory), and the custom & dedicated embedded accelerators. Extended instruction sets, CPU clock adjustments, and cache coherency are focused in this survey. It also provides insights about the trade-off and limitations of existing hardware-accelerated platforms for virtualization, as well as highlights the research roadmap in this research domain. Karagiannis *et al.* [20] reviewed all the mobile cloud networks (MCN) works and discussed the challenges associated. Alhumaima *et al.* [21] investigated the optimal number of virtual machines (VMs) to maximize the energy efficiency using Monte Carlo-based evolutionary algorithm in C-RAN. Also, Alhumaima and Raweshidy [22] developed a parameterized power model in V-RAN. The results conclude a decrease in the total power consumption of the core network in V-RAN.

There are a few works in the literature studied in terms of cost-effectiveness [23]–[28]. Wang *et al.* [23] presented a techno-economic study of a low-cost dual-site processing heterogeneous C-RAN, and optimal functional split for base stations from minimizing total cost of owners is suggested. Suryaprakash *et al.* [24], Garikipati *et al.* [25], and Lin *et al.* [26] developed a theoretical framework that can calculate the cost of V-RAN. Suryaprakash *et al.* showed that cloud processing requires approximately 10 to 15% less capital expenditure per square kilometer than traditional LTE networks. Also, it studied that most of the costs go on base stations and a mix of backhaul technologies for connectivity between base stations and data centers. In other words, the cost will be lower if the processing is done in the BBUs. This statement is also supported by Garcia-Saavedra *et al.* [17]. Checko *et al.* [27] evaluated mathematically a model with different splits from energy and cost-efficiency point of view. The obtained results enabled efficient RAN to multiplexing gains with a constraint of meeting the users' quality of service. Rost *et al.* [28] reviewed the requirements of C-RAN with an emphasis on the complexity-rate trade-off.

This work is the extension of our previous works in [29], [30], wherein the work in [29] proposes topology design, optimal routing, gateways placement selection, and disaster recovery algorithms on the same network model. The work in [30], introduces the optimization problem of the virtualization of the network, this work is extended here to cover analysis of the data rate, energy efficiency, and a combined optimization. It also recommends the operational system parameters of operators/regulators to have the best performance by adjusting their networks.

The main contributions of this work can be summarized as follows:

- Network performance is analysed in terms of data rate and power consumption with several functions splits.

Several active RHH utilization factors in the network are considered to simulate the real network fully.

- Optimisation of EE and combined optimization of power consumption and Midhaul bandwidth are evaluated considering the different function splits.
- Optimal operating parameters are recommended for similar networks. Thus, the regulators/operators may adjust the network to the recommended settings to achieve the best performance.
- The UEs switching scheme is being investigated in order to further reduce power consumption.

The rest of this paper is structured as follows. Section II discusses the network model and reviews the function splits in the literature. Section III derives the theoretical analysis, including; data rates, midhaul bandwidth, power consumption, energy efficiency, optimization of EE, and Combined optimization. Section IV addresses the simulation scheme to turn off RSs to relax the power consumption in low traffic RSs. Section V discusses and analyses the numerical expression and simulation results. Section VI concludes the research and discusses the future work.

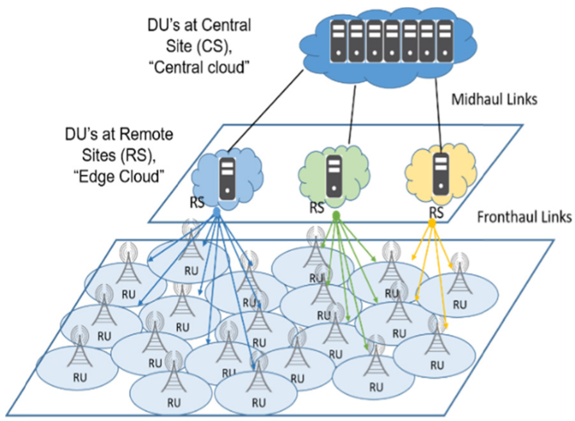

FIGURE 1. Dual site V-RAN architecture.

II. NETWORK MODEL

A. NETWORK ARCHITECTURE

Three layers in V-RAN architecture is discussed (see Fig.1). The first layer is the central cloud site (CS), which performs part of the processing and provision of the second layer. The second layer of edge cloud is called remote sites (RS) and works as aggregation points. The third layer is called the cell layer of RUs, which is deployed to provide the network with densifications the coverage of Users Equipment (UEs). Several UEs are supervised by Radio Unit (RU), where a Group of RUs are managed by one RS. This architecture model is different from the traditional heterogeneous cloud radio access network (H-CRAN), consisting of only one processing layer at BBU (equivalent to CS). A new midhaul link between the first layer (CS) and second layer (RS) is initiated using Free Space Optical (FSO) or millimeter waves (mmWave) technologies as it can cover only a few hundred meters and maintain a high-speed connection.

B. FUNCTION SPLITS

According to the 3GPP standard and ETSI, there are eight function splits [1], [2]. Moreover, Small Cell Forum (SCF) released individual functional splits according to the message's operational functions. This ensures not to add up overheads or repetition of an operation. Five function splits in the physical layer have presented in [1], [2] to investigate its effect concerning 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, resource damping, etc. While, UPs are processed on UEs basis where; equalization, inverse discrete Fourier transform, quadrature amplitude modulation, antenna damping, multi-antenna processing, forward error correction, turbo decoding, and other Layer2 & Layer3 functions are performed in this basis.

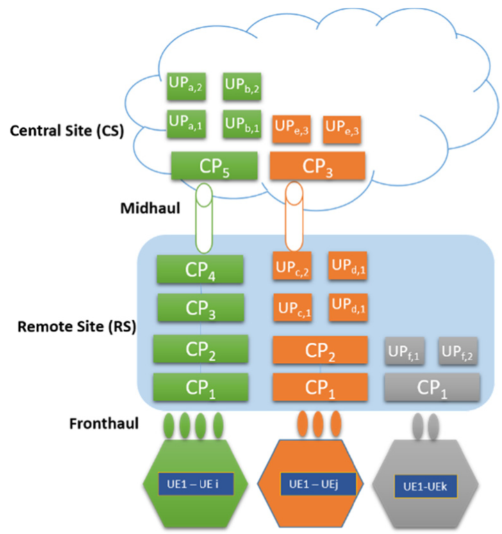

FIGURE 2. Dual Site VRAN model with the function split.

The processing chain of the dual-site CS and RS are presented, where some of the processing of CP and UP is conducted in CS and RS based on the function split (see Fig. 2). The function splits incur a different transmission rate and power. Also, the amount of CPs and UPs are determined based on the demand service after the function split is chosen. For the CP, large Bandwidth is required to send partially processed data. On the other hand, in UP, the cell's signal is processed widely but with less midhaul bandwidth requirement.

The processing in both sites is conducted in the digital-processing units (DUs), which are classified into CPs and UPs. The processing occurs in each site based on the function split as; 0% function split means that all processing happens in RS, and 100% means it happens in CS. The CS consumes less power, but it provides a high transmission capacity of the midhaul link. The usual trade-off in such a network is whether to make most of the processing at the edges to save bandwidth or make them in CS to save power consumption. Thus, the need to calculate EE in such a network is mandatory.

III. THEORETICAL ANALYSIS

This section derives and investigates numerically the key performance markers used in V-RAN system in order to provide a fully utilisation analysis of the network. Midhaul bandwidth, data rates, power consumption and EE are investigated as the performance markers for this network.

A. MIDHAUL BANDWIDTH IN V-RAN

The midhaul bandwidth can be derived as follows [9]:

$$B_{MH} = \sum\nolimits_{w\in W} \sum_{r\in R} \parallel (w_r{=}w) \, . \sum_{c\in C_r} (G_c\,(q_c) + \sum_{i\in I_c} J_i\,(P_i)) \tag{1}$$

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). The P_i is the percentage of UP of UEi and q_c is the percentage of function split of CP in cell C. $\parallel$ function is a test indicator which is used to make sure if the constraint is satisfied or not.

$$\parallel (a = b) = \begin{cases} 1, & if\ a = b \\ 0, & if\ a \neq b \end{cases} \tag{2}$$

B. DATA RATE IN V-RAN

Data rate of the system (T) is derived in terms of number of active RRHs at this time as follows:

$$T = R(N_A + FS_{CS}) \tag{3}$$

where R is the maximum achievable data rate $R = N_A R_{link}$, R_{link} is the data rate per link in CPRI protocols, N_A is the number of active RRHs in the system where N_A = NK, N = total number of RRHs in the network, and K is the utilisation factor of active RRHs in the network and FS_{CS} is the function split from CS prospective.

C. POWER CONSUMPTION IN V-RAN

The total power consumption in the network is a result of power consumption in fronthaul and midhaul. The fronthaul consumption such as the power consumed in RRH and links of RRHs, while, power consumed in CS and RS belongs to midhaul. The total consumed power can be represented as:

$$P_{total} = N_A\,(P_{RRH} + P_{Link}) + FS_{CS} P_{CS} + (1 - FS_{CS}) P_{RS}. \tag{4}$$

where P_{RRH}, P_{Link}, P_{CS} and P_{RS} are the power consumed in RRH, links, CS and RS respectively. The more function split occurs with increase value of CS percentage, as more consumption of DU hardware. The power consumption of the RRH is given as:

$$p_{RRH} = KP_A + (1 - k)P_S. \tag{5}$$

The p_{RRH} changes based on the number of active users, as it might be sleep with power P_S in case of number of active users is less than threshold and it keeps active with power $P_A = P_0 + K_{UE} p_f^{max}/\varphi$. A percentage of active RRHs (K) is introduced to simulate several availabilities of RRHs to provide real simulation of such a network. In case of some RRHs are sleeping, only power consumption comes from the generation of the servers, called static power P_S. On the other hand, P_0 is the fixed power consumption in each RRH, $K_{UE,Rs}$ is the average number of UEs in each RRH, p_f^{max} is the maximum power amplifier power and φ is the conversion factor to radio frequency from direct current. The power consumption of the CS and the RS can be derived as, respectively:

$$P_{CS} = gP_{LC} + \left(P_{CS}^{hou} + \lceil lFS_{CS} \rceil \, .P_{CS}^{DU}\right) \mu_l, \tag{6}$$

$$P_{RS} = \sum\nolimits_{r\in R_s} \left(P_{ONU} + P_{RS}^{hou} + \lceil e_r (1 - FS_{CS)} \rceil \, .P_{RS}^{DU}\right) \mu_{er}. \tag{7}$$

The power consumption in CS and RS are consisted of two parts, static and dynamic. The static part considers power consumed in the line card for fibre connection in the midhaul (g) and optical network unit for both CS and RS, respectively. While, the dynamic power consumption is usually depends on the number of active DUs $(ActiveDU|_{RS} = e_r = N_A)$ assuming that each RRH requires 1 DU for user and cell processing. l is the number of active DUs in CS which can be represented as:

$$ActiveDU|_{CS} = l = \left\lceil \frac{(UP_s)_{total}}{UPS_{RS} * r} \right\rceil or \left\lceil \frac{(CP_s)_{total}}{CPS_{RS} * r} \right\rceil. \tag{8}$$

where each RS requires 3 CPs and 15 UPs.

D. ENERGY EFFICIENCY IN V-RAN

The Energy Efficiency (EE) is the ratio of the successful data rates in the expense of power consumption in the network, and it can be derived as follows:

$$\begin{aligned} EE_{avg} &= \frac{T}{P_{total}} \\ &= \frac{N_A R + FS_{CS} R}{N_A\,(P_{RRH} + P_{Link}) + FS_{CS} P_{CS} + (1 - FS_{CS})\,P_{RS}}. \end{aligned} \tag{9}$$

E. EE OPTIMISATION IN V-RAN

The optimization problem can be defined to minimize the power consumption or to have a better EE with respect to the constraints, including number RSs and function split.

$$\max_{FS_{CS},\ r}\ EE_{avg}.$$
$$\text{Subject to}: \tag{10}$$

- Ensure the optimal number of RSs is less than maximum number or Remote sites (RSs).

$$r < R_{max}. \tag{11}$$

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

$$\| (p_i < |F_{UP}|) + \|(q_c < |F_{UP}|) = 1. \quad (12)$$

- Ensure that same DU is serving both CPs and UPs resources for a certain user. where m_i and n_i are the DU housing of UPs at RS and CS, respectively. x_c and y_c are DU housing for CPs at RS and CS.

$$(p_i < |F_{UP}|) \rightarrow (m_i = x_c), \quad (13)$$
$$(q_c < |F_{CP}|) \rightarrow (n_i = y_c)!. \quad (14)$$

- Ensure that the required service of CPs and UPs are less than DU's capacity in both sites, where L_{CP}^{RS} and L_{CP}^{CS} are the two thresholds of DUs capacity. Moreover, the processing in CS is more than in RS.

$$\sum\nolimits_{c\in c_r} H_{CP}^{RS}(q_c) \,.\|(x_c = d) \leq L_{CP}^{RS}, \quad (15)$$
$$\sum\nolimits_{c\in c_o} H_{CP}^{CS}(q_c) \,.\|(y_c = d) \leq L_{CP}^{CS}. \quad (16)$$

The proposed algorithm is presented (see Algorithm 1). The resulting throughput is considered based on the optimal energy in the entire network considering the consumed in CS and RS at different configurations. This ensures that the network is efficient and reliable with respect to several function splits within the previously discussed constraints.

Algorithm 1 NLP Optimisation of EE in V-RAN

Step 1: Initialize the network with the parameters in Table I.
Step 2: Let $K = 0.4$.
Step 3: Let $FS_{CS} = 0$.
Step 4: Solve the NLP of EE with the constraints in section III and return the fittest value.
Step 5: Let $FS_{CS} = FS_{CS} + 0.1$. If $FS_{CS} \leq 1$, go to Step 4.
Step 6: Let $K = K + 0.2$. If $K \leq 1$, go to Step 3.

F. COMBINED OPTIMISATION OF CONSUMED POWER AND MIDHAUL BANDWIDTH IN V-RAN

The combined optimization aims to find the optimal percentage of function split FS_{CS} and weight α to the normalized total power consumption P_T and midhaul bandwidth B_{MH}, where $\alpha \in [01]$. A new metric is introduced called utility function which is used to evaluate the overall network performance of bandwidth, and power consumption and it can be defined as:

$$\min_{FS_{CS},\alpha} \ \alpha P_T + (1-\alpha)B_{MH}. \quad (17)$$

IV. SWITCHING SCHEME

This section discusses the scenarios in which some DUs that are connected to RRH in a low-density RS are switched to another RRH in another high-density RS. This will lead to sleep an RRH. Consequently, the DUs responsible for this RRH will be turned off, which will relax the network's power consumption and enhance the overall EE of the network. UEs can be transferred from an RRH to its neighbour in other clusters due to the signal coverage constrains. The channel provided in this scenario is 35 channels per cluster. The optimization problem objective is to minimize the power consumed in RS with the optimal number of active DUs in RS.

$$\min_{e_r} \ P_{RS} \quad (18)$$

There is a constraint that the maximum number of channels that the cluster can handle is 35. Moreover, the UEs can communicate with only the RRH connected to it and its neighbours. An example of the network is presented in three clusters where each one is connected to one RS (see Fig. 3). Also, each RRH data is processed with one DU in the related RS. Thus, by letting RRH sleeps, its DU will be turned off as well. Each RS calculates the utilization of every RRH if the utilization of one of the RRHs is less than the maximum and its and its neighbours can service their UEs (see Algorithm 2). It will manage to make it sleep to improve the network power consumption and energy efficiency as well.

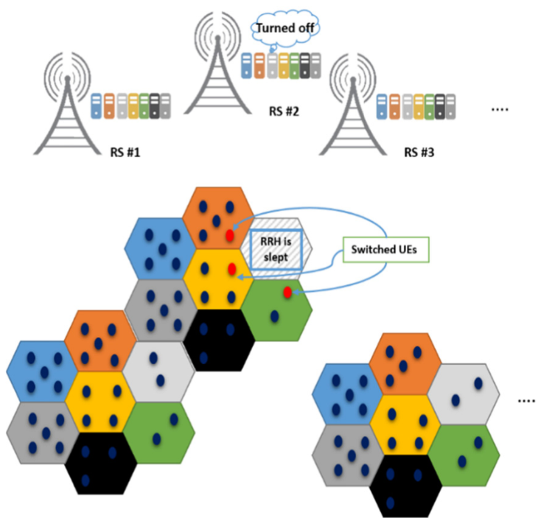

FIGURE 3. Switching architecture.

Algorithm 2 UEs Switching Procedures

1: Calculate the utilization of each RRH in RS
2. **For** i: 1 → Max. number of RRHs
3. **While** (there are connected UEs in RRH (i)) **do**
4: **if** ((Utilisation of RRH (i) < Max. Utilisation) and (Utilisation of neighbour RRH (i) < Max. Utilisation)) **then**
5: Notify the neighbour RRH (i) of the switching
6: Update the connected table
7: **end if**
8: **end while**
9: **end for**

V. ANALYSIS OF NUMERICAL AND SIMULATION RESULTS

The simulation and analysis of the network model are highlighted and presented in this section. The optimization

TABLE 1. Simulation parameters.

Description	Symbol	Value
Total Number of RRHs	N	100
Percentage of Number of active RHHs	k	0.4, 0.6, 0.8, 1
Function Split occurs from CS	FS_{CS}	$0 \rightarrow 1$
Data Rate per link	R_{link}	2.5 G bps
Power consumed in the link	P_{Link}	2 w
Power consumed while RRH is s3leep	P_S	1 w
Fixed power consumption	P_0	2 w
Maximum power amplifier power	p_f^{max}	0.13
Conversion factor	φ	1
Power Consumption for line card	P_{LC}	20
Power Consumption for DUs in CS	P_{CS}^{hou}	500
Power Consumption of the DUs in CS	P_{CS}^{DU}	100
Binary Indicator of active DUs in CS	μ_l	1/0
Power Consumption for ONU	P_{ONU}	5
Power Consumption for DUs in RS	P_{RS}^{hou}	150
Power Consumption of the DUs in CS	P_{RS}^{DU}	20
Binary Indicator of active DUs in RS	μ_{er}	0/1
User processing required per RS	UPS_{RS}	15
Cell processing required per RS	CPS_{RS}	3

problem is a nonlinear problem that is solved using a Genetic Algorithm (GA) on MATLAB (see Algorithm 1). The simulation is conducted using the given system parameters (see Table I).

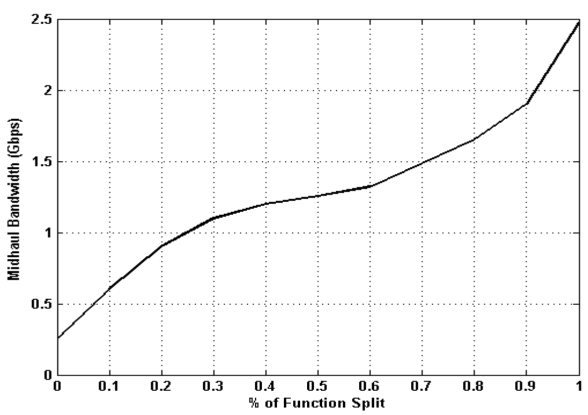

FIGURE 4. Midhaul bandwidth vs function Split in CS.

A. MIDHAUL BANDWIDTH IN V-RAN

The midhaul bandwidth is presented with several functions split from a CS perspective ($0 \rightarrow 1$) (see Fig. 4). As the processing gets to occur more at the CS, the more midhaul bandwidth is required reaching 2.5 Gbps at 100% function split from CS but with the lowest power consumption in the network and vice versa. It varies from 0.7 to 2.5 Gbps at function splits changes from 0 to 1. It is expected that such a system is to operate with these specifications as it is discussed in the small cell community.

B. DATA RATE IN V-RAN

The data rate is generated in the network with several function splits (see Fig. 5). The data rate slightly changes with the function split. This change is not observed as the function split contributes to a slight effect in the data rate. The data rate has a maximum value of 6.25×10^{20} bps at full capacity of RRHs in the network and a minimum amount of 2.5×10^{20} bps at 40% capacity of the network.

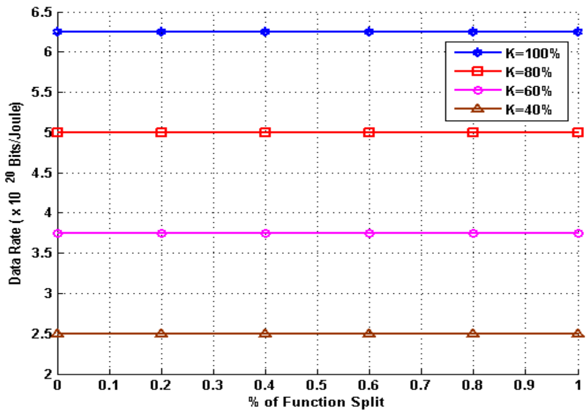

FIGURE 5. Data rate versus percentage of function split in CS.

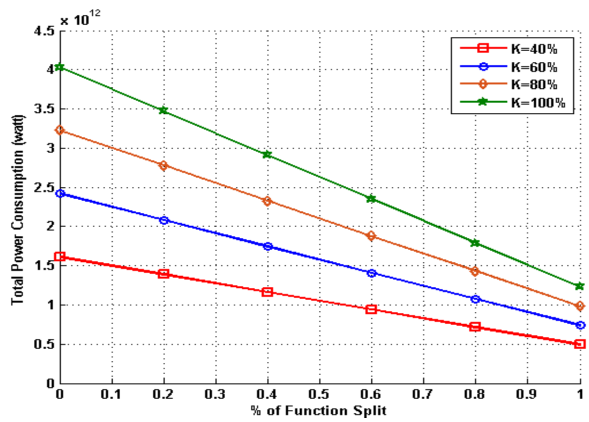

FIGURE 6. Total power consumption versus the function split in CS.

C. POWER CONSUMPTION IN V-RAN

The total power consumption is presented with the function split at several values of active RRHs (K) in the network (see Fig. 6). The consumed power at 100% active RRHs is equal to 4×10^{12} watt. This value is reduced while decreasing the active RRHs to reach 1.7×10^{12} watt at $K = 40\%$. On the other hand, the consumed power at 0% splitting is reduced to 1.3×10^{12} and 0.5×10^{12} when $K = 100\%$ and 40%, respectively.

D. EE OPTIMISATION IN V-RAN

Normalized energy efficiency (EE) is studied with the number of RSs, and the function split (see Fig. 7). The EE decreases with the increase of RSs as the power consumption increases with the increase in the number of RSs, reducing the EE. On the other hand, EE increases with the function

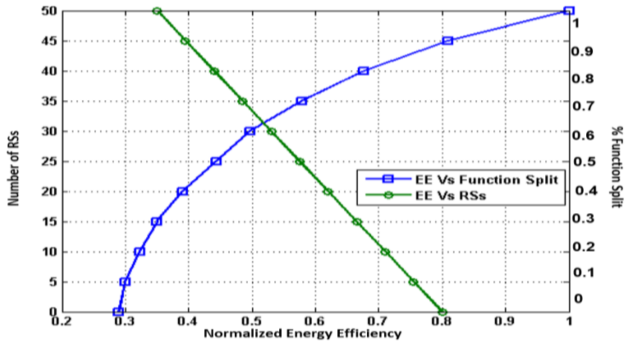

FIGURE 7. The energy efficiency versus number of CSs and function split.

split. Consequently, at 10 RSs, EE is 60% at function split of 80% in CS while 32% at function split 30%, where only 30% of the processing is done in CS and at 40 RSs. EE is about 70% at 80% of the processing at CS and 50% efficiency at 60% of the processing at CS. The variation of k is insignificant at EE as their affectivity in consumption cancels its effect in data rates.

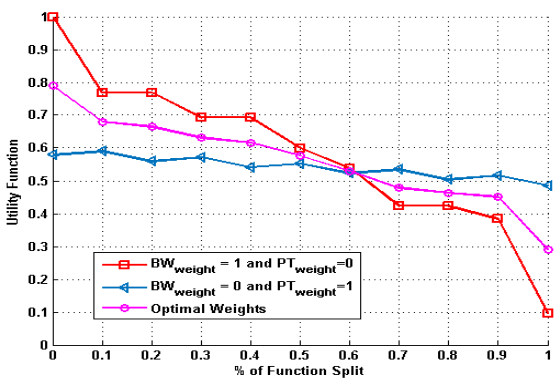

FIGURE 8. Utility function versus function split in CS at two RS.

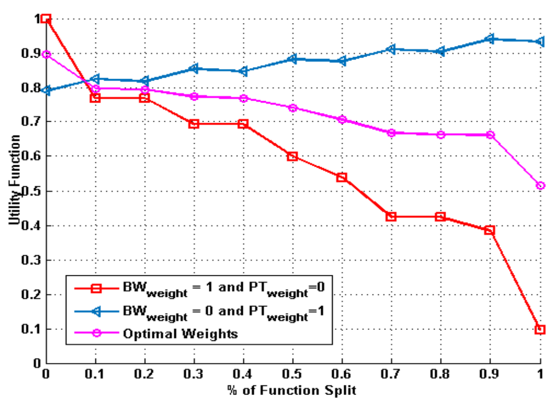

FIGURE 9. Utility function versus function split in CS at six RS.

E. COMBINED OPTIMISATION OF CONSUMED POWER AND MIDHAUL BANDWIDTH IN V-RAN

The utility function metric with the variation of the number of RSs between two to six is presented (see Figs. 8 and 9). At $\alpha = 1$, the utility function represents 100% of the midhaul bandwidth and 0% of the power consumption. On the other hand, when $\alpha = 0$, the utility function represents the power consumption as the function split moves towards RS, the power consumption increases, and midhaul bandwidth decreases. Finally, the circle-shaped curve represents a fraction of both with weights optimally that is generated from the GA. The power consumption is limited as only two, and six RSs have been considered in Fig. 8 and Fig. 9, respectively. The power consumption is varied from 0.6 to 0.5 at two RSs, and 0.8 to 0.95 at six RSs at function split from $0 \rightarrow 1$. On the other hand, the midhaul capacity is varied from 1 to 0.1 at different function split.

This paper recommends that similar networks that are only concerned with power consumption might have use $\alpha = 1$ with the system parameters discussed to have the most suitable utility function at the low function splits. On the other hand, networks that concern with the midhaul capacity can use $\alpha = 1$. In addition, the networks that require to concern with both can use $\alpha = 0.4555$ to have the performance in Figs. 8, and 9 considering RSs $= 2$ and 6. The required BW, power consumed in CS, RS and total consumption are listed with the five functions split (see Table II).

TABLE 2. Observed power consumption in CS and RS with each function split.

Split Fun.	FS of CS	BW (Mbps)	CS Power (W)	RS Power (W)	Total Power (W)
I	0	173	620	1590	2200
II	20%	933	720	1422	2142
III	30%	1075	820	1338	2158
IIIb	90%	1966	1120	834	1954
IV	100%	2457.6	1120	750	1870

TABLE 3. Minimum number of RRHs and RSs with regard of the number of UEs.

# UEs	# Active RRH	# RSs
15	3	1
20	4	1
25	5	1
30	6	1
35	7	1
40	8	2
45	9	2
50	10	2
55	11	2
60	12	2
65	13	3
70	14	3
75	15	3
80	16	3
85	17	3
90	18	4
95	19	4
100	20	4

F. SWITCHING SCHEME

The switching scheme has improved the overall network power consumption and energy efficiency, consequently. It makes some UEs transfer to another RRH and marks it as a sleep to lower the network consumption. The minimum number of RRHs and RSs can be reached in most of the cases for 100 UEs (see Table III). The Transferred UEi has to be in one of the neighbours cells as the signal strength would be able to communicate with the new RRH. The switching scheme ensures that each RRH works with half of its capacity and sleeps other RRHs, which preserve the same reliability and higher efficiency. The average energy efficiency increases from 12% to 57% based on the allocation of the UEs in the RRHs.

VI. CONCLUSION AND FUTURE WORK

This paper studied the energy efficiency, power consumption, and data rates in a virtualized radio access network (V-RAN) with function splitting in dual sites (Central and Remote) sites. A variation of active RRHs is introduced in the simulations to maintain a real study of network capacity in the network (40, 60, 80, and 100) % capacity of RRHs in the network as more as the function split is done towards CS, the less power consumption, almost constant data rates and more energy efficiency. The contribution of the function split in the data rate is insignificant compared with the consumption; consequently, energy efficiency (EE) follows the inverse behaviour of the consumption. Thus, the trade-off between a high EE (80%) at the expense of making 90% of CS processing and a low EE (30%) of CS processing at 10 RS.

The variation of the utilization factor (k) in EE is insignificant. Moreover, the consumed power at 100% active RRHs equals 4×10^{12} watt. This value is reduced while decreasing the active RRHs to reach 1.7×10^{12} watt at$K = 40\%$. On the other hand, the consumed power at 0% splitting is decreased to 1.3×10^{12} and 0.5×10^{12} when $k = 100\%$ and 40%, respectively. Furthermore, data rate changes $2.5 \rightarrow 6.2 \times 10^{20}$ bps with the same variations of k. Further, combined optimization has investigated between the power consumption and midhaul bandwidth at different functional splits. We recommend that similar networks that concern only with power consumption might have use $\alpha = 1$ with the system parameters discussed to have the most suitable utility function at the low function splits. On the other hand, networks that concern with the midhaul capacity can use $\alpha = 1$. In addition to, the networks that requires to concern with both can use $\alpha = 0.4555$ to have the performance studied in this paper. In addition, switching scheme is presented to relax the power consumption as some UEs might be transferred to other RRHs to let the low density RRH sleep.

This work can be extended to include the lower layer, which has several user types of equipment, user interference, power transmitted, received noise, power allocations, and resource blocks (RBs) allocations. The usage of RBs in optimum allocation of the resources will guarantee the users the required data rate.

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TAWFIK ISMAIL (Senior Member, IEEE) is currently an Associate Professor with the Department of Electronics and Computer Program, School of Engineering and Applied Sciences, Nile University, Egypt. He is the Director of the Wireless Intelligent Networks Center (WINC), Nile University, since September 2019. He also holds the position of Associate Professor at the National Institute of Laser Enhanced Sciences, Cairo University, Egypt. In 2015, he had Postdoctoral Research in optical and wireless communications at the Technical Institute of Microwave and Photonic Engineering, University of Graz, Austria. In 2018, he joined the Optical Wireless Communication Research Group, Department of Engineering and Sciences, University of Oxford, U.K., to work in research of quantum communication in free space. His research interests include in the broad areas including optical and wireless communications, mmWave, mobile edge computing, resource allocation, quantum cryptography, computer security, and blockchain, as well as the applications of artificial intelligence and machine learning in communication networks and healthcare.

HAITHAM H. M. MAHMOUD (Member, IEEE) received the double bachelor's degrees in electronics and communication engineering and the master's degree in communications from the Arab Academy for Science and Technology (AAST) from Lough Borough University (LU) and British University in Egypt (BUE), respectively. He is currently pursuing the Ph.D. degree with the School of Engineering, Birmingham City University (BCU), U.K. He is a Marie Curie Early Stage Researcher with Birmingham City University. He used to work as a Demonstrator for four years at BUE to conduct tutorials in several modules specialized in communications and programming along with mentoring a few students in their graduation projects. Moreover, he used to work as a part-time Research Assistant (RA) on a funded project by the National Telecommunication Regulatory Authority (NTRA) in Egypt, entitled "Heterogeneous Cloud-RAN Deployment Based on Hybrid FSO/mmWave Fronthaul Transport Network for 5G Mobile Systems". Besides, he has been publishing and reviewing tens of prestigious scientific papers in journals such as IEEE ACCESS, IEEE SENSORS, IEEE TRANSACTIONS ON INDUSTRIAL INFORMATICS, IEEE TRANSACTIONS ON NETWORK SCIENCE AND ENGINEERING and *IETE Technical Review* and IEEE conferences papers.