Study of the Centralization Level of Optical Network-Supported Cloud RAN

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***Abstract*—Radio Access Network (RAN) costs savings are expected in future Cloud RAN (C-RAN). Differently from traditional distributed RAN architecture, in C-RAN Remote Radio Heads (RRH) from different sites can share baseband processing resources from virtualized Base Band Unit (BBU) pools placed in few central locations (CO). Due to the stringent requirements of the several interfaces needed in C-RAN, optical networks have been proposed to support it. In this paper, we present the C-RAN Capital Expenditures (CAPEX) minimization problem to decide which COs should be equipped and the equipment to be installed. Several problem instances considering different Long Term Evolution–Advanced (LTE-A) configurations are solved to study the impact of the centralization level C-RAN in terms of both, CAPEX and Operational Expenditures (OPEX). Compared to the maximum centralization level, results showed remarkable costs savings when a lower level of centralization is considered.**

***Keywords*—Cloud RAN, Optical networks, 5G mobile/wireless convergence.**

I. INTRODUCTION

Radio access technologies evolution and centralized Radio Access Networks (RAN) architectures ([1], [2]) reveal new paradigms in next generation mobile networks; the commercial availability of technologies such as Long Term Evolution (LTE) requiring high capacity and strict delay constraints for complex coordination schemes among their base stations and the ever increasing Total Cost of Ownership (TCO) in mobile networks (including both Capital Expenditures (CAPEX) and Operational Expenditures (OPEX)) to satisfy the expected cell site's demand increment [2], [3] motivate research towards centralized RAN architectures. We refer the reader to the studies in [4] and [5] regarding advances in centralized RAN.

Among the main factors contributing to CAPEX increase are the need to deploy more base stations, new building locations, RF and baseband hardware, and power and cooling equipment acquisition. As for OPEX increase, site rental and power consumption are among the most meaningful.

In traditional distributed RAN architecture, RF and baseband processing hardware is co-located in the cell site and not shared among different sites, whereas in centralized RAN architectures, baseband processing is not only separated from RF processing hardware, i.e., remote radio heads (RRHs), but also centralized and it can be shared among different sites and even virtualized in Base Band Unit (BBU) pools [6]. Benefits from sharing BBU pools and statistical multiplexing in non-uniform traffic scenarios have been studied in [2], [7].

According to [8], centralized RAN architectures can be implemented in different variants, including BBU cloud. In this paper we refer to Cloud Radio Access Network (C-RAN). In C-RAN, virtualized BBU pools running in virtual machines (VMs) are hosted in different central locations and can be flexibly configured and serve RRHs from different virtualized BBU pools each time. The authors in [9] presented a 3-layered logical structure for C-RAN taking advantage of computation in a cloud environment.

Because of the stringent requirements of the several interfaces needed in C-RAN and the maturity and evolution of different optical network technologies, optical networks have been proposed to support interfaces between RRHs and BBUs (front haul network), among BBUs and between BBUs and their peering point in the mobile core network (back haul network). In [10] the authors proposed the use of Wavelength Division Multiplexing (WDM) technology to support centralized RAN. Moreover, a practical implementation was demonstrated and links up to 10 Gb/s interconnecting RRHs and BBUs reported. Although the authors in [11] proposed an energy-efficient WDM aggregation network and formally defined the BBU placement optimization problem as an Integer Linear Programming (ILP) model aiming at optimizing the aggregation network in terms of power; and the authors in [12] have recently proposed an ILP model for optimal BBU hotel placement over WDM networks in centralized RAN, still few mathematical models can be found in the literature considering optical network equipment in C-RAN.

Differently from previous works, in this paper we propose a mathematical model to study the impact of the centralization level in C-RAN architectures supported by optical networks. To that end, different centralization levels are compared in terms of CAPEX and OPEX. Specifically, the contributions of this paper are as follows:

- A Mixed ILP (MILP) model for dimensioning locations hosting virtualized BBU pools (i.e., central offices (CO)) to minimize CAPEX in terms of VMs and network equipment, while taking into account the different interfaces needed.
- From the resulting CO design, impact of centralization level is also studied from the OPEX perspective, in terms of network equipment power consumption.

The discussion is supported by representative results from realistic scenarios in section IV.

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The next section describes RAN relevant requirements and the architecture model based on LTE considered in this paper.

II. Radio Access Networks

A. Distributed and Centralized RAN

Fig. 1 illustrates both distributed and centralized RAN architectures, showing that in distributed RAN RF and baseband hardware are co-located in the site and not shared with other sites; whereas in centralized RAN, BBUs from different sites are co-located in the same BBU pool and can be shared among different RRHs along the time.

From the mobile core network perspective, both distributed and centralized architectures require to interconnect base stations and their peering point through a backhaul network (e.g., and IP/MPLS network supported by WDM). In addition to backhaul connections transporting user and control data (S1 interface), interconnection among neighbouring cells' base stations may also be required (X2 interface). While latencies in the order of tens of milliseconds are allowed in S1 interfaces, tight coordination scheme between base stations led to maximum delays allowed in the order of hundreds of microseconds for the X2 interface thus, limiting the maximum distance between base stations requiring coordination.

Moreover, compared to distributed RAN, centralized RAN architectures require a front haul network aiming at providing connectivity between RRHs and BBUs in remote BBU pools and convey radio interface data. Among the different radio interface protocols, Common Public Radio Interface (CPRI) [13] is widely used; CPRI is a bidirectional protocol and its bitrate is constant and depends on the cell site configuration. Fig. 1 illustrates the logical links supporting S1 and X2 interfaces in both distributed and centralized RAN architectures and CPRI in the centralized approach. In LTE and LTE-A technologies, CPRI requires not only huge capacity (in the order of Gb/s and tens of Gb/s), but also strict delay constraints (in the order of few hundreds μs round trip time, RTT).

B. C-RAN Architecture Model

In this paper, we consider a reference scenario based on the LTE and LTE-A technologies, where a set of geographically distributed RRHs cover certain regions and virtualized BBU pools are hosted in main COs, whereas the peering point is located in a core CO, which hosts, among others, the mobility management entity (MME) and the serving gateway (S-GW); functions that in turn could be virtualized according to [6].

To provide the required capacity to support load fluctuations in different areas along daytime, some of those RRHs can be activated or deactivated. Let us assume that activation (deactivation) of those RRHs can be done through the corresponding entity in charge of the control and management of the C-RAN. RRHs are connected to end-points through fiber links. To support CPRI links, connections from end-points to COs can be effectively implemented and dynamically modified, allowing a given RRH to be assigned to different virtualized BBU pools along the time. Moreover, to support handover and tight coordination schemes, among others, coordination among active and neighbouring RRH

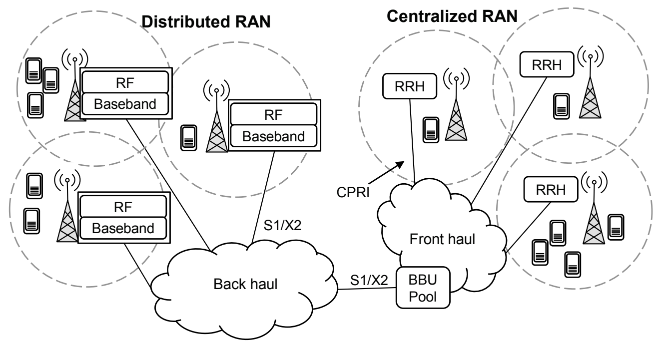

Fig. 1. Distributed and centralized RAN architectures.

needs to be considered; thus, X2 interfaces between virtualized BBUs in remote virtualized BBU pools are required. It is worth noting that, due to strict delay limitations required in X2 interfaces, not all BBUs in virtualized BUU pools in distant COs might be accessible among them. Finally, S1 links towards the aforementioned core CO (hosting MME and S-GW) need also to be established over the backhaul network; we assume than network it is based on IP/MPLS.

Fig. 2 depicts an example of the reference scenario where a set of RRHs corresponding to macro base stations (MBS) cover large areas and a set of small cells' RRHs cover smaller areas aiming at offloading cell load during peak hours. The next section faces the problem of minimizing CAPEX costs to equip main COs while satisfying demand at any time for all cells; CRPI, S1, and X2 interfaces requirements and limitations, such as capacity and maximum delay constraints, are considered.

III. The C-RAN CAPEX Minimization (CRAM) Problem

A. Problem statement

The CRAM problem can be formally stated as follows:

Given:

- A set of geographically distributed RRHs *H*; representing *N*(*h*) the subset of RRHs neighbouring RRH *h*; i.e. near RRHs operating at the same frequency band and requiring X2 interface links between them to interconnect their respective BBUs, and representing *H*(*t*) the subset of *H* with the RRHs to be activated at daytime *t*.
- The tuple $<\alpha_h, \beta_h, \gamma_h>$ representing the required capacity by RRH *h* for CPRI, S1 and X2 interfaces respectively, in the case it is active. Since required capacity is constant and depends on the configuration it can be pre-computed in advance.
- A set *V* of VMs' configurations with capabilities for BBU pools virtualization; each VM configuration *v* is defined by its cost κ_v and its number of BBUs it can virtualize λ_v; let us assume that one BBU can serve one RRH.
- A set of transponders *P*; each transponder *p* is defined by its cost κ_p and capacity φ_p; since grey or coloured transponders may be considered to support the different interfaces, the parameters δ_p^{CPRI}, δ_p^{S1}, δ_p^{X2} indicate if *p* can support CPRI, S1 or X2 interface links respectively.
- A set of line cards *C*; each line card *c* can support one type of transponder and it is defined by its cost κ_c, and number of ports to plug-in transponders ξ_{cp}.

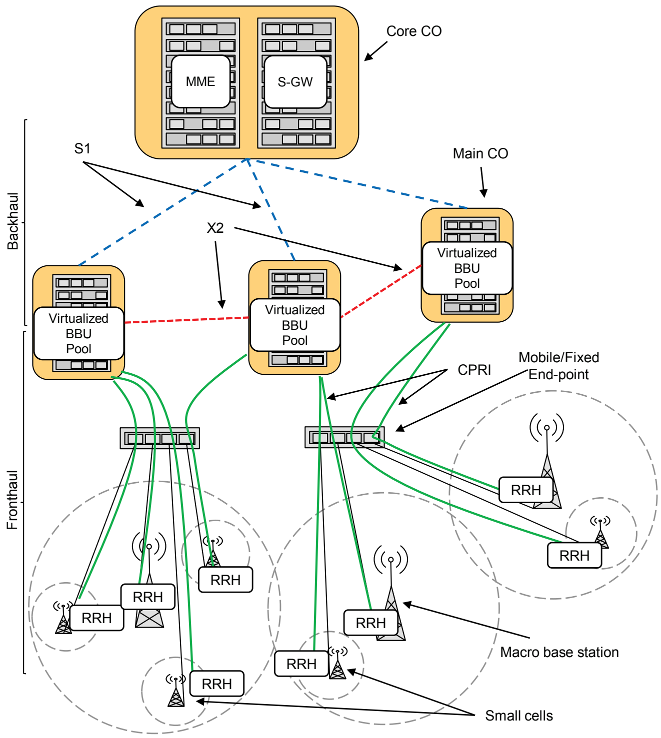

Fig. 2. Example of Cloud RAN architecture.

- A set of IP/MPLS routing equipment E; each router e is defined by its cost κ_e, its switching capacity σ_e, and the number of available slots ρ_e to plug-in line cards; the parameter η_{ec} represents if equipment e can support card c.
- A set O with main COs; each main CO can be equipped with a predefined configuration of VMs and with an IP/MPLS router.
- $O(h)$ represents the subset of main COs that can be reached by RRH h without exceeding delay imposed by CPRI requirements.
- $U(o)$ represents the subset of main COs that can be reached from main CO o without violating X2 delay constraints.
- A core CO with functions for MME, S-GW, etc.

Output: the VMs' configurations and routing equipment, lines cards and transponders to install in each main CO.

Objective: minimize the cost of VMs' configurations, routing equipment, line cards and transponders used.

B. *Mathematical model*

The following sets and parameters have been defined:

H	Set of RRHs.
O	Set of main COs.
V	Set of VMs' configurations that can be equipped in main COs.
E	Set of routing equipment that can be equipped in main COs.
T	Set of daytime hours.
P	Set of transponders.
C	Set of line cards types.
$H(t)$	Subset of H with RRHs active at time t.
$N(h)$	Subset of H with RRHs neighbouring h.
$O(h)$	Subset of O with main COs that can be accessed by RRH h without exceeding the CPRI delay constraint.
$U(o)$	Subset of O with main COs that can be reached from main CO o without exceeding the X2 delay constraint.
λ_v	Number of VMs in VMs's configuration v.
α_h	Capacity required in CPRI link by RRH h in the case of being active.
β_h	Capacity required in S1 interface link by RRH h in the case of being active.
γ_h	Capacity required in X2 interface link by RRH h in the case of being active.
φ_p	Capacity of transponder p.
δ_p^{CPRI}	1 if transponder p can support CPRI links.
δ_p^{S1}	1 if transponder p can support S1 interface links.
δ_p^{X2}	1 if transponder p can support X2 interface links.
ξ_{cp}	Number of ports in line card type c to support transponder p; 0 if line card type c does not support transponder p.
σ_e	Available capacity in routing equipment e.
ρ_e	Number of available slots in equipment e.
η_{ec}	1 if equipment e can support line card type c; 0 otherwise.
κ_v	Cost of VM configuration v.
κ_p	Cost of transponder p.
κ_c	Cost of line card type c.
κ_e	Cost of equipment e.
$bigM$	Large positive constant.

Decision variables:

x_{ov}	Binary. 1 if CO o is equipped with VM configuration v; 0 otherwise.
y_{oe}	Binary. 1 if CO o is equipped with equipment e; 0 otherwise.
l_{oc}	Integer. Number of cards of type c to equip in o.
a_{op}	Integer. Number of transponders p in CO o.
z_{hot}	Binary. 1 if RHH h is assigned to CO o at time t; 0 otherwise.
$w_{hoo't}$	Integer. Number of X2 interface links required between COs o and o' by RRH h at time t.
q_{hotp}	Binary. 1 if transponder p is equipped in main CO o to support CPRI links at time t for RRH h; 0 otherwise.
m_{otp}	Integer. Number of transponders p to equip in main CO o to support S1 interface links at time t.
$n_{oo'tp}$	Integer. Number of transponders p to equip in CO o to support X2 interface links at time t to reach CO o'.

The problem can be formulated as follows:

$$\text{Minimize} \quad \sum_{o\in O}\sum_{v\in V}\kappa_v \cdot x_{ov} + \sum_{o\in O}\sum_{e\in E}\kappa_e \cdot y_{oe} + \sum_{o\in O}\sum_{c\in C}\kappa_c \cdot l_{oc} + \sum_{o\in O}\sum_{p\in P}\kappa_p \cdot a_{op} \tag{1}$$

subject to:

$$\sum_{v \in V} x_{ov} \leq 1 \quad \forall o \in O \tag{2}$$

$$\sum_{e \in E} y_{oe} = \sum_{v \in V} x_{ov} \quad \forall o \in O \tag{3}$$

$$\sum_{v \in V} \lambda_v \cdot x_{ov} \geq \sum_{h \in H(t)} z_{hot} \quad \forall t \in T, o \in O \tag{4}$$

$$\sum_{o \in O(h)} z_{hot} = 1 \quad \forall t \in T, h \in H(t) \tag{5}$$

$$w_{hoo't} \geq \sum_{h' \in N(h)} z_{h'o't} - (1 - z_{hot}) \cdot bigM \tag{6}$$
$$\forall t \in T, h \in H(t), o \in O(h), o' \in U(o)$$

$$\sum_{o' \in O \setminus U(o)} \sum_{h' \in N(h)} z_{h'o't} \leq (1 - z_{hot}) \cdot bigM \quad \forall t \in T, h \in H(t), o \in O \tag{7}$$

$$\sum_{p \in P} \varphi_p \cdot \delta_p^{CPRI} \cdot q_{hotp} \geq \alpha_h \cdot z_{hot} \quad \forall t \in T, h \in H(t), o \in O(h) \tag{8}$$

$$\sum_{o \in O} \sum_{p \in P} q_{hotp} = 1 \quad \forall t \in T, h \in H(t) \tag{9}$$

$$\sum_{p \in P} \varphi_p \cdot \delta_p^{S1} \cdot m_{otp} \geq \sum_{h \in H} \beta_h \cdot z_{hot} \quad \forall t \in T, o \in O \tag{10}$$

$$\sum_{p \in P} \varphi_p \cdot \delta_p^{X2} \cdot n_{oo'tp} \geq \sum_{h \in H} \gamma_h \cdot w_{hoo't} \quad \forall t \in T, o \in O, o' \in U(o) \tag{11}$$

$$n_{oo'tp} = n_{o'otp} \quad \forall t \in T, o \in O, o' \in U(o), p \in P \tag{12}$$

$$a_{op} \geq \sum_{h \in H} q_{hotp} + m_{otp} + \sum_{o' \in U(o)} n_{oo'tp} \quad \forall t \in T, o \in O, p \in P \tag{13}$$

$$\sum_{c \in C} \xi_{cp} \cdot l_{oc} \geq a_{op} \quad \forall o \in O, p \in P \tag{14}$$

$$\sum_{e \in E} \rho_e \cdot y_{oe} \geq \sum_{c \in C} l_{oc} \quad \forall o \in O \tag{15}$$

$$\sum_{e \in E} \sigma_e \cdot y_{oe} \geq \sum_{p \in P} \alpha_p \cdot a_{op} \quad \forall o \in O \tag{16}$$

$$l_{oc} \leq \rho_e \cdot \eta_{ec} + (1 - y_{oe}) \cdot bigM \quad \forall o \in O, e \in E, c \in C \tag{17}$$

The objective function (1) minimizes the cost of the VM configurations, routing equipment, line cards and transponders to equip in main COs.

Constraint (2) guarantees that at most one VM configuration is assigned to a main CO. Constraint (3) ensures that a main CO is equipped with routing equipment if and only if it is equipped with a VM configuration. Constraint (4) ensures that VM configuration selected in each main CO has enough VMs to satisfy BBU virtualization for the RRHs assigned to it. Constraint (5) ensure that RRHs are assigned to one and only one accessible main CO at each time when they are active. Equation (6) accounts whether X2 interface link between main COs *o* and *o'* is required for RRH *h* at time *t*. Constraint (7) guarantees that, if RRH *h* is assigned to main CO *o*, their neighbouring RRHs are not assigned to COs that cannot be accessed from main CO *o*; i.e. to guarantee that X2 interface links would not exceed delay constraint. Constraints (8) and (9) guarantee that transponder *p* selected for CPRI link of active RRH *h* at *t* has enough capacity and that one and only one transponder is selected (note that CPRI links are not multiplexed). Constraint (10) ensures that capacity of transponders selected in main CO *o* for S1 interface links is enough to satisfy the total S1 interfaces' capacity required in *o* at each time. Similarly, constraint (11) ensures that capacity of transponders selected for X2 interface links between main COs is enough to satisfy the required capacity for X2 interfaces in *o* at each time. Constraint (12) ensures the same transponders' configuration is selected for X2 interfaces between main COs *o* and *o'*. Constraint (13) accounts the number of transponders of each type to equip in main CO *o* to guarantee the required connections at any time. Constraint (14) ensures that the cards to equip in each main CO can support the transponders selected. Constraints (15) and (16) guarantee that the switching equipment selected has enough slots and capacity respectively. Finally, constraint (17) ensures that if routing equipment *e* is assigned to main CO *o*, and it does not support line card *c*, that line card is not equipped in *o*.

Considering the particular case where the exact number of main COs to equip is given, the parameter Φ representing the number of main COs to equip is defined and the model extended with the following constraints:

$$\sum_{t \in T} \sum_{h \in H(T)} z_{hot} \geq \sum_{e \in E} y_{oe} \quad \forall o \in O \tag{18}$$

$$\sum_{e \in E} \sum_{o \in O} y_{oe} = \Phi \tag{19}$$

Constraint (18) ensures that only main COs that host BBUs assigned to active RRHs at some time are equipped, whereas constraint (19) ensures that Φ main COs are equipped.

IV. Illustrative results

A. Scenario

For evaluation purposes, we consider a scenario where 49 RRHs, e.g. representing MBSs, are geographically distributed. The outmost cells cover regions where the traffic load varies according to an office load profile and the central ones vary according to a residential profile similarly as described in [2], e.g. representing an urban area surrounded by industrial zones; Fig. 3a depicts the reference scenario.

In addition, a set of RRHs, e.g. corresponding to small cells, are also geographically distributed for offloading purposes resulting thus, in a scenario with 195 RRHs; it is worth highlighting that not all of them will be active simultaneously, since the traffic profiles vary differently along the daytime. Nonetheless, MBS' RRHs are considered always active to guarantee coverage even in off-peak hours; whereas small cells' RRHs are progressively activated (deactivated) as load increases (decreases). Fig. 3b illustrates the number of active small cells' RRHs per MBS required for the two profiles against daytime. A set of main COs that can be selected to host virtualized BBU pools is considered. Their location is illustrated in Fig. 3a. We target a maximum 150 μs RTT between RRHs and BBUs and, as a consequence, no single main CO can be accessed by all RRHs in the evaluated scenarios. One sector is considered in each cell.

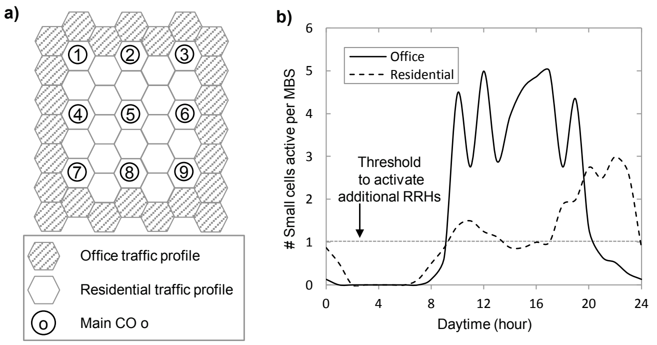

Fig. 3. Cells and main CO placement (a) and number of small cells active, per MBS, against the daytime (b).

A. CAPEX Study

CAPEX is studied from the network equipment perspective (IP/MPLS routers, line cards and transponders to equip in main COs) and different centralization levels compared. The network equipment's cost is based on the cost model in [14]. Virtualized BBU pools' cost is not considered. The MILP model described in the previous section was implemented and several instances were solved using CPLEX.

To study the impact of the centralization level in CAPEX, firstly we consider different LTE-A configurations in the previously described scenario and solve problem instances for representative daytime hours; i.e. peak and off-peak hours.

Fig. 4 shows the network equipment cost evolution against the number of main COs to equip for peak hours in office (12 h) and residential areas (22 h) and for an LTE-A 4x4 Multiple Input Multiple Output (MIMO) [15] 40MHz configuration (requiring CPRI links' capacity close to 10Gb/s, and S1 and X2 links' capacity about 630 Mb/s and 230 Mb/s respectively), Fig. 4a and b, and an LTE-A 4x4 MIMO 100MHz configuration (requiring CPRI links' capacity close to 25 Gb/s and S1 and X2 links' capacity about 1.55 Gb/s and 550 Mb/s), Fig. 4c and d. As expected, the maximum centralization level requires 2 main COs in any case. Indeed, for the 40MHz configuration (Fig. 4a and b), equipping the same 2 COs at any time with the cheapest equipment configuration, results in the minimum cost solution.

Interestingly, as soon as CPRI links' capacity increases (Fig. 4c and d), e.g., due to a configuration upgrade from 40MHz to 100MHz, the number of main COs to equip with minimum cost moves away from the fully centralized solution at peak hours. Results for off-peak hours showed that the fully centralized case, 2 COs, satisfies the demand at that time and with the minimum cost. As it can be seen in Fig. 4c and d, equipping more than 7 and 4 COs at the corresponding peak hours, increases the cost.

Considering the 100MHz configuration and aiming at dimensioning our scenario, we restricted the set of COs that can be selected to 7 main COs, corresponding to the ones that need to be equipped to satisfy demand at peak hours and that can be selected to satisfy demand at any time. The problem was solved for each hour separately and the minimum cost solutions obtained were saved. Then, each main CO was dimensioned with the minimum equipment to satisfy demand at any daytime hour. Although the proposed mathematical model can solve the problem considering all daytime hours jointly, splitting the problem into different instances per each hour allows solving it in reasonable times, while obtaining good enough solutions as it will be seen in the next paragraphs. Results showed that by equipping 7 main COs with the smallest IP/MPLS routers, demand is satisfied at any time. More specifically, required equipment in each main CO resulted in 2867.6 cost units in terms of CAPEX.

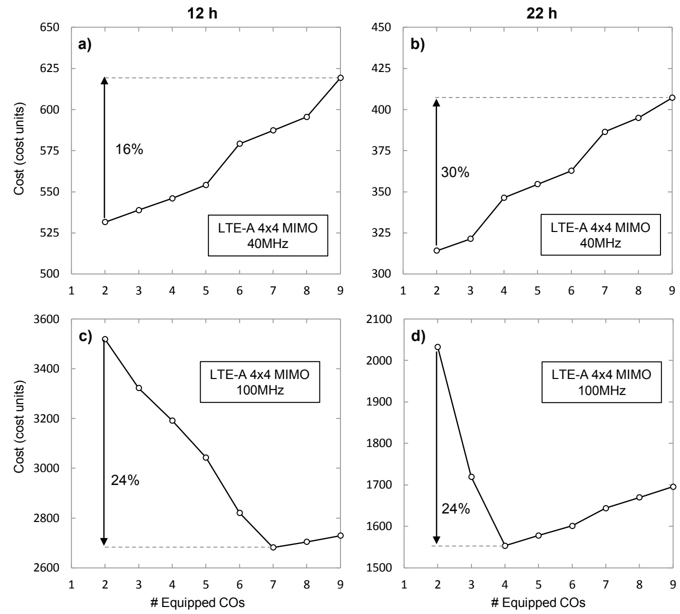

Fig. 4. Cost evolution against the number of main COs to equip for two different LTE-A configurations at daytime 12h and 22h.

Similarly, we dimensioned the same configuration scenario considering the fully centralized approach, where only 2 COs can be equipped, and a theoretical fully distributed approach, where 49 main COs are equipped, each to serve a single MBS' RRH and its small cells' RRHs. From the results, the fully centralized approach required a huge capacity router (6.72 Tb/s and 48 slots) and a small one (2.24 Tb/s and 16 slots), whereas the fully distributed required 49 of the smallest router (1.40 Tb/s and 10 slots). CAPEX value obtained for the fully centralized approach was 3518.4 cost units, whereas for the fully distributed one, was 4694.9 cost units. The solution obtained when 7 COs were equipped, represents CAPEX savings as high as 18% and 39% compared to the cases where 2 and 49 COs were equipped respectively.

Focusing on the main COs to equip hour by hour, Fig. 5 illustrates that during off-peak hours only two COs need to be equipped whereas for peak hours more main COs need to be equipped. An elastic CO network equipment use is envisioned.

B. OPEX Study

For completeness, we also study the impact of the centralization level taking into account the power consumption of the equipment along the daytime.

In line with [16], we assume that the power consumption of routers can be approximated as the summation of the consumption of the basic node, the slots cards, and the port cards. In addition, we consider a fixed component of power consumption in IP/MPLS routers related to the basic node and

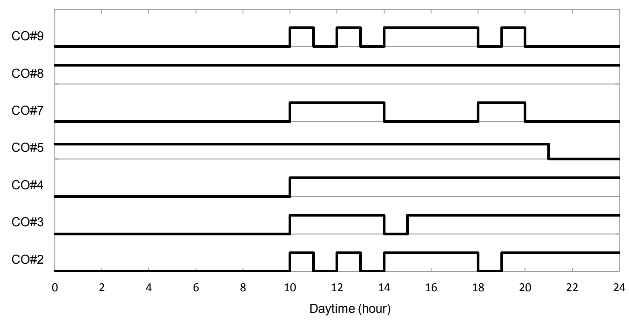

Fig. 5. Main COs to equip against daytime hours.

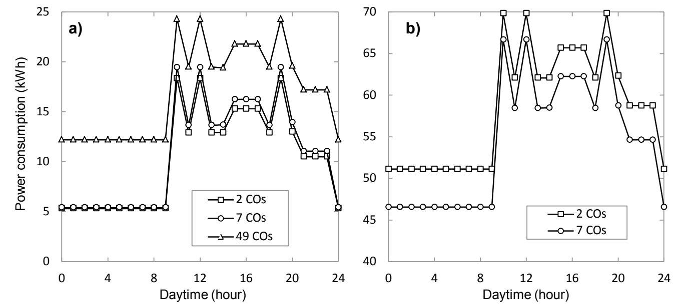

Fig. 6. Power consumption of transponders (a) and total equipment (b).

its slots power requirements and a variable contribution from the line cards and transponders in use, assuming that they only consume when they are in use.

Fig. 6 represents the power consumption of transponders (Fig. 6a) and total power consumption considering the whole equipment in all main COs (Fig. 6b) against daytime hours. As expected, since the fully centralized approach is the one requiring the lowest number of transponders to be equipped, their contribution to the power consumption is also the lowest. On the contrary, the distributed approach is the one requiring more transponders, since each main CO requires the necessary equipment not only for the CPRI interfaces, but also for the X2 and S1 interfaces. The solution requiring 7 COs to be equipped, results in a slightly increment of 5% in terms of transponders' power consumption compared to the centralized approach, and savings near 37% compared to the distributed one. Notwithstanding, the contribution to power consumption from routers and line cards needs to be considered to evaluate OPEX.

As described in the CAPEX study, because of the equipment selection for CAPEX minimization, the centralized approach requires a huge capacity router plus a small one, and the distributed approach requires 49 units of the smallest routers. For the centralized approach, it is clear that the large power consumption of the huge router will impact the total power consumption, even though, the lowest number of transponders is required. As shown in Fig. 6b, the centralization level requiring 7 COs presents lower total power consumption than the fully centralized approach; savings close to 7% are observed. Values for the fully distributed approach are not depicted in Fig. 6b, since computing only the fixed contribution from the 49 smallest routers is as high as 270 kWh (49 x 5.51 kWh). The 7 COs solution shows savings close to 82% compared to the fully distributed approach.

Finally, as showed in Fig. 6a, it is clear that for any of the approaches considered, equipment usage follows curves along daytime similarly as traffic load figures shown in Fig. 3.

V. Concluding Remarks

To study the impact of the centralization level in optical network-supported C-RAN, the CRAM problem for C-RAN CAPEX Minimization has been presented and formally defined using a MILP model.

The mathematical model was implemented and problem instances considering different centralization levels and LTE-A configurations were solved using CPLEX.

Results showed that, in the evaluated scenarios, although the maximum centralization level results in the minimum CAPEX solution for certain LTE-A configuration, as soon as higher capacities are required in different LTE-A interfaces (e.g. due to a configuration upgrade) lower levels of centralization result in CAPEX savings up to 18% compared to the fully centralized approach. Savings as high as 37% were observed compared to a fully distributed approach.

For completeness, OPEX was also studied from the solutions obtained after solving the CRAM problem. OPEX savings near 7% and up to 82% were shown for the solution requiring a low level of centralization compared to the fully centralized and fully distributed approaches respectively.

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