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Analysis of CAPEX and OPEX Benefits of Wireless Access Virtualization

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***Abstract*—Virtualization of wireless access networks dictates a new direction in the research of cost effective and energy efficient network modelling that the telecommunications industry is seeking. Different research initiatives are dealing with virtualization of wireless resources (e.g. nodes, wireless access cards, wireless spectrum) and new ideas are being put forth to leverage cloud computing in the wireless telecom domain. In this paper, we analyze the CAPEX and OPEX of our proposed virtualized wireless access network framework and show its benefits with regards to traditional network architectures. We also examine the trade-offs associated in achieving such benefits.**

I. Introduction

The process of combining hardware and software resources into a single software based entity is at the core of the notion of network virtualization. Computer researchers have done extensive investigations on virtualization in the application layer [1] and the outcome is visible in today's network architecture in the form of VLAN, VPN, overlay networks, etc.

Future network deployment strategies are driven by the omni presence of wireless links. The advent of the smart-phone culture has brought about a drastic change in the traditional voice dominated cellular networks. Consumers' *any time any where* demand for high speed data traffic is evolving the wired broadband internet towards the wireless internet. The conundrum situation of providing high capacity wireless services at a rather decreasing cost is driving major telecom operators to resort to virtualization of the networks [2]. While virtualization of the core network resources such as routers, servers, etc are either well understood or the subject of current investigations, virtualization of radio access which accounts for 40% (while the core network is responsible for 10%-30%) [3] of the total operational cost of a cellular network is receiving very little attention. Wireless virtualization also promises to alleviate the ossification problem of costly radio spectrum by ensuring its efficient use [4] [5] [6]. Major cellular vendors and operators have notably advocated wireless virtualization for cost effective and energy efficient service provisioning.

The cost structure of wireless networks has been studied for both capacity and coverage limited cases [7] [8] [3]. Cellular network operation demands extensive power consumption. This huge power demand not only is responsible for greater OPEX for the operators but also contributes to increased carbon emissions as many countries with the largest wireless usage (in absolute terms) are also dependent on fossil-based energy sources to power these networks.

The information and communications technologies (ICT) industry is, in fact, responsible for 2% to 3% [9] of the world's total carbon emissions and this carbon footprint is doubling every four years. At the same time, as a result of its potential impact in all sectors of human activity, ICT is accepted to be one of the key enablers of a low carbon economy [10]. As such, energy efficient operation of cellular networks [11] is appreciated from both the operators' power expenditures and environmental conservation perspectives. If virtualized resources are located in data centers powered by renewable energy sources, the networks can also contribute to reduce the industry's carbon footprint as well as generate eventually further OPEX savings in jurisdictions with a price on carbon emissions.

Wireless access networks account for up to 60% to 80% of the telecom's energy consumption [12]. It is therefore imperative to devise techniques that target energy efficient operation of telecom networks and at the same time reduce carbon emissions. Leveraging cloud computing and virtual networking can thus be significant drivers of so-called *Green Communications* [13], [14] in the telecom domain.

The rest of the paper is organized as follows: Section II succinctly describes the proposed frameworks for the virtual wireless access network (VWAN). CAPEX and OPEX analysis of the VWAN appears in Sections III-A and III-B respectively, including comparisons with corresponding values of a traditional network. Finally, Section IV concludes the paper with a brief discussion on the CAPEX and OPEX benefits of virtualization and the associated trade-offs.

II. Virtual wireless access network (VWAN)

Cellular access networks encompass base station controllers (BSCs) (in LTE the BSC is incorporated within the eNodeB), base stations (BSs), and the wireless medium between the BSs and the UEs. The virtualization concept stems from the efficient use of network resources and leveraging the use of distributed computing sources. In this respect, wireless network virtualization should be an intelligent amalgamation of wireless cloud computing technology; efficient spectrum sharing techniques in time, frequency, space, code domain or any combination of these; shared use of hardware resources, etc.

The absence of a conceptual definition of wireless access virtualization in the existing literature has prompted us to propose three different frameworks to implement this concept. They are: local, remote and hybrid virtualization frameworks.

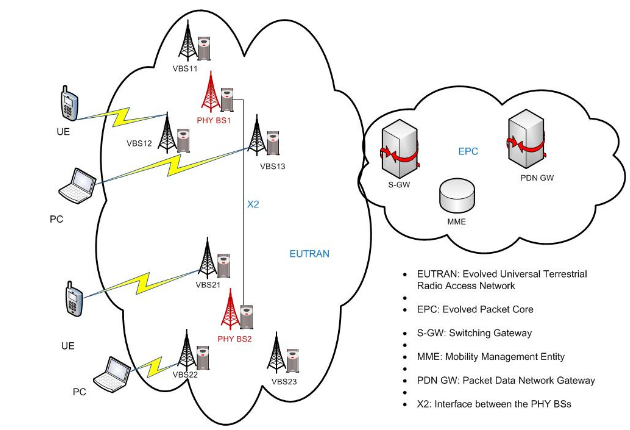

Fig. 1. Local virtualization framework

In a *local virtualization* approach (Fig-1), the individual PHY BSs are *sliced* (slicing is the process of allocating a coherent subset of physical resources of a typical PHY BS to the created virtual BSs) vertically or horizontally to create multiple virtual BSs(VBSs). The $hypervisor$, a supervising entity, is in charge of synchronous allocation of physical resources between different virtual instances.

A data center approach is adopted for *remote virualization*, where the radio equipment of the BS is segregated from the baseband processing unit. The processing of the baseband signal is centralized either in conventional telecom network equipments or in software (VBS pools) in standard IT platform [15]. Remote radio heads (RRHs) serve to interact with the user equipments (UEs).

Hybrid virtualization is a combination of the local and remote virtualization approaches. Here, baseband processing is distributed among VBS pools (the data center) and the local enhanced remote radio head (E-RRH) which will have augmented capacity for processing delay sensitive data (e.g. voice, live video traffic); this can alleviate the QoS problem for the delay sensitive traffic of the remote virtualization approach. Analysing the CAPEX and OPEX of all the three frameworks are beyond the scope of this paper. Hence, our analysis concentrates on the local virtualization approach, with subsequent works devoted to the other two frameworks.

III. CAPEX and OPEX analysis of VWAN

We have analysed the capital expenditure (CAPEX) and operational expenditure (OPEX) trends of a locally virtualized network. CAPEX refers to the cell-site construction cost as well as the cost of the radio BSs needed to cover a certain geographical area. OPEX on the other hand, is highly influenced by the power consumption of the network. It is worth noting that, while in the CAPEX analysis, the parameter of concern was relative infrastructure cost per user, in the case of OPEX, the parameter of interest was power per bit. The cost of site rent is not considered as it would merely add a constant value that is same for both the traditional and the virtualized networks (at least for local virtualization). In the process of the investigation, we also compare the results with the corresponding values for a traditional (LTE) network.

In the scenario analyzed, a certain geographical area A is considered with a certain number of operators. The total number of users (UEs) served by all the operators are kept the same for both the traditional and the virtualized networks. The number of slices in a SuperBS (SBS) corresponds to the number of operators in the traditional network. It is also assumed that the allocated spectrum per *virtual operator* [16] (in a virtualized network) is the same as that of an $operator$ (in traditional network).

A. CAPEX analysis of VWAN

Let us assume that, in the area A, n_{op} operators are serving their customers. The number of BSs required to cover an area of A square unit depend on the following parameters:

- Maximum coverage radius of a BS, R_{max}.
- Total number of users in the area A, N_{UE-t}

Assuming a coverage limited case, the total number of required BSs/operator is

$$N_{BSO} = \frac{A}{\pi R_{max}^2} \quad (1)$$

Let the user density per unit area be λ. We assume that user density is the same per operator for both the traditional and virtualized networks, i.e., $\lambda_{op} = \lambda_{sl} = \lambda$, where, λ_{op} and λ_{sl} are the user density/BS (/slice) for the respective networks. The total number of users per operator is

$$\begin{aligned} N_{UEO} &= \lambda \times A \\ &= \pi \times \lambda \times N_{BSO} \times R_{max}^2 \end{aligned} \quad (2)$$

1) For traditional network: The traditional network dimensioning parameters are:

- Number of operators, n_{op}
- Total number of users per operator in peak period, N_{UEO}
- Cost per cell site, c_{cs}
- Cost per BS, c_{bs}

The total cost for cell site construction by all the operators is

$$c_{cs-t} = n_{op} \times N_{BSO} \times c_{cs} \quad (3)$$

The cost of all the BSs operated by the operators is

$$c_{bs-t} = n_{op} \times N_{BSO} \times c_{bs} \quad (4)$$

The total infrastructure cost is

$$\begin{aligned} c_{infra} &= c_{cs-t} + c_{bs-t} \\ &= \frac{N_{UE-t}}{\pi \lambda R_{max}^2}(c_{cs} + c_{bs}) \end{aligned} \quad (5)$$

The total number of users in the network is then

$$N_{UE-t} = n_{op} \times N_{UEO} \quad (6)$$

Now, the infrastructure cost per user becomes

$$c_{infra-u} = \frac{c_{cs} + c_{bs}}{\pi \lambda R_{max}^2} \quad (7)$$

Here, it is interesting to note that the infrastructure cost per user is independent of the total number of operators in the region.

2) For locally virtualized network: A virtual network is set up in the same area A, consisting of *SuperBSs (SBSs)* serving the same number of users as in the traditional network. Those operators will now be called virtual operators (VOs) in this scenario. The number of slices (*virtual base stations (VBSs)*) of a SBS is the same as the number of operators in the traditional case. The parameters for the locally virtualized network are as follows:

- Number of slices (VBSs) per SuperBS, n_{sl}
- User density per area, λ_{SBS}
- Number of SuperBS in area A, N_{SBS}
- Cost per cell site of a SBS, c_{cs-sbs} (same as the traditional case)
- Cost of a SBS unit, $c_{sbs} = c_{bs} \times [1 + 0.2 \times (n_{sl} - 1)]$. We assume that the cost of a SBS increases linearly (with a slope of 20%) with the number of VBSs it contains.

Let us assume each SBS has the same maximum coverage radius of R_{max} as the traditional BS. Now, the total number of SBS required to cover the area A is

$$N_{SBS} = \frac{A}{\pi \times R_{max}^2} \tag{8}$$

The total number of users in area A is

$$\begin{aligned} N_{UE-t} &= \lambda_{SBS} \times A \\ &= n_{sl} \times \lambda \times \pi \times R_{max}^2 \times N_{SBS} \end{aligned} \tag{9}$$

The total cost for cell site construction for the SBS network is

$$c_{cs-sbs-t} = N_{SBS} \times c_{cs-sbs} \tag{10}$$

The total cost for the SBSs of the network is

$$c_{sbs-t} = N_{SBS} \times c_{sbs} \tag{11}$$

Now, the infrastructure cost for the SBS network becomes

$$\begin{aligned} c_{infra-sbs} &= c_{cs-sbs-t} + c_{sbs-t} \\ &= \frac{N_{UE-t}}{\pi \times n_{sl} \times \lambda \times R_{max}^2} \times (c_{cs-sbs} + c_{sbs}) \end{aligned} \tag{12}$$

Finally, the infrastructure cost per user is

$$c_{infra-SBS-u} = \frac{(c_{cs-sbs} + c_{sbs})}{\pi \times n_{sl} \times \lambda \times R_{max}^2} \tag{13}$$

We can see that the infrastructure cost per user decreases with the number of slices in the SuperBS. Fig-2 shows how the relative infrastructure cost varies with the user density for both the traditional network (TN) and locally virtualized (LV) network. While the relative infrastructure cost for a TN remains constant for a varying number of operators in area A, it decreases with the increase in the number of slices (VOs) in the LV network. The analytical results shown in table-I display the cost reduction variation with the number of slices.

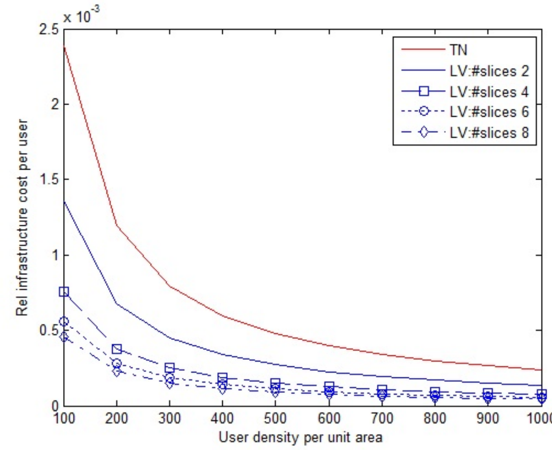

Fig. 2. Relative infrastructure cost vs user density (R=2 unit)

TABLE I. RELATIVE INFRASTRUCTURE COST REDUCTION

#slices in the SBS	Rel cost reduction (%)
2	46
4	68.33
6	76.7
8	80.83

B. OPEX analysis of a VWAN

Channel capacity with modified Shannon's formula [17] is

$$R = w \times w_{eff} \times log_2(1 + \frac{SNR}{SNR_{eff}}) \tag{14}$$

Here, w is the allocated BW/UE, SNR_{eff} is the SNR efficiency, for our analysis we set it to 1. The bandwidth efficiency is

$$w_{eff} = eff_{ac} \times eff_{cp} \times eff_{pace} \times eff_{so} = 0.56 \tag{15}$$

where, eff_{ac} = 0.9, due to adjacent channel leakage and the practical filter issue;
eff_{cp} = 0.93, due to cyclic prefix;
eff_{pace} = 0.94, due to pilot assisted channel estimation;
eff_{so} = 0.715, due to signalling overhead.

1) Traditional network power consumption model: The power consumption of different elements of a BS are:

- Transceiver power, P_{trans}
- Rectifier power, P_{rect}
- Digital signal processor power, P_{DSP}
- Power amplifier power, P_{PA}
- MW transmission power, P_{mw}
- Air cooling power, P_{air}

Power consumption for different components of a BS appears in Table-II [18]. Each antenna is associated with a transmission chain that consists of the transceiver, rectifier, digital signal processor and the power amplifier. So, the power consumption of a BS is

$$P_{BS} = n_a \times (P_{trans} + P_{rect} + P_{PA} + P_{DSP}) + P_{air} + P_{mw} \tag{16}$$

TABLE II. POWER CONSUMPTION FOR DIFFERENT PARTS OF THE BS

BS Parts	Power Consumption (W)
Digital signal processor	100
Power amplifier (SISO)	156
Power amplifier (MIMO)	10.4
Transceiver	100
Rectifier	100
Air conditioner	225
Microwave link	80

where, n_a is the number of antenna per BS. If there are N_{BSO} per operator, then the total power consumption per operator is

$$P_{BSO} = N_{BSO} \times P_{BS} \tag{17}$$

If n_{op} operators are operating in the area A, then the total power consumption in the network is

$$P_{BS-tot} = n_{op} \times P_{BSO} \tag{18}$$

The user density per unit area is λ, hence, the number of users per BS is, $\lambda \pi R_{max}^2$. And from equation-(2) the number of users per operator is

$$N_{UEO} = N_{BSO} \times \lambda \times \pi \times R_{max}^2$$

So, the total number of users served by n_{op} operators in service area A is

$$N_{UE-t} = n_{op} \times N_{UEO} = n_{op} \times N_{BSO} \times \lambda \times \pi \times R_{max}^2 \tag{19}$$

The capacity of a UE is R Mbps. The total capacity of the whole network is

$$R_{BS-tot} = N_{UE-t} \times R \tag{20}$$

Now, the consumed power per bit becomes

$$\begin{aligned} P_{bit-BS} &= \frac{P_{BS-tot}}{R_{BS-tot}} \\ &= \frac{P_{BS}}{\lambda \pi R_{max}^2 \times ww_{eff} \times log_2(1+SNR)} \end{aligned} \tag{21}$$

which is independent of the number of operators in area A.

2) Locally virtualized network power consumption model: Let us assume that the number of SBSs operating in area A is N_{SBS} and the number of slices in each SBS is n_{sl}. An SBS will have more processing capabilities than a regular BS and hence, will require more power for its cooling system as well as the MW (Microwave) link.

We model the power consumption on cooling and MW transmission to increase linearly with the number of *slices* in the SBS; we assume it to increase by 20% with each additional slice. So, the power consumption would have the form

$$P_{airSBS} = P_{air} \times [1 + 0.2 \times (n_{sl} - 1)] \tag{22}$$

$$P_{mwSBS} = P_{mw} \times [1 + 0.2 \times (n_{sl} - 1)] \tag{23}$$

The power consumption of a SBS is

$$P_{SBS} = n_{sl} n_a (P_{trans} + P_{rect} + P_{PA} + P_{DSP}) + P_{airSBS} + P_{mwSBS} \tag{24}$$

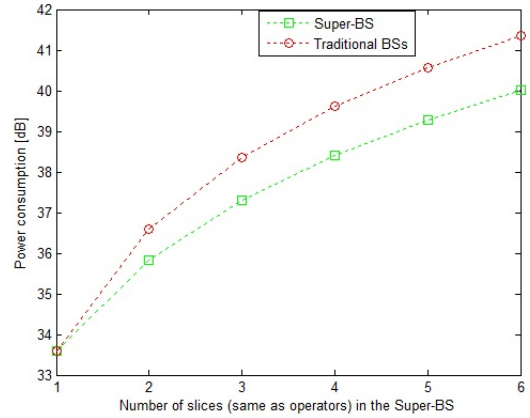

Fig. 3. Total power consumption vs #slices

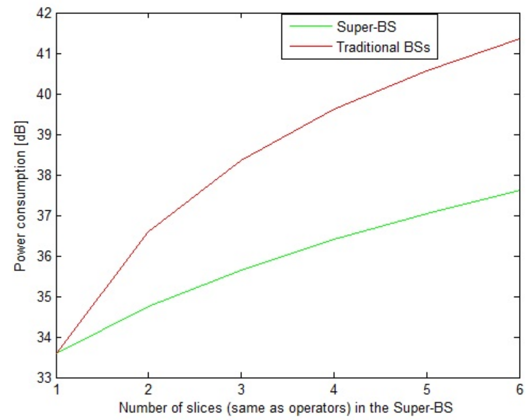

Fig. 4. Total power consumption vs #slices (shared antenna case)

Now, the consumed power per bit is

$$\begin{aligned} P_{bit-SBS} &= \frac{P_{SBS-tot}}{R_{SBS-tot}} \\ &= \frac{P_{SBS}}{n_{sl} \times \lambda \pi R_{max}^2 \times ww_{eff} \times log_2(1+SNR)} \end{aligned} \tag{25}$$

So, it is seen that the power consumption per bit decreases with the increase of *slices* in the SBS. Total power consumption in a locally virtualized network is also less than that of a traditional network while serving the same number of UEs, as is evident in Fig-3. We can see that the power consumption of a LV network is less than the traditional network as virtualization is implemented (2 or more slices).

3) Super-BS with antenna sharing by the VOs: We consider the case where each antenna is shared by different VBSs (slices). In this configuration, each slice will have its own DSP but the antennas as well as the RF chains will be shared by the existing VBSs. The RF power of a traditional BS would be

$$P_{rf} = P_{trans} + P_{rect} + P_{PA} \tag{26}$$

For a SBS, the RF power will have the following form

$$P_{rfSBS} = P_{rf} \times [1 + 0.2 \times (n_{sl} - 1)] \tag{27}$$

TABLE III. POWER SAVING PER BIT FOR DIFFERENT NUMBER OF SLICES IN THE SBS

# of slices	P_{sav}%(No antenna sharing)	P_{sav}% (Antenna sharing)
2	16.0	35.0
3	21.4	46.3
4	24.0	52.12
5	25.7	55.6
6	27.0	58.0

So, the power consumption of a SBS is

$$P_{SBS} = n_a \times P_{rfSBS} + n_{sl} \times P_{DSP} + P_{airSBS} + P_{mwSBS} \quad (28)$$

Now, the consumed power per bit becomes

$$P_{bit-SBS} = \frac{P_{SBS-tot}}{N_{SBS} \times n_{sl} \times R} \quad (29)$$

Antenna sharing gives better total power performance than the non-sharing case, as can be seen from Fig-4. Table-III shows the comparison of power saving per bit for both the no antenna sharing and the antenna sharing cases.

IV. CONCLUSION

The emerging prospect of wireless virtualization with CAPEX and OPEX benefits has prompted investigation in this area. A significant infrastructure cost reduction is possible from SBS virtualization and the gain grows with an increasing number of slices. But it should be noted that each additional slice will add to the complexity level of the required hardware implementation; the existing hardware technology can also set a hard limit on the achievable cost gain in a high capacity SBS. Virtualization will require extensive processing capabilities on the part of the SBS. Hence, highly efficient multi-core and multi-thread processors are required for baseband processing. Adept design of a *hypervisor* is also critical for ensuring fair resource sharing among residing VBSs in a SBS.

Power consumption is a major contributor to the OPEX in a cellular network. Hence, a power saving of 27% (for 6 slices in no antenna sharing case) to 58% (for 6 slices in antenna sharing case) is very compelling in this regard. For SBS cost and power consumption modelling, a linear increase with respect to the traditional BS was assumed. While it gives an intuitive figure of the corresponding quantities, the absolute figures might be different but we do not expect it to change the above analytical behaviour significantly.

From the perspective of abating GHG emissions, wireless virtualization not only promises to lower power consumption but centralizing baseband processing in wireless data centres (for remote and hybrid virtualization) can stimulate the use of *green energy* by powering those sites with air, water or solar sources.

As future work, we will carry out detailed analysis of the remote and hybrid virtualization models which is expected to provide improved CAPEX and OPEX performance as well as an edge in mitigating inter-cell interference and better management of cellular handoffs.

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