Cost Modeling for SDN/NFV Based Mobile 5G Networks

Christos Bouras*†, Panagiotis Ntarzanos†, Andreas Papazois†
*Computer Technology Institute & Press "Diophantus", Patras, Greece
†Computer Engineering & Informatics Dept., University of Patras, Greece
bouras@cti.gr, ntarzanos@ceid.upatras.gr, papazois@ceid.upatras.gr

***Abstract*—This paper presents a techno-economic analysis on the integration of new technologies in 5G mobile networks, in order to fulfil the requirements provided by ETSI organization. Therefore "softwarization" of 5G networks is imperative and becomes a reality through new technologies, such as Software Defined Networking (SDN), Network Function Virtualization (NFV) and Cloud Computing. In this context, this paper provides a cost model in order to estimate the Capital Expenditure (CAPEX), the Operational Expenditure (OPEX) and the Total Cost of Ownership (TCO) for the proposed architecture. Furthermore, the proposed techno-economic model is used in order to estimate the above-mentioned network costs for the proposed network architecture and these costs are compared with the corresponding costs of a traditional network architecture. The experimental results verify and even exceed the ambitious predictions for cost reduction, due to the integration of those state of the art technologies in next-generation architectures.**

***Keywords*—5G, SDN, NFV, Cloud-RAN, techno-economics.**

I. INTRODUCTION

The rapidly increasing amount of mobile devices and multimedia data traffic, are pushing to re-architect the current generation of the cellular mobile communication. The 5G networks are deeply characterized by 3 unique features: ubiquitous connectivity, extremely low latency and ultra-high speed data transfer [1]. Therefore, Telecommunication Service Providers (TSPs) are obliged to purchase and operate new physical infrastructures, hire engineers with high qualifications for operating this equipment and also requires dense deployments of terminating network equipment such as Base Stations (BSs). All these lead to high Capital Expenditure (CAPEX) and Operational Expenditure (OPEX) for TSPs, therefore it is important to reduce the factors affecting the Total Cost of Ownership (TCO) for a mobile network operator and mobile services provider. Furthermore, the mismatch between the requirements of the market and capabilities provided by network equipment, and also the demand for resource sharing. Modern telecommunication society becomes a witness of the convergence of cloud networking, fast connectivity and high processing power taking place over the existing Internet model [2]. Significant paradigms such as Software-Defined Networks (SDN) and Network Functions Virtualization (NFV), if appropriately designed and deployed, can definitely help in fulfilling the above mentioned requirements: as a matter of fact, an efficient integration of networks and IT could allow important cost savings, and the acquisition of more flexibility in service provisioning.

Concerning OPEX, automated operation processes could restrict human intervention, reducing employment costs and faulty network operations. Additionally, as far as CAPEX is concerned, a flexible, agile and nearly optimal provisioning of functions and services, can definitely reduce equipment costs and allows postponing investments. For instance, TSPs spend 60-80% of CAPEX on Radio Access Network (RAN) technologies that cannot be always up-to-date with the current status of technology [3]. Moreover, according to China Mobile Research Institute, by adopting Cloud-RAN 15% CAPEX reduction and 50% OPEX reduction can be achieved, based on China Mobile research on commercial networks [4].

In this work a 5G network architecture is proposed integrating the above mentioned state of the art technologies. This paper fundamental goal is to provide a cost model in order to estimate network costs for the proposed architecture in comparison with the corresponding costs of a traditional network architecture. This paper comes to fill a gap in the current limited and dispersed bibliographical, scientific, and academic research in this field with a complete techno-economic analysis concerning Evolved Core Network (EPC) and RAN for a 5G mobile network architecture.

The paper is structured as follows: after the brief introduction presented in the current section, Section II continues with an analysis of the above mentioned state of the art technologies and with a presentation of the way they are all combined together in the proposed architecture. Based on the proposed architecture, in Section III the cost models are developed for RAN and EPC network. In Section IV the experiment concerning CAPEX and OPEX reduction percentages between the traditional network architecture against the proposed architecture is conducted and the relevant graphic results are presented. Finally, in Section V the paper is concluded and some ideas for future research activity are listed.

II. MODEL STRUCTURE AND GENERAL ASSUMPTIONS

As it was discussed earlier, the techno-economic analysis indicates that SDN and virtualization of network equipment leads to significant reduction of CAPEX for network operators. NFV implements network functions through software running on commodity servers, in contrary with conventional networks which implement these functions on dedicated hardware. NFV can support the abstraction of functions related to networking procedures from hardware to software, through the employment of a "hypervisor level" and allows the agile distribution of operations throughout network nodes, data centers etc. Hence, by not acquiring nor updating specialized hardware, TSPs save huge costs [5].

Concerning SDN, by separating control and data plane it is possible for the operator to eliminate dependencies on a specific vendor, increase the speed of introducing new features and reduce TCO. More specifically, according to [6], 58,04% CAPEX reduction can be achieved for the SDN based sharing scenario in comparison with the conventional architecture. OpenFlow is considered as the key enabler of SDN. It is a standard communications protocol defined between the control and forwarding planes for an SDN system. OpenFlow allows direct access to and control of the forwarding plane of network devices, i.e., switches, either physical or virtual. The path of

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TABLE I: Blade Server Resources

CPU	**Memory**	**Storage**	**Network**
2xXEON (2x4 cores)	64 GB ECC RAM	2 TB RAID 1-HDD	4x10 GB

packets through the SDN-enabled network is determined by controlling software running on a separate OpenFlow network controller.

Moreover, physical equipment sharing among several mobile operators allows them to achieve efficient use of existing network resources, fewer sites and wider coverage. Network virtualization is a method where physical resources in a network are split into slices. Each slice is absolutely isolated from the rest ones and can be tied to a given network device dynamically. This technique allows different operators to use of the same infrastructure in parallel.

Cloud-RAN is a concept for decoupling the baseband processing from the radio units. This technology allows the processing to take place at a central data center thus reducing the cost for the necessary network redundancy. Cloud-RAN offers easier deployment of these new technologies and significantly improves the network's overall operation efficiency by updating the signaling with EPC, in order to reflect the differences between Cloud-RAN and traditional BSs. The virtualized interface will provide access to EPC with an abstracted image of the physical resources associated with a given Cloud-RAN BS, for whom from this point the SBS symbol will be used. [7]. SBS is a software defined BS on which a certain number of virtual BSs can be deployed and operated by different TSPs. According to the model proposed in [8], the total cost of a SBS unit increases linearly (with slope 20% with the number of vBSs deployed on it). By presenting EPC with an abstracted view of the available equipment the information exchange can be reduced to only the required signalling, requesting bandwidth for the transmission of useful data [9].

Isolating EPC from RAN allows innovation to continue in both areas, without negatively impacting intercommunication between the two. Decisions for optimally low latency are best made at the BS and do not require continuous signalling for obtaining information from the the rest of the network. Physical equipment are amped to directly, with signaling being transferred to EPC. By virtualizing EPC, according to ACG research [10], 68% CAPEX reduction and 67% OPEX reduction can be achieved. The Cloud-RAN controller is also able to provide slicing of the network resources to allow for RAN sharing between operators. The implementation and configuration of connections between virtual machines within a SDN environment is typically undertaken by SDN controllers and through the OpenFlow protocol that manages both physical and virtual switches.

In order to virtualize EPC, a typical XEON blade server can be used for the virtual machine hosting, which capabilities and resource capacity is shown in TABLE I. Moreover, according to [11], it is assumed that VM resources hosted on XEON blade server have a fixed configuration as showed in TABLE II. The adoption of the above-mentioned technologies, implement a flexible and cost-efficient architecture as depicted in Fig. 1, in which the proposed cost model is based.

III. COST ANALYSIS

In this section the cost models for establishing and operating a mobile network are provided. In the first case scenario it is supposed that a network which uses the traditional RAN architecture is deployed, and in the second case scenario the network uses the proposed RAN architecture. In both cases, the virtualization technology building a virtual EPC (vEPC) is used, in order to acquire the above mentioned benefits.

TABLE II: Provided VM Capacity per Blade Server

VMs	**CPU**	**Memory**	**Storage**	**Network**	**Packet Processing**
4 VMs max	2 cores per VM	8 GB per VM	250 GB per VM	10 Gbps max	1.9 Mpps per VM

A. CAPEX Analysis of RAN

1) Traditional Network: The dimensioning parameters for a traditional RAN architecture are:

- n_{op}: Number of operators.
- C_{cs-sbs}: Cost per cell site.
- C_{BS}: Cost per BS.
- N_{BSO}: Number of BSs per operator.

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

$$C_{cs-sbs-total} = n_{op} * N_{BSO} * C_{cs-sbs}$$

The cost of all the BSs operated by the operators is:

$$C_{BStotal} = n_{op} * N_{BSO} * C_{BS}$$

The total CAPEX for a traditional RAN architecture is then:

$$\begin{aligned} CAPEX_{traditional} = C_{cs-sbs-total} + C_{BStotal} = \\ n_{op} * N_{BSO} * (C_{cs-sbs} + C_{BS}) \end{aligned} \quad (1)$$

2) Virtualized Network: The parameters for a locally virtualized RAN architecture are the following:

- n_{vs}: Number of sliced virtual BSs per SuperBS.
- l_{SBS}: User density per each area.
- N_{SBS}: Number of SuperBS in a given area A.
- R_{max}: Maximum coverage radius of a BS.
- C_{cs-sbs}: Cost per cell site of a SBS (same as the traditional case).
- C_{SBS}: Cost of a SBS unit, where C_{SBS}=C_{BS}* [1+0.2*(n_{vs}-1)] as it was assumed in Section II.

The number of users in a given area A is:

$$N_{UE} = l_{SBS} * A = n_{vs} * l * pi * R_{max}^2 * N_{SBS}$$

The total cost for cell site construction for the SBS network becomes:

$$C_{site} = C_{cs-sbs} * N_{SBS}$$

The total cost for the SBSs of the network is:

$$N_{sbso} = C_{SBS} * N_{SBS}$$

Therefore the total CAPEX concerning the virtualized RAN architecture becomes:

$$\begin{aligned} CAPEX_{RAN} = C_{site} + C_{sbso} = \\ \frac{N_{UE}}{n_{vs} * l * pi * R_{max}^2} * (C_{cs-sbs} + C_{SBS}) \end{aligned} \quad (2)$$

B. OPEX Analysis of RAN

The power consumption the results from an analysis of different components of a BS are:

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

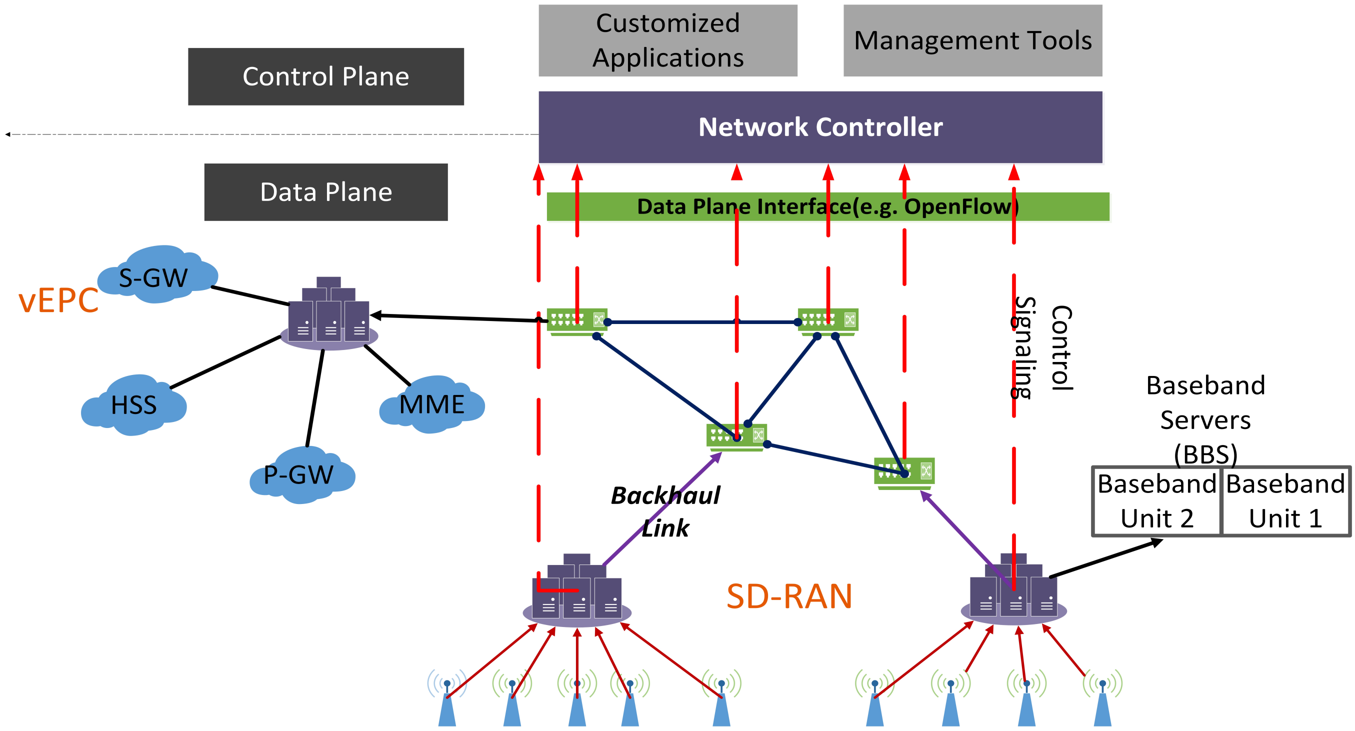

Fig. 1: The proposed SDN/NFV based mobile 5G network architecture.

1) Traditional network power consumption model: Each antenna has its own transceiver, rectifier, digital signal processor and power amplifier. Thus the estimated power consumption is given as follows:

$$P_{BS} = n_a * (P_{trans} + P_{rect} + P_{PA} + P_{DSP} + P_{air} + P_{mw}) \quad (3)$$

where n_a is the number of antennas per BS.

2) Virtualized Network: It is assumed that the number of SBSs operating in area A is N_{SBS} and the number of slices in each SBS is n_{vs} and it is clear that an SBS will require more power for its cooling system as well as the MW link. Following the assumption above, it is further assumed that the power requirement per SBS is to increase by 20% with each additional slice the SBS contains. Following this, the power consumption becomes:

$$P_{airSBS} = P_{air} * [1 + 0.2 * (n_{vs} - 1)]$$

$$P_{mwSBS} = P_{mw} * [1 + 0.2 * (n_{vs} - 1)]$$

In this scenario, it was decided to use antenna sharing by the virtual operators in order to reduce the cost even more, so each slice has its own DSP but the antennas as well as the RF chains are shared between the virtual BSs (vBSs). For a given SBS, the consumed RF power has thus the following form:

$$P_{rfSBS} = (P_{trans} + P_{rect} + P_{PA}) * [1 + 0.2 * (n_{vs} - 1)]$$

Therefore, the power consumption of a SBS becomes:

$$P_{SBS} = n_a * P_{rfSBS} + n_{vs} * P_{DSP} + P_{airSBS} + P_{mwSBS} \quad (4)$$

The total OPEX for RAN architecture, will be the product of the deployed BSs in area, the energy consumption per BS and the KWH cost. The total OPEX becomes:

$$OPEX_{RAN} = P_{SBS} * N_{SBS} * C_{KWH} \quad (5)$$

C. CAPEX Analysis of Virtualized EPC

As it was mentioned in Section I, NFV technology allows processing, storage and networking jobs to be performed within virtual machines on standard computing hardware. In order to fully exploit the benefits of the virtualization technology, it is strongly proposed to deploy virtualized EPC in 5G network architecture. The parameters for a virtualized EPC architecture are:

- C_{place}: Cost for setting up or leasing a data center.
- $C_{servers}$: Total cost of server equipment.
- $C_{license}$: The total cost of the one-time license fees have to be paid, in order to acquire the software components regarded as virtualized EPC network functions (VNFs).

The total cost for acquiring the necessary number of servers is:

$$C_{servers} = n_{servers} * C_{perServer}$$

where $n_{servers}$ is the total number of servers needed by the network in order to operate and $C_{perServer}$ is the cost of a server unit. As it was discussed earlier, the VNF software license fee for the software components of vEPC's network functions is calculated as CAPEX, thus:

$$\begin{aligned} C_{license} = C_{HSS} + C_{MME} + C_{S-GW} + \\ C_{P-GW} + C_{oVS} + C_{OFcontroller} \end{aligned}$$

Finally, it is concluded that the total CAPEX for vEPC becomes:

$$CAPEX_{vEPC} = C_{servers} + C_{license} + C_{place} \quad (6)$$

D. OPEX Analysis of Virtualized EPC

The VNF software of vEPC's network functions runs in VMs hosted by big commercial off the shelf servers. The OPEX of vEPC derive from the power consumption of the servers needed to host the required number of VMs in order to deploy a fully-operating vEPC. Given the set-ups presented in TABLE I and TABLE II, the number of required VMs for a specified resource usage demand is determined by the maximum VM requirement for each capacity demand per VNF, is specified by using the following formula (e.g. virtualized HSS):

$$VM_{CPU} = ceil(\frac{CPU_{HSS}}{CPU_{perVM}})$$

$$VM_{MEM} = ceil(\frac{MEM_{HSS}}{MEM_{perVM}})$$

$$VM_{NET} = ceil(\frac{NET_{HSS}}{NET_{perVM}})$$

$$VM_{PPS} = ceil(\frac{PPS_{HSS}}{PPS_{perVM}})$$

$$VM_{STR} = ceil(\frac{STR_{HSS}}{STR_{perVM}})$$

$$VM_{perHSS} = max(VM_{CPU}; VM_{MEM}; VM_{NET}; VM_{PPS}; VM_{STR};)$$

Based on the above maximum calculation, the required VMs of all vEPC's virtual elements are mapped onto the offered VM capacity of the server hardware, as depicted in Table II. The number of servers required to cover the virtual network elements VMs requirements is:

$$n_{serversHSS} = \frac{VMrequired_{perHSS}}{VMs_{perserver}}$$

Finally, it is concluded that the total OPEX for vEPC becomes:

$$OPEX_{vEPC} = n_{servers} * P_{perserver} * C_{KWH} \tag{7}$$

E. TCO-Total Cost of Ownership

Based on the above-mentioned formulas and the provided techno-economic analysis, TCO for the proposed network architecture is:

$$\begin{aligned} TCO = & \\ & = Cost_{vEPC} + Cost_{RAN} \\ & = CAPEX_{RAN} + OPEX_{RAN} \\ & + CAPEX_{vEPC} + OPEX_{vEPC} \\ & = \frac{N_{UE}}{n_{vs} * l * pi * R_{max}^2} * (C_{cs-sbs} + C_{SBS}) \\ & + P_{SBS} * N_{SBS} * C_{KWH} \\ & + n_{servers} * P_{perserver} * C_{KWH} + \\ & (C_{servers} + C_{license} + C_{place}) \end{aligned} \tag{8}$$

IV. EXPERIMENTATION

In this Section an experiment is carried out comparing the capital and operational costs for a mobile network. The comparison is made between the traditional and the proposed network architecture for the network implementation, based on the number of the deployed BSs. The chosen range concerning the number of the deployed BSs, is an average based on a survey of the existing BS sites in Sweden. In fact an average is considered that includes residential areas, industry areas and central parts of various cities, according to [12].

In the first phase of the experimentation, the traditional BS deployment strategy is followed and scenarios where 10, 20, 30, 50, 80, and 100 deployed physical BSs are examined, which is a wide enough range to have an adequate picture of various deployment scenarios. In the second phase of the experimentation the proposed network architecture is used. In this case the fact that up to 6 vBS can be deployed on a physical SBS is exploited. Specifically, when, e.g., 10 BSs are needed to cover a geographical area, in case the proposed architecture is used, 2 SBSs are deployed and on each one 5 vBSs (2*5=10 BSs) are deployed. From this point, the proposed implementation is represented as 2x5, where the first number represents the number of the SBSs and the second number represents the number of vBSs on each SBS.

TABLE III: RAN and vEPC parameters and their values.

Parameter	***Value***
RAN	
n_{vs}	up to 6 virtual BS per SBS [8]
l_{SBS}	500 users [12]
N_{SBS}	10-100 BSs per km^2 [12]
C_{cs-sbs}	5.000 €[13]
C_{SBS}	15.596 €(zero vBSs deployed) [1]
P_{trans}	100 Watt [8]
P_{rect}	100 Watt [8]
P_{DSP}	100 Watt [8]
P_{PA}	10.4 Watt [8]
P_{mw}	80 Watt [8]
P_{air}	225 Watt [8]
n_{op}	10 different operators [12]
n_a	4 antennas [1]
EPC	
CPU per S/P-GW	4,00 (CPU) [11]
Mem per S/P-GW	32,00 (GB) [11]
Net per S/P-GW	10,00 (Gbps) [11]
Pps per S/P-GW	7,353 (Mpps) [11]
HDD per S/P-GW	40,00 (GB) [11]
CPU per MME	8,00 (CPU) [11]
Mem per MME	40,00 (GB) [11]
Net per MME	5,00 (Gbps)[11]
Pps per MME	3,676 (Mpps) [11]
HDD per MME	1.000,00 (GB)[11]
CPU per HSS	8,00 (CPU) [11]
Mem per HSS	32,00 (GB) [11]
Net per HSS	5,00 (Gbps) [11]
Pps per HSS	3,676 (Mpps) [11]
HDD per HSS	3.000,00 (GB)[11]
CPU per OF controller	8,00 (CPU) [11]
Mem per OF controller	32,00 (GB) [11]
Net per OF controller	2,00 (Gbps)[11]
Pps per OF controller	1,471 (Mpps) [11]
HDD per OF controller	40,00 (GB) [11]
CPU per oVS	1,00 (CPU) [11]
Mem per oVS	8,00 (GB) [11]
Net per oVS	4,00 (Gbps) [11]
Pps per oVS	5,882 (Mpps)
[11] HDD per oVS	40,00 (GB) [11]
$C_{license}$	5.000,00 €[3]
C_{place}	10.000,00 €[3]
P_{server}	1332 Watt [2]
C_{server}	5.262,00 €[2]
C_{KWH}	0.25 €[3]

Based on these assumptions, the experiments are carried out

[1] https://www.winncom.com/en/products/998-03-536

[2] http://www.dell.com/us/business/p/poweredge-m630/pd

[3] These assumptions constitute an average of each parameter based on Internet research, therefore may be realistic but not precise.

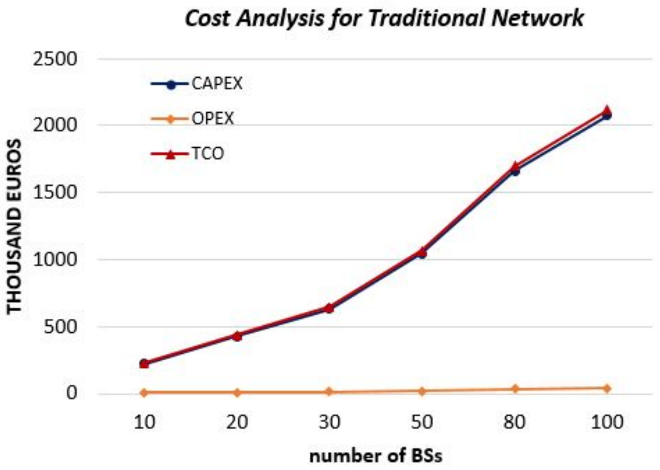

Fig. 2: Cost analysis for traditional network architecture

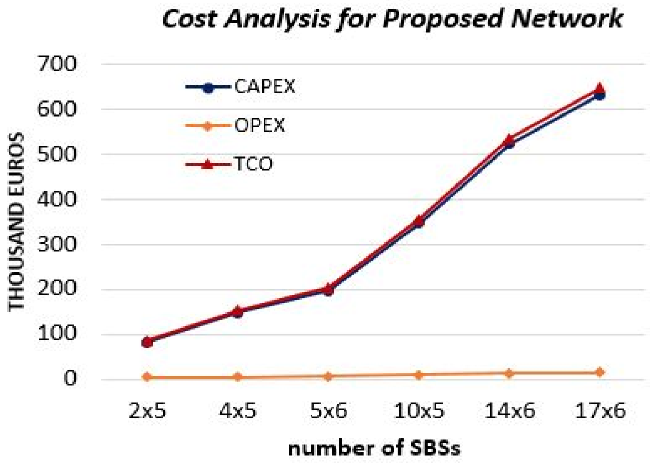

Fig. 3: Cost analysis for proposed network architecture exploiting SBSs

for the scenario described above, using parameters and their values as shown in TABLE III. This table lists parameters that have either been retrieved from literature review or they have been set by consulting other sources in the Internet, personal communications, etc. In the following graphs the experimental results are presented and a comparison of the above mentioned costs is made between the traditional and the proposed architecture.

Furthermore, Fig. 2 illustrates the three types of cost, i.e., CAPEX, OPEX, as well as their sum TCO, for a traditional network deployment. On the other hand, Fig. 3 depicts the same types of cost but for the proposed softwarized network architecture.

As it was expected, the first important observation from Fig. 2 and Fig. 3, is that both in traditional and proposed network implementation cases, OPEX is significant smaller than CAPEX and the vast majority of TCO is due to CAPEX. Moreover by comparing the costs between the two figures, it is obvious that using the proposed architecture instead of the traditional one, significant OPEX and CAPEX reductions can be achieved. Following this and based on the above mentioned experiments, OPEX, CAPEX and TCO for each case are compared separately and the reduction percentage for each one of the above mentioned costs is computed, in case the proposed architecture is adopted.

At this point it should be noted that the main CAPEX contributor for a network operator is the physical equipment costs. To lower this cost burden for the TSPs, in the proposed architecture the use of virtualization technology and resources sharing among the physical infrastructure is adopted. Following this observation, Fig. 4 depicts an overview of the CAPEX savings for both traditional and proposed architectures. However, it is clear that in the proposed architecture in which vBSs are used yields in significant CAPEX reduction that reaches almost 70% based on the results of the proposed cost model. The result surpasses the predictions for CAPEX reduction by adopting these state of the art technologies, which were mentioned earlier in Sections I and II.

Each cost category is compared to the counterpart cost of the traditional architecture scheme. The adoption of technologies such as NFV/SDN is expected to significantly reduce service provider OPEX. Following this, the experimental results in Fig. 5 depict a comparison between OPEX for each architecture and it is obvious that in case the proposed architecture is used, OPEX reduction of 63% can be achieved based on the results of the cost model for the above mentioned values.

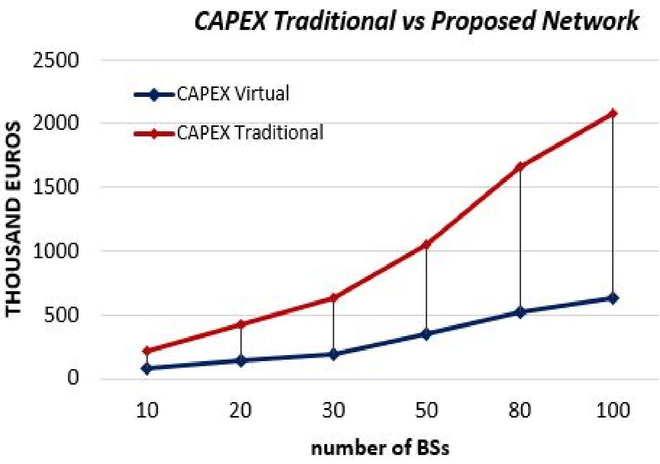

Fig. 4: CAPEX analysis for traditional versus proposed network architecture.

To conclude the experimentation results, Fig. 6 depicts a TCO comparison between the traditional and the proposed architecture. Again the cost savings in the case of the softwarized network are again huge. In more detail, in the case the proposed virtual network deployment is used, a significant TCO reduction of 69% can be achieved based on the results of the cost model for the above mentioned values, as shown in Fig. 6.

Additionally, in order to point out the importance of these cost savings to a given mobile network operator, the following formula is used to compute the average growth rate, i.e., the rate of the cost increment, based on the number of the deployed BSs for each architecture:

$$R = [\frac{TCO_{i+1} - TCO_i}{TCO_i}]^{(1/items-1)} - 1 \qquad (9)$$

where TCO_i is the TCO for an examined number of BSs. Based on the value of index i, the number of BSs can take values from the set $\{10, 20, 30, 50, 80, 100\}$ and the value of TCO_i is calculated accordingly. The amount $items$ is the total number of the different TCO_i examined, i.e. up to 6 in the examined case. Finally, R is the average growth rate for a given mobile network operator. By applying (9) on the examined

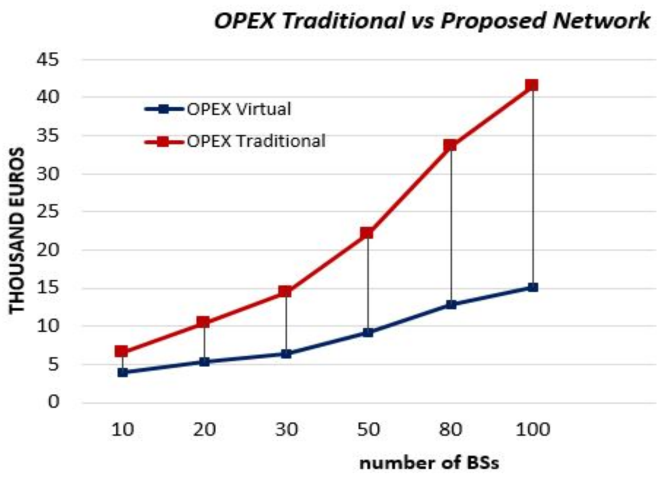

Fig. 5: OPEX analysis for traditional versus proposed network architecture.

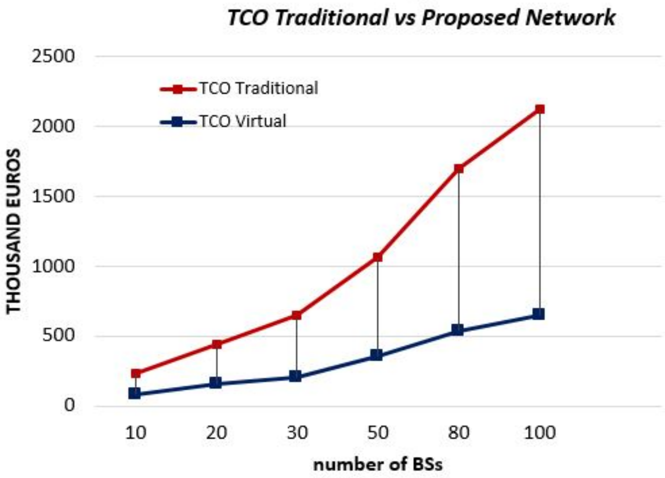

Fig. 6: TCO analysis for traditional versus proposed network architecture.

experimental scenario it is concluded that the growth rate is 45% for the traditional and 40% for the proposed architecture based on the number of the deployed BSs. Therefore further expansion of the network deployment appears to have a cost the increases with lower rate in the case of the proposed network architecture.

V. CONCLUSIONS & FUTURE WORK

Industry, academia and research projects strongly align their strategies towards adopting the above mentioned state of the art technologies in their positioning for 5G race. The analysis approach used in this paper, provides a framework for understanding the impact of NFV/SDN/Cloud-RAN on a network operator's TCO. Based on the proposed architecture, a flexibly adjustable techno-economic model is presented providing detailed view of network architecture from technical as well as economical perspective.

This techno-economic model is used to conduct experiments which showed that a significant infrastructure cost reduction is possible from SBS and EPC virtualization. The quantitative analysis performed reveals that the proposed 5G architecture provides significant TCO savings. The experimental results show that, for the reference case:

- The considered OPEX could be reduced by 63% in comparison with the traditional scenario.
- The considered CAPEX could be reduced by 68% in comparison with the traditional scenario.
- The considered TCO could be reduced by 69% in comparison with the traditional scenario.

Following this, it is concluded that adopting the proposed network architecture and these state of the art technologies in general, significant cost reductions can be achieved. The development of new architectures for 5G, comes with several issues involving load balancing, interference removal, scalability etc.. Moreover, it needs to be compatible with the existing network infrastructure in order to allow smooth transfer in this interesting new era.

Possible future steps of this work can include the application of the proposed techno-economic models on real deployments as well as their exploitation in order to identify and apply ways for further reduction of the various expenses of 5G deployments.

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