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Energy Efficient Network Function Virtualization in 5G Networks

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ABSTRACT

A Number of merits could be brought by network function virtualization (NFV) such as scalability, on demand allocation of resources, and the efficient utilization of network resources. In this paper, we introduce a framework for designing an energy efficient architecture for 5G mobile network function virtualization. In the proposed architecture, the main functionalities of the mobile core network which include the packet gateway (P-GW), serving gateway (S-GW), mobility management entity (MME), policy control and charging role function, and the home subscriber server (HSS) functions are virtualized and provisioned on demand. We also virtualize the functions of the base band unit (BBU) of the evolved node B (eNB) and offload them from the mobile radio side. We leverage the capabilities of gigabit passive optical networks (GPON) as the radio access technology to connect the remote radio head (RRH) to new virtualized BBUs. We consider the IP/WDM backbone network and the GPON based access network as the hosts of virtual machines (VMs) where network functions will be implemented. Two cases were investigated; in the first case, we considered virtualization in the IP/WDM network only (since the core network is typically the location that supports virtualization) and in the second case we considered virtualization in both the IP/WDM and GPON access network. Our results indicate that we can achieve energy savings of 22% on average with virtualization in both the IP/WDM network and GPON access network compared to the case where virtualization is only done in the IP/WDM network.

1. INTRODUCTION

The current mobile system has evolved from circuit-switched based analogue voice network to a formidable system supporting hundreds of thousands of various applications and a very huge number of users. We are just at the dawn of the conversion to ubiquitous high data rate network that connects anything to anything anytime and anywhere. Therefore, the next generation mobile network will not only connect people, but anything that needs the use of its resources. Various devices will join this network such as medical devices, meteorological equipment, traffic and security cameras, household appliances, etc. As a result, the next generation mobile network will affect many spheres of human life and the growth in traffic will continue during the 5G era beyond 2020 [1, 2]. Mobile operators and service providers will have to deal with a 1000 fold increase in traffic compared to the levels in 2010 [3] and they have to properly address a number of challenges due to this huge amount of traffic such as bandwidth requirements and power consumption. In order to address the power consumption challenges, in [4] we have proposed an energy efficient virtual network embedding (EEVNE) approach for cloud computing networks. In [5] we have introduced a framework for energy efficient cloud computing over IP/WDM networks. We have examined energy efficient future HDTV in [6] and investigated the role of physical topology optimization on energy efficiency in IP/WDM networks in [7]. We also evaluated the use of renewable energy sources in the design of IP/WDM core networks in [8] in order to reduce the carbon footprint contribution of ICT networks.

The authors in [9] have introduced the concept of network function virtualization (NFV) and its benefits in 5G networks. They focused on its deployment in radio access networks (RAN) because network operators and service providers showed interest in virtualization in the RAN since the RAN accounts for around 70% to 80% of the total energy requirements [3]. Although the term virtualization has been used widely in mobile networks especially in the cloud radio access network (C-RAN), it only refers to the case where multiple base stations share resources or cooperate with each other [10-12] in what is called “BBU pooling”. Here, we go further by deploying a new architecture that exploits the benefits NFV in both the mobile core network and the RAN with the goal of minimizing power consumption. The rest of the paper is organized as follows: In Section 2 we discuss virtualization in mobile networks and present the proposed architecture. In Section 3 we present the results obtained from the MILP model and conclude the paper in Section 4.

2. VIRTUALIZATION IN MOBILE NETWORK

Virtualization in 5G networks will provide a high level of scalability and flexibility [13] and a number of functions in the mobile network could be implemented by virtual machines and provided on demand. The authors of [14] show that NFV will become an essential technology in 5G. According to the third generation partnership project (3GPP) the latest mobile core network is the evolved packed core (EPC)[15]. There are five main functions in the EPC [16, 17]; (i) the packet data network gateway (P-GW), (ii) the serving gateway (S-GW), (iii) the mobility and management entity (MME), (iv) the policy control and charging role function (PCRF), and (v) the home subscriber server (HSS). In our work, all these functions are virtualized and provided on demand. Their locations and migration are also optimized according to demand. In addition to the EPC functions we also virtualize the functions of the BBU of the eNB. The BBU entity is separated from the RRH and virtualized; in this case the RRH will be connected directly to the core network through optical links as shown in Figure 1. For virtual machine hosting and data processing close to the RAN, we have used GPON in the optical front-haul. In addition to the deployment of GPON as a front-haul, we have attached the mobile home office (mobile core) to the IP/WDM core network. With the deployment of GPON, the location range of the virtual machines is extended to include the optical front-haul. Hence the candidate nodes, which might host the virtual machines, are increased and distributed along the path from the mobile home office to the radio access network over the IP/WDM and GPON networks. With such a scenario a virtual machine of any type (mobile core network or BBU) can be placed, replicated, or migrated in ONU, OLT, or in the IP/WDM node as well.

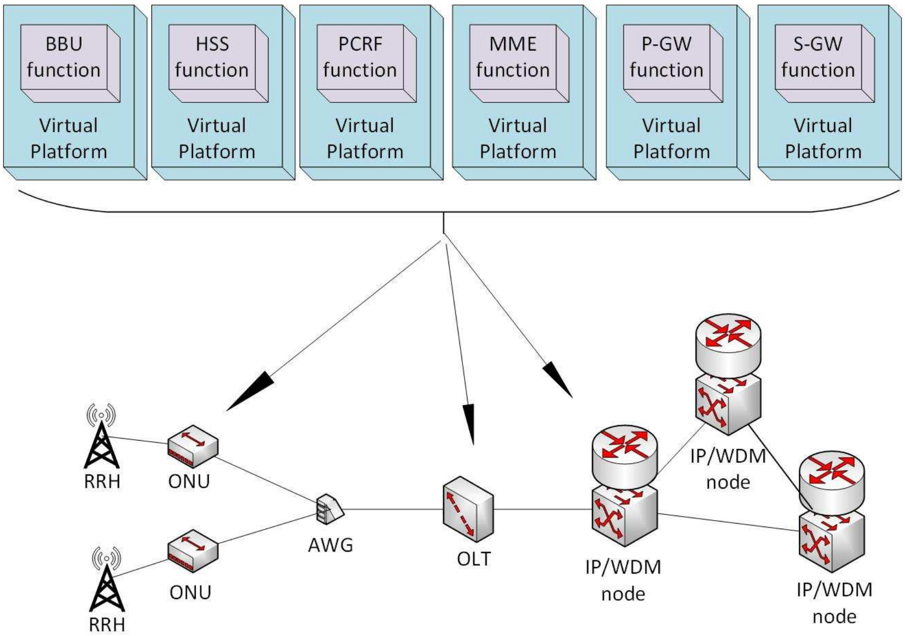

Figure 1. Proposed architecture for virtualization in 5G

We have developed a MILP model for energy efficient virtualization in 5G networks. The model minimizes the power consumption associated with the RRH requests and optimizes the location of the virtual machines. We have assumed two different virtual machine types: mobile core network functions virtual machines (CNVMs) and BBU functions virtual machines (BBUVMs). To capture a range of processing scenarios and account for factors such as variation in the BBU processor type or number of cycles per instruction, we have examined five scenarios with different ranges of normalized workload (NWL) of BBUVMs and CNVMs as shown in Table 1. The power consumption of a virtual machine is modelled as a function of the normalized workload. In modelling the power consumption of the network we consider three power-consuming parts: IP/WDM network, GPON, and the RRH.

Table 1: Virtual machines workload (%) of different scenarios

Scenario / Workload %	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Core VM	1 – 10%	2 – 20%	3 – 30%	4 – 40%	5 – 50%
BBU VM	0.25 – 0.5%	0.5 – 5 %	0.75 – 7.5%	1 – 10%	1.25 – 12.5%

3. RESULTS

We consider two groups of 15 ONUs and each ONU is connected to one RRH while each group of the ONUs is connected to one OLT. The two OLTs are connected to only one of 5 IP/WDM nodes (typically a connection is established to one of the nearest core nodes, here we considered 5 such close nodes) as illustrated in Figure 2. This architecture represents the virtualization infrastructure of our model. Also we consider a situation where each RRH requests one BBUVM, and each BBUVM in turn requests one CNVM. We uniformly and randomly distribute 14 BBUVMs (we also considered a larger and smaller number of BBUVMs, but report here the case of 14 BBUVMs) over the 30 RRH nodes. The same distribution method is used with the distribution of 14 CNVMs over the BBUVMs. Five scenarios, shown in Table 1, have been used with different ranges of workloads for both BBU VMs and CNVMs and the results are shown in Figure 3. It is clearly seen from Figure 3 that the power consumption increases due to the increase in the virtual machine workloads. This increase in the power consumption however, is not very crucial because the number of virtual machines is the same in all the scenarios. The power consumption of both virtualization with and without the use of network elements in the GPON is shown in Figure 4.

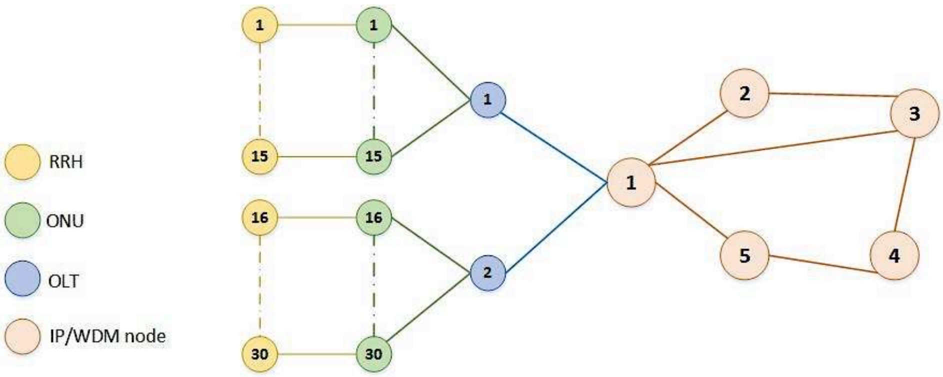

Figure 2. Network topology used in the MILPoptimization

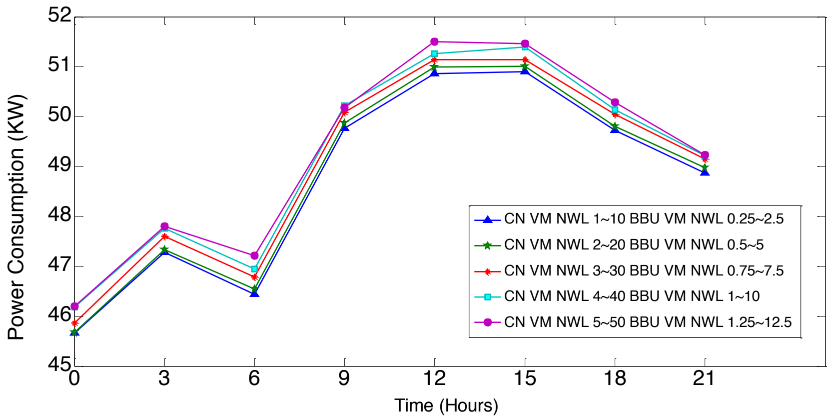

Figure 3. Power Consumption under different VM workloads

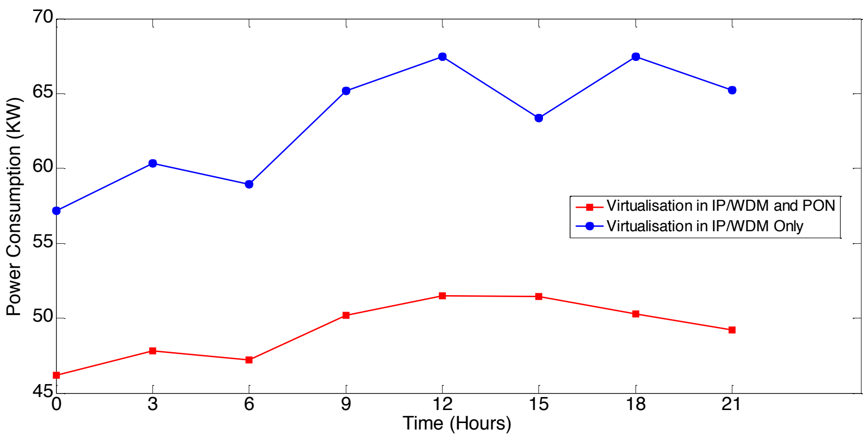

Figure 4. Power Consumption of Virtualization in IP/WDM only and in IP/WDM and PON

Virtualization in both the IP/WDM and GPON networks shows an average saving in power consumption of 22% compared to the case where virtualization occurs only in the IP/WDM network. Virtualization in the GPON network adds a high level of flexibility due to virtual machine behaviour. The virtual machines can be migrated, replicated, or distributed according to the demand and the satisfaction of our goal, which is the minimization of total power consumption. For a particular RRH, the demand does not need to travel along the network to be served or processed if the virtual machine is placed close to it in ONU or in OLT. As a result the power consumption will decrease due to the shorter route taken by the demand. In addition, if the BBU VM and its serving CNVM are placed in the same node, the power consumption due to the internal traffic between them will be zero because they are processed in the same node.

4. CONCLUSIONS

In this paper we have introduced a new architecture for future 5G networks employing network function virtualization and using GPON as the preferred radio access network backhaul technology. We have investigated the energy efficiency brought about by virtualizing both the BBU and mobile core functions by allowing virtual machine instances to be created in both the GPON nodes (ONUs and OLTs) and IP/WDM nodes (since the core network is typically the location of infrastructure that supports virtualization). Virtualization in both IP/WDM and GPON nodes shows energy savings of 22% on average compared to the case where virtualization is done only in the IP/WDM core network nodes. In future, we will consider internal traffic between core network virtual machines, processing delay, and caching. These considerations will add trade off challenges to the work and they will affect virtual machine behaviour and location.

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REFERENCES

[1] B. Bangerter, S. Talwar, R. Arefi, and K. Stewart, "Networks and devices for the 5G era," *Communications Magazine, IEEE,* vol. 52, pp. 90-96, 2014.

[2] A. Gohil, H. Modi, and S. K. Patel, "5G technology of mobile communication: A survey," in *International Confereference on Intelligent Systems and Signal Processing (ISSP)*, pp. 288-292,2013.

[3] P. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, "Design considerations for a 5G network architecture," *Communications Magazine, IEEE,* vol. 52, pp. 65-75, 2014.

[4] L. Nonde, T. E. H. El-Gorashi, and J. M. H. Elmirghani, "Energy Efficient Virtual Network Embedding for Cloud Networks," *Journal of Lightwave Technology,* vol. 33, pp. 1828-1849, 2015.

[5] A. Q. Lawey, T. E. El-Gorashi, and J. M. Elmirghani, "Distributed Energy Efficient Clouds Over Core Networks," *Journal of Lightwave Technology,* vol. 32, pp. 1261-1281, 2014.

[6] N. I. Osman, T. El-Gorashi, L. Krug, and J. M. H. Elmirghani, "Energy-Efficient Future High-Definition TV," *Journal of Lightwave Technology,* vol. 32, pp. 2364-2381, 2014.

[7] X. Dong, "On the Energy Efficiency of Physical Topology Design for IP over WDM Networks," *Journal of Lightwave Technology,* vol. 30, pp. 1931-1942, 2012.

[8] X. Dong, T. El-Gorashi, and J. M. H. Elmirghani, "Renewable energy in IP over WDM networks," in *International Conference onTransparent Optical Networks (ICTON)*, pp. 1-8, 2010.

[9] P. Demestichas, A. Georgakopoulos, D. Karvounas, K. Tsagkaris, V. Stavroulaki, J. Lu*, et al.*, "5G on the horizon: Key challenges for the radio-access network," *IEEE Vehicular Technology Magazine,* vol. 8, 2013.

[10] B. Haberland, F. Derakhshan, H. Grob-Lipski, R. Klotsche, W. Rehm, P. Schefczik, *et al.*, "Radio base stations in the cloud," *Bell Labs Technical Journal,* vol. 18, pp. 129-152, 2013.

[11] C. Liu, K. Sundaresan, M. Jiang, S. Rangarajan, and G.-K. Chang, "The case for re-configurable backhaul in cloud-RAN based small cell networks," in *Proceeding IEEE INFOCOM*, pp. 1124-1132, 2013.

[12] J. Madden, "Cloud RAN or small cells?," *Wireless Online Magazine (April 30, 2013),* 2013.

[13] E. Dahlman, G. Mildh, S. Parkvall, J. Peisa, and J. Sachs, "5G wireless access: requirements and realization," *Communications Magazine, IEEE,* vol. 52, pp. 42-47, 2014.

[14] J. G. Andrews, S. Buzzi, W. Choi, S. Hanly, A. Lozano, A. C. Soong, *et al.*, "What will 5G be?. arXiv preprint," *arXiv preprint arXiv:1405.2957,* 2014.

[15] 3GPP. *Releases*. Available: http://www.3gpp.org/specifications/67-releases

[16] C. Monfreid, "The LTE Network Architecture-A Comprehensive Tutorial," *Alcatel-Lucent White Paper,* 2012.

[17] Alcatel-Lucent. Introduction to Evolved Packet Core. *Alcatel-Lucent White Paper*. Available: http://www.alcatel-lucent.com