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Procedia Computer Science 113 (2017) 130–137

Procedia Computer Science

www.elsevier.com/locate/procedia

The 8th International Conference on Emerging Ubiquitous Systems and Pervasive Networks (EUSPN 2017)

Cost Analysis of SDN/NFV Architecture over 4G Infrastructure

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Abstract

Two complementary architectures, software defined networking (SDN) and network function virtualization (NFV) are emerging to comprehensively address several networking issues. In this work, we introduce the most embraced virtualization concepts proposed by SDN and NFV architectures. We quantitatively evaluate hardware and energy cost savings with these two SDN and NFV architectures compared to the existing state-of-the-art network 4G hardware technologies.

Keywords: Computer Networks; Software Defined Networking (SDN); Network Function Virtualization (NFV); 4G

1. Introduction

Connected devices on the Internet which are commonly known as Internet of Things (IoT) are increasing continuously at an alarming pace. There should be adequate network infrastructure facilities to handle the data explosion. One challenge is that IoT devices are globally distributed. The network infrastructure should be able to reach all these globally distributed devices. This is an enormous challenge and a huge investment in infrastructure by any single service provider. Since users are subscribed to many different service providers, and are globally distributed, it is impossible for each service provider to have its own separate network to serve its own subscribers. As new technology emerges, the hardware becomes quickly obsolete leading to huge recurring costs by each service provider[1,2].

A new sharable architecture is needed which is flexible to the changing demands of the subscribers of each service provider. This is particularly the case when the number of subscribers are changing for each of the service providers that are involved in infrastructure sharing. The demand for the network resources will always be dynamically changing. The sharable architecture should ensure that adequate resources are allocated to the service providers based on their current needs, and plan to reserve resources for future predicted needs.

Another key issue is the network reconfiguration required in order to accommodate changing traffic characteristics such as bandwidth and delay requirements[3]. The security and service provisioning policies will keep on changing

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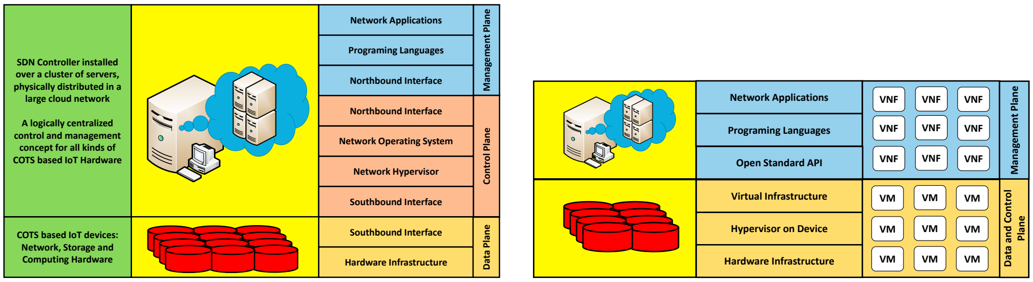
10.1016/j.procs.2017.08.328



(a) SDN Architecture[5] (b) NFV Architecture

Fig. 1. Architecture Conceptual Diagrams

with time as new business applications are added to serve users on the network. Packet handling policies have to be modified and high layer processing may have to be incorporated to newly added traffic[4]. As a result the location of the firewalls, load balancers, and other special purpose gateways have to be changed based on new policies. Such re-configuration will be an issue in the shared network scenario when multiple service providers will be using a common network infrastructure. Because of all these concerns, isolation of network resources and strict confidentiality must be maintained between service providers.

In this work, futuristic software defined networks (SDN) and network function virtualization (NFV) architectures are discussed. Cost analysis is performed to analyze the benefits of such sharable SDN and NFV based network architectures.

2. Software Defined Network (SDN) based IoT Architecture

In the new paradigm of software defined network (SDN) based virtualization, all the IoT network elements are simply forwarding devices without any intelligence instilled in them which can control and forward data traffic. These are simply COTS based equipment that receive commands from a separate software agent residing on remote servers. The entire network management and control operations reside in this software which is generally called SDN controller. The SDN controller is regarded as the brain of the entire network. The SDN controller resides on multiple physically distributed servers in a large cloud network. Besides residing on multiple servers, the SDN controller software behaves to logically control the network in a centralized manner. The control and management policies are seemed to be applied at the central location that reflects on the entire span of the network. This logical central control of the network will tremendously reduce the burden of network operators as it will avoid configuration errors across the network which is quite common in today's networks. Open and standard interfaces are developed between the data, control, and management planes that allows heterogeneous devices to connect to network without any effort. This is not possible with the current traditional networks where it is difficult to connect heterogeneous devices.

The three different planes namely data, control, and management planes in the SDN architecture are shown in Fig. 1. The data plane resides on the actual network hardware which are various COTS based IoT devices. The data plane is connected to the control plane through a southbound interface. The actual device virtualization takes place in the control plane residing in the SDN controller. Fig. 1 shows that the control plane in the SDN controller consists of a network hypervisor module for virtualization of the COTS based IoT devices. The SDN controller consists of both control and management planes as separate layers. These control and management planes communicate with each other using the northbound interface. The control plane also consists of the network operating system that controls the entire network as a single logical entity.

3. Network Function Virtualization (NFV) based IoT Architecture

The conceptual diagram for network function virtualization (VNF) based architecture is shown in Fig. 1. Instead of a network hypervisor, this virtual layer in form of hypervisor is located on the device itself. The hypervisor creates virtual machines (VMs) on these physical hardware which is referred as virtual infrastructure in the conceptual

Table 1. Definition of Input Variables for 4G network.

Input variable	Description
$M = \{1, 2, ..., m\}$	Number of service providers
$V = \{1, 2, ..., c_m\}$	Number of customers of service provider m
$R = \{r_1, r_2, ..., r_m\}$	4G Router installed by service providers
$U = \{u_1, u_2, ..., u_m\}$	Unit cost of the 4G router installed by service provider
$k_i, i \in \{1, m\}$	Number of simultaneous sessions handled by router r_i
$k_v, v \in \{1, c_m\}$	Average number of sessions occupied by customer v
$e_i, i \in \{1, m\}$	Energy consumed by router r_i per day.

diagram[6]. The virtual hardware can be accessed using an open standard API. The higher level programming languages can access these standard set of open APIs to create virtual network functions (VNFs). The VNFs can be created using a central software manager running on a separate server farm. The resources can be allocated and released on the fly using a software manager similar to software controller in SDN architecture[7]. On the otherhand, VNF enable devices can also be controlled using a central SDN controller so that both architectures can coexist and function together[8].

The three basic components of the VNF architecture are: **a) Physical Hardware:** The hardware is any bare-metal machine that hosts resources such as CPU, Memory, and storage. **b) Virtual Hypervisor Layer:** This virtual layer is the software layer that runs on the bare-metal hardware that manages the resources such as CPU power, memory, and storage capacity. **c) Virtual Machine:** The guest virtual machine is a software that emulates the architecture and functionalities of the physical platform using a fraction of hardware resources. As a result, a particular physical hardware can host more than one VM. The maximum number of VMs that can be hosted on a physical hardware is dependant on the resources of the physical hardware and the amount of resources used by each VM[9].

The key advantage of VNF and SDN architectures is that a general purpose COTS based servers can be incorporated in enterprize class networks for Big Data handling and computation. Even the physical layer processing of the cellular mobile networks can be implemented in these COTS servers[10]. This is a big step for telecommunication industry as it will transform the entire cellular network architecture. It will dramatically reduce the capital investment and reduce the energy consumption by resorting to cloud based data centers. However, it is yet to test the performance of such a network and only the future trials can be able to answer these questions through developing good test bed networks for active user trials. Multiple tenants will be able to share cloud based SDN and NFV architecture based virtualized network resources to improve profit margins and achieve reduced spending on infrastructure[11,12].

4. Cost Analysis for SDN/NFV Architecture over 4G Infrastructure

The cost analysis in this section will provide comparison of the cost incurred for traditional 4G hardware networks and futuristic networks that make use of cloud enabled SDN/NFV based architecture.

4.1. Cost Analysis: Baseline 4G Network

Suppose that a central 4G router r_i will be able to handle k_i sessions and costs u_i dollars for a service provider i to procure it and configure in his own network n_i. Let the shelf-life of the routers be x years, after which they have to be replaced. Suppose that there are m such service providers in the same business using their own kind of 4G central router r_i. Now suppose that each service provider m has total customers, say c_m. Each customer v, $v \in \{1, c_m\}$ uses on average k_v sessions. Suppose the average energy consumption of router r_i is e_i per day. All the input variables are summarized in Table 1.

The number of routers needed by service provider i to support all of its customers and the associated cost for x years is given by

$$n_i = (k_v/k_i) \times c_i \tag{1}$$

$$C_i = n_i \times u_i \tag{2}$$

where n_i is the number of routers needed and C_i is the cost incurred for service provider i for x years. The energy consumption for service provider i is given by E_i as follows

$$E_i = n_i \times e_i \tag{3}$$

Therefore the total cost of all m service providers for the period of x years is given by C as follows

$$C = \sum_{i=1}^{m} (n_i \times u_i) \tag{4}$$

Similarly, the total energy consumption per day is given by E as follows

$$E = \sum_{i=1}^{m} (n_i \times e_i) \tag{5}$$

4.2. Cost Analysis: Network with SDN/NFV based Architecture

Suppose that a SDN/NFV architecture based network offers a virtual machine (VM) that can handle $\widetilde{k}$ simultaneous sessions. Let the cost of leasing each of these VM per year is $\widetilde{u}$ dollars. The energy consumed by a VM per day is $\widetilde{e}$. Suppose that all m service providers use a common sharable SDN/NFV based network. Supposing that all other input variables for the service providers is the same, such as their number of customers and their behavior on the network, it can be seen that the number of VMs needed by service provider i to support all of its customers and the associated cost for x years is given by

$$\widetilde{n}_i = (k_v/\widetilde{k}) \times c_i \tag{6}$$

$$\widetilde{C}_i = \widetilde{n}_i \times \widetilde{u} \times x \tag{7}$$

where $\widetilde{n}_i$ is the number of VMs needed and $\widetilde{C}_i$ is the cost incurred for service provider i for x years. The energy consumption of the service provider i is denoted by $\widetilde{E}_i$, and is given by following equation.

$$\widetilde{E}_i = \widetilde{n}_i \times \widetilde{e} \tag{8}$$

For quantitative comparison, let

$$\widetilde{k} = \alpha_i \times k_i \tag{9}$$

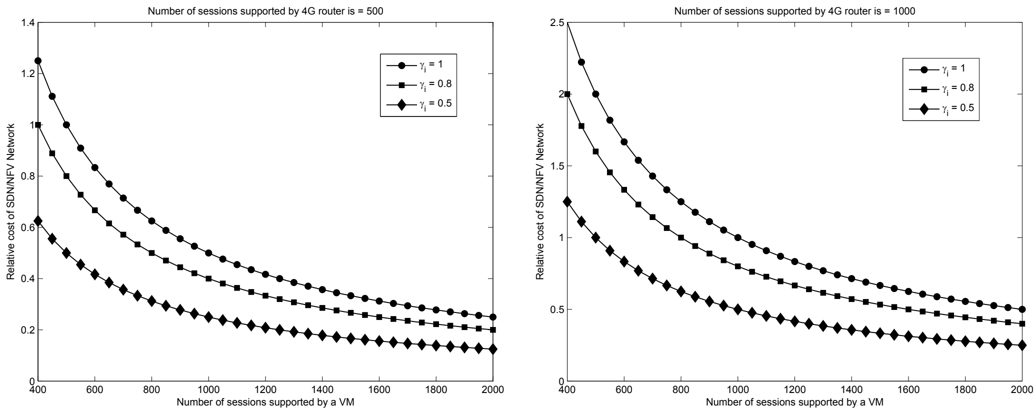
$$\widetilde{u} \times x = \gamma_i \times u_i \tag{10}$$

$$\widetilde{e} = \beta_i \times e_i \tag{11}$$

The cost incurred by service provider i for using SDN/NFV based network for x years, expressed in terms of the cost of its 4G networks is given by $\widetilde{C}_i$ as follows

$$\widetilde{C}_i = \frac{\gamma_i}{\alpha_i} \times C_i \tag{12}$$

For the cost reduction under SDN/NFV architecture γ_i/α_i should be less than 1. If both VM and 4G router handle same number of sessions, the cost of VM should be lower than that of the 4G router cost. However, when a VM supports more sessions than the 4G router, there is more relaxation on VM cost. But it is expected by Industry experts that VMs will be more powerful and yet be less costly than 4G routers. The necessary and required condition is that $\alpha_i > \gamma_i$.



(a) The 4G router supports 500 sessions (b) The 4G router supports 1000 sessions

Fig. 2. Relative cost comparison of SDN/NFV VMs with respect to 4G network hardware for a single service provider *i*

The percentage cost reduction for service provider *i* for using SDN/NFV architecture based shared network is given by the following expression, denoted by Γ_i.

$$\Gamma_i = \begin{cases} \frac{C_i - \widetilde{C}_i}{C_i} \times 100 \\ \frac{\alpha_i - \gamma_i}{\alpha_i} \times 100 \end{cases} \tag{13}$$

For energy consumption in SDN/NFV, it can be expressed in terms of 4G parameters as

$$\widetilde{E}_i = \frac{\beta_i}{\alpha_i} \times E_i \tag{14}$$

Next, the total cost of all *m* service providers for the period of *x* years is given by $\widetilde{C}$ as follows

$$\widetilde{C} = x \times \widetilde{u} \times \sum_{i=1}^{m} \widetilde{n}_i = C \times \frac{\sum_{i=1}^{m} \frac{n_i}{\alpha_i}}{\sum_{i=1}^{m} \frac{n_i}{\gamma_i}} \tag{15}$$

Similarly, the total energy consumption per day is given by $\widetilde{E}$ as follows

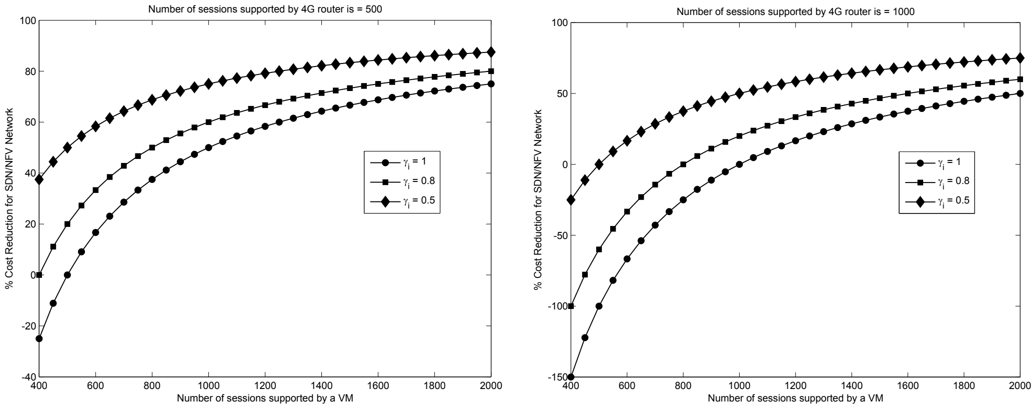
$$\widetilde{E} = \widetilde{e} \times \sum_{i=1}^{m} \widetilde{n}_i \tag{16}$$

The overall energy consumption in SDN/NFV based network expressed in terms of the energy consumption of 4G router based network is given as follows.

$$\widetilde{E} = E \times \frac{\sum_{i=1}^{m} \frac{n_i}{\alpha_i}}{\sum_{i=1}^{m} \frac{n_i}{\beta_i}} \tag{17}$$

4.3. Results

The cost and energy consumption comparison between two completely different technologies is undoubtedly very complex as it has to take many hardware specific aspects into consideration. Empirical results will be more substantial to reveal the actual cost and energy consumption. However we are already aware from industrial experts that new COTs based server platforms have evolved to become more powerful to emulate the special purpose network hardware in terms of packet processing speeds and yet consume lesser power. So we take this information in the form of variable parameters to study the relative cost and energy consumptions between SDN/NFV networks and 4G networks as the



(a) The 4G router supports 500 sessions (b) The 4G router supports 1000 sessions

Fig. 3. Percentage cost reduction for using SDN/NFV VMs for a single service provider *i*

above model has illustrated. This model will nevertheless provide insight on cost and energy savings as function of many different important factors.

One of the important metric is the number of sessions supported by a device. We refer a session is a constant piece of hardware resource used to serve a user. In general, a user may use more that one session on the device. This was reflected in our model presented before. In SDN/NFV based network, VMs are allocated for the service providers to serve the traffic of their customers. For this purpose, the VMs in the SDN/NFV based network are also described in terms of the number of sessions supported and the amount of energy they consume. Fig. 2 shows the variation of cost for a certain service provider *i* when using VMs of SDN/NFV network relative to the cost incurred while using 4G hardware. In our model and all the presented results, we assume that all customers have traffic all the time for an infinite time period. Though this assumption is not valid, it represents the worst case scenario, which will also eliminate the multiplexing gain from shared SDN/NFV network resources. Therefore the relative cost reduction is real and quantitative for the parameters of interest.

The relative cost and energy consumption reduction for service provider *i* in SDN/NFV network is a dependant on how powerful the VM is and at the same time how cost effective and energy efficient it is. For instance, Fig. 2 displays results for the case where the 4G router supports 500 sessions for instance. We vary the performance capacity of VM of SDN/NFV network by changing the number of sessions supported from 400 to 2000. As a worst case, we assumed that VM rent cost is same as buying a 4G router and maintaining it for its entire shelf-life. We obviously see that SDN/NFV network costs more if the VMs are not powerful enough. However, when VM start supporting more sessions than 4G router, the cost of SDN/NFV network falls down. When the actual cost of renting a VM is below the actual cost of owning a 4G router, the network cost for the service provider *i* is considerably lower. When VM are very powerful and supports 2000 sessions, the cost of renting VMs on SDN/NFV network falls considerably.

The SDN/NVF technology has to catchup with traditional specialized hardware technology, particularly when the 4G technology is more powerful. This is illustrated in Fig. 2, where the 4G router now supports 1000 sessions instead of 500 sessions as shown in the previous result. Thus we gradually increase the strength of 4G technology and see how that would effect the relative cost of sharing the SDN/NFV network. It is quite clear that unless the VMs have not shown real progress in strength and be economically viable, we will not witness the same amount of cost reduction while using the SDN/NFV technology. However, we still see that the relative cost of leasing the VMs in SDN/NFV network saves cost, quite substantially, for the service provider *i*. This would be the key to the success of the virtualization technology.

The cost reduction for SDN/NFV network in percentage is shown in Fig. 3 for cases where 4G router supports 500 and 1000 sessions respectively. It can be seen from these two results that between 40 % to 80 % cost reduction can be observed depending on the success of SDN/NFV technology in providing cheaper alternative and better processing power. The results have considered very nominal values for γ_i that are practically suitable. However as already mentioned, the cost is relative to the existing 4G hardware technology. It is assumed that 4G hardware is expensive compared to COTS hardware, which is true in the current existing scenarios. Enabling COTS servers to be more

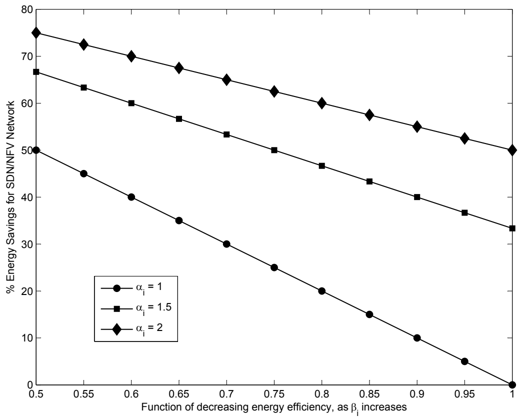


Fig. 4. Percentage energy savings for using SDN/NFV VMs for a single service provider i.

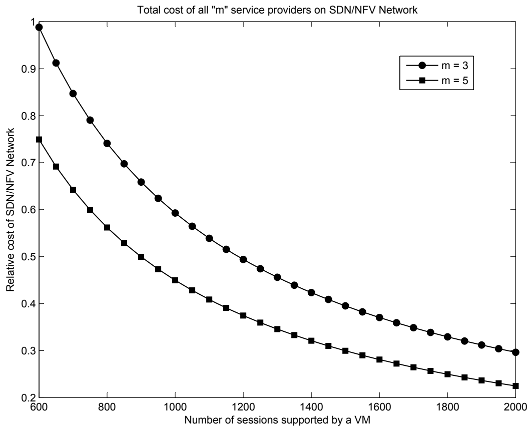


Fig. 5. The total cost over all service providers sharing SDN/NFV network.

powerful with efficient virtualization software is another key factor in reducing cost of SDN/NFV networks. The feedback from experts from research and industry has a strong indication for higher savings in SDN/NFV technology. The energy savings from using the SDN/NFV network, for service provider i, is shown in Fig. 4.

For the case of multiple service providers, we consider two scenarios, first with 3 service providers, and the second with 5 service providers. For the case of 3 service providers, $k_v = \{1, 2, 3\}$, $k_i = \{700, 800, 1000\}$, $\gamma_i = \{0.5, 0.6, 0.7\}$, and $c_i = \{1500, 2000, 2500\}$. For another network scenario consisting of 5 service providers, $k_v = \{1, 2, 3, 4, 5\}$, $k_i = \{500, 600, 700, 800, 1000\}$, $\gamma_i = \{0.3, 0.4, 0.5, 0.6, 0.7\}$, and $c_i = \{1500, 2000, 2500, 3000, 3000\}$. The total cost savings over all the service providers sharing the common SDN/NFV network is shown in Fig. 5. Similarly, the total energy savings over all the service providers, while using the SDN/NFV network is shown in Fig. 6. From these two results it can be seen that even when the SDN/NFV does not take multiplexing gain, it still provides substantial cost and energy savings. In our future work, we are interested in seeing how the opportunistic resource access and the multiplexing gains will provide more energy and cost savings in the shared SDN/NFV network.

5. Conclusion

In this work, a cloud based SDN/NFV network was studied and a mathematical model is presented that compares the cost and energy consumption between the SDN/NFV network and a typical 4G network. All key metrics are taken as variable functions to study their effect on the overall cost and energy consumption in the SDN/NFV network.

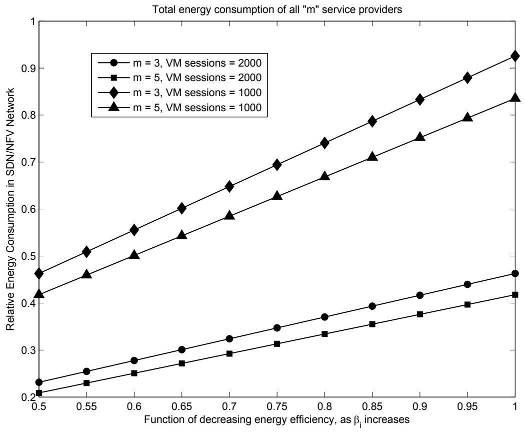


Fig. 6. Overall energy savings while using shared SDN/NFV network.

Adhering to the common assumptions in the literature, the proposed model investigates the relative cost and energy consumption for both single service provider and all the service providers in the system as a whole that are involved in SDN/NFV network sharing. By eliminating the possibility of any multiplexing gain, we have still found considerable cost reductions and energy savings in SDN/NFV based networks. The results have substantiated the claims of many gains achievable through successful deployment of networks based on software virtualization.

6. Acknowledgments

This research is sponsored by King Abdulaziz City for Science and Technology (KACST) and Prince Sultan University (PSU).

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