Quantitative Analysis of Dynamically Provisioned Heterogeneous Network Services

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***Abstract*—Services in Network Function Virtualization (NFV) can have a variety of requirements such as data rates, latencies, and cost that can change during the lifecycle of services. To meet these requirements, various hardware and software resources are suggested for implementing Virtualized Network Functions (VNFs). However, meeting all service requirements using one implementation option is not always possible. For example, to improve the performance of VNFs, using acceleration hardware is proposed. Although acceleration hardware can improve the performance of a network function, as they are expensive appliances, they increase the cost of services; this might not be desirable for a particular service user or load that can be handled by cheaper resources. Dynamically provisioning services can solve this problem in which different implementations of VNFs are switched on the fly as service requirements change. In this paper, we analyse this service provisioning approach. To this end, we: (1st) classify different types of services that can benefit from dynamic provisioning and (2nd) analyse the dynamic service provisioning of NFV services in terms of performance, cost, and management overhead by experimenting an example VNF.**

I. Introduction

Inspired by Could computing, Network Function Virtualization (NFV) is proposed to reduce capital and operational expenditures of telecommunication providers. In NFV, traditionally hardware-based Network Functions (NFs) such as Firewall and Load Balancer are virtualized and offered as software products running on commodity off-the-shelf (COTS) hardware. These software products are called Virtual Network Functions (VNFs). Services in the context of NFV are composed of one or multiple VNFs that are chained together to deliver a service.

NFV services can have a variety of requirements that can change during the lifecycle of services. These requirements can be, for example, different data rates, latencies, and cost. To meet these requirements, various hardware resources or software structures are suggested [1] [2] [3]. Usually, however, there are trade-offs between different hardware resources or software structures to realise a service, and there is no one single solution that can meet all requirements. For example, to improve the performance of compute- and network-intensive NFs, using acceleration hardware such as Graphics Processing Unit (GPU) or Field-Programmable Gate Array (FPGA) is proposed [4] [1].

Although acceleration hardware can improve the performance of network functions, as they are expensive appliances, they increase the cost of services; this might not be desirable for a particular service user or load that can be handled by cheaper resources. This problem can be solved by dynamically provisioning network services: we switch to a different service implementation on the fly as service requirements change. This can provide service performance most suitable to the given requirements. For example, consider two versions of a Deep Packet Inspection (DPI) NF: v1 is a CPU-based, v2 an FPGA-based implementation. On one hand, deploying v1 would perform well and be cheap when the input data rate is low but it would not perform well for high data rates. On the other hand, v2 performs better at high data rate but is too expensive at low data rates [1]. To make a trade-off between these two DPI versions, a service package consisting of both versions can be used that allows us to deploy the right version and then switch between them on the fly as the input data rate changes. We call this type of services *multi-version services*, a concept that is proposed in our previous work [5]. While the idea looks promising in theory, an experimental evaluation of such a service provisioning approach is still missing.

In this paper, we contribute to the dynamic provisioning of network services that are realised on heterogeneous resources based on different requirements. To this end, we classify different types of services that can benefit from dynamic provisioning and analyze this approach in terms of performance, cost, and management overhead. We considered a virtual transcoder (vTC) as a case study and implemented a COTS-based and a GPU-assisted virtual transcoder. We evaluated these vTC versions by metrics such as resource utilization and processing time. Based on this evaluation, we analysed the cost of vTCs running on cloud-based COTS and acceleration resources. We, further, evaluated the management overhead of dynamic service deployment by measuring the deployment time of vTCs.

The rest of the paper is structured as follows. In Section II and III, we elaborate on the concept of multi-version services and review related work, respectively. Dynamic service provisioning is evaluated in Section IV, and, finally, we conclude the paper in Section V.

II. Multi-version Services

Multi-version services are service packages consisting of multiple deployment versions of services that can be switched on the fly to meet different service requirements. As NFV services are usually a chain of Virtual Network Functions

(VNFs) delivering a service, multi-versioning can be provided in two levels: (1) on the function level, called Multi-Version Network Functions (MVNFs), and (2) on the service level, called Multi-Version Network Services (MVNSs).

A. Multi-Version Network Function (MVNF)

MVNF is a function package consisting of multiple deployment versions of a network function. MVNFs can be categorised into three types: (1) MVNFs with conventional software versions, (2) MVNFs with different virtualization techniques, and (3) MVNFs with different hardware implementations as illustrated in Fig. 1. Below, we explain each of these types in details.

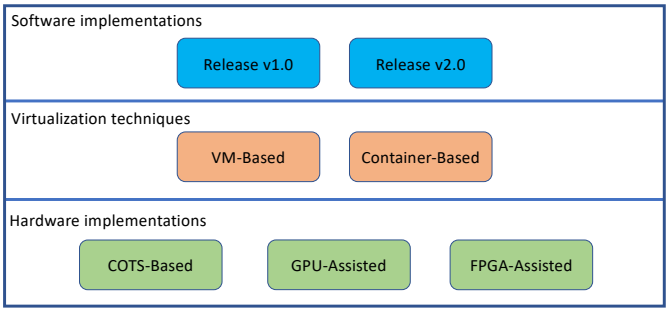


Fig. 1: Different types of multi-version network functions (MVNFs)

MVNFs with multiple conventional software versions: In this type of MVNFs, network functions based on their requirements are provided in different conventional software versions. In the context of multi-version services, changing to different release versions of a network function can be performed to optimise different objectives such as resource usage. For example, consider two versions of a DPI: (v1) provides intrusion detection but (v2) supports both intrusion detection and prevention. Although v2 provides more functionalities, it generates more overhead for the system as it requires more resources to perform both functionalities. Intrusion prevention might not be required for all cases; therefore, switching between these two versions as required can optimise resource utilization.

MVNFs available for multiple virtualization techniques: MVNF implementations can also be categorised based on virtualization techniques. Two main techniques are Virtual Machine (VM) and Container. VM is an application environment that is installed on a software component. This software component, called hypervisor, works as an agent between the application environment and the underlying hardware and allows multiple operating systems to run simultaneously on top of a single physical host. Each VM running on top of the hypervisor not only runs a full copy of the operating system but also a copy of all the needed hardware. This adds up overhead in terms of RAM and CPU cycles, even though it is still economical compared to running a separate physical host. By contrast, with containers, there is no hypervisor and multiple containers can directly run on a single operating system and share its kernel. This makes containers lightweight (megabytes in size), more resource-efficient, and quicker to start compared to VMs. However, achieving all these benefits is not cost-free as sharing the operating system kernel degrades the level of isolation and makes containers vulnerable [6]. For example, causing a kernel panic by one container can take down the entire host and, consequently, all other containers on the host. This creates a trade-off between using VMs and container for implementing VNFs. Containers are a good solution when resource utilization and agility is important while VMs are better solutions when isolation is of higher importance. Fig. 2 illustrates the architectural differences between VMs and Containers.

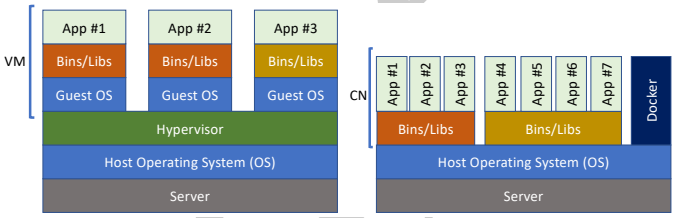


Fig. 2: Architectural differences between virtual machines (left) and containers (right)

MVNFs with multiple hardware implementations: Using acceleration hardware such as FPGA and GPU is suggested to improve the performance of VNFs. As mentioned before, there is a trade-off between performance and cost of using acceleration hardware. To have the best balance between cost and performance of VNFs, MVNFs with multiple hardware implementation versions can be used. DPI is an example of VNFs as such. DPI consists of network intensive processes that is not complex and can be serialized and offloaded on, for example, FPGA resources. However, as experimented by Nobach et al. [1], for processing large packets the performance of a COTS-based DPI is almost the same as an FPGA-based DPI. Therefore, dynamic usage of these two versions based on the input packet size can balance the cost and performance of the service. Firewall, Network Address Translation (NAT), and OpenFlow switch are some other VNF examples that can be realised as MVNFs which are experimented in [2] and [7].

B. Multi-Version Network Service (MVNS)

MVNS is a service package that consists of multiple deployment versions of a network service chain. MVNSs fall into two groups: (i) MVNSs with different MVNF types and (ii) MVNSs with different VNFs. In the following, these two groups are described in detail.

MVNSs with different MVNF types: MVNSs consist of different deployment versions of a network service chain. Each deployment version in this type can have different VNF types. As an example, shown in Fig. 4, a chain consisting of DPI, Firewall, and Network Address Translation (NAT) VNFs is used in the data centre between the data centre router and the servers to provide value-added services [8]. This chain can be deployed differently as the requirements change. For

instance, for DPI, we can have two versions: (1) DPI having only IDS functionality and (2) DPI having both Intrusion Detection System (IDS) and Intrusion Prevention System(IPS) functionalities to provide different levels of security. For NAT, two versions of FPGA-assisted and COTS-based implementations can be considered to have the best trade-off between the performance and cost of the service, and, for the Firewall, VM-based and Container-based versions can be deployed when either isolation or performance is more important, respectively. In the example shown in Fig. 4, version 1 can be used when security is more important and version 2 can be used when the main requirements are to have better resource utilization and lower latency. In this type of MVNMs, the service package also consists of multiple MVNFs packages.

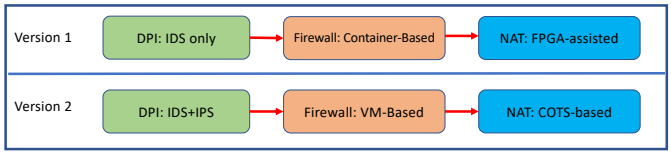


Fig. 3: Example of Multi-Version Network Services (MVNSs) with different Multi-Version Network Function (MVNFs) types

MVNSs with different VNFs: This type of multi-version services can consist of VNFs with different functionalities. In this case, although all versions of a service are developed to achieve the same aim, they use different numbers of VNFs to do so. An example of such a service is a Personal Security Application (PSA) (shown in Fig. 4) that is offered by service providers to secure user connectivity to the Internet [9]. Depending on the level of security requested by the service user, PSA can contain different VNFs. For example, a basic PSA service can contain a VPN and a firewall to provide secure connectivity. The same service can be improved by adding a Tor[1]to provide anonymity for the service user. The third version of the PSA service could include a proxy to provide ad block functionality that improves the user's quality of experience. Depending on requested requirements, different versions of PSA service can be used.

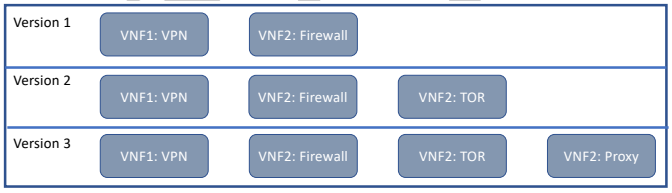


Fig. 4: Example of Multi-Version Network Services (MVNSs) with different VNFs

III. Related Work

Studies in the context of dynamic service provisioning and multi-version services can be categorised into (i) studies related to evaluating VNFs realised with different implementation options and (ii) studies related to analysing the dynamic deployment of multi-version services. The former category supports the idea of the multi-version services as it can prove that there are trade-offs between using different implementation options of VNFs. This validates the idea of having multi-version services in a system as without such trade-offs, there would not be any need to have multiple versions of a service, but simply scaling a single version of service up and down would be all that is needed for optimal performance. The latter category analyses the overhead generated by dynamically service provisioning which is more associated with management and orchestration of these services.

There are multiple studies in the first category. For example, Nobach et al. [1] studied the performance and cost of COTS-based DPI versus FPGA-based DPI. In this work, they implemented a DPI that uses COTS resources for all its tasks and another one that offloads network-intensive tasks onto FPGA resources. They have evaluated the throughput and latency of these DPIs having the size of input packets as a parameter. The results of their evaluation show a clear trade-off between performance in terms of throughput and latency and costs. Using FPGA-based DPI for packet sizes up to 512 bytes can improve the throughput up to 124 times. Also, it can improve the latency up to 6 times. However, in the case that packet sizes are bigger than 512 bytes, the performance improvement becomes negligible. With that, we can observe that the use of FPGA-based DPI is not a proper solution for large packets as it costs 2.3 times more than COTS-based DPI without having a significant performance improvement.

Also, Araújo et al. [10] studied the use of GPUs to assist packet processing in DPIs. To this end, they implemented and evaluated a CPU-based and a GPU-assisted DPI. Both DPIs are based on the Snort IDS[2], with the GPU-assisted DPI adapted to execute on a GPU. They evaluated the DPIs based on three metrics including processing time, resource utilization and overall latency. The results show that the GPU-assisted DPI can process packets up to 19 times faster than CPU-based DPI. Also, for resource utilization, GPU-assisted DPI shows a better result as it uses 4 times less CPU core and memory than CPU-based DPI. However, the overall latency shows a quite different trend as, in this metric, CPU-based DPI has up to 31 times better overall latency compared to GPU-assisted DPI. This result shows that the use of GPU in the case of DPI is not always beneficial and that there is a trade-off between resource utilization and total latency.

Han et al. proposed PacketShader[7], a framework that enables offloading computation and memory-intensive operations to GPUs. In this study, a softwarised GPU-assisted OpenFlow switch has been implemented and tested against a softwarised COTS-based switch to quantify the gain of using GPU as an accelerator for packet processing. The OpenFlow switch implemented in this study captures the packets and extracts the flow keys from the packet header and matches them

[1]https://www.torproject.org/download/, accessed May 14, 2019

[2]https://www.snort.org/ accessed, May 20, 2019

against the exact-match entries in the hash table. The COTS-based OpenFlow switch runs all tasks including the flow key extraction, hash value calculation and lookup for exact entries, linear search for wildcard matching and follow-up actions in CPU. In the GPU-assisted switch, however, hash value calculation and the wildcard matching tasks are offloaded to a GPU. For the evaluation, the throughput of switches was measured with the flow table size as a parameter. The results show that a GPU-assisted OpenFlow switch can have up to 10 times better throughput than the COTS-based one. Their evaluation results also show that the highest throughput improvement is achieved when the number of flow entries is high (1M of exact entries and 1k of wildcard entries), but in the opposite situation, when the number of flow entries is low the throughput improvement is negligible. This indicates that, in the case of low number of flow entries, COTS-based switch can keep up well and provide cheaper switches than the GPU-assisted switch.

For the second category, however, there have not been many studies. In our previous work [5], we have evaluated dynamically deployment of multi-version services using simulation. However, an experimental evaluation of multi-version services along with cost and management overhead analysis is missing.

IV. Quantitative Analysis

We have conducted an experimental evaluation to analyse dynamically provisioning multi-version services. In this evaluation, virtualized Transcoder (vTC) has been used as a case study as it consists of compute-intensive processes that can be offloaded to acceleration hardware. A transcoder provides functionalities such as converting video encoding format and spatial resolution, video transposing, and video transcasting. These functionalities are provided to adjust the original video to the viewer's network datarate, device resolution, frame rate and so on. Transcoder is used in both Video On Demand (VOD) (e.g., Youtube, Netflix) and live-streaming services to provide high-quality video streaming experience for the viewers [11]. Employing vTC as an example, we have analysed performance, cost, and management overhead of multi-version services, which is discussed in the following.

A. Performance Analysis

To analyse the performance, we have implemented two versions of a vTC: (v1) a COTS-based vTC that is designed to only utilise CPU for video processing and (v2) a GPU-assisted vTC that offloads compute-intensive processes to GPU. Both versions are based on FFmpeg[3], which is a software-based transcoder providing a wide range of transcoding functionalities. To emulate the NFV environment, we have deployed vTCs on KVM-based virtual machines. Fig. 5 shows the test-bed set-up used for the evaluation. It consists of four VMs: VM #1 hosts a packet generator that breaks down videos to Group of Picture (GOP) [11] and embeds them into Real-time Transport Protocol (RTP) packet payloads to be sent to vTCs, VM #2 runs the COTS-based vTC, VM #3 hosts the GPU-assisted vTC, VM #4 receives the transcoded videos from vTCs and display them using a video player. All VMs were running on a server equipped with an Intel(R) Xeon(R) W-2123 CPU at 3.60GHz (8 Processors), 8 GB DDR4 RAM, and an Nvidia GeForce RTX 2080 GPU.

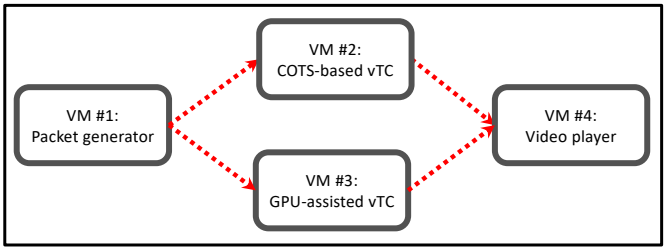


Fig. 5: The test-bed set-up used for the evaluation

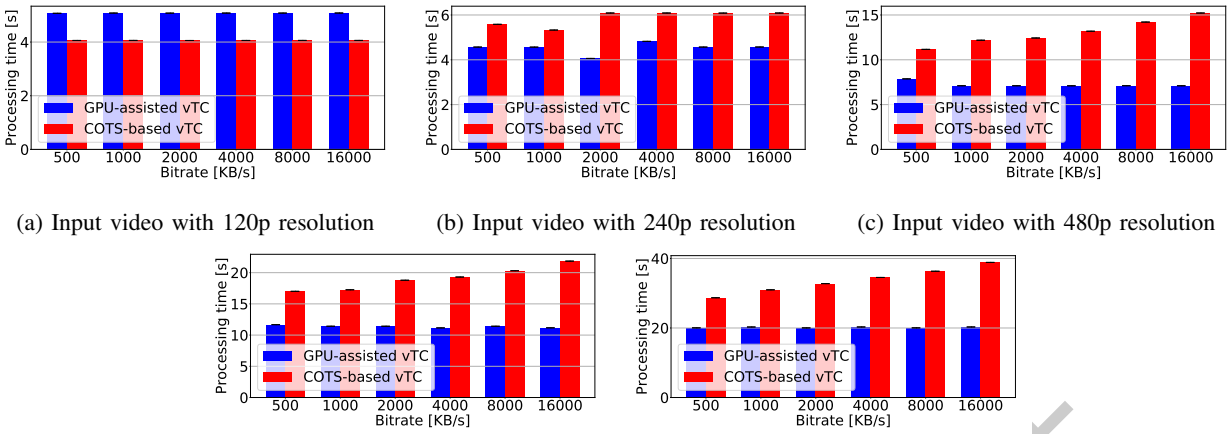
We have considered two metrics namely the video transcoding processing time for the entire video and CPU/GPU utilization. These two metrics are considered as processing time can affect the total latency of video streaming services and CPU/GPU utilization is an indicator of the service cost. Parameters of the evaluation are the video bitrate and resolution. For a range of video resolutions, we have experimented the performance of vTCs. For each video resolution, we ran the test for a range of input bitrates. Both transcoders convert the incoming video format to H.264 format. Also, big buck Bunny[4] video have been used as the input video.

The video processing time results, illustrated in Fig. 6, show that the GPU-assisted vTC processes the videos much faster than the COTS-based vTC when the video has a high resolution and bitrate. Fig. 6e shows that the processing time difference can reach up to 40 seconds for videos with 1080p resolution and 1.6 MB/s Bitrate, which is indeed a remarkable difference. However, the processing time difference decreases as the video resolution gets lower. For example, looking at processing times for videos with 240p resolution (Fig. 6b), we see that the processing time difference goes down up to 1 second and, for 120p resolution videos (Fig. 6a), the COTS-based vTC even outperforms the GPU-assisted vTC. This is because, in the case of GPU-assisted vTC, there is an extra CPU and GPU communication overhead that does not exist in the COTS-based vTC. This increases the total processing time of the GPU-assisted vTCs; however, as this overhead is very low, it has no significant impact on the processing time of high-resolution videos.

The CPU utilization evaluation results are depicted in Fig. 7. As expected, the trend is the same as what we got in the video processing time evaluation. While the GPU-assisted vTCs utilizes less CPU for *high-resolution videos* (Fig. 7e), COTS-based vTC uses less CPU to process *low-resolution videos*. This is because there is no processing associated with exchanging data between CPU and GPU in the COTS-based

[3]https://ffmpeg.org/, accessed May 18, 2019

[4]http://bbb3d.renderfarming.net/download.html, accessed May 27, 2019



(a) Input video with 120p resolution (b) Input video with 240p resolution (c) Input video with 480p resolution

(d) Input video with 720p resolution (e) Input video with 1080p resolution

Fig. 6: Transcoding processing time for videos with different resolutions (with 95 % confidence interval - error bars are too small)

vTC. Looking at the results, the CPU utilization of GPU-assisted vTC remains between 30 % to 50 % for all video resolutions, however, COTS-based vTC utilization varies from 20 % for the 120p resolution (Fig. 7a) to 250 % for 1080p resolution (Fig. 7e). 250 % CPU utilization means 3 CPU cores are used for the process in which 2 of them are fully utilized and the other is 50 % utilized.

We have also measured the GPU memory utilization of GPU-assisted vTC. The results are shown in Fig. 8. Performing this evaluation, we observed that changing the input bitrate does not change the GPU utilization and it always remains constant. However, the GPU utilization increases as the input video resolution gets larger.

Based on the processing time and resource usage evaluation, we observe that there is a trade-off between using COTS-based and GPU-assisted vTCs. Although using GPUs can improve the processing time of vTC in some cases, in some other cases it is not a suitable implementation option as it increases the resource usage while not providing any performance improvement. This backs up the idea of multi-version services and dynamical service provisioning as using the right vTC version for the given input video can significantly improve performance and reduce resource usage.

B. Cost Analysis

We have also analysed the cost of running COTS-based and GPU-assisted vTCs. In the performance analysis, we observed how much CPU core and GPU memory are needed to run COTS-based and GPU-assisted vTCs, respectively. Having these data, we have looked at Amazon's EC2 price list[5] to see how much it costs to provide these resources in a virtualized cloud environment. In our analysis, Amazon's general-purpose "t2" instances are considered as possible instances to provide required resources for vTCs. For the GPU case, we consider the price of elastic graphics instances "eg1"[6] that allows GPU to be attached to EC2 instances.

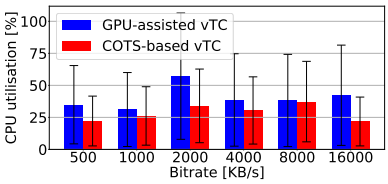
The results of the cost analysis are illustrated in Fig. 8. It shows the cost of providing resources for different versions of the vTC for one hour. While the costs of GPU-assisted vTC remains constant for all video resolutions, the cost of COTS-based vTC shows an increasing trend as the video resolution increases. These results show that the use of COTS-based vTC for video with 1080p resolutions is inefficient both performance-wise and cost-wise. The same holds true for using GPU-assisted vTC to process videos with 120p and 240p resolutions. For the video with 480p and 720p resolutions, although GPU-based vTC performs better, it costs more compared to COTS-based vTC.

C. Management Overhead Analysis

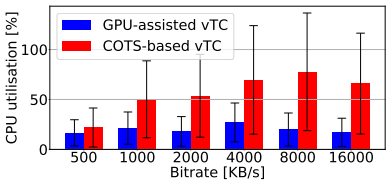
Management overhead of multi-version services also needs to be considered. One of the main factors in multi-version service management is the service deployment time. In a static service deployment, deployment time does not play an important role as the service is deployed only once and the service usage is started once the service is deployed. But in the dynamic deployment scenario, we switch between different versions multiple times during the lifecycle of the service. In this situation, it is important to know how much delay version switching adds to the total latency of the service. To this end, we have also measured the deployment time of vTCs. We performed the measurement for two types of vTCs: (1) a Container-based vTC and (2) a VM-based vTC. A MANO framework called Pishahang [12] has been utilized for this evaluation. Pishahang is an NFV multi-domain orchestrator that supports orchestration of VM- and Container-based services. In Pishahang, VM-based services are managed

[5]https://aws.amazon.com/ec2/pricing/on-demand/, accessed May 20, 2019

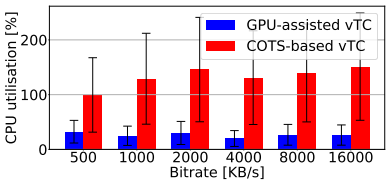
[6]https://aws.amazon.com/ec2/elastic-graphics/, accessed May 20, 2019



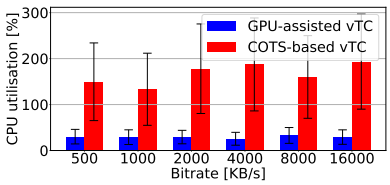
(a) Input video with 120p resolution



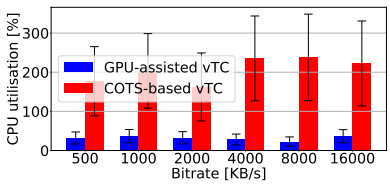
(b) Input video with 240p resolution



(c) Input video with 480p resolution



(d) Input video with 720p resolution



(e) Input video with 1080p resolution

Fig. 7: Transcoding CPU utilization for videos with different resolutions (with 95 % confidence interval)

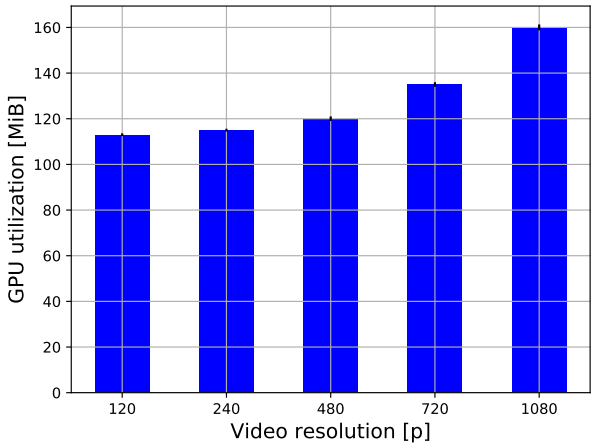


Fig. 8: Memory usage of GPU-assisted vTC for videos with different resolutions (with 95 % confidence interval - error bars are too small)

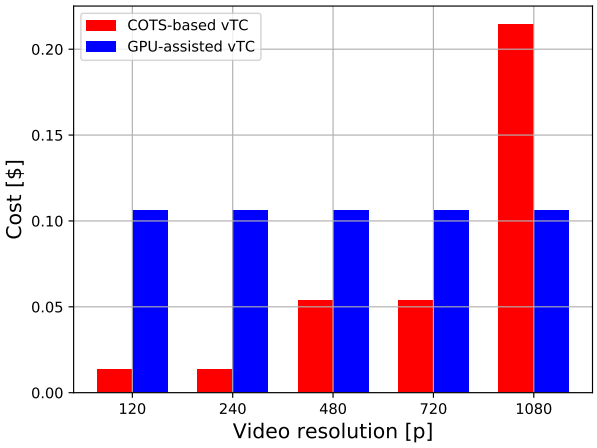


Fig. 9: Cost of running different versions of vTC on AWS resources for one hour

by OpenStack[7] and Container-based services are managed by Kubernetes[8].

As shown in Fig.10, there is a significant deployment time difference between VM-based and Container-based vTCs. While for CN-based vTC, it takes 2.57 seconds to get deployed, VM-based vTC takes more than one minute to get to the operational stage. Most of the deployment time for both container and VM is taken by the Virtual Infrastructure Manager (VIM) that spins up the VM or the container. The image downloading time is excluded from this time. From these results, we observe that in the case of using VM-based vTC, starting VM from scratch is not time-efficient and other solutions such as cold, warm, and live migrations [13] should be considered. We also observed that, form the deployment time point of view, CN-based vTCs are significantly better solutions for dynamic service deployment as they have negligible deployment time compared to VM-based vTC.

[7]https://www.openstack.org/, May 20, 2019

[8]https://kubernetes.io/, accessed May 20, 2019

V. Conclusion and Future Work

In this paper, we analysed the dynamic provisioning of NFV services. Services that can benefit from such a provisioning approach are categorised and discussed. To analyse different aspects of this approach, we used vTC as a VNF example and analysed the performance, cost, and deployment time of COTS-based and GPU-assisted vTCs.

In this work, we observe that there are many VNFs that can benefit from dynamic deployment and that having such an approach can be used to improve the performance while guaranteeing the cheapest price for a particular service. Using vTC as a case study, we observe that using GPUs can accelerate

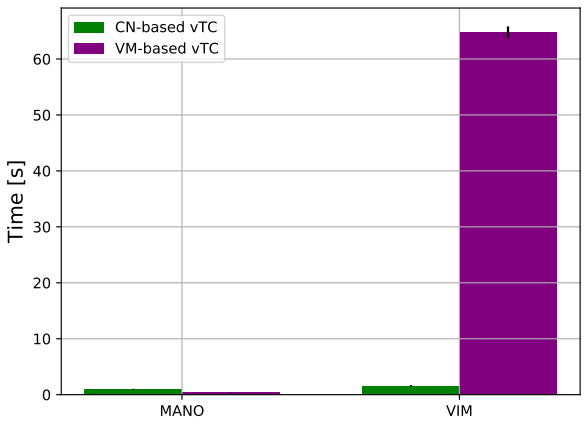


Fig. 10: The deployment time of different vTC versions (with 95 % confidence interval - error bars are too small)

the performance of vTC for high-quality videos while low-quality videos can be handled better by COTS-based vTCs and be cheaper at the same time. Our management overhead analysis shows that using VMs are not the best virtualization option when it comes to switching service versions on the fly as it generates a significant delay. On the other hand, containers seem to be a better virtualization environment as the deployment time of these resources is quite low.

Our future work will be in the context of load prediction for multi-version services. It is important to know in which load situation version switching should be performed during the lifecycle of multi-version services. For example, in a situation where version switching should be performed many times in a very short period of time, it would not be efficient to do so as it could significantly increase the service total latency.

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