On Network Function Virtualization Services for IoT

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Abstract. The network function virtualization (NFV) virtualizes basic network functions, which are now provided by routers, switchers, firewalls, load balancers... and deploys the virtualized functions to the Virtual Machine (VM) instances. This brings more flexibility into the current network architectures, since adding a new function does not require to deploy a new hardware device, which would bring additional costs and is time consuming. The virtualization technique allows the network to simply adapt to the current requirements (load, functionality).
The flexibility as other advantages of NFV are highly relevant for the concept of Internet of Things, where the challenge is to connect billions of heterogeneous devices.
There are computing models like: 5G networks, mobile-edge computing, fog computing which pave a way for IoT. The NFV plays a big role in each of them. This work describes these computing models and identifies the application of NFV in these models.

1 Introduction and motivation

The hardware based network-elements, also known as middleboxes form the basis for most of today's operational networks. The basic functionality of middleboxes is to filter, transfer or to manipulate the packets traveling through the network. They are deployed in various elements of the network from firewalls, intrusion detection systems, network address translators to traffic accelerators...
On one hand middleboxes are very useful, but their usefulness also brings some drawbacks. Since they are hardware based, they are hard to manage, because if there is a need for some new feature in the network, then a new hardware need to be deployed. This process of deploying can take a lot of time [11]. Scaleability is another issue of middleboxes, because they cannot be easily scaled up and down according to the current demand. The introduction of the Fifth generation of Mobile networks (5G), which should support Internet of Things (IoT), where the challenge is to connect billions of heterogeneous devices, will require highly configurable devices. As an example, one can imagine a huge system connecting logistics, automotive, environment and other parts of the industry. Because middleboxes are expensive to manage and it can take a lot of time to interchange them, they would not be enough to fulfill the requirements of IoT [11].
To address these issues, NFV was introduced. NFV brings many benefits in

comparison to current practices. NFV decouples software from hardware. The decoupling enables independent evolution of the used hardware and software and allows network services, which are running now on routers, firewalls, load balancers... to be hosted in virtual machines (VMs). This also means that, for example server capacity can be increased through only software changes (migration of the VM to more powerful physical machine), which will save a lot of time and costs. As an example we can imagine: if an application requires more bandwidth it's enough to move the VM to another physical machine, which fulfills our requirements.
NFV enables flexible network function deployment, this advantage stems from the decoupled software and hardware, they can perform some tasks independently. When some hardware resource is already installed, the software instantiation can be performed automatically using e.g. cloud technologies. This automation enables to deploy network services faster. The decoupling gives more flexibility on the network elements, which enables to scale the NFV according to the actual traffic[1].
NFV is often combined with software defined networking (SDN) to achieve better results. SDN is an architecture that enables the behavior of network devices to be directly programmable using well-defined interfaces instead of programming devices using only vendor-specific APIs and protocols. SDN makes the network devices controllable by a central element. Nowadays SDN shows increase of control in data centers [12] [5].
This work is structured as follows: Section 1 briefly explains the idea behind NFV and references the works, which presented an approach to deploy NFV in the network. Section 2 briefly summarizes most important references used in this work. Section 3 firstly explains the NFV architecture and tries to identify the usage of NFV in various network infrastructures (IoT, edge computing, mobile-edge computing, fog computing) and also shortly explains architecture of the infrastructures. Last section 4 ends up this work with a short summary of most important parts of this work.

2 Related work

This sections provides a summary of most important references used in this work.
Martins et al. [11] identified the drawbacks of commonly used middleboxes in computer networks. They introduce ClickOK, a software high-performance virtualized platform. ClickOK uses the principle of NFV to address the issues of middleboxes. Han et al. [8] explain advantages of the NFV and identifies use cases, which benefit from the usage of NFV in the network. Inam et al. [9] presented the usage of network slices in the architecture of 5G networks. Through network slices, they show the importance of virtualization in 5G networks. They concentrate on the knowledge base used for SLAs negotiation in the network service lifecycle management. Chao Hu et al. [18] explain the concept of Mobile Edge Computing (MEC), as its benefits and applications. In their work they de-

scribe MEC as an approach complementary to NFV. However they refer MEC together with NFV and SDN as key enablers of 5G Networks. Wang et al. [16] introduce an approach called MobiScud. MobiScud is basically an application of Mobile Edge Computing, because it's an architecture, where virtual machines run near their users in the network. Yi et al. [17] describe the limitations of cloud computing and provide a survey of fog computing model, which address the limitations. They provide some scenarios, which benefit from the introduction of fog computing. However there are still some issues related to the design of fog computing networks, these are also identified and discussed in their paper.

3 The application of NFV in computing models

This section provides high level description of NFV framework as given in the specification [1]. The NFV framework consists of three main components:

- Virtualized Network Function (VNF): implementation of network function, which is able to run on NFV Infrastructure.
- NFV Infrastructure (NFVI): contains hardware-based resources and virtual instantiation of these resources.
- NFV Management and Orchestration: control and management layer of hardware-based and software resources, which create the virtualization infrastructure; manages the instatiation scaling, termination and update of the events during the lifecycle of VNFs; manages the virtualization of computational, network, storage resources and their interaction with VNF plus deployment to VMs instances. Its task is to find a cause of performance issues and to collect information, which can be used for future possible optimization [8].

Figure 1 shows the framework in a simple diagram.

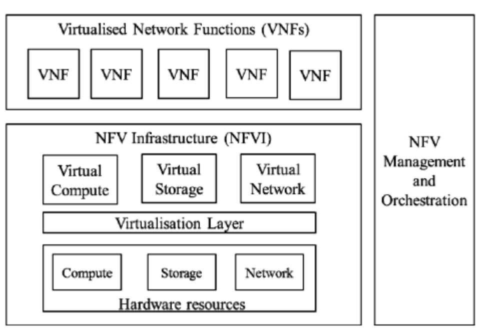

Fig. 1. High-level NFV framework as given by ETSI specification[1].

NFV framework takes care of the instantiation and management of VNFs, as well as the relationships between VNFs. Different NFV technologies can be

deployed in each of the framework's components, depending on the requirements of a organization, which is using the NFV framework [1].
Martins et al. [11] presented ClickOK, a high-performance, virtualized software middlebox platform. They reference Hypervisor-based technologies as limited candidate for the platform, because they can support only small number of tenants and have unsatisfactory network performance. Their requirements were to built a platform, on which software middleboxes from different vendors, running on different operating systems can work. The tenants running on the platform should share common hardware and sufficient isolation should be implemented to support the requirement. Their platform should have high throughput and low delay and should be scaleable to quickly scale out with high demand and scale down when demand finishes.
Batalle et al. presented an implementation of virtualized routing function over an OpenFlow-enabled network in their article[3]. The main components of their implementation are the following: OpenFlow controller for analyzing the packets (if it's IPv4 or IPv6 ...) and sending it to the virtualized routing function; 2nd component presents the implementation of virtualized routing function as a resource in OpenNaaS; the last component is the communication protocol between the OpenFlow controller and routing function. The evaluation of their prototype's execution has shown the count reduction of routing devices, which consequently reduces the costs. By using proactive routing is possible to avoid sending too many requests to the routing function virtualization, which reduces overall Round-Trip delay time (RTT). Then they were able to reduce the number of flow entries in the switches. This reduction is possible because, the intelligence of the system is transferred to external machine, the external machine can perform some calculations and reuse information for the routes.
Lemke [10] briefly explains the importance of distribution in NFV networks. VNFs can be divided into multiple components, each running in a separate VM at a different location. Distribution is important in NFV networks, because many application in today's networks have demands (listed below), which are difficult to fulfill by the today centralized architecture of the networks.

- Low network offload: Most of the network capacity is used by data and video traffic. Because streaming video and data from a central point in a centralized architecture is inefficient, distributed architecture offers new possibilities like multi-casting or content distribution to overcome this inefficiency.
- Low latency and jitter: Data can travel at very high speed all over the world. But the bigger is the distance, the higher is the count of switches, routers and other equipments along the way. Each of these network equipment causes additional delays. Distributed architecture shortens the distance, traveled by the data, and thus the delays caused by network elements are lesser.
- Increased reliability and availability: Applications running in a distributed architecture don't have a single point of failure, thus it's simpler and quicker to recover from failures including possible natural disasters.
- Improved security: Distributed networks could potentially bring more risk because it increases the locations of possible attacks, and once an attacker

has infiltrated to the network, the attacker can float the important parts of the network. Thus applications needs to be secure and carefully distributed, which would enable to quarantine attack in the location, where it was performed leaving the rest of the network safe.
– Government regulation: It may be required, that some critical data need to be stored within a national boundaries.

Han et al. describes a few use cases of NFV in their work [8]. Including virtualization of

– Cellular Base Station
– Mobile Core Network
– Home Network

Cellular Base Station Virtualization: The Radio Access Network (RAN) consists of base stations transmitting the signal to mobile devices. RAN of traditional cellular networks needs to be prepared to handle the maximum expected traffic on the network, which is obviously not always the case, which lead to wasting the resources. The spectrum resources are limited, therefore the frequency of the base stations need to be reused. The base station's equipment needs to be placed at a physical space, which brings additional costs. These and also others are the limitations of RAN architecture. Virtualization has brought the evolution of RAN architecture through the introduction of Cloud RAN. Cloud RAN virtualizes some components of the network. The virtualization has enabled dynamic provision of the resources to avoid wasting them. Cloud RAN enables to perform software upgrades of the devices easily, which enables the adoption of fast evolving today's advanced technologies into the RAN. Cloud RAN also reduced costs for physical space which was needed before.
Mobile Core Network Virtualization: It's hard and ineffective to add/replace some function in todays mobile core network, because it can require new equipment to be deployed, which brings costs and is time consuming. The mobile core network needs to be provisioned for the maximum load too, which can also bring drawbacks like wasting resources and thus makes the scaleability harder. By virtualizing of the network functions it's possible to achieve flexible, easily maintainable and scaleable architecture.
Home Network Virtualization: The NFV technology is used to virtualize components like firewall, NAT router, VPN gateway in a home network. As these functions are virtualized and moved to data centers, the providers need only to provide Internet access to the devices for their customers for a low price.

The following subsections identify the usage of NFV in different architectures of the network.

3.1 NFV in 5G networks

Inam et al. [9] present a basic architectural view of the 5G networks and explained where VNFs will be used in the 5G network structure. This section

references their work to provide an overview about the structure of 5G networks. This section also identifies some of the candidates for virtualization in 5G networks.
5G networks are introducing a platform to fulfill demanding requirements of IoT applications. 5G networks require a higher level of automation to deal with many heterogenous devices, which need to be interconnected by the IoT. To bring the higher level of automation, the 5G networks introduced network slices. This is where virtualization comes to play, network slice is seen as a virtualized network functions (VNFs), which provide isolation between services by partitioning of the resources. The concrete partitioning depends on the service requirements. As figure 2 shows, the network slices also bring a shift from vertical paradigm to horizontal implementation.

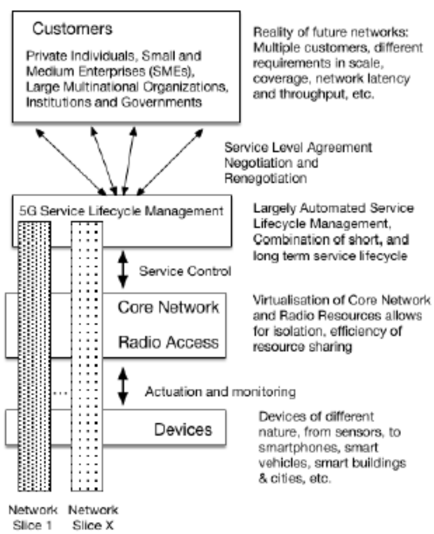

Fig. 2. The paradigm shift from vertical implementations of current generation of mobile networks to 5G. [9]

Figure 3 shows an architecture of 5G network, the 5G network consists of the following layers:

1. User layer
2. 5G Service Lifecycle Management Layer
3. Orchestration and Control layers
4. Radio Access and Core Network layer
5. Devices layer

User layer is an interface for the users to communicate with the 5G Service Lifecycle Management Layer. Customers can submit their SLAs requirements to

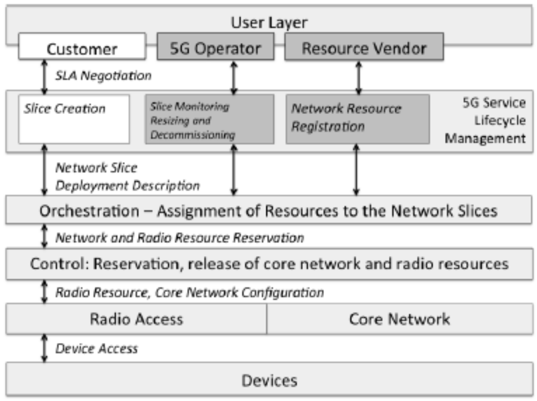

Fig. 3. A high-level architectural view of a 5G network. [9]

the system using this interface.
5G Service Lifecycle Management Layer is responsible for the negotiation and creation of SLAs based on the customer's requirements. Inam et al. [9] introduce an approach to create the SLAs using a knowledge base (consists of models provided by experts and generated automatically using machine learning techniques), which enable the customers to submit their requirements in a high level form (for example how many devices will be connected to the network) and the process in this layer will take care for the translation of the high level requirements to the concrete low level requirements (throughput, latency ...). From the derived SLAs and VNFs definitions (VNFs definitions are also stored in the knowledge base), the network slice description can be generated and later deployed.
Orchestration and Control layers receive the network slice description from the previous layer and deploys the slice on hardware-based resources. As explained in section 1, VNFs can be understood as software self-functional components (firewalls, load balancers ...) running isolated in VMs, deployed on physical resources and replacing the functionality, which was previously provided by specific hardware devices. Multiple such VNFs together form a network slice. The virtualization brings many benefits within, as scaleability, reduction of deployment time, simplification of service's the management, because it all runs in an virtualized environment. The whole network slice including its VNFs needs to be managed (monitored, modified ...) by the service layer of the corresponding application during its lifetime.
Radio Access and Core Network layer consists of radio access components (WiFi access points, base stations ...) and core network functions (authentication, billing and charging ...).
Devices layer contains all physical devices connected to the system (from short-range devices (personal networks) to long range (LTE, GSM))[9].

As explained before, 5G Network are introducing a platform for IoT, which implies that the number and density of connected devices will dramatically increase. To serve the requests of all these devices 5G Network need to fulfill the demanding requirements including extreme low latency, massive bandwidths, extreme base station, very dense network of devices, very high carrier frequencies... To achieve all these requirements 5G networks might expand to radio access networks [15]. Sun et al. presented an exemplary network with key technologies for 5G in their work [15], these technologies are good candidates for virtualization, but there are challenges in virtualizing these, therefore the it opens new research questions. Candidates for the virtual network function listed below:

- Using Milimeter-Wave in 5G networks enables us to achieve super wide bandwidth, because it covers broad range of frequencies. Milimeter-Wave technology is a good candidate for virtualization, but it requires high device precision for high data rate and high quality transmission, which will increase the complexity of NFV design.
- Massive multiple-input multiple-output (MIMO) enables to serve multiple time more mobile users, improves the energy efficiency, brings significant reduction of latency... Because of all these benefits, it's important, but challenging to virtualize the functionality of Massive MIMO and integrate the work of NFV and SDN in this component.
- Another interesting field where to apply NFV is Cloud-RAN. Cloud-RAN was introduced to provide mobile broadband Internet access to wireless customers. It provides a centralized base-band pool, where radio units connect to baseband units (BBU)[15]. Abdelwahab et al. [2] studied the potential CAPEX and OPEX savings resulted from virtualizing of the BBUs (Baseband Units). They performed a testing to compare the number of needed BBUs in a virtualized and non-virtualized infrastructure at maximum traffic. They found out, that up to 25% of the BBUs count can be saved in a virtualized environment (if a single BBU supports 256 processing units). These savings stem from these benefits: traffic from a cell site can be served by a virtual BBU (pooled from a resource pool) instead of by a specific BBU, this means that the BBUs can be reused; second benefit is that the total number of required BBUs in a non-virtualized environment must be able to manage the maximum traffic of each cell site, while in a virtualized environment we need "only" the count corresponding to the maximum of the aggregate traffic. The aggregate traffic is less, because the maximum traffic of the individual cell sites occur in different time intervals. The number of saved BBUs represents the CAPEX savings. The OPEX savings were observed from the average number of active BBUs. The basic idea is that a virtual BBU becomes active only if the request cannot be served by already active BBUs. At the end of the comparison around 30% savings were observed in the virtualized architecture.

Abdelwahab et. al. [2] presented a flow for 5G RAN, where NFV and SDN enable the implementation of 5G communication technologies such as Downlink(DL)/Uplink(UL) CoMP and Inter-Cell D2D. In this flow the VNF Manager includes OpenFlow controller, which effectively realizes the DL/UL CoMP and Inter-Cell D2D communication. DL CoMP enables the BBUs to communicate while parallel delivering data from one to many cell-sites. UL CoMP is in principle the same only in the opposite direction: communication from many cell-sites to one.

3.2 NFV near the edge

This section firstly briefly describes the idea and benefits of Mobile Edge Computing 3.2.1 and Fog Computing 3.2.2 and to the end tries to identify the possibilities of NFV's placement and application in these computing models as well as the challenges attached to it 3.3.

3.2.1 Mobile Edge Computing brings a huge potential of improvements to the existing cloud platform. Because many services, which people are using every days (social networks, navigation tools, video streaming services ...) are running on cloud computing platform. There are many compute intensive tasks (image processing), which are nowadays being performed directly on mobile devices, which decreases battery life as a consequence. These compute intensive operations can be carried out of the mobile devices and be executed on the edge of the network to achieve very-low latency and high bandwidth and maximize user experience. That's an basic idea behind mobile edge computing [7].
MEC is a new technology bringing IT services with cloud computing-capabilities to the edge of the mobile network in close proximity to mobile users. This brings a benefit, which enables some small tasks of an application to be executed at the edge of the network, in local clouds. This decreases latency and increases bandwidth. Operators provide their Radio Access Network (RAN) edge to authorized third-parties, allowing them to flexible and rapidly deploy their applications and services. MEC is also a step towards 5G networks, because 5G networks will benefit from programmable functions of virtualized network elements and MEC tries to bring more programmable approaches into mobile networks and also causes better results in latency and bandwidth [18].
MEC is also, as NFV, based on a virtualized platform but in complementary approach to NFV. NFV virtualizes (the previously) hardware-based network functions, while MEC framework focuses on running an application at the edge of the network in some VM [16]. Since both technologies run on similar infrastructures, it would bring benefits to the operators to host both technologies on the same platform [18]. Beside this benefit, MEC together with SDN and NFV will be key players to gain low latency and high bandwidth and in the infrastructure, which is able to connect trillions of devices[7].
Wang et al. [16] introduce an architecture called MobiScud, approach motivated by CloudLet [13], which integrates SDN and cloud platform technology in a backwards compatible fashion to fulfill the requirements of computationally intensive applications. MobiScud uses a highly distributed cloud platform, where a private VM of the user can be deployed to perform compute-intensive operations at the

edge of the network. MobiScud also monitors the message exchange between the user and the mobile network. It uses the existing live VM migration techniques to migrate the VM to the nearest cloud platform (at the edge) as the user is moving, without disrupting the ongoing connections.
The VM instance, running close to user is very important, because it brings the following benefits within:

– The compute-intensive operations (facial recognition, speech translation, image processing ...) can be executed with ultra-low latency. Since the current mobile network architecture is centralized, it cannot support such compute-intensive operations, because all traffic is currently tunneled to operator gateways before entering the Internet, which causes long delays.
– The applications requiring exchange of sensitive data (personal health-care data...) are not exposed to a high risk of unnecessary attacks, because the sensitive data don't need to be sent far away, over potentially untrusted networks to cloud-platform providers.
– Virtualization brings (among other things) this advantage: It's simple to add/modify functionality to elements of the network, since these elements are not limited by vendor specific APIs.

3.2.2 Fog Computing brings the computational power of cloud computing to the edge of the network, closer to the end users. *This also explains the name fog, because fog (in meteorology) is simply a cloud on to the ground (closer to the end users)*. Fog computing introduces a way for complex applications and services running in future Internet (IoT) to deliver results in a short time. Because the idea of fog computing is to use computational power of today's network elements (routers, set-top boxes, access points ...) named fog nodes to become new servers and perform computational-intensive tasks. Figure 4 shows a basic high level architecture of fog computing.
Cisco [4] listed some of the benefits of using fog computing. The IoT data

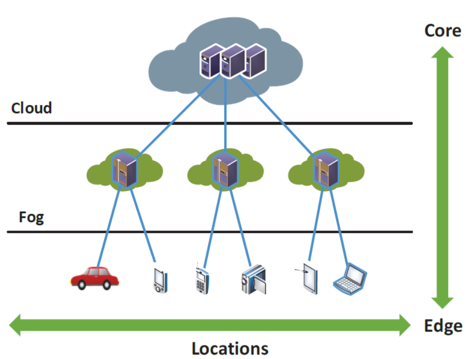

Fig. 4. High level fog computing model [14].

are kept close to where it was collected and does not need to be send over the core network, which minimizes latency and saves gigabytes of traffic and keeps sensitive data in the network location where are they from.
Although fog computing brings cloud closer to the users and thus operations being now executed in cloud can be performed much quicker, it doesn't replace the cloud. The cloud still plays the big role in fog computing. Fog nodes receive data from IoT devices in real time, perform some operation in the node and send response back to the user in a short time. Beside that, fog node's task is also to send some data summaries to the cloud, so the cloud aggregates the data from multiple fog nodes and can perform some big data analytic on them.
The concept of fog computing is similar to MEC technology described in section 3.2.1 and also to the concept of mobile cloud computing (MCC). MCC represents an infrastructure, in which the data storage and data operations are carried out by the cloud outside the mobile devices. However fog computing is seen as a combination of both MEC and MCC [17].

3.3 NFV in fog and mobile-edge computing

I decided to put the identification of NFV possibilities of both fog and mobile-edge computing to this section, because they are highly related to each other. Although NFV hasn't been studied together with fog computing usage yet[17], there are possibilities for its placement at the edge. The logical centralization of VNFs enables to obtain access to network status, interference maps, flow parameter and operator preferences. This information can be used by various VNFs and enables the operators to implement a VNFs with certain functionality at the edge of the network (e.g. to offload user traffic), and VNFs with another functionality at the core (e.g. load balance traffic) [2].
One of the presented open research problems by Abdelwahab et al. [2] is where to place the VNFs pool initially (at the edge of the network or near the core). Although VNFs with real time constraints should be placed near the edge and VNFs with coordination constraints should be placed near to the core.
Another challenge of deploying NFV to the edge is the management of very dense small network. The small cell in the network should be self manage the lifecycle of various VNFs (migration, updating...) [6].
Batalle et al. [3] presented an implementation of routing function virtualization in their work also state that it's reasonable to logically centralize the routing knowledge, which makes it simple accessible for VNFs running in the small cells. As this section shows, there are still many open challenges with NFV running at the edge, but it can still bring all of the benefits for the providers as it brings in the core of the network.

4 Conclusion

This sections provides a summary of all important parts of this work.
Middleboxes technology are part of many elements of todays networks. Although

they are very useful, the practice is showing that they are not enough flexible to meet the increasing requirements of networks (mainly requirements of IoT)[11]. To address these issues, NFV was introduced. NFV virtualizes the network functions(routes, firewalls...), which were previously running on a hardware-based devices (routers, switches...). The virtualized network functions are hosted in VMs instances and deployed on physical machines. This enables the network to adapt to the current demand. Besides other benefits, NFV increases flexibility, scaleability, decouples software from hardware, and enables flexible network function deployment [1].
Mainly the flexibility is very suitable for the concept of IoT. Therefore virtualization is an important part of 5G network. 5G network introduces the usage of network slices, which are basically composed of multiple VNFs. The network slices are generated from the SLAs submited by consumer and later deployed on the network structure. Multiple network slice can be deployed on one network structure, but the isolation between them has to be preserved. The network slices are scaleable and can be adapted to the current demand [9]. There are many candidates for NFV in a 5G network. Virtualizing of these brings many benefits, but is quite challenging, because it increases the complexity of NFV design [15]. The tests show that virtualizing of the BBUs in Cloud-RAN 5G network brings CAPEX and OPEX savings, achieved by the reduction of the BBUs count in network environment[2]. Although NFV seems to bring many benefits for the network providers, there are still many research question left open [2] [15].
Mobile edge computing brings and idea to run computational-intensive operations in VM at the edge of the network outside the mobile device, but still close to the user. The thing, that VM is running close to the user is very important, because it brings many advantages: compute-intensive operations can be executed with ultra low latency and high bandwidth; sensitive data don't need to be send over many potentially untrusted networks; increases flexibility. As the user is moving accross many access points his VM is migrating and "following" him along the way. But the migration doesn't destroy the currently running task in the VM [16].
Fog computing is a technique seen as a combination of Mobile edge computing and Mobile cloud computing. Fog computing brings the cloud closer to the user. It uses the computational power of network elements (router, set-top boxes...) called fog nodes to perform intensive tasks and introduces local cloud through this way. The user can let running his VM instance in local cloud. There are many use cases, which will benefit from the introduction of fog computing: Augmented Reality (AR) and Real-time video analytics applications; Content Delivery and Caching; Mobile Big Data Analytics [17].

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