New immersive interface for zero-touch management in 5G networks
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Abstract—Network management have posed ever-increasing complexity with the evolution of virtualized and softwarized mobile networking paradigm, demanding advanced network visualization and automation technologies to address this significant paradigm shift. This paper provides a novel holographic immersive network management interface that extends the standardized ETSI Zero-Touch Network and Service Management (ZSM) reference architecture to allow network administrators to understand real-time automated tasks in a 5G network without human intervention. This augmented reality based system has been validated and prototyped using Microsoft Hololens 2 in a realistic 5G infrastructure.

Index Terms—Zero-Touch Management, Augmented Reality, 5G, Network Topology, Multi-tenancy

I. INTRODUCTION

Virtualization and softwarization are cornerstone technologies for 5G and beyond next-generation networks. These technologies have led to a significant reduction of capital expenditure (CAPEX) thanks to the employment of commercial-off-the-shelf computers and the better usage of available resources due to the consolidation of workloads. However, the complexity of the networks has also significantly increased with the introduction of virtual switches, routers, kernel-bypass networking technologies and others. This complexity would result in a notable increase of operational expenditure (OPEX). Consequently, Zero-Touch Management (ZTM) has become a hot topic currently in the process for standardization, e.g., by the European Telecommunications Standards Institute (ETSI) Zero-Touch Network and Service Management (ZSM) working group [1]. The main aim of ZTM is the automation of configuration, monitoring and control tasks in large-scale networks to obtain a full end-to-end architecture framework designed for closed-loop automation without requiring human intervention. The usage of ZTM is expected to enable automating essential network management tasks that are traditionally manually handled by network administrators to be executed automatically by a computer system. This will accomplish a substantial reduction in OPEX.

In this context, ZTM targets to achieve autonomic management of large-scale 5G networks using automation as a key technology. However, when an autonomous system takes the control of the network, it makes autonomous decisions at different speeds. Thus, the human can easily miss out at least part of the information about the system’s behaviour or may be unable to understand the underlying reason why the system is behaving in such a way at runtime. It leads to the challenge and requirement of monitoring and judging if the ZTM system is functioning correctly in a timely and direct fashion.

To address these problems, it entails the creation of a novel visualization-based immersive approach that enables network administrators to interact with a ZTM system in an intuitive manner, by introducing an immersive graphical user interface (GUI) that allows humans to understand the autonomic processes being executed. This GUI should provide debugging capabilities so that the user can visualize and understand the behaviour of the autonomous system and determine the correctness of the behaviour. The design of this ZTM GUI is the main motivation of this work.

The key innovations achieved in this work are as follows:

- A novel extension of the ETSI ZSM framework with holographic capabilities to enable the attachment of holographic interfaces.
- A new immersive holographic Human-Computer Interface assuming a full autonomous behaviour and the user being a spectator that can visualize the current status of
the system and the different actions taken by the ZTM system.

- Both the extended framework and the GUI have been designed, prototyped and validated using a 5G multi-tenant network testbed deployed in our premises.

The rest of the paper is structured as follows. Section II provides an overview of the state of the art in Zero-Touch Network Management systems and debugging methods. Section III presents the proposed system architecture. Section IV describes the proposed holographic GUI. Section V presents the validation and performance results. Finally, Section VI concludes the paper.

II. RELATED WORK

There has always been an interest in automating any network management task. Since the advent of virtualization and softwareization technologies, this particular area of research has gained momentum where researchers, projects, and standardization bodies have been able to make progress towards closed-loop automation of network and service management operations. This is the case of the H2020 SELFNET project [2], [3] that based the core of its investigation on addressing autonomic network management framework to achieve self-organizing capabilities in managing 5G network infrastructures. Researchers in [4], [5] show closed-loops of operational processes and tasks executed automatically to address particular use cases. More recently studies based in Zero-touch systems [1], [6] have paved the way for introducing a common architecture for a new Zero-touch network and Service Management paradigm.

Despite the numerous advances made in recent years in this area, the human being has been always interested in to supervise and to closely monitor decisions made by any autonomous systems. Analyzing network behaviour and its current status is an imperative feature for network administrators to confirm the correct functioning of all services running on top of the network architecture. The incoming 5G Networks impose high requirements with respect its flexible and dynamic topology [7], which are even pushed to the extreme in Zero-touch Systems [1], where Virtual Network Functions (VNFs) and/or network links may be instantiated or destroyed as part of an orchestrated plan to address any issue or improvement in the network without human intervention (and probably without even knowing it) [8], [9]. However, typical monitoring systems do not auto-discover devices or networks (being necessary to configure each device that needs to be monitored with a configuration file) and barely offer a WebApp where data can be viewed in an old-fashioned graphical web-based frontend. In [10] authors provide an open-source software for integrating Nagios [11] and OpenStack [12] to achieve an adaptive distributed monitoring architecture automatically deployed in the cloud infrastructure. Software-Defined Network (SDN) Controllers such as OpenDayLight [13] also present advanced monitoring capabilities including auto-discover functionalities, multi-tenant isolation and graphical interfaces. Skydive [14] and Midonet [15] are advanced open-source real-time network topology tools able to discover physical and overlay networks of both virtual machines and containers with multi-tenant support. However, none of the aforementioned solutions offers a complete answer where 5G mobility of the user equipment (UE) needs to be tracked, 5G VMs are dynamically migrated or specialized hardware such as radio equipment also needs to be monitored. Furthermore, none of the monitoring tools found in the state of the art has the ability to monitor any combination of the administrative domains (including the E2E) of a 5G network architecture.

Our contribution aims to present the first of the next generation monitoring tools that harness the benefits of future 5G networks to in turn provide them back high-quality, real-time and visually understandable information by providing an immersive human-machine interface.

III. PROPOSED FRAMEWORK ARCHITECTURE

Fig. 1 illustrates the core concept of the ZSM reference architecture produced and approved by the ETSI Zero touch network and Service Management Industry Specification Group (ZSM ISG) [16]. The ZSM architecture is divided into different areas representing the separation of multiple management domains (MDs) which are responsible for their own full-automation of operations shown in Fig. 1 as Monitoring, Analysis, Decision and Actuation. This architecture seeks of modularity, extensibility, scalability and resiliency as its main principles. The E2E MD is in charge of coordinate and orchestrate between the multiple MDs (and their services) belonging to different administrative entities, thus achieving and end-to-end management and reducing the overall system’s complexity. Every MD, including the E2E, provides a set of ZSM service capabilities by management functions that expose and/or consume a set of service end-points. These services and consequently, its produced data, can be in turn used by any E2E service (e.g., intelligence services) to feed domain-level and/or cross-domain mechanisms. Throughout the cross-domain integration fabric (depicted in the middle of the figure) it is enabled an access to reach, if required, exposed cross-domain endpoints. It is worth noting that some services are only provided and consumed locally inside the management domain (by using the intra-domain integration fabric) and do not provide any cross-domain service/data exposure.

The E2E automation and zero-touch management of network services and infrastructures rely on the ability of close the management loop. Fig. 1 illustrates Management Domains that are composed by the following service management functions: (1) The monitoring component in charge of collecting performance information about the managed resources of such domain; (2) The analytic component that is in charge of the autonomous detection of alarms that need to be handled in the system; (3) The decision making component is in charge of the autonomous decision to handle and/or mitigate the alarms; (4) The actuator in charge of the enforcing of the decisions into the MD; And finally, (5) the topology inventory has all the information about devices, ports, flows, connections and other relevant metadata about the infrastructure of the MD.
Management Domains not only provide access to their ZSM services but are also capable to consume ZSM services provided by other MDs. Similarly, other consumers such as vertical applications can consume ZSM services exposed by the E2E service management domain and the intra-management domains. In summary, the ZSM framework reference architecture offers cross-domain data services that can be consumed by: a) The E2E service management domain; b) Management intra-domains; c) Any other ZSM Framework consumer.

The ZSM framework reference architecture follows the current trend to move away from static management systems to more flexible sets of management services. This contribution leverages the ZSM framework reference architecture to provide a novel service. Fig. 1 depicts (top-right corner) an E2E service and its interfaces, which are described in the following section, to provide holographic network management capabilities.

IV. PROPOSED IMMERSIVE INTERFACE FOR ZTM

This section describes the proposed Immersive Interface for Zero-Touch Network and Service Management. This interface has been integrated in an Augmented Reality headset to provide full 3D immersive view of the autonomous management that is happening in the network (see Fig. 2). The interface provide a full spectator view where users can interact with their voice and hands to explore the topology. This exploration system provides a 3D logical representation where are rendered all the Physical Machines (PMs), Virtual Machines (VMs), Physical Switches, Software Switches (Open vSwitch \(^1\) and Linux Bridges), Physical Routers, Remote Radio Heads (RRHs) and UE. This information is stored in the "Topology Inventory" of the ZSM architecture and discovered by the network probes installed in the different components of the architecture.

Fig. 2 shows an example of visualization of a network topology. Every box in the figure represent a different type of device. This topology has two different levels in the Z axis. On the top, the Virtual Networks are rendered where all the VMs are allocated. In this case, it can be distinguish VMs with two colors. This means that there are two different tenants sharing the infrastructure and each color represent the owner of each one of them. The VMs are linked to a PM that host such VM in the bottom level. This bottom level represents the Physical Network. PMs are connected between them through different switches. In this topology, it can be seen four Core PMs placed in the centre of the network and 4 Edge PMs placed on the boundaries of the topology. All the PMs placed in the Core segment are also connected to other servers that give access to different services. Every PM in the Edge segment have two 5G RRHs connected that give access to UE devices to the network. Furthermore, it can be appreciated some warnings triangles on top of some devices. Those warnings represent alerts that have happened to something related to those devices. This view allow the administrator to explore the complete network and understand their interconnections. VM migrations are shown in real-time when happening.

Moreover, the user can access the metrics for every single device and every single device port managed in the infrastructure. To get access to the available metrics of a concrete device the user can tap on the box that represent this device. This will open the perspective shown in Fig. 3. This figure shows the internal layout of a device. Each sphere rendered on the device represents an interface. If the user tap on them it will show the metrics available for such interface. The device of Fig. 3 has three physical interfaces. Inside of the device there are two software switches than can be also clicked. These software switches have more interfaces that follow the internal datapath of the device. The spheres on top of the device are the logical interfaces that provide connectivity to the VMs hosted in this PM. On top of the device there are different holographic buttons for every real-time metric available for this device. This information is provided by the monitoring architectural component of the ZSM architecture. Then, to visualize the metric the user just tap on it.

Fig. 4 shows what happen when the CPU Usage metric is selected. This action opens a graph board using the units provided by this metric. In this case is a percentage metric that varies through the time. The system start rendering the real-time values provided by the monitoring system.

\(^1\)Open vSwitch is available at [http://www.openvswitch.org/](http://www.openvswitch.org/)
In addition, users can visualize events that are taking place in real-time for all the previous components cited. When the user clicks the warning on top of the device, the perspective shown in Fig. 5 appears. This perspective shows the list of events received for this device. The events are represented in three colors, red, yellow, and green. Red is used for alerts that are automatically detected but are not automatically mitigated and thus require human intervention. These alerts are generated by the anomaly-based analytics module of the ZSM framework. The yellow alert represents events that are automatically detected and the system knows how to solve them but requires human confirmation to be automatically enforced. The steps to solve the alert are provided by the decision making module. Finally, green alerts are used when the framework components of detection, decision, and mitigation have already applied a complete solution to mitigate the alert without human intervention. These alerts will not last indefinitely, so they will be removed after a certain period of time set by the user or when being seen/addressed. Notice that when the user is exploring the topology, only one colored alert is shown on top of the devices despite the number of alerts associated to it. In this case, the color rendered will be the one belonging to the most critical alert (red > yellow > green).

A. Implementation Details

The interface has been prototyped and implemented in Unity3D using C# for the scripting backend. The system
supports both holographic headset: Microsoft HoloLens 1st and 2nd Gen. To make it possible for the gesture interactions with holograms, it adopted the Mixed Reality ToolKit version 2.1.0 provided by Microsoft. In order to communicate with all the components in the ZTM system, the system employed RabbitMq, which provides good scalability results and support for different platforms. Nonetheless, Hololens (1st Gen) run over a x86 architecture, and for this reason RabbitMq client had to be adapted using the C client compiled for x86 and wrapped, making it compatible for Universal Windows Platforms over WinRT. All the messages exchanged followed a JSON format. Newtonsoft.Json was employed to serialize and deserialize these JSONs.

V. Empirical Validation and Performance Results

This section presents the validation and scalability tests conducted using the proposed interface.

A. Testbed Description

The execution of all the tests have been carried out using a realistic 5G infrastructure deployed in our premises. This infrastructure is composed of 20 PMs in the core of the network and four PMs in the edge; each one of these edge PMs has connected two RRHs and each one of those RRHs has connected eight UE devices. This infrastructure is shared by two tenants that have VM instances in every PM. The RRHs are Ettus USRP B210 SDR DUs. Each PM in the infrastructure is a high-performance laptop EUROCOM Sky X9E3, with Intel CPU i7 7700K 4.2GHz and 64GB RAM DDR4-2400. The UE devices in the infrastructure correspond to different IoT devices distributed along the campus. However, to test the scalability of the proposed framework, these UE devices have been extended using the emulation mode supported by the 5G Radio Access Network (RAN) and Core network stack. OpenAirInterface was employed as 5G stack and OpenStack was used for the management of the resources. OpenDayLight and OpenVSwitch were incorporated as a SDN control framework.

B. Interface Validation

To validate the proposed GUI, the screenshots shown in Fig. 2, Fig. 3, Fig. 4 and Fig. 5 have been taken as a demonstration of the functional validation of the system. These screenshots were taken in the Microsoft HoloLens 2 headset and they show the deployed architecture in our premises, providing evidence of the system running in real-time. The total time to render this topology in the interface took approximately 15 seconds from cold-start in Microsoft HoloLens 2 and after that, it yielded 25 frames per second (FPS) performance providing real-time immersive experience for the user.

C. Performance Results

To provide scalability results for the implemented interface, the UE devices connected to the network have been extended using the emulation mode. Thus, the total number of UE ranged exponentially from 64 to 2048 (64, 126, 256, 1024 and 2048). These performance results were conducted using the Microsoft HoloLens 2 headset.

Fig. 6 shows the time that the GUI took to render all the devices in the topology since it received the first one until the last one was rendered. The graph shows similar results in the first three scenarios that correspond to topologies with 64, 128 and 256 UE devices in total. However, the three following ones (512, 1024, 2048) show an exponential trend. It took around 50 seconds for the scenario with 512 UE, around 2 minutes for the scenario with 1024 UE and less than 6 minutes for the scenario with 2048 UE. This exponential trend was due to the number of polygons drawn by the headset. The hardware is limited in this kind of devices since the rendering of 3D elements is an expensive task that requires GPU processing. These results indicate how much it took for the system to converge, allowing the user to start using it with a complete view of the network. However, it does not imply a scalability problem as indicated next.
Future work will target at further improving scalability of the proposed system. To this end, it is planned to integrate the interface with holographic remote rendering, which would allow extracting the hosting to an external computer. This would enable access to powerful external resources and offload the holographic headset.

**VI. Conclusions**

This paper presents a novel immersive holographic Human-Computer interface for Zero-Touch Network and Service Management systems. The GUI has been designed and implemented to be a debugging tool for network administrators and users in general, in order to provide an spectator view and allow them to understand the current state of the overall network and the actions taken by the autonomous system. The ETSI ZSM framework has been extended to allow the integration with the proposed interface. The interface has been validated over a realistic 5G multi-tenant network testbed. Scalability results have been performed by ranging different sizes of network topologies. These results have determined that the scalability is limited by the hardware where the application is deployed. However, when measuring the FPS, relevant results have been obtained in the frame rate after drawing the complete topology (around 25 FPS) for a topology size of 2138 devices.

**References**


