Scalable Monitoring for Multiple Virtualized Infrastructures for 5G Services

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Abstract— **This paper presents a high level architecture and functionality details of the monitoring framework that has been implemented and integrated within the SONATA project, in order to support the management of 5G services under the Software Defined Networking / Network Function Virtualization (SDN/NFV) paradigm. The innovative framework, extending the functionality of Prometheus.io, is unique in its support for multiple Points of Presence (PoP), its extensibility using Websockets, and its availability as open-source.**

Keywords-NFV/SDN; Cloud Computing; Monitoring; SDN; NFV; Network Services.

I. INTRODUCTION

In the next years, 5G infrastructure will become a ubiquitous, flexible and programmable network that will be in the core of every social, business and cultural process, enabling both economic growth and social prosperity. In order to achieve this goal, the 5G vision poses significant technical challenges that must be fulfilled, including the concept of agile programmability and supporting the introduction of management mechanisms for the efficient instantiation of innovative services across heterogeneous network components, virtualized infrastructures and geographically dispersed cloud environments.

One of the important issues to be addressed in this new era of 5G service management is related to network and service monitoring, demanding for collecting data and metrics on the performance and usage of the resources involved in the lifecycle management of 5G services. However, the already available monitoring tools do not achieve the requirements stemming from the services envisioned in the 5G landscape, since they are in most of the cases: (i) intrusive and heavy-handed for short-lived, lightweight network function instances, (ii) not able to follow the fast pace of management changes enforced by continuous dynamic scheduling, provisioning and auto-scaling, (iii) not covering the requirements of all the involved

emerging technologies, including deployments in both hypervisor-based and containerized manner, as well as monitoring data collection from different cloud environments. This paper presents the monitoring framework that has been implemented within the SONATA project, providing an interactive monitoring framework capable of offering real-time data collection, processing and alerting to all involved stakeholders of an SDN/NFV-enabled service platform, i.e., service developers, service platform operators and end-users, under heterogeneous cloud-enabled computing environments.

In Section II, we present the related state of the art, while in Section III the monitoring requirements for 5G services are discussed. Section IV includes the high-level architecture and functionality of our monitoring framework. Section V discusses the scalability of the proposed implementation, while Section VI includes our conclusions and future work.

II. STATE OF THE ART

Network monitoring has been an active research topic for more than three decades. Well-established protocols such as Simple Network Management Protocol (SNMP) [1] and Internet Protocol Flow Information Export (IPFIX) [2] are already successfully applied for gathering network metrics through either passive or active measurements. However, network metrics in isolation are not very useful in services-oriented systems; they have to be aggregated and consolidated with service- and resource-related information to produce an integrated picture of the performance of the provided service. Hence, another category of monitoring tools is mostly focusing on computation, storage and memory resources of the infrastructure or the deployed service/application, such as Nagios [3] and Zabbix [4]. One of the most advanced and modern monitoring tools is Prometheus [5] that is an open-source service monitoring system, based on a time series database that implements a highly dimensional data model, where time series are identified by a metric name and a set of key-value pairs. Moreover, Prometheus provides a flexible query language,

allowing slicing of collected time series data in order to generate ad-hoc graphs, tables, and alerts. Most importantly, Prometheus provides probes that allow bridging of third-party data into Prometheus in a "pull" fashion, but also supports "push" through an already implemented gateway.

Recently, the concepts of SDN and NFV in combination with the advent of Cloud Computing and containerization of services, has dictated the implementation of monitoring tools in conformance with the respective technologies that will allow the retrieval of SDN-based, per-flow information directly via the Application Programming Interface (API) of the Openflow controller (e.g., OpenDaylight Statistics REST API [6]), the collection of monitoring data within Docker containers via cAdvisor tool [7] as well as the performance monitoring of cloud infrastructures and instantiated services, such as Monasca for OpenStack [8]. Following these trends, the programmability of 5G software network infrastructure will require a flexible and expandable monitoring tool to complement the management of the deployed innovative services, integrating the benefits of the abovementioned tools in a unified framework. During the last years a remarkable effort has been made on the development and integration of such monitoring frameworks under different viewpoints: In [9], the authors introduce a management solution for cloud federation that automates service provisioning and achieves seamless deployment of services across a future internet cloud federation; however, this framework lacks inherent support for NFV deployment. In [10], the challenges of proper NFV monitoring are discussed, focusing on the process of collecting NFV Infrastructure (NFVI) metrics and processing them at Virtualized Infrastructure Management (VIM) level. Finally, in [11], the authors present a monitoring and discovery framework for self-organized network management in virtualized and software defined networks that, is relevant to the management of 5G services under the SDN/NFV paradigm, but lacks proof in terms of scalability.

III. Monitoring Framework Requirements for 5G Services

This section presents the requirements related to monitoring arising from the use case scenarios of SONATA EU-funded project [12], acting as drivers for the monitoring architecture design that has been followed (Table I).

TABLE I. Requirements Fulfilled by the SONATA Monitoring Framework

Req. name	Description	KPIs
VNF status monitoring	Provide a high level state for each VNF	Provide a dashboard displaying status data
VNF placement and metrics modification during runtime	Allow the user to deploy VNFs at arbitrary points into the network and modify metrics parameters in runtime.	SLA/QoS metrics related to deployment time, cost, etc and interfaces for modification of metrics and thresholds.
Timely alarms for SLA violation	Provide alarms for SLA violations in a timely manner.	Proven performance and scalability of the message bus and websocket creation

Req. name	Description	KPIs
VNF real-time monitoring	VNFs will generate in real time information useful for monitoring and response.	Monitoring frequency, time to process alerts.
Quality of service monitoring	Metrics generation and degradation detection of network traffic, should be supported and reported.	Traffic QoS, packet loss, delays.
Monitoring Framework Scalability	Scalable to support multiple and heterogeneous infrastructures and a high traffic load.	Support for multi-PoP and multi-tenancy federated environment.

Although not specifically mentioned in the above-mentioned requirements, it is required that monitoring system must collect data from Virtual Network Functions (VNFs) deployed on virtual machines and containers in different infrastructures. Additionally, in order to facilitate the resource orchestration process, SONATA monitoring system must collect and offer information related to the available resources of the infrastructure, as mandated by VNF placement. Thus, monitoring system must be able to collect data from the underlying infrastructures comprising the SONATA ecosystem. Moreover, the monitoring system must be able to accommodate VNF-specific alerting rules for real-time notifications. Also, the presented SONATA monitoring framework will offer the capability to developers to define service-specific rules, whose violation will inform them in real-time. Finally, there is one requirement related to the Quality of Service that demands special attention with regards to sampling period and monitoring accuracy and another one, directly related to scalability of the SONATA monitoring framework with respect to the Service Platform and respective infrastructures.

IV. High-Level Architecture and Functionality of Monitoring Framework

In a nutshell, the SONATA monitoring framework collects and processes data from several sources, offering the developer the ability to activate metrics and thresholds in order to capture generic or service-specific behaviour. Moreover, the developer can define rules based on metrics gathered from one or more VNFs deployed in one or more NFVIs in order to receive notifications in real time. In general, the developer is able to subscribe to a message queue or he can get the alert notifications by email and/or SMS on his smartphone. Most importantly, monitoring data and alerts are also accessible through an API or directly accessing a websocket URL. The internal architecture of Monitoring Framework is depicted in Figure 1 and explained in the next subsections.

A. Collecting data from several sources

It is of paramount importance to collect monitoring data from as many as possible sources. In the implemented framework, there are four different types of sources for collecting data: 1) *container probe* which runs inside the container-based VNFs to collect data related to their performance, 2) *VM probe* that collects data from Virtual Machines (VMs) hosting VNFs, 3) *OpenFlow probe* which is a Python software that utilizes OpenDayLight API to

collect data from the OpenFlow controller, and 4) *OpenStack probe* that has also been developed as a software module (in Python language) that uses OpenStack API to collect data from all OpenStack components.

B. Push Gateway

This component is part of the open source Prometheus monitoring solution [5] that has been adopted and extended to cover the needs of SONATA Monitoring Framework. Push Gateway is utilized so that the probes/sources use HTTP POST method to "push" monitoring data to the Push Gateway, while Prometheus server collects the data in a predefined time interval. The advantage of this approach is that in the case of the deployment of a new service, there is no need for the Prometheus monitoring server to search for data related to the newly deployed VNF, but rather collect them from the PushGateway.

C. Prometheus Monitoring Server

Prometheus is an open-source service monitoring system, based on time series database that implements a highly dimensional data model. A time series entry is identified by a metric name and a set of key-value pairs. Prometheus has a sophisticated local storage subsystem (LevelDB), which is essentially dealing with data on disk and relies on the disk caches of the operating system for optimal performance. Prometheus server is responsible for collecting the data and communicating with the time-series database for retrieving data upon request.
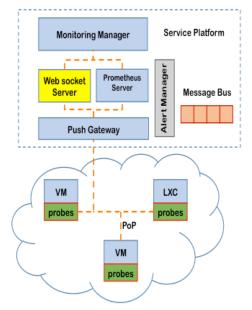

Figure 1: Monitoring Framework high-level architecture.

D. Monitoring Manager

The monitoring manager is a Django-based server that offers APIs to the users with respect to the monitoring data of their instantiated 5G services, including: 1) the relation among services, network functions, NFVIs and users, 2) the ability to modify rules and thresholds during service/function

runtime, 3) the reconfiguration of Prometheus server, 4) the ability to define the notification methods in case of alert generation, 5) the definition of a new websocket to get data in real-time and many other features.

E. Alert Manager

As previously discussed, the Alert Manager is responsible (along with the implementation of a message queuing mechanism, such as RabbitMQ) for sending notifications about firing alerts to the subscribed users. After this notification, the user can take advantage of the API to further investigate the fault or activate a websocket to receive real-time monitoring data.

F. Websocket server

The implementation of websockets (Tornado web server) allows the user to collect streaming data from VNFs that have been deployed in the Service Platform. This is highly beneficial to the developers, as they would be able to monitor the performance of a new service in real environment. Prior to the establishment of a new websocket, the user must be aware of the metrics collected per VNF, the VNFs comprising his deployed Network Services and other related information and this information is already provided by the existing Monitoring Manager API framework, as depicted in Figure 2.
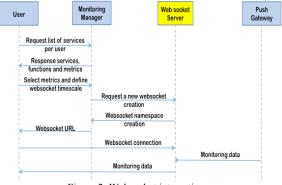

Figure 2: Websocket interactions.

After selecting the VNF and the respective metrics to be sent, the user requests the creation of a new websocket from the Monitoring Manager. After checking the validity of the request, the Monitoring Manager communicates with the Websocket server that creates and sends a new URL for the user to connect to and where metric values are pushed.

V. SCALABILITY AND DISTRIBUTED ARCHITECTURE

One of the cornerstones of the monitoring framework implementation was to deliver a carrier-grade solution that would fulfill scalability requirements in a multi-PoP environment. As noticed from Figure 3, several components of the Monitoring Framework had to be distributed across the SONATA PoPs. First, each PoP must have its own websocket server to accommodate developers' demands for streaming data, although the management of websockets is handled by the Monitoring Manager instance in a centralized way. Second, Prometheus Monitoring servers follow a distributed (cascaded) architecture. The local Prometheus

servers collect and store metric data from the VNFs deployed in the PoP, while only the alerts are sent to the federated Prometheus server for further processing and forwarding to the subscribed users. Moreover, the alerting rules and notifications are based on monitoring data collected in different PoPs and thus the decision must be made on a federation level. Another scalability requirement concerns the large flow of data from the monitoring probes to the Monitoring Server and its respective database that might affect the service performance in extreme cases. In this respect, an architectural decision to address this scalability issue was to support a distributed architecture regarding the monitoring server and its database, working in a cascaded fashion along with proper modifications on component level. In particular, the functionality of the monitoring probe will change so that it will not send data to the monitoring server in cases where the value difference is less than a threshold defined by the developer.

VI. CONCLUSIONS AND FUTURE WORK

The innovative SONATA monitoring framework builds further on state-of-the-art technology including RabbitMQ, Prometheus and Websockets, enabling a multi-PoP framework with extensible and user-friendly monitoring of NFV services involving both containers and Virtual Machines, empowering service management components to dynamically react on triggered monitoring alerts. As a future work, in the context of 5G-TANGO EU-funded project [13], the described Monitoring Framework will be further enhanced by introducing the concept of autonomic management, as described in the respective European Telecommunication Standardization Institute (ETSI) documents [14].

ACKNOWLEDGMENT

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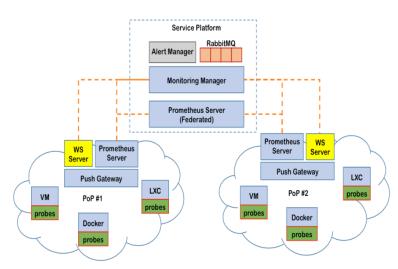
Figure 3: Architecture addressing scalability requirements with respect to the monitoring framework.