

Department of Computer Science  
Computer Networks Research Group

## Project Report



### Management of ServiCes Across MultipLE clouds

#### Authors:

ARKAJIT DHAR  
ASHWIN PRASAD SHIVARPATNA VENKATESH  
BHARGAVI MOHAN  
DEEKSHA MYSORE RAMESH  
SANKET KUMAR GUPTA  
SUHEEL SHRIRANGAPURA NAZEERSAB  
VIVEK JAGANATH

#### Supervisors:

Prof. Dr. Holger Karl | Sevil Dräxler | Hadi Razzaghi Kouchaksaraei

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# TODOs

■ Content to be added . . . . .	18
■ Content to be added . . . . .	18
■ Add content . . . . .	26
■ Explain about the machine configuration used to run the experiments, what OS, how many servers and what VIMs where installed, what is the configuration and how python-mano-wrappers were used to send the requests. . . . .	34
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# Motivation

The rapid growth of mobile data services driven by mobile internet has led to substantial challenges of high availability, low latency, high bit rate and performances in networks. The recent development of Network Function Virtualization (NFV) and Software-Defined Networks (SDN) have emerged as key enablers for 5G networks. There has been a paradigm shift in networking with the recent developments in network virtualization technology. NFV involves decoupling of the hardware components from the software components of a network function. NFV requires a central management and orchestrations (MANO) framework in order to fully deliver end-to-end services of an application. There are multiple open source as well as industrial implementations of MANO framework in the market.

End-to-end network service delivery requires chaining of the Virtual Network Functions (VNFs) across different Internet Service Providers (ISPs) which in turn have their own MANO frameworks. In order to seamlessly create a network service by utilizing the VNF within each of the MANO frameworks, the need of interoperability among different MANO frameworks is of utmost importance.

## 1.1 Problem Description

European Telecommunications Standards Institute (ETSI) defines the reference architecture for a MANO framework. Each network service is composed of multiple network functions virtually linked and orchestrated by a MANO framework. The network services require a descriptor which contains the details of all the VNFs, virtual links and forwarding graph of VNFs. Each of the VNFs contains its own Virtual Network Function Descriptor (VNFD) and the information about the number of virtual machines it requires. Different MANO frameworks have their own descriptor schemata pertaining to the standard defined by ETSI. This framework-specific Network Service Descriptor (NSD) hinders the orchestration and management of VNFs between different MANO frameworks.

Firstly, the project aims at tackling the above mentioned problem with the implementation of translator and splitter engines, which would help translate the NSD and divide the VNFs to be deployed on different MANO frameworks, thus creating a framework-independent network service chain. Secondly, the project aims at the implementation of a MANO adaptor, that allows interaction between different MANO frameworks, exposes the network service instantiation interfaces of the underlying MANO frameworks and retrieves monitoring information about the network service status. The adaptor will mainly address MANO scalability challenges and perform state management. Lastly, the project aims at integrating these individual modules in order to provide an end-to-end network service delivery across different MANO frameworks.

## 2.1 MANO Frameworks

In this section, a few MANO frameworks and their NSD schemata are listed (list of a few parameters and their description). Among several frameworks, the plan is to select a few and set them up locally, deploy network services and support them in the project. This list is subjected to future additions or removals.

### 2.1.1 Pishahang

Pishahang is a framework consolidated from state-of-the-art NFV and Cloud management and orchestration tools and technologies. Pishahang is a framework for jointly managing and orchestrating virtual network functions and cloud-based microservices.

Pishahang deploys, manages and orchestrates complex services by consolidating and extending current Cloud and NFV tools and technologies [KDK18].

#### Network Service Descriptor Section

Parameter	Description
Vendor	Identifies the network service uniquely across all network service vendors.
Name	Name of the network service without its version.
Version	Names the version of the NSD.
Author	It's an optional parameter. It describes the author of NSD
Description	It's an optional parameter, provides an arbitrary description of the network service.

Table 2.1: Pishahang: Network Service Descriptor Section



**Network Functions Section**

Parameter	Description
network_functions	Contains all the VNFs that are handled by the network service.
Vnf_id	Represents a unique identifier within the scope of the NSD
Vnf_vendor	As part of the primary key, the vendor parameter identifies the VNF Descriptor
Vnf_name	As part of the primary key, the name parameter identifies the VNF Descriptor
Vnf_version	As part of the primary key, the version parameter identifies the VNF Descriptor
Vnf_description	It's an optional parameter, a human-readable description of the VNF

Table 2.2: Pishahang: Network Functions Section

**2.1.2 Open Source MANO(OSM)**

OSM is an open source management and orchestration stack in compliant with ETSI NFV information models. OSM architecture splits between resource orchestrators and service orchestrators [dSPR<sup>+</sup>18]. Table 2.3 lists the parameters of NSD schema. [Doc]

Parameter	Description
id	Identifier for the NSD
name	NSD name
Short-name	Short name which appears on the UI
vendor	Vendor of the NSD
logo	File path for the vendor specific logo. For example, icons/mylogo.png. The logo should be a part of the network service.
description	Description of the NSD
version	Version of the NSD

Table 2.3: OSM: Network Service Descriptor

**2.2 Virtualized Infrastructure Manager (VIM)**

VIM is one of the three functional blocks specified in the Network Functions Virtualization Management and Orchestration (NFV-MANO) architecture. VIM is responsible for controlling and managing the NFV Infrastructure (NFVI), by provisioning and optimizing the allocation of physical resources to the virtual resources in the NFVI. Performance and error monitoring is also a key role of the VIM. Popular VIMs are discussed in the following sections.

### 2.2.1 OpenStack

OpenStack<sup>1</sup> is a community-driven open source cloud resource management platform. Compute, storage, and networking resources in a data center can be provisioned using Application Program Interfaces (APIs) or web dashboard provided by OpenStack component, for instance, NOVA is a component which can provide access to compute resources, such as virtual machines and containers. Network management is enabled by NEUTRON component which handles the creation and management of a virtual networking infrastructure like switches and routers. SWIFT component provides a storage system. By making use of many such components, OpenStack can deliver complex services by utilizing an underlying pool of resources.

### 2.2.2 Kubernetes

Kubernetes<sup>2</sup> (K8s) is an open-source platform for automation and management of containerized services, it manages computing, networking, and storage infrastructure. Kubernetes was initially developed by Google and now under Cloud Native Computing Foundation. Kubernetes Architecture consists of (1) Master server components – it is the control plane of the cluster and act as the gateway for administrators (2) Node Server Components – servers which are performing work by using containers that are called nodes, they communicate with the master component for instructions to run the workload assigned to them. Kubernetes provides comprehensive APIs which are used to communicate between the components and with the external user.

---

<sup>1</sup><https://www.openstack.org/>

<sup>2</sup><https://kubernetes.io/>

## Scramble architecture

Scramble is a tool to realize scalability with hierarchical orchestration. While the higher level orchestrator (Parent MANO) still controls the life-cycle of the deployed network services, scramble acts as a bridge between parent MANO and lower level orchestrator (child MANO) thus allowing interconnection between different MANO's to provide end-to-end service.

### 3.1 Architecture

The services of scramble resides as a plugin within MANO frameworks such as SOTANA/Pishahang and Open Source MANO (OSM) and enables cross MANO communication. Service requests received by the higher level MANOs in the hierarchy can be routed to lower level MANOs using scramble plugin based on monitoring parameters.

Each child MANO's in-turn contains scramble plugin which allows multiple other MANO's to be added as a child hence achieving hierarchical orchestration (See Figure ??).

Scramble is composed of three main services.

- Translator
- Splitter
- Wrapper(adaptor)

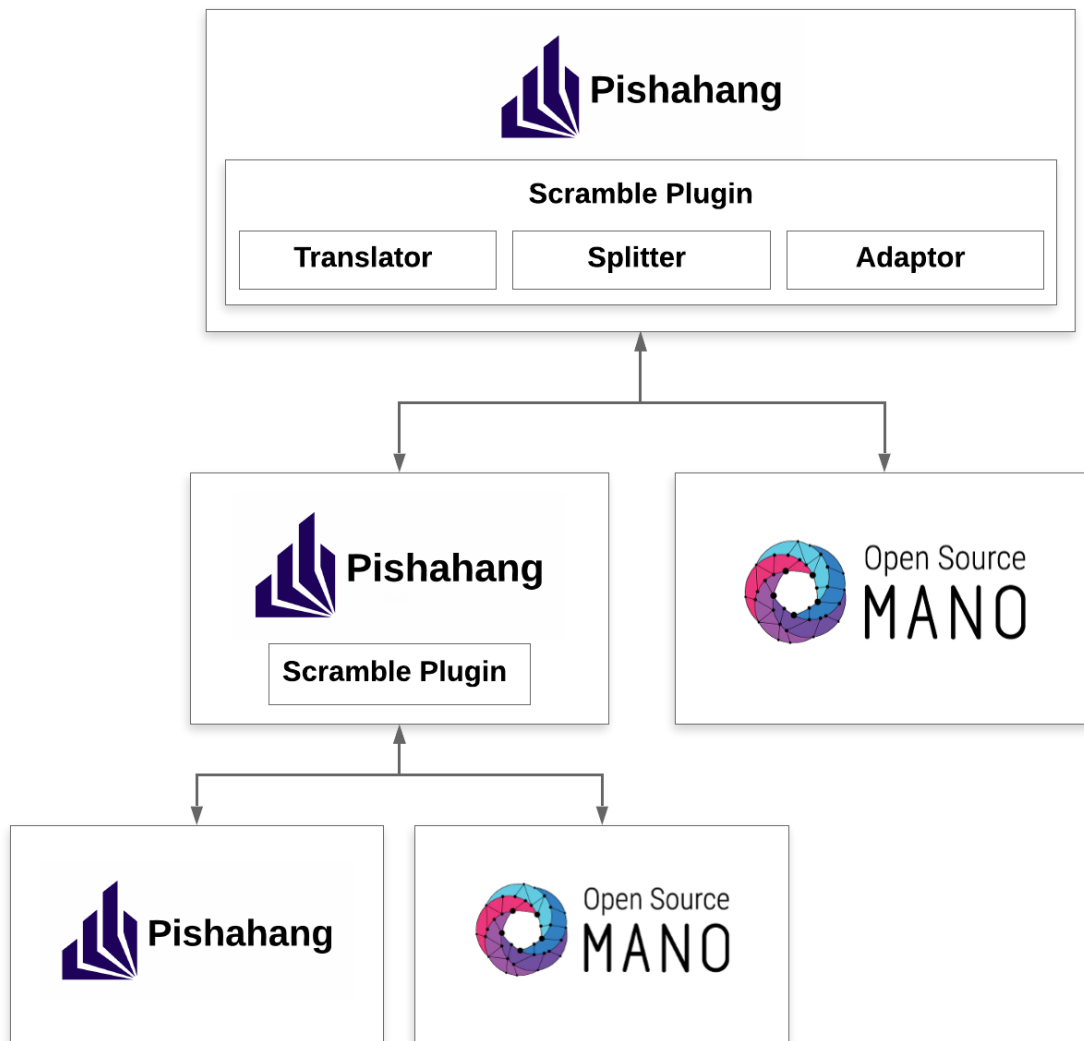


Figure 3.1: Scramble Architecture

## Work Packages

### 4.1 Translator

In a hierarchical architecture involving different MANOs, there is a need of conversion of network descriptors to schemas of respective MANO. Service Descriptor Translator (SDT) serves the purpose of translating network descriptors, namely NSDs and VNFDs from schema of SONATA Pishahang to that of OSM and vice versa.

In a scenario, where a parent MANO, say Pishahang decides to deploy one of the network services in its lower hierarchy MANO, say OSM, the NSD and VNFD(s) need to be converted to the descriptor schema of OSM. In such an event, the Scramble plugin calls the translator service and sends the descriptors to the SDT, where the translation of the descriptors takes place and the translated descriptors are sent to Adaptor utility for deployment in appropriate MANO. Figure 4.1 gives a high level view of Translator.

Scramble plug-in installed within the parent MANO forwards the network descriptors with service request to Scramble Main-Engine. Main-Engine checks the service request and sends the network descriptors to Translator along with the information of destination schema. On receiving the network descriptors, SDT translates the same to requested schema and calls the validator function to validate the translated network descriptors. Once validation is complete, the translated descriptors will be sent to Adaptor for deployment.

#### 4.1.1 Architecture & Work flow

#### 4.1.2 Usage

The Translator engine consists of the following modules:

1. descriptorReader
2. descriptorWriter
3. utilities
4. translator
5. validator

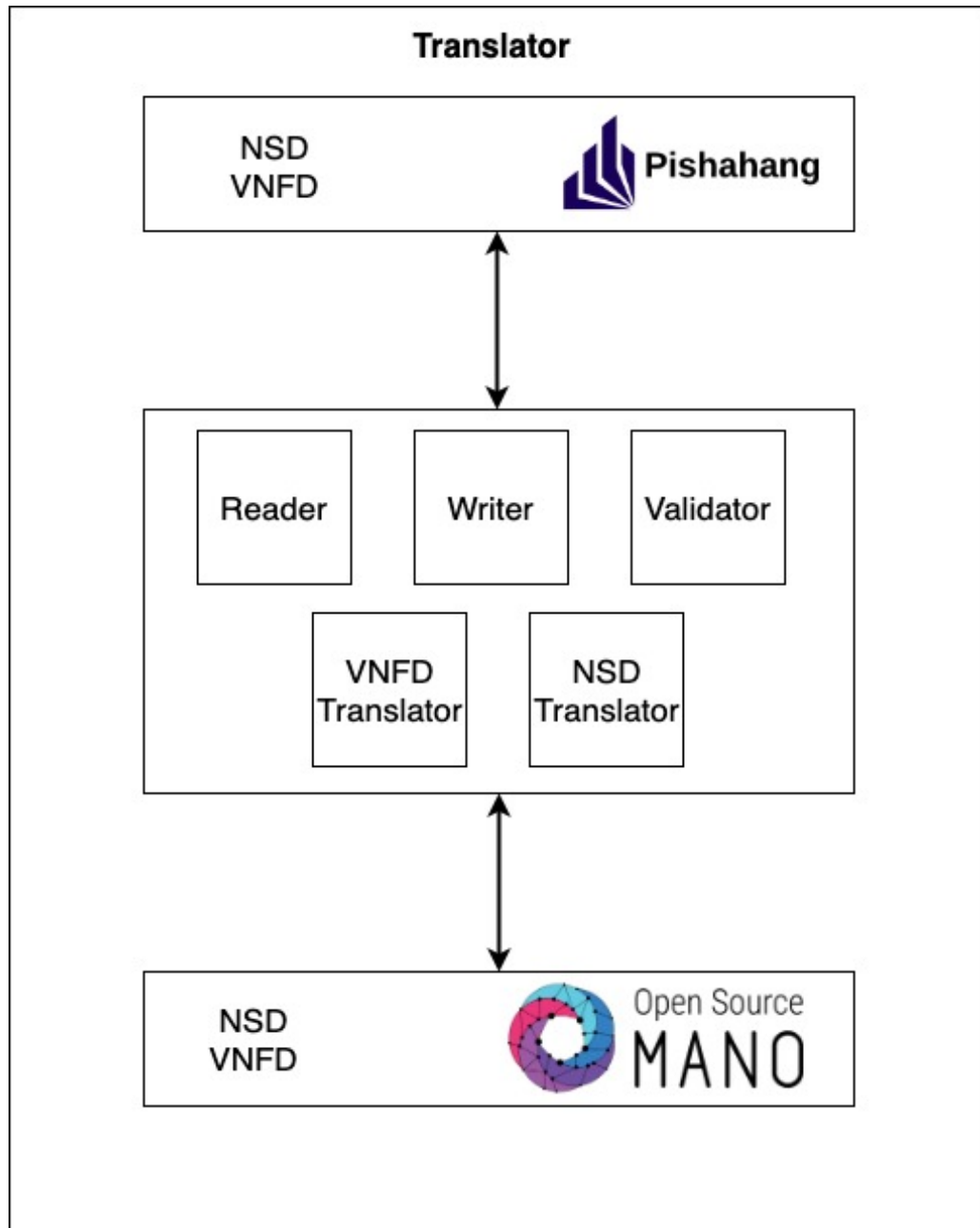


Figure 4.1: Transltor

**descriptorReader**

This module is responsible to read a json/dictionary input (NSD/VNFD) and iterate over the keys and return a generator of an object to the calling program. This generator can be transformed to any python data structure for ease of use and navigation.

The input to this module is a json or dictionary object.

```

1 from descriptorReader import read_dict
2
3 pishahang = pishahang_descriptor ## the descriptor as a json or dict object
4
5 ### reading a dict/ json content into a pandas dataframe
6 reader = read_dict()
7
8 pishahang_dataset = pd.DataFrame(
9 reader.dict_parser(pishahang, 'root', 1, '0|preroot|0'),
10 columns=['parent_level', 'parent_key', 'level', 'key', 'value', 'lineage'])
11
12
13 pishahang_dataset.sort_values(ascending=True, by=['level', 'parent_key'], inplace=True)
14 pishahang_dataset.fillna('NULL', inplace=True)
15 pishahang_dataset.reset_index(drop=True, inplace=True)

```

**descriptorWriter**

This module is responsible to read a python pandas Dataframe input and output a nested json/dictionary maintaining the nested structure in the dictionary.

```

1 from descriptorWriter import write_dict
2
3 ### writing from a pandas dataframe to a dict/json object
4 writer = write_dict()
5 pishahang_descriptor = writer.translate(pishahang_dataset.sort_values(by='lineage'))

```

**utilities**

This module is responsible for transforming the keys and map the corresponding values between sonata and osm descriptors. The module includes the 4 functions for translating between sonata and OSM descriptors.

1. translate\_to\_osm\_nsd()
2. translate\_to\_osm\_vnfd()
3. translate\_to\_sonata\_nsd()
4. translate\_to\_sonata\_vnfd()

**translator**

This is the interface where the actual translation request comes in. After a translation request is received along with a descriptor, it calls the above modules translate and validate the descriptors (NSD/VNFD).

This following function translates OSM descriptor to Pishahang.

```

1 import pymongo
2 from validate import validator
3 from utilities import setup
4
5 def toSonata(received_file):
6
7     client = pymongo.MongoClient("mongodb://mongo:27017")
8     setup_obj = setup(client)
9     validate_obj = validator()
10
11     if 'vnfd:vnfd-catalog' in received_file:
12
13         ## mongoDB document object to store the translated vnfd
14         doc = setup_obj.db_descriptors["translated_vnfd"]
15
16         ## getting a translated sonata vnfd
17         translated = setup_obj.translate_to_sonata_vnfd(received_file)
18
19         ## validating the translated descriptor which returns a "True"/ "False" string
20         check = validate_obj.sonata_vnfd_validate(translated)
21
22         if check == "True":
23             ## insert into mongoDB as a Document
24             temp = doc.insert_one(translated)
25             translated_ref = temp.inserted_id
26
27         elif 'nsd:nsd-catalog' in received_file:
28
29             ## mongoDB document object to store the translated nsd
30             doc = setup_obj.db_descriptors["translated_nsd"]
31
32             ## getting a translated sonata nsd
33             translated = setup_obj.translate_to_sonata_nsd(received_file)
34
35             ## validating the translated descriptor which returns a "True"/ "False" string
36             check = validate_obj.sonata_nsd_validate(translated)
37
38             if check == "True":
39                 ## insert into mongoDB as a Document
40                 temp = doc.insert_one(translated)
41                 translated_ref = temp.inserted_id
42
43     return {"descriptor":translated , "VALIDATE STATUS" :check}

```



The following function translates Pishahang descriptor to OSM.

```

1 import pymongo
2 from validate import validator
3 from utilities import setup
4
5 def toOsm(received_file):
6
7     client = pymongo.MongoClient("mongodb://mongo:27017")
8     setup_obj = setup(client)
9     validate_obj = validator()
10
11     if 'network_functions' in received_file:
12
13         ## mongoDB document object to store the translated nsd
14         doc = setup_obj.db_descriptors["translated_nsd"]
15
16         ## getting a translated osm nsd
17         translated = setup_obj.translate_to_osm_nsd(received_file)
18
19         ## validating the translated descriptor which returns a "True"/ "False" string
20         check= validate_obj.osm_validator(translated)
21
22         if check == "True":
23             ## insert into mongoDB as a Document
24             temp = doc.insert_one(translated)
25             translated_ref = temp.inserted_id
26
27         elif 'virtual_deployment_units' in received_file:
28
29             ## mongoDB document object to store the translated vnfd
30             doc = setup_obj.db_descriptors["translated_vnfd"]
31
32             ## getting a translated osm vnfd
33             translated = setup_obj.translate_to_osm_vnfd(received_file)
34
35             ## validating the translated vnfd which returns a "True"/ "False" string
36             check= validate_obj.osm_validator(translated)
37
38             if check == "True":
39                 ## insert into mongoDB as a Document
40                 temp = doc.insert_one(translated)
41                 translated_ref = temp.inserted_id
42
43     return {"descriptor":translated, "VALIDATE STATUS" :check}

```

### validator

The validator validates the descriptors presented for translation. It differentiates between OSM, Pishahang and Sonata descriptors and also between NSD's and VNFD's. The sonata descriptor validation is mainly based on schema, implemented using python library jsonschema.draft4validator, this library helps by proving the complete path of the error which comes very handy while debugging. The Validation for OSM is slightly complex than that compared to sonata validator, OSM validator can be divided into two parts. the first part validates the descriptors using schema with the same setup as that of sonata and the second part uses python object class for validation, this is done to replicate the validation method used by OSM hence to make sure that any descriptor that is validated by translator will be accepted by OSM.

### 4.1.3 Challenges

#### 4.1.4 Future scope of this work package

Translator engine currently doesnot support the following:

1. Forwarding Graph
2. Juju charms in OSM
3. Monitoring Parameters

#### **Juju charms in OSM**

MANOs provide programmable and flexible management and orchestration of VNFs. OSM provides this flexibility through juju charms and Pishahang provides this through SSM/FSM (a container based solution). Because of these technological differences, direct translation between juju charms in OSM, and SSM (Service Specific Manager) and FSM (Function Specific Manager) in Pishahang is not possible.

As an alternative, it is possible to add charms functionality to Pishahang so that a descriptor containing juju charms can be deployed in both Pishahang and OSM with direct translation. This can be achieved by adding or modifying below things in Pishahang.

1. Modify packaging and unpacking techniques in Pishahang to accept charm package along with descriptors
2. Add additional keys in descriptors to mention charm name, actions and vnf index similar to OSM
3. Update Pishahang installation code to install juju and charm programs and tools
4. Create an interface to execute actions on VNFs
5. Create new container or component to perform actions on specified VNFs
6. Manage removal or deletion of charms after life cycle of Network Service

## 4.2 Splitter

Splitter helps in splitting a Network Service (NS) into multiple sub Network services which can be deployed and instantiated individually on Internet Service Providers (ISPs) located over a vast geographical region spanning multiple domains and are orchestrated by different MANO frameworks. Splitter calls Service Descriptor Translator if there is a need to translate the NS if it is to be deployed on a different MANO framework.

In this work package, a Service Descriptor Splitter (SDS) is implemented which splits the NSD of a network service. SDS takes NSD as an input that contains all the information elements which can be extracted to generate separate NSDs. In the proposed approach, the service graph is extracted from the input NSD and is split into subgraphs that result in a separate NSD which includes a set of elements such as VNFs, Virtual Links (VLs), forwarding graphs of VNFs etc, according to the specific MANO framework.

### 4.2.1 Architecture & Work flow

Service Descriptor Splitter consists of following functional items which

- The total number of NFs mentioned in all the set matches the number of NFs defined in the NSD.
- There are no invalid NFs in the sets received.

After validation the actual splitting starts. We have created classes for different sections of a NSD which encapsulate all the attributes and its values into a single unit which makes it very easy to process. Once the objects are set they are passed to different splitting functions based on there type. We have two different processing units for OSM and SONATA. Following are some functions responsible for splitting the NSD.

- **Set General information:** This function copies all the general information from the main NSD to the sub NSDs. Information includes Vendor, author, Version, Descripton etc.
- **Split Network Functions:** This function splits the Network functions from NSD to sub sets according to the request parameter received.
- **Split Virtual Links:** When a NSD is splitted into different parts, its topology changes. Change in topology results in changing of Virtual Links. For example if A, B and C are three Nfs and we are splitting them in such a way so that A and B remain in one NSD and C in separate NSD. A virtual link between B and C now does not make sense. So this link should be broken down and B's output should be connected to the external end point which was connected to C's input earlier. This function splits these kind of Virtual Links.
- **Split Forwarding Graph:** As explained in the above section, once the topology changes, the respective Forwarding graph also changes. Split forwarding graph pulls out the set of connection points and newly created virtual links and sets them in the sub NSDs.

Once the Splitting is done, create file is responsible for creating YAML files depending on the number of sub NSDs created. These files are saved in the file system which can be downloaded or moved forward to the adopter for deployment purpose. Following figure ?? graphically represents the splitting architecture.

### 4.2.2 Usage

SDS is implemented as a micro-service which can be used independently from Translator or Wrapper by making a post call to the SDS. Following code snippet describes how to call SDS using POST call.

```

1 splitter_url=http://$HOST:8003/Main_splitter/split
2
3
4 # Body: descriptor contains NSD, vnfid_set contains set of VNF ids
5 nsd = { 'descriptor' : descriptor , 'sets': vnfid_set}
6
7 LOG.info("Calling Scramble Splitter..." )
8 response = requests.post(splitter_url ,
9                           data=json.dumps(nsd_to_split))
10
11 print(response)

```

Listing 4.1: POST call to SDS

Following are some of the important functions which helps SDS in splitting the NSD with respective code snippet.

### Basic Python classes for NSD Schema

#### Splitting

"splitsonata" calls the splitting function one by one to split the list of objects created out of NSD. Following code snippet shows the sequence of function calls.

```

1
2 def split_sonata(self):
3     if self.validate() is not False:
4         self.create_new_function_sets()
5         self.set_connection_point_refs_for_virtual_functions()
6         self.split_network_function()
7         self.set_connection_points()
8         self.split_virtual_links()
9         self.split_forwarding_path()
10        self.set_general_information()
11        return self.create_files()
12    else:
13        print("Validation Failed!!")

```

Listing 4.2: Sequence of function calls

#### Validate

Validate method validates the request coming from the MANOs. For example, if MANO is requesting a NSD to be split into three parts but the original NSD contains just two VNFs then the SDS will throw validation error.

```

1
2 def validate(self):
3     size = 0
4     list_network_function = []
5     for network_function_set in self.network_function_sets:
6         size = size + len(network_function_set)
7         for network_function in network_function_set:
8             list_network_function.append(network_function)
9

```

```

10         if size != len(self.utilityFunctions.list_nf):
11             return False
12         if len(list_network_function) != len(set(list_network_function)):
13             return False

```

Listing 4.3: Splitting Request Validation

### Split Network Functions

Content to be added

### Split Forwarding Graph

Content to be added

### 4.2.3 Challenges

The NSD schema of Pishahang and OSM contains a lot of elements. However the challenge we faced was choosing which elements to include for splitting. We tackled it by including mandatory elements and few optional elements from the schema which were present in the input NSD.

### 4.2.4 Future scope of Service Descriptor Splitter

SDS can currently split NSD of Pishahang and OSM. SDS is built in such a way that it can be implemented for MANO frameworks as well. To implement SDS for a new MANO framework one can refer the implementation of either Pishahang or OSM. First step would be to create basic python classes from the NSD schema of the MANO framework then writing the utility functions to pull the information from the NSD file and store it in the objects of the basic python classes. Lastly writing splitting functions to actually split the list of objects in two or more parts.

Also, the current implementation considers all mandatory elements and a few optional elements from a NSD schema for splitting which can be extended to include other fields (Provided they are present in the input NSD for splitting).

Current implementation of SDS can split a forwarding graph of a NSD (Pishahang) with just three VNFs. Splitting of a forwarding graph is implemented by keeping future implementation for more than three VNFs in mind (Refer Splitting of Forwarding graph section)

### 4.3 Adaptor

Facilitating easy communication between MANOs is an important aspect of scramble. Adaptor is a component that enables communication between MANOs by wrapping the REST APIs of MANOs in python code.

Python MANO Wrappers (PMW) is a uniform python wrapper library for various implementations of NFV Management and Network Orchestration (MANO) REST APIs. PMW is intended to ease the communication between python and MANO by providing a unified, convenient and standards oriented access to MANO API.

To achieve this, PMW follows the conventions from the ETSI GS NFV-SOL 005 (SOL005) RESTful protocols specification. This makes it easy to follow and the developers can use similar processes when communicating with a variety of MANO implementations.

PMW is easy to install, use and well documented. Code usage examples are available along with the detailed documentation at the following link <https://python-mano-wrappers.readthedocs.io/en/adaptor/>.

PMW is planned and released as an independent library. In scramble, PWM helps in inter communication of different instances of MANO, thereby creating opportunity for more advanced feature set, for example, hierarchical scaling. Operations such as on-boarding of NSD and VNFD, instantiation and termination of NS can be performed with ease.

#### 4.3.1 Architecture & Work flow

Standards based approach is a fundamental design principle behind PMW's design. A Common interface template is defined in compliance with SOL005 which contains the blueprint for all the methods mentioned in the standards. These methods are divided into different sections as per SOL005 into the following:

- **auth:** Authorization API
- **nsd:** NSD Management API
- **nsfm:** NS Fault Management API
- **nsbcm:** Lifecycle Management API
- **nspm:** NS Performance Management API
- **vnfpkgm:** VNF Package Management API

In the figure 4.2, different sections of PMW are visualized. As part of the scramble project, support for Open Source MANO (OSM) and Sonata was implemented based on the common interface. This is represented by the dotted lines to OSM and Sonata modules. These modules are based on the common interface and implement the methods it has defined. Wrappers also support additional functionalities of Pishahang, which is an extension of Sonata.

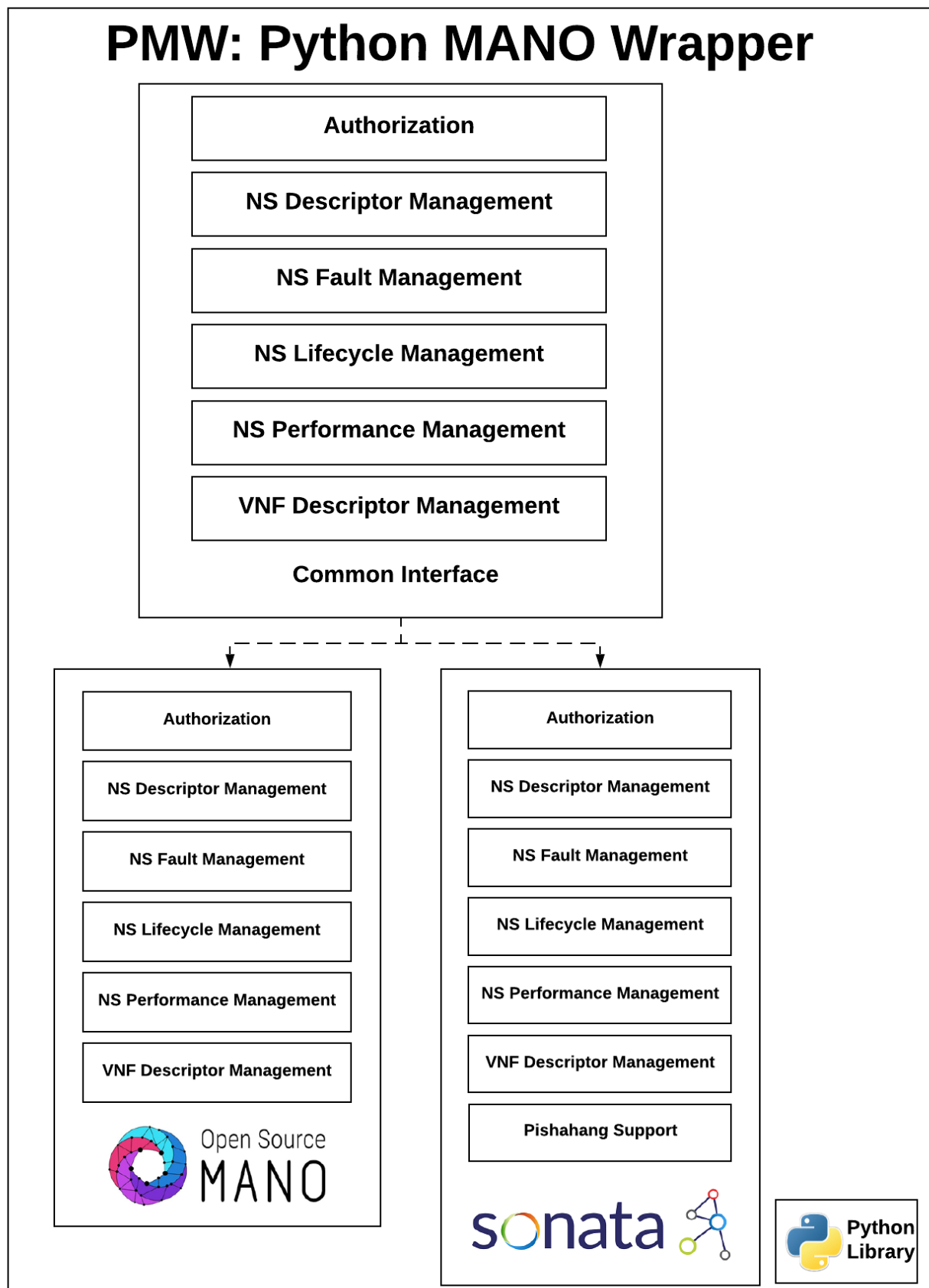


Figure 4.2: PWM Common interfaces

### 4.3.2 Installation and usage

PWM can be installed using pip by using this command `pip install python-mano-wrappers`.

A simple script to get started with PWM is shown in the Listing 4.4, here, the wrappers are imported and a client object is created according to the MANO type. Currently supported are OSM and Sonata. Such a client object can be used to make REST calls relevant to the MANO type. An example usage to retrieve all the network service descriptors of OSM can be seen from the listing 4.5, here, the OSMClient module is used to first fetch an auth token and further using the auth token to fetch the relevant information, in this case NSD descriptors.

```

1 import wrappers
2
3 username = "admin"
4 password = "admin"
5 mano = "osm"
6 # mano = "sonata"
7 host = "osmmanodemo.com"
8
9 if mano == "osm":
10     _client = wrappers.OSMClient.Auth(host)
11 elif mano == "sonata":
12     _client = wrappers.SONATAClient.Auth(host)
13
14 response = _client.auth(
15     username=username, password=password)
16
17 print(response)

```

Listing 4.4: Simple wrapper code to fetch token

```

1 import wrappers
2
3 osm_nsd = wrappers.OSMClient.Nsd(HOST_URL)
4 osm_auth = wrappers.OSMClient.Auth(HOST_URL)
5
6 _token = json.loads(osm_auth.auth(
7     username=USERNAME,
8     password=PASSWORD))
9
10 _token = json.loads(_token["data"])
11
12 response = json.loads(osm_nsd.get_ns_descriptors(
13     token=_token["id"]))
14 response = json.loads(response["data"])

```

Listing 4.5: Code to fetch all NSDs in OSM

### 4.3.3 Challenges

Implementing such a python wrapper for a REST API is straight forward from the implementation perspective. However, the challenges that we faced are when identifying the required functional documentation from the respective MANOs. OSM and Sonata do not yet fully support the ETSI suggested endpoints and this combined with the lack of unified documentation, made it difficult in the beginning to decide on the scope of supported functionalities.



#### **4.3.4 Future scope of wrappers**

PWM is built with easy maintainability and feature addition in mind. PWM makes it easy to add support for other MANOs. We expect MANO developers to use the common interface that we have suggested to add support to their REST APIs in python.

## Goals and Use Cases

In this chapter, the intended goals of the project and some use cases are being discussed.

### 5.1 Goals

The goal of the project is to develop a software suite which facilitates inter-operability between MANO frameworks, thereby enabling the management of a network service across a multi-vendor environment. To achieve this, the software suite is divided into 3 individual work packages (WPs), which are initially developed in parallel and are merged later. In the following sections, the individual goals of these work packages are explained in detail.

#### 5.1.1 Service Descriptor Translator (SDT)

In this work package, a translator engine for a NSD is implemented. The Network Function Virtualization Orchestrator (NFVO) is the main orchestration unit of a MANO framework that manages the lifecycle of a network service. One of the main functions of a NFVO is registering a network service, by on-boarding it's NSD to the network service catalog. In a scenario where a network service is to be deployed among two different MANO frameworks, having their own respective NSD schema, SDT engine would help in translating a NSD schema from one MANO framework to the other framework.

#### 5.1.2 Service Descriptor Splitter (SDS)

In the production environment, a network service is deployed over a vast geographical region spanning multiple domains. In such scenarios, there is a need to split a network service into smaller network services and deploy it over multiple domains. In this work package, a Service Descriptor Splitter (SDS) is implemented which splits the NSD of a network service. SDS takes NSD as an input that contains all the information elements which can be extracted to generate separate NSDs. In the proposed approach, the service graph is extracted from the input NSD and is split into subgraphs that result in a separate NSD which includes a set of elements such as VNFs, Virtual Links (VLs), forwarding graphs of VNFs etc, according to the specific MANO framework.

#### 5.1.3 MANO Adaptor (MA)

A key component of a MANO framework is Virtualized Infrastructure Manager (VIM), which helps in assigning the hardware resources to virtual resources. The MANO framework has specific adaptors

to communicate with their respective VIMs. For instance, Sonata (2.1.1) MANO framework has adaptors for OpenStack (2.2.1) and Kubernetes (2.2.2). However, when there is a spike in the service request beyond the capabilities of a single MANO instance, multiple MANO instances should be instantiated to balance the load. The goal of this work package is to build an adaptor that facilitates interaction between different instances of MANO frameworks, thereby exposing the underlying MANO framework's interfaces and enabling monitoring of the underlying service states.

Apart from the implementation of MA, the plan is to investigate MANO scalability challenges

## 5.2 Use Cases

### 5.2.1 Cross-MANO Framework Interaction

The MANO frameworks used by every network service provider varies from one another. The software suite with the help of SDT and SDS enables the deployment of network services across different frameworks.

For instance: Consider two network service Operators using different MANO frameworks. One of them uses Sonata framework [DKP<sup>+</sup>17] and another operator uses OSM framework [Ers13]. These frameworks have different NSD schemata(refer 2.1.1 and 2.1.2). NSD schemata contain VNFs, virtual links, and VNF forwarding graphs and also describes the deployment of a network service. By using a translator and splitter, these NSD schemata can be translated and split into a framework-specific schema. With this, operators can deploy and manage network services across different MANO implementations.

### 5.2.2 Hierarchical Orchestration

By using MA, dynamic instantiation of multiple MANO instances and inter-operability between different MANO frameworks can be achieved. The operator will be able to handle the resources in an efficient manner, as one MANO framework can manage a limited number of service requests, operators can explore options to include additional MANO instances under the existing MANO instance to mitigate the traffic load on a single instance. The resources can be provisioned based on the number of requests. This helps the operator in extending their profitability.

**Actors :** The Network Service Providers who would use features of SCrAMbLE.

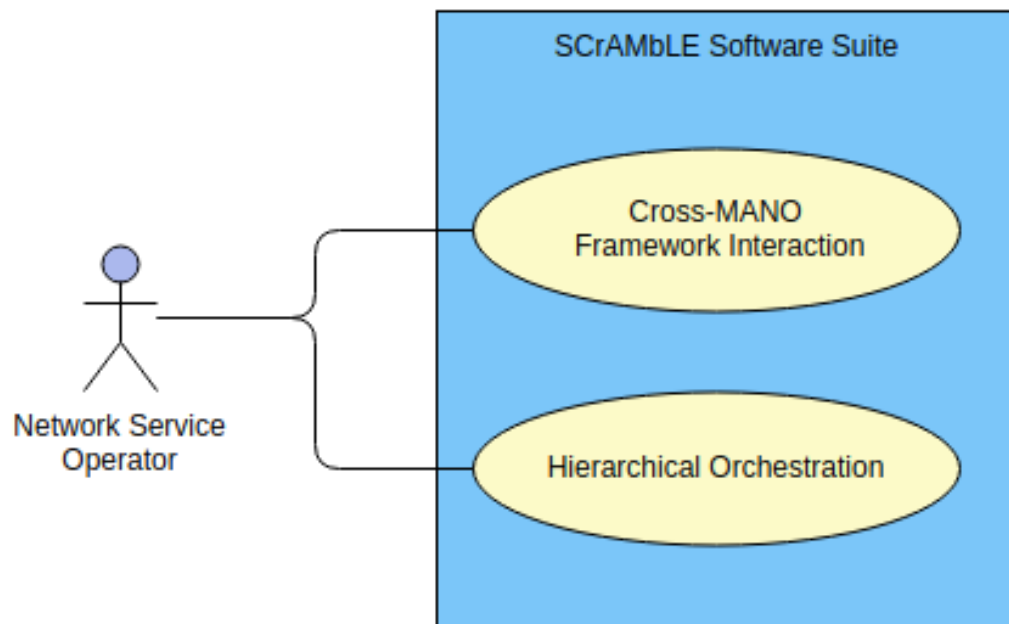


Figure 5.1: Use Case Diagram

## MANO Scalability

In this chapter we discuss the two directions we explored to investigate MANO orchestrator scalability. First, we discuss the scalability plugin that was added to pishahang. The scalability plugin adds 3 main functionalities to pishahang, 1) spawn new child instances of pishahang by allocating new physical resources, 2) Redirecting requests from parent MANO to the child instances and 3) managing the state of child instances. Second, we discuss the experiments conducted on OSM and Pishahang to understand the resource utilization. We also propose a more generic framework to characterize and analyze MANO under load.

### 6.1 Introduction

Add content

#### 6.1.1 Definition of scaling

‘Scalability’ is defined in different ways in various academic work. Some of the definitions are listed below.

- "The ability of a particular system to fit a problem as the scope of that problem increases (number of elements or objects, growing volumes of work and/or being susceptible to enlargement)." [?]
- "Scalability of service is a desirable property of a service which provides an ability to handle growing amounts of service loads without suffering significant degradation in relevant quality attributes. The scalability enhanced by scalability assuring schemes such as adding various resources should be proportional to the cost to apply the schemes." [?]
- "Scalability is the ability of an application to be scaled up to meet demand through replication and distribution of requests across a pool or farm of servers." [?]
- "A system is said to be scalable if it can handle the addition of users and resources without suffering a noticeable loss of performance or increase in administrative complexity" [?]

#### 6.1.2 Why does a MANO need scaling?

In recent years, distributed systems have gained an increase in the number of users and resources. Scaling such a system is an important aspect when large user requests have to be served without

compromising system performance or increase in administrative complexity. In terms of MANO, when there are a large number Network Service(NS) instantiation of various network functions, they need to be instantiated considering all the relevant metrics of the system.

**System load:** In a distributed system, the system load is the large amount of data that is to be managed by network services increasing the total number of requests for service. The load on a MANO can be defined in terms of it's load on NFV Orchestrator (NFVO) to process large number of tasks like on-boarding, instantiation and monitoring of VNFs. The NFVO of a MANO receives monitoring information which also increases the load on NFVO triggering it to scale the network service across multiple MANOs in a distributed system [?].

**Lifecycle Management & service provisioning:** To provision a network service, the NFVO of a MANO's functionality include instantiation, global resource management scaling in/out , event correlation and termination of services. These functionalities form the lifecycle of NS. With the increase in instantiation of NS over a distributed network, the lifecycle management of each service is a overhead, hence increasing the provision time. This can be better handled when the MANO can be scaled out. To manage services with a closer proximity of geographical region, MANOs could be scaled in.

## 6.2 Scalability Plugin

MANO framework faces scalability challenges in large-scale deployments. The amount of infrastructure a single instance of MANO framework can manage is limited. The scaling of MANO should be addressed to avoid it from being the bottleneck in the NFV paradigm.

We propose a hierarchical scaling mechanism for MANO by implementing and evaluating a scalability plugin (SPL) in pishahang. SPL adds the following features to pishahang 1) Spawn/Terminate child MANO instances, 2) State management between instances, 3) Redirection of requests from parent instance to child instances and 4) Monitoring of system load on all instances

### 6.2.1 Architecture

SPL is built based on the "base plugin framework" of SONATA. The figure 6.1 from SONATA documentation shows the high-level architecture of the SONATA MANO framework. The plugins communicate over the message broker using AMQP with other plugins and together facilitate the functions of MANO.

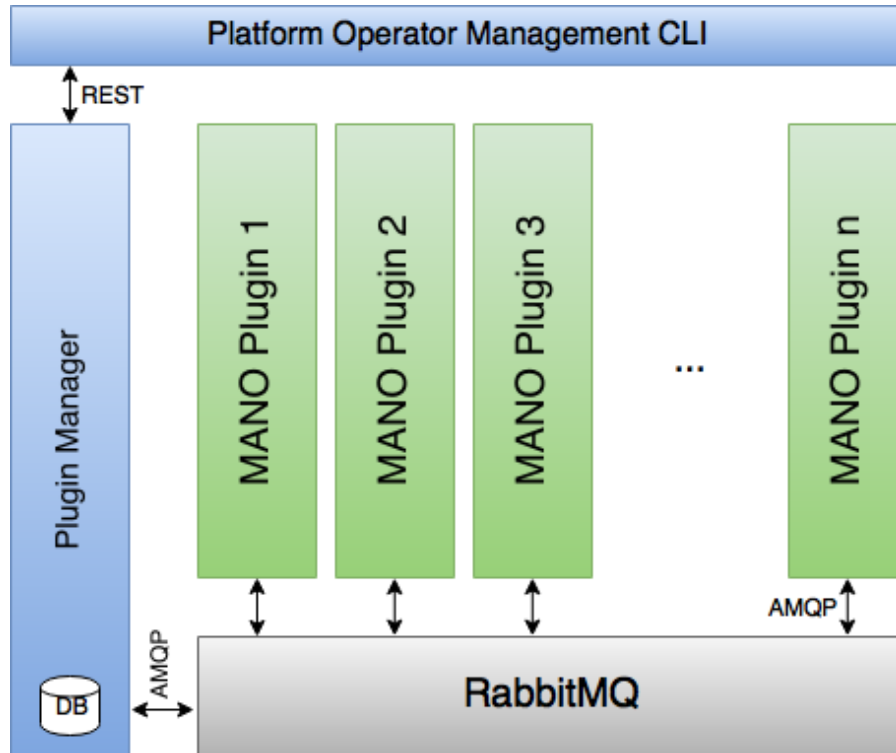


Figure 6.1: SONATA MANO plugin architecture

The architecture of the scalability plugin is shown in the figure 6.2. SPL mainly consists of 1) **Scaling Manager:** is responsible for the overall workflow of the SPL, which includes monitoring, spawning, termination and state management of MANO instances. 2) **MANO Manager:** is responsible for sending the on-boarding and instantiation requests to the parent MANO using python-mano-wrappers. SPL co-ordinates with the service lifecycle management plugin in pishahang to provide the features discussed above. The workflow of this is discussed in the further sections.

## Scaling Manager

Features of the scaling manager are discussed briefly in this section.

### Monitoring

SPL needs to continuously monitor the system resource utilization and take scaling decisions based on that. We are using the *average system load* values given by the linux kernel for taking the scaling decisions. System load is the number of processes which are being executed by the CPU or in waiting state. The linux kernel provides 3 average values of system load calculated over a period of 1, 5 and 15 minutes.

As a proof of concept, SPL uses *5m* and *15m* moving averages as a heuristic for scaling decisions. *1m* average is not considered to avoid taking decisions on a short lived spike in system load. SPL has the following simple rule set listed below, note that the configurable threshold value is used to take relevant actions. For simplicity, we consider "0.7" as the threshold value as it is generally used in the wild by system administrators.

- **Rule 1**

If *5m* load average is more than the *threshold* value, then, SPL will consider this as a warning sign and start preparing a child MANO instance.

- **Rule 2**

If *15m* load average is more than the *threshold* value, then, SPL will consider this as a critical sign and start redirecting service requests on the parent mano to the child MANO instance.

- **Rule 3**

If *15m* load average of both the parent and child instances are less than the *threshold* value, then, SPL will consider this as decreasing load and terminate the child MANO instance.

List 6.1: Scaling Plugin Rules

### SLM Communication

The monitoring of the load information happens in the SPL, however, the service requests are handled by the SLM plugin. SLP communicates information about the current load of the instances to the SLM and based on this response, SLM decides whether to continue serving the request or to forward it to one of the child MANOs.

The forwarding logic is implemented on the SLM plugin of pishahang. The forwarding logic includes on-boarding the VNFD/NSD and instantiating it.

### Spawning

Spawning refers to the action of instantiating a child instance of pishahang by allocating new physical resources on existing infrastructure. According to Rule 1 from 6.1, when the threshold is reached, a request to instantiate a new instance is sent to the Mano Manager. Mano Manager will instantiate a new instance of pishahang and returns the IP address of the newly deployed instance. This new instance is now added to the list of child MANO instances and continuously monitored.



**Termination**

Once the load on the parent MANO and child MANO instances are reducing, it becomes unnecessary and expensive to use the allocated physical resources of the child MANO. According to Rule 3 from 6.1, the termination request of the child MANO is sent to the MANO Manager and the metadata generated by the child instances are saved on the parent instance. Metadata that is saved includes the VNF records and network service records.

**MANO Manager**

MANO Manager is responsible for the end communication with the parent MANO. MANO Manager receives an instantiation request from the Scaling Manager and uses python-mano-wrappers to make an instantiation request to the parent MANO to instantiate a child MANO instance.

MANO Manager will wait for successful instantiation of the instance and return the IP address of the instance to the Scaling Manager.

**Service Descriptors**

We designed a basic function descriptor and service descriptor in the schema supported by the pishahang MANO framework. The descriptors are stored as part of the scaling plugin and used by the MANO Manager to on-board and instantiate upon request. We have created the descriptors for both OSM and Pishahang.

**MANO Image**

A Virtual Machine (VM) image with MANO pre-installed is used along with the service descriptors to spawn new instances of MANO. As a proof of concept, we have created images with OSM and pishahang. However, the pishahang image that was created was unstable and has unexpected behavior. These images are first created locally and later uploaded to the VIM where the instances will be created. In our tests we used OpenStack as the VIM.

**6.2.2 Workflow****SLM with SLP**

The workflow of how the SLM and SLP interacts is shown in the figure 6.3. At first, an instantiation request comes into the parent mano instance and this is first seen at SLM. SLM will then request SLP for the current system load status. If the parent MANO is loaded, SLP will reply with the details of the child MANO instance, which will then be used by SLM to redirect the incoming request by on-boarding and instantiating the network service on the child instance. If the parent MANO is not loaded, then, SLM will continue its normal flow to deploy the network service

**Scaling Plugin Workflow**

In the figure 6.4, we visualize the rules set of SLP from the List 6.1. SLP is always in the monitoring loop and takes actions according to the system load and the rules set.

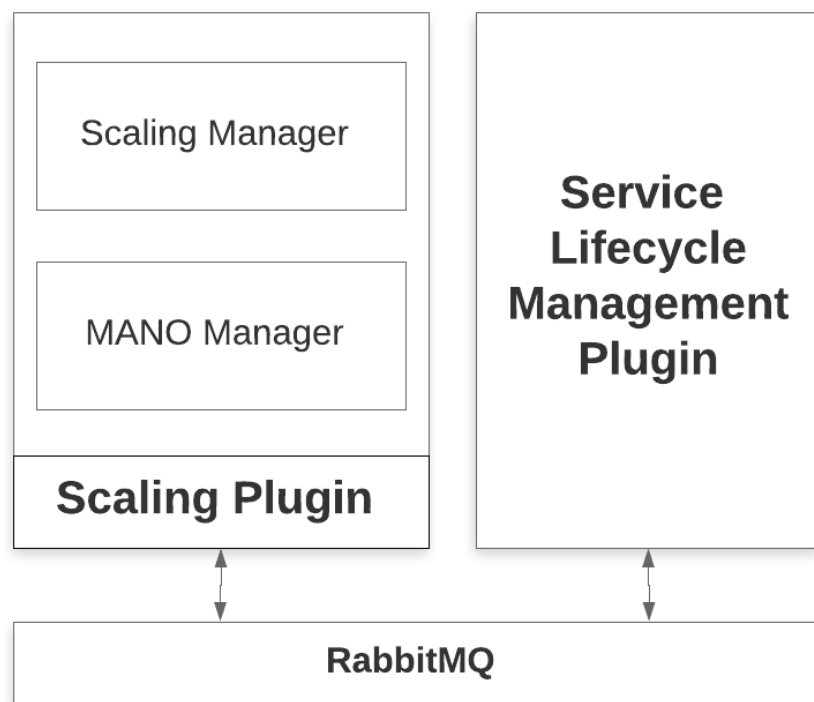


Figure 6.2: Scaling plugin architecture

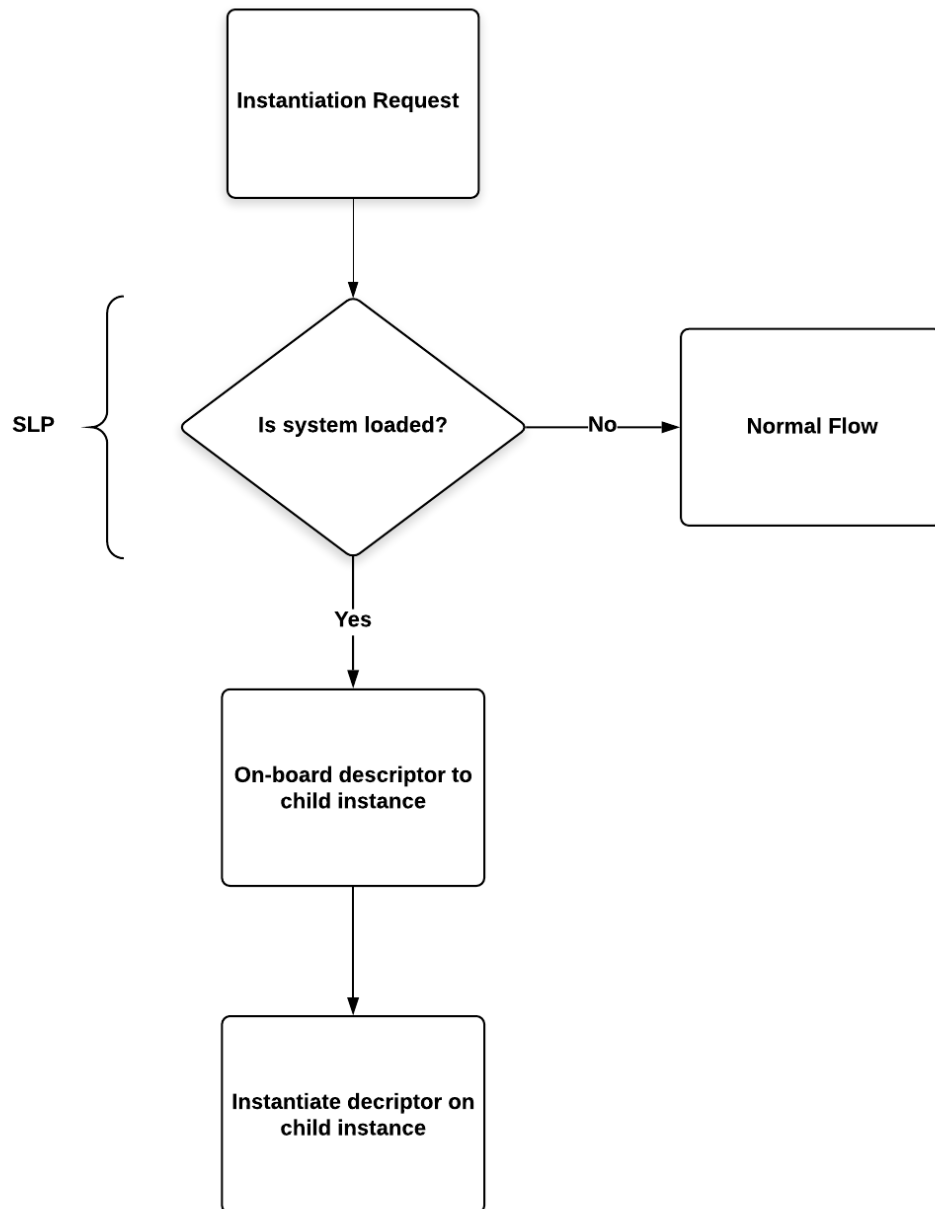


Figure 6.3: Service Lifecycle Manager with Scaling Plugin Workflow

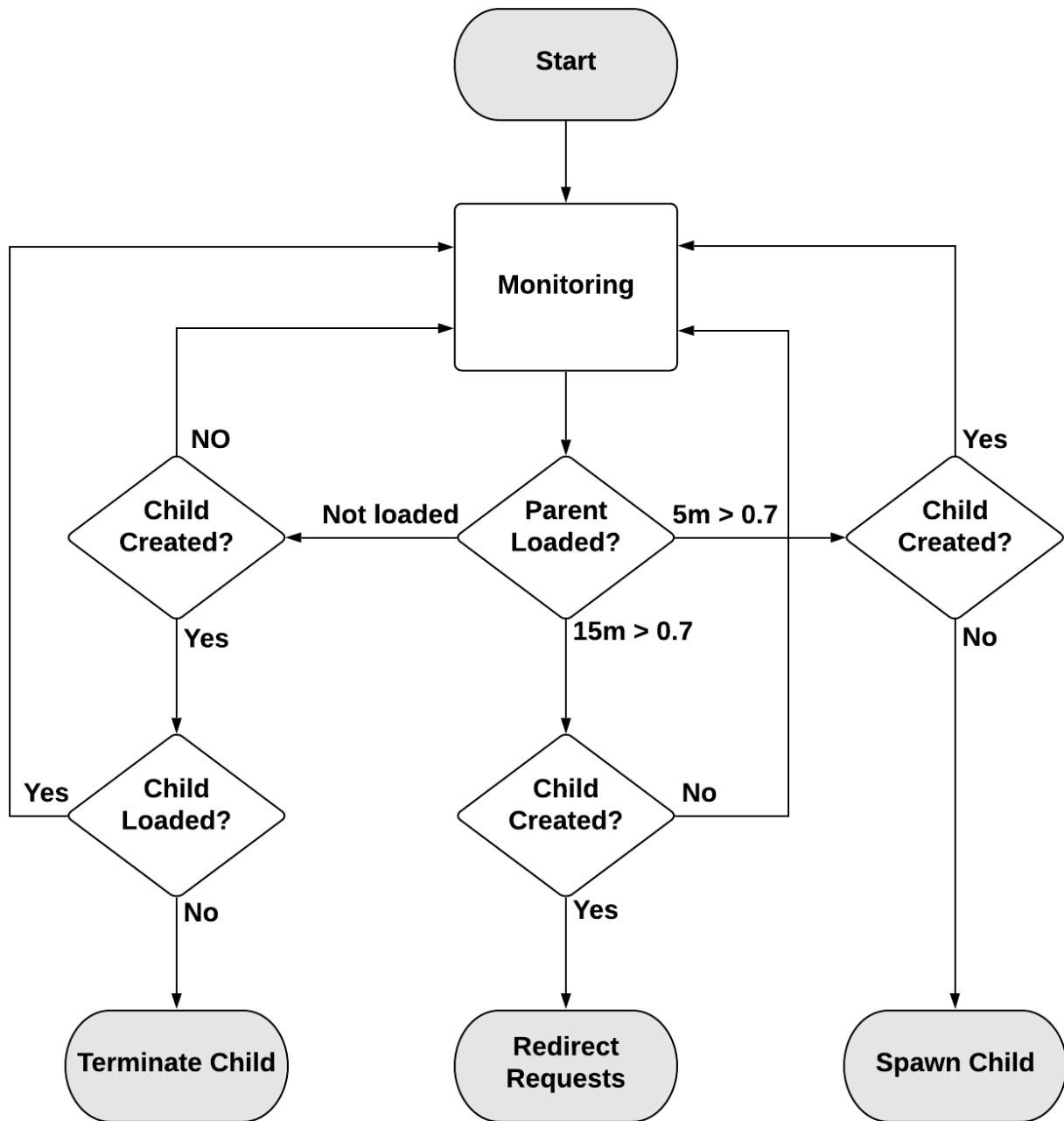


Figure 6.4: Scaling Plugin Workflow

## 6.3 Experiments

One other task under the MANO scalability investigation was to observe the resource utilization in OSM and Pishahang. To do this we used our own python-mano wrappers to instantiate multiple requests at a time. The next step was to decide on the number of service requests to instantiate. We could simply instantiate any number (like 1,000 or 5000) of service requests but we had to make sure all those requests get successfully instantiated. For this, the infrastructure was the only crucial factor. We used a 16 core virtual machine for

### 6.3.1 Testbed

Explain about the machine configuration used to run the experiments, what OS, how many servers and what VIMs where installed, what is the configuration and how python-mano-wrappers were used to send the requests.

Basically explain the whole experiment setup that was used to conduct the experiment.

### 6.3.2 OSM Results

The 6.5, 6.6 and 6.7 shows the CPU utilization, memory utilization and CPU utilization through the life cycle of the experiment respectively. Let us consider the important dockers in each case and list their functionalities to realize why they have consumed maximum CPU.

#### CPU utilization

The 6.5 shows CPU utilization. The first 5 OSM dockers are:

- **osm\_ro**: This is the Resource Orchestrator for OSM. The resource orchestrator is responsible for co-ordinating resource allocation across multiple geo-distributed VIM types. It is responsible in processing the resource-allocation requirements of the VNF as per parts of the VNFD and driving the VIM to allocate appropriate compute, network, and storage resources for the deployment of VNFs with their interconnection.
- **osm\_lcm**: This is the Life Cycle Management module for OSM. This docker is responsible for set of operations related to the life cycle of a VNF and NS
  - *NS LCM operations*: 1) On-board Network Service 2) Instantiate Network Service 3) Scale Network Service 4) Update Network Service by supporting Network Service configuration changes Create, delete, query, and update of VNFFGs associated to a Network Service. 5) Terminate Network Services
  - *VNF LCM operations*: 1) Instantiate VNF (create a VNF using the VNF on-boarding artefacts) 2) Scale VNF (increase or reduce the capacity of the VNF). 3) Update and/or Upgrade VNF (support VNF software and/or configuration changes of various complexity). 4) Terminate VNF (release VNF-associated NFVI resources and return it to NFVI resource pool)
- **osm\_mon**: This is the monitoring module for OSM. The main task of this docker is to retrieve metrics from VIM. It keeps polling VIM every 30 seconds.
- **osm\_ro\_db**: This is called RO database module. RO module in OSM maintains its own database called ro-db. (RO module is usually edited to enable or disable this particular module) This module takes care of database related operations. According to the osm/ro.git, ro-db stores different IDs like vnfd id, osm id, tenant id, vim id etc. There is something called scenario. ro db stores these scenarios and scenario ID and then a scenario gets executed when the scenario id matches with the right tenant id, osm id and vnfd id. It stores vim actions, vim actions and they are processed sequentially.
- **osm\_nbi**: North Bound Interface of OSM. Restful server that follows ETSI SOL005 interface. It is the unique entry point for all the interactions with the OSS/UI system. This serves as the interface for MANO operations. (OSM's NBI offers all the necessary abstractions to allow clients for the complete control, operation and supervision of the NS.)

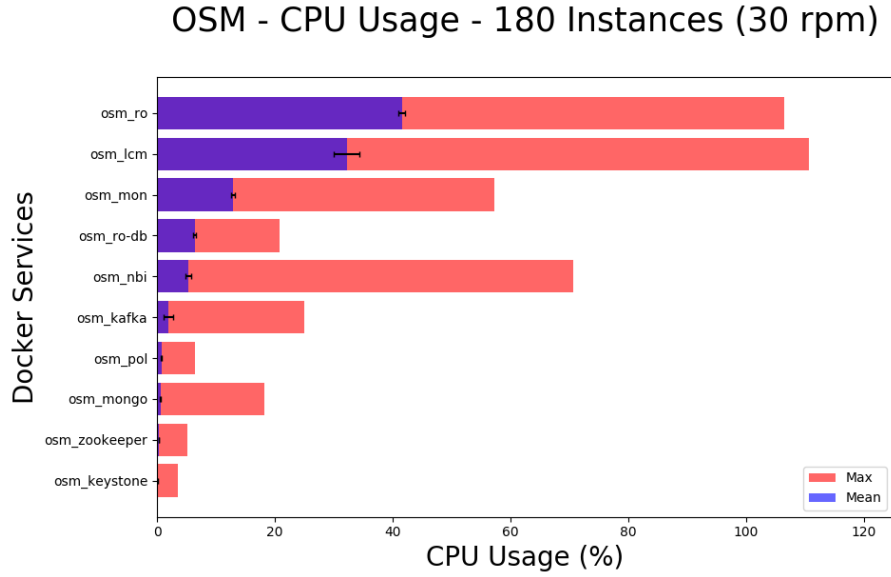


Figure 6.5: OSM CPU

### Memory Utilization

The first 5 OSM dockers in memory utilization graph are:

- **osm\_mongo:** This is a common non relational database for OSM modules.
- **osm\_kafka:** This module provides a Kafka bus used for OSM communication.
- **osm\_nbi:** This is the north bound interface for OSM module. The functionalities of this module remains the same(as explained in the previous subsection)
- **osm\_light-ui:** This docker is an implementation of a web GUI to interact with the North-bound API. (The framework allows editing, validating, visualizing the descriptors of services and components both textually and graphically)
- **osm\_ro\_db:** This is the RO database. The functionalities of this module remains the same (as explained in the previous subsection)

### Lifecycle

We now have the life cycle graphs of the entire experiment. This shows the distribution of the CPU usage among the top 3 dockers throughout the experiment. The experiment lasted for about 10 minutes.

We can observe that the ro module of OSM got continuous requests over the time and at the end all the termination requests came at once. Also LCM , mon modules continously processed the requests. mon module retrieved metric information continuously and the same trend remains throughout the experiment.

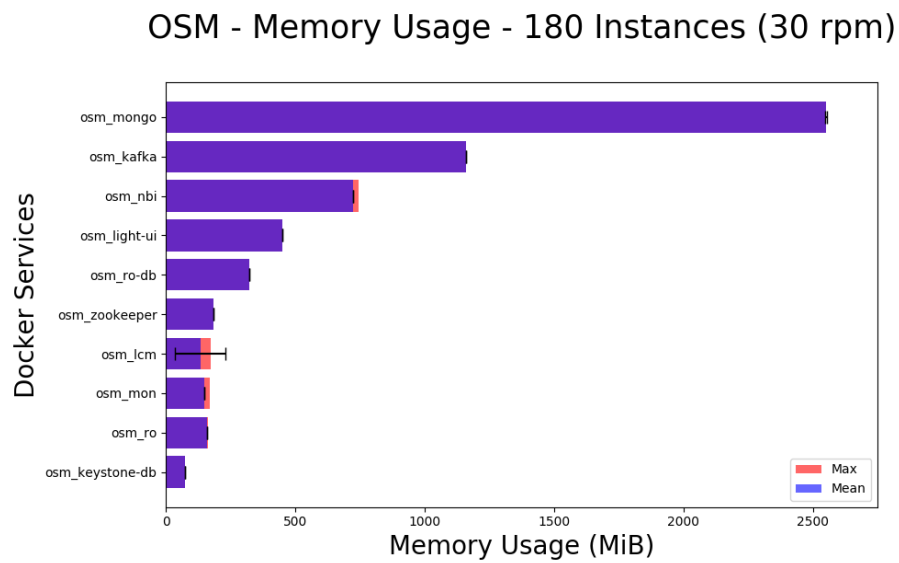


Figure 6.6: OSM MEM

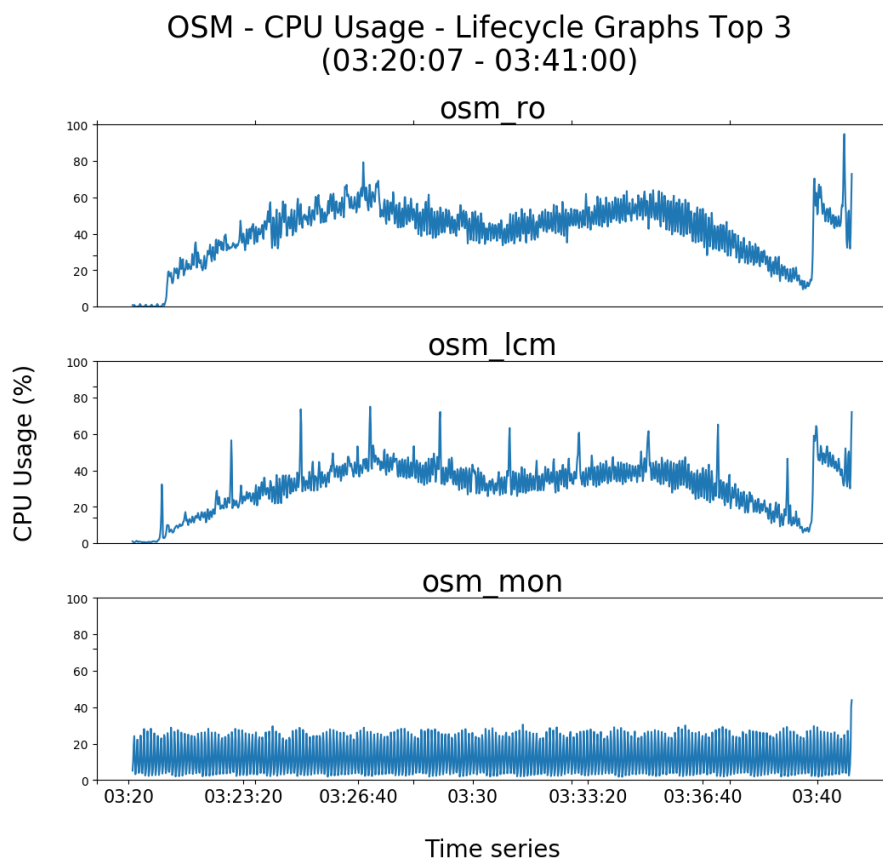


Figure 6.7: OSM LS



### 6.3.3 Pishahang Results

Pishahang Just like you did in the presentation, explain the functionalities of the top 5 dockers and why they are taking

#### CPU

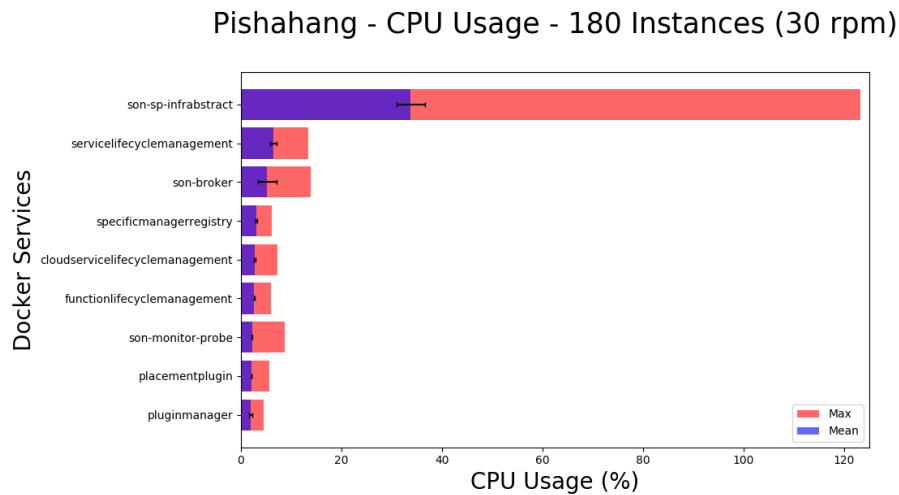


Figure 6.8: Pishahang CPU

#### Memory

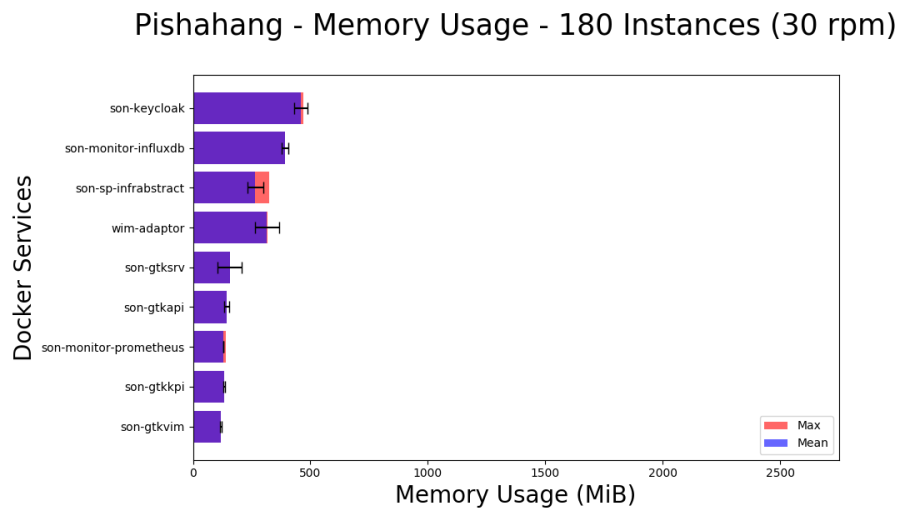


Figure 6.9: Pishahang MEM

#### Lifecycle

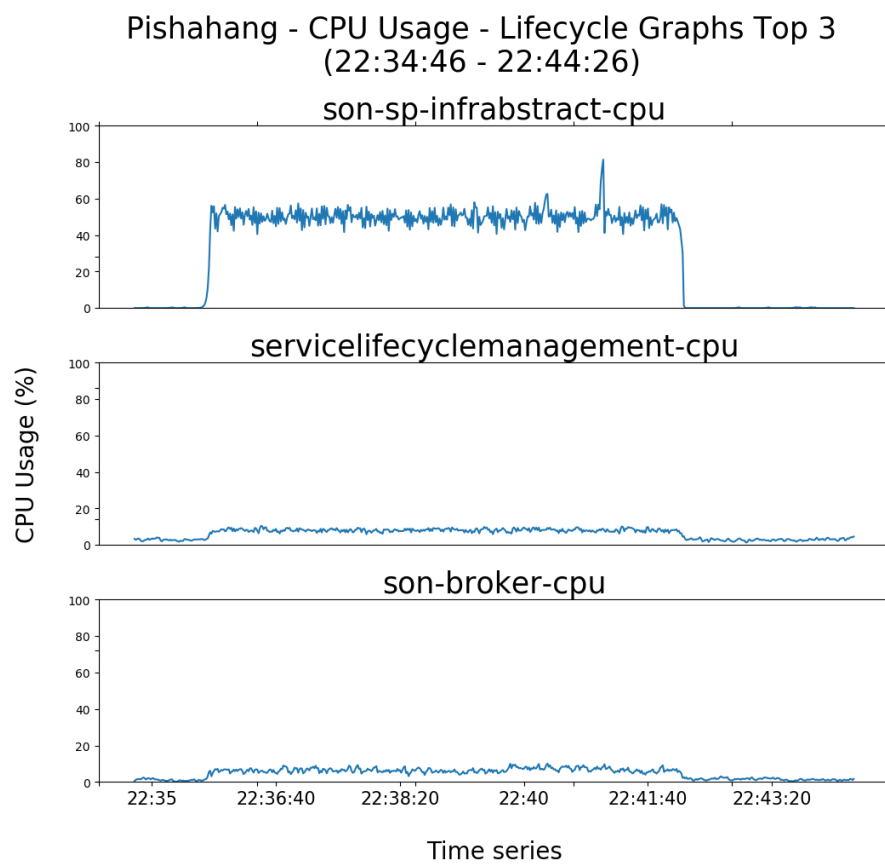


Figure 6.10: Pish LS

### 6.3.4 Summary of issues of the experiment

Blockers: VIM support issues, openstack not stable, k8 not supported in OSM. Why 180. RPM issues

### 6.3.5 Inference from the experiment

about identifying the top dockers, some more info about the lifecycle graphs

## 6.4 MANO Benchmarking Framework

### 6.4.1 Introduction

MANO Benchmarking Framework (MBF) is a result of a small script that was used to run the experiments discussed in the previous sections. The idea of MBF is to provide MANO developers with a generic framework for running experiments on MANO. MBF mainly provides the following 1) Easy interfacing with MANO instances by using python-mano-wrappers, 2) Ability to run experiments with different service descriptors, 3) Collection of performance metrics in convenient data format and 4) Flexible graphing mechanism of the collected data.

### 6.4.2 Design

MBF is designed for ease of use and low barrier to entry for developers. We explain the choice of tools that are used in MBF in the following list.

- **Netdata**<sup>1</sup> is the metrics monitoring system for MBF. Netdata captures relevant system metrics and provide powerful APIs to query the recorded data in a suitable format.
- **Python** as the choice of scripting language was obvious as the MANOs itself are implemented in python.
- **python-mano-wrappers** is used to provide access to REST APIs of MANOs from python.
- **Docker** is used to containerize MBF, thus making it easy to distribute and portable.
- **Matplotlib** is the graphing library for MBF due to its flexibility and ease of use.
- **Flask** as a python server that can be used to provide additional interactions with the experiment runner.

### 6.4.3 Parameters and KPIs

#### Parameters

MBF has experiment parameters that can be altered. The following parameters are supported

- **Descriptors** NSDs and VNFDs can be changed. a list of NSDs/VNFDs is also supported. When a list of descriptors are provided, the experiment will be run for each of the descriptors.
- **Number of instances** Total number of instantiation requests to be sent to the MANO.
- **Number of runs** number of re-runs of the same experiment to be run. This is performed to measure the variance in results.
- **Requests per minute (RPM)** The rate at which the instantiation requests are sent to the MANO
- **Observation Time** The observation time after the instantiation requests are sent. This can be used to collect metrics post instantiation to observe how MANO behaves in the monitoring phase.
- **Inter-experiment Delay** is the time between experiment runs. This is altered to give enough time for the VIM to terminate and cleanup instances from the previous experiment runs if any.

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<sup>1</sup><https://github.com/netdata/netdata>

- **Skip experiment on error** if set to true, the current run is skipped due to a failed instance on the VIM.

#### 6.4.4 Key Performance Indicators

MBF stores resource utilization metrics during the experiment and generates graphs to visualize the results. However, these are only examples and the further possibilities are supported by the framework. The metrics are stored as CSV files.

- **CPU** Overall system CPU usage is recorded as well as the individual docker micro service CPU usage metrics are stored.
- **Memory** Overall system memory usage along with the individual docker micro service memory usage is stored.
- **System Load** The 1m, 5m and 15m moving averages of system load values provided by the linux kernel is stored.
- **Status Tracking** The status of all instances are stored by polling the VIM every 5 seconds over the experiment lifetime. This enables to track the status change over time.
- **End-to-end Deployment Time** is the time elapsed to deploy all the instances on the VIM.
- **Individual Deployment Time** is the time taken by each instance for deployment. This is also split into time taken by MANO and VIM.

#### 6.4.5 Steps for experiment run

The steps to run a basic experiment is detailed in this section. The following instruction is to run an experiment with 90 instances on OSM using an network service with 1 VNF.

1. Git clone the experiments-branch<sup>2</sup>
2. Build and start the docker container
3. Change experiment variables in the relevant scripts for respective MANOs
  - **OSM** – *run-experiment-osm.py*
  - **Sonata (Pishahang)** – *run-experiment-sonata.py*
  - **Sonata Container Orchestration (Pishahang)** – *run-experiment-sonata-k8*
4. Run the relevant script from inside the container. The experiment will now run and stores result files in the same directory
5. Use the result parser from the `experiments/results/csv-result-parser.py` to parse the results and store it in a format suitable for graphing
6. Use the graph plotter on the parsed files to generate the graphs  
`experiments/results/plot-graphs.py`

The commands required to run these are listed in the readme file here,  
<https://github.com/CN-UPB/MANO-Benchmarking-Framework/blob/master/README.md>

**Note:** *This process is being streamlined to reduce some redundant steps and will be released in the next version of MBF.*

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<sup>2</sup><https://github.com/CN-UPB/MANO-Benchmarking-Framework>

### 6.4.6 Example Use Cases

In this section we demonstrate a few use cases of MBF. The framework facilitated easy experimentation, collection and analysis of metrics in the following cases. However, in-depth analysis of what the metrics and graphs mean are out of scope of this document.

#### Comparison of different network services

We compared the performance metrics of different NSDs/VNFDs and visualized it. For this, we provided 6 different network service descriptors to the experiment runner. First 3 NS consisted of a cirros image as a VNF with 1, 3 and 5 VNFs per NSD and the other 3 NS consisted of an ubuntu image as a VNF with 1, 3 and 5 VNFs per NSD.

The experiment stores the KPIs listed in the previous section, along with the graphs visualizing the differences. This graph is produced for each micro-service showing the resource utilization of each NS under different number of instantiations. As an example, the figures 6.11 and 6.12 show the CPU utilization of the OSM microservice LCM and RO respectively.

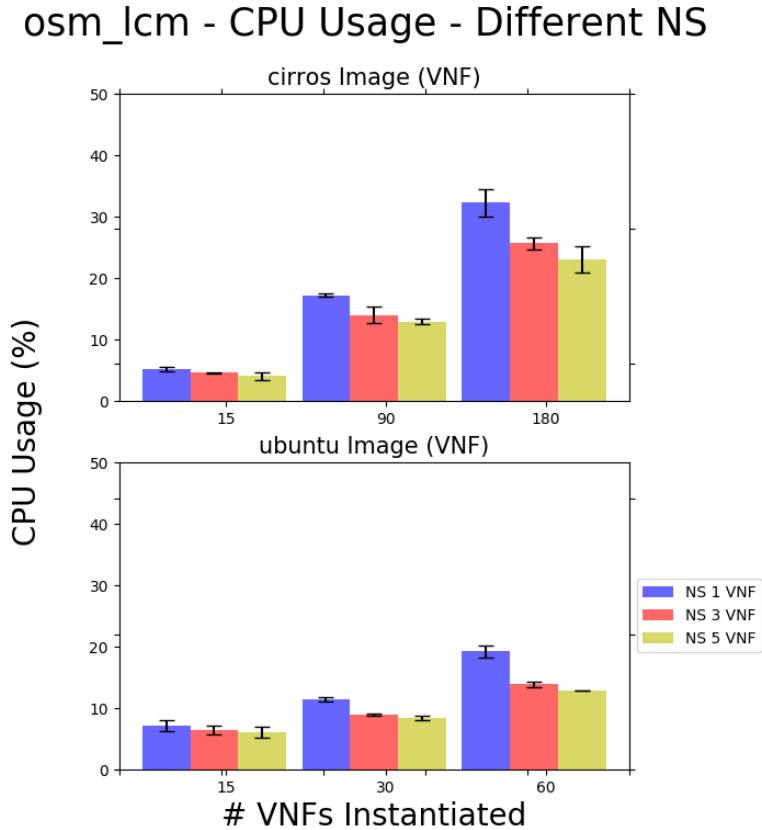


Figure 6.11: CPU usage of OSM microservice LCM

#### Container vs VM Orchestration

Pishahang supports container orchestration on kubernetes and OSM supports VM orchestration on OpenStack. We compared the performance of orchestrating similar network services on VM and containers. In the figure 6.13, the graph on top shows the average time distribution between MANO and VIM for deploying one network service with one VNF. The bottom graph in the figure 6.13 shows the

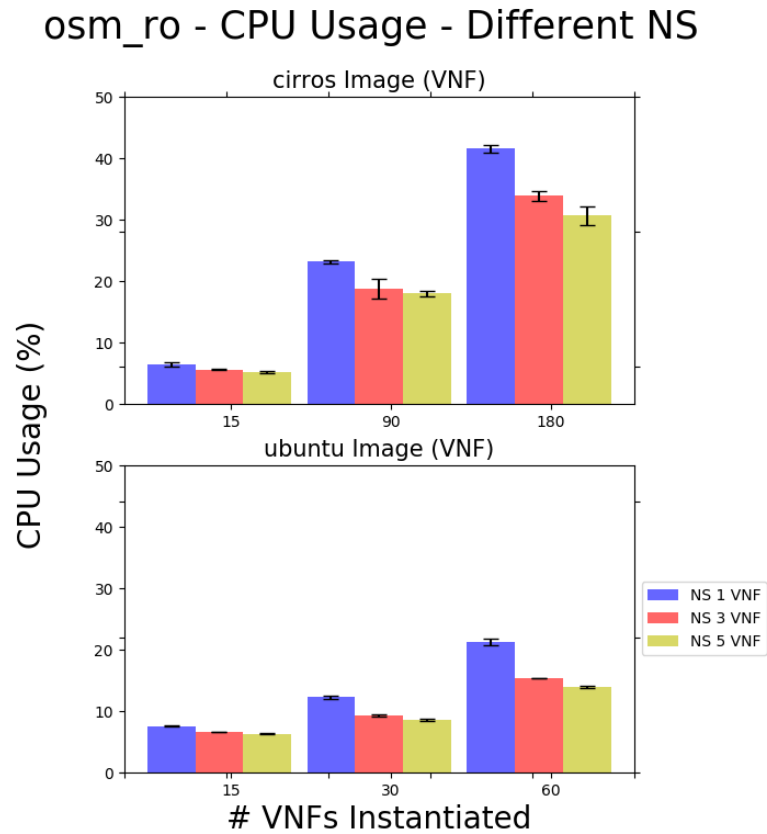


Figure 6.12: CPU usage of OSM microservice RO

total time taken to deploy 90 instances of a network with one VNF. The time taken to deploy similar VNFs is significantly less for containers, which is expected as containers are light weight compared to a VMs.

*Note:* Pishahang support for VM orchestration is not stable, hence, we could not perform similar VM experiments on Pishahang for this comparison.

### Scaling Plugin Evaluation

To be filled along with the scalability plugin docs

Child MANO lifecycle graph 6.15. Parent MANO lifecycle graph 6.16.

#### 6.4.7 Future scope

## OSM (VM) vs Pishahang (Docker) - 90 Instances

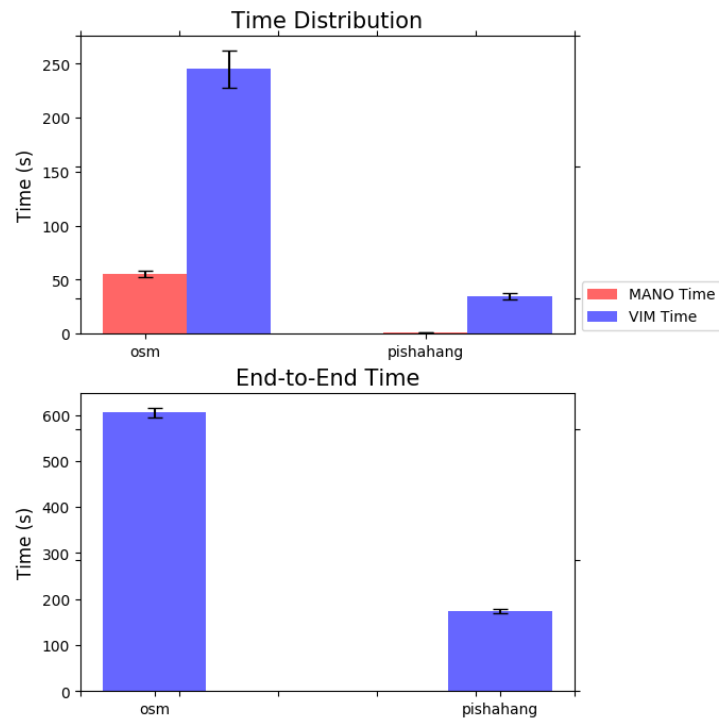


Figure 6.13: Time distribution in MANO and VIM

## OSM (VM) vs Pishahang (Docker) - 90 Instances

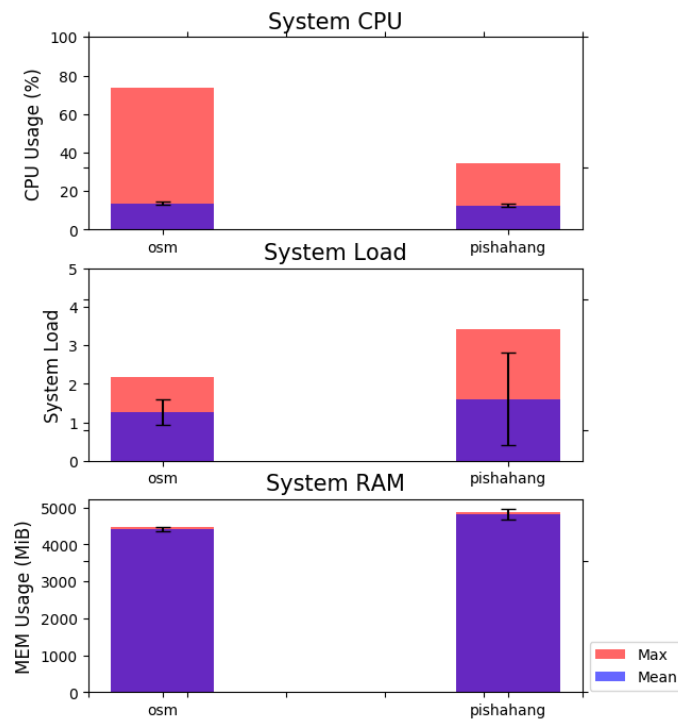


Figure 6.14: System resource utilization



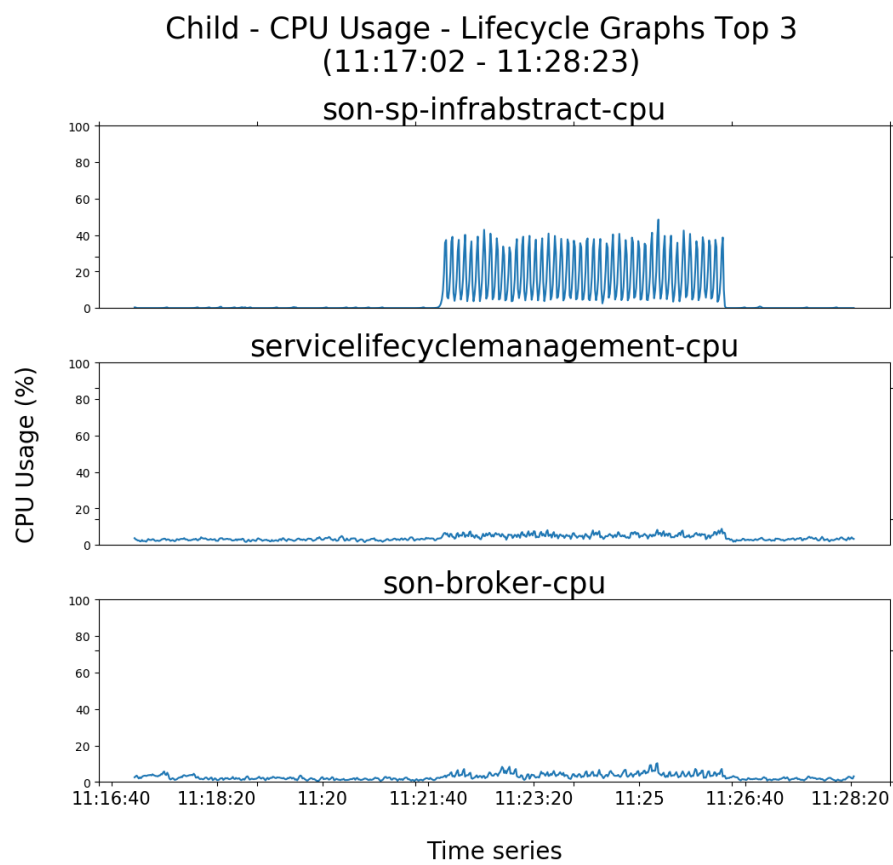


Figure 6.15: Child scaling

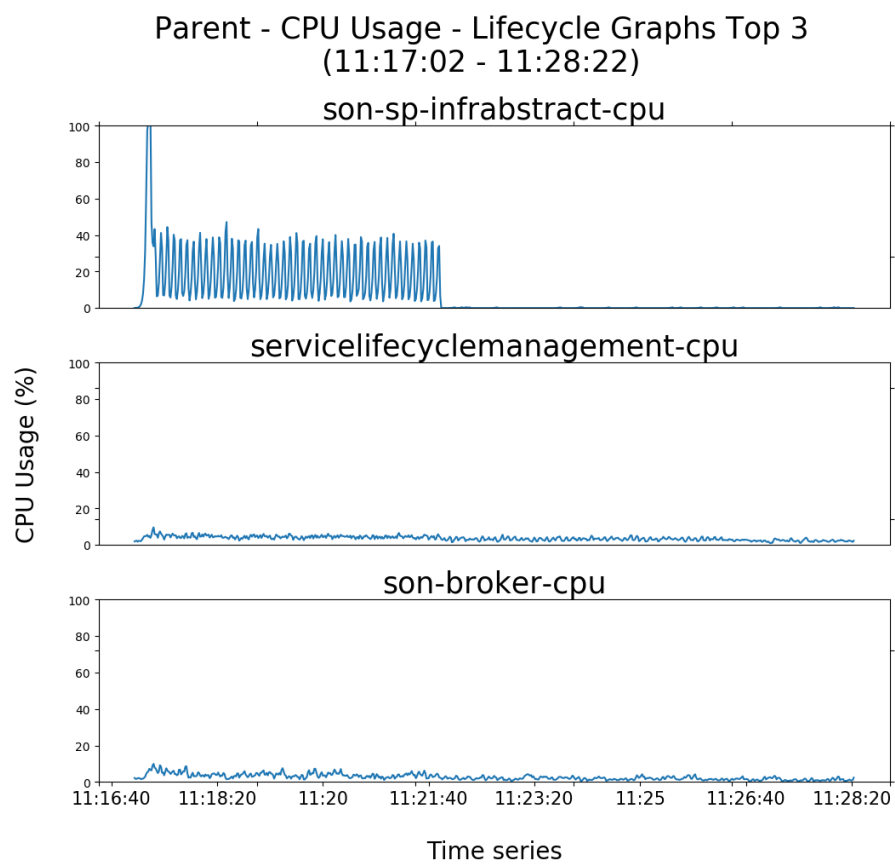


Figure 6.16: Parent Scaling

## Related Work

In this chapter, the relevant research efforts that can be used to achieve the goals are discussed. Firstly, the standards and specifications for orchestration and management of NFV in the section are discussed 7.1. The fundamental aspect of a service deployment is the NSD, in the section 7.2 the trends and options of NSDs and research papers that try to mitigate the interoperability challenges between different MANO frameworks are discussed. Section 7.3 will be a brief account of the MANO scalability problem.

As this is the initial project proposal, the state-of-the-art could change progressively and the approach will be updated accordingly.

### 7.1 Standards and Specifications

SDN decouples network control from forwarding with programmable ability. With the decoupling and programmability, SDN brings many benefits such as efficient configuration, improved performance, higher flexibility [XWF<sup>+</sup>15]. ETSI NFV [NFV2] architecture virtualizes network functions and enables dynamic and flexible selection of service functions. In ETSI NFV architecture, Network Function Forwarding Graph (VNF-FG), which consists of multiple network functions, is defined to describe network service. Internet Engineering Task Force (IETF) Service Function Chaining (SFC) working group also proposes the SFC architecture in RFC 7665 [HP15]. An SFC defines an ordered set of network Service Functions (SFs) for delivery of end-to-end services. Reference [QE16] designs a protocol named Network Service Header (NSH) to decouple the service from topology. An intelligent control plane is proposed to construct service function chains but does not consider the multi-domain situation [B<sup>+</sup>16].

ETSI NFV designs a basic frame for NFV-MANO. It defines VIM, VNF Manager (VNFM) and NFV Orchestrator (NFVO) for management and orchestration of Network Functions Virtualization Infrastructure (NFVI), VNF and network services [ETS14].

### 7.2 Network Service Description and Interoperability

The description of the network service plays an important role in integration and interoperability of different MANO frameworks. According to ETSI, network service is the “composition of network functions and defined by its functional and behavioral specification.” Following this approach, a network service can be defined as a set of VNFs and/or Physical Network Functions (PNFs), with virtual links (VLs) interconnecting them and one or more virtualized network function forwarding graphs(VNFFGs)

describing the topology of the network service.

Garay et al. [GMUJ] emphasize on NSD, required to allow the different components to inter-operate by comparing the NSD templates by OpenStack (HOT<sup>1</sup>) and OASIS (TOSCA<sup>2</sup>). A strawman model is proposed in the paper to address the upcoming interoperating challenges. The aim is to build a mechanism to translate the NSDs in order to facilitate the interoperability between different MANO frameworks.

### 7.3 Scalability and Hierarchical Orchestration

MANO framework faces significant scalability challenges in large-scale deployments. The amount of infrastructure a single instance of MANO framework can manage is limited. Network service scaling with NFV is discussed in paper [AHOLA<sup>+</sup>18]. It also shows different procedures that the Network Function Virtualization Orchestrator (NFVO) may trigger to scale a network service according to ETSI specifications and how NFVO might automate them. Abu-Lebdeh et al. [ALNGT] explores the effects of placement of MANO on the system performance, scalability and conclude by suggesting hierarchical orchestration architecture to optimize them. They formally define the scalability problem as an integer linear programming and propose a two-step placement algorithm. A horizontal-based multi-domain orchestration framework for Md-SFC(Multi-domain Service Function Chain) in SDN/NFV-enabled satellite and terrestrial networks is proposed in [LZF<sup>+</sup>]. The authors here address the hierarchical challenges with a distributed approach to calculate the shortest end-to-end inter-domain path.

The main intention is to answer the MANO scalability challenges, by exploring the optimal number of MANO deployments in a system and optimal hierarchical level. Also, how to manage the state of such a system dynamically.

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<sup>1</sup>Heat orchestration template (HOT) specification:

[http://docs.openstack.org/heat/rocky/template\\_guide/hot\\_spec.html](http://docs.openstack.org/heat/rocky/template_guide/hot_spec.html)

<sup>2</sup>Topology and Orchestration Specification for Cloud Applications (2013):

<http://docs.oasis-open.org/tosca/TOSCA/v1.0/os/TOSCA-v1.0-os.html>



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## CHAPTER 8. CONCLUSION

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