PADERBORN UNIVERSITY
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Department of Computer Science
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Investigation of MANO scalability challenges

S C r A M b L E

Management of ServiCes Across MultipLE clouds

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1 Introduction

Scalability in the recent times has become one of the most important factors of the cloud environment. In this paper we discuss scalability, provide an insight about the effects of scaling and investigate some scaling approaches that could be incorporated to scale NFV management and network orchestration (MANO) system.

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)." [fur]

- "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." [LK]

- "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." [CMK]

- "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" [noa]

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) instantiations 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 [STCP17].

1.3 Metrics to assess a scalable system

In this section, a few metrics that are important in terms of a MANO server are introduced.

- **Speedup** Speedup measures how the rate of doing work increases with the number of processors, compared to one processor, and has an ideal linear speedup value. [JW]
- **Response time**: Service response time of a MANO is a time period from when a service invocation message is arrived to a MANO on the provider side to when a response for the invocation is returned to the service consumer.
- **Throughput**: It is a metric which measures the efficiency of a MANO to handle service invocations within a given time.
- **Cost**: High scalability under high service loads is an expensive affair. There is always some additional cost involved in planning a scalbility strategy.
- **Performance**: MANO should be able to handle the growing amount of service loads. Scalability should take into account MANOs' ability to manage high service loads without deteriorating Qos.
- **Fault tolerance**: This refers to the ability of a MANO to continue operating without interruption when it's components fail

2

Scalability Approaches

Some of the scaling approaches from various academic work are discussed in this chapter. In each section a brief introduction about each scalability approach and the relavance of a specific approach to our context of research (MANO scalability) has been discussed.

2.1 Service replication

«««< HEAD A technique to clone services running on other nodes to stabilize the service load among different nodes without causing any damage to the ongoing operations. Services that are replicated secure additional resources provided by the new nodes for handling larger service load. In other words, service replication enhances service scalability and reduces the risk of QoS degradation by handling larger service loads. In a case study, Falatah and Omar [FB], performed an analysis by varying the system load. Firstly, a variable for service load is set. The service load is a number of service invocations within a unit time. For the case study, the unit time was set to be 500ms. That is, if ten invocations occur within 500ms, then the service load is 10. To show an effectiveness of service replication, they simulate the service replication scheme for seventeen different volumes of service load. On each service load, conventional service system is compared with service replication strategy in terms of average response time. ======= A technique to clone services running on other nodes to stabilize the service load among different nodes without causing any damage to the ongoing operations. Services that are replicated secure additional resources provided by the new nodes for handling larger service load. In other words, service replication enhances service scalability and reduces the risk of QoS degradation by handling larger service loads. In a case study, [FB] Falatah and Omar performed an analysis by varying the system load. Firstly, a variable for service load is set. The service load is a number of service invocations within a unit time. For the case study, the unit time was set to be 500ms. That is, if ten invocations occur within 500ms, then the service load is 10. To show an effectiveness of service replication, they simulate the service replication scheme for seventeen different volumes of service load. On each service load, conventional service system is compared with service replication strategy in terms of average response time. »»»> [Updated] scalability research document : 2nd draft

Service replication is easier when the server is stateless, but the MANO will have a database, user session and various managed services. Simply replicating servers cannot be the solution as multiple MANOs using a single database will lead to a bottleneck. Hence, database clustering or database replication is also needed to maintain uniformity across the databases. Service replication increases availability and parallelism.

2.2 Service Migration

Service migration is a strategy of placing a service on a different node when a particular node cannot provide high QoS due to a hardware/software problem or due to the physical distance between consumers and providers. After service migration, the migrated service performs the same role that it was supposed to performed on the unstable node and the unstable node is removed from the list of service nodes. The removal of this unstable node reduces overall QoS degradation. Lee and Kim [LK] conducted a simulation where the service was migrated to a node that is located closer to consumer. There is also an assumption made that the response time is directly proportional to the distance. Hence, a service is migrated to the fastest node in terms of response time.

«««< HEAD In terms of MANO, it manages VIMs. There is a close association between MANOs and VIMs to get an NS instatiated. Mere migration of a MANO server closer to the user will not make the communication time between MANO and VIM faster. Therefore, in MANOs case, it seems like service replication is a better strategy.

2.3 Proactive scaling

Proactive scaling also known as scheduled scaling is mostly done in a cloud by scaling at predictable, fixed intervals or when big traffic stream is anticipated. A well-designed proactive scaling system enables providers to schedule capacity alterations based on a plan. With scheduled scaling, one can set when to increase the capacity or number of servers and when to decrease them. To implement proactive scaling, one should first understand expected traffic flow, which means the providers should have some kind of statistics which indicates the desired (usual) traffic, deviation (usually high) from expected traffic [FB] [Ree]. This type of scaling is suitable for servers that will have increased load during known days

The MANO should be able to use traffic statistics and decide a scaling action. At the specified times, it should scale up with the values for normal, minimum or maximum traffic surges.

2.4 Reactive scaling

A reactive scaling strategy also known as auto-scaling adjusts its capacity by adding or removing, scaling up or down resources. This type of scheme could be useful when the scheduled scaling plan goes wrong in proactive scaling. Cloud providers as well as cloud agencies require periodic acquisition of performance data for maintaining QoS. In addition, reactive scaling enables a provider to react quickly to unexpected demand. The crudest form of reactive scaling is utilization-based i.e. when CPU, RAM or some other resource reaches a certain level of utilization, the provider adds more of that resource to the environment [FB] [Ree]. This type of scaling is suitable for servers that will have increased load only for a few days which cannot be predetermined.

In MANOs' terms, the plan is to develop a "Scalability Manager" plugin that could be installed in every MANO which helps scaling more children MANOs. It is the responsibilty of the scalability manager to scale MANOs and redirect the requests to the child MANO. Scaling decisions can be done when relevant metrics of a particular MANO reaches the threshold.

2.5 Predictive scaling

This type of scaling uses machine learning to predict the traffic stream of a server/application dynamically so that the capacity changes can be done accordingly, It collects data from all the server instances and various other data points and uses well trained machine learning models to predict the flow of traffic. This model would make use of one day's data and then the data is re-evaluated every 24 hours. This type of scaling strategy will be useful where servers are affected with cyclic periodic loads.

In terms of MANO, this type of scaling uses data from MANO instances and predicts the load on the server with the help of a machine learning model. This strategy is yet to be explored more to be incorporated in MANO.

======= In terms of MANO, they typically manage VIMs. There is a close association between MANOs and VIMs to manage the lifecycle of an NS. Mere migration of a MANO server closer to the operator will not make the communication time between MANO and VIM faster. Instead, migrating a service to a new instance of MANO closer to the VIMs will ease the communication between them hence improving the response time of service requests. »»»> [Updated] scalability research document : 2nd draft

2.6 Service System Scaling - Dynamic node scaling

To scale a distributed system with nodes spread over different locations, management components which help in monitoring the status of all these nodes are needed. Lee and Kim [LK] propose two key components to manage service scalability, Global Scalability Manager (GSM) and Regional Scalability Manager (RSM).

The key role of GSM is to manage service scalability. It balances service load in the system by obtaining the current status of nodes that are listed in the service system and designs a scalability strategy.

RSM component is installed on all the service nodes. It observes the status of its node and communicates it to the GSM. RSM also executes the scalability strategy based on instructions from the GSM. These two components assist the service system to add or remove new nodes dynamically at run-time.

Service Scalability Assuring Process

1. Define metrics for scalability measure. This metric are used to decide the raw data to be collected from services and to compute scalability in further steps.

2. Certain techniques from QoS monitored services are used to collect the set of raw data items [AS08] [ZLC].

3. Analyze scalability metrics. If the metrics indicate an acceptable scalability level then continue step 2 and 3 where if the metrics indicate a need to repair the below averaged scalalability then execute the following steps.

4. Develop a remedy plan for improving the below averaged scalability considering the current status of monitored service. Scalability assuring strategies like service replication and/or service migration could be adopted depending on the complexity and nature of the suffered service.

5. The selected scalability strategy is executed and this is quite often an automated process.

6. Inspect the result of the strategy and understand from the entire procedure as to how to improve the scalability. If the outcome of the process is valuable, then both the consequence and the remedy plan are logged for future uses thus making it a smart scalability framework.

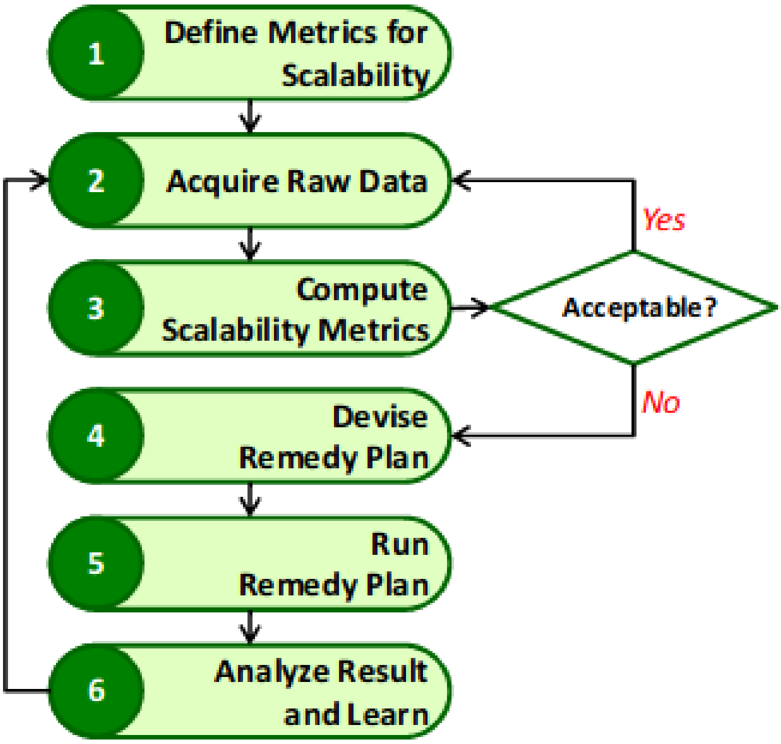

Figure 2.1: Service scalability Assuring Process from [LK]

Similarly In MANO's context, the metrics defined in section 1.3 could be the basis for deciding the scalabiliy. GSM and RSM can be developed as part of MANO's ecosystem. The scalability strategy can be a hybrid of the approaches discussed in this chapter. GSM can also be responsible for state management. When scaling down a MANO, the lifecycle management of certain network services which are a part of this MANO and other metadata are all transferred to a new active MANO and the old MANO is deleted from the list of active MANOs.

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2.7 Hierarchical Service Placement

Service placement in a centralized network model lacks scalability. The service orchestrator in the centralized network model has a detailed view of all nodes/servers. A centralized placement algorithm maintaining all the information of all users and nodes is not a feasible approach. Maini et al. [MPGR] investigates a hierarchical solution where the overall orchestration domain is split into geographical sub-domains.

In this model, the authors refers to a node as an Execution Zone (EZ - Services will be deployed in datacenters/clouds). The high-level orchestrator has limited visibility of EZ and user demands within a sub-domain - it sees only the aggregate of user demands and the aggregate of EZ capacities within a particular sub-domain. The high-level orchestrator places service instances at the coarse granularity of sub-domain only. Subsequent sub-domain orchestrators undertake a further placement algorithm with the scope of that sub-domain to determine in which specific EZs what quantity of service instances should be placed to meet the specific demand pattern of user requests within that sub-domain [MPGR].

There are many ways of sub-dividing an overall orchestration domain into sub-domains. One option is to map sub-domains onto the same geographical area covered by resolution domains: the entity responsible for resolving user requests to EZs with available session slots. Another option is to consider multiple hierarchical levels of service orchestration and placement. The author models two levels of analysis. ======= »»»> [Updated] scalability research document : 2nd draft

3

Scalability Techniques

This chapter discusses three types of scalability techniques that could be adopted in any of the scalability approaches in 2

3.1 Proactive scaling

Proactive scaling also known as scheduled scaling is mostly done in a cloud by scaling at predictable, fixed intervals or when big traffic stream is anticipated. A well-designed proactive scaling system enables providers to schedule capacity alterations based on a plan. With scheduled scaling, one can set when to increase the capacity or number of servers and when to decrease them. To implement proactive scaling, one should first understand expected traffic flow, which means the providers should have some kind of statistics which indicates the desired(usual) traffic, deviation (usually high) from expected traffic [FB][Ree].This type of scaling is suitable for servers that will have increased load during known days

In MANOs' terms, the MANO should be able to use these statistics and decide a scaling action. At the specified times, it should scale up with the values for normal, minimum or maximum traffic surges.

3.2 Reactive scaling

A reactive scaling strategy also known as auto-scaling adjusts its capacity by adding or removing, scaling up or down resources. This type of scheme could be useful when the scheduled scaling plan goes wrong in proactive scaling. Cloud providers as well as cloud agencies require periodic acquisition of performance data for maintaining QoS. In addition, reactive scaling enables a provider to react quickly to unexpected demand. The crudest form of reactive scaling is utilization-based i.e. when CPU, RAM or some other resource reaches a certain level of utilization, the provider adds more of that resource to the environment[FB][Ree]. This type of scaling is suitable for servers that will have increased load during few unknown days.

In MANOs' terms, the plan is to develop a software called as "scalability manager" that could be installed in every MANO which helps scaling more children MANOs. It is the responsibilty of the scalability manager to scale MANOs and redirect the requests to the child MANO. This is done when the NS instances that are assigned to a particular MANO reaches the threshold.

3.3 Predictive scaling

This type of scaling uses machine learning to predict the traffic stream of a server/application beforehand so that the capacity changes can be done accordingly, It collects data from all the VM instances and various other data points and uses well trained machine learning models to actually predict the flow of traffic. This model would make use of one day's data and then the data is re-evaluated every 24 hours. This type of scaling strategy will be useful where servers are affected with cyclic periodic loads.

In terms of MANO, this type of scaling uses data from MANO instances and predicts the load on the server with the help of a machine learning model. This strategy is yet to be explored more to incorporate this in MANO.

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In this model, the author refers a node as an Execution Zone (EZ - Services will be deployed in datacenters/clouds). The high-level orchestrator has limited visibility of EZ and user demands within a sub-domain - it sees only the aggregate of user demands and the aggregate of EZ capacities within a particular sub-domain. The high-level orchestrator places service instances at the coarse granularity of sub-domain only and subsequently each sub-domain orchestrator undertakes a further placement algorithm with the scope of that sub-domain only to determine in which specific EZs what quantity of service instances should be placed to supply the required number of session slots to meet the specific detailed demand pattern of user requests within that sub-domain [MPGR].

There are many ways of sub-dividing an overall orchestration domain into sub-domains. One option is to map sub-domains onto the same geographical area covered by resolution domains: the entity responsible for resolving user requests to EZs with available session slots. Another option is to consider multiple hierarchical levels of service orchestration and placement. The author models two levels of analysis.

The overview of this approach is that the lower-level domain is invisible to high-level orchestrator, the service placement problem can be subdivided into smaller units. One of them can be placed at the high level working at coarse granularity and the others: each per sub-domain can operate at a lower level with increased amount of information and decreased geographical exposure. In this way the optimisation algorithms can be executed with reduced quantities of information, increasing scalability.

4 Effects of scaling

Scaling affects the system properties in many ways, this chapter discusses some of the effects of scaling.

4.1 Availability

Availability describes how often a service can be used over a defined period of time. Scalability approaches such as service replication increases the availability of a system.

How to estimate the availability of a system

Most service outages are the result of misbehaving equipment. These outages can be prolonged by misdiagnosis of the problem and other mistakes in responding to the outage in question. Determining expected availability as stated in [Ree] involves two variables:

1. The likelihood that one will encounter a failure in the system during the measurement period.
2. How much downtime is expected in the event the system fails.The mathematical formulation of the availability of a component is:

$$a = (p - (c * d))/p \tag{4.1}$$

where a = expected availability
c = the % of likelihood that there is a server loss in a given period
d = expected downtime from the loss of the server
p = the measurement period

4.2 Reliability

Reliability is often related to availability, but it's a slightly different concept. Specifically,reliability refers to how well one can trust a system to protect data integrity and execute its transactions [Ree].

The cloud presents a few issues outside the scope of the application code that can impact a system's reliability. Within the cloud, the most significant of these issues is how persistent data is managed. In particular, any time one loses a server, loss or corruption of data becomes a concern.

4.3 Heterogeneity

Heterogeneity refers to the state of being diverse. The scaling in a distributed system is also affected by the heterogeneity of systems involved. The administrative dimension of the scaling constitutes to the problem regarding heterogeneity focusing of both hardware and also software required, to deliver the services efficiently. One of the solutions to such a problem is coherence. In a coherence system, the different administrative systems have a common interface [oN94].

Administration in a MANO framework

The administrative domain in an NFV architectural framework is majorly divided into Infrastructure domain and Tenant domain. Infrastructure domains are defined based on the criteria like type of resource such as networking, compute and storage in traditional data-centre environments, by geographical locations or by organisation. The tenant domains are defined based on the criteria like by the type of network service, etc. In a MANO, multiple infrastructure domains may co-exist, providing infrastructure to a single or multiple tenant domain. The VNFs and Network Services reside in the tenant domain which consumes resources from one or more infrastructure domains [PTM+].

Multi-MANO Interworking

To achieve a better provisioning of network services in a multiple MANO system, two or more Service Platforms (SPs) cooperate or one orchestrator leverages on the NFV interface on the other orchestrator to instantiate functions, services. The infrastructure domain of a MANO is segmented to accommodate the demands of separate organisation hence deploying a hierarchy of service platforms that need to collaborate in order to deploy NFV end-to-end services. The interaction between the two MANOs is achieved by mapping the services and infrastructure domains of the MANO.

In a hierarchical placement of the two MANO service platforms, it either supports complete outsourcing of a network service for deployment in a lower service platform or split the service deployment across two MANO SPs. Hence, the NFVO of the upper MANO constitutes a resource orchestrator (RO) along with network service orchestrator (NSO) to facilitate the services.

According to [dSPR+18], for a network service to support across multiple administrative domains, they require coordination and synchronisation between multiple involved infrastructure domains which are performed by one or more orchestrators. The ETSI approaches for multiple administrative domains are depicted in the figure below.

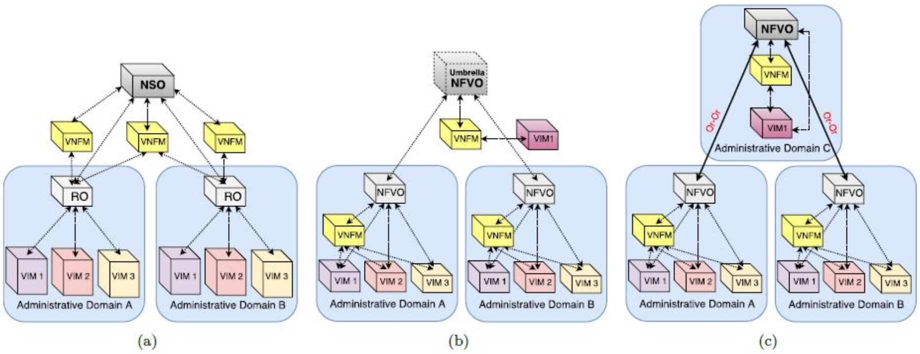


Figure 4.1: ETSI approaches for multiple administrative domains. Adapted from [dSPR+18]

In the above figure 3.1, (a) refers to a approach in which the orchestrator is split into two components (NSO and RO), (b) refers to a approach with multiple orchestrators and a new reference point: Umbrella NFVO and (c) refers to a approach that introduces hierarchy and the new reference point Or-Or.

5

Scaling a Network Service

The scaling of a network service plays a key role while handling the system load on a MANO or for a better performance. The network service contains a NSD that limits the instantiation levels of an NS instance, by defining them as the discrete set of levels addressing the number of instantiation levels required while scaling a network service [AHOLA^{+}18].

According to [AHOLA^{+}18], the deployment flavors of an NSD contains information about the instantiation levels permitted for an NS instance, with the help of information from VNFDs and VLDs. The VNF flavour of the VNFD specifies which part of VNFCs are to be deployed. The NS flavour selects the part of VNFs and VLs to be deployed as a part of NS. With this information it defines the instantiation levels. The below figure shows the scaling attributes of an NSD.

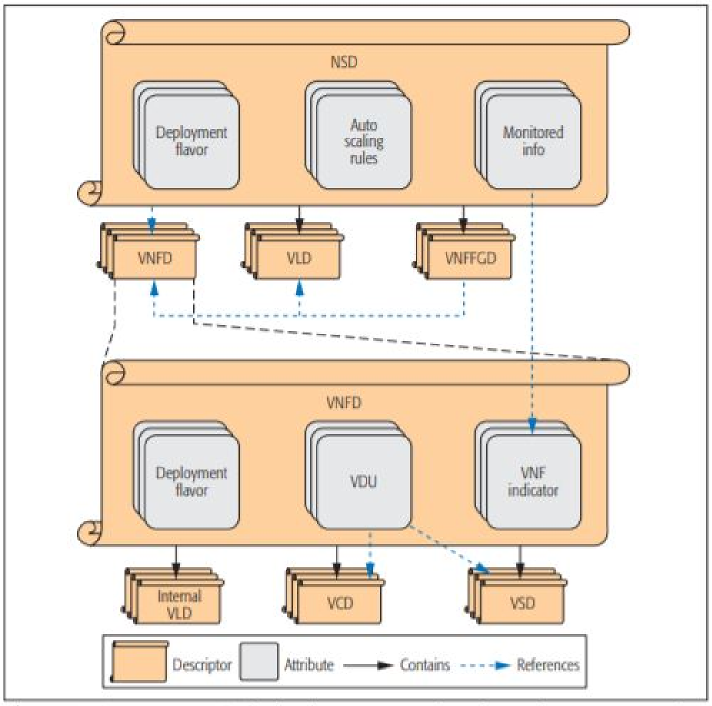


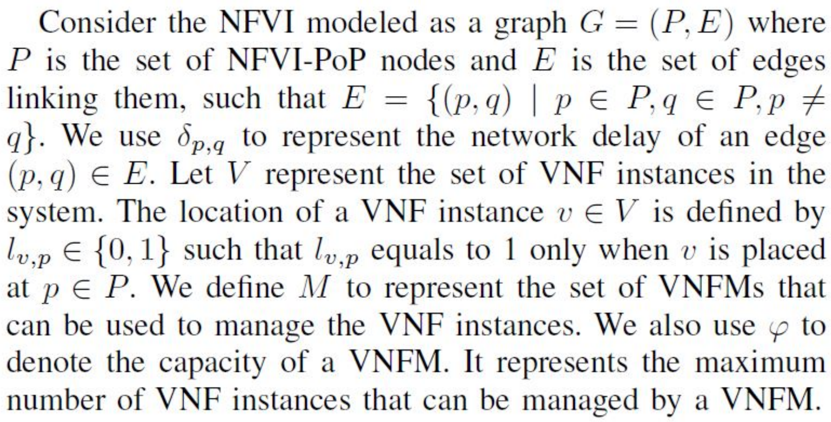
Figure 5.1: NSD structure. Adapted from [AHOLA^{+}18]

6

Capacity of NFVOs and VNFMs

In distributed NFVI environment or when network services are spanned over large geographical areas, the number of VNF instances are likely to increase. In a MANO, during the increase on the system load, the number of requests for a service increases, and in turn the number of VNF instances. Hence, there should be adequate number of VNFMs and NFVOs to manage the VNF instances. To determine the capacity of NFVO and VNFM, the Integer Linear Programming (ILP) formula is proposed [ALNGT17].

The below formula determines the optimal number of NFVOs and VNFMs required in a distributed system [ALNGT17].



Consider the NFVI modeled as a graph $G = (P, E)$ where P is the set of NFVI-PoP nodes and E is the set of edges linking them, such that $E = \{(p, q) \mid p \in P, q \in P, p \neq q\}$. We use $\delta_{p,q}$ to represent the network delay of an edge $(p, q) \in E$. Let V represent the set of VNF instances in the system. The location of a VNF instance $v \in V$ is defined by $l_{v,p} \in \{0, 1\}$ such that $l_{v,p}$ equals to 1 only when v is placed at $p \in P$. We define M to represent the set of VNFMs that can be used to manage the VNF instances. We also use φ to denote the capacity of a VNFM. It represents the maximum number of VNF instances that can be managed by a VNFM.

Decision Variables:

$h_p \in \{0,1\}$: (1) indicates that a NFVO is placed at $p \in P$, (0) otherwise.

$r_{q,p} \in \{0,1\}$: (1) specifies that $q \in P$ is assigned to the NFVO which is placed at $p \in P$, (0) otherwise.

$x_{m,p} \in \{0,1\}$: (1) designates that $m \in M$ is placed at $p \in P$, (0) otherwise.

$y_{v,m,p} \in \{0,1\}$: (1) indicates that $v \in V$ is assigned to $m \in M$ which is placed at $p \in P$, (0) otherwise.

Mathematical Model:

$$\textit{Minimize} \quad \sum_{p \in P} h_p + \sum_{m \in M} \sum_{p \in P} x_{m,p} \tag{1}$$

Subject to:

$$\sum_{p \in P} r_{q,p} = 1, \quad \forall q \in P \tag{2}$$

$$r_{q,p} \leq h_p, \quad \forall q, p \in P \tag{3}$$

$$r_{p,p} = h_p, \quad \forall p \in P \tag{4}$$

$$\sum_{p \in P} x_{m,p} \leq 1, \quad \forall m \in M \tag{5}$$

$$\sum_{m \in M} \sum_{p \in P} y_{v,m,p} = 1, \quad \forall v \in V \tag{6}$$

$$y_{v,m,p} \leq x_{m,p}, \quad \forall v \in V, m \in M, p \in P \tag{7}$$

$$l_{v,q}\, y_{v,m,\acute{p}}\, r_{\acute{p},p} \leq r_{q,p}, \quad \forall v \in V, m \in M, q, \acute{p}, p \in P \tag{8}$$

$$\sum_{v \in V} \sum_{m \in M} \sum_{q \in P} y_{v,m,q}\, r_{q,p} \leq \Phi\, h_p, \quad \forall p \in P \tag{9}$$

$$\sum_{v \in V} y_{v,m,p} \leq \varphi\, x_{m,p}, \quad \forall m \in M, p \in P \tag{10}$$

7 Conclusion

The main goal of this paper is to aggregate the factors affecting the scalability of a MANO. Scalability is an important factor in cloud environments which accommodates the demanding needs and also not affecting the system's performance. The report further states the system load in terms of the load on the NFVO of a MANO. The scaling in a distributed MANO system is affected by the availability of a service and its reliable quotient. The report further describes the effect of diverse administrative domains of a MANO framework and how it can be addressed by a coherence mean. Scalability approaches from various research papers are discussed.

The report further addresses the effects involved to scale a MANO, also briefing about scaling a network service. The further steps involved in the research is narrowing down to one of the scaling approaches to scale a MANO.

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