

MATHEMATICAL MODELLING OF NETWORK ORCHESTRATORS IN DISTRIBUTED ENVIRONMENT

A Scientific & Mathematical Approach
Toward Managing NFVI and Its Nodes



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Abstract

This paper describes the mathematical model and description of concepts of distributed network systems making use of NFVI & NFVO using graph theory-based modelling. The idea of decomposing elements as vertices and edges to represent a concept towards unleashing distributed virtual objects using integrated linear programming to understand the underlying issue.

Introduction

Network Functions Virtualization (NFV) induces profound changes in the architecture of fixed and mobile networks. It decouples the network function software from the underlying hardware, allowing it to run on commodity hardware. Resultantly NFV provides the necessary flexibility to enable an agile, cost-effective, and on-demand service delivery model combined with automated management. While Network Function Virtualization continues to draw attention from industry and academic researchers, NFV technology promises to reduce capital and operating expenses, making networks more scalable and flexible with increased service agility. However, despite the unprecedented interest it has gained, there are significant challenges associated with network and function management and orchestration that need to be addressed before NFV can advance

to reality in industrial deployments, let alone deliver on the anticipated gains. . This white paper gives an overview of the MANO framework proposed by the European Telecommunications Standards Institute. Network management systems will remain pivotal in NFV, coordinated with the MANO entities through a clear separation of roles and identities. MANO entities will deal with those aspects related to the virtualization mechanisms, while network management functions are expected to manage features associated with the semantics of the specific network services being provided by the composition of VNFs and, potentially, physical nodes. These network management systems include Element Management, Cross Domain Network Manager, and Cloud & Hosted Operating Systems.



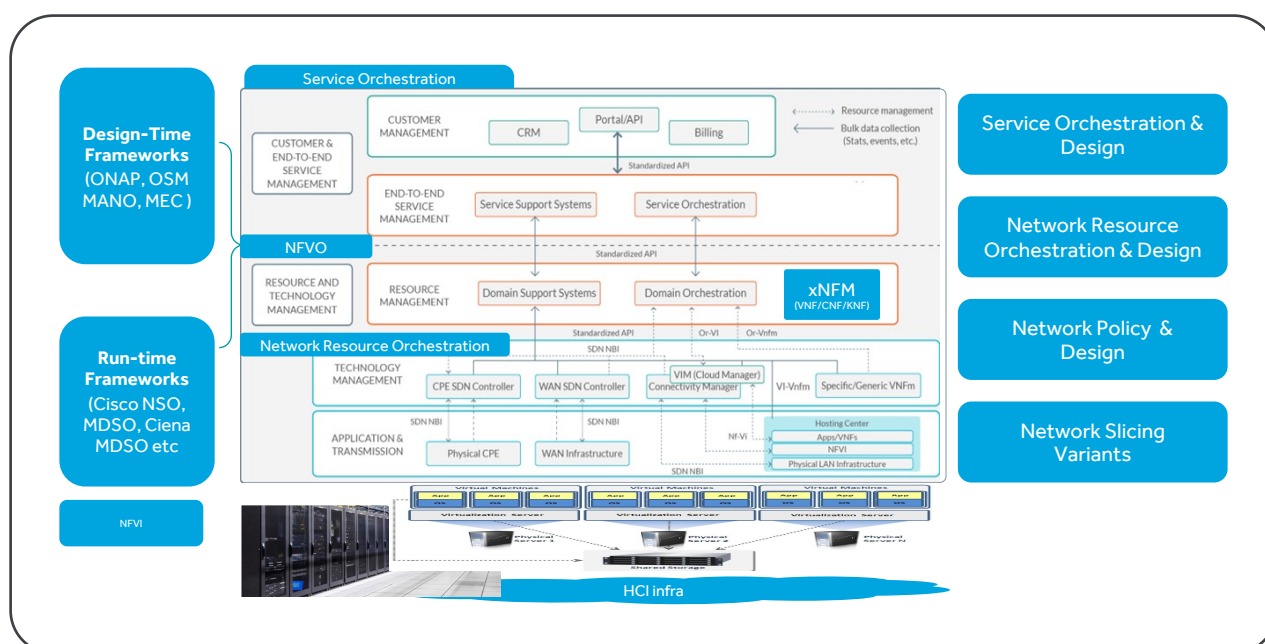
Mathematical Exploration toward Solution Descriptors

The European Telecommunications Standards Institute developed Network Functions Virtualization Management and Orchestration framework. This framework consists of VIM, NFV orchestrator and Virtualized/Containerized/Kubernetes Network Function Manager (xNFM) functional blocks responsible for managing network service's lifecycle and their associated VNFs. However, they face significant scalability and performance challenges in large and distributed NFV-deployed systems.

To solve this issue of managing VIM-NFVO-xNFM integration and scalability, we shall represent them by a linear programming formulation model of the problem statement and propose a two-step management algorithm.

Let us solve this issue first with Network Orchestrator.

- A. Hierarchical orchestration techniques have been long employed in NFV to address various challenges, such as orchestration across single and multi-technology network domains to address the NFV MANO scalability and performance challenges for large-scale centralized and distributed NFV systems.
- B. The challenge of identifying the optimal number and location of NFVO, xNFM to manage a given set of xNF instances distributed over a set of NFVI-Presence of Points. To mathematically describe this problem, we can attempt a Linear Programming approach with Graph Theory to address the formulation of the issue. Specifically, we could deploy Integer linear programming to articulate the issue.



Consider a distributed NFV Infra consisting of multiple NFVI-Point of Presence located in different regions and interconnected through a WAN network. The architecture supports two or three-layer hierarchical-based orchestration based on ETSI Architecture. The bottom layer encompasses a set of NFVOs; each performs the same functionality as defined by the ETSI NFV-ISG MANO framework. At the top layer is a Global Service Management Orchestrator responsible for

the end-to-end service orchestration management across multiple NFVOs. The bottom-most representation is NFVI is decomposed into domains such that their number is equivalent to the number of Sub-NFVO's. The architecture enables the system to scale the number of NFVOs and VNFM's and meet different scenarios' scalability and performance requirements. However, finding their number and placement is challenging.

Problem Definition & Goal

We, formally, can define the main actors as follows:

- 1) Group of NFVI-Point of Presence,
- 2) Group of xNF (x-VNF/CNF/KNF) instances with location,
- 3) DGSMO Location.

Our goal is to find out:

- 1) Optimal number and placement of NFVOs needed in an NFV system,
- 2) NFVI-Point of Presence assigned to each NFVO
- 3) Number and placement of VNFMs in each domain and,
- 4) VNF instances assigned to each VNFM.

The goal should be to minimize gradually the number of NFVOs and VNFMs while fulfilling the capacity and delay constraints. We make the following assumptions, namely:

- 1) VNF instance and its Element Manager are deployed at the same NFVI-Point of Presence,
- 2) VIM manages resources within one NFVI-Point of Presence, and it is placed at that NFVI-Point of Presence and,
- 3) Functional blocks communicate over the same network links.



Mathematical Model Definition & Variables

Let us use Graph theory to solve this issue. Consider the NFVI modelled as a directed graph.

$G = (P, E)$, where P is the NFVI-Point of Presence nodes set.

E is the network edge set linking them, such that $E = \{(p, q) \mid p \in P, q \in P, p \neq q\}$.

$\delta p, \delta q$ represents the network delay of an edge $(p, q) \in E$.

V represents the set of VNF instances in the system.

Location of a VNF instance $v \in V$ is defined by $lv, p \in \{0, 1\}$ such that lv, p equals to 1 only when v is placed at $p \in P$.

M represents the set of VNFM that can be used to manage the xNF instances. φ denotes the capacity of a VNFM. It represents the maximum number of xNF instances that a VNFM can manage.

We consider that an NFVO has capacity defined in terms of the maximum number of xNF instances in its domain.

- We employ Φ to refer to this capacity.
- Assume that the DGSMO is deployed at a given NFVI-Point of Presence.

We define $w_p \in \{0, 1\}$ to indicate the DGSMO location, such that w_p is equal to 1 only if the DGSMO is placed at $p \in P$.

There is an upper bound on the acceptable network delay between various functional blocks to ensure predictable system performance.

We use ψ to denote the maximum acceptable delay between an NFVO at the DGSMO and the VIM on the other hand.

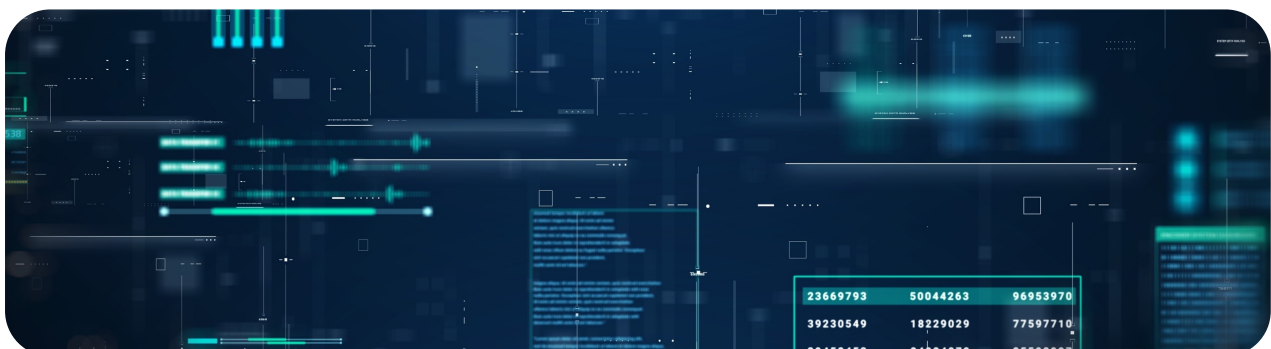
VNFM can manage different VNF types, which can impose different requirements on the network delay over the VNFM reference points.

Define the upper bound on network delay between a VNFM and other functional blocks per VNF instance.

Ωv indicates the maximum acceptable delay between the NFVO and the VNFM assigned to VNF instance v .

Employ ωv to denote the upper bound on the delay between the VNF instance v and its designated VNFM.

Going with our assumptions (2) and (3) of the problem statement, ωv also represents the maximum acceptable delay between the VNFM and the VIM of NFVI-Point of Presence where v is located.



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

$$\text{Minimize } \sum_{p \in P} h_p + \sum_{m \in M} \sum_{p \in P} x_{m,p} \quad (1)$$

$$\text{Subject to: } \sum_{p \in P} r_{q,p} = 1, \forall q \in P \quad (2)$$

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

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

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

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

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

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

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

$$\sum_{v \in V} y_{v,m,p} \leq \phi x_{m,p}, \forall m \in M, p \in P \quad (10)$$

$$x_{m,p} \leq \sum_{v \in V} y_{v,m,p}, \forall m \in M, p \in P \quad (11)$$

$$w_{p,q} h_p \delta_{p,q} \leq \psi, \forall (p, q) \in E \quad (12)$$

$$r_{q,p} \delta_{p,q} \leq \Psi, \forall (p, q) \in E \quad (13)$$

$$l_{v,p} y_{v,m,q} \delta_{p,q} \leq \omega_v, \forall v \in V, m \in M, (p, q) \in E \quad (14)$$

$$y_{v,m,q} r_{q,p} \delta_{p,q} \leq \Omega_v, \forall v \in V, m \in M, (p, q) \in E \quad (15)$$



Minimised Objective Function Constraint Defined

The objective function constraints listed are as follows

- | | |
|------------------|--|
| Constraint - (1) | (Eq.1) seeks to minimize the number of NFVOs and VNFM as their number is a measure of the operational cost of the NFV management and orchestration. |
| Constraint - (2) | stipulates that one NFVO is responsible for the resource orchestration of a NFVI-Point of Presence, i.e. a NFVI-Point of Presence belongs exactly to one domain. |
| Constraint - (3) | ensures that the NFVI-Point of Presence q can be assigned to the NFVO at NFVI-Point of Presence p when there exists an active NFVO at p . |
| Constraint - (4) | indicates that a NFVO should be placed within its domain boundaries. |
| Constraint - (5) | ensures that a VNFM can be placed only at one NFVI-Point of Presence. |
| Constraint - (6) | indicates that each VNF instance should be assigned to one VNFM. |
| Constraint - (7) | stipulates that a VNF instance can be assigned to VNFM m placed at NFVI-Point of Presence p only when m exists at p . |
| Constraint - (8) | indicates that a VNF instance and its designated VNFM should exist in the same domain. |

We enforce the capacity constraints of NFVO and VNFM by (9) and (10).

- | | |
|-------------------|---|
| Constraint - (11) | ensures that a VNFM is active only when it manages at least one VNF instance. |
|-------------------|---|

Constraints - (12)-(15) enforce the delay limits in the system.

Note that the constraints (8), (9) and (15) are non-linear constraints and can be linearized by replacing them with linear constraints (16)-(21) as follows

$$lv,q zv,m,p,p' \leq rq,p, \forall v \in V, q, p, p' \in P \quad (16)$$

$$\sum_{v \in V} \sum_{m \in M} \sum_{q \in P} zv,m,q,p \leq \Phi hp, \forall p \in P \quad (17)$$

$$zv,m,q,p \delta p,q \leq \Omega v, \forall v \in V, m \in M, (p, q) \in E \quad (18)$$

$$zv,m,q,p \leq yv,m,q, \forall v \in V, m \in M, (p, q) \in E \quad (19)$$

$$zv,m,q,p \leq rq,p, \forall v \in V, m \in M, (p, q) \in E \quad (20)$$

$$zv,m,q,p \geq yv,m,q + rq,p - 1, \forall v \in V, m \in M, (p, q) \in E \quad (21)$$

Proposed Mathematical Solution

We propose a two-step management algorithm to solve the problem.

1. Firstly, decompose the NFVI into one or more domains and place a single NFVO in each domain. This step is performed through a metaheuristic search method employing local search methods used for mathematical optimization search-based algorithm which will be discussed later in section IV-A. However, the algorithm generally aims to minimize the number of NFVOs in the system.
2. It gives the solution of decision variables h_p and $r_{q,p}$ that satisfies the model constraints (2)–(4), (12) and (13). Besides, this step disregards the placement of VNFMs themselves. However, we assure that the solution design would allow future VNF placement to satisfy the VNF delay constraints, i.e. constraints (14) and (15).
3. To do so, we impose additional constraints on the solution to ensure that
 - a. $\forall v \in V, \exists p' \in P$ such that: $l_{v,q} r_{q,p} r_{p,p'} \leq \omega v, \forall q, p \in P$ - (22)
 - b. $l_{v,q} r_{q,p} r_{p,p'} \delta_{p,p'} \leq \Omega v, \forall q, p \in P$ - (23)
4. The constraints (22) and (23) guarantee that for every VNF instance v , there exists a NFVI-Point of Presence p' in the same domain where a VNF can be placed to manage v while fulfilling the delay constraints.
5. After that, in the second step, we place the needed VNFMs for each domain and map the VNF instances onto the VNFMs. We do that by utilizing the VNF placement algorithm presented in our earlier work [11].
6. This step provides the solution of decision variables $x_{m,p}$ and $y_{v,m,p}$. The obtained solution satisfies the model constraints (5)–(11), (14) and (15).
7. Use Metaheuristic search method employing local search methods used for mathematical optimization search-based algorithm to place the NFVOs and define the boundaries of their domains.
8. Metaheuristic search method employing local search methods used for mathematical optimisation
9. [12] is a widely adopted meta-heuristic that guides a local search procedure to explore the solution space beyond local optimality. It starts the search process from an initial solution and iteratively explores the neighbour solutions.
10. Each iteration uses movements to produce a set of neighbor solutions and employs an objective function to evaluate them. The search continues till the stop criteria are met.

Summary and Conclusion

Adoption of hierarchical service orchestration architecture to overcome the scalability and performance challenges of NFV management and orchestration is the key understanding arrived at. This architecture defragmentation enables the system to scale out the number of NFVOs and VNFMs and meet various scalability and performance requirements.

In this context, we have addressed the problem of finding the optimal number of NFVOs and VNFMs along with their placement. We have formulated the problem as ILP and proposed a two-step management algorithm.

Legends Used

NFV – Network function virtualization

NFVI – Network function virtualized Infrastructure

NFVO – Network function virtualization and orchestration

VNFM – Virtual Network function virtualization

VIM – Virtual Infra Manager

DGSMO – Distributed Global Service Management Orchestrator

ILP - Integrated Linear Programming

About the Author



Joe has 28 years of experience in the IT & Telecom Domain including Network Engineering & Communication Service Providers Business verticals. He has been associated with CTO Office-based functioning and heading early technology adoption into solution conceptualization, design & development and taking it to global T1 & T2 customers. He has built about 14+ platforms & products for customers and internal developments for NG-OSS/BSS, Green Energy Management Platform, Radio Network Emulators, Cloud Car & Software Defined Vehicle. He led various customer projects as the chief architect, where he was involved in architecture inception definition, development & rollout of telecom products for T1 & T2 customers across the globe. His expertise is in areas of homegrown and COTS tools in areas of Telecom B/OSS, SDN NFV, Disaggregation of Telecom & Automotive domains - Softwarisation, Containerisation & Virtualisation of Wireless & Wireline Systems, Telco Cloud, Edge Networks, 5G & 6G ORAN Radio Networks, Network Automation - Resource & Service Orchestration, RT & Non-RT RIC Controller, Interface Specs Packet Core implementations & Automotive domain - Cloud Car & Software Defined Vehicle.

He is a senior member at IEEE ; member at ACM and a contributing member to various technical forums such as FB-TIP, ORAN Alliance, TSDSI-SDO, TMF, ETSI, LF-ONAP, Akrino ,OAI, SOAFEE, CENT-OS & Ubuntu Automotive SIG & an Invited Speaker at many of these forums

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