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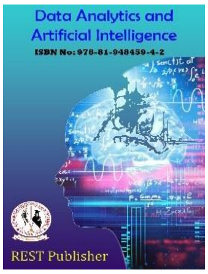

Efficient NFV Orchestration and Management in Multi-Tenant Environments using the ARAS Method

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Abstract: *In contemporary network infrastructure, the effective orchestration and management of Network Function Virtualization (NFV) within multi-tenant environments holds significant importance. This encompasses the streamlined deployment, scalability, and fine-tuning of virtualized network functions, aimed at fulfilling a wide array of tenant needs. This harmonious coexistence of various user services not only optimizes resource employment but also elevates the overall performance of the network. The research importance of orchestrating and managing Network Function Virtualization (NFV) in multi-tenant environments is significant, as it plays a central role in optimizing how resources are allocated, ensuring the effective delivery of services, and facilitating scalability in contemporary network infrastructures. With the growing integration of virtualized functions to cater to a variety of tenant requirements, proficient orchestration and management are essential for mitigating conflicts, enhancing resource allocation efficiency, and upholding service quality. Tackling these complexities is instrumental in enabling multiple tenants to coexist smoothly within a shared virtualized framework. The study utilizes the ARAS (Adaptation, Reconfiguration, Automation, and Slicing) approach to explore the orchestration and management of NFV within multi-tenant environments. ARAS integrates adaptive methodologies, dynamic reconfiguration, automated procedures, and network slicing to examine the distribution of resources, enhance performance, and ensure the segregation of tenants. Alternative and Evaluation Parameters taken as Through the utilization of the ARAS approach, this study investigates the coordination and administration of NFV within multi-tenant settings, concentrating particularly on platforms such as OpenStack, Open Baton, Tacker, ONAP, and Kubernetes. The assessment encompasses metrics such as the duration of automated deployment, the rate of successful service execution, the level of resource utilization, and the instances of service disruption. Employing the ARAS methodology, this study ranked NFV orchestration options in multi-tenant settings, evaluating key metrics. ONAP showcased superior performance, with Kubernetes in second place. OpenStack, Tacker, and Open Baton demonstrated differing efficiencies, offering insights for enhancing NFV management across diverse multi-tenant contexts.*

Keywords: *Network Function Virtualization, Software-Defined Networking, Virtual Overlay Network, virtual network functions and MCDM.*

1. INTRODUCTION

In recent years, the rise of cloud technologies has extended its influence on telecommunications networking, leading to the virtualization of network components within telecommunication clouds. ETSI has taken proactive measures to support and drive this transformation, delineating the virtualization of network elements through the establishment of ETSI Network Function Virtualization (ETSI NFV) within various working groups [1]. A significant outcome of ETSI NFV is the formulation of the Reference Architecture by the Management and Orchestration (MANO) working group. In the initial phase of ETSI NFV, which concluded by the end of 2014, this Reference Architecture was primarily crafted without incorporating security considerations. Despite a dedicated working group focusing on security, the precise integration and orchestration of security within the Reference Architecture have yet to be clearly defined [2,3]. As phase 2 of ETSI NFV commences, the focus is on moving towards a partially normative approach, encompassing tasks such as delineating interfaces among the entities operating within the Reference Architecture. Given the significance of security within a diverse vendor and tenant environment in NFV, a comprehensive consideration and specification of security measures are crucial. This effort aims to bolster confidence in the operation of virtualized telecommunications networks running on NFV infrastructures [4]. An equally significant, if not more crucial, aspect pertains to ETSI NFV's primary objective of achieving extensive control over the NFV ecosystem through automation and orchestration. To fully realize this fundamental aim, it becomes imperative to automate security orchestration within the dynamic NFV environment – an integral facet that complements NFV orchestration. To facilitate this, the ETSI NFV Reference Architecture introduces a Security Orchestrator. Recognizing security as a conventional end-to-end network responsibility, its scope needs to transcend the boundaries of the NFV environment to encompass hybrid networks that incorporate both physical and virtualized network components [5]. Ordinarily, the Software-Defined Networking (SDN) controller for each Virtual Overlay Network (VON) operates within its dedicated host. The deployment process involves selecting from various available open-source software solutions such as OpenDaylight, Floodlight, Trema, POX, and others. A standardized interface between the SDN controller and the Overlay Network Hypervisor (ONH) is employed for tasks like network exploration and connection establishment. This standardization enables the use of any SDN controller implementation to manage a VON. Consequently, when a fresh VON is dynamically instantiated through the ONH, it necessitates the manual installation and configuration of an SDN controller implementation on a dedicated server. Moreover, the setup also encompasses establishing connectivity between the ONH and the SDN controller servers, typically situated within a Network Operation Center (NOC) [6]. At the heart of network slicing lies the fundamental idea of creating distinct, isolated virtual networks within a shared virtualized infrastructure platform. Each individual instance of such a slice is comprised of interconnected virtual network functions (VNFs) and virtual links (VLs), following a predefined sequence outlined by a VNF forwarding graph (VNFFG). This orchestrated arrangement is tailored to provide a particular network service, encompassing functionalities like virtual evolved packet core (vEPC), virtual radio access network (vRAN), and similar capabilities [7]. The infrastructure resources, including compute, network, and storage, are abstracted and then dynamically assigned to individual slices. These network slices, in turn, provide various network services that are utilized by higher-level application service instances linked to specific verticals. Consequently, a single network slice's services can be shared among multiple application services, or conversely, a single application service instance can leverage the capabilities of multiple slices [8]. A credible network slice management and orchestration (MANO) system is required to manage the infrastructure resources, network slices, and service instance(s) to ensure reliable service delivery within the quality of service (QoS) bounds. In this regard, the European Telecommunications Institute (ETSI) Network Functions Virtualization (NFV) has developed an NFV-MANO framework for the life cycle management (LCM) of NFV infrastructure (NFVI) resources (compute, network, storage) and the VNFs/VLs forming network slice or network service (NS) instance(s) [9]. The owner of the NFV Infrastructure (NFVI) has the capability to accommodate several tenants, each of whom is furnished with a customized allocation of resources tailored to fulfill their respective service demands. This designated allocation of resources defines the scope of the tenant domain. Within this domain, tenants possess the ability to create and deploy numerous Network Service (NS) instances, catering to external clients, all while operating within the confines of their assigned resource quota. As an integral aspect of their service, the NFVI owner extends MANO services to manage the diverse NS instances associated with different tenants. However, the existing design of the NFV-MANO framework predominantly centers on the centralized management of NS instances across multiple tenants. This centralized approach inherently brings about performance limitations and administrative complexities [10]. The coexistence of human-centric and machine type applications will impose very diverse functional and performance requirements that the 5G network will have to support, such as broadband everywhere and enhanced mobility management. The 5G architecture should be future proof in terms of performance by realizing heterogeneous KPIs and their varying target ranges as well as in terms of flexibility by concurrently supporting multiple network services (voice, eMBB1, URLLC, V2X, gaming, etc.). Multi-tenancy will realize cost savings to be expected when hosting multiple logical mobile network instances on a largely shared infrastructure [11]. The concept of fifth generation (5G) network systems and platforms entails offering an expanded array of services to cater to a diverse range of service verticals, such as automotive, industry, smart city, e-Health, and logistics. These verticals generate substantial traffic volumes with distinct yet demanding criteria for performance, security, and dependability. Consequently, a significant challenge arises in effectively overseeing a multitude of varied and sizable (isolated) services originating from these heterogeneous verticals while ensuring they adhere to specified quality parameters, specifically service level agreements (SLAs). This intricate task of managing such a diverse set of services within the confines of quality expectations is addressed through the network slicing paradigm [12].

2. MATERIALS AND METHODS

Using the ARAS approach, this research examines the management and orchestration of NFV in environments with multiple tenants. The study centers on OpenStack, Open Baton, Tacker, ONAP, and Kubernetes, evaluating factors including automated deployment duration, service success rate, resource efficiency, and service disruption duration. The ultimate goal is to improve the comprehension and refinement of NFV management in a range of tenant-centric situations.

Automated Service Deployment Time (min): This assessment evaluates how efficiently each NFV orchestration platform deploys services in a multi-tenant context. A shorter deployment time signifies optimized resource allocation, contributing to quicker service provisioning and heightened tenant satisfaction.

Service Request Success Rate (%): This metric gauges the orchestration systems' competence in managing and fulfilling service requests from multiple tenants. A higher success rate indicates the orchestration platform's robustness in addressing concurrent tenant demands, ensuring dependable service delivery.

Resource Consumption Overhead (%): The analysis delves into the impact of NFV orchestration on resource consumption within a multi-tenant environment. Lower overhead percentages highlight efficient resource utilization, which is vital for upholding performance standards, minimizing resource waste, and accommodating diverse tenant workloads.

Average Service Disruption Time (min): This parameter measures the resilience and fault tolerance of NFV orchestration in multi-tenant scenarios. A shorter average disruption time showcases the orchestration platforms' ability to swiftly manage failures and reconfigure services, thereby minimizing disruptions to tenant operations and upholding service continuity.

ARAS Method: The Attribute-Ranking Approach to Sustainability (ARAS) method is a systematic decision-making framework that plays a pivotal role in evaluating and prioritizing alternatives based on multiple attributes while taking into account sustainability considerations. As organizations and individuals increasingly seek to make choices that align with ecological, social, and economic sustainability, the ARAS method offers a structured and transparent way to navigate complex decision scenarios [13]. The origins of ARAS can be linked to the emergence of decision analysis during the mid-20th century. Decision analysis aimed to provide structured approaches for making complex decisions by incorporating quantitative and qualitative factors. As decision-making challenges became more intricate, the need arose for methods that could effectively evaluate alternatives based on multiple criteria. This gave rise to the field of MCDA, which sought to provide systematic frameworks for assessing alternatives considering diverse attributes [14,15]. The Attribute-Ranking Approach to Sustainability (ARAS) is a decision-making methodology designed to guide complex choices by systematically evaluating alternatives based on multiple attributes, all while considering sustainability criteria. This method is a significant contribution to the field of multi-criteria decision analysis (MCDA), providing a structured framework for decision-makers to prioritize and select the most suitable options in situations where various conflicting factors need to be considered [16]. The Attribute-Ranking Approach to Sustainability method operates on a set of key principles that guide its structured decision-making process. It begins with the identification of relevant attributes or criteria, which are then normalized to a common scale to ensure fair comparisons. Decision-makers assign weights to each attribute based on their relative importance, reflecting the priorities of the decision context. Alternatives are then evaluated against these attributes, with scores calculated for each based on predefined formulas [17,18].

These individual attribute scores are aggregated to generate an overall score for each alternative. Finally, alternatives are ranked according to their aggregated scores, enabling decision-makers to prioritize and select the most suitable options that align with the desired objectives and sustainability criteria. This systematic approach ensures a comprehensive evaluation of alternatives while facilitating transparent and well-informed decision-making [19,20]. The ARAS method finds application across diverse domains, including business and economics for strategy formulation and investment decisions, environmental management to prioritize projects based on ecological impact, engineering for evaluating solutions, urban planning in assessing infrastructure projects, and healthcare for resource allocation and policy design, all while incorporating sustainability and multi-criteria considerations [21]. The ARAS method offers numerous advantages, notably its ability to comprehensively evaluate alternatives across multiple attributes, providing a holistic view of potential trade-offs and synergies. By integrating sustainability criteria, ARAS promotes environmentally and socially responsible decision-making. The method's transparency enhances stakeholders' understanding of the decision process, while its flexibility accommodates various attribute types and objectives. ARAS empowers decision-makers to make informed choices, aligning with broader goals and values. It contributes to well-rounded, ethically sound decisions across domains, from business and engineering to urban planning and healthcare, thereby fostering sustainable outcomes and responsible resource allocation [22,23]. While the ARAS method offers a structured approach to decision-making, it has limitations. Subjectivity in assigning attribute weights can introduce bias, and interpreting trade-offs between attributes can be complex. Additionally, data availability and accuracy may pose challenges. Future directions may focus on refining weight assignment techniques, addressing data uncertainties through advanced modeling, and integrating emerging technologies such as artificial intelligence to enhance attribute evaluation [24].

3. ANALYSIS AND DISCUSSION

TABLE 1. NFV Orchestration and Management in Multi-Tenant Environments

Alternatives	Automated Service Deployment Time (min)	Service Request Success Rate (%)	Resource Consumption Overhead (%)	Average Service Disruption Time (min)
max or min	20	98	5	3
OpenStack	10	95	10	5
Open Baton	15	90	15	10
Tacker	20	85	20	8
ONAP	8	98	5	3
Kubernetes	12	93	8	4

In Table 1, an assessment of different NFV orchestration and management options within multi-tenant setups is presented, focusing on crucial performance metrics. The evaluated choices, comprising OpenStack, Open Baton, Tacker, ONAP, and Kubernetes, are contrasted in relation to metrics such as time for automated service deployment, success rate of service requests, overhead in resource consumption, and the average duration of service disruptions. OpenStack stands out with the swiftest automated deployment time (10 minutes) and a relatively high service success rate (95%). Notably, ONAP and the alternative boasting the shortest automated service deployment time (8 minutes) showcase optimal service disruption durations (3 minutes).

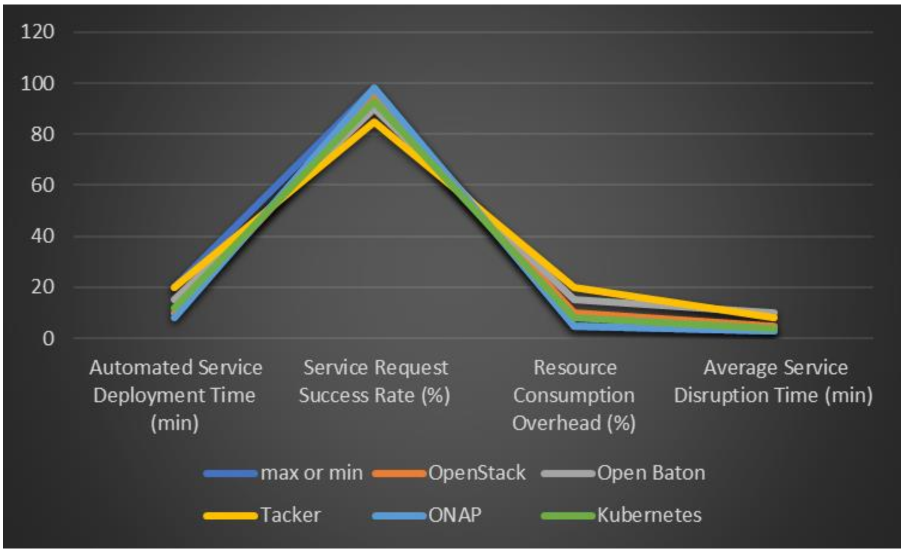

FIGURE 1. NFV Orchestration and Management in Multi-Tenant Environments

Figure 1 illustrates an evaluation of diverse NFV orchestration and management alternatives in multi-tenant environments, centering on essential performance indicators. The assessed options, including OpenStack, Open Baton, Tacker, ONAP, and Kubernetes, are juxtaposed based on criteria such as automated service deployment time, service request success rate, resource consumption overhead, and the average duration of service interruptions. Particularly noteworthy is OpenStack, which distinguishes itself with the quickest automated deployment time (10 minutes) and a relatively elevated service success rate (95%). Significantly, ONAP and the alternative with the briefest automated service deployment time (8 minutes) showcase optimal service disruption durations (3 minutes).

TABLE 2. Normalized Matrix

0.2353	0.1753	0.2697	0.2484
0.1176	0.1699	0.1348	0.1491
0.1765	0.1610	0.0899	0.0745
0.2353	0.1521	0.0674	0.0932
0.0941	0.1753	0.2697	0.2484
0.1412	0.1664	0.1685	0.1863

Displayed in Table 2 is a standardized matrix created using the ARAS approach, evaluating different NFV orchestration options. The metrics assessed comprise automated deployment duration, success rate of service requests, resource overhead, and service interruption. OpenStack demonstrates positive ratings in service deployment and success, ONAP stands out for its minimal disruption time, while Tacker and Open Baton reveal varying performance trade-offs.

TABLE 3. Weight Matrix

0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25
0.25	0.25	0.25	0.25

In Table 3, a weight matrix is presented, assigning equal significance (0.25 weight) to each factor: automated service deployment time, success rate of service requests, resource consumption overhead, and average service disruption time. This approach ensures a fair evaluation of various NFV orchestration and management options based on these metrics.

TABLE 4. Weighted Normalized Matrix

0.05882	0.04383	0.06742	0.06211
0.02941	0.04249	0.03371	0.03727
0.04412	0.04025	0.02247	0.01863
0.05882	0.03801	0.01685	0.02329
0.02353	0.04383	0.06742	0.06211
0.03529	0.04159	0.04213	0.04658

Table 4 presents a weighted and normalized matrix generated through the ARAS method, assessing NFV orchestration and management options. The values are adjusted and weighted to showcase how each alternative performs in terms of automated service deployment time, service request success rate, resource consumption overhead, and average service disruption time.

TABLE 5. optimality function Si AND utility degree Ki

Alternatives	optimality function Si	utility degree K_i
max or min	0.23218	1
OpenStack	0.14287	0.615357519
Open Baton	0.12547	0.540416527
Tacker	0.13698	0.58999094
ONAP	0.19689	0.847987681
Kubernetes	0.16560	0.713263028

In Table 5, the ARAS method calculates the optimality function (Si) and utility degree (Ki) for different NFV orchestration and management options. The optimality function indicates each alternative's proximity to the ideal solution, with values closer to 1 representing better performance. The utility degree reflects the relative effectiveness of each alternative, with higher values indicating stronger utility.

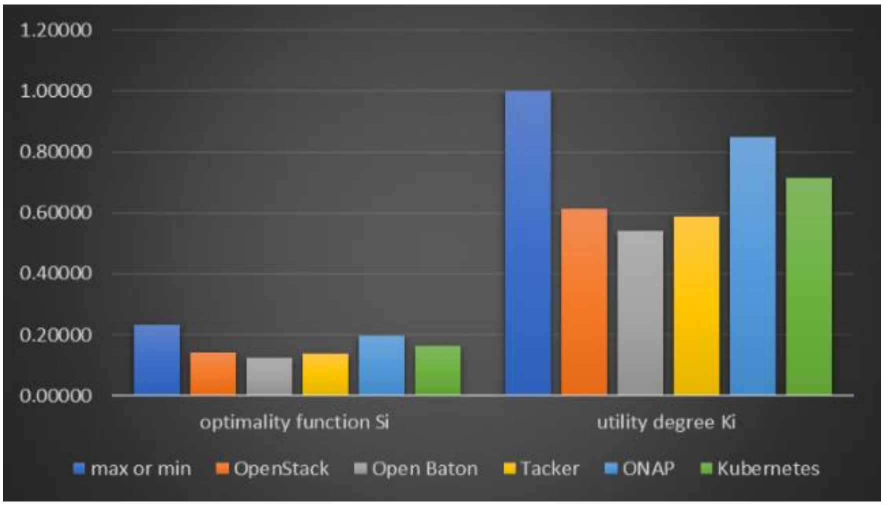

FIGURE 2. optimality function Si AND utility degree Ki

Figure 2 illustrates the results obtained from the application of the ARAS method to evaluate the optimality function (Si) and utility degree (Ki) for various alternatives in NFV orchestration and management. The optimality function indicates the extent to which each option approaches the ideal solution, with superior values denoting enhanced performance across assessed factors. OpenStack demonstrates a commendable optimality function of 0.14287, indicating a relatively favorable proximity to the ideal benchmark. Open Baton and Tacker exhibit similar optimality functions of 0.12547 and 0.13698, respectively. Notably, ONAP distinguishes itself with a higher optimality function of 0.19689, implying robust performance. The utility degree (Ki) gauges the overall effectiveness of each choice, with ONAP recording the highest value (0.847987681), underscoring its substantial utility within the context of multi-tenant scenarios.

TABLE 6. Rank

Alternatives	Rank
OpenStack	3
Open Baton	5
Tacker	4
ONAP	1
Kubernetes	2

Table 6 presents the ranking of different NFV orchestration and management options as assessed by the ARAS method. The ranking reflects the comparative effectiveness of each alternative, where lower ranks correspond to better performance. ONAP achieves the highest rank (1), highlighting its exceptional performance across evaluated factors. Following closely, Kubernetes secures the second rank (2), underscoring its noteworthy performance. OpenStack is placed third (3), Tacker fourth (4), and Open Baton fifth (5), establishing a distinct performance hierarchy within multi-tenant settings.

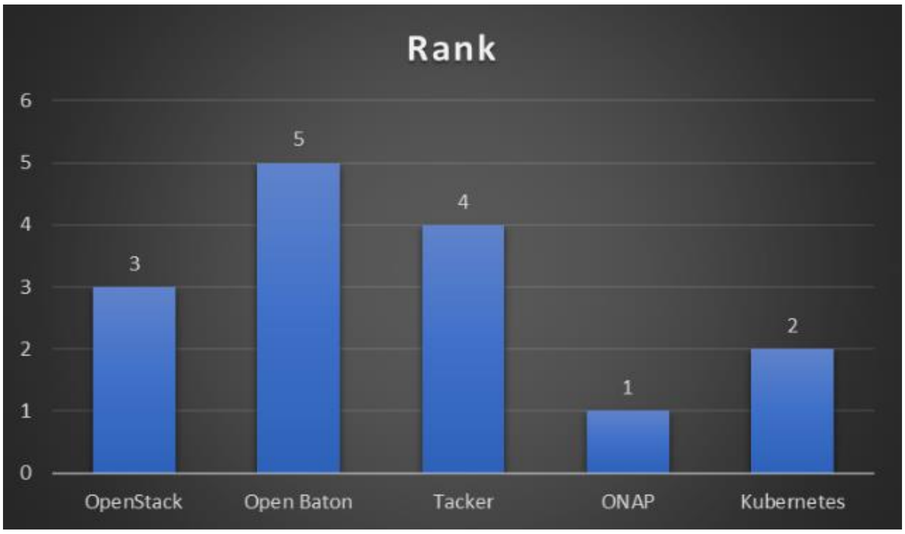

FIGURE 3. Rank

Figure 3 illustrates the evaluation results of various NFV orchestration and management choices using the ARAS method. The ranking indicates the relative efficacy of each option, with lower ranks indicating superior performance. ONAP attains the top position (Rank 1), showcasing its exceptional performance across the considered criteria. In close pursuit, Kubernetes secures the second position (Rank 2), highlighting its commendable performance. OpenStack claims the third spot (Rank 3), while Tacker holds fourth (Rank 4), and Open Baton ranks fifth (Rank 5), delineating a clear hierarchy of performance within multi-tenant environments.

4. CONCLUSION

Network Functions Virtualization (NFV) allows network functions like firewalls and load balancers to run as software on off-the-shelf servers rather than proprietary hardware, providing more flexibility and agility. In a multi-tenant setting, a shared NFV infrastructure provides virtual network functions to multiple tenants. Efficient orchestration and management are vital to automate deployment while segregating tenants and ensuring resources. The orchestrator is key to coordinating lifecycle management, service chaining, resource allotment, and end-to-end service provisioning across virtual functions. Essential capabilities involve multi-VIM support, access controls, usage quotas, customized portals, tenant-aware service chaining and monitoring, and self-service automation. Tackling these orchestration challenges is critical to harnessing the advantages of NFV in multi-tenant environments. This research utilized the ARAS methodology to holistically assess and rank a range of NFV orchestration and management alternatives within multi-tenant environments. By conducting a comprehensive examination of crucial performance metrics such as automated service deployment time, success rate of service requests, overhead in resource utilization, and average service disruption duration, we gained insights into the comparative advantages of each option. Particularly noteworthy is ONAP's outstanding performance, excelling in all evaluated aspects, while Kubernetes demonstrated noteworthy performance securing the second rank. OpenStack, Tacker, and Open Baton also displayed varying degrees of efficiency, collectively contributing to a distinct hierarchy of performance. These findings provide valuable insights for enhancing NFV management across diverse multi-tenant scenarios.

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