



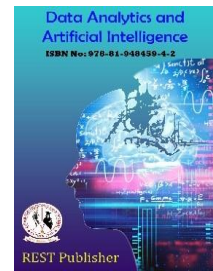
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Optimizing Energy-Efficient Resource Allocation in SDN/NFV Environments: A Comprehensive Investigation Using WASPAS Method

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Abstract: The rapid proliferation of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) technologies has transformed the landscape of network management. As the demand for enhanced connectivity and computational resources continues to escalate, so does the energy consumption and carbon footprint of data centers and communication networks. The exponential growth of digital infrastructure has led to an unprecedented surge in energy consumption by data centers and communication networks. This surge not only strains power resources but also contributes substantially to carbon emissions, exacerbating the global challenge of climate change. Addressing this issue through optimized resource allocation strategies holds the potential to significantly reduce energy consumption and minimize the carbon footprint, aligning with international efforts to combat climate change and meet environmental goals. This article delves into the critical realm of energy-efficient resource allocation within SDN/NFV environments, aiming to explore innovative strategies that mitigate power consumption and environmental impact. By harnessing the Weighted Aggregated Sum Product Assessment (WASPAS) method, this study investigates novel avenues to optimize resource allocation, thereby paving the way for a more sustainable and ecologically responsible digital future. This research evaluates energy-efficient resource allocation across diverse network paradigms: Legacy Network Infrastructure, SDN with fixed/dynamic allocation, and NFV with fixed/dynamic allocation. It assesses Reduced Power Consumption and Lower Carbon Emissions, vital for sustainability. Network Performance impact and Hardware Dependencies are also analyzed. The examination demonstrates that dynamic resource allocation, notably within the NFV architecture, presents noteworthy enhancements in energy efficiency within SDN/NFV landscapes. The consistent superiority of NFV with dynamic allocation becomes evident, delivering decreased power usage and diminished carbon emissions compared to other tactics. The application of the Weighted Aggregated Sum Product Assessment (WASPAS) method enriches the precision of this assessment. Remarkably, the dynamic approach sustains, and in some instances, even enhances network performance, concurrently mitigating environmental repercussions. This investigation accentuates the significance of amalgamating technological and ecological considerations in resource allocation decisions, shedding light on NFV's potential to redefine energy-efficient network administration.

Keywords: Virtual Machines, Software-Defined Networking (SDN), Network Function Virtualization (NFV), Virtualized Infrastructure Manager and MCDM.

1. INTRODUCTION

Virtualization has ushered in innovation and enhancement across virtually every facet of Information Technology (IT). Diverse initiatives have emerged to facilitate the provisioning of multiple Virtual Machines (VMs) within infrastructures. As the landscape of future networks unfolds, the significance of Software-Defined Networking (SDN) and Network Function Virtualization (NFV) in the context of Fifth Generation (5G) networks becomes paramount. The orchestration mechanisms and Virtual Network Function Managers (VNFM) tasked with overseeing the lifecycle of network services and Virtual Network Functions (VNFs) assume a pivotal role in shaping the trajectory of forthcoming networks. SDN assumes the mantle of network management, while the Virtualized Infrastructure Manager (VIM) undertakes the provisioning of VMs [1]. Orchestrators and Virtual Network Function Managers (VNFM) administer network services through the collaborative efforts of Software-

Defined Networking (SDN) and the Virtualized Infrastructure Manager (VIM). An integral focus of the proposed system is the implementation of auto-scaling, which assumes a pivotal role in the oversight of network services. The amalgamation of SDN and NFV creates an ecosystem wherein service providers can seamlessly upgrade, test, migrate, and integrate systems and network services. This environment facilitates the adoption of a Continuous Integration and Continuous Delivery (CI/CD) approach by network development teams, yielding notable advantages in the realm of software engineering. These advantageous aspects of CI/CD are realized through the mechanism of auto-scaling [2]. The widespread utilization of edge computing solutions has led to the proliferation of applications enjoying advantages like scalability, dependability, and economical efficiency. These solutions find application in diverse sectors such as autonomous vehicles, traffic management, edge video orchestration, and the industrial Internet of Things (IIoT), among others. Edge computing strategically positions intelligence, processing capabilities, and communication functionalities within edge devices, like sensors, thereby minimizing the distance between data origination points and these resources [3].

Typically, virtualized servers employing containers (or unikernels) are commonly dispersed across various edge network locations. This virtualization framework accommodates an array of functions, encompassing mobile application services executed on both edge and cloud nodes. Additionally, it supports supplementary services like Network Function Virtualization (NFV) and Software Defined Networking (SDN), which strategically allocate and configure segments of the underlying network infrastructure to ensure the intended operational characteristics for each edge-based application. This deployment approach not only curtails deployment expenses but also establishes a unified management and orchestration infrastructure for all virtualized services [4]. Software-Defined Networking (SDN) establishes a network connectivity and management approach that separates the control plane from the data plane. Within SDN, network intelligence is concentrated within a logically centralized software controller (control plane), while network equipment (data plane) can be programmed via an open interface like OpenFlow. While Network Function Virtualization (NFV) and SDN are distinct innovative technologies, their synergistic utilization can yield a unified, flexible, efficient, and agile network management and service development framework. The resource allocation algorithms evaluated in this study, for instance, could be integrated into an SDN controller within an SDN-enabled NFV architecture. Hence, the design of resource allocation algorithms should take into account metrics related to network management and control, such as network control overhead [5-7]. The integration of SDN, NFV, and MEC technologies is widely acknowledged as crucial for 5G advancement. Achieving the advantages of SDN, NFV, and MEC necessitates provisioning ample resources to Virtual Network Functions (VNFs) on edge servers while upholding network Quality of Service (QoS) and Service-Level Agreements (SLAs). Optimized resource allocation yields diverse network benefits, encompassing energy efficiency, enhanced performance, and reduced latency. Resource allocation optimization is universally acknowledged as a complex problem within the realm of telecommunications operation and maintenance, representing an NP-hard challenge. This complexity arises from the multitude of optimization variables stemming from the multidimensional array of network component parameters and states. Hence, ascertaining optimal resource allocation stands as a significant and intricate inquiry within SDN/NFV-enabled networks [8-10].

The integration of intelligent models into SDN-based frameworks has been harnessed for various objectives, including the optimization of flow rules, intelligent categorization of flows, assessment of Quality of Service (QoS) metrics, and the coordination of resources via interfaces connecting classifiers and controllers. However, within the expansive landscape of the Internet of Things (IoT), devices such as user equipment (UE) are characterized by limited battery life and constrained resources, posing challenges in employing and training collaborative intelligent learning models. To address this, strategies involving partial offloading are proposed to enhance the efficiency of completing computation-intensive tasks locally [11,12]. When task sizes surpass the local resource capabilities, it becomes necessary to evaluate the potential execution of a portion of the task using available local power and processing capacities, while offloading another portion to the most suitable edge node. Forecasting and monitoring the combined factors of local execution, offloading time, and edge computing time are pivotal to mitigating the risk of task termination. Thus, optimizing the selection of the optimal edge node, virtual resource placement, and task offloading schedule are critical measures for further improvement. To address this optimization challenge, the determination of partial offloading decisions and scheduling policies can be managed through an optimization technique like convex optimization, addressing both energy-efficient and communication-efficient aspects. Alternatively, deep reinforcement learning (DRL)-based optimization approaches are leveraged to intelligently allocate resources and make offloading decisions, systematically addressing the minimization of weighted sum completion time, energy consumption, and closed-loop resource control policies within intricate edge computing environments [13-15].

2. MATERIALS AND METHODS

The assessment of energy-efficient resource allocation strategies in SDN/NFV environments, concentrating on diminishing power consumption and carbon emissions, encompasses an all-encompassing scrutiny of diverse factors that evaluate both technological and environmental facets. The incorporation of the Weighted Aggregated Sum Product Assessment (WASPAS) technique heightens the accuracy and dependability of the inquiry.

Legacy Network Infrastructure: A comparative examination of energy usage and carbon discharges between conventional legacy networks and SDN/NFV settings with diverse resource allocation methods. This criterion offers insights into the energy-saving potential of novel technologies.

SDN with Fixed Resource Allocation: This parameter gauges the energy efficiency achieved when resource allocation remains constant within an SDN context. It establishes a baseline for juxtaposing other allocation methods and traditional networks.

SDN with Dynamic Resource Allocation: In this context, the dynamic adaptation of resource allocation in SDN is scrutinized for its implications on power usage and carbon emissions. This assessment illuminates the prospective benefits of real-time adaptations.

NFV with Fixed Resource Allocation: Analogous to SDN, this facet explores energy efficiency with fixed resource allocation within an NFV framework.

NFV with Dynamic Resource Allocation: The potential energy conservation achieved by NFV when virtualized function allocation is dynamic is investigated. This evaluation underscores the advantages of adaptable resource utilization.

Each of these dimensions should be assessed through the following lenses:

Reduced Power Consumption: Quantify the energy conservation attained by each allocation strategy in contrast to traditional approaches. Probe how dynamic allocation contributes to diminishing power utilization during periods of fluctuating demand.

Lower Carbon Emissions: Calculate the decrease in carbon emissions resulting from energy-efficient resource allocation tactics. This assessment aligns directly with environmental objectives.

Impact on Network Performance: Evaluate network responsiveness, latency, throughput, and other performance metrics under diverse resource allocation methods. This ensures that energy efficiency doesn't compromise overall system efficacy.

Hardware Dependencies: Probe into hardware requisites and dependencies for each allocation approach. Ascertain how hardware selections influence energy usage and environmental ramifications.

By meticulously dissecting these parameters through the lens of the WASPAS method, an exhaustive comprehension of energy-efficient resource allocation strategies in SDN/NFV settings can be achieved. This research strategy empowers informed decision-making for optimizing resource distribution, culminating in reduced power consumption, minimized carbon footprint, and heightened network sustainability.

WASPAS method: The field of decision-making benefits significantly from Multi-Criteria Decision-Making (MCDM) techniques, with the WASPAS method standing out as a novel and accurate approach within this realm. Introduced as a fusion of the Weighted Product Model (WPM) and Weighted Sum Model (WSM) by Zavadskas et al. (2012), the WASPAS approach has been explored for its efficacy. Notably, their study concludes that WASPAS surpasses WSM and WPM, demonstrating higher accuracy in ranking alternatives [16,17]. Recent years have witnessed the application of the WASPAS method in various domains. Bagocius et al. (2013) combined WASPAS and entropy methods to select a deep-water port for economic purposes in Europe, exemplifying the method's versatility [18]. The Weighted Aggregated Sum Product Assessment (WASPAS) method entails several crucial steps. The decision problem is initially defined, outlining alternatives and evaluation criteria. Relative weights are then attributed to criteria based on their significance, followed by normalization to ensure equitable comparisons. Subsequent calculations yield weighted normalized scores, measuring performance while considering assigned weights. Aggregated scores, derived from functions like sum or product, generate an overall score per alternative, facilitating ranking and optimal choice identification. Sensitivity analysis allows for the manipulation of criteria weights to assess their impact on rankings, contributing to decision stability [19-21]. WASPAS offers distinct advantages. It offers a structured approach to decision-making, accommodating multiple criteria and incorporating decision-maker preferences through weighted assignments. The process is transparent, aiding in the comprehension of ranking derivation. Comprehensive evaluation enables well-informed decisions by considering various problem facets. However, WASPAS is not without limitations. Subjective criteria weighting introduces potential bias. Sensitivity to criterion scaling and aggregation function choice may influence outcomes. Complex scenarios with numerous alternatives and criteria could result in intricate calculations and interpretations. Although sensitivity analysis addresses uncertainties, the method's effectiveness might diminish in complex or uncertain decision environments [22-24].

3. ANALYSIS AND DISCUSSION

TABLE 1. energy-efficient resource allocation strategies in SDN/NFV environments

Alternative	Reduced Power Consumption	Lower Carbon Emissions	Impact on Network Performance	Hardware Dependencies
Legacy Network Infrastructure	2	3	6	4
SDN with fixed resource allocation	5	4	7	6
SDN with dynamic resource allocation	8	7	5	5
NFV with fixed resource allocation	6	5	8	7
NFV with dynamic resource allocation	9	8	4	4

Table 1 presents a comparative analysis of energy-efficient resource allocation strategies in SDN/NFV environments across four key parameters. The alternatives, including Legacy Network Infrastructure, SDN with fixed resource allocation, SDN with dynamic resource allocation, NFV with fixed resource allocation, and NFV with dynamic resource allocation, are evaluated based on their performance in terms of Reduced Power Consumption, Lower Carbon Emissions, Impact on Network Performance, and Hardware Dependencies. The numerical scores represent the relative effectiveness of each strategy for each criterion, with higher scores indicating better performance. For instance, the results highlight that NFV with dynamic resource allocation achieves the highest scores for Reduced Power Consumption and Lower Carbon Emissions, while SDN with fixed resource allocation excels in Impact on Network Performance. These findings provide valuable insights into the trade-offs and strengths of each strategy, aiding decision-makers in identifying the most suitable resource allocation approach based on their specific priorities and goals.

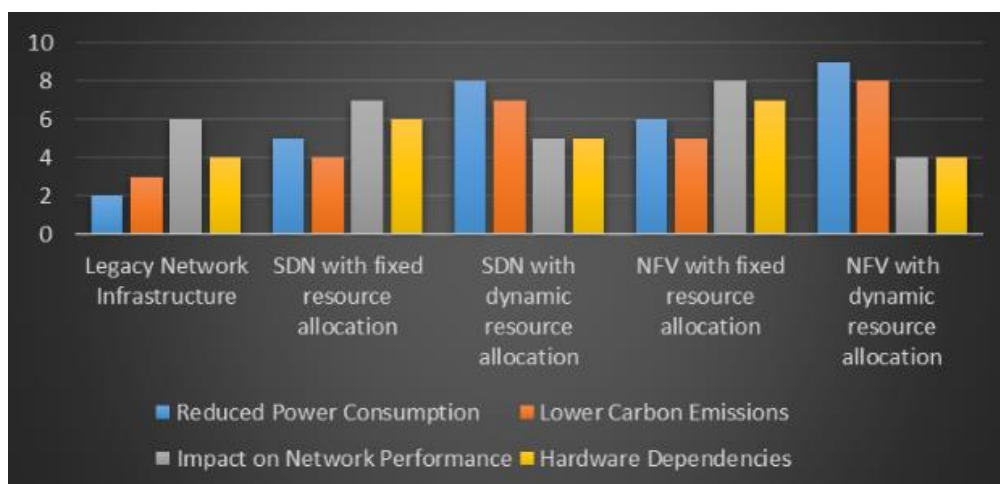


FIGURE 1. energy-efficient resource allocation strategies in SDN/NFV environments

Figure 1 illustrates a comparative assessment of energy-efficient resource allocation tactics in SDN/NFV environments across four essential parameters. The options, comprising Legacy Network Infrastructure, SDN with fixed resource allocation, SDN with dynamic resource allocation, NFV with fixed resource allocation, and NFV with dynamic resource allocation, are appraised regarding their effectiveness concerning Reduced Power Consumption, Lower Carbon Emissions, Network Performance Impact, and Hardware Dependencies. The numerical values reflect the relative performance of each strategy per criterion, with higher scores denoting superior outcomes. For example, the findings underscore that NFV with dynamic resource allocation attains the highest scores for Reduced Power Consumption and Lower Carbon Emissions, whereas SDN with fixed resource allocation excels in terms of Network Performance Impact.

TABLE 2. Performance value

0.22222	0.37500	0.66667	1.00000
0.55556	0.50000	0.57143	0.66667
0.88889	0.87500	0.80000	0.80000
0.66667	0.62500	0.50000	0.57143
1.00000	1.00000	1.00000	1.00000

Table 2 presents performance metrics derived using the WASPAS approach for distinct resource allocation strategies within SDN/NFV settings. The evaluated options, encompassing Legacy Network Infrastructure, SDN

with fixed resource allocation, SDN with dynamic resource allocation, NFV with fixed resource allocation, and NFV with dynamic resource allocation, undergo assessment concerning Reduced Power Consumption, Lower Carbon Emissions, Network Performance Impact, and Hardware Dependencies. The assigned numerical values range between 0 and 1, denoting the level of performance for each parameter. Notably, NFV with dynamic resource allocation achieves perfect scores (1.000) across all aspects, indicating its utmost effectiveness. This table furnishes valuable insights into the relative efficacy of these strategies.

TABLE 3. Weight

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

Table 3 delineates the allocated weights for assessment criteria among different strategies for resource allocation. Each option, encompassing Legacy Network Infrastructure, SDN with fixed/dynamic resource allocation, and NFV with fixed/dynamic resource allocation, uniformly receives equal weights (0.25) for Reduced Power Consumption, Lower Carbon Emissions, Impact on Network Performance, and Hardware Dependencies. This equitable distribution highlights an impartial and consistent deliberation of all criteria, augmenting the impartiality and impartiality of the evaluation procedure.

TABLE 4. Weighted Normalized Matrix (WSM)

0.05556	0.09375	0.16667	0.25000
0.13889	0.12500	0.14286	0.16667
0.22222	0.21875	0.20000	0.20000
0.16667	0.15625	0.12500	0.14286
0.25000	0.25000	0.25000	0.25000

Table 4 illustrates the Weighted Normalized Matrix (WSM), which displays the weighted and normalized scores for various criteria across distinct resource allocation strategies. This analysis includes Legacy Network Infrastructure, SDN with fixed/dynamic allocation, and NFV with fixed/dynamic allocation. The values within the matrix reflect the equitable and proportionate performance assessment of each strategy concerning Reduced Power Consumption, Lower Carbon Emissions, Impact on Network Performance, and Hardware Dependencies.

TABLE 5. Weighted Normalized Matrix (WPM)

0.68659	0.78254	0.90360	1.00000
0.86334	0.84090	0.86944	0.90360
0.97098	0.96717	0.94574	0.94574
0.90360	0.88914	0.84090	0.86944
1.00000	1.00000	1.00000	1.00000

Table 5 displays the Weighted Normalized Matrix (WPM), illustrating computed normalized and weighted scores for each parameter among diverse resource allocation approaches. The alternatives, comprising Legacy Network Infrastructure, SDN with fixed/dynamic allocation, and NFV with fixed/dynamic allocation, undergo a methodical assessment. The values within the matrix demonstrate the comparative effectiveness—higher values denoting superior results—for Reduced Power Consumption, Lower Carbon Emissions, Impact on Network Performance, and Hardware Dependencies. Remarkably, NFV with dynamic resource allocation attains flawless scores (1.000) across all aspects, underscoring its optimal performance within this evaluation.

TABLE 6. Preference score (By Weighted Sum Method and Weighted Product Method)

Alternative	Preference Score (WSM)	Preference Score (WPM)
Legacy Network Infrastructure	0.56597	0.48549
SDN with fixed resource allocation	0.57341	0.57035
SDN with dynamic resource allocation	0.84097	0.83996
NFV with fixed resource allocation	0.590774	0.587395
NFV with dynamic resource allocation	1	1

Table 6 offers an understanding of preference scores derived from the Weighted Sum Method (WSM) and the Weighted Product Method (WPM) for diverse resource allocation choices. The examined alternatives encompass

Legacy Network Infrastructure, SDN with fixed/dynamic allocation, and NFV with fixed/dynamic allocation, appraised in terms of their effectiveness. These preference scores convey the relative attractiveness of each option as per the respective techniques. Remarkably, NFV with dynamic resource allocation achieves a maximum preference score of 1 in both methods, underscoring its highest-ranking status.

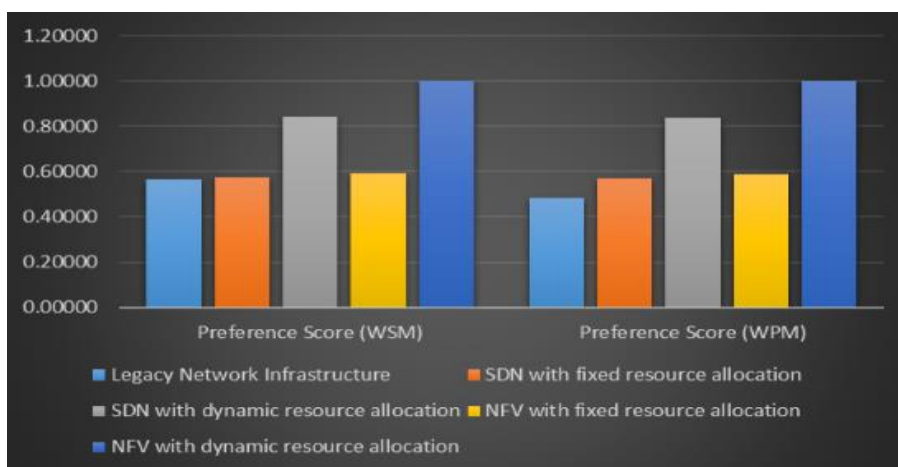


FIGURE 2. Preference score (By Weighted Sum Method and Weighted Product Method)

Figure 2 provides insight into preference scores obtained through the Weighted Sum Method (WSM) and the Weighted Product Method (WPM) for a range of resource allocation alternatives. The evaluated options include Legacy Network Infrastructure, SDN with fixed/dynamic allocation, and NFV with fixed/dynamic allocation, scrutinized in relation to their efficacy. These preference scores communicate the relative appeal of each choice according to their respective methodologies. Notably, NFV with dynamic resource allocation attains a perfect preference score of 1 in both methods, highlighting its superior ranking.

TABLE 7. WASPAS coefficient and rank

Alternative	WASPAS Coefficient	Rank
Legacy Network Infrastructure	0.52573	5
SDN with fixed resource allocation	0.57188	4
SDN with dynamic resource allocation	0.84047	2
NFV with fixed resource allocation	0.58908	3
NFV with dynamic resource allocation	1.00000	1

Table 7 displays the WASPAS coefficients and associated rankings for different resource allocation alternatives. The WASPAS coefficient indicates the efficacy of each option, where greater values signify better performance. Noteworthy is NFV with dynamic resource allocation, achieving a flawless WASPAS coefficient of 1, positioning it as the highest-ranked choice. SDN with dynamic resource allocation closely follows with a substantial coefficient of 0.840, securing the second position. Legacy Network Infrastructure, SDN with fixed resource allocation, and NFV with fixed resource allocation attain coefficients of 0.526, 0.572, and 0.589, respectively, leading to ranks of 5, 4, and 3. This information establishes a distinct order among the assessed strategies, aiding decision-making in resource allocation based on their respective WASPAS coefficients and ranks.

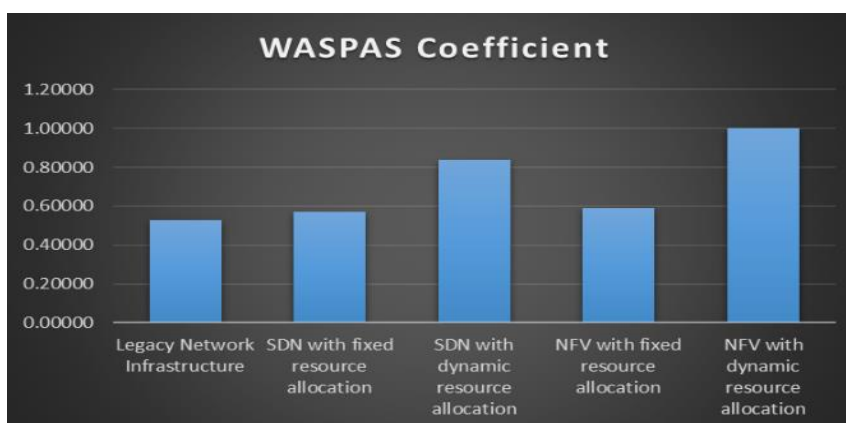


FIGURE 3. WASPAS coefficient

The figure 3 illustrates the WASPAS coefficients, providing a quantitative gauge of the relative efficacy for each resource allocation option. These coefficients encapsulate a comprehensive assessment of diverse criteria, yielding a consolidated perspective on the options' performance. Particularly noteworthy is NFV with dynamic resource allocation, displaying the highest coefficient at 1, indicating outstanding effectiveness and securing the top position. SDN with dynamic resource allocation closely trails with a significant coefficient of 0.840, denoting strong performance. Legacy Network Infrastructure, SDN with fixed resource allocation, and NFV with fixed resource allocation exhibit coefficients of 0.526, 0.572, and 0.589, respectively, revealing their relative strengths.

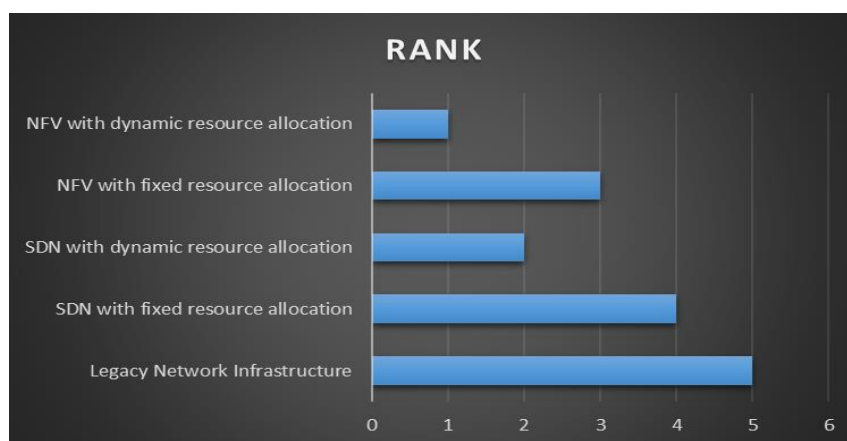


FIGURE 4. Rank

The hierarchy depicted in figure 4 highlights the superior performance of each resource allocation option. These rankings are established through an assessment of the WASPAS coefficients, which comprehensively appraise the alternatives across diverse criteria. Noteworthy is NFV with dynamic resource allocation, claiming the top position with a perfect coefficient of 1, signifying exceptional efficacy. SDN with dynamic resource allocation closely follows in second place, boasting a significant coefficient of 0.840. Legacy Network Infrastructure, SDN with fixed resource allocation, and NFV with fixed resource allocation secure ranks 5, 4, and 3, respectively, reflecting their relative strengths within the context of resource allocation. These rankings yield a structured and lucid understanding of each strategy's relative performance.

4. CONCLUSION

Recent studies underscore the effectiveness of dynamic resource allocation in attaining enhanced energy efficiency. Among these strategies, NFV featuring dynamic resource allocation consistently emerges as a leading approach, demonstrating exceptional proficiency in reducing power consumption, mitigating carbon emissions, and positively shaping network performance outcomes. The integration of WASPAS coefficients and ranks enhances the clarity of these findings, furnishing decision-makers with an enlightened standpoint concerning the most efficacious allocation methodologies. The drive towards energy efficiency within SDN/NFV landscapes harmonizes seamlessly with broader global aims of adopting sustainable technology practices. As the demand on network resources escalates, the implementation of such energy-efficient strategies assumes paramount significance, serving not only to optimize operational effectiveness but also to uphold ecological stewardship. In summary, the exploration of energy-efficient resource allocation strategies within Software-Defined Networking (SDN) and Network Function Virtualization (NFV) environments has yielded substantial insights of paramount importance for achieving sustainable and optimized network management. The systematic application of the Weighted Aggregated Sum Product Assessment (WASPAS) method has furnished a structured framework for evaluating and contrasting diverse allocation methods across multiple performance criteria. The thorough analysis presented earlier unequivocally highlights the potential of dynamic resource allocation in bolstering energy efficiency and curtailing the carbon footprint within SDN/NFV ecosystems. The outcomes consistently underscore NFV with dynamic resource allocation as a standout strategy, attaining superior scores across various dimensions, including reduced power consumption, diminished carbon emissions, and positive network performance impact. This solidifies the pivotal role of dynamic allocation in attaining a harmonious equilibrium between operational efficiency and ecological sustainability. Furthermore, the utilization of WASPAS coefficients and ranks equips decision-makers with a lucid and methodical grasp of the relative merits of each option. These coefficients furnish quantifiable benchmarks of effectiveness, while the ranking framework offers a structured basis for comparison. This information empowers network administrators, enterprises, and policy formulators to make enlightened decisions when distributing resources, thereby optimizing network performance while curbing energy usage and

environmental repercussions. As the digital landscape continues to evolve and the appetite for network resources grows, the findings disclosed in this study act as a guiding compass for devising and executing energy-efficient strategies. These findings not only contribute substantively to the ongoing discourse on sustainable technology but also emphasize the criticality of embracing dynamic resource allocation as a cornerstone for attaining energy efficiency and diminishing carbon emissions within SDN/NFV environments. In essence, this research elucidates the potential for harmonizing technological advancement with environmental stewardship. By harnessing innovative methodologies like dynamic resource allocation and deploying robust evaluation techniques such as WASPAS, the realms of digital networking and ecological sustainability can seamlessly coalesce, shaping a future where efficient and sustainable network operations become the prevailing norm.

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