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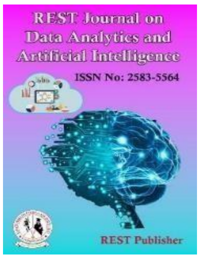

Unveiling Performance Evaluation: Unmasking NFV Infrastructure Against Traditional Hardware Networks Using TOPSIS Method

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***Abstract**: The swift advancement of networking technologies has given rise to Network Function Virtualization (NFV) as a promising avenue for enriching network adaptability, scalability, and cost efficiency. This article delves deeply into the essential endeavour of appraising the effectiveness of NFV infrastructure and drawing a parallel with conventional hardware-based networks. Through the utilization of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method, the primary objective of this study is to identify possible bottlenecks and prospects for enhancement within both approaches. In recent times, NFV has garnered substantial attention owing to its capability to uncouple network functions from dedicated hardware, allowing their operation within virtualized environments. While this shift offers agility and economic advantages, it simultaneously introduces intricacies necessitating meticulous performance evaluation. On the other hand, traditional hardware-based networks, while tried and assessed, may encounter constraints in promptly acclimating to dynamic requisites. As a result, an all-encompassing assessment framework becomes indispensable to accurately assess the genuine potential of NFV infrastructure. A robust research approach is utilized in this study, characterized by a quantitative analysis framework. Key performance indicators such as latency, throughput, resource utilization, and scalability are assessed and contrasted between Network Function Virtualization (NFV) infrastructure and conventional hardware networks. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methodology is implemented to pinpoint performance limitations and potential enhancement zones within both paradigms.* Evaluation and Alternate parameters taken as *in this study, Scalability, Resource Utilization, Latency, and Energy Consumption serve as assessment parameters, while contrasting Traditional Hardware, NFV with Software Acceleration, NFV with GPU Acceleration, NFV with FPGA Acceleration, and Cloud-based NFV configurations. The results presented in the evaluation demonstrate the effectiveness of different Network Function Virtualization (NFV) alternatives using the TOPSIS method. NFV with GPU Acceleration emerges as the top-performing choice, closely followed by NFV with FPGA Acceleration. These alternatives exhibit superior proximity to the ideal solution, as indicated by their high Closeness Coefficient (Ci) values and top ranks. NFV with Software Acceleration ranks third, showcasing favorable performance. Cloud-based NFV and Traditional Hardware secure lower ranks, implying comparatively less optimal performance. The Closeness Coefficient values and ranks provide a clear and concise basis for decision-making, guiding the selection of NFV alternatives with greater alignment to desired outcomes.*

Keywords: *Network Function Virtualization, Virtual Machines, Network Functions, Scalability, Resource Utilization and MCDM.*

1. INTRODUCTION

Network Function Virtualization (NFV) refers to the deployment of software-based data-plane network functions on standard commodity hosts. The underlying idea is that NFV can potentially lead to reduced capital expenditures (capex) and operational expenditures (opex) compared to the conventional approach of using specialized hardware for implementing data-plane network functions in traditional switches/routers and middlebox appliances. The initial enthusiasm for NFV was evident among communication service providers, who joined forces on a collaborative white paper in 2012 [1] to explore its potential benefits. Subsequently, the European Telecommunications Standards Institute (ETSI) established the Network Functions Virtualisation Industry Specification Group (NFV ISG). NFV comprises three essential architectural components: (i) Network

Function Virtualisation Infrastructure (NFVI), (ii) Network Functions (NFs), and (iii) Management and Network Orchestration (MANO). The NFVI encompasses both hardware, which could be a single computer or a compute cluster, and framework software. This software offers functions that NFs commonly require, including dynamic scaling and NF placement. The scope of software-based dataplane network functions spans from fundamental packet forwarding to intricate middlebox tasks like intrusion prevention systems. These NFs, when executed on Virtual Machines (VMs), are termed Virtual Network Functions (VNFs). The MANO component encompasses management functions such as Fault, Configuration, Accounting, Performance, and Security (FCAPS), as well as orchestrators that oversee service chains comprising multiple NFs [2,3]. Cloud data centres have enhanced their operational efficiency and adaptability by utilizing virtualization methods, enabling the streamlined management of dynamically generated server instances, often in a centralized manner. This transformative trend is mirrored in the realm of both wide area networks and data centre networks through the implementation of software-defined networking (SDN) and network function virtualization (NFV). SDN introduces a logically centralized control plane capable of dynamically guiding packet trajectories among network devices according to programmable policies, thereby affording flexibility [4,5].

NFV revolutionizes networks, shifting them from hardware appliances that rely on specialized application-specific integrated circuits (ASICs) to software that operates within virtual machines (VMs) on standard off-the-shelf (COTS) hardware. This transformation aims to enhance flexibility and reduce costs. When coupled with SDN, NFV has the potential to fundamentally reshape network deployment and management strategies. The transition to a software-driven environment facilitated by NFV simplifies the deployment of network services, empowering them with greater potency and adaptability. This enables the realization of intricate topologies and feature-rich network functions, which surpass the capabilities of hardware-based counterparts. However, the performance constraints of commodity hardware and the overhead introduced by server virtualization platforms have hindered the complete migration of high-performance network processing away from hardware-based routers and middleboxes [6,7]. Network Functions (NF) or middleboxes play a vital role in contemporary networks, providing support for a diverse array of functions encompassing security (such as firewalling and intrusion detection) and performance optimization (like caching and proxying). Presently, the deployment and management of middleboxes pose significant challenges. This is predominantly due to the necessity of following cumbersome procedures, including dealing with a variety of specialized hardware interfaces and manually configuring the chaining of middleboxes to achieve the desired network behaviour. Moreover, recent research demonstrates that the count of middleboxes in enterprise networks, datacenter setups, and Internet Service Provider (ISP) networks is comparable to the number of physical routers [8].

Hence, the challenges mentioned earlier are compounded by the intricacy arising from the extensive array of network functions that a network provider must manage, resulting in elevated operational expenses. Furthermore, apart from the expenditures associated with manual middlebox deployment and chaining, the requirement for frequent hardware upgrades contributes to significant capital investments. As a solution, Network Function Virtualization (NFV) has been suggested to transition middlebox processing from dedicated hardware appliances to software operating on standardized hardware. Alongside the potential reduction in procurement and maintenance costs, NFV is anticipated to enable network providers to harness the advantages of virtualization for managing network functions, encompassing attributes such as elasticity, performance enhancement, and flexibility [9]. Despite persistent endeavours to realize the implementation of NFV, there has been limited progress in effectively executing the placement and arrangement of virtual network functions within physical infrastructures. This challenge is notably intricate for two primary reasons. Firstly, the positioning and chaining of virtual network functions can potentially lead to impractical end-to-end latencies. This predicament is exacerbated by the inherent higher processing times associated with virtualization, which can fluctuate based on the nature of the network function and the hardware setup of the hosting device. Secondly, the allocation of resources must be carried out judiciously to prevent excessive or inadequate provisioning. Consequently, the strategic placement of network functions and the programming of network flows in an economically viable manner, while concurrently ensuring acceptable end-to-end delays, stand as crucial prerequisites for facilitating the practical adoption of NFV within operational environments [10,11].

2. MATERIALS AND METHODS

In this research endeavour, the central facets of network performance being evaluated and juxtaposed encompass Scalability, Resource Utilization, Latency, and Energy Consumption. These metrics collectively offer a comprehensive perspective on a network's adeptness in accommodating shifting demands, optimizing the use of available resources, minimizing data transmission delays, and efficiently managing energy consumption. Scalability pertains to a network's proficiency in managing a growing user base, devices, or requirements while upholding operational efficiency and responsiveness. Resource Utilization gauges the effectiveness by which network resources, including processing power, memory, and bandwidth, are employed to execute tasks and functions. Latency signifies the time lag between triggering an action and witnessing its initial response, a factor that significantly influences real-time communication and reactivity. Energy Consumption evaluates the quantity of electrical energy consumed by network components and devices during their operation, influencing operational expenses and ecological impact. This study involves scrutinizing and comparing diverse network configurations, including the conventional Traditional Hardware approach, where network functions are executed on dedicated physical hardware. Additionally, the study investigates alternative implementations of Network Function Virtualization (NFV):

NFV with Software Acceleration: Virtualized network functions are executed using software-based acceleration techniques.

NFV with GPU Acceleration: Graphics Processing Units (GPUs) are harnessed to augment processing speed and performance of virtualized network functions.

NFV with FPGA Acceleration: Field-Programmable Gate Arrays (FPGAs) are utilized to achieve specialized and efficient processing of network functions.

Cloud-based NFV: Network functions are deployed and managed within a cloud computing environment, providing scalability and adaptability.

Through a comprehensive evaluation of these distinct network configurations based on the specified performance metrics, this research endeavours to unveil insightful perspectives on their respective strengths, weaknesses, and overall performance attributes. This analysis contributes to a deeper comprehension of the capacities and trade-offs inherent in different NFV and traditional hardware paradigms within the realm of networking.

TOPSIS method: The assessment of Multiple Criteria Decision Making (MCDM) challenges often involves the utilization of the evaluation method "TOPSIS." This technique finds widespread application in various practical scenarios, including appraising a company's financial stability, contrasting economic outcomes, and evaluating modern production methods. However, it is essential to acknowledge certain limitations [12]. Regrettably, the "TOPSIS technique" is not without significant issues. One concern is the possibility of "rank reversal," an occurrence where the "order of preference for the alternatives" changes based on the introduction or removal of a choice from the decision-making context [13]. This can lead to instances of "Total rank reversal," where priorities undergo a complete reversal, turning once-favoured options into unfavourable ones. In "MCDM," the objective is to assess and evaluate multiple alternatives across various variables. The aim is to provide decision-makers with a range of choices. As practical situations often involve competing criteria, it's unlikely that a single solution can satisfy all criteria simultaneously. Consequently, a balanced approach is sought based on decision objectives. The "Negative Ideal Solution (NIS) most similar to the Positive Ideal Solution (PIS)" is considered the optimal choice in accordance with TOPSIS' guiding principle. The final score is determined using the closeness metric [14-16]. While the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) offers notable advantages, such as user-friendliness and the ability to assess multiple criteria concurrently, it also has inherent limitations. Subjective criteria weighting can introduce bias, and the method's simplicity may not adequately address intricate criterion interactions. Additionally, TOPSIS assumes criteria independence, a condition that might not hold in real-world scenarios. Its lack of a rigorous mathematical foundation raises concerns about theoretical robustness. Handling extensive datasets can pose computational challenges, and its inability to incorporate uncertainty limits its utility in uncertain contexts. While advantageous, decision-makers must carefully consider these pros and cons when opting for TOPSIS in practical decision-making [17-19].

3. ANALYSIS AND DISCUSSION

TABLE 1. Performance Benchmarking of NFV Infrastructure

Alternative	Scalability	Resource Utilization	Latency	Energy Consumption
Traditional Hardware	3	4	4	5
NFV with Software Acceleration	4	3	3	3
NFV with GPU Acceleration	5	4	3	4
NFV with FPGA Acceleration	4	5	3	4
Cloud-based NFV	3	4	4	3

Table 1 provides an evaluation of the performance benchmarks for various alternatives in Network Function Virtualization (NFV) infrastructure, focusing on Scalability, Resource Utilization, Latency, and Energy Consumption. Traditional Hardware demonstrates a moderate scalability with a rating of three, while both NFV with GPU Acceleration and NFV with FPGA Acceleration exhibit high scalability, earning scores of 5. NFV with Software Acceleration and Cloud-based NFV display differing levels of scalability, achieving scores of 4 and 3, respectively. Resource Utilization is appraised, with Traditional Hardware and NFV with FPGA

Acceleration taking the lead with impressive scores of 4 and 5, signifying efficient resource utilization. NFV with Software Acceleration and Cloud-based NFV attain a score of 3, while NFV with GPU Acceleration secures a score of 4. Latency is examined, and all options except NFV with FPGA Acceleration and NFV with GPU Acceleration are assigned a score of 3, denoting similar latency levels. Both NFV with FPGA Acceleration and NFV with GPU Acceleration earn a score of 3, indicating marginally reduced latency. In terms of Energy Consumption, Traditional Hardware ranks highest with a score of 5, indicative of greater energy usage. NFV with Software Acceleration and NFV with FPGA Acceleration both achieve a score of 4, suggesting relatively efficient energy consumption. NFV with GPU Acceleration and Cloud-based NFV share a score of 3, implying superior energy efficiency.

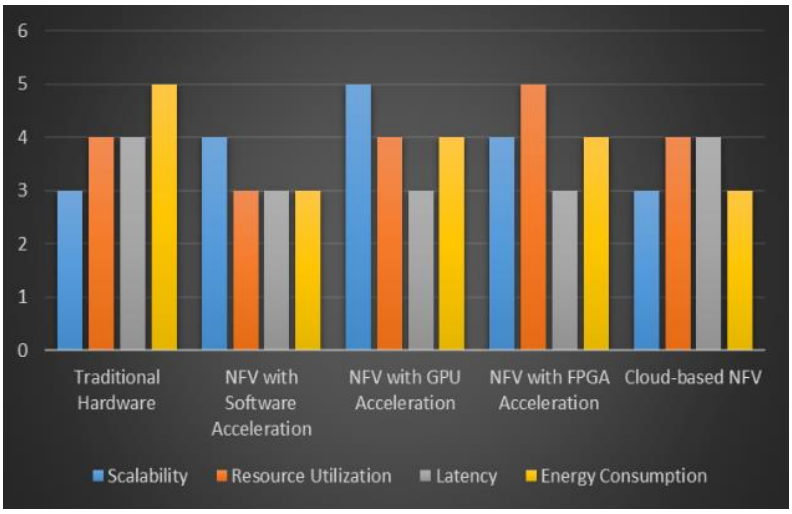

FIGURE 1. Performance Benchmarking of NFV Infrastructure

Figure 1 assesses the performance benchmarks of different Network Function Virtualization (NFV) alternatives, with a focus on Scalability, Resource Utilization, Latency, and Energy Consumption. Traditional Hardware displays moderate scalability (rated 3), whereas NFV with GPU and FPGA Acceleration demonstrate notable scalability (score 5). NFV with Software and Cloud-based NFV present varying degrees of scalability (4 and 3, respectively). Resource Utilization is highest for Traditional Hardware and NFV with FPGA (rated 4 and 5), while NFV with Software and Cloud-based NFV achieve a score of 3, and NFV with GPU scores four. Latency shows consistent scores of three for most cases, except for NFV with FPGA and GPU, which exhibit slightly reduced latency (also scored 3). In terms of Energy Consumption, Traditional Hardware receives the highest score (5), while NFV with Software and FPGA attain a score of 4. NFV with GPU and Cloud-based NFV both achieve a score of 3, indicating better energy efficiency.

TABLE 2. Normalized Data

0.3464	0.4417	0.5208	0.5774
0.4619	0.3313	0.3906	0.3464
0.5774	0.4417	0.3906	0.4619
0.4619	0.5522	0.3906	0.4619
0.3464	0.4417	0.5208	0.3464

Displayed in Table 2 is the normalized data obtained via the TOPSIS technique, depicting the comparative effectiveness of distinct Network Function Virtualization (NFV) choices concerning Scalability, Resource Utilization, Latency, and Energy Consumption. Notably, NFV alternatives incorporating GPU and FPGA Acceleration showcase elevated scalability and resource utilization. Conversely, NFV options employing Software Acceleration and Cloud-based approaches exhibit advantageous attributes in terms of latency and energy consumption. In contrast, Traditional Hardware exhibits shortcomings across multiple dimensions.

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 presents the distribution of weights assigned to different evaluation criteria for Network Function Virtualization (NFV) options. Each alternative, such as Traditional Hardware, NFV with Software Acceleration, NFV with GPU Acceleration, NFV with FPGA Acceleration, and Cloud-based NFV, is uniformly allocated a weight of 0.25 for Scalability, Resource Utilization, Latency, and Energy Consumption. This equitable allocation implies an equal consideration of all criteria during decision-making, streamlining the evaluation process and fostering a consistent approach to assessing the various alternatives.

TABLE 4. Weighted Normalized Matrix

0.0866	0.1104	0.1302	0.1443
0.1155	0.0828	0.0976	0.0866
0.1443	0.1104	0.0976	0.1155
0.1155	0.1380	0.0976	0.1155
0.0866	0.1104	0.1302	0.0866

Presented in Table 4 is the Weighted Normalized Matrix generated through the application of the TOPSIS methodology. It delineates the comparative effectiveness of different Network Function Virtualization (NFV) alternatives concerning Scalability, Resource Utilization, Latency, and Energy Consumption. Notably, NFV with GPU Acceleration emerges with the highest ratings, underscoring its excellence in Scalability and Resource Utilization. Additionally, NFV with FPGA Acceleration showcases commendable Resource Utilization. In contrast, Traditional Hardware and Cloud-based NFV exhibit relative shortcomings across multiple dimensions.

TABLE 5. the ideal best (A+) and ideal worst values (A-)

A+	0.1443	0.1380	0.0976	0.0866
A-	0.0866	0.0828	0.1302	0.1443

Table 5 illustrates the optimal best (A+) and unfavourable worst (A-) values for each criterion within the scope of Network Function Virtualization (NFV) assessment. A+ designates the most advantageous measures, showcasing NFV alternatives excelling in Scalability (0.1443), Resource Utilization (0.1380), and Latency (0.0976), while emphasizing minimized Energy Consumption (0.0866). Conversely, A- represents suboptimal values, highlighting elevated Energy Consumption (0.1443) and Latency (0.1302), along with reduced Resource Utilization (0.0828) and Scalability (0.0866).

TABLE 6. separation of each alternative from the ideal solution (Si+) and from the negative-ideal solution (Si-)

Alternative	SI Plus	Si Negative
Traditional Hardware	0.0921	0.0276
NFV with Software Acceleration	0.0623	0.0723
NFV with GPU Acceleration	0.0399	0.0774
NFV with FPGA Acceleration	0.0408	0.0760
Cloud-based NFV	0.0718	0.0640

Table 6 illustrates the results obtained from applying the TOPSIS method to evaluate how each Network Function Virtualization (NFV) alternative deviates from the ideal (Si+) and negative-ideal (Si-) solutions. A smaller Si+ value indicates a closer proximity to the ideal solution, while a smaller Si- value suggests a greater divergence from the negative-ideal solution. Traditional Hardware records the highest Si+ value (0.0921) and the lowest Si- value (0.0276), indicating a moderate alignment with the ideal and a substantial departure from the negative ideal. In contrast, NFV with GPU Acceleration achieves the most favorable Si+ (0.0399) and the highest Si- (0.0774), highlighting its advantageous positioning concerning the ideal and significant deviation from the negative-ideal solution.

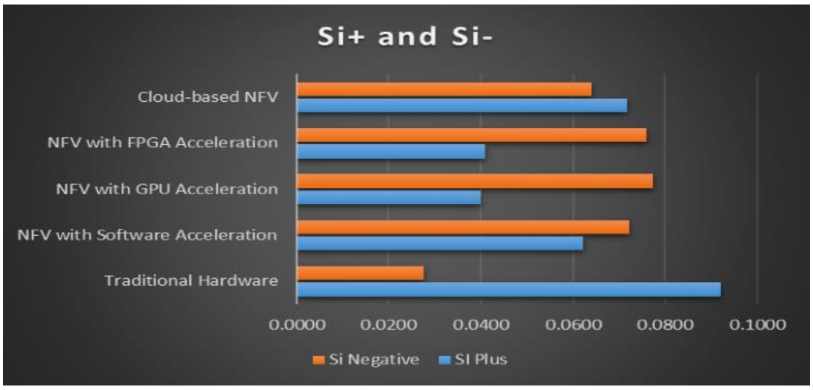

FIGURE 2. (Si+) and (Si-)

Figure 2 depicts the outcomes derived by employing the TOPSIS method to assess the extent of departure of each Network Function Virtualization (NFV) alternative from the ideal (Si+) and negative-ideal (Si-) benchmarks. A diminished Si+ value signifies closer proximity to the ideal solution, while a reduced Si- value implies a more pronounced deviation from the negative-ideal solution. Traditional Hardware records the highest Si+ value (0.0921) and the lowest Si- value (0.0276), indicating a moderate alignment with the ideal and a significant divergence from the negative ideal. In contrast, NFV with GPU Acceleration achieves the most favorable Si+ (0.0399) and the highest Si- (0.0774), underscoring its advantageous position relative to the ideal and substantial deviation from the negative-ideal solution.

TABLE 7. Closeness Coefficient (Ci) and Rank

Alternative	Ci	Rank
Traditional Hardware	0.2306	**5**
NFV with Software Acceleration	0.5371	**3**
NFV with GPU Acceleration	0.6596	**1**
NFV with FPGA Acceleration	0.6505	**2**
Cloud-based NFV	0.4713	**4**

Table 7 displays the Closeness Coefficient (Ci) and associated Ranks, resulting from the utilization of the TOPSIS method for evaluating Network Function Virtualization (NFV). The Ci values signify the relative proximity of each alternative to the ideal solution; higher Ci values indicate a stronger alignment. Leading the ranking is NFV with GPU Acceleration, securing the highest Ci value (0.6596) and showcasing exceptional overall performance. Following closely is NFV with FPGA Acceleration (Ci: 0.6505) at the second rank, while NFV with Software Acceleration (Ci: 0.5371) takes the third position. Cloud-based NFV (Ci: 0.4713) and Traditional Hardware (Ci: 0.2306) hold the fourth and fifth ranks, respectively, reflecting their comparative standings within the assessment.

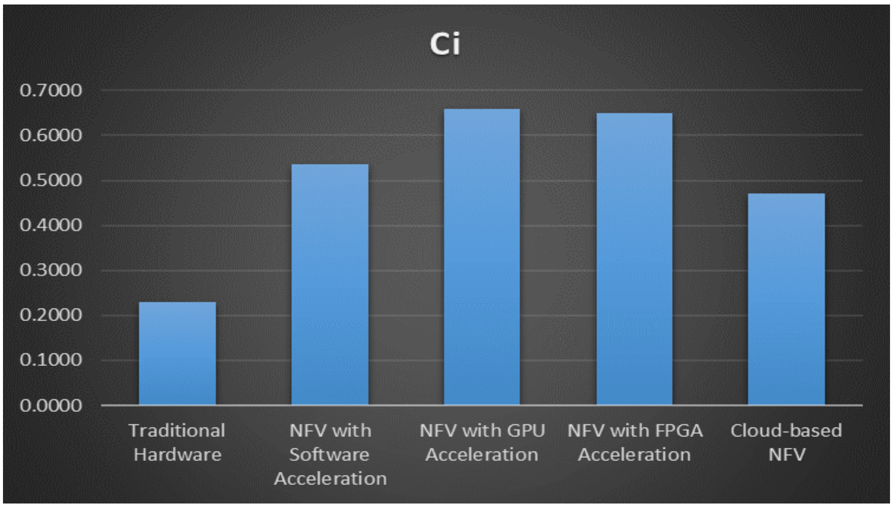

FIGURE 3. Closeness Coefficient (Ci)

In the context of figure 3, the closeness coefficient values offer insights into the relative effectiveness of the NFV alternatives. NFV with GPU Acceleration secures the highest Ci value (0.6596), implying its strong alignment with the ideal solution and, consequently, its exceptional performance in comparison to other alternatives. Similarly, NFV with FPGA Acceleration follows closely with a high Ci value (0.6505), signifying its competitive standing. NFV with Software Acceleration obtains a Ci value of 0.5371, indicating its favorable performance but with some degree of distance from the ideal solution. Cloud-based NFV and Traditional Hardware exhibit Ci values of 0.4713 and 0.2306, respectively. While Cloud-based NFV shows a relatively moderate closeness to the ideal solution, Traditional Hardware lags behind, suggesting a notable disparity between its performance and the optimal attributes.

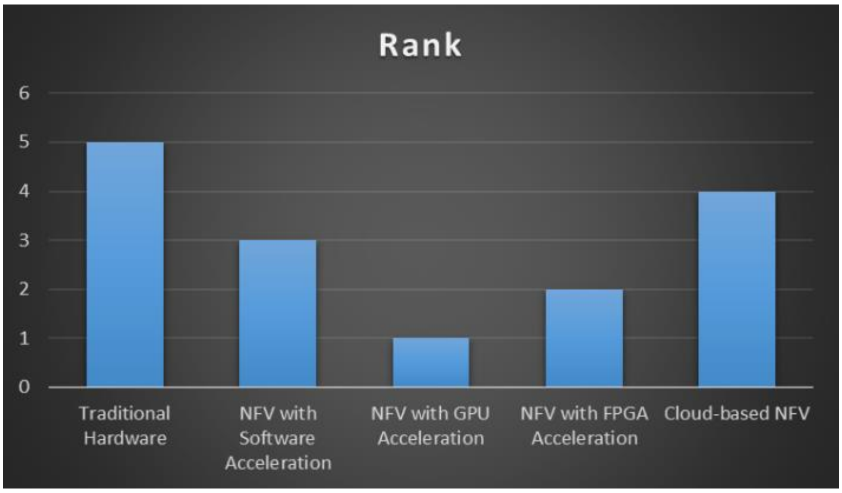

FIGURE 4. Rank

The significance of the rank values depicted in Figure 4 lies in their role of assessing and contrasting the effectiveness of distinct Network Function Virtualization (NFV) options using the TOPSIS methodology. These ranks stem from the Closeness Coefficient (Ci) values, which measure how closely each alternative approaches the optimal solution. Lower ranks denote a stronger alignment with the ideal solution and thus a more favorable performance outcome. Notably, NFV with GPU Acceleration attains the top rank (Rank 1) by securing the highest Ci value (0.6596), underscoring its outstanding performance and close proximity to the ideal. Following closely, NFV with FPGA Acceleration claims Rank 2 (Ci: 0.6505), reaffirming its robust competitive position. Occupying Rank 3 (Ci: 0.5371), NFV with Software Acceleration showcases commendable performance albeit with some gap from the leading alternatives. Cloud-based NFV and Traditional Hardware secure the fourth and fifth ranks respectively, reflecting comparatively lower performance levels based on their Ci values (0.4713 and 0.2306).

4. CONCLUSION

The assessment of Network Function Virtualization (NFV) infrastructure and its comparison with conventional hardware-based networks is crucial for advancing the efficiency, scalability, and overall performance of contemporary communication systems. The establishment of robust methodologies, combined with the application of the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) approach, offers a structured framework to achieve these goals and facilitate informed decision-making. The methodologies outlined facilitate a comprehensive evaluation of NFV infrastructure performance by defining pertinent evaluation criteria, accurately collecting data, standardizing metrics, assigning suitable weights, and computing scores. This methodical approach ensures a comprehensive exploration of NFV's capabilities, allowing for an equitable and well-rounded contrast with traditional networks. The TOPSIS method, with its emphasis on both positive and negative ideal benchmarks, introduces objectivity by quantifying the closeness of alternatives to these standards, aiding in ranking and prioritizing solutions. Comparative analysis between NFV and traditional networks provides a nuanced insight into their respective strengths and limitations. Identifying bottlenecks where NFV falls short or where both alternatives face challenges direct attention toward crucial areas necessitating enhancement. Equally significant is pinpointing domains where NFV outperforms traditional networks, highlighting avenues to leverage NFV's inherent advantages. The TOPSIS method enhances decision-making by furnishing a structured framework to assess intricate alternatives. The Closeness Coefficient (Ci) values serve as a transparent and concrete gauge for ranking NFV options, simplifying the selection of the most viable configurations that closely align with the optimal solution. Such data-informed decision-making heightens the prospects of successful NFV implementations, where resources are judiciously allocated, and performance bottlenecks are addressed. As communication systems evolve, NFV signifies a transformative paradigm shift. Its effective integration demands a well-considered approach that balances innovation with practicality. Through systematic evaluation of NFV performance and a comparative analysis against traditional networks using robust methodologies and the TOPSIS method, organizations can strategically enhance their network structures, optimize resource utilization, minimize latency, and ensure energy-efficient operations. This holistic perspective empowers stakeholders to make well-founded choices, fostering the realization of NFV's potential and propelling communication networks toward a more agile, scalable, and efficient future.

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