Neutrosophic MCDM Model for Evaluation and Selection best 5G Network Architecture

Myvizhi M.[1*]

[1*]Department of Mathematics, KPR Institute of Engineering and Technology, Coimbatore, Tamilnadu, India

Emails:myvizhi.m@kpriet.ac.in

Abstract

Understanding the efficacy, efficiency, and viability of 5G network design in addressing the needs of the current digital age relies heavily on its assessment. This paper summarizes the assessment of 5G network design, including the evaluation methodology, evaluation techniques, and major conclusions. Infrastructure needs, network capacity, security, interoperability, and cost-effectiveness are just some of the topics it brings up. In order to overcome obstacles and guarantee 5G's effective deployment and performance in real-world settings, the abstract finishes by stressing the need of constant review and improvement of network design. This paper used the single valued neutrosophic set to overcome the uncertain data in evaluation 5G network architecture. The single valued neutrosophic set integrated with multi-criteria decision making (MCDM) tools to evaluate and select best 5G network architecture. The single valued neutrosophic TOPSIS method used to select best 5G network architecture.

Keywords: Neutrosophic Set; MCDM; Network; IoT; 5G Network Architecture.

1. Introduction

Wireless communications and networking are poised for radical change with the arrival of 5G technology. 5G, the next generation of mobile networks, is expected to significantly improve data transfer speeds, latency, capacity, and connection. The architectural design of 5G is one of the primary factors determining its capabilities and performance. The 5G architecture defines the structure, capabilities, and interconnections of the network, and is used as a guide throughout implementation and maintenance[1], [2].

The success of this new technology depends on how well the 5G architecture is planned. Enhanced mobile broadband, enormous Internet of Things (IoT) deployments, mission-critical communications, and ultra-reliable low-latency applications are just some of the applications and services that may benefit from this infrastructure. The network's capabilities, scalability, flexibility, dependability, security, and cost-effectiveness are all affected by the design[3], [4].

Multiple 5G network architecture frameworks have been suggested by the research and development community and industry players. Architectures like this are developed with 5G's varied needs and applications in mind. Network operators, politicians, and technology suppliers all have an important role to play in evaluating potential architectures and making a final decision on the best option. It calls for an in-depth familiarity with the different architectural choices, their advantages and disadvantages, and how well they work in various deployment contexts[5], [6].

The purpose of this study is to examine and compare several 5G architectures to better understand their salient features, capabilities, and consequences. This study intends to go into the specifics of these architectures to shed light on how they could affect network performance and which use cases would be most suited to them. The article will also analyze

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the trade-offs and elements to think about when choosing the best architecture, including deployment size, cost, performance needs, and future scalability[7], [8].

Multiple criteria, including network needs, deployment scenarios, scalability, flexibility, latency, reliability, security, and cost-effectiveness, must be taken into account while determining the optimum 5G design. So the concept of multi-criteria decision-making (MCDM) is used due to various criteria. The MCDM models do not achieve high accuracy due to not dealing with uncertain data. So, we integrated the MCDM models with the neutrosophic set to deal with uncertain data[9], [10].

Due to the nebulous and complicated nature of real-world choice issues, it is not always easy for individuals to express their thoughts quantitatively. Zadeh came up with the novel idea of using fuzzy sets with a range of membership degrees to handle ambiguous data, and other researchers have broadened the field's potential uses. However, fuzzy systems are incapable of dealing with ambiguous or contradictory data. Smarandache was the first to propose using Neutrosophic NSs to address the issue. Independent truth-value membership, indeterminacy-membership, and falsity-membership make this a generalization of sets like the classical set, fuzzy set, intuitionistic fuzzy set, etc[11], [12].

Non-standard intervals with fuzzy bounds are used to define NSs, which makes them difficult to use in engineering and research. To cope with partial, inconsistent, and inaccurate fuzzy information, Wang et al. created SVNSs, which are the subtypes of NSs but may be readily applied to actual scientific and engineering disciplines[13], [14].

One of the goals of multi-criteria decision making (MCDM) is to rate options for making a choice according to how well they meet a set of criteria. Traditional techniques of multi-attribute decision making (MCDM) rate choice alternatives based on how similar or different they are from certain reference points, such as the best ideal option, the worst solution, or the average answer. In most cases, just one yardstick is utilized to determine a rating. These approaches based on a single reference point are often insensitive to outlying possibilities. To overcome this obstacle, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) family of algorithms has been created and frequently used to provide a ranking of choice alternatives relative to two criteria. A positive ideal solution (PIS) is the best answer, whereas a negative ideal solution (NIS) is the reverse. Distances from PIS and NIS are used to rank decision options. In other words, a superior option is one that reduces the distance to PIS while increasing the distance to NIS. Fuzzy sets, intuitionistic fuzzy sets, Pythagorean fuzzy sets, and other theories of uncertainty have been used to expand the class of TOPSIS procedures[15], [16]. In order to address MCDM issues, it has also been integrated with linguistic variables, rough sets, and grey theory. This paper extend the TOPSIS set under the single valued neutrosophic set.

2. Challenges of 5G Network Architecture

There are several obstacles that must be overcome throughout the rollout and installation of a 5G network design. When it comes to 5G network design, some of the biggest obstacles are:

Upgrades to existing infrastructure are essential for the successful deployment of 5G networks. To provide high-speed and low-latency connection, a dense network of tiny cells consisting of base stations and antennas must be deployed. Coordination with local authorities and overcoming obstacles like site acquisition, zoning rules, and the availability of appropriate places are often necessary for the successful installation of these new parts of infrastructure, which may be time-consuming and expensive[17], [18].

Spectrum Availability: 5G networks depend on a broad variety of transmission frequencies, from the very low to the very high. One difficulty is in securing enough spectrum for 5G networks. Spectrum allocation and management, dealing with interference difficulties, and coordinating spectrum use among many parties may be difficult in any setting, but particularly in highly crowded locations[19], [20].

Capacity and scalability of the network: New technologies like the Internet of Things (IoT), augmented reality (AR), and virtual reality (VR) will need 5G networks to handle enormous spikes in data traffic. The increasing demand for bandwidth-intensive applications poses a serious issue to ensuring enough network capacity and scalability. To effectively manage and extend their networks, network operators must invest in cutting-edge technologies like network slicing, edge computing, and cloud-based infrastructure[21], [22].

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Security and Privacy: With the rise of IoT devices and the heavy reliance on data in 5G networks, it is more important than ever to implement stringent measures to protect users' personal information. Concerns have been raised about the impact on network security, data protection, and privacy laws as a result of the expanded attack surface and possible vulnerabilities. To reduce these dangers, it's crucial to use strong security measures including encryption protocols, authentication methods, and privacy-enhancing technology[23], [24].

Standards and interoperability in 5G networks are challenging because of the wide variety of suppliers and technology used. It might be difficult to ensure compatibility and integration between various parts and nodes in a network. Interoperability, compatibility of equipment, and a healthy market may all be achieved via the creation and implementation of global standards for 5G networks[25], [26].

Energy efficiency: 5G networks might have greater energy needs due to the higher data demands and higher tiny cell densities. It is difficult to manage 5G networks' energy efficiency and lower their carbon impact. In order to lessen their influence on the environment, network operators should investigate energy-saving strategies, optimize network installations, and think about switching to renewable energy.

The costs and benefits of investing in the infrastructure, spectrum licenses, and technical advancements necessary for 5G network deployment and evolution are substantial. The issue for network operators is to provide cheap and competitive pricing for customers while making a fair return on their investments. Network operators face significant difficulties when trying to strike a balance between the expense of infrastructure expansion and the income potential of new services[27], [28].

Compliance with different legislative and policy frameworks relating to spectrum allocation, network security, privacy, and data protection is essential for the successful rollout of 5G networks. Network operators have difficulties in complying with laws, managing regulatory obligations, and adjusting to new rules due to the shifting regulatory environment and varying policies among nations.

Network operators, technology providers, legislators, and others must work together to find solutions to these problems. If these problems can be solved, 5G networks can be deployed and its full potential can be realized, allowing for game-changing applications and services across many sectors[29], [30].

3. Neutrosophic MCDM Model

This section extends the single valued neutrosophic set with the TOPSIS method to rank and select best 5G network architecture[31], [32], Figure 1 shows the flowchart of this study.

Step 3.1 Collect the set of criteria and alternatives based on the 5G network.

Step 3.2 Construct the decision matrix between criteria and alternatives.

Step 3.3 Compute the weights of criteria

Step 3.4 Normalize the decision matrix

The normalization matrix is performed by the cost and profit criteria.

$$t_{ij} = \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})} \quad (1)$$

$$t_{ij} = \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})} \quad (2)$$

Step 3.5 Calculate the weighted decision matrix

$$h_{ij} = w_j t_{ij} \quad (3)$$

Step 3.6 Determine the positive and negative ideal solution

$$I_j^+ = \max h_{ij} \quad (4)$$

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$$I_j^- = \min h_{ij} \quad (5)$$

Step 3.7 Compute the distance from positive and negative ideal solution for every option

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(h_{ij} - I_j^+\right)} \quad (6)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(h_{ij} - I_j^-\right)} \quad (7)$$

Step 3.8 Compute the utility function

$$u_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (8)$$

Step 3.9 Rank the 5G network architecture.

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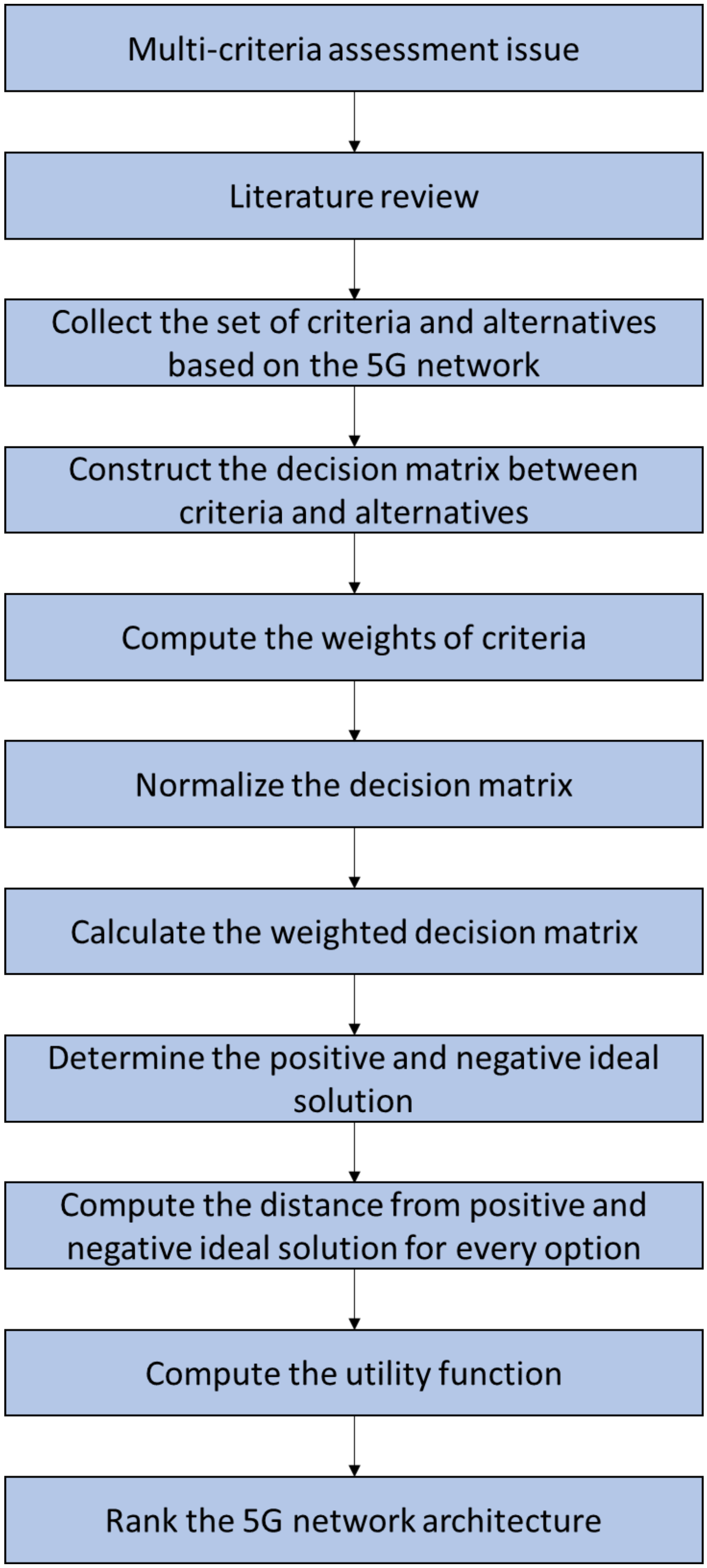

Figure 1: The flowchart of the multi-criteria evaluation problem.

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4. Results

This section summarizes the results of single valued neutrosophic TOPSIS method. This paper collected ten criteria and five alternatives to be evaluated.

To guarantee the architecture is suitable for the desired use cases and offers a solid basis for the network, numerous factors should be taken into account while assessing potential 5G architectures. Some popular measures used to assess 5G network design include:

To facilitate a wide variety of applications, such as improved mobile broadband, the Internet of Things (IoT), and mission-critical communications, the architecture must support high data rates, low latency, and higher capacity. Each use case has unique performance requirements, and the system should fulfill those needs.

The design has to be scalable so it can handle the ever-increasing data volume and ever-increasing number of connected devices. It has to be able to accommodate a rapidly growing network without slowing down or otherwise degrading performance.

The architecture has to be malleable enough to accommodate a variety of deployment use cases and keep up with the rapid pace of technological development. It should make it possible to add new services, technologies, and functions to an existing network without causing major problems.

High availability of services requires an architecture with built-in redundancy and fault tolerance. To prevent interruptions in service and keep operations running smoothly, it must have built-in redundancy, failover methods, and effective fault management.

Network and user data should be kept private, secure, and always accessible by including strong security procedures in the design of the architecture. Secure communication methods, authentication systems, and data privacy should all be addressed.

The capability to create several virtual networks on the same physical infrastructure, known as "network slicing," should be included in the design. varied use cases have varied needs, hence the network should be able to be segmented to offer those services, isolation, and quality of service assurances.

The design has to encourage interoperability between various network components, pieces of hardware, and suppliers. To be easily integrated and interoperable with other components in the ecosystem, it must use standard interfaces and protocols.

The architecture has to include strong methods for management and orchestration to provide successful network operations, monitoring, and service delivery. Network performance and resource utilization may be improved with the use of automation, real-time analytics, and control features.

To be cost-effective, the design must strike a good balance between performance and price. To make sure the network is sustainable economically, it should think about things like equipment prices, energy efficiency, running costs, and the whole price of ownership.

Future-proofing means that the design may change to include new technologies and use cases as they emerge. It should be backward-compatible with existing wireless networks and provide easy upgrades and improvements via migration.

Organizations may pick a 5G architecture that meets their needs, optimizes performance, and lays a strong basis for the deployment and operation of their 5G networks by taking into account these factors throughout the examination of 5G architecture alternatives.

Step 3.1 This paper collect the ten criteria and five alternatives to evaluated in this study.

Multiple criteria, including network needs, deployment scenarios, scalability, flexibility, latency, reliability, security, and cost-effectiveness, must be taken into account while determining the optimum 5G design. Several different 5G designs have been suggested, however the following five are among the most prominent:

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With the Non-Standalone (NSA) architecture, 4G networks may be used with the addition of 5G capabilities. It creates a new 5G radio access network (RAN) and uses the 4G core network (EPC) for control plane functionality. While this design makes it easier and cheaper to roll out 5G, it may not support all of the sophisticated features and capabilities of 5G networks.

The Standalone (SA) Architecture is a 5G network that operates independently of the current 4G infrastructure. The 5G RAN is accompanied by a new 5G core network (5GC). The complete capabilities of 5G, such as network slicing, ultra-low latency, and huge IoT support, are made possible by SA architecture. However, a whole network redesign is necessary, and implementation costs might go up as a result.

The radio operations are kept decentralized in Remote Radio Units (RRUs) but the baseband processing activities are centralized in a cloud-based infrastructure known as the Centralized Unit (CU) in the Cloud-RAN architecture. The advantages of C-RAN include enhanced efficiency in the use of resources, greater scalability, and simplified administration. It allows for sophisticated RAN features to be deployed and efficient resource allocation.

The baseband processing operations may be split into two distinct groups using the DU and CU architecture. The Centralized Unit (CU) is housed in a data center, whereas the Distributed Unit (DU) is positioned nearer the radio access network. This design improves scalability, reduces front haul needs, and permits versatile deployment choices.

To facilitate interoperability and vendor-agnostic deployments, open RAN (O-RAN) design seeks to decouple the various RAN components. Open interfaces and standardization are encouraged, giving operators more freedom in their component selection. By encouraging competition and reducing reliance on a single provider, O-RAN may help businesses save money, time, and effort.

The needs and goals of the deploying organization will determine the optimal 5G architecture to use. Existing infrastructure, deployment size, performance requirements, cost constraints, and planned expansion should all be taken into account. If you want to know which architecture is best for a certain deployment situation, you need to do some research and weigh the pros and downsides of each. To evaluate the efficacy and compatibility of various designs, businesses may choose to conduct proof-of-concept experiments and seek advice from professionals in the field.

Step 3.2 Construct the decision matrix between criteria and alternatives.

Step 3.3 Compute the weights of criteria as shown in Figure 2.

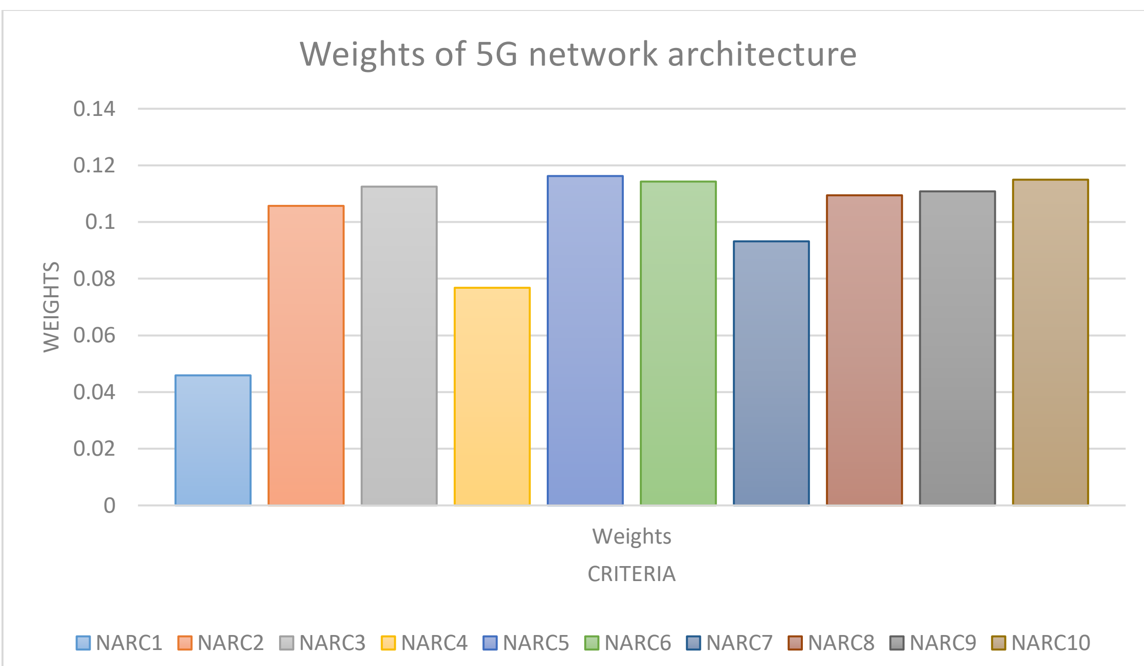

Figure 2: The weights of ten 5G network criteria.

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Step 3.4 Normalize the decision matrix by using Eqs. (1 and 2) as shown in Table 1.

Table 1: The normalized decision matrix

	$NARC_1$	**$NARC_2$**	**$NARC_3$**	**$NARC_4$**	**$NARC_5$**	**$NARC_6$**	**$NARC_7$**	**$NARC_8$**	**$NARC_9$**	**$NARC_{10}$**
$NARA_1$	0.327806	0.321103	0.42422	0.253907	0.245889	0.169764	0.407963	0.215313	0.472723	0.505812
$NARA_2$	0.351419	0.300519	0.374839	0.495015	0.655478	0.629854	0.591768	0.76852	0.587301	0.446735
$NARA_3$	0.356836	0.793041	0.703336	0.425939	0.381943	0.536627	0.203346	0.435734	0.175847	0.151235
$NARA_4$	0.730618	0.298049	0.21059	0.513837	0.160303	0.378373	0.492478	0.361197	0.253171	0.568314
$NARA_5$	0.3285	0.298049	0.374839	0.495015	0.581643	0.378589	0.446646	0.206615	0.580166	0.44579

Step 3.5 Calculate the weighted decision matrix by using Eq. (3) as shown in Table 2.

Table 2. The weighted normalized decision matrix

	$NARC_1$	**$NARC_2$**	**$NARC_3$**	**$NARC_4$**	**$NARC_5$**	**$NARC_6$**	**$NARC_7$**	**$NARC_8$**	**$NARC_9$**	**$NARC_{10}$**
$NARA_1$	0.015046	0.03395	0.047732	0.019505	0.028586	0.019405	0.038022	0.023568	0.052398	0.058154
$NARA_2$	0.01613	0.031774	0.042175	0.038027	0.076204	0.071997	0.055153	0.084121	0.065098	0.051362
$NARA_3$	0.016378	0.083847	0.079137	0.032721	0.044404	0.06134	0.018952	0.047695	0.019491	0.017388
$NARA_4$	0.033534	0.031512	0.023695	0.039473	0.018636	0.043251	0.045899	0.039536	0.028062	0.06534
$NARA_5$	0.015078	0.031512	0.042175	0.038027	0.06762	0.043275	0.041628	0.022616	0.064307	0.051253

Step 3.6 Determine the positive and negative ideal solution by using Eqs. (4 and 5)

Step 3.7 Compute the distance from positive and negative ideal solution for every option by using Eqs. (6 and 7)

Step 3.8 Compute the utility function by using Eq. (8)

Step 3.9 Rank the 5G network architecture as shown in Figure 3. The security and privacy criteria is the highest weight.

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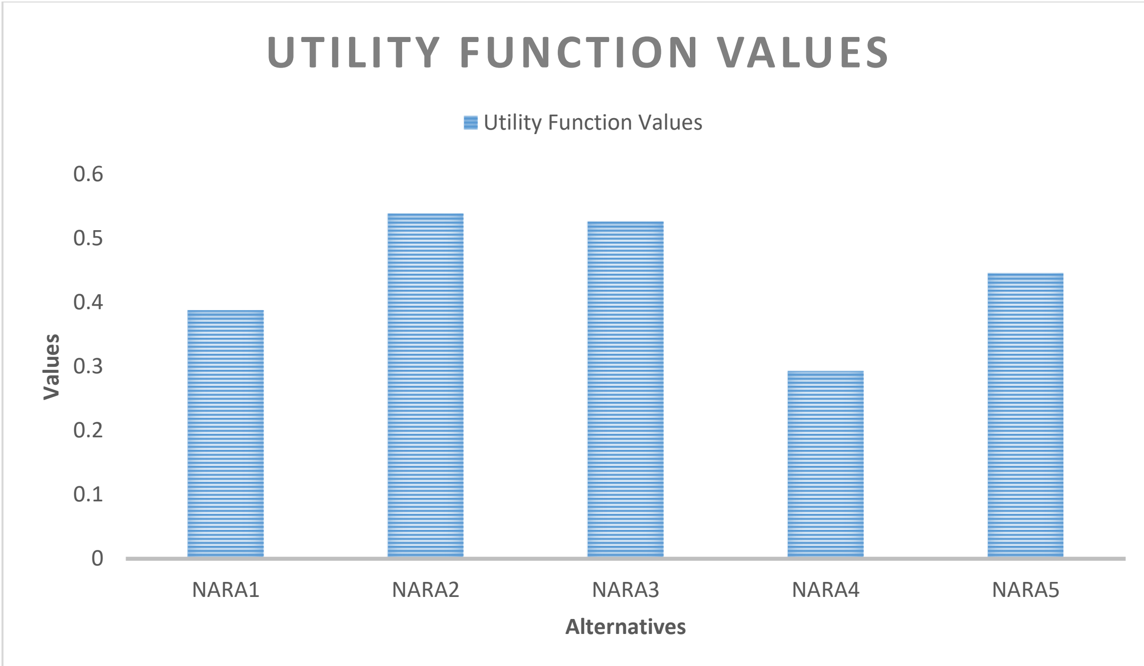

Figure 3: The valued of utility function.

5. Conclusions

The study of the 5G network design has shown its benefits, drawbacks, and room for development. The results of a careful analysis allow us to derive many important conclusions:

Compared to earlier generations, 5G network design provides considerable gains in data rates, capacity, and latency, as shown by the assessment. Promising achievements have been achieved in providing high-speed and low-latency connections via the deployment of tiny cells, network slicing, and cutting-edge technologies like beamforming and Massive Multiple-Input Multiple-Output (MIMO).

The research has shown several difficulties in establishing a 5G network's physical infrastructure. Significant challenges are posed by site acquisition, zoning requirements, and the lack of appropriate sites for tiny cells. To overcome these obstacles, network providers, regulatory organizations, and local authorities must work together to expedite the rollout of necessary infrastructure.

The research has shown the need for stringent security and privacy controls in the design of 5G networks. With so many devices being linked together and so much data being sent over 5G networks, protecting user privacy is more important than ever. Effective implementation of encryption protocols, authentication procedures, and privacy-enhancing technologies is necessary to reduce dangers.

In order to guarantee interoperability and compatibility across various components and manufacturers in 5G network architecture, evaluation has indicated the necessity for worldwide standards. Seamless integration, easier invention, and more robust competition are all made possible by the creation and widespread use of standardized protocols and interfaces.

Evaluations have shown that 5G network implementation and upgrading calls for substantial expenditures with uncertain returns. It is difficult for network operators to make a profit while keeping prices low and competitive for customers. The financial sustainability of 5G networks depends on efficient infrastructure development, optimized network management, and the investigation of income sources from new services.

The performance, problems, and potential of 5G have been better-understood thanks to the study of its network design. Tackling these issues and tapping into 5G networks' full potential will need continuous assessment, improvement, and

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stakeholder participation. 5G networks may become a game-changing technology that allows a broad variety of creative applications and services in the digital age by meeting infrastructure needs, assuring security, fostering interoperability, and optimizing prices. This paper used the single valued neutrosophic TOPSIS to assess the 5G network architecture. This paper used ten criteria and five alternatives to be evaluated. The security and privacy has the highest importance in all criteria.

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