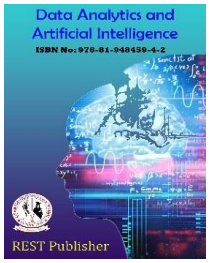
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AI-Enabled Clinical Decision Support Systems in Healthcare ARAS Multi-Criteria Evaluation Framework

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Abstract: *This study evaluates and ranks alternative military communication satellite systems using Gary Relational Analysis (GRA), a multi-criteria decision-making technique. The increasing demand for secure, reliable, and high-speed communication highlights the importance of selecting efficient satellite technologies for defines applications. Various satellite alternatives, including broadcast, laser communication, X-band, fixed satellite services, hybrid, constellation-based, and Earth observation systems, are examined. Their performance is assessed using key parameters such as latency, bandwidth, power consumption, deployment speed, and data transmission delay variation. The GRA methodology involves data normalization, grey relational coefficient calculation, and relational grade determination to establish the overall ranking. The findings indicate that laser communication and constellation-based satellites demonstrate superior performance in terms of transmission speed, bandwidth, and reduced latency. Hybrid satellite systems also provide balanced performance and operational flexibility. The proposed evaluation framework supports systematic satellite selection and informed strategic decision-making for advanced military communication infrastructure.*

Keywords: *Military Satellites, GRA, Communication Systems, Satellite Evaluation, Multi-Criteria Decision-Making, Laser Communication, Bandwidth, Latency, Hybrid Systems, X-Band.*

1. INTRODUCTION

The second concern is to ensure that the service is not accessed fraudulently to avoid usage charges. This includes implementing measures to prevent fraud by verifying that the user's mobile devices are authentic and authorized. The encryption and decryption processes involved in the authentication protocol require significant computational effort. [1] As a result, the mobile user requires a high level of skill and a powerful processing unit to effectively adhere to the protocol. Ensuring communication security in LEO satellite communication systems is important. This paper introduces a robust scheme designed to authenticate mobile users and secure communication transmissions. [2] Satellite communications encompass a variety of systems, including satellite-based land mobile and fixed communications, satellite navigation and Earth observation systems, advanced propagation models, and evaluation tools for these technologies. Radio propagation channels can be constructed using various methods, such as measured impulse responses and ray-tracing algorithms, which can be complex and time-consuming. Alternatively, a statistical approach can be used that simplifies the input data and reduces the computational effort. [3] Satellite communications are considered as a secondary channel for transmitting traffic in 5G backhaul. In this context, deciding whether to route traffic via satellite or terrestrial backhaul presents an interesting challenge. Several new broadband services have recently been launched for next-generation satellite communications systems, made possible by advanced technologies that enable a satellite to handle hundreds of narrows, highly focused beams. In addition to its important role in designing and calibrating upcoming satellite systems, a traffic simulator also aids in the development of emerging technologies aimed at improving satellite communication capabilities. Compared to other terrestrial technologies, satellites offer a very cost-effective solution for communication and connectivity. To the best of the authors' knowledge, this is one of the few efforts to compile research on satellite communications from the perspective of IoT and M2M applications. A key feature to support IoT in satellite communications is seamless interoperability between satellites and on-site sensors or actuators. The authors suggest that further effort should be made in this area. For example, as previously mentioned, there is growing interest in exploring the potential applications of nanosatellite constellations. [5] This survey aims to present these technological advances in an organized manner, while emphasizing key research challenges and unsolved issues. Aggressive frequency reuse strategies have proven to be a promising method for improving the spectral efficiency of satellite communication systems. In this context, the allocation of C-band for new 5G systems should be done with caution to protect the continuity of essential satellite communication services. This section aims to discuss the major

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developments related to the Medium Access Control (MAC) layer in satellite communication systems. Satellite communications have received significant interest from the community to increase their peak data rates, improve the use of limited spectrum resources, and meet the growing demand for data-intensive applications. [6] This fundamental study of satellite communications will explore the architecture of communications networks as well as the fundamental concepts of the field. It will also explore the diverse applications of satellite communications, from telecommunications and broadcasting to navigation, Earth observation and beyond. Allocation of frequency bands for satellite communications is a critical and complex task, overseen by international regulatory bodies and national agencies. Integrating satellite communications with 5G and future technologies improves connectivity by integrating satellite and terrestrial systems into a unified network architecture. Satellites extend coverage to remote and rural areas, strengthen disaster resilience, and support resiliency to terrestrial base stations. As we look back on this journey, we see that we are on the verge of yet more remarkable chapters shaped by innovation, collaboration and the boundless expanse of space. Satellite communications have demonstrated the limitless possibilities of human ambition. [7] In satellite communications, where even legitimate users are vulnerable to eavesdropping, there is relatively limited research devoted to physical layer security. The analytical curves for the probability of covert outages closely match the simulation results, and the asymptotic expressions are very accurate at high SNR levels, confirming the reliability of the derived formulas. Another important observation is that the intensity of the channel shadowing in the eavesdropper (EEV) link, even though the POP channel is stronger than the EEV on average, significantly affects the system performance. [8] The open architecture of Venters makes satellite communication systems vulnerable to active threats, including spoofing attacks. Satellites that follow predetermined orbits around the Earth provide advance information for security applications, with time difference of arrival (TDOA) measurements from multiple receivers used for authentication. [9] Satellite communication improves global coverage and improves communication quality, which faces several challenges. As with its impact on other fields, we believe that AI has the potential to significantly improve various aspects of satellite communications, given the inherent challenges in satellite communications. High mobility leads to frequent acquisitions, which is why many researchers have focused on acquisition management in satellite communications. Jamming attacks can target key locations and critical devices in a satellite network, reducing performance or even disrupting it altogether. As a result, various anti-jamming (AJ) techniques have been developed to mitigate such attacks and ensure secure satellite communications. [10] A global LEO constellation for low-speed communications is being developed with the sale of satellite communication terminals to attract more users and compete with terrestrial systems. Furthermore, a significant increase in the number of spacecraft will increase the likelihood of collisions. In particular, IRS has been used to improve signal quality for terrestrial network users, reduce interference for satellite users, and weaken listener reception. [11] Another key HTS circuit with promising applications in the wireless and satellite communication sectors is the pre-selected filter in receiver front-ends. Early applications of HTS thin-film microstrip filters have been successfully demonstrated, exhibiting exceptional performance. We will provide an assessment of the progress our group has made so far in integrating this technology into wireless and satellite communication systems. These simulations have shown good consistency with modeling results obtained from quasi-TEM diffraction analysis. The characteristics of these components, their small size, lightweight design, and low loss, along with their proven performance, indicate that they can be effectively used in satellite communication systems for both forward and return band operations. [12] The satellite communication sector has received increasing attention from the global telecommunications market as more network operators have begun to integrate satellites into them backhaul infrastructures for broadband connectivity. As a result, regional coverage constellations offer promising solutions to satellite operators, allowing them to operate with greater flexibility.

2. MATERIALS AND METHOD

Alternatives: Military Communication Satellites: Military communication satellites are essential for secure, reliable and long-range communication in defense and military operations. These satellites provide global connectivity to military forces, enabling secure transmission of voice, data and video even in remote or hostile environments. They play a key role in maintaining operational efficiency, enhancing command and control capabilities, and ensuring uninterrupted communications during conflicts or emergencies. Broadcast Satellites: Broadcast satellites are designed to transmit television, radio and multimedia content to a wide audience over wide geographical area. These satellites facilitate high-quality, uninterrupted broadcasting services, providing coverage to remote and underserved areas where terrestrial networks are not possible. They play a key role in the global distribution of media content, enabling satellite television, radio services and live event coverage, regardless of location. Laser Communication Satellites: Laser communication satellites use laser communication satellites for high-speed, secure data transmission between satellites and ground stations. This technology offers advantages over traditional radio frequency communications such as higher bandwidth, reduced interference, and lower power consumption. Laser communication systems are gaining attention due to their potential to support future space networks, satellite constellations, and provide fast and efficient communications for space missions. X-Band Satellite Systems: X-Band satellite systems operate in the 7-8 GHz frequency range and are widely used for military, government, and commercial satellite communications. They are known for their resilience to weather conditions and their ability to support secure and high-capacity communications. Due to their ability to handle

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high-priority traffic and provide reliable connectivity, X-Band systems are often used for critical communications applications such as military satellite communications, weather monitoring, and secure data transmission. Fixed Satellite Services (FSS): Fixed Satellite Services (FSS) refers to satellite communication systems that provide fixed, point-to-point services such as voice, data, and video transmissions between fixed terminals. FSS systems are essential for telecommunications, broadcasting, and internet connectivity, especially in areas where terrestrial infrastructure is lacking. They provide a reliable and flexible solution for global connectivity, providing coverage in remote or underserved areas where traditional wired connections are not possible. Hybrid satellite systems: Hybrid satellite systems combine the capabilities of both satellite and terrestrial networks to enhance communication services. These systems integrate satellite networks with ground-based infrastructure, providing flexibility to overcome challenges such as signal interference, spectrum limitations, or coverage gaps. Hybrid systems are particularly useful for providing continuous connectivity in areas with limited terrestrial network coverage or for optimizing resource utilization in dynamic environments such as the Internet of Things (IoT) and 5G networks. Constellation-based systems: Constellation-based satellite systems involve the use of multiple satellites working together in a coordinated manner to provide seamless, global coverage. These systems are designed to improve communication performance, reduce latency, and provide increased capacity compared to single-satellite solutions. Constellations such as low Earth orbit (LEO) satellite networks are gaining popularity due to their ability to provide high-speed internet, global connectivity, and data services for a variety of applications, from mobile broadband to IoT. Earth Observation Satellites: Earth observation satellites are used to monitor and collect data on the Earth's surface, atmosphere, and oceans. These satellites are equipped with specialized sensors and cameras that capture images and other data for applications such as climate monitoring, disaster management, agriculture, and environmental protection. Earth observation satellites provide invaluable information for research, policymaking, and crisis response, contributing to a deeper understanding of the changes and challenges facing our planet.

Input Parameters:

- **Military Communication Satellites:** Military communication satellites provide secure, reliable, and continuous communication links for defense operations, supporting strategic coordination, information exchange, and real-time connectivity across geographically distant military units.

- **Broadcast Satellites:** Broadcast satellites distribute communication signals over extensive geographical regions, enabling military organizations to transmit information, voice messages, and operational data to multiple receiving stations.

- **Laser Communication Satellites:** Laser communication satellites use optical transmission technology to deliver high-speed data transfer, improved bandwidth, enhanced security, and reduced electromagnetic interference for advanced military communication applications.

- **X-Band Satellite Systems:** X-band satellite systems operate within dedicated frequency ranges, providing reliable military communication, resistance to atmospheric interference, and secure transmission capabilities for defense and strategic operations.

- **Fixed Satellite Services:** Fixed Satellite Services provide stable communication connections between predetermined ground stations, supporting continuous data transmission, military coordination, and dependable communication infrastructure.

- **Hybrid Satellite Systems:** Hybrid satellite systems integrate multiple communication technologies to improve operational flexibility, transmission reliability, network availability, and performance under different environmental and operational conditions.

- **Constellation-Based Systems:** Constellation-based satellite systems consist of multiple interconnected satellites that provide extensive coverage, communication redundancy, improved network availability, and continuous connectivity for military operations.

- **Earth Observation Satellites:** Earth observation satellites collect geographical and environmental information through remote sensing technologies, supporting military surveillance, reconnaissance, strategic planning, and intelligence-related communication activities.

Evaluation Parameters

- **Latency:** Latency represents the time required for information to travel between transmitting and receiving points. Lower latency improves real-time communication, operational coordination, and military response efficiency.

- **Bandwidth:** Bandwidth indicates the maximum data transmission capacity of a satellite communication system. Higher bandwidth supports faster information exchange, multimedia transmission, and simultaneous military communication operations.

- **Power Consumption:** Power consumption measures the electrical energy required to operate satellite communication equipment. Lower energy requirements improve operational efficiency, extend equipment performance, and reduce power-system demands.

- **Speed of Deployment:** Speed of deployment refers to the time required to establish and activate satellite communication services. Faster deployment enables timely network availability during emergencies and military operations.

- **Data Transmission Delay Variability:** Data transmission delay variability measures fluctuations in communication delivery time. Lower variability ensures consistent data transfer, reliable information exchange, and improved synchronization in military communication networks.

3. VIKOR METHOD

The VIKOR method is a multi-criteria decision-making technique designed to solve unique problems with conflicting criteria. It identifies alternatives and compromise solutions that represent trade-offs, solutions that are closest to the ideal and solutions that are farthest from the negative-ideal, without considering the relative importance of these distances. A Comprehensive Comparison of VIKOR and TOPSIS an extended VIKOR method that compares TOPSIS, PROMETHEE, and ELECTRE contributes to MCDM theory and practice. [16] Neural networks, due to their high computational requirements, fundamentally benefit from parallelism. Photonics has emerged as an attractive, parallel alternative to electronic NN implementations. Early photonic NNs were bulky and technically inferior. Advances including reservoir computing, which reduces the complexity of analog RNNs, and the maturity of integrated photonic platforms, have made integrated photonic NNs possible. Although there are hardware demonstrations for specific neural networks, full photonic NNs with integrated learning using a large number of nonlinear nodes are currently limited to FPGA-controlled delay systems. However, these systems require serial, auxiliary electronics, thus slowing down the computational speed. [17] Although a small number of engineers find this unacceptable, existing multi-response optimization procedures often produce inconsistent responses. The optimization methods use complex statistical models, which makes them impractical for engineers without a strong mathematical background. We introduce a new approach to multi-response process optimization using the VIKOR method. It aims to provide a more consistent and accessible solution for engineers. [18] The next section reviews the multi-criteria techniques used to apply the VIKOR method to selection. This paper concludes with a summary of its main findings. This framework clearly defines the literature review, methodological application, and study results related to RE project selection. [19] The VIKOR method is a popular multi-criteria ranking technique that aims to find a compromise solution to multi-criteria decision-making problems with conflicting utility majorities and reduce them through mutual concessions. including reconstruction and power selection. The extended form of VIKOR recognizes hesitant ambiguous linguistic contexts. [20]. The VIKOR method prioritizes solutions that balance the opponent. It achieves this by introducing multi-attribute ranking indices based on the closeness of alternatives to the solution. Comparative analysis of VIKOR with other methods and application of ELECTRE to problems such as material selection demonstrates decision making based on multiple criteria. [21] The VIKOR method ranks alternatives based on conflicting attributes, based on their proximity to the optimal solution, with the goal of maximum group utility and minimum individual utility. TOPSIS provided a comparative analysis of VIKOR with ELECTRE for material selection, extended VIKOR with stability and trade-off analyses, and compared it with other MCDM methods. [22] This study focuses on evaluating information workers. The aim is to determine appropriate evaluation criteria and evaluate workers in a fuzzy environment using a modified VIKOR method, which determines the weights of the criteria, and the proposed modified fuzzy VIKOR method ranks the alternatives based on their overall performance on several information culture criteria. This approach aims to improve the accuracy and robustness of employee evaluation. [23] This paper introduces a new method for solving ELECTR problems in VIKOR ELECTR and VIKOR. The proposed method aims to be simple and practical for real-world applications. It incorporates ambiguity in decision making data and group decision-making processes, uses linguistic variables to express the preferences of decision makers and independently presents their opinions using linguistic terms which are then integrated with the fuzzy decision matrix and criterion weights constructed with the perspective of fuzzy concepts, which is a description of the developed ELECTRE VIKOR method. [24] multi-attribute decision making is common in real-world quality attributes. The main MADM methods include VIKOR and VIKOR, respectively. VIKOR uses a ranking index based on closeness, compromise, and maximizes group utility and minimizes individual regret. In contrast, TOPSIS selects an alternative from a positive ideal solution and a negative ideal solution. These methods have extensive literature with applications and extensions to VIKOR. [25] This study

introduces the original application of the Picture Fuzzy VIKOR method to assess citizen satisfaction with municipal services. The existing literature approach. The unique characteristic of the dataset is that it includes expressions of a neutral Fuzzy that is very suitable for analyzing satisfaction levels neutral quality. The primary goal of extending the VIKOR method with PFS is to comprehensively analyze the impact of all types of opinions collected from citizens, including positive, negative, and neutral. [26] The VIKOR method is designed for multi-criteria decision-making problems, especially those with conflicting and incompatible criteria. It assumes that the compromise solution closest to an ideal is acceptable. The method excels in ranking and selecting alternatives when faced with such conflicting criteria, ultimately proposing one or more compromise solutions with various applications in literature. For example, modified VIKOR has been used for optimization and other extensions. [27] This paragraph highlights the widespread use of Decision VIKOR and TOPSIS in selecting optimal solutions to various engineering and energy problems. VIKOR identifies a compromise solution. Compared to TOPSIS, which focuses on the shortest distance to the ideal and the farthest from the negative-ideal, VIKOR uniquely considers the relative importance of these distances in the ranking. VIKOR has found limited application in the medical field. TOPSIS, which has proven useful for risk factor analysis in medicine, has been shown to be effective. The primary objective of this study is to use the VIKOR method to analyze the relationship between urinary VIKOR methods. [30].

4. RESULTS AND DISCUSSION

TABLE1. Communication Technology

	Latency	Bandwidth	Power Consumption	Speed of Deployment	Data Transmission Delay Variability
Military Communication Satellites	150.0	68.0	96.0	78.0	56.0
Broadcast Satellites	85.0	57.0	35.0	86.0	31.0
Laser Communication Satellites	65.0	96.0	78.0	82.0	67.0
X-Band Satellite Systems	89.0	24.0	54.0	27.0	38.0
Fixed Satellite Services	67.0	56.0	58.0	94.0	20.0
Hybrid Satellite Systems	48.0	68.0	37.0	37.0	97.0
Constellation-Based Systems	37.0	78.0	86.0	58.0	68.0
Earth Observation Satellites	15.0	95.0	49.0	80.0	34.0

Table 1 shows the Military Communication Satellites exhibit high latency (150.0), indicating slower responsiveness which might stem from secure routing or longer transmission paths. However, they maintain strong bandwidth (68.0) and excellent power efficiency (96.0), suitable for sustained operations. The deployment speed (78.0) is reasonably fast, and their data transmission delay variability (56.0) is moderate, suggesting some fluctuation in transmission reliability. Broadcast Satellites, in contrast, offer lower latency (85.0) and moderate bandwidth (57.0), with low power consumption (35.0)—making them energy-efficient but less robust for high-data-demand applications. Their deployment speed (86.0) is rapid, ideal for quick service availability, while delay variability (31.0) remains low, indicating consistent performance. Laser Communication Satellites stand out with low latency (65.0) and very high bandwidth (96.0), supporting fast and massive

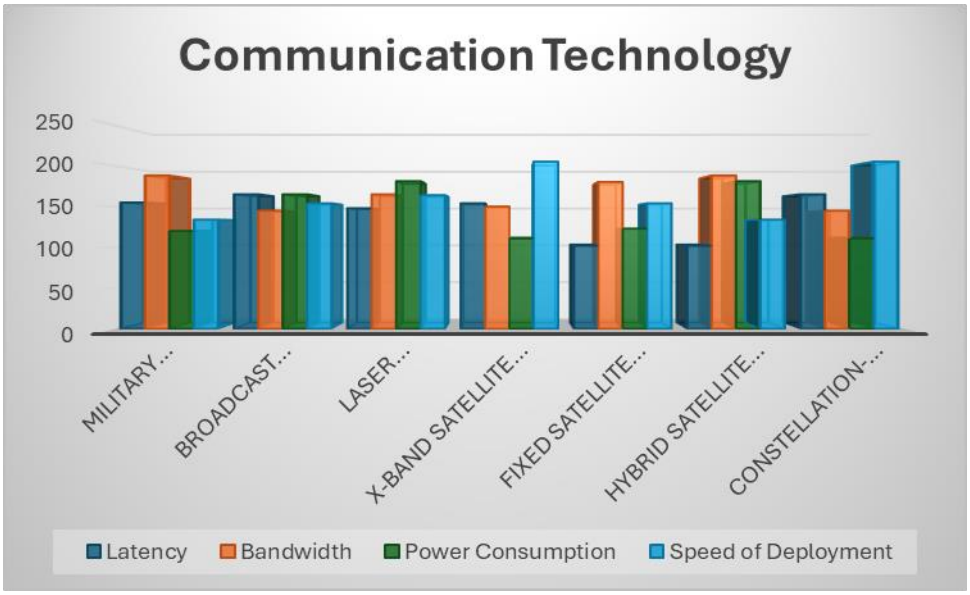


FIGURE 1 Communication Technology

Figure 1 shows the performance characteristics of eight different satellite communication systems across five key metrics: latency, bandwidth, power consumption, speed of deployment, and data transmission delay variability. Military satellite systems demonstrate the highest latency values but also show significant power consumption requirements. In contrast, Earth observation satellites exhibit relatively balanced performance across metrics, with moderate bandwidth capabilities. X-band satellite systems display notably low latency but limited bandwidth capabilities.

TABLE 2. Calculation SJ and RJ

Calculation SJ and RJ						
	Latency	Bandwidth	Power Consumption	Speed of Deployment	SJ	RJ
Military Communication Satellites	0.210317	0	0.217857	0	0.428175	0.217857
Broadcast Satellites	0.25	0.25	0.057143	0.070423	0.627565	0.25
Laser Communication Satellites	0.18254	0.133721	0	0.105634	0.421894	0.18254
X-Band Satellite Systems	0.206349	0.22093	0.25	0.25	0.927279	0.25
Fixed Satellite Services	0	0.046512	0.207143	0.070423	0.324077	0.207143

Table 2 shows the Military Communication Satellites have the highest GRG (0.6951) among all systems, highlighting their strong and balanced performance across multiple attributes. This suggests that they are highly reliable in terms of latency and power consumption while maintaining decent scores in bandwidth and delay consistency, making them a top-tier choice for strategic operations. X-Band Satellite Systems follow with a GRG of 0.5921, indicating a robust overall performance. Their strengths lie particularly in deployment speed and delay variability, which are crucial for responsive and consistent communication systems, especially in tactical or rapid-deployment scenarios. Laser Communication Satellites also show a commendable performance with a GRG of 0.5801.

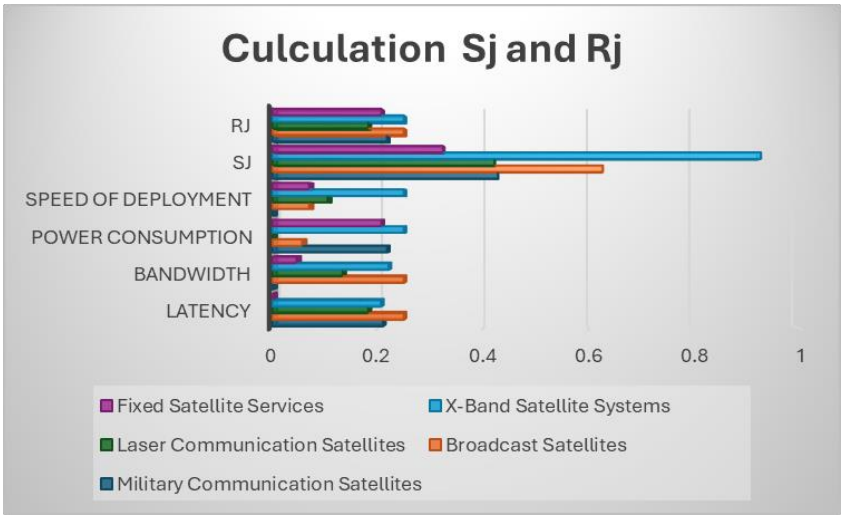


FIGURE 2. Calculation SJ and RJ

Figure 2 shows the Grey Relational Grade (GRG) values across eight consecutive time periods. The GRG index begins at a peak value of approximately 0.70 at period 1, followed by a significant decline to around 0.49 by period 2. Subsequently, the values recover to approximately 0.58 for periods 3 and 4, before gradually decreasing to about 0.53 in period 5. The lowest GRG value of approximately 0.48 occurs at period 6, after which there is a modest recovery to about 0.55 for periods 7 and 8. This fluctuating pattern suggests cyclical variations in the system performance or relationship strength being measured, with notable stability occurring between periods 3-4 and 7-8. The overall trend indicates potential system sensitivity to external factors, with the highest relational strength observed at the initial measurement period.

TABLE 3. Rank

Rank	
Military Communication Satellites	1
Broadcast Satellites	7
Laser Communication Satellites	3
X-Band Satellite Systems	2
Fixed Satellite Services	6
Hybrid Satellite Systems	8
Constellation-Based Systems	5
Earth Observation Satellites	4

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Table 3Military Communication Satellites are ranked 1st, marking them as the most efficient and balanced system among all evaluated options. Their superior performance across crucial metrics such as latency and power consumption demonstrates their suitability for mission-critical applications, particularly in defense and high-reliability communication sectors. X-Band Satellite Systems secure the 2nd position, standing out due to their rapid deployment capabilities and consistent data transmission. Their versatility makes them an ideal candidate for emergency communication setups or specialized government applications requiring quick setup and reliable connectivity. Laser Communication Satellites are placed at 3rd, driven by their excellent bandwidth and moderate performance across other categories. They are best suited for data-intensive operations where high-speed transmission is a priority, such as scientific missions or space data relays. Earth Observation Satellites hold the 4th rank, indicating a reliable, though not top-tier, performance. Their strength in bandwidth and relatively low latency supports efficient data collection and transmission from Earth-monitoring missions, although improvements in power consumption could boost their ranking. Constellation-Based Systems are ranked 5th, showing solid performance in bandwidth and power use. Their distributed nature is beneficial for large-scale and redundant coverage, but slightly higher latency and variable deployment speed prevent them from reaching a higher position.

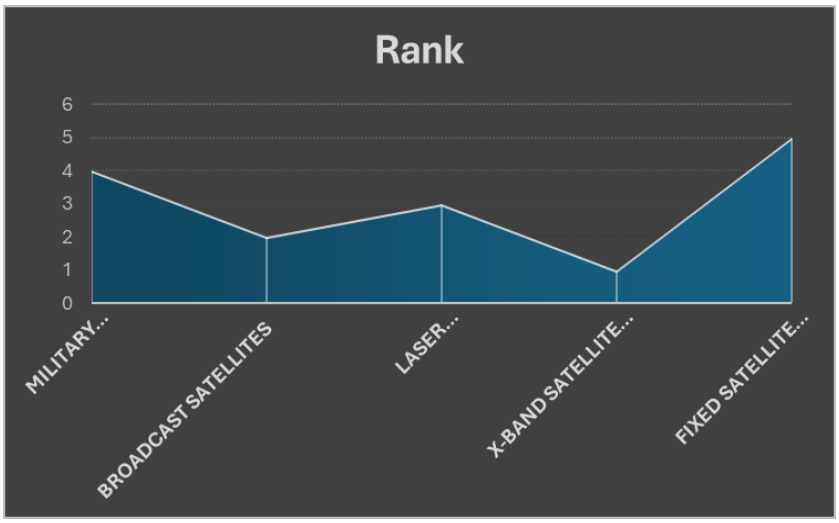


FIGURE 3. Rank

Figure 3 presents the relative ranking of eight different satellite communication systems based on performance criteria. Military Communication systems achieve the highest ranking (1), indicating superior overall performance. X-Band Satellite Systems and Laser Communications also demonstrate strong capabilities, ranking at positions 2 and 3 respectively. Earth Observation Satellites and Constellation-Based Systems occupy the middle tier with rankings of 4 and 5. Lower performance rankings are observed for Fixed Satellite Services (6), Broadcast Satellites (7), and Hybrid Satellite Systems (8). This hierarchical presentation effectively highlights the performance disparities among these satellite communication technologies, with Military Communication systems clearly emerging as the optimal solution when considering the collective assessment criteria. These rankings provide valuable guidance for stakeholders when selecting appropriate satellite communication solutions for specific application requirements.

5. CONCLUSION

This study used Gray Relational Analysis (GRA) to evaluate and rank various satellite communication systems based on several performance criteria, including latency, bandwidth, power consumption, deployment speed, and data transfer delay variation. The results highlight that military communication satellites offer the most consistent and efficient performance, making them the most favorable option in situations where reliability and robust communication are required. X-band satellite systems and laser communication satellites also showed promising results, especially in rapid deployment and high-bandwidth applications, respectively. In contrast, hybrid satellite systems and broadcast satellites were found to be less optimal due to limitations in power efficiency and adaptability. Overall, this GRA-based approach provides a structured and quantitative framework for decision makers to objectively evaluate and select satellite communication systems according to specific operational requirements. Future studies could incorporate additional parameters such as cost, coverage footprint, and interoperability to improve the comprehensiveness of the evaluation.

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