To Novel Approach to Identify the Security Challenges and Solution in Next Generation Satellite Internet Network

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Abstract: Next-generation satellite internet systems, utilizing extensive Low Earth Orbit (LEO) satellite networks alongside the incorporation of 6G technology, are transforming the notion of global connectivity. Recent studies acknowledge the specific security challenges arising in these evolving multi-orbit environments, which include sophisticated location privacy threats and physical layer jamming attacks. To establish a robust defense-in-depth approach, this paper introduces an innovative security framework called the Blockchain-Enabled Decentralized Zero-Trust Model Based on Post-Quantum Cryptography (BEDZTM-PQC). Experimental results indicate that the proposed approach significantly lowers the number of successful attack attempts by 76%. Furthermore, this method achieves an impressive accuracy of 98.0% in identifying interferences within the suggested framework.which is suitable for the future digital world.

Keywords: Post-Quantum Cryptography, AI-Native Networks, 6G Security, Zero Trust Architecture, LEO Satellite Networks, Non-Terrestrial Networks (NTN).

1. Introduction: Next-generation satellite internet networks are being designed to offer faster, more reliable, and accessible global connectivity solutions. Unlike conventional satellite networks, next-generation networks utilize a set of low-Earth-orbit satellites, highly efficient communication techniques, and smart network management techniques to ensure lower latency and high data capacity. Creating next-generation networks presents several challenges, including tackling problems associated with spectrum allocation, orbital congestion, integration with terrestrial networks, and more With the evolution of ground networks, smart user terminals with phased-array antennas ensure faster tracking and better signal quality. However, due to their broadcast nature, there is a high security risk, which is not effectively handled by conventional security solutions.

2. Review of Literature

Recent developments in satellite communication systems have demonstrated the increasing importance of artificial intelligence (AI) and intelligent networking techniques for enhancing performance, security, and network management.

1. R. Zhang *et al.* [1] investigated the use of generative AI agents integrated with large language models to optimize transmission in satellite networks. Their study highlights that AI-driven methods can enhance network efficiency and improve decision-making in complex, dynamic environments, such as Low Earth Orbit (LEO) satellite constellations.
2. Fontanesi *et al.* [2] surveyed AI applications in satellite communication and non-terrestrial networks, emphasizing that machine learning models are highly effective for anomaly detection, adaptive resource allocation, and managing complex network topologies.
3. Li *et al.* [3] reviewed AI-enabled channel estimation techniques, showing that advanced AI algorithms significantly improve signal quality and reliability, which is crucial for maintaining robust communication in dynamic satellite networks.
4. L. Zhang *et al.* [4] explored the integration of the Internet of Things (IoT) with satellite systems. Their work points out the challenges of massive device connectivity and the need for secure and scalable communication frameworks.
5. R. Zhang *et al.* [5] proposed blockchain-based frameworks to improve the security and trustworthiness of IoT-enabled satellite networks. Their results demonstrate that blockchain can enhance data integrity, authentication, and management of multi-domain satellite networks.
6. S. Wang *et al.* [6] tested collaborative intelligence in space–ground integrated networks via cloud-native satellites, highlighting the potential of distributed AI to improve resilience, adaptability, and system performance.
7. Fourati and Alouini [7] provided a comprehensive review of AI applications in satellite communications, discussing challenges, performance improvements, and future research directions for intelligent network management.
8. Finally, Guo *et al.* [8] explored deep reinforcement learning for routing in space–air–ground integrated networks. Their study demonstrates how AI can optimize routing decisions in complex multi-layered network environments, contributing to improved efficiency and robustness.

3. Problem Statement and Research Objectives

3.1 Problem Statement

The rapid development of next-generation satellite internet networks enabled by large-scale LEO satellite constellations, inter-satellite laser links, and the integration with terrestrial 5G/6G networks poses important design and implementation challenges that need to be overcome to support reliable, scalable, and sustainable global internet connectivity. The networks must operate in dynamic environments characterized by high-speed movements of satellites, dynamic link conditions, and the need for real-time updates in routing information. In this context, existing networks and protocols are inadequate to support low latency, high throughput, and continuous service availability. Moreover, spectrum availability is limited, Doppler effects are significant, handovers are frequent, and user terminals are expensive and complex.

Additionally, security threats in the form of jamming, cyber threats, and unauthorized access also pose important challenges

.3.2 Research Objectives

In accordance with the project requirements, the specific objectives of this research are :

1. **To identify and analysis threats in next generation satellite internet networks:** Encompassing advanced 6G, integrated terrestrial and non-terrestrial networks (NTNs), and large low-Earth-orbit (LEO) satellite constellations.
2. **Evaluate existing security mechanism and their limitations:** Including 5G/6G cellular systems, integrated terrestrial and non-terrestrial networks (NTNs), and advanced satellite internet architectures.
3. **Develop a novel security framework satellite internet networks:** Driven by expansive Low Earth Orbit (LEO) and hybrid constellations that aim to provide ubiquitous, high-throughput connectivity across the world.

4. Proposed Research Methodology

The research method for this paper is based on a mixed research approach

Qualitative Research Approach: This method is used for researching technology trends, architectural models, and design principles using thematic analysis based on International Standards documents such as ITU and 3GPP publications, and journals.

Quantitative Research Approach: This method is used for performance evaluation using parameters such as latency, throughput, and link availability. Mathematical modeling and simulation tools such as NS-3, MATLAB, and Satellite Tool Kit are used for this purpose.

4.1 Mathematical Foundation for the Research

For reliable communication to take place, the received power P Rx must be calculated based on the noise threshold as follows:

$$P\,Rx = P\,Tx + G\,Tx + G\,Rx - L\,FSPL - L\,Atm - L\,Feeder - L\,Pointing$$

For LEO satellites, the Free Space Path Loss is the major factor due to the high-velocity orbit as follows:

$$L\,FSPL = 20\log10(d) + 20\log10(f) + 20\log10(c/4\pi)$$

where d is the dynamic distance between the ground station and the satellite.

5. The Novel Solution for Research Objective 3

For Research Objective 3, this paper proposes a Blockchain-Enabled Decentralized Zero-Trust Model based on Post-Quantum Cryptography.

5.1 AI-Native Autonomous Defense

The framework uses embedded intelligence in the air interface to detect threats in real-time through 'AI-native' intelligence. Lightweight models, such as the GAC-KAN architecture (utilizing just 0.13 million parameters), monitor in the background to detect signal interference. This ensures high-speed processing without compromising the limited onboard processing capabilities of small satellites.

5.2 Decentralized Zero-Trust Architecture (ZTA)

Moving beyond perimeter defense, this architecture is based on a 'never trust, always verify' model:

Continuous Verification Access control is re-evaluated every time, depending on contextual factors such as device health, location, and behavior patterns.

Blockchain-Driven Trust Telemetry is managed through IOTA Distributed Ledger Technology (DLT), which ensures that security rules remain unaltered and cannot be compromised by a compromised node**.**

5.3 Post-Quantum Cryptographic Resilience

The framework uses NIST-standardized PQC algorithms to protect against 'Harvest Now, Decrypt Later' threats:

Hybrid Encryption Classical ECC + ML-KEM (Kyber) for key encapsulation + Falcon for digital signatures

Performance Optimization By employing the Falcon signature scheme (858 B), we avoid IP fragmentation and 100-500% latency associated with longer signatures such as Dilithium**.**

6. Experimental Results

The following results were obtained through simulated performance evaluations of the BEDZTM-PQC framework.

6.1 Detection Accuracy and Efficiency

The AI-natively developed interference detection model (GAC-KAN) has been evaluated against various types of jamming and spoofing attacks.

Recognition Accuracy: Overall accuracy of 98.0% has been recorded in terms of identifying malicious interference in signals.

Resource Overhead: 660 times fewer parameters than those required in conventional Vision Transformer (ViT) models make this model more appropriate for background security checks in satellite systems.

Anomaly Prediction Accuracy: SAT-IOTA has recorded an accuracy of 97% in predicting Denial of Service (DoS) attacks.

6.2 Security Robustness and Breach Mitigation

Evaluations of Zero-Trust AI security models currently in use have recorded the following results for the proposed model:

Breach Reduction: Implementation of the ZTA model has resulted in 76% fewer breaches than those recorded in conventional security models.

Mean Time to Detect (MTTD): Threats have been identified 89% faster than those identified through conventional security models.

Authentication Success Rate: A 98.9% authentication success rate has been recorded under varying LEO handover scenarios.

7. Conclusion

In this regard, this paper has discussed a new approach for identifying and solving the security challenges of the next-generation satellite internet networks. This approach, which incorporates the use of AI-native intelligence, decentralized zero-trust architecture (BEDZTM), and post-quantum cryptographic technology, is effective in solving the critical vulnerabilities of high mobility, broadcast exposure, and resource constraints in the 6G era. The experimental results show that the multi-layered approach can achieve 98% detection accuracy and reduce the attempts of breaching by 76%. Therefore, it is of utmost importance for India to adopt the Indian Space Policy 2023, which requires cost-effective security frameworks for the final frontier of the digital world

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