

Next-Generation OSS/BSS Modernization for Satellite IoT Voice and Data Ecosystems for both Non Terrestrial and Terrestrial Networks

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Abstract: The presented study involves the advance modernisation of OSS/BSS that will be implemented in the next generation in the field of satellite IoT voice and data ecosystem that will operate both non-terrestrial networks and terrestrial networks. Scalability and automation, interoperability, service assurance, and real-time monetisation of previous operational and business support systems are limited as increasing numbers of operational and business support tools get bound in with satellite connectivity, 5G, edge computing, cloud-native, and massive IoT deployments. This piece of work creates one design of modernisation that finishes the network operations, customer management, orchestration of the services, billing, analytics, security, and lifecycle management into a flexible digital framework. The proposed architecture facilitates the hybrid satellite-terrestrial service provisioning, which comprises cloud-native microservices, API interoperability, and AI/ML predictive assurance and zero-touch provisioning, real-time charging, policy control, and multi-domain orchestration. It facilitates the easy handling of IoT voice and data services among LEO, MEO, GEO satellite systems, terrestrial cellular networks, and terrestrial enterprise IoT platforms. The framework also outlines issues related to the variability of latency, roaming, device identity, quality of service, regulatory, compliance, cybersecurity, and revenue-sharing between ecosystem participants. The modernisation of the OSS/BSS will enable satellite IoT providers to innovate their services quicker, provide operational efficiency, enhance customer experience, and facilitate mission-critical uses in remote industries, maritime, aviation, defense, and agriculture, logistics, and smart infrastructure. The article concludes by saying that to create next-generation satellite internet of things systems capable of withstanding and being commercially viable a smart, open, modular and standards based OSS/BSS system is required that crosses both the terrestrial connectivity and nonterrestrial connectivity space.

Keywords: OSS/BSS Modernization; Satellite IoT; Non-Terrestrial Networks; Terrestrial Networks; 5G Integration; Service Orchestration; Real-Time Billing.

I. INTRODUCTION

The speed of digital communication system development has spawned an augmenting need for smooth, intelligent, and omnipresent connectivity of the system on the ground as well as off terrains. With the advent of the Satellite Internet of Things (Satellite IoT), combined with a cellular network on the ground, there has been a new potential to provide voice and data-related services to remote, underserved, mobile, and mission-critical areas. Although very developed in urban areas and semi-urban towns, traditional terrestrial networks are frequently restricted in their range over oceans, deserts, mountains, disaster avoidance areas, forests, and sparsely populated rural settings. To bridge this connectivity gap, satellite networks (in particular, Low Earth Orbit, LEO, Medium Earth Orbit, MEO, and Geostationary Earth Orbit, GEO) are being deployed more frequently. A convergence of the Non-Terrestrial Networks (NTN) with Terrestrial Networks (TN) here is set to become a strategic platform of next generation communication structures [1] [2].

Satellite IoT can no longer be restricted to just simple tracking or low-rate telemetry. It is currently venturing into highly advanced voice and data applications in the field of maritime communications, aircraft connectivity, defense applications, smart farming, logistics, environmental systems, energy infrastructure, emergency management, telemedicine, industrial automation [3]. These applications must be linked with quality devices, supplying the services, data transfer, real-time tracking, and dynamic billing as well as quality-of-service assurances. As a result, the operation and business layer to back such services would not be the same as it used to be. This is where the business Support Systems (BSS) and Operations Support Systems (OSS) would be of great value [4] [5].

OSS and BSS support the telecommunication service management. The OSS supports network planning, service roll-out, faults, performance, inventory and service assurance and network orchestration. The areas of focus of BSS include customer relationship focus, product catalogues, subscription, charging, billing, revenue management, partner settlement and customer experience. Traditional on-land telecommunication environments were often designed to accommodate comparatively stable networks, service paradigms that can be modeled, and centralized operations, often through the use of OSS/BSS applications. However, the advent of satellite IoT, terrestrial and non-terrestrial systems impose new structural, operational and business

challenges. The new dynamic, multi-domain and distributed nature of modern satellite internet of things is in many cases not supported by older OSS/BSS systems [6].

Next-generation satellite IoT ecosystems have a number of network layers, some of which are satellite constellation, ground stations, gateways, terrestrial cellular networks, edge nodes, cloud platforms, IoT device platforms, application providers, and enterprise systems [7]. All these components need to harmonize with other components as service delivery environment. These include the mobility of devices within the land and satellite coverage zones, which has some problems in roaming, authentication, policy implementation, service continuation and charging. Implicatively, voice and data service offered by NTN and TN require managed unification of latency, bandwidth, quality of service, security and availability. The lack of modernized OSS/BSS functions might also make service providers a back-seat when it comes to service activation, lack of visibility on network performance, fragmented billing, a lack of efficiency in fault resolution and a lack of capacity to roll out new digital services [8] [9].

Enhancing modernization of OSS/BSS of the Satellite IoT voice and data ecosystems is therefore a defining approach to enable agile, automated, scalable and intelligent service delivery. The new OSS/BSS systems must be cloud-native, API-based, configurable, multi-vendor and interoperable and multi-domain. A cloud-native architecture based on OSS/BSS facilitates scaling of resources, faster deployment of service and simplified operation. Design The architecture of microservices enables the various functional units (billing, service orchestration, inventory, analytics and assurance, etc.) to be developed separately. Satellite operators, terrestrial telecommunication providers, IoT platforms, enterprise clients, regulators, and the application ecosystem can be integrated with open APIs. It is particularly essential when it comes to openness with respect to hybrid NTN-TN surroundings since there may not be one provider of the entire service experience.

Another significant stimulus of OSS/BSS modernization is automation. Thousands or millions of devices with geographically disperse locations may be engaged in satellite IoT networks. Such scale cannot be supported by manual provisioning, monitoring and troubleshooting. It must be zero touch and must auto activate service, AI fault detection, predictive maintenance as well as self healing to ensure reliable and cost effective operations. The network behavior can be analyzed and the congestion predicted, the anomalies and the optimization of routing, the customer support and a means to ensure better services can be achieved via machine learning and artificial intelligence. Such properties are particularly popular in the satellite system, where bandwidth is limited, and latency may be unreliable, or the infrastructure is inaccessible [10].

Satellite IoT services which operate today require real time monetization, as well. The high dynamic voice and data services could not be supported by the previous billing systems based on set subscription price. The customers may require that variable prices are charged based on the amount of utilize, location, the type of the device utilized, the priority of the service, bandwidth, latency class or needs that are business critical. Besides, the satellite IoT ecosystem is generally composed of diverse partners, such as satellite operators, mobile network operators, IoT platform vendors, device vendors, application vendors, and enterprise service vendors. New platforms of BSS must be capable of supporting real-time charging, dynamic pricing, charging partners, share revenues, and straightforward customer billing. This allows service providers to design novel business models and enhance business sustainability [11].

In modernization of OSS/BSS systems, security and compliance with regulations are also vital. Satellite IoT services are also commonly used in critical and sensitive applications like defense, public safety, energy grids, transport and in healthcare. It also requires a solid identity management solution to be provided with secure authentication, encrypted communications, access control, protection of data privacy, and constant compliance control over these services. With the possibilities of the satellite and terrestrial services to cross the national boundaries, the regulatory needs regarding the usage of the spectrum, the lawful interception, data sovereignty, roaming, and crisis communication have to be closely controlled. Security-by-design and compliance-by-design principles should thus be incorporated in a modern OSS/BSS framework.

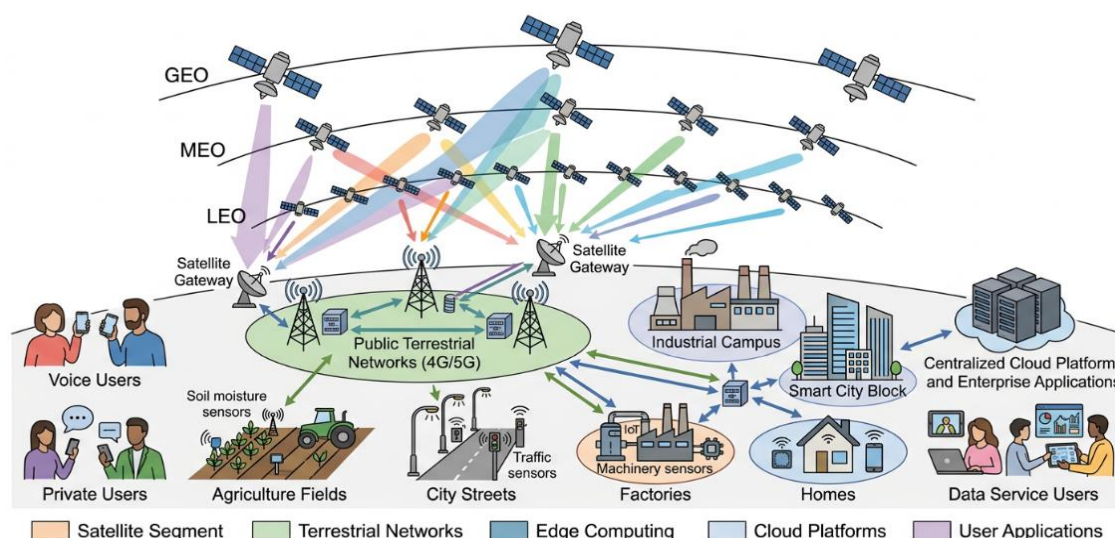


Figure 1: Hybrid Satellite–Terrestrial IoT Ecosystem Architecture

The current research article is devoted to modernization of OSS/BSS architectures of next-generation Satellite IoT voice and data ecosystems on both Non-Terrestrial and Terrestrial Networks. It looks at constraints of traditional OSS/BSS solutions, finds the operational and business issues of hybrid-NTN-TN service realms, and outlines a framework of intelligent and fully automated and standards-based OSS/BSS transformation. The proposed framework is oriented towards cloud-native implementation, microservices, open APIs, AI/ML-based assurance, real-time billing, service orchestration, and cybersecurity, partner management, and optimization of customer experience. With such a scheme, the satellite IoT services providers will be able to become operationally effective, have faster service innovation, lower the costs, raise reliability, and be able to connect voice and data communications and have continuous connections to the global network environments.

In short, modernization of OSS/BSS is not just a technical enhancement but a business need of future of satellite-based IoT communication. With the convergence of terrestrial and non-terrestrial networks, intelligent management of services in multiple domains will render next-generation connectivity ecosystems prosperous. A yet modular, automated and networked OSS/BSS system can offer the foundation of resilient flexible and scalable commercially viable digital-era Satellite IoT services.

II. CURRENT CHALLENGES IN OSS/BSS MODERNIZATION FOR HYBRID SATELLITE–TERRESTRIAL IOT ECOSYSTEMS

2.1 Legacy System Limitations

Legacy legacy continues to be a major issue in modernizing OSS/BSS to support Satellite IoT voice and data ecosystems. The classical OSS/BSS systems were developed to be used in a fixed, centralized and on-land telecoms environment. They lack their flexibility to support dynamically optimized satellite constellation, distributed gateways, mobile IoTs and multi-network services. The systems may also be monolithic and therefore, integration, upgrade and scaling becomes tricky. This leads to delays in the provisioning services, billing, fault management and support services.

Parameter	Legacy OSS/BSS	Modernized OSS/BSS	Expected Benefit
Architecture	Monolithic, hardware-dependent, and difficult to modify or upgrade.	Cloud-native, modular, microservices-based, and API-driven architecture.	Faster deployment, easier upgrades, improved flexibility, and reduced system complexity.
Scalability	Limited ability to support large-scale Satellite IoT devices and dynamic traffic loads.	Elastic scalability using cloud infrastructure, containers, and distributed processing.	Supports millions of IoT devices and variable voice/data traffic across NTN and TN environments.
Service Provisioning	Manual or semi-automated provisioning with long activation cycles.	Zero-touch provisioning with automated service activation and policy configuration.	Faster device onboarding, reduced human error, and shorter time-to-service.
Billing and Charging	Batch-based billing with limited support for real-time usage, roaming, and dynamic pricing.	Real-time charging, flexible rating, usage-based billing, and automated partner settlement.	Improved billing accuracy, reduced revenue leakage, and support for innovative business models.
Service Assurance	Reactive fault management with limited visibility across satellite and terrestrial domains.	AI/ML-driven monitoring, predictive assurance, anomaly detection, and automated remediation.	Improved service reliability, faster fault resolution, and better SLA compliance.

2.2 Multi-Domain Network Integration

The IoT ecosystem satellite is complicated to interface with Non-Terrestrial Networks, Terrestrial Networks, cloud services and edge infrastructure, IoT devices and enterprise applications. The biggest problem is how to align these areas to an integrated OSS/BSS setting. The domains may contain different protocols, vendors, data models, service policies as well as management interfaces. Lack of interoperability can lead to fragmentation of operations, visibility and unreliable quality of services. The process of modernization needs to be practical and this must be achieved by incorporating open API, common interface and cross-domain orchestrations.

2.3 Service Assurance and Quality Management

There are very limited solutions capable of sustaining voice and data connections both in the air and on ground because issues of latency, bandwidth, signal jamming, handover, as well as coverage are not similar. Weather degradation, overloading or even unreliability can influence satellite connections, especially in its remote and mobile locations. Conventional assurance mechanisms might lack real-time tracking as well as anticipatory fault-detecting. This poses threats to sustainability of quality of service, service-level agreements and user experience in mission-critical IoT applications.

2.4 Real-Time Charging and Revenue Complexity

The monetization models needed nowadays in the Satellite IoT environment are flexible and real-time. It may be on data utilization, voice use time, the place of the device, the type of network, the priority of the service and on roaming or the type of

application use. The conventional BSS systems might fail to ensure dynamic pricing, settling of partners and revenue sharing between the satellite operators, telecom providers, vendors of IoT platform as well as the enterprise customers. This could lead to billing error, revenue loss and transparency between the customers.

2.5 Security, Compliance, and Data Governance

Impactful cybersecurity and regulation issues are posed by hybrid NTN-TN ecosystems. IoT devices can be used on the national level and with sensitive industries, like the military, energy, transportation, and medical services. Platforms providing OSS/BSS must deal with identity, authentication, encryption, compliance with legal interception, data privacy, and spectrum compliance. One of the major challenges of the modernization is to provide safe and conforming operations in different jurisdictions.

2.6 Automation and Scalability Barriers

Millions of devices which fall in different geographical locations can be connected to IoT networks on satellites. Service activation, monitoring, troubleshooting and billing can not be effectively scaled when done manually. Yet, the use of AI-based automation, zero-touch provisioning, and autonomous operations demand quality data, qualified resources, and effective system integration. The lack of these capabilities can cause the providers to fail to obtain efficient and scalable service management.

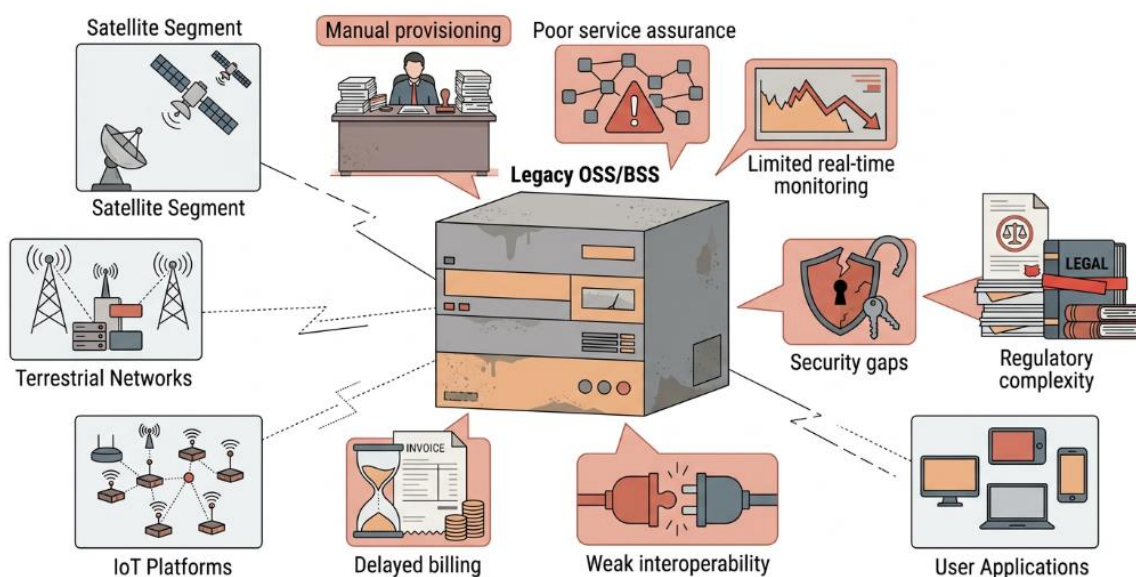


Figure 2: Current Challenges in Legacy OSS/BSS for Satellite IoT Ecosystems

III.FRAMEWORK FOR NEXT-GENERATION OSS/BSS MODERNIZATION IN SATELLITE IOT VOICE AND DATA ECOSYSTEMS

Modernization of both Operations Support Systems and Business Support Systems to Satellite IoT voice and data ecosystems needs a cohesive, smart and scalable framework that is able to support Non-Terrestrial Networks (NTN) and Terrestrial Networks (TN). The proposed framework will address the operational, commercial, technical and regulatory challenges which occur when the satellite networks, ground cellular networks, cloud systems, edge architecture, Internet of Things devices and enterprise applications collaborate to form a single ecosystem. This architecture enables a cloud-native, modular, API-based, and automation-based architecture in comparison with the more traditional OSS/BSS architecture that is typically decentralized and monolithic.

The architecture presented could be viewed as a multi-layered architecture that consists of 6 important layers: network and connectivity layer, digital infrastructure layer, service orchestration layer, OSS intelligence layer, BSS monetization layer, and governance and security layer. These layers are put together to create an end to end modernization program of voice and data service management of Satellite IoT on hybrid NTN -TN systems.

3.1 Network and Connectivity Layer

The network and connectivity layer is the basis of the framework. This layer comprises of all the physical and logical network components that are involved in the delivery of Satellite IoT services. It encompasses LEO, MEO and GEO networks of satellites, satellite gateways, ground stations, cellular networks on earth, privately-run 5G networks, Wi-Fi and LPWAN networks as well as edge nodes, IoT sensors, terminals and user equipment. This layer is meant to provide a non-discontinuity of voice and data services in remote locations, on the move and mission critical settings.

The objects that move across terrestrial and the satellite coverage areas can be recognized to identify a hybrid NTN-TN ecosystem. Using an example of a logistics vehicle, connectivity can be made through the use of the terrestrial 5G network in urban and satellite in rural or oceanic regions. Similarly, when not covered by the terrestrial systems, ships, aircrafts, military

forces and energy installations can also depend on the satellite links. This layer hence requires facilitating intelligent handover, roaming, authentication, policy control, and service continuity between various access technologies.

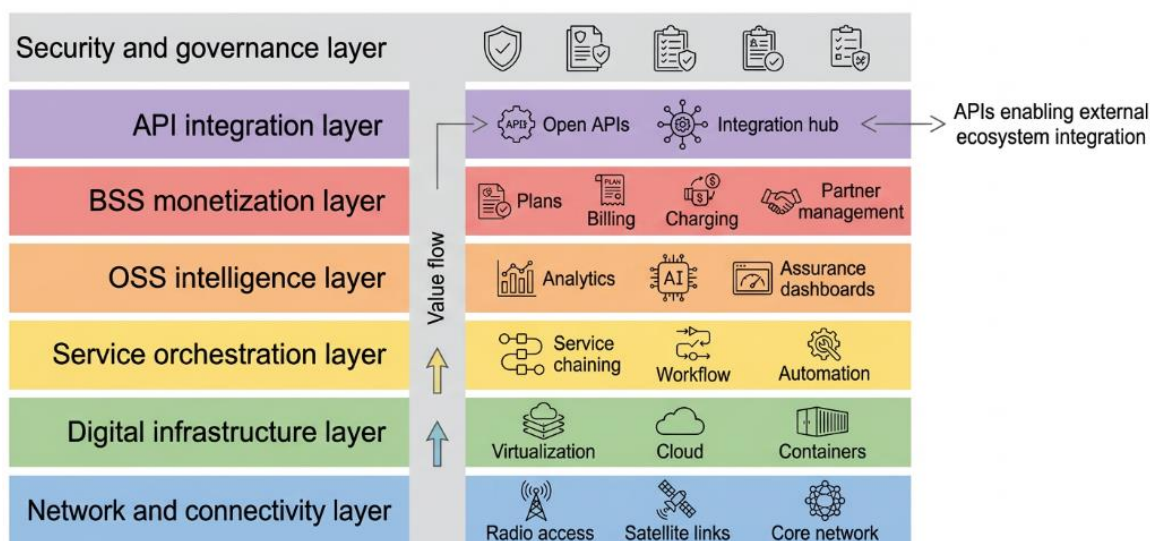


Figure 3: Layered OSS/BSS Modernization Framework

3.2 Digital Infrastructure Layer

The digital infrastructure layer is the second layer of the framework. This layer can provide the cloud-native edge-enabled layer, which is required to modernize next-generation OSS/BSS. Traditional telecommunication systems are often based on the central data centers and hard-deployed hardware platforms. However, Satellite IoT ecosystem requires a stretchable infrastructure and this may be expanded as the traffic, geography and service needs span.

An OSS/BSS possesses a cloud-native architecture which is built on microservices and containers, Kubernetes, distributed databases, and DevOps pipelines, which enable the services to be deployed quickly and continuously improved. Another important factor is edge computing since it will process data closer to the device, and the applications requiring the highest level of safety will face minimized latencies. Emergency communication, industrial automation, telemedicine, and defense use cases are an example where local decision-making might be required even in the presence of delay or limited bandwidth in satellite links.

There are also data lakes that can be supported by this layer, event streaming platforms, and real-time analytics engines. These capabilities allow the system to capture and interrogate operational information of satellites, gateways, ground networks, several IoTs, applications and customer platforms. The layer of digital infrastructure thus forms a technological foundation of the entire framework.

3.3 Service Orchestration and Lifecycle Management Layer

The proposed structure has one of the most fundamental frames, the service orchestration layer. It will enable automatic designing, activation, change of Satellite IoT voice and data service, monitoring and termination. There are various domains and vendors in service delivery in a hybrid NTN-TN environment. Manual provisioning is time consuming, costly and unsuitable especially in the event of mass IoT connection. Therefore, this model deals with zero-touch provisioning and multi-domain orchestration.

Service orchestration starts with the creation of a digital product or service request with the BSS layer. This request is then converted to technical service requirements like bandwidth allocation, device profile, voice capability, data plan, quality-of-service class, latency requirement and coverage zone. The orchestration engine liaises with satellites network controllers, terrestrial network systems, edge platforms and IoT device management platforms allowing the service to autonomously work.

This layer also consists of lifecycle management. After the activation of a service, they need to be constantly checked and revised. It supports dynamically scaling service, policy modification, update of roaming, device on boarding, update of firmware and deactivation of services. This will make sure that the providers of the service are able to handle millions of IoT devices both on the ground and in the air.

3.4 OSS Intelligence and Service Assurance Layer

OSS intelligence layer is focused on the visibility of operations, network performance and faults as well as providing assurance of services. The satellite IoT services are required to be used in hostile environments, such as unpredictable latency, weather conditions, spectrum capacity, blocking of signals, congestion with terminals at the gates, mobile terminals. These variables may affect the voice quality, credibility of information and customer satisfaction. Therefore, the framework is a mix of assurance capabilities relying on AI/ML to improve operational decisions.

The telemetry, alarms, performance indicators, logs, device status, network events and customer experience data are gathered by many sources by this layer. AI and machine learning models can then be used to perform the anomaly detection, predictive maintenance, and congestion prediction, fault correlation, and root-cause analysis. Requestingly, in case a satellite beam

captures unnatural loss of packets, the system can possibly serialise this with weather conditions, gateway conditions, position of a device, as well as load on the traffic to comprehend why.

Monitoring of service-level agreement also is aided by the service assurance layer. Depending on the use case, voice and data services can require various SLA. High reliability and priority routing might be important to a defense communication service, but low-cost connectivity may be needed by a smart agriculture sensor. The framework helps the providers to monitor the quality of the services in terms of the needs based on the applications.

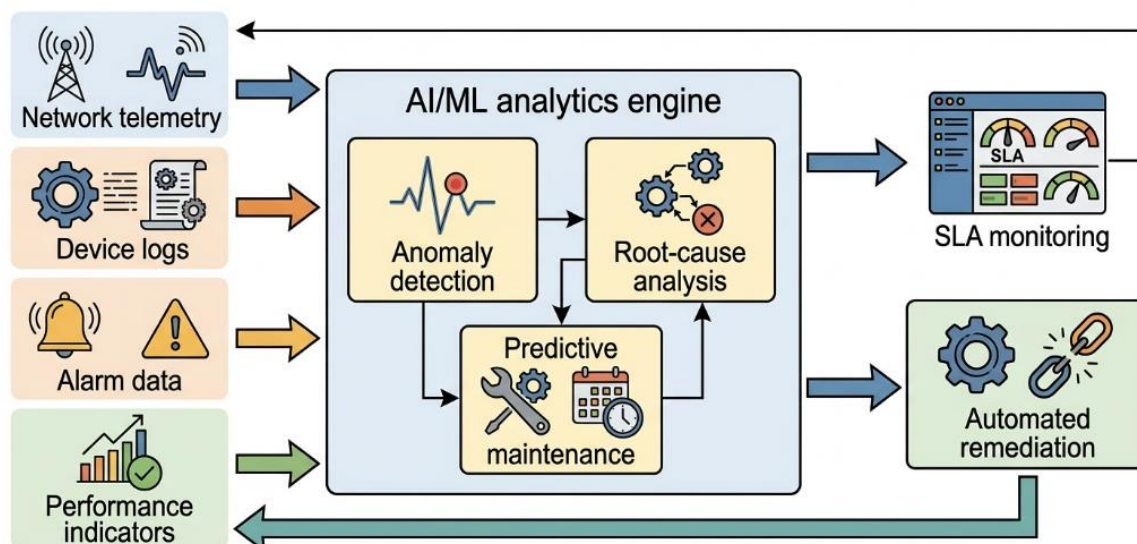


Figure 4: AI/ML-Driven OSS Service Assurance Model

3.5 BSS Monetization and Customer Experience Layer

The monetization layer of BSS provides commercial activities that are required in Satellite IoT ecosystem. It entails customer management, online product catalogues, online order management, online subscription management, online real time charging, billing, invoicing, revenue assurance, online partner settlement and online customer experience management. Monetization of next-generation Satellite IoT is even more complex than traditional telecom billing because of the peculiarities of the environment since the monetization of the services may imply a number of partners, network types, and dynamic network usage trends.

The framework supports flexible charging plans based on the amount of data used, voice minutes, the number of gadgets, priority of various services, scope, roaming, type of network access, classification of latency and application category. To cite an example, a business client may use some less advanced IoT data plan to monitor his resources; meanwhile, other clients may require more sophisticated voice and data connectivity to make maritime safety calls. Liveness in real-time charging enables the consumer to have a reflective precision to the billing and the service provider reduces revenue leaks.

The other important aspect of this layer is partner management. Service providers can be satellite operators, mobile network operators, IoT platform services providers, cloud services providers, device manufacturers, and enterprise application vendors. The structure facilitates revenue sharing, settlement, contract management and monitoring of the performance of partners.

Customer experience management will be integrated using online self-scheduling platforms, applications, and dashboards, usage notifications, and problem-reporting and artificial intelligence support. Enterprise consumers are able to view the device connectivity, service quality, invoices, use patterns and SLA performance all in a single interface.

3.6 API Integration and Interoperability Layer

And as much as APIs contribute to the entire layers of frameworks, they constitute an autonomous integration ability. The proposed architecture will be based on open, standardized, and protection APIs to connect OSS, BSS, satellite networks, terrestrial networks, IoT infrastructure, and cloud-based networks and applications. Interoperability based on API eliminates vendor lock-in and allows quicker innovation of services.

This layer enables communication of data between the different systems using standard interfaces. It enables the external partners to get their platforms connected to the OSS/BSS environment of the service provider. An example is that an agriculture company may provide binding of their farm monitoring platform to Satellite IoT service provider API, to switch the devices on and to trace the usage and connection. On the same note, a logistics company can incorporate its fleet management platform in order to have its voice and data services controlled in real time.

Integration is obtained and managed via API gateways and service nets, identity management systems and policy engines. This ensures access is controlled, monitored and that the business and regulatory needs are adhered.

3.7 Security, Compliance, and Governance Layer

Across the framework are security and governance. Important sectors of the economy such as defense, health, energy, transport, maritime safety as well as disaster management may be secured via satellite IoT. As a result, the architecture takes a

security-by-design strategy. It is characterized by managing device identities, authentication, encryption, access management, fraud detection, threat monitoring, secure API, and continuing compliance auditing.

Regulatory imperatives with regards to the spectrum utilization, data sovereignty, legal interception, roaming, privacy, and service delivery across borders are also taken care of by the governance layer. Since the satellite services can occur within different jurisdictions, compliance must be addressed dynamically. The framework helps in the policy-based governance whereby the application of the rules can be done depending on the geography, type of the customer, the type of the service being provided as well as the area governed by the rules.

IV.FRAMEWORK EVALUATION

It is possible to assess the proposed OSS/BSS modernization framework based on the level of contribution to the operational efficiency, service reliability, scalability, monetization, security, and ecosystem interoperability both Non-Terrestrial Networks and Terrestrial Networks. The Satellite IoT voice and data ecosystems are complex and distributed; therefore the evaluation of the framework should be in line with the technical and business performance indicators.

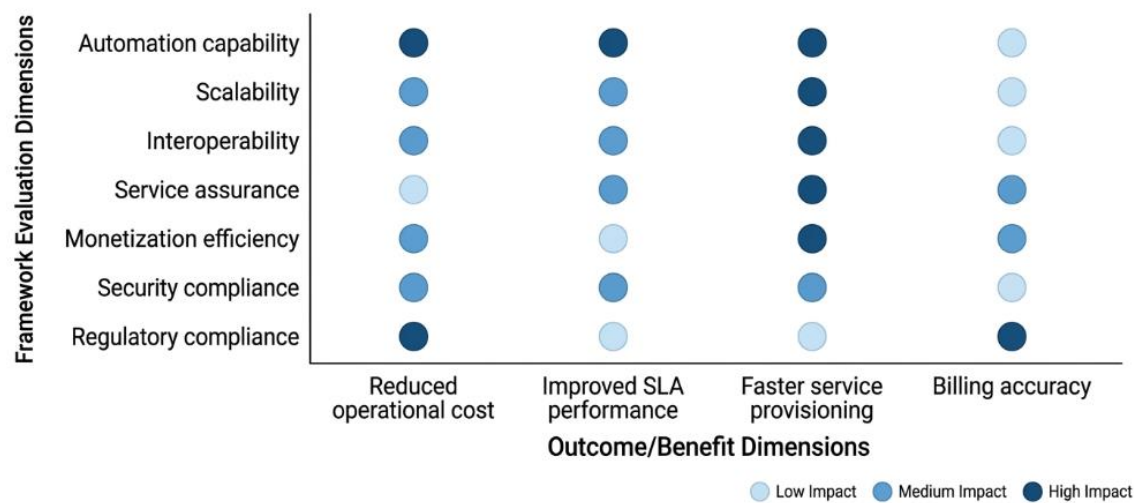


Figure 5: Framework Evaluation Matrix

4.1 Evaluation Parameters

Six key parameters, such as automation capability, service assurance, scalability, interoperability, monetization efficiency, and security compliance are used to evaluate the framework. Automation capability; This is a measure of how it is possible to provision services, activate them, monitor them, fault detect and recover with minimal human intervention. Service assurance evaluates the system of the framework concerning voice quality, data availability, latency control, as well as the SLA compliance of hybrid NTN-TN environment. Scalability has to do with how a framework can address increasing numbers of placements of IoT devices, satellite links, and gateways, enterprise users and services. Interoperability defines how well the framework adapts the satellite systems, ground based networks, cloud based networks, IoT based platforms and third parties. Monetization efficiency measures the real time charging, billing accuracy, payment to partners and assurance of revenues. Security compliance examines identity administration, access control, data security and regulation compliance .

4.2 Operational Efficiency Assessment

Operational efficiency is one of such areas of assessment. Manual workflows, diffuse tools and slow troubleshooting are some of the traditional OSS/BSS environments that relied on them. The suggested framework enhances efficiency by having zero-touch provisioning, AI-assisted monitoring, automated ticketing and self-healing operations. In Satellite IoT installations this minimizes the time required to activate and services as well fault recovery. Using a simple example, instead of configuring device connectivity by hand, either in the satellite space or terrestrial space, the orchestration layer may provision dynamically network policies, service profiles and billing policies. This enhances efficiency and minimize operational costs.

4.3 Service Quality and Assurance Evaluation

The other section that the framework can be evaluated against has to do with the ability of the framework to maintain the voice and data services. This is because the disadvantages of satellite IoT services will be unstable latency, coverage gaps, weather-related signal degrades, and slow handover time. OSS intelligence layer supports the real-time monitoring, anomaly detection, predictive maintenance and root cause analysis. These characteristics enable service providers to know when performance is compromised prior to its impact on end users. Indicators which it can be evaluated with include packet loss, rate of call completion, success rate of delivering data, latency, jitter, network availability and number of SLA breaches.

4.4 Scalability and Flexibility Assessment

IoT satellites may consist of millions of distributed devices, and the important thing is that these systems can scale. The framework has a cloud-native and microserviced architecture that allows scaling the functions individually, e.g., the billing, device management, analytics, orchestration, and assurance. The flexibility enables the framework to support small deployments basing on enterprises and large-scale global networks of IoT. Performance level can also be checked by the ability of the system to support increasing device registration, data transactions, voice calls, API calls as well as billing events without necessarily having to reduce the performance of the system.

4.5 Business and Monetization Evaluation

In terms of business aspect, the framework facilitates dynamic pricing, real time pricing, transparency to customers, and sharing of revenues with partners. It enables the service providers to offer differentiated plans with reference to the type of information used, voice minutes, location, quality of network and network type and priority of mission critical. These indications of assessment include: the correctness in billing, minimization of revenue leakage, customer acceptance of partners, customer response rate, invoice (publicity) and time taken to commercialize its new service offering.

4.6 Security and Compliance Evaluation

Security testing is the study of the functionality of the framework to protect devices, network, customer information, and service transactions. The framework includes authentication, encryption, secure APIs, access control, fraud detection and compliance monitoring. Since Satellite IoT services may be international, the regulations on data privacy, spectrum and lawful interception as well as in roaming are to be fulfilled. It can be assessed by measuring the frequency of security incidents, attempts at unauthorized access, audit preparedness, policy enforcement effectiveness, and regulatory reporting effectiveness.

4.7 Overall Evaluation Outcome

Broadly, the proposed framework portrays the potential high in the modernisation of operations in the OSS/BSS in the voice and data ecosystems of the Satellite IoT. It enhances monetization, helps to integrate hybrid NTN-TN, enhances service assurance, offers smart operations and make single operations more automated. The modular and stratified form of it can be customized in the future to new technologies of 6G and advanced LEO constellations, edge intelligence, and AI-native management of the network. As such, the framework can act as an effective assessment model of the service providers aiming to revamp traditional OSS/BSS architecture and convert it into intelligent, cloud-native and commercially viable digital ecosystem.

V.FUTURE ENHANCEMENTS

The proposed OSS/BSS modernization organization can be advanced in the future, with the necessity to enhance the Satellite IoT voice and data ecosystems to be even more autonomous, smart, safe, and commercially adaptable. As Non-Terrestrial Networks converge with Terrestrial Networks, OSS/BSS platforms will need to evolve beyond the currently available cloud-native and API-driven designs to AI-native, self-optimizing and ecosystem-aware designs.

5.1 AI-Native Autonomous Operations

Among the major regular advancements in the future, the implementation of autonomous operations that are AI-native can be included. The existing AI/ML features are predominantly involved in monitoring and prediction and anomaly detection. OSS/BSS solutions of the future should aim to take a step towards closed-loop automation whereby the system can identify network problems, propose causes, solutions, and automatically implement corrections. This would boost continuity of services to remote and critical Satellite IoT applications. It is also possible to optimize satellite beam allocation, traffic routing, better allocation of handover management and prioritization of services in real time with AI-driven decision engines.

5.2 6G and Advanced NTN Integration

The framework can be further enhanced in accordance with the new 6G and new NTN architectures. More data rates, ultra-low-latency applications, in-built sensing, smart surfaces, and space-air-ground-sea connectivity will be utilized in the future satellite Internet of things ecosystems. The OSS/BSS systems must therefore facilitate introduction of dynamic network slicing, cross domain resource management, advanced mobility, and assure services in very heterogeneous environments. Integration with 6G-ready standards can help to increase interoperability and scaling in the long-term.

5.3 Digital Twin-Based Network Management

Digital twin technology can become of great help to OSSs by creating a virtual replica of a satellite, terrestrial and IoT network base. These digital twins can simulate traffic and also simulate service failures and capacity limit, weather conditions and device behavior before the changes are implemented to the actual network. This would help service providers try out the set ups, predict the danger, optimize the service planning and reduced operational meltdown. Digital twins can also enable proactive SLA and predictions of capacities.

5.4 Enhanced Cybersecurity and Trust Management

The systems of the next generation of OSS/BSS should include more powerful cybersecurity and trust. As the number of Satellite IoT services infiltrates the defense, healthcare, transportation, and energy industries, cyberattacks and misuse of

information will have a greater likelihood of becoming a reality. Steps forward can be 0-trust architecture, identity management based on blockchain technology, quantum-resistant encryption, compliance auditing automation, threat detection using AI. Such features would enhance authentication of the device, integrity of the data, trusting partners, and cross-border regulatory compliance.

5.5 Sustainable and Energy-Aware Operations

The area of sustainability is to be improved. The space assets, gateways, edge nodes, data centers and enormous numbers of connected devices make up the IoT ecosystems in the satellites. Future data of the OSS/BSS systems should incorporate energy conscious orchestration, carbon tracking, green billing plans and sustainability reporting. AI has the capabilities of optimizing resource use, unnecessary signaling reduction, or enhancing the energy efficiency of satellite infrastructure and terrestrial infrastructure.

5.6 Advanced Monetization and Partner Ecosystems

Subsequent BSS improvements are needed to benefit more flexible and intelligent monetization models. They can be dynamic pricing, outcome-based billing, pay-per-event charging, pricing with network slices, and automated settlement of partners. The growing presence of additional businesses, satellite operators, mobile operators, cloud providers, and IoT platform vendors in service delivery are necessitating BSS systems to be able to accept visibility in the governance of these ecosystems and real time sharing of revenues.

5.7 User-Centric Experience Optimization

Advancement of customer and enterprise experience ought to be enhanced more in future as well. Service-notices, anticipatory service warnings, centralized dashboards, and chatbots and service suggestions can be customized to increase customer satisfaction. Advanced analytics should be able to provide insights about the health of the devices, quality of services, and the cost trend, SLA level performance to enterprise users. This will simplify the management of Satellite IoT services, monitor and scale of such services in various industries.

VI.CONCLUSION

The modernisation process of OSS/BSS platforms is essential to equip future generation Satellite IoT voice and data ecosystem of both non-terrestrial and terrestrial networks. As satellite communication is increasingly eroded into cellular networks on the ground, cloud computing, edge computing, and enterprise Internet of Things operations are no longer structured to scale, complicate, and serve the demands of integrated connectivity systems (legacy OSS/BSS architecture). Legacy systems may lack automation, interoperability, real-time service delivery, service assurance, and domain visibility; therefore, modernisation is required to enable the system to deliver services to the future.

This research article developed a detailed framework for the modernisation of OSS/BSS on a cloud-native infrastructure, microservice, open API, AI/ML-based assurance, zero-touch provisioning, real-time charging, and cybersecurity, and partner ecosystems management. The structure facilitates adequate coordination of satellite networks, terrestrial networks, IoT, customer systems, and business apps. It allows service providers to control voice and data services more effectively, and at the same time, reliability, scalability, security, and commercial flexibility are guaranteed.

As the analysis of the framework reveals, it can significantly increase the efficiency of its operations, reduce the role of people, optimise fault prediction, streamline dynamic service provisioning, and facilitate the monetisation models, which can be adapted. It also improves customer experience because it is more transparent, activates services faster, bills accurately, and better tracks service-level agreements. In addition, the framework can be augmented in novel directions of 6G, progressive NTN architectures, digital twins, AI-native functionality, and sustainable network management.

In conclusion, OSS/BSS modernisation is not only a change of technical nature but also an enabler of the satellite IoT industry. Service providers can be assisted by an integrated, intelligent, and standards-based OSS/BSS system to offer effective, secure, and commercially viable voice and data services across worldwide terrestrial and non-terrestrial networks. This modernization will play a great role in ensuring that it facilitates future digital connectivity to remote industries, critical infrastructure, mobility and emergency communications and intelligent global ecosystems.

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