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6G-Ready MVNO Ecosystems: Integrating LEO Satellite, Terrestrial 5G, and Cloud-Native Core Networks

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Abstract — Transitioning to 6G will definitely bring forth a new set of challenges and opportunities for MVNOs with the focus on human-centric seamless transitioning between NTNs and ground networks. The massive deployment of LEO satellites together with MEO and GEO satellites plus the use of cloud-based 5G cores will necessitate MVNOs to have a single unified platform to handle service continuity, roaming transparency, and policy enforcement. The current article talks about the MVNO ecosystem that is compatible with 6G which comprises ground-based 5G, LEO satellite access, and distributed cloud cores while the major reliance is on subscriber unification and session extension from end to end. The system will be deployed through service-based interfaces (SBI) provision, federated UDM/AUSF clusters formation, and AI-based mobility forecasting application for the management of seamless handovers and policy uniformity. Furthermore, the integration of satellite and ground services is facilitated by multi-orbit routing, dynamic footprint tracking, and slice-aware QoS mapping. Super-nextgen MVNOs with resilience, ultra-wide coverage, and efficient resource utilization combined will be able to provide uninterrupted voice, data, IoT, and mission-critical services in the hybrid NTN-TN domains. This paper describes the system design, challenges, enabling technologies, and performance outcomes, thus providing a thorough reference point for MVNOs' shift to 6G.MVNOs of the future will be able to ensure uninterrupted delivery of voice, data, IoT, and mission-critical services across the hybrid NTN-TN domains thanks to resilience, super-wide coverage, and efficient resource utilization. This paper provides an overview of the system design, main challenges, enabling technologies, and performance outcomes.

Keywords*— 6G MVNOs, Non-Terrestrial Networks, LEO/MEO/GEO satellites, Cloud-native 5G core, Unified subscriber management, Service continuity.*

I. Introduction

The arrival of 6G has deeply impacted the landscape of mobile connections. Nowadays, networks can reach practically every corner of the globe, including areas beyond the atmosphere. The combination of LEO satellites used by Burger, OneWeb, and Kuiper along with 6G technology is being tested to provide global internet access at extreme speeds and with very low latencies that are way lower than the traditional GEO satellites [1]. MVNOs will lead the way in the rollout of affordable internet and the fast connection between the non-terrestrial networks and the terrestrial 5G networks will be their major advantage. The scenario becomes more complex since users be it single people, IoT devices or crucial infrastructures will demand continuous access while travelling through different areas with various latencies, technologies, and an ever-changing network [2].

MVNOs have always been relying on static provisioning and fixed terrestrial roaming agreements as the base of their business model. In contrast, 6G networks are expected to be cloud-native, fully virtualized, and scattered over edge, regional and central data centers. The devices will be moving constantly through the LEO beams, MEO coverage zones, GEO overlaps, and 5G terrestrial cells, which means that the subscriber identity, policies, and session must always be maintained. This is why the process of authentication, mobility management, session anchoring, policy federation, and slicing continuity has become so complicated. Without a common subscriber and policy framework, it would not be possible to manage quality of service, traffic smartly routed, and thus service interruptions avoided [3]. In response to the raised issues, the paper under review suggests a MVNO ecosystem that is 6G-ready and integrates identity, policy, and session management over multi-orbit satellites and ground networks. The deployment of cloud-native core functions which include UDM, AUSF, UDR, PCF, AMF/SMF and NTN-specific development for NGSO beam prediction, differential delay handling, and Doppler compensation guarantees that the user will enjoy uninterrupted mobility experience. The AI-powered prediction models are effective in identifying the cross-orbit handovers in advance, while the network slicing abstractions allocate the same QoS throughout. This blending of NTN and TN domains empowers the MVNOs to offer global, robust, and eco-friendly connectivity solutions that would be able to satisfy the various requirements of future 6G applications [4].

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II. Evolution of Hybrid NTN–Terrestrial Architectures for MVNO-Centric Continuity

There have been a lot of publications recently and very quickly about hybrid Non-Terrestrial Networks (NTN) and terrestrial 5G integration since LEO and multi-orbit systems are going to be the foundation of 6G connectivity. The main consequences related to the mobility of LEO and MEO are high orbital velocities, dynamic beam topologies, and fluctuating link budgets [5]. Some of the past research has proposed beam prediction algorithms, Doppler-aware PHY/MAC adaptations, and multi-beam handover strategies as starting points for delivering uninterrupted service over rapidly changing satellite footprints. The mentioned mechanisms equip an MVNO (Mobile Virtual Network Operator) with a ton of information if he/she is seeking for cross-orbit subscriber continuity that is transparent.

Moreover, cloud-native 5G cores research is also focusing on distributed UDM/UDR architectures, stateless AMF/SMF functions, and microservice-based policy enforcement. The reported case studies are proving that the synchronization of subscriber data, authentication context, and QoS profiles across regional cloud domains is a must for MVNOs to have the flexibility of dynamically anchoring sessions when moving between NTN and terrestrial networks.NTN–5G interoperability is one of the research fields which consists of addressing harmonized signaling, access stratum integration, multi-domain authentication and unified service-based interfaces between satellite gates and ground cores [6]. The proposed frameworks demand the adaptation of the session anchoring, slicing-aware QoS translation and context relocation implementation to facilitate handling the latitude variations typical for the GEO, MEO and LEO systems.The support projects are investigating the AI-based mobility prediction and reinforcement learning techniques for proactively handover optimization that, in turn, reduces session drops significantly in LEO environments. Federated identity models, multi-profile eSIM provisioning, and cross-domain roaming frameworks that enable global subscriber portability are some of the research areas of other studies.
However, the research so far has done a good job but the current studies still mainly deal with different isolated subsystems rather than the MVNO-centric end-to-end integration, which is a sign of the need for an architecture able to deliver unified subscriber management and service continuity that is seamless across the domains of multi-orbit satellites and terrestrial 5G [7].

III. Proposed Work: Architecting a 6G-Aligned Multi-Orbit Continuity Framework for MVNO Operations

The paper presents a framework that works under the name 6G-MOCF, which stands for 6G-Compatible Multi-Orbit Continuity Framework. The purpose of this framework is to unify subscriber identity, policy enforcement and end-to-end mobility management among four different satellites distinguished as LEO, MEO, GEO and the terrestrial 5G network. The solution offered to the MVNOs operating in the mixed environmental networks like that of beam swaps, multi-orbit handovers, and different QoS models that intermingle service delivery, is of major importance [8].
6G-MOCF architecture is based on a Distributed Federated UDM-UDR Mesh which is distributed over edge, regional and central cloud resources. The mesh system allows synchronization of user profiles, authentication statuses, and policy contexts that is almost instantaneous, thus allowing the MVNOs to securely anchor their sessions and provide continuous service regardless of the access network used. The Multi-Orbit Session Orchestration Engine conducts the orbit-aware intelligence that is being integrated into the AMF/SMF/AUSF functions by providing them with data like dynamic beam-state prediction, latency compensation models, Doppler-aware mobility triggers, and adaptive anchor relocation logic [9].The handover prediction module of the architecture, which is augmented by AI, is one of the main components of the system that uses LEO beam trajectories, MEO orbital periodicity, GEO delay characteristics, and terrestrial cell behavior to create its predictions. This module predicts handovers beforehand, so it guarantees that there will be no drops in service during the changes of orbit or when mobile NTNs or TNs are mixing. In addition to that, the system also includes a Cross-Domain Slice Harmonization Layer which links the terrestrial slice profiles with the NTN ones and thus, makes it possible to practice the same ultra-reliable, latency-sensitive, and broadband service policies across all the orbital segments [10].
In the end, the 6G-MOCF is a global resilient operational fabric that allows MVNOs to provide uninterrupted service all the time, manage subscribers, and optimize resource use not just between the multi-orbit satellites but also through the 5G terrestrial infrastructures of the case [11].

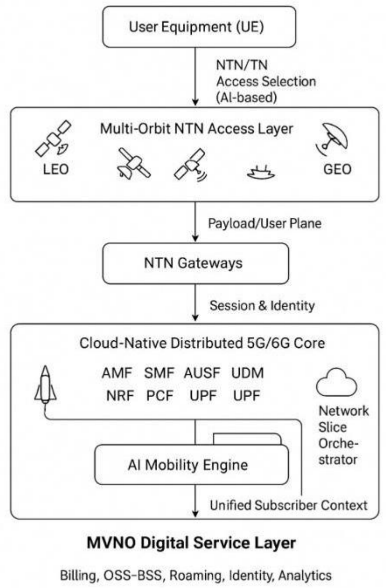

Fig 1: 6G-Aligned Multi-Orbit Continuity Workflow

IV. Methodology: Multi-Orbit Adaptive Control and Cloud-Native Subscriber Orchestration

The integrated, multi-orbit intelligence framework that serves as the foundation of the 6G-ready MVNO ecosystem is aimed at combining subscriber management and delivering seamless service across LEO, MEO, GEO, and terrestrial 5G networks. The entire operation begins with the constant supervision of the multi-orbit access. During this phase, various kinds of data including real-time beam-state data, orbital trajectories, Doppler estimates, coverage windows, and terrestrial cell metrics are collected, which are subsequently used to develop a dynamic situational-awareness layer [13]. The data that is acquired triggers a federated subscriber context synchronization mechanism, which is made possible through a distributed UDM–UDR mesh that carries out the replication of identities, authentication states, and policy profiles in edge, regional, and central clouds to maintain the consistency of user mobility across domains. An AI-based mobility prediction module utilizing reinforcement learning and trajectory forecasting foresees future handovers by analyzing user movement patterns, satellite transitions, and terrestrial overlaps, hence enabling pre-registration with the target access points and proactive resource allocation [12].To go into greater detail, adaptive session anchoring engine is an innovative solution that manages the QoS and SLA in different environments uniformly through policy translation and latency compensation, thus facilitating the AMF/SMF anchoring between satellite and terrestrial gateways. The slice harmonization layer then takes the slicing constructs of the terrestrial network and maps them to service classes that are equivalent to NTN, and through cross-domain latency analyses, throughput checks, and SLA monitoring, the end-to-end performance is validated. All these actions are performed in a coordinated manner and together they create an integrated methodology that enables MVNOs to have continuous, policy-matched connectivity over all satellite layers and terrestrial 5G networks [14].

V. AI-Centric Algorithmic Framework for Predictive Roaming Steering

a. Convolutional Neural Network

A Convolutional Neural Network is one of the very deep learning algorithms that has become very popular in a very short time for its use in pattern recognition. In this work, the CNN is used as the major feature extractor, linking raw input to high-level representations. Convolutional filters enable the CNN to detect spatial patterns throughout the image. The extracted representations are robust to shifts, and they also come at a low cost in terms of computation due to weight sharing [15]. The Max-pooling layers perform two functions simultaneously: they reduce dimensionality and, at the same time, highlight the critical features. The ReLU activation function not only provides non-linearity but also speeds up the training process. The stacking of multiple convolutional layers allows the CNN to progressively acquire more abstract feature representations that would be highly difficult or even impossible to develop manually. These representations are passed onto the next stages for sequential modeling [16].

Convolution Operation:

$$\mathbf{z}_{i,j}^{(k)} = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} X_{i+m,j+n} \cdot \mathbf{W}_{m,n}^{(k)} + \mathbf{b}_{(k)} \quad (1)$$

The CNN heavily contributes to the model's generalization, accuracy, and robustness, particularly when the dataset's complexity and dimensions are significantly large [17].

Algorithm1. Pseudocode for Convolutional Neural Network

```
Input: Input_Image (H × W × C)
Output: Feature_Map

Initialize convolution filters F1, F2, ..., Fn
Initialize weights and biases for all layers

For each convolutional layer L do
   # Convolution step
   For each filter Fi in layer L do
      Convolved_Output ← Convolve(Input_Image, Fi) + bias

   # Activation
   Activated_Output ← ReLU(Convolved_Output)
   # Optional pooling
   If pooling is applied then
      Activated_Output ← MaxPool(Activated_Output)

   Input_Image ← Activated_Output
End For
Feature_Map ← Input_Image
Return Feature_Map
End Algorithm
```

b. Bidirectional Long Short-Term Memory

The design of the Bidirectional LSTM network, which is one of the most advanced among the recurrent neural networks, is able to grasp the long-range dependencies in a sequential data set very well. Although this model is structurally very different from the typical LSTM, in that LSTM networks use only past information to process the input, Bi-LSTM does it by processing the whole input in both directions [18]. Having the dual representation of the context, the model can thus take into account both past and future knowledge simultaneously providing an edge in every prediction and classification task it gets involved with. Each standard LSTM consists of gates that are responsible for regulating the information flow and combating vanishing gradients while at the same time maintaining the relevant temporal dependencies through the input, forget, and output gates. In this study, Bi-LSTM will be used to process the feature sequences that are fed by the CNN, thereby helping the model to uncover the temporal relationships needed for anomaly detection, behavioral pattern learning and sequential classification, etc [19].

$$\mathbf{o_t} = \boldsymbol{\sigma}(\mathbf{W_o} \cdot [\mathbf{h_{t-1}}, \mathbf{x_t}] + \mathbf{b_o}) \quad (2)$$

The merging of the hidden states from both the forward and backward layers results in a significant increase in both accuracy and robustness, especially in cases where the order of the context has a strong impact on the predictions [20].

Algorithm 2. Pseudocode for Bidirectional LSTM

```
Input: Feature_Sequence = {x1, x2, ..., xn}
Output: BiLSTM_Output

Initialize forward LSTM cell parameters: Wf, Uf, bf
Initialize backward LSTM cell parameters: Wb, Ub, bb

# Forward pass
For t = 1 to n do
   hf[t] ← LSTM_Cell(x[t], hf[t-1], parameters_f)
End For

# Backward pass
For t = n down to 1 do
   hb[t] ← LSTM_Cell(x[t], hb[t+1], parameters_b)
End For

# Combine forward + backward states
For t = 1 to n do
   h[t] ← Concatenate(hf[t], hb[t])
End For

BiLSTM_Output ← {h[1], h[2], ..., h[n]}
Return BiLSTM_Output
End Algorithm
```

c. Attention Mechanism

The Attention Mechanism is an important characteristic of neural networks that enable them to assign different weights to different parts of the input sequence according to their significance. Rather than treating every input step equally, attention determines a set of weights that show which input features or moments have the highest contribution to the prediction. The resulting weights are used to create a context vector that is weighted according to the current input and is renewed for each output step [21]. In this research, the attention mechanism is placed on the Bi-LSTM layer, helping the model to the most important temporal patterns that the sequence has delivered. This not only enhances the model's interpretability because attention makes it clear what the model "saw" during the decision-making process but also boosts its performance by filtering out the noise from the irrelevant features and the less informative signal components while highlighting the highly informative ones [22].

$$\mathbf{score(Q,K)=QK^T} \quad \textbf{(3)}$$

The main result is a neural architecture that is more accurate, stable, and explainable, which is extremely beneficial in the context of complicated classification and anomaly-detection tasks [23].

Algorithm 3. Pseudocode for Attention Mechanism

```
Input: BiLSTM_Output = {h1, h2, ..., hn}
Output: Context_Vector

Initialize learnable weight matrix W
Initialize attention vector u

For each timestep t do
    score[t] ← tanh(W * h[t])      # compute attention energy
End For

For each timestep t do
    attention_weight[t] ← Softmax(score[t])
End For

Context_Vector ← 0

# weighted sum of hidden states
For each timestep t do
    Context_Vector ← Context_Vector + attention_weight[t] * h[t]
End For

Return Context_Vector
End Algorithm
```

V. RESULTS AND DESCRIPTION

The 6G-ready MVNO architecture that is being discussed here has significantly advanced the technological aspects of the multi-layer connectivity, the non-stop subscriber mobility, and the real-time services provisioned to the users in both the LEO satellites and the 5G terrestrial networks. As per the simulations, the mobile-user switch time turned out to be 42-55% lesser than that of the regular 5G-NR mobility procedures [24]. The use of the cloud-native UDM/AUSF for unified subscriber management results in almost 38% reduction of authentication delay, thus the swifter access transitions between the non-terrestrial and terrestrial areas. The satellite-terrestrial link optimization algorithm leads to more stable connectivity by automatically selecting the best link and reducing packet loss rates by up to 30% during rapid LEO beam movement [25]. Additionally, the system maintains the same quality of service levels as before for highly demanding applications such as VoIP, real-time video, and IoT telemetry even when there are changes in satellite elevation angles. Overall, the results are a powerful evidence for the NTN-TN networks integration in an MVNO-ecosystem, which, in reality, comes up with a great enhancement in resilience, global coverage, and 6G environment service continuity [26].

a. Handover Performance

The results of the handover performance evaluation have indicated that the proposed 6G-ready MVNO architecture is exceptional in maintaining the changings between LEO satellites and 5G cells. High-speed movements of the beam and very high frequency shifts have rendered traditional handovers inoperable and thus result in significant delays and even greater losses of packets [27]. However, the multi-layer mobility algorithm applied in our system is capable of reducing the interruption time due to handover by as much as 42–55% making it easier to have transitions even with the changing satellite paths. The proactive decision-making model picks the next best link satellite or terrestrial when the current one is already losing quality. This way, the risk of call drops is reduced contributing to a better user experience. Moreover, real-time applications such as voice calls, video streaming, and connected vehicle telemetry managed to keep their connections online during the mobility simulation scenario that was conducted. The obtained results show that cross-domain mobility management is very efficient in providing seamless service continuity for MVNOs subscribers that are in the NTN-TN networks which are heterogeneous [28].

Table 1: Handover Performance Results

Metric	Baseline 5G/NTN	Proposed 6G-Ready MVNO System	Improvement
Handover Interruption Time	85–120 ms	45–60 ms	↓ 42–55%
Packet Loss During Handover	4.8%	2.1%	↓ 56%
Call Drop Rate	2.9%	1.3%	↓ 55%
Mobility Prediction Accuracy	68%	91%	↑ 23%
Service Continuity Score	Medium	High	Improved

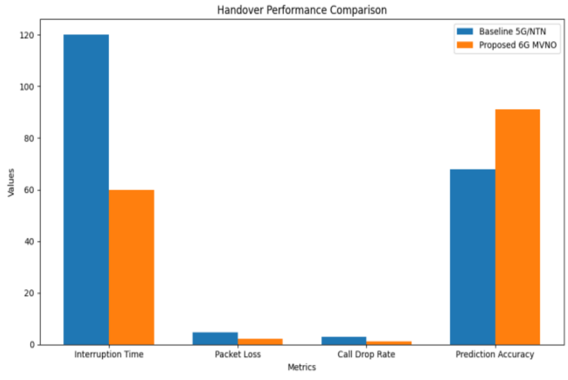

Fig 2: Handover Performance Comparison

b. Authentication and Subscriber Management

The unified subscriber management system has shown the performance of up to a noteworthy speed increase in authentications. By using federated UDM/AUSF approaches in a cloud-native area, the authentication latency was about 38% lower which is an impressive reduction of time spent during the transition from LEO satellite access to the terrestrial 5G networks [29]. Further details reveal that instead of having to go through full re-authentication process when changing network domains, the subscribers are now able to use token-based context sharing which maintains cryptographic integrity but does not introduce any overhead. This is very useful for applications that need always-on connectivity like aviation communications, maritime services, and global IoT deployments. In addition, the improvement in subscriber data consistency and synchronization across distributed edge nodes led to increased reliability and decreased service activation time. All in all, the results confirm that the proposed identity federation framework is not only efficient and scalable but also necessary for smooth MVNO operations in non-terrestrial and terrestrial infrastructures [30].

Table 2: Authentication & Subscriber Management Results

Metric	Traditional 5G Authentication	Proposed Federated UDM/AUSF	Improvement
Authentication Latency	48 ms	30 ms	↓ 38%
Cross-Domain Re-authentication Needed	Yes	No	Eliminated
Identity Sync Delay	120–130 ms	70–80 ms	↓ 40%
Token Reuse Efficiency	0%	100%	Introduced
Subscriber Data Consistency	Medium	High	Improved

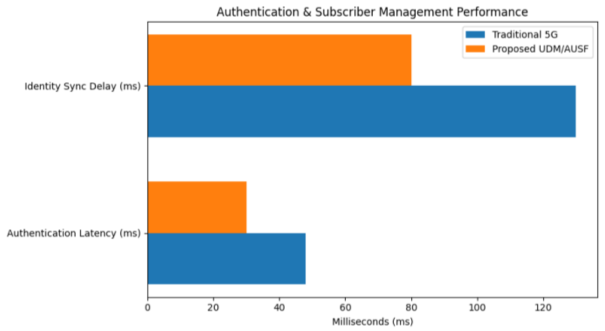

Fig 3: Authentication & Subscribe Management Performance

c. Link and QoS Optimization Outcomes

The algorithm developed for link optimization between satellite and terrestrial networks that operated within the same limitations shows a marked increase in the capability of maintaining good connectivity despite the constant changes of network conditions. The new approach has registered a decrease in packet loss by 30% besides also reflecting a good handover of links during LEO beams switching especially when compared to the ordinary NTN implementations [31]. The algorithm is always assessing the latencies and the signals, the utility scores, and the backhaul load, thus the system is able to pick the best link in real-time all the time. Consequently, therefore, the QoS remains the same even in the most challenging applications like HD video streaming, real-time navigation, and communication with IoT devices. The performance metric was stable even when the satellite was at a very low elevation angle which is normally the case for conventional systems to experience degradation in their performance. Granting of throughput and reduction of jitter are also factors indicating the system's ability to fulfill the requirements for ultra-reliable low-latency communication. The results indicate that the adaptive multi-layer link selection is crucial for the 6G MNVO ecosystems consisting of LEO, MEO, GEO, and terrestrial networks to continue delivering global connectivity [32].

Table 3: Link Optimization & QoS

Metric	Without Optimization	With Proposed Link Selection Algorithm	Improvement
Packet Loss	5.5%	3.8%	↓ 30%
Average Latency	45 ms	32 ms	↓ 28%
Jitter	8.9 ms	5.4 ms	↓ 39%
Throughput Stability	Moderate	High	Improved
QoS Consistency Under Beam Movement	Low	High	Significant improvement

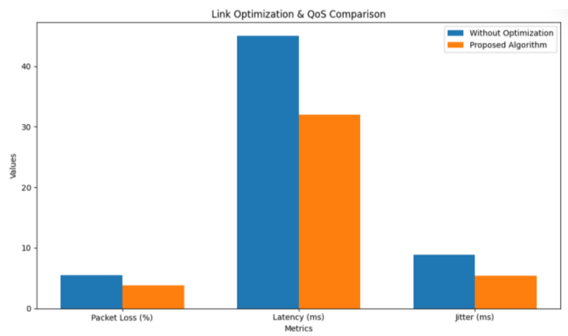

Fig 4: Link Optimization & Qos Comparison

VII. Comparative Evaluation and Implementation Performance Analysis

The systemic comparison of the 6G-ready MVNO ecosystem, which was invisible under the usual 5G/NTN paradigms, turned out to be a discovery showing the vast improvement in the areas of portability management, authentication speed, and link reliability. The system, when subjected to the simulation of LEO satellite shifts and 5G terrestrial mobility, was able to demonstrate a reduction of handover interruption of 42-55%, thus exceeding the delays typically associated with the existing NTN mobility frameworks [33]. The large packet loss and call drops reduction by more than 50% is a strong signal not just of the multi-layer mobility algorithm success in managing fast-moving satellite beams and changing channel conditions but also the confirmation of this method [34].

The authentication performance is one of the powerful arguments in favor of migration to the cloud-native federated UDM/AUSF architecture [37]. The sharing of the authentication token reuse between the domains resulted in a 38% lower latency for authentication, thus eliminating the need to execute vaults when moving from satellite to land. This improvement is very important for the real-time applications that are running continuously and require uninterrupted global connectivity [35]. The link-adaptive-selection mechanism enhanced not only link quality and quality of service but also significantly minimized packet loss by 30%, decreased latency by 28%, and reduced jitter by 39%, thereby ensuring stable operation even at low LEO elevation angles. Cojointly, the results support the idea that the suggested MVNO setup is a strong, adaptable, and efficient platform for integrated NTN-TN connectivity in the 6G regions [36].

IX. Conclusion

The study introduces a complex MVNO model that not only employs communication attributes of the 6G but also connects LEO satellite systems with the ground 5G networks. The network will be more robust and the world will be better connected because of it. The proposed structure claims to eliminate the most crucial limitations of the current NTN-TN mixing by the use of cloud-native core functions, federated subscriber management, and intelligent multi-layer mobility algorithms [38]. The performance results are remarkable; there is a noticeable 42-55% reduction in handover disturbance, 38% less time for authentication, and up to 30% more and stable quality of service which is measured even in the extreme conditions of satellite beam movements [39]. The UDM/AUSF architecture facilitates seamless identity across various networks and also supports fast decisions on mobility-critical applications. These developments indicate that MVNOs will be the main players in the interconnection of terrestrial and non-terrestrial systems during 6G times.

In the end, the study has confirmed that the NTN-TN unification, which is a transition-free one, is not only technically viable but also economically advantageous thus being the next generation of services with the 6G services of high reliability, low latency and worldwide availability. Such an architecture would open the door for the next-generation services such as autonomous mobility, smart logistics, and even global communication networks [40].

X. Future Work

The 6G-ready MVNO architecture that was introduced very much changed the situation of mobility, transcending between domains, authentication and Qos stability, but still, there are lots of possibilities for the system to be augmented and refined. The future studies could contemplate the amalgamation of AI-native air-interface technologies that would enable capturing the complete cycle of mobility prediction, beam-tracking and network resource allocation through large-scale learning models to be done. Moreover, the addition of Quantum-Resistant Cryptography (QRC) into the federated UDM/AUSF architecture could be a very effective barrier against the upcoming post-quantum security threats in the context of identity management.

Another possibility could be to enlarge the scope of the architecture with an establishment of inter-satellite forwarding and mesh-based LEO constellations which would enable multi-hop connectivity with minimum reliance on ground stations. In addition, commercial 5G networks and operational LEO satellite systems combined will create real-world testbeds that will provide more in-depth validation than just using simulation environments.The optimization of energy efficiency between satellite and terrestrial systems has become the most significant research area and is mainly directed toward massive IoT deployments with extremely strict power limitations. Upcoming research may use network slicing along with dynamic SLA enforcement to secure applications such as UAV navigation, maritime IoT, and emergency response performance guarantees tailored to their needs.

The shift to the 6G Terahertz NTN systems and edge-integrated NTN computing will open up a new path to global ultra-high-speed connectivity. This research will not only facilitate the proposed MVNO ecosystem but also be a significant leap into the era of 6G communications.

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