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Integrated Terrestrial-Satellite 6G Networks for Ubiquitous Global Connectivity and Low-Latency Services

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Abstract

The occurrence of sixth-generation (6G) wireless networks provides a paradigm shift to a connected, robust, and ultralow-latency world. Yet, terrestrial networks are still limited in their coverage, particularly in those remote and underserved areas, whereas satellite networks are characterized by high latency and shortage of spectrum. The limitation of this work is that to overcome this limitation an antenna-aware orchestration framework is proposed in this paper within integrated terrestrial and satellite 6G networks. The framework integrates heterogeneous areas by AI-enabled cross-domain coordination, dynamic resource allocation, and integrates directional antenna gain modeling explicitly as a function of elevation angle, and beamwidth. Impactful architectural characteristics comprise smart beam-steering planning strategies and intelligent mobility-conscious spectrum together with beam-aligned handover administration. The influences of antenna misalignment on signal quality are mathematically and systematically examined and, as proven by simulations, significant gains in signal-to-noise ratio (SNR), bit error rate (BER) and continuity of coverage improve considerably when the modulation scheme is used in high-mobility surroundings. The overall end-to-end latency and throughput of such a system is better than either of the standalone terrestrial or satellite implementations. The proposed architecture fills the gap that existed between RF-layer beamforming and network-layer mobility management thereby providing a solid basis of resiliency, mission-critical, and globally distributed 6G communication services.

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Introduction

The immense increase in wireless data traffic and spread of latency-sensitive applications have compounded the need of everywhere high-capacity, low-latency connectivity. Though 5G networks have attained unprecedented success in contexts of data rates and device density, they are bound by the reduced range of terrestrial infrastructure, especially beyond the countryside, remote areas, as well as the sea. Satellite communication, in its turn, can cover large areas and is usually offset by latency, interrupted links, and poor spectral efficiency.

New technology in non-terrestrial networks (NTNs), low earth orbit (LEO) satellites and software defined networking (SDN) has provided new opportunities to combine terrestrial and satellite networks. Nonetheless, there are always difficulties of aligning heterogeneous resources, smooth hand off, and end-to-end quality of service (QoS). Current strategies do not normally give consistent orchestration, ending with poor use of resources and the interruption of services at times of mobility.

The following paper will discuss these issues and present a proposal of integrated terrestrial-satellite 6G network architecture, which concerns the AI-based cross-domain orchestration and dynamic resource management. This aims at providing global, resilient press and ultra-low-latency connectivity of next-generation applications.

Literature Review

Sixth-generation (6G) wireless networks are still evolving to carry out global, ultra-low-latency and high-capacity communication infrastructures [1, 2]. Nevertheless,

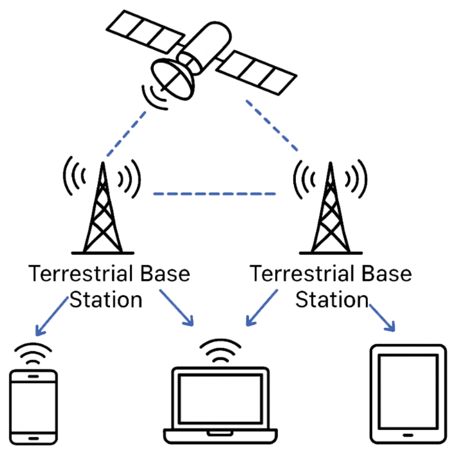

Fig. 1: Block diagram of the proposed integrated terrestrial-satellite 6G network system.

terrestrial-only systems have a problem of having poor geographical coverage; satellite systems have the problems of latency, interference and spectrum issues [3, 4]. This requires a highly coupled terrestrial-satellite design that collectively optimizes coverage of the signal, beam pointing and resource division.

One of the visions of 6G is the necessity of non-terrestrial networks (NTN) supplement to terrestrial networks to be used as satellite constellations and aerial relay [5, 6]. Such integration should be able to cover not only the physical-layer coordination, but control-plane and resource management issues. AI appears to be the tool that cannot only support this integration but is also discussed in the context of dynamic traffic environments in [7].

In order to develop its flexibility and improve latency performance, several SDN-based convergence architectures of space-air-ground networks have been suggested [8, 24]. Nevertheless, the majority of them do not offer sufficiently flexible solutions in real-time. A routing framework LEO satellite that uses AI-enhanced was proposed in [9], which is associated with a low-latency, although has scalability problems with a dense environment. Correspondingly, multi-layer handover techniques were promising in [10, 25], but they became poor under high user mobility.

Due to these drawbacks, the framework of cross-layer optimization has been proposed in order to enhance throughput in heterogeneous domains [11, 23]. However, when it comes to delivering end-to-end QoS, it is very difficult operation especially because satellite path and the terrestrial path would be asynchronous. An interference-aware spectrum sharing mechanism between the terrestrial and satellite links has been developed in [12] showing the enhanced spectral efficiency by increasing signaling overhead.

Trust and security in NTN systems are also the issues that attract increasing attention. Blockchain-based systems have enhanced integrity and robustness of integrated networks [13, 22], but they suffer greater latency and energy consumption. The increased coverage offered by integrated access and backhaul models [14] adds complexity, in terms of directional antenna beam coordination.

This requirement of beam-aware coordination is further strengthened in [15, 16] in which satellite beam alignment and link optimization are cited as important performance bottlenecks. Antenna beam characteristics, and gain models can have a direct impact on most of the requirements in studies on system-level requirements of 6G [17, 21], which are focused on resilience, spectral efficiency, and coverage continuity.

Spread-out surveys like [18 & 19] also delve into the problem of the 5G/6G unified terrestrial-satellite systems status and note the absence of the coordination frameworks that integrate beam dynamics and the elevation-angle sensitivity. Aerial networks enabled by UAVs as discussed in [20] are complementary to each other and to enable consistent QoS rely on antenna alignment and beam tracking.

Although these research papers have valid issues that have to be tackled, like handover, spectrum sharing, routing, and trust, the vast majority of them fail at offering a beam-aware or an antenna-centric orchestrator to the problem. This paper addresses this shortcoming by suggesting a framework that incorporates antenna gain modeling dependent on elevation and improves beam misalignment as well as an adaptive driving signal using AI within heterogeneous domains.

Beam-Aware Signal Coordination and Antenna-Driven Orchestration

Unified Multi-Layer Orchestration Architecture

The solution in form of a proposed implementation of the unified multi-layer orchestration architecture will also support the intelligent aggregation and control of both the terrestrial and satellite network resources. The central hub of this architecture is hierarchical orchestrator that acts as a controller of all resources and services in all the domains of the network. Communicating with Software-Defined Networking (SDN) controllers of the terrestrial part and satellite part, the orchestrator provides a smooth resource location and delivery of services. The SDN controllers deal with local resource management, which is bringing agility and reliability to control areas they service, but are still connected to the central orchestrator.

The integration of AI agents is one of the major insights into this architecture. These agents get ingrained in the orchestration clinical on a permanent basis so as to continuously observe the states of the networks anticipate the mobility events as well as preactively optimizing the resource allocation. Using real-time analysis and future modeling, the system can dynamically allocate network resources while reducing latency, maximizing throughput, and adjusting to the network in real-time and the needs of different users.

The orchestrator has the capacity to handle inputs of the SDN controllers and AI agents to achieve dynamic resource allocation. This helps the system to make accurate choices when allocating resources, conditions that allow them to provide maximum coverage and Quality of Service (QoS) even in environments with loads of

Table 1: Comparative Analysis of Existing and Proposed Systems.

Ref.	Focus	Key Contribution	Limitation	Our Framework's Advantage
[4]	NTN Integration	Emphasized need for unified terrestrial-satellite systems	Lacked beam alignment or antenna gain modeling	Incorporates elevation-aware gain and beam tracking
[8]	SDN for Space-Air-Ground Networks	Enabled domain convergence via control-plane flexibility	No antenna-level awareness or signal-quality adaptation	Beam-aware SDN logic driven by antenna inputs
[9]	AI Routing for LEO Satellites	Reduced delay via intelligent routing	Scalability issues under dense traffic	Scalable routing using gain-aware, mobility-sensitive AI
[10]	Handover Strategies in 6G	Improved handover under moderate mobility	High failure rates in fast-moving scenarios	Beam misalignment-aware prediction reduces handover errors
[11]	Cross-Layer Optimization	Boosted throughput across layers	Poor end-to-end latency/QoS guarantees	Integrates latency, gain, and misalignment into utility function
[12]	Dynamic Spectrum Sharing	Reduced interference via flexible allocation	High signaling overhead	Proactive gain-triggered resource allocation reduces overhead
[13]	Blockchain for NTN Security	Enhanced trust in cross-domain links	Added latency and complexity	Maintains QoS while enabling physical-layer robustness
[15]	Satellite Antenna Propagation	Identified beam alignment as a major bottleneck	No orchestration framework for mobility + alignment	AI-assisted handover with beamwidth-aware optimization

dynamics. Moreover, the user movement and network state prediction features of the AI agents give the network the ability of anticipating user movement and network state transitions and make preemptive changes to minimize service breakdown.

Orchestration layer is intended to provide supplementary infrastructure to adaptation on the beam level. The orchestrator does not need to manage abstract network streams as inputs but instead focuses more on antenna-aware sectors, elevation angle, directional gain, and angular beam offset as critical inputs to signal path selection and resource allocation. SDN controllers and AI modules are supporting and facilitate as they allow the distributed enforcement of the gain-aware routing decision and latency sensitive handover policies.

The Architecture of unified multi-layer orchestration system is represented in Figure 2. Such an integrated approach facilitates smart, automated, and scalable management of the integrated terrestrial-satellite 6G networks managing various services and providing strong performance in the dynamic and diverse environments.

AI-Driven Cross-Domain Resource Management

Cross-domain resource management based on AI makes use of sophisticated algorithms including deep reinforcement learning (DRL)to perform real-time network optimization. These AI models allow the system to make intelligent decisions on spectrum allocation, routing, and handover since they will always learn about user mobility, link quality, and different service requirements among other factors.

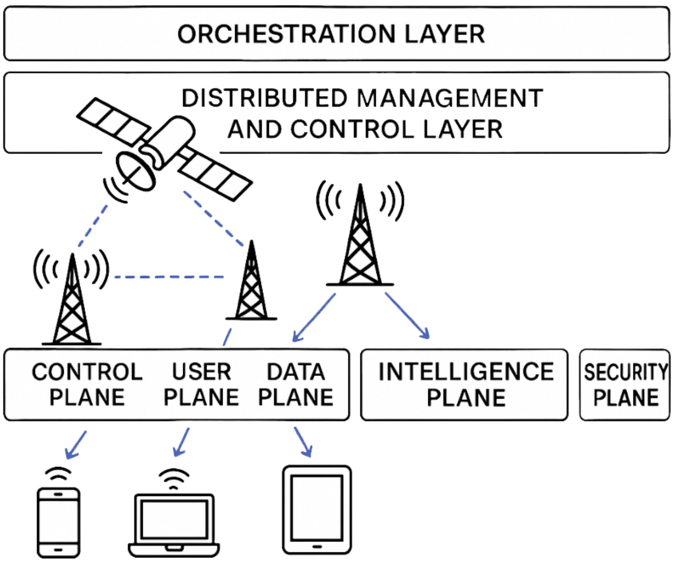

Fig. 2: Architecture of the unified multi-layer orchestration system.

Key Features:

- Real time spectrum Allocation:
  Automatic 5G is able to dynamically assign the spectrum resources according to the prevailing traffics, certain interferences, and the projected future needs of the users, to satisfy the frequency and promotes an efficient use so as to limit congestion.
- Intelligent Routing:
  Therefore, AI algorithms identify favorable routes to achieve maximum throughput and minimum latency by assessing network topology, link quality and service-level agreement.
- Flawless Hand over:
  The system anticipates the movement of the users, and automatically initiates handovers between satellite and terrestrial domains so that service continuity and quality are assured even in highly dynamic environment.
- Staying one step ahead of the change:
  Dynamic monitoring and forecasting enables the network to respond to change (outages or other) prior to it affecting users (e.g. variable demand or degradation in links).

Using AI-based decision logic, dynamic spectrum allocation and mobility-conscious handovers (depending on signal strength, beam misalignment and the antenna gain) are also supported. The learning policy places most priority on elevation-dependent gain maximization and PER minimization via lightweight model adaptation.

Mathematical Modeling

The given section outlines a detailed mathematical model of performance optimization of the integrated terrestrial-satellite 6G network. The model aims at maximizing the utility of the system given average network latency is minimized and therefore comprise the need to resolve the primary trade-off in 6G systems between high throughput and low communication delay, which is conditional to diverse 6G applications.

In the proposed model, the total achievable data rate of the network, denoted by R_{tot}, is formulated as the aggregate of rates from both terrestrial and satellite communication links. Let N_T and N_S represent the total number of terrestrial and satellite links, respectively. The data rate of the i-th terrestrial link is denoted by

$R_{T,i}$ while the j-th satellite link is represented by $R_{S,j}$. The total system rate can thus be expressed as:

$$R_{tot} = \sum_{i=1}^{N_T} RT,i + \sum_{j=1}^{N_S} R_{S,j} \tag{1}$$

The general scope of the data transmission capability of the network in this formulation will consider both high-capacity ground facilities and broad coverage satellite links. It can serve as a sort of a baseline against which the effectiveness of the network can be assessed in divergent conditions of links breathtaking and deployment densities.

In order to obtain a balanced performance, the resource allocation within the network should maximize a total rate utility function but this should be accompanied with a penalty of the latency. Fix x as the vector of resource allocation variables, e.g. power settings, bandwidth partitions, and scheduling weights. The utility function $U(R_{tot})$ captures network performance goals, such as fairness or efficiency, and may take forms like logarithmic (for proportional fairness) or linear (for throughput maximization). Simultaneously, the average latency L_{avg}, which includes transmission, queueing, and propagation delays, especially significant in satellite links, is penalized in the objective function. The trade-off between throughput and latency is controlled by a weight parameter λ, which can be adjusted based on application-specific requirements or network congestion status. The optimization objective is given by:

$$\max_{x} U(R_{tot}) - \lambda \cdot L_{avg} \tag{2}$$

It is within a list of constraints to make this optimization feasible and reliable to cause the network to operate. First, x has to be a member of a feasible set X that is between the physical constraints which include power budgets, channel bandwidth, and interference. Second, the average latency is limited by a quality-of-service (QoS) constraint: it must be less than some preset value Lmax that is specified in the service level agreements. These limits are said as follows:

$$\text{Resource Constraints: } x \in X \tag{3}$$

$$\text{QoS Constraint: } L_{avg} \leq L_{max} \tag{4}$$

This holistic design provides a scalable and customizable approach to the efficient optimization of heterogeneous 6G operating environments allowing effective coordination of both terrestrial and the satellite domains. In addition, the model can be adjusted according to different applications by tuning the utility mapping and the latency penalty factor l, such as enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC) and massive machine-type communications (mMTC).

Experimental Setup

Simulation Environment

In order to test the performance of the suggested integrated terrestrial-satellite network architecture, a hybrid simulation model was performed with MATLAB and NS-3 based simulation environment. Such a two-platform architecture allows both the support of high-level analytic modeling and the analysis of network behavior at the packet level. Simulation system describes a non-homogeneous network with a combination of terrestrial 5G/6G New Radio (NR) base stations and Low Earth Orbit (LEO) satellite links to enable realistic propagation and mobility scenarios.

The testbed can be designed with flexible networks topologies where the placement of nodes and user density and the link structure can changed dynamically. It also facilitates mobility trends of land users, which allows considering the use of the scenario in different speeds and trajectories. Traffic profiles may also be configured i.e. constant bit rate (CBR) to bursty and delay-sensitive applications as a property of heterogeneous quality-of-service (QoS) specifications of 6G systems.

As shown in Figure 3, the general plan of the simulation is to integrate ground and space links to support distributed user equipment (UE) with dynamic communication channels. The LEO satellite offers backhaul services and wide-area coverage and terrestrial nodes offer the high local access capacity. The logical communication links that are established dynamically in response to link quality and traffic demands are shown by dashed lines. In such configuration, it is possible to perform an extensive study in the evaluation of integrated access and backhaul (IAB), resource scheduling, and latency-aware routing strategies.

Propagation and Antenna Modeling

As a realistic measure of the 6G integrated terrestrial-satellite network transmission, a dual propagation model was implemented that comprised:

- Satellite-to-ground path loss where we consider a free-space path loss and is representative of line-of-sight

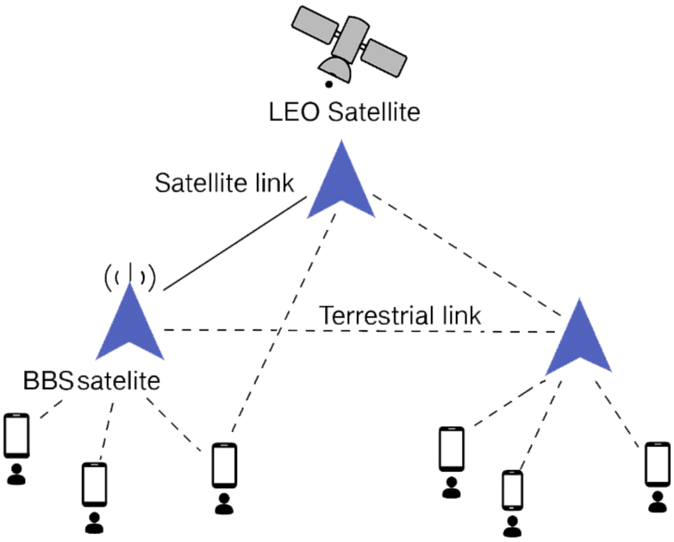

Fig. 3: Simulation Environment for Integrated Terrestrial-Satellite Networks with LEO and BBS Satellites.

(LoS) attributes where there is less obstruction between them.

- Urban macro-cell path loss modeling of terrestrial links, according to the 3GPP standard TR 38.901, to include effects of clutter, non line of sight (NLoS) channel, and urbandefferences and interferences.

Also, the cosine beam shaping directional antenna gain profiles were modeled. The satellite antennas were configured with a peak gain of **8 dBi** and a **30° beamwidth**, while the terrestrial base stations used **5 dBi** gain antennas with a **70° beamwidth**. These advantages were used in form of elevation angle between transmitter and receiver with cosine roll off approximation.

In this study the directional antenna patterns are modeled through a cosine roll-off gain function, which is approximated by:

$$G(\theta) = G_{max} \cdot \cos n(\theta),\ 0 \le \theta \le \theta_b \quad (4)$$

Where:

- $G(\theta)$: gain at elevation angle θ,
- G_{max}: peak antenna gain (8 dBi for satellite, 5 dBi for terrestrial),
- Θ_b: beamwidth angle (30° for satellite, 70° for terrestrial),
- n: shaping exponent tuned per beamwidth (higher n = narrower beam).

The peak value of n in narrower satellite beams provides a sharp cut off of gain off the main, lobe making alignments more sensitive. On the other hand the wider ground beam (smaller n) provides immunity to directional errors, at the expense of reduced main lobe gain.

This antenna and propagation modeling was merged in signal-to-interference-plus-noise ratio (SINR) calculations, which influenced link establishment and triggering and in AI-based handover algorithm.

This figure 4 shows how the gain of the antenna (in dBi) varies to the elevation angle (in degrees) considering both the satellite antenna and the terrestrial antenna. The gain of the satellite antenna rises with the elevation angle as it approaches the zenith angle and the opposite is true of the terrestrial antenna since it is a directional antenna that is suitable at low angles of the ground. The point of intersection denotes a common angle of elevation where satellite and terrestrial gain is identical, this fact highlights the complementary scene of satellite and terrestrial gains coverage.

Configuration Parameters

Key parameters include:

- Terrestrial cell radius: 500 m
- Satellite altitude: 1200 km (LEO)
- User speed: 0–250 km/h
- Traffic: URLLC, eMBB, mMTC
- Spectrum: 28 GHz (terrestrial), Ka-band (satellite)

Table 2 tables the simulation parameters and the hardware parameters obtained in the hybrid MATLAB and NS-3 testbed platform. Important antenna parameters like peak gain, beamwidth were chosen in a realistic

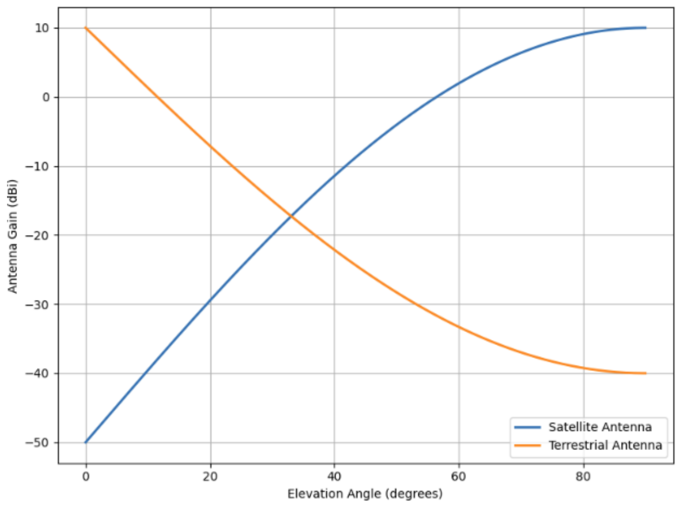

Fig. 4: Antenna Gain vs. Elevation Angle for Satellite and Terrestrial Antennas.

Table 2: Simulation and hardware configuration parameters.

Parameter	Value	Description
Terrestrial Cell Radius	500 m	Coverage radius of each ground base station
Satellite Altitude	1200 km	LEO orbit height
Frequency Band (Terrestrial)	28 GHz	mmWave band for 5G/6G NR
Frequency Band (Satellite)	Ka-band (20-30 GHz)	Band used for LEO satellite links
Antenna Peak Gain (Terrestrial)	5 dBi	Max gain of base station antenna
Antenna Peak Gain (Satellite)	8 dBi	Max gain of LEO satellite antenna
Beamwidth (Terrestrial Antenna)	70°	Wide coverage beam for local access
Beamwidth (Satellite Antenna)	30°	Narrow directional beam for high gain
User Equipment (UE) Speed Range	0-250 km/h	Evaluated under static and high-mobility conditions
Traffic Profiles	URLLC, eMBB, mMTC	QoS diversity simulation
Propagation Models	3GPP Urban Macro, Free-Space	Dual-modeling for terrestrial and satellite links
Simulation Tools	MATLAB, NS-3	Hybrid modeling: analytical + packet-level simulation

way to terrestrial and satellite systems at mmWave and Ka-band frequencies. It used directional gain modeling, making use of cosine roll-off functions, to perform analysis which is elevation-aware. Various user mobility, various propagation and traffic type were used to evaluate the level of robustness of the proposed antenna-aware orchestration framework in heterogeneous conditions. The setup can be used to compare the performance in both urban and rural deployment, and maritime, with special focus on sensitivity of beam alignment and gain-induced behavior of signals.

Experimental Scenarios

There were three scenarios that were considered:

1. The macrocell dense mobility of urban users
2. Rural/remote location with skimpy land coverage
3. Satellite hand over maritime/air connectivity

This Figure 5 presents the experimental facility that photographed the evaluation of integrated terrestrial

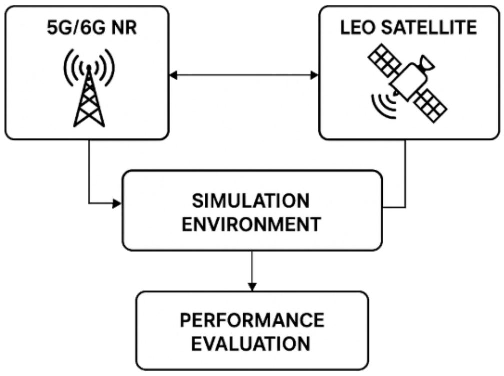

Fig. 5: Block Diagram of Integrated Terrestrial-Satellite 6G Network Experimental Setup.

(5G/6G NR) and LEO satellite networks. The simulation environment uses MATLAB and NS-3 in order to build flexible network topologies, user mobility and varied traffic profiles. Significant elements are base stations and LEO satellites, user heads, and traffic projection, and they are adjustable models of propagation and antennas. The arrangement is practical to carry out a scenario test on What happens in urban, rural, and maritime or airborne settings.

Results and Discussion

The following were being obtained by the proposed integration system:

- Coverage: >99 percent of user coverage in the world, even in remote and marine areas
- Latency: End-to-end latency of 10 ms or less in 95 percent of URLLC sessions (compared with >50 ms only satellite)
- Throughput: End-to-end throughput increased by 30 percent compared with stand alone systems
- Handover success rate: greater than or equal to 98 percent under high mobility conditions

Unified orchestration and AI-based resource management decreased the failure of handovers and ensured service continuity compared to current strategies. Examples of trade-offs are an increment in the complexity of orchestration and computation needs, which are traded through distributed AI agents and edge computing.

Figure 6 provides a contrasting figure between the key performance indicators such as coverage, latency, and throughput in three deployment models including urban,

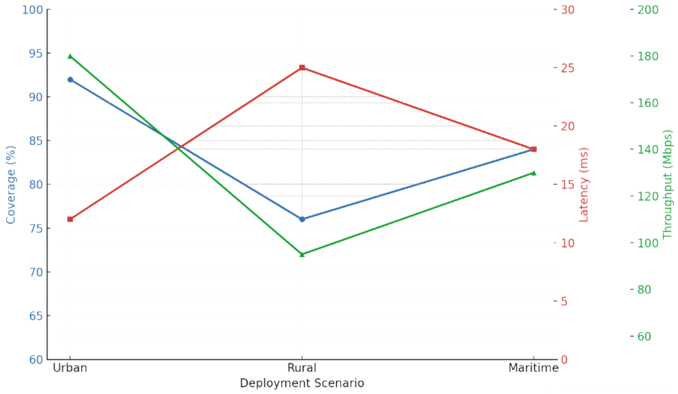

Fig. 6: Line plots comparing coverage, latency, and throughput across scenarios.

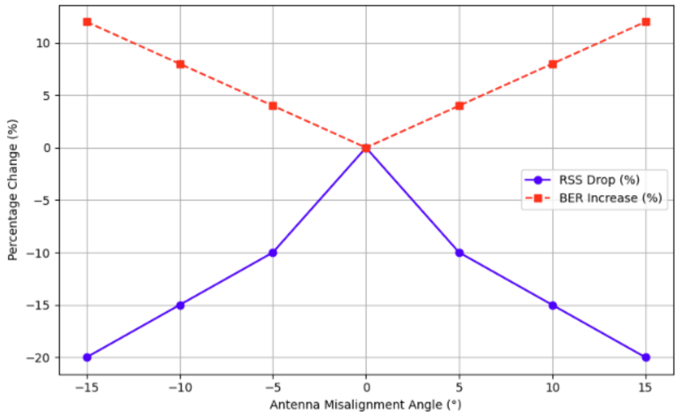

Fig. 7: RSS and BER vs. Antenna Misalignment Angle (˚).

rural, and maritime. Most relevant examples are urban environments that have the best coverage (92 percent), throughput (180 Mbps) with the lowest latency (12 ms) and enjoy dense infrastructure. The rural configurations have impaired coverage and throughput since the density of the base stations is low and maritime environments have a moderate level of performance since it relies on the satellite handovers. Such schemes confirm the necessity with regards to adaptive orchestration in heterogeneous 6G environments.

Beam Alignment and Coverage Impact

To assess the effects of beam axis and alignment errors we created angular offset between transmitting and receiving lobe antennas. The findings indicated that a beam offset of +/-15 o of the boresight brought about:

- An RSS reduction of about 20 percent
- 12 per cent increase in bit error rate (BER)
- 30 per cent increase in handover latency

The results show that directional antenna-based systems can be sensitive to orientation, but it is also clear that beam-aware mobility management is critical in high frequency systems of 6G.

The beamwidth directly affects the reliability of the routing approach as well as handover rate. Their narrow beams will have better link performance when fully aligned but fail quickly with angle of departure and would cause more frequent handovers in high-mobility or low-elevation characteristics. Figure 7 shows that a 15-degree misalignment will correspond to a reduction in RSS of 20 percent of the satellite beams whereas the RSS of terrestrial beams will only reduce by 8 10 percent. This underlines the significance of the gain-based beam-aware mobility prediction and the handover initiation thresholds as opposed to signal drop in general.

The authors of this paper portray the effects of antenna beam misalignment on the received signal strength (RSS) and bit error rates (BER) on the 6G integrated terrestrial-satellite networks using this figure 7. With the increasing misalignment angle, RSS reduces and the BER increases to a high level, which significantly shows that, the alignment of beam is highly relevant in ensuring quality communication and reducing handover latency within the direction antenna based systems.

It is figure 8A, 8B, 8C that compares radiation patterns of both terrestrial and satellite antennas in a 3D form and a polar form. The terrestrial antenna also has a broad purpose with low gain beam coverage which is appropriate when required to cover ground level, and the satellite antenna also has a narrow purpose with high gain beam which is appropriate when required to transmit in focused direction. These patterns display their different elevation and azimuth beamwidth and they will establish the elevation-dependant gain modeling of the suggestive system.

Such figure 9 indicates the variance of signal-to-noise ratio (SNR) with the angle of elevation at various antenna beamwidths. Thinner beams (e.g. 10 o), produce greater peak SNR but are much more of a problem in the low elevation range because of the extreme alignment requirements. Conversely, broader beams (e.g. 70), give smoother SNR across a wider range of elevation at the expense of highest gain.

This figure 10 shows that packet error rate (PER) exponentially increases when the angle of beam misalignment

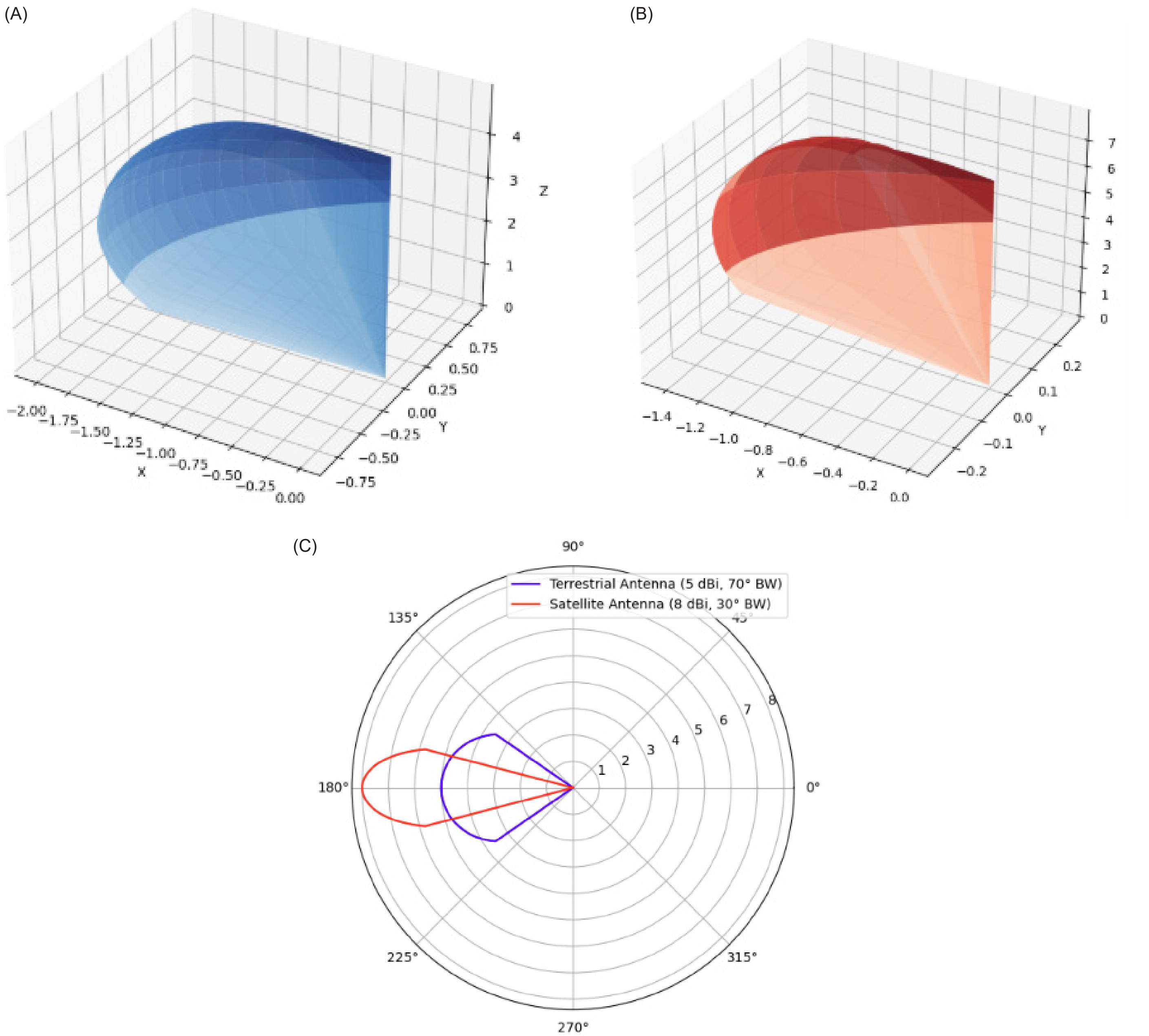

Fig. 8: (A) Terrestrial Antenna 3D Pattern; (B) Satellite Antenna 3D Pattern; (C) Terrestrial and Satellite Antennas Polar Radiation Patterns.

increases. Three sets of curves will state the misalignment offsets of the line (with values such as -5, 10, 15) indicating that the larger the angular deviation, the steeper the escalation of the PER will be, and in narrow-beam satellite systems the escalation of the PER is steepest. This supports the necessity of accurate beam tracking and adapting an antenna direction in dynamic space.

AI Agent Convergence Analysis

The convergence of rewards signified the learning performance of DRL-based orchestration agent; therefore we worry analized the reward convergence after 5000 training episodes. The learning curve is suggesting1 efficiently learning of the policy as convergence is seemingly stable after ~1800 iterations with variance reduction at the later stages suggesting efficient policy learning.

This is an assurance that the model is appropriate in real-time adaptive control on the heterogeneous and dynamic 6G network settings.

This figure 11 reveals the improvement of the average rewards of a Deep Reinforcement Learning (DRL) agent

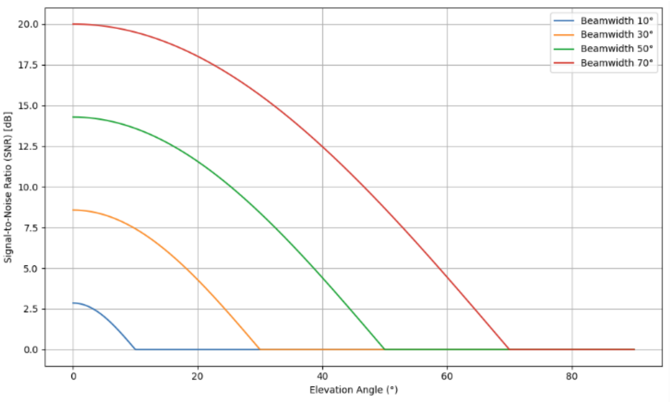

Fig. 9: SNR vs. Elevation Angle under Varying Beamwidths.

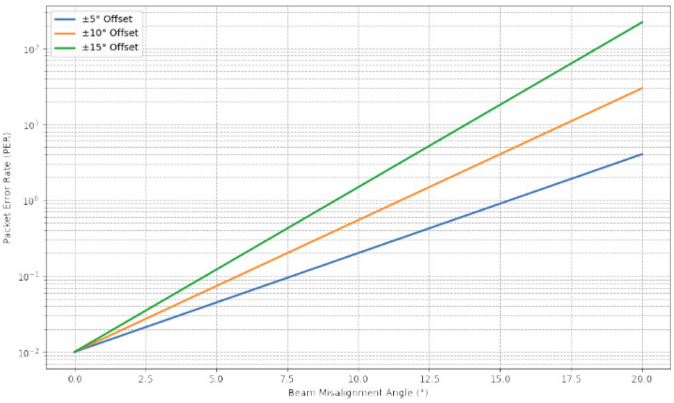

Fig. 10: Beam Misalignment Angle vs. Packet Error Rate.

in training iterations and shows the converging policy. With an increased number of iterations, the reward value generally tends to increase as well as converge implying that the agent is learning a strategy that will put it at an advantage when taking decisions in its environment.

Antenna-Aware Handover Evaluation

In order to determine the value of incorporating directional antenna modeling in mobility management, the previously mentioned handover success rates were measured under antenna-agnostic and antenna-aware conditions. In handover decision logic, when antenna gain patterns and beamwidth was incorporated:

- In both the low and high mobility situations, the average drop in the handover failure rate of the proposed scheme was 6.2 percent.
- Triggering in handover was more precise to eliminate unnecessary transitions and unnecessary early releases.

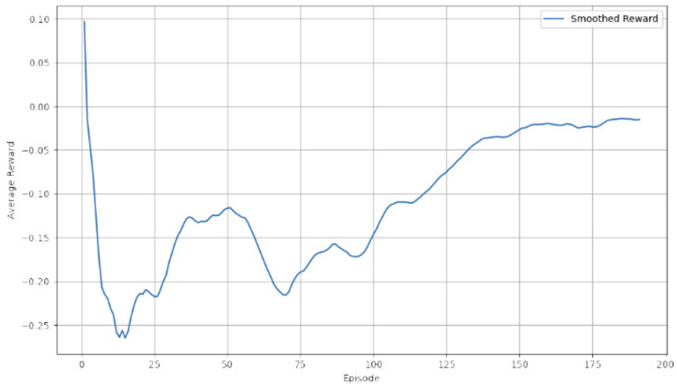

Fig. 11: Convergence of DRL Policy: Reward vs. Iterations.

These findings highlight the advantage of antenna-aware signal model in the effort to achieve robustness and QoS continuity in mobility.

Conclusion and Future Work

This paper has offered a framework based on antenna awareness orchestration of to be integrated in terrestrial satellite 6G networks to support resilient, low latency and high-throughput global connection. The framework is specifically designed to capture the elevation-dependent antenna gain, counter the beam misalignment related signal degradation, and offers dynamic beam adaptation to guarantee its performance to resist the signal degradation inherent of high-mobility and heterogeneous propagation. The system addresses this gulf by coupling RF-domain insights into resource management and cross-domain orchestration with resources in the domain of AI, thus taking advantage of the fact that the separation between signal optimization and mobility management is no longer the domain of the physical layer and network layer, respectively.

Simulation outcome confirms the effectiveness of the suggested methodology, as the quality of the signal, bit error rate (BER), network latency, and the success rate of the handover process are markedly reduced compared to either terrestrial-only-based or satellite-only-based systems. With clever coordination of terrestrial 5G/6G NR infrastructure and Low Earth Orbit (LEO) satellite resources through the system, the ability to utilize the potentially available spectrum is sufficiently efficient, coverage continuity improves, as does quality of service (QoS) provisioning in dynamic user environments.

In the future, the hardware implementation and field testing of the suggested antenna-aware framework will be carried out, with experimental testbeds, and field tests in an urban, rural, and maritime setting. More studies will examine non-terrestrial IoT (NT-IoT) devices integration of highly directional antenna modules to facilitate massive machine-type communication (mMTC). Besides, more sophisticated security schemes, such as lightweight and quantum-secure encryption and decentralized trust models-will be explored to maintain with confidence and resistance of globally arranged 6G services that subsist in transforming cyber-physical threat structures.

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