

REGENERATIVE LEO SATELLITE ARCHITECTURES FOR RESILIENT 6G PPDR COMMUNICATIONS

Balaji Kirubakaran , Maximilian Burr , Tomaso de Cola , Jiri Hosek 

ABSTRACT

Large-scale natural disasters often damage terrestrial communication infrastructures, leading to major connectivity outages at a time when reliable communications are critical for public protection and disaster relief (PPDR) operations. While sixth-generation (6G) connectivity relies on low Earth orbit (LEO) non-terrestrial networks (NTNs), transparent satellite architectures schedule traffic at the ground segment, which restricts real-time adaptability under quickly changing disaster conditions. This article explores how resilient PPDR communications can be made possible by regenerative LEO NTN architectures with on-board resource management. A Stackelberg-based scheduling framework is adopted to efficiently manage limited satellite bandwidth while reinforcement learning (RL) enables dynamic policy adaptation in response to traffic surges. The proposed approach supports heterogeneous traffic with explicit prioritization of mission-critical emergency messages. The proposed framework is evaluated for regenerative satellite payloads with and without differentiated traffic handling using user satisfaction as the performance metric, together with latency, reliability evaluation and energy consumption considerations associated with on-board computation. The results indicate that priority-aware on-board resource management supports sustained service continuity for mission-critical users, while non-critical traffic experiences a gradual reduction in satisfaction under congestion.

RESILIENT 6G NTN FOR DISASTER SCENARIOS

Global catastrophic events like earthquakes, floods, and wildfires have frequently challenged terrestrial communication infrastructures. Recent events, such as the earthquakes in the Republic of Türkiye [1], severe flooding in various parts of Europe, and continuous wildfire occurrences in North America and Australia, have shown that communication outages frequently occur even when parts of the cellular infrastructure are physically functional. In these scenarios, critical outage has commonly been caused by power supply failures, broken backhaul links such as fiber cable damage, and increased spikes in traffic demand [2] produced by emergency services and people affected. Meanwhile, severe weather conditions

have shown how rapidly the whole coverage areas can become isolated when power, transportation, and communication infrastructures are simultaneously impacted. These observations have increased interest among mobile network operators (MNOs), satellite network operators (SNOs), national emergency management authorities, researchers, and space agencies such as the European space agency (ESA) in using non-terrestrial networks (NTNs) as a backup and resilient connectivity layer for public protection and disaster relief (PPDR) management. Low earth orbit (LEO) [3] satellite constellations, typically operating at altitudes of about 300-1500 km, are currently considered to be a key component of sixth-generation (6G) connectivity [4] due to their global coverage, continuous availability, and independence from local ground infrastructure. Within the 3GPP NTN framework [5], as investigated in Release-17 technical reports including TR 38.811 and TR 38.821, LEO satellites are considered a complementary solution for providing essential communication services when terrestrial networks are partially or fully unavailable. However, disaster scenarios are characterized by highly dynamic traffic patterns and heterogeneous service requirements that place significant stress on network-level capacity allocation and prioritization mechanisms, making service continuity and reliability more challenging. In such environments, conventional NTN deployments based on transparent satellite payloads usually rely on ground-segment based resource management and traffic prioritization, which may limit their real-time flexibility and resilience under frequent and unpredictable changes in traffic demand and network availability.

To address these challenges, regenerative satellite architectures [6] have recently attracted increased attention. By hosting selected radio access network (RAN) functions directly on the satellite payload, SNOs enable LEO NTNs to serve as a complementary connectivity layer in disaster scenarios. This approach provides on-board control of radio and processing resources, ensuring service continuity for essential communication services, particularly for PPDR operations, when terrestrial networks are partially or fully unavailable. Such capabilities are especially critical for maintaining emergency messaging, command-and-control signaling, and situational awareness traffic under constrained

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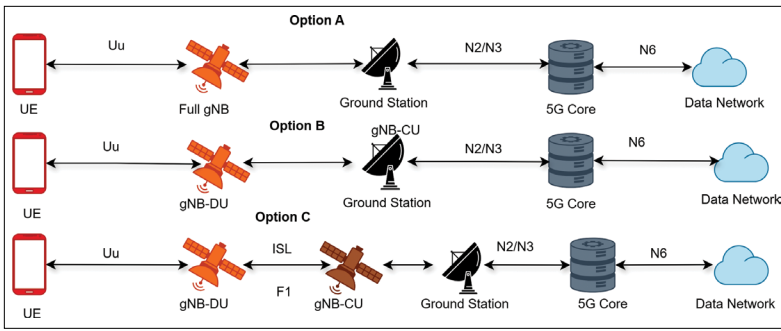


FIGURE 1. Regenerative NTN Architectural Options.

satellite resources, where explicit traffic prioritization becomes necessary.

The main contributions of this work are summarized as follows: investigation of the role of regenerative LEO satellite architectures in supporting resilient and PPDR-oriented communications for disaster scenarios; analysis of regenerative architectural options and their implications for on-board capacity allocation, traffic prioritization, and system-level responsiveness under interrupted terrestrial connectivity; development of a message scheduling framework with explicit priority handling based on game-theoretic principles, augmented with reinforcement learning (RL) for adaptive priority tuning under dynamic traffic and load conditions, enabling differentiated handling of mission-critical and non-critical traffic within limited satellite resource budgets; and comparative system-level evaluation of regenerative satellite systems with and without differentiated scheduling, using user satisfaction ratio as the key performance indicator (KPIs), along with latency, reliability and energy consumption analysis to assess both delay performance and computational cost at the satellite.

The outcomes show how traffic differentiation and capacity allocation mechanisms can improve service sustainability and predictability for mission-critical communications in disaster situations. The presented insights aim to support MNOs, SNOs, public safety agencies, and government authorities in making informed architectural and resource management decisions for future 6G NTN deployments framework.

REGENERATIVE 6G NTN ARCHITECTURES: DESIGN OPTIONS AND CHALLENGES

In large-scale disaster scenarios, terrestrial communication infrastructure and centralized ground processing may be partially or fully unavailable, making it difficult to sustain reliable connectivity using transparent NTN architectures. In regenerative NTN architecture physical and access layer functions are carried out directly on the satellite payload [7]. Regenerative payloads facilitate on-board processing across multiple protocol layers, starting from radio-frequency (RF) front-end operations, including filtering, frequency conversion, and amplification, followed by physical-layer baseband processing such as demodulation, decoding, coding, and modulation, and extending to higher-layer functions such as switching and routing. The regenerative payloads enable different architectural configurations, ranging from full

gNB implementations on board the satellite, as considered in 3GPP NTN architectures, to alternative functional split options, in which Distributed Unit (DU) functionalities are implemented in space while Central Unit (CU) functionalities remain on the ground. Under such split-based configurations, traffic must be terminated at a ground gateway to access higher-layer RAN functions. Further, the use of inter-satellite links (ISLs), operating in radio-frequency or optical bands, enables traffic forwarding across the satellite constellation without immediate dependence on ground gateways when full gNB functionality is hosted in space, and inherently relies on regenerative processing.

Figure 1 illustrates the considered regenerative architectural options. In Option (a), the satellite hosts the full gNB protocol stack, including the Radio Unit (RU), DU, and CU, on-board payload, while the connection toward the 5GC is established via the NG interface. This option enables on-board protocol termination, but its practical applicability depends on the processing capabilities available on the satellite payload and its scalability for larger systems. In Option (b), the satellite hosts the RU and DU, while the CU remains on the ground and is connected via the F1 interface. This configuration aligns with the standardized split option 2, but its operation is sensitive to the delay tolerance of the F1 interface when transported over satellite links. Finally, in Option (c), the RU and DU are implemented on board Satellite 1, while the CU is hosted on Satellite 2, with connectivity between the DU and CU implemented over an optical inter-satellite link (O-ISL) implementing the F1 interface, which is subject to stringent latency requirements. Connectivity toward the 5GC is maintained via the NG interface over the feeder link.

Regenerative NTN systems introduce a set of design challenges that arises from the natural dynamics of non-terrestrial platforms and the limitations of spaceborne payloads [8]. Satellite motion causes the time-varying propagation conditions, including Doppler shifts, variable link delays, and changing coverage areas. These dynamics directly impact synchronization, mobility management, and radio resource allocation which requires adaptation mechanisms that differ from those used in terrestrial 5G networks.

Further, the regenerative NTN operation is characterized by prolonged and non-uniform propagation delays [9] due to satellite altitude and, where applicable, inter-satellite routing. Although LEO systems minimize average delay compared to higher-orbit constellations, delay variability remains significantly higher than in terrestrial networks. The large geographic footprints of NTN radio cells further introduce differential delay effects and operational complexity, especially when service coverage spans several regions. Channel characteristics in regenerative NTN environments also differ significantly from terrestrial propagation models [10]. Strong line-of-sight conditions, atmospheric effects, and platform-specific antenna patterns influence link behavior and necessitates specific channel modeling and link adaptation strategies. Also, the execution of radio access functions on board the satellite is constrained by payload-specific limitations, including restricted power budgets, processing capacity,

and thermal dissipation, which impact the achievable functionality and adaptability of regenerative systems. These factors highlight the necessity of regenerative NTN designs that specifically take payload limitations and dynamic propagation conditions into account. Practical regenerative NTN solutions, especially in disaster and emergency communication scenarios, concentrate on sustaining stable operation and service continuity under variable and resource-constrained conditions rather than terrestrial-equivalent performance.

RADIO RESOURCE MANAGEMENT AND TRAFFIC SCHEDULING IN NTN

Radio resource management (RRM) coordinates the allocation of limited wireless resources, including spectrum, power, and time, to satisfy diverse quality-of-service (QoS) requirements while maintaining throughput and fairness [11]. Traffic scheduling, a key RRM function, determines how these resources are assigned using schemes such as round-robin (RR), proportional fair (PF), and priority-based scheduling. In NTNs, RRM is considerably more challenging due to high mobility, dynamic topology, heterogeneous links, and long propagation delays. These characteristics create strong interactions among network entities, making conventional scheduling approaches less effective. Consequently, game-theoretic frameworks have emerged as a promising solution by modelling these interactions and enabling distributed, adaptive, and efficient resource allocation. The following sections review the major game-theoretic approaches for RRM and traffic scheduling in NTNs.

GAME-THEORETIC FOUNDATIONS FOR RESOURCE MANAGEMENT IN 6G NTN

Game-theoretic approaches provide a systematic framework to model the interactions among multiple decision-making entities competing or cooperating for limited network resources. This is attractive for dynamic and resource-constrained 6G NTN settings, where game-theoretic formulations explicitly model the objectives, strategies, and constraints of each entity, in contrast with standard optimization-based approaches. In regenerative NTN systems, resource management involves complex interactions between the satellite side controller, user services, and potentially multiple satellite nodes. Depending on the relationship between these entities, different game-theoretic formulations have been examined including cooperative games, auction-based mechanisms, matching games and non-cooperative approaches. These models maximize coordination, scalability and control flexibility in different ways. Figure 2 summarizes the most significant classes of game-theoretic approaches under consideration for NTN resource management.

1) Cooperative Games for Joint Resource Optimization: Cooperative game models take into account scenarios in which multiple entities coordinate their decisions to maximize a common objective. Cooperative approaches in satellite networks can enable resource sharing between satellites through mechanisms such as ISLs, joint spectrum utilization and distributed processing.

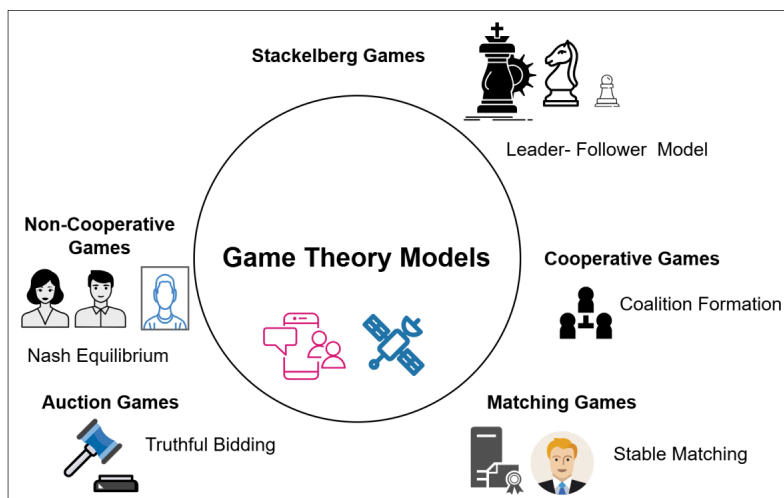


FIGURE 2. Game-Theoretic Models.

This cooperation can enhance the efficiency and continuity of service in the case of dense constellations.

2) Auction-Based Games for Competitive Resource Allocation: Auction-based strategies model resource allocation as a competition between entities that express their demands by means of bids or estimations. The different services of NTN systems can provide priority indicators or utility values, so that the satellite controller can distribute the available resources according to predefined allocation rules. The main advantage of auction-based methods is their flexibility to handle heterogeneous service demands.

3) Matching Games for Satellite-User Association: Matching games are responsible for determining the stable matchings of different groups of entities according to their preferences and resource requirements. In NTN environments, matching-based approaches can optimize satellite-user associations in terms of channel quality, available capacity and service requirements. Matching mechanisms are effective for association and connectivity management but mainly focus on the relationship between users and serving satellites.

4) Non-Cooperative Games for Distributed Decision Making: Non-cooperative games are situations in which players maximize their own objectives, subject to the constraints imposed by the sharing of resources. Such methods have been widely studied for distributed wireless resource management including power control, spectrum access and scheduling problems. The main advantage of non-cooperative formulations is the scalability, as entities can make decisions based on local information, without the need for centralized coordination.

5) Hierarchical Control Through Stackelberg Games: Stackelberg games are a class of hierarchical decision problems where the leader first commits to a strategy and the followers respond to the leader's strategy by choosing their own strategies as best as possible. Unlike other game-theoretic approaches, Stackelberg games explicitly model leader-follower relationships, making them suitable for centralized resource management, as compared to modeling

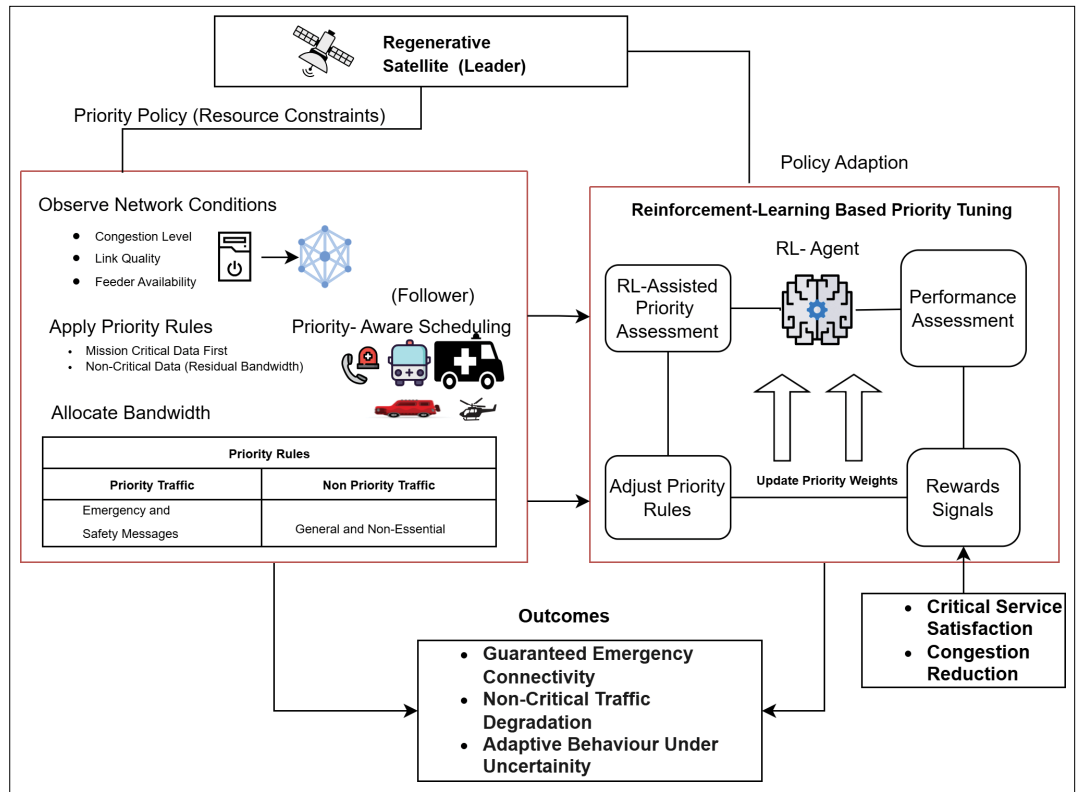


FIGURE 3. Hierarchical Resource Management Framework for Regenerative NTN Operation.

player's interactions as symmetric. In regenerative LEO NTN systems, the on-board gNB naturally plays the role of a leader, controlling resource allocation, queue management and service prioritization, while heterogeneous traffic classes adapt their resource demands to such decisions. Similar hierarchical formulations have been studied for power control, spectrum allocation and priority-aware scheduling in UAV-assisted and satellite-enabled networks [12].

The above discussion illustrates that different game-theoretic formulations provide different advantages for NTN resource management depending on the system objectives and operation constraints. But their applicability depends on the specific needs of the given scenario. In cooperative games, the participating entities need coordination and exchange of information, which can lead to increased signaling overhead in highly dynamic environments. For auction based mechanisms, appropriate valuation models are needed to model the demands for the services, which may not be easy for mission critical communications. In the matching games, the users and serving nodes association optimization is the primary objective. The non-cooperative approaches can have a limited control on the prioritization of the resources due to the independent decision-making of the players. We consider the requirements of regenerative NTN systems where centralized resource control and differentiated treatment of heterogeneous services are essential, and adopt the Stackelberg framework. Considering the requirements of regenerative NTN systems where the centralized resource control and the differentiated treatment of heterogeneous services are essential, in this work, we adopt the Stackelberg framework. Its hierarchical leader-follower structure naturally

captures the interaction between the onboard gNB and the heterogeneous traffic classes, which allows for a priority-aware resource allocation but it also keeps scalability and implementation feasibility.

HIERARCHICAL RESOURCE MANAGEMENT FOR REGENERATIVE NTN OPERATION AND ENERGY CONSUMPTION

Figure 3 illustrates the application of a Stackelberg-inspired hierarchical resource management mechanism for traffic prioritization in regenerative NTN systems. Mission-critical traffic classes associated with emergency response, public safety, and command-and-control services impose minimum service requirements, while non-critical and best-effort traffic adapts to the remaining capacity. The bandwidth required to sustain acceptable performance for mission-critical services is denoted by B_{crit} , and the total bandwidth available at the regenerative satellite is denoted by B_{tot} . The resource management policy ensures that sufficient capacity is reserved for mission-critical traffic whenever $B_{crit} \leq B_{tot}$, after which the residual bandwidth is allocated to non-critical traffic. As a result, non-critical services adjust their transmission behavior according to the leader-imposed priority constraints, while mission-critical traffic remains protected.

This hierarchy is implemented through priority-aware scheduling on the regenerative satellite using locally observable network indicators such as feeder availability, congestion level, and link quality. Congestion reflects the relationship between aggregate traffic demand and available capacity, link quality determines the achievable

efficiency of the access link, and feeder availability constrains the maximum usable payload throughput. These indicators collectively define whether the system operates under normal or over-loaded conditions. At each scheduling interval, mission-critical traffic is served first to satisfy its QoS requirements, while remaining resources are allocated to non-critical traffic in a best-effort manner. As congestion increases and aggregate demand exceeds B_{tot} , the scheduler preserves B_{crit} , and non-critical traffic adapts to the shrinking residual bandwidth, resulting in managed service degradation of non-essential services.

While the hierarchical structure defines protected traffic classes, RL adapts prioritization strength over time. We model the scheduling problem as a Markov Decision Process (MDP). The RL agent observes system indicators and adapts the prioritization accordingly. The model is trained offline in a simulation and the converged policy is deployed on-board for inference-only operation. Lightweight inference without any on-board training or optimization is used in real-time satellite scheduling ensuring low complexity and practical deployment. This approach is well suited for LEO satellite applications such as disaster response and environmental monitoring.

To assess the energy consumption of the proposed framework, we consider both computational energy usage and its impact on onboard lithium-ion battery dynamics. The computational modules consume power P_c over execution durations $\tau_{s,j}$ and $\tau_{e,j}$ during sunlight and eclipse phases [13], resulting in energy consumption terms $P_c \tau_{s,j}$ and $P_c \tau_{e,j}$, respectively. This computational demand directly affects the energy balance of the lithium-ion battery, which operates under cyclic charge-discharge behavior across sunlight and eclipse periods. During sunlight, harvested energy must support both mission-critical loads and computation, while during eclipse the lithium-ion battery supplies the entire energy demand. Consequently, the additional energy consumption introduced by the proposed framework remains bounded by the available battery capacity B_{max} and is compatible with the operational constraints and longevity considerations of lithium-ion battery systems in LEO satellite platforms.

SYSTEM-LEVEL MODELING OF REGENERATIVE NTN OPERATION IN DISASTER SCENARIOS

In a multi-satellite LEO constellation, the proposed resource management framework operates in a distributed and handover-aware manner. Each regenerative satellite performs access-link resource management locally based on the instantaneous traffic demand, link quality, and congestion conditions within its coverage area. As satellites move, users are handed over between satellites according to visibility conditions, with handover decisions determined using indicators such as elevation angle and remaining service time. Upon handover, the newly serving satellite applies the same priority rules and target QoS constraints, ensuring continuity for mission-critical traffic. The learning-assisted component operates on a slower time scale, adapting prioritization strength based on long-term performance trends, while fast scheduling decisions remain local to each satellite.

Based on this per-satellite operation principle, the performance evaluation adopts a snapshot-based single-satellite abstraction, where the simulation interval is shorter than the visibility duration of an individual LEO satellite. Within this snapshot, a single satellite effectively dominates access-link resource provisioning, capturing the essential dynamics of priority enforcement and congestion handling during a satellite pass, while remaining representative of constellation-wide operation as the same logic is applied repeatedly across satellites over time. LEO satellite is assumed to provide Ku-band user-link coverage over the affected area. Users within the satellite beam footprint share fixed access-link bandwidth resources on both the downlink and uplink, which are dynamically partitioned among mission-critical and non-critical services according to the considered scheduling policies. The study focuses on user-segment (access-link) performance in both transmission directions.

The total number of user equipments (UEs) modeled within the affected area represents first responders, public safety personnel, and civilians. The UE population is split into two traffic classes: (i) mission-critical users, who are involved in command-and-control signaling, emergency coordination, and situational awareness; ii) non-critical users, which generate best-effort traffic, such as messaging and basic information access, without strict throughput guarantees. Traffic demand is modeled using an abstract rate-based representation to evaluate scheduling and service differentiation under congestion. Mission-critical traffic, representing first-responder communications and essential data exchange, is characterized by a fixed target rate corresponding to minimum service requirements, while the offered demand varies randomly within a bounded range above this target to capture moderate load fluctuations during emergency operations. Non-critical traffic is modeled as elastic, best-effort demand with variable rates relative to a reference target, reflecting its ability to adapt to available resources without strict QoS guarantees. The aggregate offered load is configured to exceed the available system capacity, creating a congested operating condition representative of disaster scenarios. A distance-dependent path-loss formulation combined with elevation-angle-dependent excess loss and lognormal shadowing is used to model the downlink channel between the regenerative satellite and UEs. This method accounts for degradation at low elevation angles caused by obstruction and blockage while reflecting the line-of-sight nature of NTN links. The user data rate depends on the allocated bandwidth and the instantaneous access-link channel conditions, subject to the requested traffic demand.

Different access-link resource partitioning and scheduling strategies are evaluated to benchmark regenerative NTN operation under disaster-related traffic demand. Equal-share (RR), PF, and random scheduling are considered as baseline schemes. These methods are fairness-oriented and do not explicitly differentiate between traffic priorities. To ensure a minimum level of service during congestion, a certain amount of satellite bandwidth is permanently assigned to mission-critical users in a priority-based baseline with a fixed reservation.

Parameter	Specification
Orbit Type	LEO
Satellite Altitude	500 km
Carrier Frequency (Downlink)	12 GHz
Carrier Frequency (Uplink)	14 GHz
Channel Bandwidth (Downlink)	250 MHz
Channel Bandwidth (Uplink)	62.5 MHz
Number of User Terminals (N)	300
Mission-Critical User Ratio	30%
Beam Radius	100 km
UE Transmit Power (Uplink)	23 dBm
Satellite Receiver G/T (Uplink)	5 dB/K
Mission-Critical Target Rate (DL)	1.5 Mbps
Mission-Critical Target Rate (UL)	250 kbps
Non-Critical Target Rate (DL)	1 Mbps
Non-Critical Target Rate (UL)	200 kbps
RL Inference Delay	3 ms
Transmission Time Interval (TTI)	1 ms
Harvested Solar Energy (H_j)	115 - 125 (Wh per cycle)
Subsystem Energy ($E_{s,j} + E_{e,j}$)	85 - 95 (Wh per cycle)
RL Computation Energy ($P_c \tau_j$)	3 - 5 (Wh per cycle)

TABLE 1. Simulation Parameters for the Ku-Band NTN User-Link Scenario.

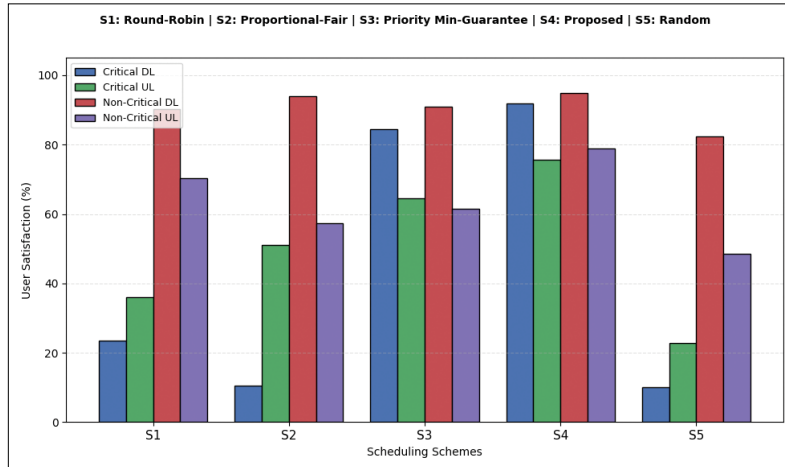


FIGURE 4. Mission-Critical and Non-Critical User Satisfaction in the Downlink and Uplink under Different Scheduling Schemes.

In the proposed approach, the satellite dynamically chooses the percentage of resources set aside for mission-critical traffic using a hierarchical, Stackelberg-inspired allocation framework. This reservation is adjusted over time based on observed service reliability using a RL mechanism. The simulated scenarios are designed to represent congested operating conditions, under which the role of priority enforcement becomes evident

in the performance results. Unlike the baseline schemes, which rely on fixed scheduling rules, the proposed method enables adaptive prioritization in response to time-varying traffic demand and link conditions, thereby improving the robustness of essential communications in disaster scenarios.

System performance is evaluated using the user satisfaction ratio, defined as the percentage of users whose achieved average data rate meets or exceeds a predefined service-dependent data-rate. Satisfaction is assessed separately for the downlink and uplink and independently for mission-critical and non-critical traffic classes. The evaluation is conducted using a Python-based Monte Carlo simulation of a LEO NTN spot-beam scenario, where users are randomly distributed within the coverage area and experience time-varying channel conditions, including shadowing and blockage, as well as fluctuating traffic demands. Scheduling decisions are applied at millisecond granularity over a one-hour simulation period, allowing the system behavior to be observed under sustained load conditions. The specific target rates adopted for each service type in both link directions are summarized in Table 1 and reflect the minimum rate requirements of the corresponding applications considered in this study. Table 1 provides a summary of the performance metrics taken into consideration [14], [15].

NUMERICAL ASSESSMENT AND LESSONS LEARNED

This section discusses the system-level performance results obtained for regenerative NTN operation under disaster-related load conditions and summarizes the key insights drawn from these results.

USER SATISFACTION ACROSS MISSION-CRITICAL AND NON-CRITICAL SERVICES IN DOWNLINK AND UPLINK

Figure 4 presents the mission-critical and non-critical user satisfaction achieved under different scheduling schemes for the downlink and uplink in the considered Ku-band LEO NTN scenario. Fairness-oriented baselines, such as RR and PF scheduling, provide limited satisfaction, particularly on the uplink, as they do not explicitly account for service priority. The random allocation scheme results in the lowest satisfaction due to the absence of structured resource sharing. The priority-aware minimum-guarantee approach improves mission-critical satisfaction by reserving a fixed portion of resources, although its performance is bounded by the use of a static reservation parameter. The proposed Stackelberg-based scheme attains higher mission-critical satisfaction on both downlink and uplink by adapting the reserved resource share in response to observed traffic and channel conditions, with the adaptation realized through a lightweight RL mechanism, without increasing the available system bandwidth. These results indicate that adaptive prioritization can support more reliable mission-critical service delivery under congested disaster scenarios. At the same time, Figure 4 also shows the impact on non-critical user satisfaction under the same scheduling schemes. As resources are prioritized to support mission-critical services, a reduction in non-critical performance is expected. Compared to the baseline approaches, the proposed scheme exhibits a more controlled reduction in non-critical

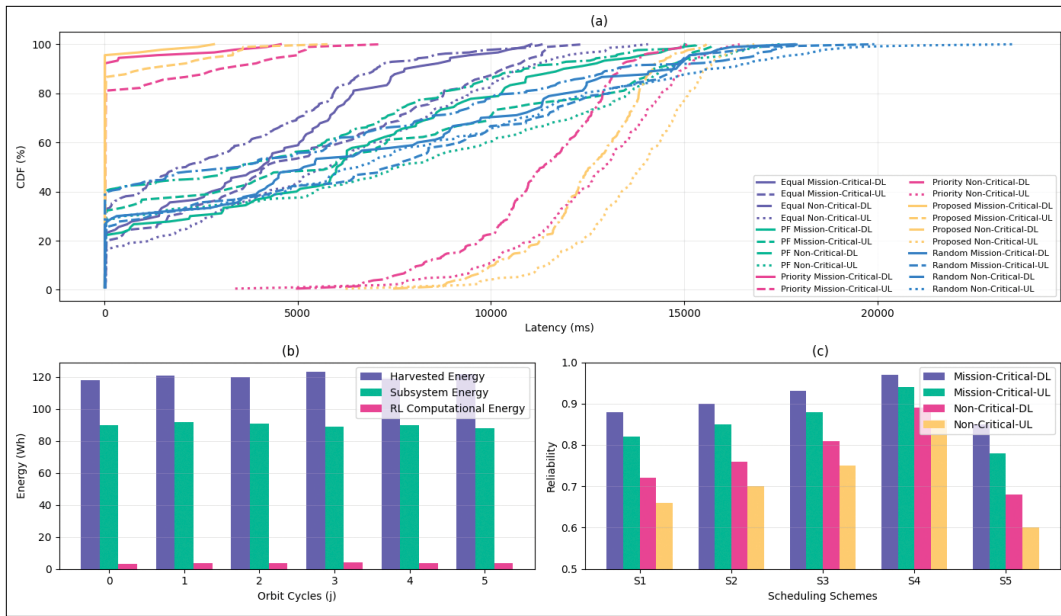


FIGURE 5. Performance Evaluation of the Considered NTN Scheduling Framework. a) Latency CDF Performance. b) Energy Consumption Analysis. c) Reliability Analysis

satisfaction on both downlink and uplink. Rather than aggressively suppressing best-effort traffic, it maintains a reasonable level of service while preserving priority guarantees for critical users. This behavior indicates that the proposed approach can limit the impact on non-critical users while sustaining reliable mission-critical communications under congested disaster conditions.

LATENCY PERFORMANCE IN LEO SATELLITE NTN SYSTEMS

This work highlights that latency is one of the critical QoS indicators for evaluating scheduling performance in LEO satellite NTN systems, beyond conventional rate-oriented metrics. Latency in the considered system is influenced by queueing, transmission, propagation, and scheduler processing delays. In particular, the proposed RL-based scheduler introduces a small runtime inference overhead, while training is assumed to be performed offline. Figure 5(a) shows that the proposed scheduling approach achieves improved latency performance for mission-critical traffic while maintaining acceptable performance for non-critical users under both uplink and downlink conditions. Although the learning-based scheduler introduces additional inference processing, its impact is negligible compared to the reduction in queueing delay achieved through adaptive and priority-aware resource allocation.

ENERGY CONSUMPTION IN ONBOARD COMPUTATION

The energy consumption of onboard computation is evaluated together with the satellite's overall power budget, including harvested energy and subsystem load. The results show that the energy required for the proposed RL-based scheduler is small compared to the total subsystem energy demand across orbital cycles. As shown in Figure 5(b), harvested solar energy is sufficient to support both subsystem operation and onboard computation during sunlight-eclipse cycles. The RL computation energy remains a minor portion of the total energy consumption, indicating that the proposed approach does not significantly affect the satellite energy budget. Thus, the results

indicate that the proposed scheduling method is feasible in terms of onboard energy usage.

RELIABILITY ANALYSIS

In addition, reliability is evaluated in terms of successful packet delivery under finite-buffer queueing conditions. Since packet loss mainly occurs due to queue overflow during congestion, reliability is closely related to queue stability and efficient resource allocation. Figure 5(c) shows the proposed RL-based scheduler improves reliability by dynamically prioritizing mission-critical traffic and reducing buffer congestion under varying traffic conditions. Compared to conventional scheduling approaches, the proposed method achieves higher reliability and lower performance variability for both uplink and downlink traffic, demonstrating improved QoS support in heterogeneous NTN environments.

TOWARD EXPERIMENTAL AND SEMANTIC-AWARE NTN OPERATION

In the proposed framework, prioritization is driven by service reliability and traffic class, without explicitly considering the informational value or timeliness of transmitted data. From a semantic communication perspective, this relates to transmitting only task-relevant information rather than full raw data. Incorporating semantic relevance and Age of Information (AoI) would allow prioritization to reflect both data usefulness and freshness. Within the hierarchical architecture, these metrics can be added as inputs to the learning-based priority adaptation process without changing the underlying scheduling mechanism, enabling better handling of congestion and improving performance in time-critical scenarios such as disaster response.

CONCLUSION

This study investigates regenerative NTN architecture for resilient disaster communications where terrestrial connectivity is impaired. Priority-aware processing at the satellite payload enables efficient support for heterogeneous traffic, especially

mission-critical services, under dynamic and resource-constrained conditions, while considering latency, reliability and energy constraints. Although not intended to outperform terrestrial networks, the results show that priority-aware and RL-assisted resource management improves service sustainability for critical traffic, with acceptable degradation for non-critical users.

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BIOGRAPHIES

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