
Beyond Dead Zones: A Service-Continuity Architecture for Terrestrial 5G and Non-Terrestrial Smartphone Networks

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Abstract.

Non-terrestrial networks (NTN) are moving from niche satellite services to a standardized extension of mobile networks. However, direct-to-device satellite connectivity for consumer smartphones cannot be treated as a conventional coverage handover because terrestrial and satellite links differ in delay, Doppler behavior, bandwidth, sky visibility, power cost, mobility, and emergency-service obligations. This paper proposes a service-continuity architecture for smartphones operating across terrestrial 5G and NTN access. The framework places a device-aware continuity manager above radio access selection, classifies services into emergency, messaging/location, delay-tolerant telemetry, voice, and broadband tiers, and selects an access path using service criticality, link readiness, battery cost, user guidance, and policy constraints. The contribution reframes TN-NTN integration from a coverage-extension problem into a cross-layer service-orchestration problem for 5G-Advanced and future 6G consumer devices. The architecture is positioned against 3GPP NTN evolution, Supplemental Coverage from Space policy, current smartphone satellite-user experience, O-RAN NTN deployment considerations, and direct-to-device industry trends.

Keywords. Terrestrial 5G, non-terrestrial networks, direct-to-device satellite, smartphone connectivity, service continuity, 5G-Advanced, Open RAN, emergency communications.

1. INTRODUCTION

Fifth-generation mobile systems have improved capacity and latency in dense markets, yet mobile coverage remains geographically and operationally incomplete. Rural highways, mountainous terrain, maritime and aviation corridors, disaster zones, and temporary outage areas continue to expose the limits of terrestrial infrastructure. Non-terrestrial networks (NTN), including satellite and high-altitude platform segments, are therefore becoming an essential complement to terrestrial mobile networks. 3GPP defines NTN as networks or network segments using airborne or spaceborne vehicles to host relay nodes or base-station functions, and it identifies LEO, MEO, GEO, and HAPS deployment classes [1].

The direct-to-device (D2D) opportunity is strategically important because it changes satellite connectivity from a specialized terminal market to a consumer-device continuity layer. GSMA Intelligence describes telco-satellite convergence as an industry-wide movement and reports 91 telecom operator partnerships with satellite companies [6]. Similarly, 5G Americas notes that direct-to-cellular services are emerging first around emergency and messaging use cases, with future evolution toward higher-speed LEO-based services [5].

This paper argues that smartphone TN-NTN integration should not be framed as merely eliminating dead zones. A stronger architecture is required: one that preserves user intent even when full broadband continuity is not technically or commercially feasible. A satellite

link may support emergency messaging, location sharing, or delay-tolerant telemetry while still being unsuitable for general application traffic. The proposed framework therefore defines seamlessness as service continuity, not uninterrupted IP throughput.

2. BACKGROUND: WHY NTN IS NOT A NORMAL HANDOVER

Terrestrial handover assumes comparatively stable cells, short propagation delay, mature neighbor measurements, and continuous network visibility. NTN changes these assumptions. 3GPP highlights that LEO and MEO satellites move at high velocity, causing moving cell patterns, higher Doppler variation, faster propagation-delay variation, and enhanced beam-management requirements [1]. For non-geostationary constellations, service continuity also depends on coordinated handover among satellites and gateways [1].

The consumer smartphone experience demonstrates these constraints. Apple explains that satellites move rapidly, have low bandwidth, and are hundreds of miles from Earth; in ideal conditions a satellite message may take about 30 seconds, while foliage or obstructions can delay or prevent connection [3]. These limits are not product defects; they are architectural properties of handheld satellite access. Therefore, the continuity layer must decide not only where to connect, but what service should continue, degrade, defer, or be blocked.

Regulation is another design input. The FCC Supplemental Coverage from Space (SCS) framework enables satellite communications on spectrum previously allocated only to terrestrial services, with interim emergency call and text routing requirements for 911 access [2]. ITU also emphasizes that blending satellite and terrestrial mobile networks raises spectrum and competition-policy issues that may require regulatory updates [8]. A smartphone continuity architecture must therefore combine radio metrics with policy and emergency-service rules.

3. PROPOSED SERVICE-CONTINUITY ARCHITECTURE

Figure 1 summarizes the proposed architecture. The smartphone exposes device context and service intent, the network contributes terrestrial and NTN availability, and policy functions decide which service should be carried on which access. The architecture is deliberately service-tiered because a single access-selection rule cannot optimize emergency SOS, short messaging, voice, IoT telemetry, and broadband data at the same time.

Device Context	Service Continuity Manager	Access Options	Policy / Outcome
battery, location, mobility, sky view, app state, emergency state	service tiering, degradation rules, access score, user guidance	5G/LTE, roaming, Wi-Fi, NTN D2D, satellite backhaul	5GC policy, emergency routing, charging, regulatory limits, UX state

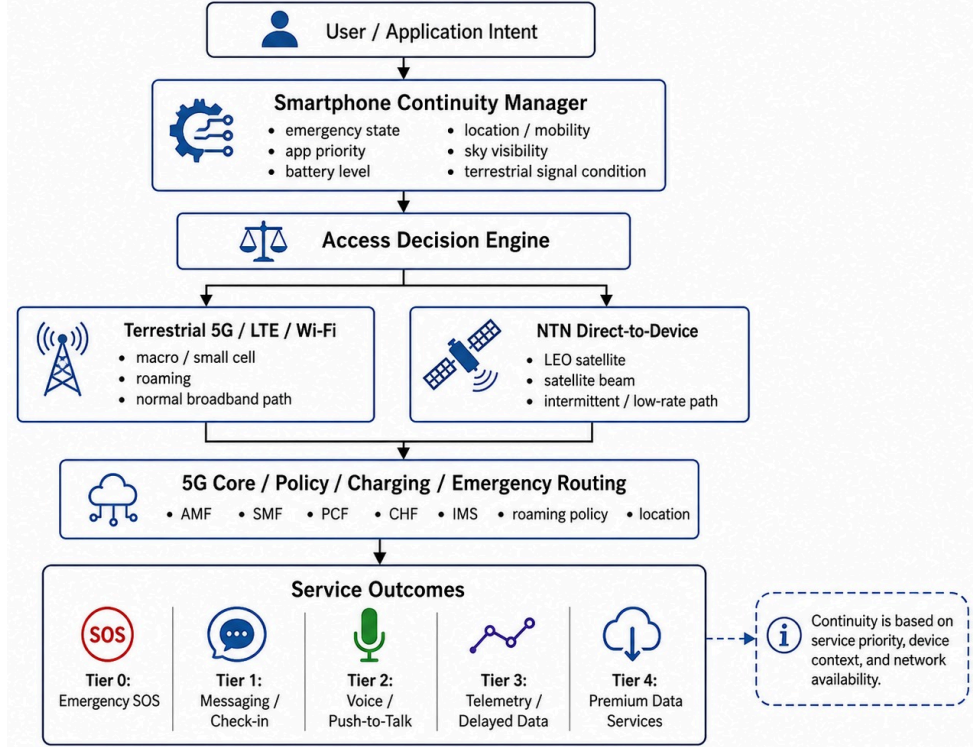


Figure 1. Device-aware service-continuity architecture for TN-NTN smartphone operation.

The continuity decision can be represented as a service-aware access-selection score:

$$A^* = \arg \max_a \{ C_s R_a - E_a - D_{\{s,a\}} - P_{\{s,a\}} \} \quad (1)$$

where A^* is the selected access, a is a candidate access path, C_s is service criticality, R_a is estimated link readiness, E_a is battery and acquisition cost, $D_{\{s,a\}}$ is expected service degradation, and $P_{\{s,a\}}$ is the policy or regulatory penalty. The formulation is intentionally interpretable so that emergency service, user guidance, and operator policy can override generic throughput-maximization.

4. SERVICE-TIERED CONTINUITY MODEL

Table 1 defines the service-tier model. The key design principle is that satellite fallback should be activated first for services with high social value and low bandwidth demand, and only later for bandwidth-rich applications. This avoids misleading users into expecting full cellular equivalence while still enabling meaningful continuity when terrestrial service is absent.

Tier	Service class	Continuity objective	Typical action
0	Emergency SOS, public warning, disaster check-in	Reachability before richness	Force guided NTN acquisition; prioritize location

1	Short messaging, location sharing, roadside assistance	Low-rate user intent continuity	and emergency text. Send compact messages; expose delay and sky-view guidance.
2	Telemetry, agriculture, remote sensors, app state sync	Delay-tolerant continuity	Store, forward, batch, or schedule transmissions.
3	Voice or push-to-talk	Selective real-time continuity	Enable only if link budget, policy, and capacity support it.
4	General Internet and media applications	Best-effort future broadband	Degrade, defer, or restrict until terrestrial access returns.

Table 1. Proposed service-tier model for smartphone TN-NTN continuity.

The model also supports standards evolution. 3GPP Release 17 introduced normative NTN requirements, including service continuity between terrestrial and satellite access networks, roaming, optimized selection or reselection, and mobility across supported access networks [1]. Release 19 studies add regenerative payload architecture, store-and-forward satellite operation, UE-satellite-UE communication enhancements, management for NTN-TN and NTN-NTN mobility, and application enablement for predictable intermittent connectivity [1]. Ericsson describes Release 19 regenerative payloads as placing a complete gNB on the satellite, enabling stronger integration, inter-satellite mobility, routing, and store-and-forward capability [7].

5. IMPLEMENTATION CONSIDERATIONS

First, the smartphone must avoid blind satellite scans. Satellite acquisition can be expensive in energy and user attention, so the device should enter NTN mode only when terrestrial service is absent or below the minimum continuity threshold for the active service tier. Device-side inputs include GNSS availability, orientation, inertial motion, map context, last terrestrial cell, battery state, application priority, and emergency state.

Second, the network must expose policy rather than only signal metrics. The 5G core, satellite partner, and terrestrial operator need a shared view of emergency routing, lawful spectrum use, roaming agreements, charging, and supported service classes. The FCC SCS model is relevant because it frames satellite-terrestrial service as a licensed collaboration between terrestrial spectrum holders and participating satellite operators [2].

Third, Open RAN and intelligent control can improve observability. O-RAN Alliance states that O-RAN-based NTN integration is important for connecting users where terrestrial networks do not exist and that its NTN work covers architecture integration, current status, future challenges, and security considerations [4]. This supports a future design in which

RAN Intelligent Controller applications use satellite ephemeris, beam load, terrestrial cell outage data, and service-tier policy to guide access steering.

Fourth, user experience must state the service truth. When satellite is available only for messaging or emergency traffic, the device should not simply display generic coverage. It should expose continuity states such as emergency-only, message-ready, delayed-data, voice-capable, or broadband-ready. These states reduce user confusion and align expectations with actual link capability.

6. EVALUATION METHODOLOGY

A practical evaluation can be performed without confidential operator data by combining coverage maps, satellite-visibility assumptions, synthetic mobility traces, and emulated service classes. Field validation can later measure real acquisition and service results across rural highways, trails, disaster-response zones, coastal routes, and remote agricultural areas. The architecture should be judged by user-intent preservation rather than peak throughput alone.

Metric	Definition	Why it matters
Coverage recovery time	Time from terrestrial loss to first usable continuity tier.	Measures practical dead-zone recovery.
Critical reachability probability	Probability that Tier 0 or Tier 1 service is completed.	Prioritizes safety and essential communication.
Battery cost per session	Energy used for discovery, pointing guidance, and transmission.	Prevents continuity from draining the device.
Degradation correctness	Whether applications are mapped to the right continuity tier.	Avoids false expectations and failed sessions.
Policy-compliance rate	Share of decisions satisfying emergency, spectrum, roaming, and charging rules.	Links engineering to deployability.

Table 2. Evaluation metrics for service-continuity performance.

7. CONCLUSION

Terrestrial 5G and NTN integration should be understood as a service-continuity problem rather than a simple coverage-extension problem. Consumer smartphones cannot assume that satellite access is equivalent to terrestrial broadband, especially under low bandwidth, obstruction, power, mobility, and regulatory constraints. The proposed architecture introduces a device-aware continuity manager, service-tier classification, interpretable access scoring, and policy-aware orchestration. This approach can preserve emergency reachability, low-rate messaging, telemetry, and selected real-time services while honestly degrading or deferring applications that cannot be supported by the available NTN link. As 3GPP, regulators, operators, satellite providers, and Open RAN ecosystems converge, service-tiered continuity offers a practical path from today's emergency satellite experiences to future 5G-Advanced and 6G ubiquitous connectivity.

8. REFERENCES

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Biographies

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Kiran Garde is working at Comcast as Sr. Manager -Mobile development and telecom engineering, with 4+ years at Comcast Xfinity Mobile managing the end-to-end lifecycle of the Apple device portfolio, which represents ~70% of subscribers base. He is leading end-to-end certification and launches for Apple devices, including bi-annual releases, iOS betas, 5G SA/VoNR, and CBRS private 5G, building scalable processes that optimized KPIs like latency and handovers while driving customer experience and business growth.