

# Adaptive Terminal Architecture for Multi-Orbit SATCOM

Design Requirements for Software-Defined Ground Segments

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## THE MULTI-ORBIT OPERATIONAL REALITY

Defense operators now have access to three orbit classes simultaneously:

### LEO

~350–1,500 km

- Low latency
- High throughput capacity
- Frequent handovers

### MEO

~8,000–12,000 km

- Balanced coverage
- Wide coverage per satellite
- Moderate latency

### GEO

~36,000 km

- High stability
- Wide-area single-hop coverage
- Higher latency

**The constellations are deployed. The terminal is the bottleneck.**

## WHY STATIC TERMINAL CONFIGURATIONS FAIL

Terminals optimized for one orbit class expose three failure modes during multi-orbit operation:

01

### Link Budget Mismatch

RF parameters calibrated for one orbit class produce suboptimal power allocation on another, degrading link margin and reducing throughput headroom.

02

### Transport Layer Misconfiguration

Congestion control carries stale bandwidth and RTT estimates across a handover. After an RTT increase, BBR's minimum-RTT filter can hold the old value for up to 10 seconds<sup>1</sup>, stalling throughput recovery.

03

### Power Management Drift

Amplifier control loops calibrated for one link environment cannot track a new operating point efficiently, producing either wasted margin or saturation risk.

**Result: a performance gap that persists across RF, transport, and power layers simultaneously after every orbit transition.**

<sup>1</sup> BBR minimum-RTT filter window = 10 s in BBRv1 (Cardwell et al., ACM Queue, vol. 14, no. 5, 2016) and in the IETF BBRv3 draft (draft-ietf-ccwg-bbr).

## ARCHITECTURAL REQUIREMENTS FOR ORBIT-ADAPTIVE TERMINALS

### **R1 Orbit-Aware Configuration Management**

Terminals must hold validated profiles per orbit class, covering RF, modem, transport, and power parameters, ready for deterministic, immediate activation.

### **R2 Low-Latency Profile Switching**

Profile transitions must complete within the orbit handover time budget. Switching latency spanning multiple round-trip times compounds rather than closes the performance gap.

### **R3 Cross-Layer Coordination**

RF, modem, and transport layers must switch together. Asynchronous reconfiguration creates transient mismatches that degrade performance across all layers simultaneously.

### **R4 Adaptive Power Management**

PA operating points and thermal management must track the new link environment. Carrying prior-orbit power calibration into a new orbit class wastes capacity or risks saturation.

# Digital IF Interoperability as the Architectural Enabler

1

### Digitization enables software control of the RF chain

Analog IF interfaces fix the signal path in dedicated hardware. Digitized IF exposes RF parameters to software, so profile switching becomes a software command.

2

### DIFI interoperability extends reconfiguration across vendors

Without a common digital IF standard, digital IF interfaces are vendor-specific. DIFI gives orbit-adaptive control a common interface to build on across multi-vendor terminal ecosystems.

3

### Interoperability is the prerequisite for defense-grade resilience

Multi-orbit defense architectures combine terminals from multiple primes. DIFI-compliant interfaces ensure adaptive reconfiguration is not constrained to single-vendor deployments.

## A DESIGN FRAMEWORK FOR ADAPTIVE TERMINAL ARCHITECTURE

Three functional layers, each mapped to the R1–R4 requirements baseline:

### Orbit Profile Store

Pre-validated parameter sets per orbit class, activated on trigger instead of computed during the handover window

R1, R4

*profile data*

### Configuration Management Layer

Orbit event detection → profile selection from the store → switch trigger dispatch

R1, R2

*switch trigger*

### Cross-Layer Coordination Interface

Synchronized dispatch to RF, modem, transport, and power subsystems in a single atomic operation

R3

*synchronized dispatch*

RF

Modem

Transport

Power

## DESIGN RATIONALE: WHY THE REQUIREMENTS ARE NECESSARY

Each requirement addresses a distinct failure mechanism that static architectures cannot resolve:

**R1 + R2**

### **Why pre-validated profiles, activated deterministically?**

On-the-fly parameter computation during a handover window introduces variable latency under the worst operating conditions. Pre-validated profiles eliminate computation from the critical path entirely.

**R3**

### **Why atomic cross-layer dispatch?**

Sequential reconfiguration (RF first, then modem, then transport) creates windows where layers are mismatched. A terminal transmitting at GEO power with LEO transport settings produces neither correct outcome. Coordination must be simultaneous.

**R4**

### **Why adaptive power management, not a fixed PA setpoint?**

Free-space path loss differs by roughly 25–36 dB<sup>1</sup> between LEO and GEO distances, so a PA operating point tuned for one orbit is far from optimal for the other. Carrying prior-orbit calibration forward risks saturation or wasted margin.

<sup>1</sup> FSPL delta =  $20 \cdot \log_{10}(d_{\text{GEO}} / d_{\text{LEO}})$  at nadir, using LEO 550–2,000 km and GEO 35,786 km (Slide 2). Excludes slant range, antenna gain, and EIRP.

## KEY TAKEAWAYS

1

Multi-orbit performance is an engineering decision made at the terminal.

2

Static terminal configurations fail across all three layers simultaneously during orbit transitions: RF, transport, and power.

3

Orbit-adaptive terminals require four capabilities working together: orbit-aware configuration management, low-latency profile switching, cross-layer coordination, and adaptive power management.

4

Digitized IF and DIFI interoperability standards are the architectural prerequisite for software-defined reconfiguration at multi-vendor scale.

# Questions & Discussion

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