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MVPS Terrestrial Mobile and Vehicular Profile: Coherence Monitoring under Cellular Handover and Radio-Access Scheduling

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Abstract

This document defines the terrestrial member of the Multi-Vantage Path Snapshot (MVPS) domain trio (space, sea, land). It targets vantages that move on land -- vehicles, trains, drones -- connected through cellular (5G/LTE) radio access, where the bounded joint clock-skew axiom A1 is stressed not by clock drift (GNSS is normally available) but by handover between base stations and slot-based scheduling jitter.

The profile is DEFENSIVE: it concerns detection of coherence anomalies (intrusion, communications tampering, rogue base stations). It defines no navigation, targeting, or kinetic function. The document proves A1 holds on the deployment tick under explicit cellular-timing budgets, gives a closed-form maximum handover interruption, proves Doppler is dominated at terrestrial speeds, and inherits the core theorems via the MVPS Architecture-Invariance Theorem. All properties are validated by scripts/validate_terrestrial_mobile.py (7/7 PASS, exit 0) and recorded in evidence/terrestrial_mobile_receipt.json.

Status of This Memo

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1. Introduction

MVPS detects network-propagating anomalies by measuring the coherence of an observed state across multiple spatially independent vantages. Its theorems are surface-independent: they hold where the five MVPS axioms hold, by the Architecture-Invariance Theorem [I-D.melegassi-iab-mvps-architecture].

Terrestrial deployments where the vantages MOVE -- fleets of vehicles, trains, drones operating over cellular radio -- are common and important, and they stress the timing assumptions differently from sea or space. On land the satellite sky is normally available, so clock holdover is not the issue; the issue is that a moving vantage hands over between base stations and rides slot-based scheduling, both of which perturb timing.

1.1. The Space/Sea/Land Trio

This profile is the land member of the MVPS domain trio:

- o space: the orbital profile [I-D.melegassi-ippm-mvps-orbital-coherence], stressing propagation delay and Doppler over LEO links;
- o sea: the maritime profile [I-D.melegassi-ippm-mvps-maritime-edge], stressing intermittent connectivity and GNSS-denied holdover;
- o land: this document, stressing cellular handover and radio-access scheduling jitter.

Each re-establishes the same axiom (A1) under its domain’s specific stress and inherits the rest.

1.2. Defensive Scope and Non-Goals

This profile is strictly DEFENSIVE: detection of anomalies in network and timing telemetry (intrusion, comms tampering, rogue base stations).

This document does NOT define and MUST NOT be claimed to define any navigation, guidance, targeting, or kinetic function, nor any output other than coherence-anomaly detection and audit logs.

2. Terminology

eps_sync: GNSS/PTP residual at the base station.

eps_ta: timing-advance residual of the UE alignment.

tau_jit: radio-access scheduling jitter (slot-based).

tau_ho: residual mis-timing during or after a handover.

T_tick: the deployment coherence tick.

Make-before-break: a handover that keeps the source link until the target is ready (NR DAPS), giving tau_ho near zero.

The key words "MUST", "MUST NOT", "SHOULD", "MAY" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals.

3. The Cellular Joint-Skew Model

A GNSS-disciplined base station holds time to eps_sync; the UE is aligned by Timing Advance to eps_ta. Slot-based scheduling bounds delivery jitter by tau_jit (5G numerology mu: slot = 1 ms / 2^mu; LTE about 1 ms). A handover adds a residual tau_ho, near zero for make-before-break and about the interruption time otherwise. The effective joint skew is

```
skew_eff = 2 * ( eps_sync + eps_ta ) + tau_jit + tau_ho .
```

Doppler is treated separately and shown dominated in Section 6.

4. Re-establishing Axiom A1 (Lemma L-TER-1)

Axiom A1 holds on tick T_tick iff

```
skew_eff = 2*(eps_sync+eps_ta) + tau_jit + tau_ho  <  T_tick.
```

For representative budgets:

```
5G-uRLLC (DAPS): skew_eff = 0.128 ms  < 100 ms tick
LTE (break-before-make): skew_eff = 33.0 ms  < 1000 ms tick
high-speed rail (300 km/h, frequent HO): 54.0 ms < 100 ms tick
```

All satisfy A1 (validator check L-TER-1).

5. Maximum Handover Interruption (Lemma L-TER-2)

Solving skew_eff = T_tick for the handover residual gives

```
tau_ho_max = T_tick - tau_jit - 2*(eps_sync + eps_ta).
```

For the 5G-uRLLC budget, tau_ho_max is about 99.87 ms at a 100 ms tick. The practical reading is that the binding term on land is the handover interruption; make-before-break drives tau_ho toward zero, so even sub-second ticks have ample margin.

6. Doppler Is Dominated (Lemma L-TER-4)

The time uncertainty contributed by Doppler over one tick is (v/c)*T_tick. At v = 300 km/h, v/c = 2.78e-7, so over a 100 ms tick the term is about 27.8 ns -- under 1% of the radio-access jitter. It is therefore absorbed and does not appear in the skew model (validator check L-TER-4: 11.0 ns, 83.4 ns, 27.8 ns across the three budgets).

7. Inheritance of the Core Theorems

If A1 holds (Section 4) and the compromised-vantage fraction f < 1/2, then by the Architecture-Invariance Theorem [I-D.melegassi-iab-mvps-architecture] the core results inherit verbatim:

- T1 multi-vantage D^2 dominates per-vantage max-z;
- T2 Phi_D concentration under the null;
- T3' empirical-quantile false-alarm calibration;
- T9 Byzantine robustness of the geometric-median aggregator.

No core theorem is re-derived (validator check A-TER-INHERIT).

8. Byzantine and Spoofed Vantages

A vehicular fleet must assume some vantages are compromised or spoofed. For f < 1/2 the geometric-median aggregator has finite max-bias b(f) = C*f/(1-2f) (after [Minsker]; MVPS imported result I12), diverging only as f -> 1/2 (validator check B-TER-1: b(0.2)=0.333, b(0.4)=2.000).

9. Rogue Base Stations (Conjecture C-TER-1)

It is plausible that a coordinated rogue / false base-station cluster (an IMSI-catcher fleet) injects a rank-low, correlated timing/identity signature across mobile vantages that the multi-vantage detector flags before any single UE alarms. This is stated as a CONJECTURE, not a theorem, with a falsification protocol (observable: cross-vantage correlated TA / cell-identity anomaly vs per-UE max-z; data: fleet RAN measurement reports plus a controlled false-base-station testbed; test: Wilson 95% lower bound on detection-time gain > 0; blocker: licensed spectrum for the testbed). The profile’s guarantees do NOT depend on this conjecture.

10. Operational Logging

Deployments SHOULD log events using the MVPS operational log format [I-D.melegassi-opsawg-mvps-logging], anchoring opportunistically; the handover and cell-change events are themselves useful audit records.

11. Numerical Receipt

scripts/validate_terrestrial_mobile.py evaluates seven checks (L-TER-1..4, A-TER-INHERIT, B-TER-1, C-TER-1) over the budgets above and writes evidence/terrestrial_mobile_receipt.json with per-scenario skew and Doppler values, the closed-form handover tolerance, the inherited theorem list, the defensive non-claims, and a SHA-256 of its own canonical body. All seven checks PASS (exit 0).

12. Security Considerations

The profile is a detection and audit capability; no kinetic or targeting surface is added. Its value is early, coherent detection of intrusion, comms tampering, and radio-layer attacks across a mobile fleet, with a tamper-evident audit trail (Section 10).

Rogue-base-station detection is a conjecture (Section 9) and MUST NOT be relied upon as a guarantee. Quantum-era integrity of logs and anchors follows the Proof Envelope [I-D.melegassi-ippm-mvps-proof-envelope].

13. IANA Considerations

This document has no IANA actions.

14. References

14.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, May 2017.

[I-D.melegassi-iab-mvps-architecture] Melegassi, L., "MVPS Architecture Invariance", draft-melegassi-iab-mvps-architecture-00, 2026.

14.2. Informative References

[I-D.melegassi-ippm-mvps-orbital-coherence] Melegassi, L., "MVPS Orbital Coherence", draft-melegassi-ippm-mvps-orbital-coherence-00, 2026.

[I-D.melegassi-ippm-mvps-maritime-edge] Melegassi, L., "MVPS Maritime and Tactical-Edge Profile", draft-melegassi-ippm-mvps-maritime-edge-00, 2026.

[I-D.melegassi-opsawg-mvps-logging] Melegassi, L., "The MVPS Operational Log Format", draft-melegassi-opsawg-mvps-logging-00, 2026.

[I-D.melegassi-ippm-mvps-proof-envelope] Melegassi, L., "MVPS Proof Envelope", draft-melegassi-ippm-mvps-proof-envelope-00, 2026.

[Minsker] Minsker, S., "Geometric median and robust estimation in Banach spaces", Bernoulli 21(4), 2015.

Appendix A. Worked Budgets (Normative)

The three budgets of Section 4 (5G-uRLLC, LTE, high-speed rail) and the infeasible control (150 ms handover at a 100 ms tick) are the normative vectors. A conformant implementation MUST reproduce, for each, the skew_eff value and the A1 verdict emitted by scripts/validate_terrestrial_mobile.py.

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