Mesh-Derived Coordinates: Cooperative Localization With On-Demand Densification

by Nick Clark | Published April 25, 2026

GNSS Is the Single Point of Failure in Autonomous Systems

Almost every autonomous system today resolves position by combining GNSS (GPS, Galileo, BeiDou, GLONASS) with inertial dead-reckoning. The architecture works in benign conditions and fails predictably outside them. Urban canyons produce multipath. Forest canopy produces signal loss. Indoor environments produce no signal at all. Deliberate jamming and spoofing are documented in defense theaters and increasingly in commercial critical-infrastructure attacks.

Existing fallbacks (RTK base stations, UWB anchor networks, V2X CPM) require pre-installed infrastructure. RTK requires a known-good base station. UWB requires anchored beacons. V2X CPM requires roadside units. None of these scale to disconnected operation, expeditionary deployment, or GNSS-denied geographies without significant pre-positioning.

The architectural gap is that no current coordinate primitive is anchorless: every system assumes it can resolve to a global frame through authoritative external anchors. When the anchors are unavailable, the system degrades or fails.

1. The Primitive: Cooperative Multi-Modality Ranging

Mesh-derived coordinates produce positions through mutual ranging between participating units across any of fifteen-plus modalities: UWB time-of-flight, lidar reflection, radar, optical fiducial range, RFID proximity, NFC adjacency, acoustic echo, BLE RSSI, magnetic dipole, GNSS pseudorange (when available), inertial integration, visual SLAM correspondence, and others.

Each range observation is governance-credentialed: the contributing unit signs the observation with its credential, the range modality and uncertainty are declared, and the observation is recorded with lineage. The receiving unit evaluates each observation for admissibility before integrating it into the coordinate solution.

The cooperative nature is structural. A unit doesn't position itself by passively receiving anchors; it positions itself by exchanging credentialed range observations with neighbors. The neighbors don't have to be anchors; they can be other operating units, infrastructure devices, or temporary beacons.

2. Anchor-Less Relative-Frame Bootstrap

When no authoritative absolute-frame anchors are present (no GNSS, no surveyed RTK base, no known beacons), the mesh bootstraps to a relative-only frame. The first participating unit defines the origin; subsequent units are positioned relative to the existing frame; the frame is internally consistent without reference to any external coordinate system.

The relative frame is a first-class coordinate space. Operating units, infrastructure devices, and observations all carry positions in the frame; coordination, navigation, and actuation proceed identically to absolute-frame operation. The frame does not need to be anchored to be useful.

When authoritative anchors later appear (a GNSS-receiving unit joins, a surveyed reference becomes available), the relative frame promotes to absolute by computing the rigid transform between the two frames. Existing position records are re-expressed; ongoing operations continue without disruption.

3. Credentialed Range Observations Reject Spoofing Structurally

Adversarial range injection — spoofed GPS pseudoranges, fake UWB beacons, manipulated RTK base broadcasts — defeats current localization stacks because the receiver has no way to authenticate the originator. The mesh-coordinate primitive rejects this structurally: every range observation is signed by its originator's credential.

A spoofed GPS satellite produces an observation whose credential fails: the signing identity does not match a credentialed authority. The observation is rejected at the admissibility gate, not at the coordinate-solution layer. Similarly for fake UWB beacons and manipulated RTK broadcasts: failure occurs at the credential verification step before the observation enters the multilateration computation.

This shifts the adversary's required capability from 'inject a plausible RF signal' to 'compromise a credentialed authority.' The latter is a structurally harder attack.

4. Lineage-Bound Multilateration

The coordinate solution is itself a governed observation: the position estimate is signed by the producing unit, the contributing range observations are referenced by lineage, the multilateration algorithm and parameters are declared, and the resulting uncertainty bound is computed from the input uncertainties.

This makes positions auditable. A position dispute (e.g., 'were you in the restricted zone at time T?') is resolved by walking the lineage from the position back to the contributing range observations and verifying each contribution's credential and uncertainty.

Lineage-bound multilateration also enables cross-jurisdictional position acceptance: a position computed under one authority's anchors can be accepted by another authority through credential verification of the underlying range observations, without requiring re-survey or re-computation.

5. Reference-Node Densification On Demand

Where the mesh's existing coverage is insufficient — disaster zones, expeditionary deployment, GNSS-denied operations, indoor environments without pre-installed infrastructure — additional reference nodes are deployed on demand. The deployable nodes are airdropped, drone-positioned, hand-placed, or vehicle-mounted, and self-integrate into the coordinate mesh upon activation.

Each deployable node carries a credential issued by the deploying authority, broadcasts its own position estimate (initially relative-only, promoting to absolute when external anchors appear), and contributes range observations to its neighbors. The node's deployment, activation, and integration are recorded in lineage.

Densification deployment is a first-class operating mode. The mesh expects to operate at varying coverage densities and adapts the coordinate solution accordingly: high-coverage regions produce sub-meter positions, sparse-coverage regions produce meter-scale positions with declared uncertainty, and regions below minimum coverage produce no position (rather than producing a confidently-wrong position).

6. Coordinate-Frame Federation Across Authorities

Multiple authorities (a city DOT, a state DOT, a port authority, a federal aviation authority, a defense theater command) maintain their own credentialed coordinate frames. The federation primitive composes across them: a unit operating across multiple authorities consumes range observations from each, with the multilateration computation producing a position consistent across all admitted authorities.

Authority-frame disagreement is structural rather than failure: when two authorities' frames are misaligned, the unit observes the misalignment, produces position estimates expressed in each frame, and propagates the disagreement upstream for resolution.

This is the underlying mechanism by which civilian and military airspace, federal-state highway boundaries, port-customs custody zones, and similar multi-authority spaces can be navigated without pre-negotiated coordinate-frame interoperability.

7. What This Is Not

This is not collaborative SLAM. Collaborative SLAM aggregates visual or lidar observations across robots; the mesh-coordinate primitive is medium-agnostic and credential-bound. Collaborative SLAM solutions can be one of the contributing modalities.

This is not RTK / NTRIP networking. RTK requires authoritative base stations and broadcasts uncredentialed corrections. The governed primitive can consume RTK as one of many credentialed range modalities.

This is not assured-PNT (Position, Navigation, and Timing) work like DARPA's STOIC. Those programs harden against jamming and spoofing within a fixed architecture. The governed primitive changes the architecture: ranges are authenticated, operation is anchorless when needed, and densification is a first-class deployment mode.

Conclusion

Mesh-derived coordinates provide positions in environments where current localization stacks fail: GNSS-denied, expeditionary, indoor, contested, sparse-infrastructure. Cooperative cross-modality ranging makes positions resilient to the loss of any single modality. Credential-bound observations reject spoofing structurally. Anchor-less bootstrap and on-demand densification enable operation without pre-positioned reference infrastructure.

This is disclosed under USPTO provisional 64/049,409. The architecture composes with mesh-derived time (joint spatial-temporal solution) and with marker-track transport (markers as credentialed reference nodes), forming the foundation for the matched-pair settlement and n-party coordination primitives that depend on physical proximity verification.