

How to Get Positioning Underground or Indoors Where GPS Fails

If you are building a robot, a wearable, or a fleet that has to know where it is inside a warehouse, a mine, a tunnel, or a steel-framed building, satellite positioning stops helping the moment the sky is gone. This guide teaches an architectural approach to that problem: derive coordinates cooperatively from a governed mesh of credentialed reference observations instead of a global constellation. It describes an architecture disclosed in U.S. Provisional Application No. 64/049,409, the Mesh-Derived Coordinates inventive step, not a shipping library. You implement it yourself.

What You Are Building

You are building a positioning capability for an environment where satellite navigation does not reach: a basement, a parking structure, a mine or tunnel, a ship's hull, a dense indoor facility, or anywhere the sky view is blocked or the signal is jammed. The units that need a position might be autonomous robots, vehicles, drones, or people carrying wearable devices. What they all share is a hard requirement: a coordinate they can act on, with a known uncertainty, produced without waiting on a satellite fix that will never arrive.

The approach taught here does not try to sneak a satellite signal into a place it cannot go. Instead it treats the coordinate frame as something the participants build among themselves. Agents that can measure distance to each other, plus a set of credentialed reference points, cooperatively compute where everyone is. This is the Mesh-Derived Coordinates inventive step disclosed in U.S. Provisional Application No. 64/049,409. This guide walks the architecture and how you would build toward it.

Why the Obvious Approaches Fall Short

The obvious first move is satellite navigation (GPS, GNSS). It is excellent outdoors with sky view and useless without it. Satellite systems depend on acquiring broadcast signals from centrally operated constellations; where those signals are denied, blocked, or spoofed, positioning simply stops. That is the structural fact the filed disclosure names directly: acquisition is required for positioning and its denial precludes positioning.

The second move is to lean on assisted or differential positioning, which sharpens a satellite fix using reference-station networks run by a positioning-service operator. This helps precision outdoors but inherits the same dependency: it still needs the satellite signal, and it needs someone else's reference infrastructure to be present and reachable.

The third move is a single-modality indoor beacon system: fixed-identifier access points, Bluetooth beacons, or ultra-wideband anchors. These work indoors, but two structural gaps recur. First, they are typically locked to one ranging modality, so the same deployment cannot fall back to acoustic ranging when radio is congested or to optical ranging when radio is denied. Second, systems built on static identifiers (fixed beacon addresses, satellite pseudo-random-noise codes, fixed-identifier access points) are, as the disclosure notes, vulnerable to identifier spoofing, because nothing about the identifier proves the observation is trustworthy.

None of these give you a self-referencing frame that the participants own, that authenticates each measurement, and that degrades gracefully when the environment changes. That gap is what the architecture below addresses.

The Architecture

The disclosed primitive treats a shared coordinate reference frame as a first-class thing the mesh produces cooperatively, rather than a signal it receives. Per the filing, it is directed to the governance-chain-preserving generation, maintenance, consumption, and federation of a coordinate frame produced by participating mesh agents through inter-agent ranging, anchor observation admission, and credentialed frame definition, without dependence on any specific external positioning infrastructure. The named components, each traced to Chapter 16 of the spec, are:

- **A credentialed inter-agent ranging mechanism.** Participating agents produce range observations to each other using at least one of many ranging modalities. The disclosure states the primitive admits 15-plus ranging modalities integrated into a single coordinate graph, spanning radio-frequency, optical, acoustic, and other measurement media. The point of admitting many modalities is that the same architecture keeps working when one medium is denied.
- **An anchor observation admission interface.** This admits credentialed anchor position contributions: reference points whose position is known and vouched for. In the broader disclosure, passive markers serve as anchor nodes, but an anchor is any credentialed known-position contribution.
- **A cooperative localization engine.** This determines agent positions through multilateration from the admitted range observations and anchor positions. This is the core solve: given distances and some known points, compute where everyone is.
- **A transitive localization extender.** When an agent cannot range directly to enough anchors, its position is produced through neighbor references, chaining position outward across the mesh so agents deep in a structure can still be located through the agents between them and the anchors.

- **A coordinate-frame specifier.** This defines the frame's type, origin, orientation, scale, and temporal association. Because the frame type is something you specify rather than inherit from a satellite constellation, you can bind to a geographic frame when one is available or work in a purely local frame when it is not.
- **A precision-and-uncertainty propagator.** Ranging precision and ranging covariance are propagated through the localization chain to produce a per-position uncertainty estimate. Every position comes with a stated uncertainty, which is what lets a consumer decide whether the fix is good enough to act on.
- **An ambiguity-resolution mechanism.** When multilateration admits more than one solution, this selects among them.
- **An adversarial-range rejection mechanism.** This rejects spoofed, injected, or otherwise inadmissible range observations. Combined with authenticating each range observation through the governance-chain identity, this is the disclosure's answer to the identifier-spoofing weakness of static-identifier systems.
- **An anchor-less bootstrap mechanism.** When no anchor observations are available at all, the primitive produces a relative-only coordinate frame from zero-anchor conditions. Agents know their positions relative to each other even before any absolute anchor exists.
- **A coordinate-frame federation mechanism.** This aligns two or more independently maintained mesh-derived coordinate systems, so separate meshes (say, two wings of a facility) can be joined.
- **A self-healing topology maintainer.** This updates the coordinate graph as agents fail, leave, or join.
- **An evidential-fusion mechanism.** Mesh-derived positions can be combined with externally sourced positions (satellite navigation, inertial dead-reckoning, visual-inertial odometry, any external source) through the composite admissibility evaluator. The mesh does not have to be the only source; it fuses with whatever else is admissible.

- **A coordinate-lineage recorder.** Each range observation, localization event, frame definition, uncertainty update, ambiguity resolution, rejection, federation, and consumption is recorded in the governance-chain lineage, so any position's derivation can be reconstructed.

The disclosure also describes **reference-node densification**: because precision is bounded by ranging-modality accuracy and reference-node density within ranging distance, you can improve precision on demand by deploying more reference nodes that integrate into the existing frame. The named deployment forms include pre-placed permanent nodes, drone-positioned nodes, airdropped expendable nodes, vehicle-deployed nodes, and hand-placed nodes, with deployment intervals bounded by the form.

How to Approach the Build

You are implementing this yourself. A reasonable order of work:

1. **Pick your ranging modalities for the environment.** Underground and indoors, choose modalities that survive the medium. The architecture is modality-agnostic by design; your job is to select the ones that measure well in your space and to keep a fallback. Each modality feeds the same coordinate graph.
2. **Define the anchor model.** Decide what serves as a credentialed anchor and how its known position is attested. Anchors are what tie your mesh to a meaningful frame. Plan for the case where you have few or none.
3. **Build the range-observation record with identity and admissibility.** Each range observation should carry the credential that authenticates it, so the rejection mechanism can throw out spoofed or injected ranges. An illustrative interface sketch, faithful to the disclosed fields and clearly not a shipping API:

```
# illustrative only (not a runnable library)
RangeObservation:
  from_agent          # credentialed identity
  to_agent_or_anchor
  modality            # one of the admitted ranging modalities
  measured_distance
  ranging_precision   # feeds uncertainty propagation
  credential           # authenticates this observation
  lineage_ref         # link into the governance chain
```

4. **Implement cooperative localization plus the transitive extender.** Start with direct multilateration from anchors, then add neighbor-referenced position so agents that cannot see enough anchors are still located through their neighbors. This is what makes deep-interior positioning possible.
5. **Propagate uncertainty as a first-class output.** Do not emit a bare coordinate. Carry ranging precision and covariance through the chain so every position has a stated uncertainty, and let consumers gate their actions on it.
6. **Handle the zero-anchor case explicitly.** Implement anchor-less bootstrap so the mesh yields a usable relative frame before any anchor is admitted, then upgrade to an anchored frame as anchors appear.
7. **Add federation and self-healing.** Support aligning independent frames and updating the graph as agents come and go, so a real deployment does not collapse when topology changes.
8. **Plan densification.** Decide, per environment, how you will add reference nodes where precision falls below your threshold, and how those nodes integrate into the existing frame.

What This Does Not Give You

This is an architecture, not a drop-in library. There is no package to install and nothing here "just works" out of the box. The filing describes components and their relationships; you build, tune, and validate the implementation, including the actual ranging hardware, the solver, and the credentialing.

It is not benchmarked or productized. The disclosure does not state accuracy figures, ranges, update rates, or fleet sizes, and neither does this guide; do not treat any of the above as a performance guarantee. Precision, by the disclosure's own terms, is bounded by your ranging-modality accuracy and reference-node density, which are properties of your deployment, not of the architecture.

It also does not conjure position from nothing. You still need agents that can measure distance to each other or to anchors; in a genuinely empty space with a single isolated device and no reference of any kind, there is nothing to cooperate with. And where satellite navigation already works well and cheaply (open outdoor sky view), it may remain the simpler choice, or the right external source to fuse with rather than replace.

Disclosure Scope

The Mesh-Derived Coordinates approach described in this guide is disclosed in U.S. Provisional Application No. 64/049,409. Every mechanism described above traces to that filing. This guide is educational: it teaches an architectural approach so a skilled developer can understand and build toward it. It is not a warranty, not a performance representation, and not an offer of software or an SDK. You are responsible for your own implementation and for validating it in your environment.

Mesh-Derived Coordinates (</mesh-coordinates>) [All 40 steps → \(/inventive-steps\)](#)

es)

Cooperative localization with credentialed ranges. Densification on demand.

Provisional application

PRIMARY TECHNICAL DISCLOSURE

- [Mesh-Derived Coordinates: Cooperative Localization With On-Demand Densification \(/articles/mesh-derived-coordinates-cooperative-localization-with-on-demand-densification\)](/articles/mesh-derived-coordinates-cooperative-localization-with-on-demand-densification)

SECONDARY TECHNICAL

- [Multi-Modality Cooperative Ranging \(/articles/mesh-coordinates/multi-modality-ranging\)](/articles/mesh-coordinates/multi-modality-ranging)
- [Cooperative Localization Across Mesh Units \(/articles/mesh-coordinates/cooperative-localization\)](/articles/mesh-coordinates/cooperative-localization)
- [Relative Frame Bootstrap Without Absolute Reference \(/articles/mesh-coordinates/relative-frame-bootstrap\)](/articles/mesh-coordinates/relative-frame-bootstrap)
- [Credentialed Range Observations With Lineage \(/articles/mesh-coordinates/credentialed-range-observations\)](/articles/mesh-coordinates/credentialed-range-observations)
- [Lineage-Bound Multilateration \(/articles/mesh-coordinates/lineage-bound-multilateration\)](/articles/mesh-coordinates/lineage-bound-multilateration)
- [Anti-Spoofed Observation Rejection \(/articles/mesh-coordinates/anti-spoofed-rejection\)](/articles/mesh-coordinates/anti-spoofed-rejection)
- [Reference Node Densification \(/articles/mesh-coordinates/reference-node-densification\)](/articles/mesh-coordinates/reference-node-densification)
- [Airdroppable and Rapidly-Deployable Reference Nodes \(/articles/mesh-coordinates/airdroppable-deployable-nodes\)](/articles/mesh-coordinates/airdroppable-deployable-nodes)
- [Coordinate Frame Federation Across Mesh Regions \(/articles/mesh-coordinates/coordinate-frame-federation\)](/articles/mesh-coordinates/coordinate-frame-federation)
- [Cross-Jurisdictional Coordinate Alignment \(/articles/mesh-coordinates/cross-jurisdictional-alignment\)](/articles/mesh-coordinates/cross-jurisdictional-alignment)

APPLICATIONS · GENERAL

- [How to Position Forces When GPS Is Jammed: GNSS-Denied Defense PNT \(/articles/mesh-coordinates/gnss-denied-defense-positioning\)](/articles/mesh-coordinates/gnss-denied-defense-positioning)
- [GNSS-Denied Positioning for Underground Mining, Tunneling, and Subterranean Operations \(/articles/mesh-coordinates/subterranean-operations-positioning\)](/articles/mesh-coordinates/subterranean-operations-positioning)
- [Urban Canyon Positioning Without GNSS Lock: Cooperative Ranging for City Streets \(/articles/mesh-coordinates/urban-canyon-civilian-positioning\)](/articles/mesh-coordinates/urban-canyon-civilian-positioning)

- [GNSS-Independent Positioning for Autonomous Ships at Sea \(/articles/mesh-coordinates/autonomous-shipping-ocean-positioning\)](/articles/mesh-coordinates/autonomous-shipping-ocean-positioning).
- [DDoS-Resilient Positioning: Jamming and Spoofing Defense Through Mesh Cooperation \(/articles/mesh-coordinates/ddos-resilient-positioning\)](/articles/mesh-coordinates/ddos-resilient-positioning).
- [Drone Airspace Integration: GNSS-Independent BVLOS Positioning with Credentialed Lineage \(/articles/mesh-coordinates/drone-airspace-integration\)](/articles/mesh-coordinates/drone-airspace-integration).
- [Indoor Medical Positioning for HIPAA-Compliant Hospital RTLS \(/articles/mesh-coordinates/indoor-medical-positioning\)](/articles/mesh-coordinates/indoor-medical-positioning).
- [High-Accuracy Positioning for Mass-Market Mobile Without Reliable GNSS \(/articles/mesh-coordinates/sub-meter-mass-market\)](/articles/mesh-coordinates/sub-meter-mass-market).

APPLICATIONS · SPECIFIC

- [Hexagon SmartNet Alternative: Governed Cooperative Positioning \(/articles/mesh-coordinates/hexagon-smartnet\)](/articles/mesh-coordinates/hexagon-smartnet).
- [Locata Alternative: Cooperative Mesh Coordinates Beyond Site-Specific Pseudolites \(/articles/mesh-coordinates/locata-positioning\)](/articles/mesh-coordinates/locata-positioning).
- [NextNav Pinnacle vs Cooperative Multi-Modality Positioning \(/articles/mesh-coordinates/nextnav-pinnacle\)](/articles/mesh-coordinates/nextnav-pinnacle).
- [Apple UWB vs Governed Mesh Coordinates: The Cooperative Positioning Layer Above U1 \(/articles/mesh-coordinates/apple-ubw\)](/articles/mesh-coordinates/apple-ubw).
- [Decawave/Qorvo UWB Alternative: Governed Cooperative-Ranging Substrate \(/articles/mesh-coordinates/decawave-ubw\)](/articles/mesh-coordinates/decawave-ubw).
- [Septentrio GNSS vs Governed Cooperative Positioning \(/articles/mesh-coordinates/septentrio-gnss\)](/articles/mesh-coordinates/septentrio-gnss).
- [Topcon Positioning Alternative: GNSS-Independent Mesh Coordinates \(/articles/mesh-coordinates/topcon-positioning\)](/articles/mesh-coordinates/topcon-positioning).
- [u-blox GNSS Alternative: Cooperative, GNSS-Independent Positioning \(/articles/mesh-coordinates/u-blox-gnss\)](/articles/mesh-coordinates/u-blox-gnss).

[Mesh-Derived Coordinates overview → \(/mesh-coordinates\)](/mesh-coordinates)