

Whitepaper v1.0

Decentralized Positioning & Timing from Signals of Opportunity

A passive, receive-only DePIN architecture that turns existing radio broadcasts into a global positioning layer — without transmitting a single watt, without any spectrum license, in any jurisdiction.

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Abstract

Global Navigation Satellite Systems are a single point of failure for modern civilization. GPS, GLONASS, Galileo, and BeiDou operate from medium Earth orbit on weak signals that are trivially jammed and increasingly spoofed. Every proposed terrestrial alternative based on purpose-built low-frequency transmitters runs into the same wall: the regulations that govern license-free spectrum make useful positioning physically impossible at permitted power levels, and the jurisdictions that matter most — the US, Canada, UK, and EU — do not even agree on whether radiating transmission is allowed below 1 MHz.

Azimuth takes a fundamentally different approach. Instead of building new transmitters, the network deploys passive software-defined radio receivers that listen to signals already saturating the radio environment — LTE and 5G cell tower reference signals, digital television pilots, FM radio subcarriers, and LEO satellite downlinks. These signals were designed for communication, but they carry precise timing information that can be repurposed for positioning through Time-Difference-of-Arrival computation and signal fingerprinting. Because Azimuth nodes only receive, they require no spectrum license in any jurisdiction on Earth.

This whitepaper presents the technical foundations, regulatory analysis, network architecture, and economic model for Azimuth — a Decentralized Physical Infrastructure Network that crowdsources positioning and timing from the signals that are already there.

01

The Problem

GPS was designed in the 1970s for military navigation. Today it underpins civilian air traffic control, financial transaction timestamps, power grid synchronization, autonomous vehicles, precision agriculture, emergency response dispatch, cellular network timing, and the daily lives of billions. A system designed for one purpose has become the invisible substrate of modern infrastructure — and it is remarkably fragile.

The signal arriving at a GPS receiver is roughly 10^{-16} watts — twenty billion times weaker than a typical Wi-Fi signal. A \$30 jammer purchased online can deny GPS coverage across an entire city block. State-level actors routinely spoof GPS in conflict zones, diverting aircraft and disrupting maritime navigation across hundreds of kilometers. Indoor environments, urban canyons, and underground spaces receive no usable GPS signal at all.

The economic exposure is staggering. A 2019 RTI International study commissioned by NIST estimated that a sustained GPS outage would cost the United States alone \$1 billion per day, with cascading effects across telecommunications, finance, agriculture, and emergency services. The EU's 2023 PNT resilience assessment reached similar conclusions for European infrastructure.

The Core Vulnerability

Every GNSS constellation shares the same failure mode: weak signals from 20,000+ km away, passing through atmosphere and urban environments to reach receivers at power levels indistinguishable from noise. No amount of satellite redundancy fixes the physics of the downlink.

The question is not whether GNSS-independent positioning is needed — governments and researchers unanimously agree it is. The question is what architecture can deliver it at scale. Azimuth argues that the answer is not building new transmitters, but intelligently exploiting the transmitters that already exist.

02

Why Existing Alternatives Fail

The most intuitive alternative to satellite positioning is terrestrial transmission at low frequencies, where radio waves follow the Earth's curvature for hundreds or thousands of kilometers. This is the principle behind LORAN-C, eLoran, and time-signal stations like WWVB and DCF77. Several projects — including DePIN proposals — have attempted to build decentralized, license-free versions of these systems. They all fail for the same interconnected reasons.

2.1 The Regulatory Landscape Splits the World in Two

The four jurisdictions most relevant to any global positioning system — the United States, Canada, the United Kingdom, and the European Union — take irreconcilable approaches to license-free transmission below 1 MHz.

The US and Canada offer a near-identical “LowFER” allocation at 160–190 kHz: 1 watt DC input to the final RF stage, with the total antenna plus transmission line capped at 15 meters. Within the band, these rules permit radiating transmission — electromagnetic waves propagating into the far field.

The UK and EU take the opposite approach. Under Ofcom IR 2030 and ERC Recommendation 70-03 Annex 9, every license-exempt sub-1.6 MHz allocation is explicitly inductive — restricted to loop coil antennas for near-field magnetic coupling. Field-strength limits are specified in dBμA/m at 10 meters, deep within the reactive near field at LF wavelengths. The regulation does not merely discourage far-field propagation; it is engineered to prevent it.

Jurisdiction	Best LF/MF Option	Power / Field Limit	Antenna	Radiating?
US (FCC § 15.217)	160–190 kHz	1 W DC input	15 m total	Yes
Canada (RSS-210 § B.1)	160–190 kHz	1 W DC input	15 m total	Yes
UK (Ofcom IR 2030)	119–135 kHz	66 dBμA/m @ 10 m	Loop coil only	No
EU (ERC 70-03 Annex 9)	119–135 kHz	66 dBμA/m @ 10 m	Loop coil only	No

There is no frequency below 1 MHz where all four jurisdictions permit license-exempt radiating transmission at power levels useful for ground-wave positioning. The amateur 2200-meter and 630-meter bands exist but require individual licensing and utility-company registration — categorically incompatible with a permissionless DePIN deployment.

2.2 Antenna Physics Is the Binding Constraint

Even where LowFER rules permit radiating transmission, the antenna size limit makes useful range physically impossible. At 175 kHz the wavelength is 1,714 meters. A 15-meter antenna is 1/114th of a

wavelength — a vanishingly small radiator. The radiation resistance of such a short monopole is roughly 30 milliohms, while real-world ground and loading-coil losses run 10–50 ohms.

RADIATION EFFICIENCY

$$\eta = R_{\text{rad}} / (R_{\text{rad}} + R_{\text{loss}}) \approx 0.03 \, \Omega / 30 \, \Omega \approx 0.1\%$$

A perfectly engineered Part 15 LowFER station radiates approximately 1–5 milliwatts of effective isotropic radiated power. Documented reception ranges under real-time ground-wave conditions are 20–100 km in quiet rural areas, collapsing to 1–20 km in suburban environments. The transcontinental receptions celebrated in the LowFER community are nighttime skywave detections using deep signal integration over minutes — impossible to use for real-time positioning.

For context, every operational LF positioning or timing system — LORAN-C, eLoran, WWVB, DCF77 — operates between 60 and 100 kHz at 30 kilowatts to 1 megawatt of effective radiated power. That is 80–100 dB more power than a Part 15 station. Better signal processing helps, but it cannot bridge ten orders of magnitude.

2.3 TDOA Precision Limits

Meter-class positioning requires sub-3-nanosecond timing resolution (the speed of light gives the conversion: 1 ns corresponds to 30 cm). The Cramér–Rao lower bound on TDOA precision is dominated by bandwidth:

CRAMÉR–RAO BOUND ON TIME-OF-ARRIVAL

$$\sigma_{\tau} \geq 1 / (2\pi \cdot \beta_{\text{rms}} \cdot \sqrt{(2 \cdot B \cdot T \cdot \text{SNR})})$$

A LowFER antenna with a Q of approximately 18 caps usable bandwidth at roughly 10 kHz. This sets a fundamental precision floor near 1 microsecond — equivalent to approximately 300 meters of position error per range measurement, even at high SNR. The LF noise floor is dominated by atmospheric sources (primarily lightning), not thermal noise, so adding more nodes does not lower it.

LORAN-C achieved 100-meter accuracy with 20 kHz of bandwidth at 100 kHz center frequency, backed by 250-kilowatt transmitters and continent-scale baselines. eLoran pushed this to 8–20 meters using surveyed additional secondary factor maps. A milliwatt DePIN node with a 10 kHz bandwidth cannot approach either figure.

2.4 The Synchronization Paradox

A TDOA positioning network requires transmitter clocks synchronized to roughly 1 nanosecond. There are exactly three ways to achieve this: GPS-disciplined oscillators (which defeats the purpose of a GPS alternative), fiber or PTP backhaul (the approach taken by NextNav, at enormous centralized cost), or RF self-synchronization (which requires high bandwidth and good geometry — both unavailable at LF frequencies).

At a generous 5 km per-node radius, covering the continental United States alone would require 4–8 million synchronized nodes, each sporting a 15-meter vertical antenna with a ground radial system and loading coils. In urban environments where node radii collapse to 1–2 km, the density requirement escalates further. This is not a consumer-installable product.

Key Insight

The LF physics that makes time signals like WWVB and DCF77 work — long range, building penetration — is inseparable from the continent-scale transmitter power those systems use. You cannot get the same propagation from milliwatts on residential rooftops.

03

Signals of Opportunity: The Third Path

If building new low-frequency transmitters fails on regulatory, physical, and economic grounds, and satellite constellations remain inherently fragile, a third path exists: exploit the transmitters that are already there.

The modern radio environment is dense with high-power, precisely timed signals that were designed for communication but carry exploitable timing information. LTE and 5G base stations continuously broadcast synchronization signals — Primary and Secondary Synchronization Signals, Cell-specific Reference Signals, and in 5G NR, dedicated Positioning Reference Signals. Digital television stations emit high-power pilot carriers with stable, predictable timing. FM radio stations carry RDS subcarriers with embedded timing data. LEO satellite constellations are adding thousands of new downlink signals each year.

This approach — known in the research community as Signals-of-Opportunity (SoOP) positioning — has been the subject of active academic research for over a decade. Published work has demonstrated 10–100 meter accuracy using LTE signals alone, with sub-10-meter results when multiple signal types are fused. The critical insight is that a SoOP receiver is purely passive: it only receives, never transmits. This means:

No spectrum license is required — receiving is legal in every jurisdiction on Earth. No interference is possible — a passive receiver cannot affect any other system. No new infrastructure is needed

— the transmitters already exist and are maintained by telecom operators, broadcasters, and satellite operators for their own commercial purposes.

The bandwidth problem that cripples LF approaches vanishes at UHF and microwave frequencies. An LTE signal occupies 10–20 MHz of bandwidth — three orders of magnitude more than the 10 kHz available at LF. 5G NR signals can span up to 400 MHz. The Cramér–Rao bound on timing precision scales inversely with bandwidth, which is why SoOP positioning achieves meter-class accuracy where LF systems are limited to kilometer-class.

The antenna problem likewise disappears. At 2 GHz, a quarter-wave antenna is 3.75 centimeters. An RTL-SDR dongle with a small whip antenna receives efficiently across the entire band of interest. There is no 1/114-wavelength efficiency catastrophe.

The Azimuth Insight

The positioning signals are already everywhere. Cell towers, TV stations, and FM transmitters blanket the inhabited world with precisely timed broadcasts at power levels that dwarf GPS by 60–100 dB. The missing piece is not the signal — it is the network of receivers to exploit it.

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Azimuth Network Architecture

Azimuth is a crowdsourced network of passive SDR receiver nodes that continuously observe the radio environment, extract timing and signal-characterization data from ambient broadcasts, and report structured observations to a decentralized aggregation layer. The aggregation layer fuses observations from multiple nodes to produce positioning fixes and radio environment maps that can be queried by applications.

4.1 Signal Targets

Azimuth nodes are designed to acquire timing data from multiple signal classes simultaneously. Each class offers different strengths in coverage, bandwidth, power, and geometric diversity.

Signal Class	Frequency Range	Bandwidth	Timing Signals	Coverage
LTE / 4G	700 MHz – 2.6 GHz	10–20 MHz	PSS, SSS, CRS, PRS	Urban + suburban, dense

Signal Class	Frequency Range	Bandwidth	Timing Signals	Coverage
5G NR	600 MHz – 39 GHz	20–400 MHz	SSB, CSI-RS, PRS	Urban, very high precision
Digital TV	470–890 MHz	6–8 MHz	Pilot carriers, TPS	Wide-area, high power
FM Radio	88–108 MHz	200 kHz	RDS subcarrier	Ubiquitous, building penetration
LEO Satellites	10–30 GHz	50–250 MHz	Downlink sync	Global, sky-ground diversity

Multi-signal fusion is central to the architecture. Any individual signal type has gaps — LTE coverage thins in rural areas, DTV is absent in some geographies, 5G NR is urban-only in early deployment. By correlating timing data across multiple signal classes, Azimuth achieves both wider coverage and higher positioning precision than any single source provides.

4.2 Node Tiers

Tier 0 — Mobile Observer

Free

The onramp. Users run the Azimuth Android app on their existing phone — no hardware purchase required. The app passively collects cell tower survey data (CellInfo: cell ID, RSRP/RSRQ/SINR, timing advance, PCI, carrier frequency), GNSS raw measurements (pseudoranges, carrier phase, Doppler, CNO via Android GnssMeasurement API), WiFi signal surveys, and WiFi RTT where supported. All observations are GPS-tagged. This data builds the radio environment map that Tier 1+ SDR nodes' timing observations are resolved against.

Android 8.0+ • Cell/GNSS/WiFi • GPS-tagged
• \$0 • [Download APK](#)

Coming Soon

Tier 1 — BYOD

~\$30

The SDR entry point. Participants plug a \$30 RTL-SDR V4 dongle into any Windows or Linux machine, install the Azimuth daemon, and begin observing. The RTL-SDR V4 covers 500 kHz to 1.766 GHz with 2.4 MHz instantaneous bandwidth — sufficient to acquire LTE synchronization signals, FM RDS, and DTV pilots. Timing is derived from the host system clock with NTP discipline.

500 kHz – 1.766 GHz • 8-bit ADC • 2.4 MHz BW • NTP

Coming Soon

Tier 2 — Dedicated Node

~\$150–250

Future

Tier 3 — Coherent Array

~\$400–600

A purpose-built unit with a GPS-disciplined oscillator providing nanosecond-class timing, outdoor antenna placement for optimal signal reception, and 24/7 unattended operation. Higher-quality ADC and wider instantaneous bandwidth enable simultaneous multi-band observation.

GPSDO timing • Outdoor antenna • 24/7 operation

The premium tier. A multi-channel coherent receiver (such as KrakenSDR) with a 5-element antenna array enables both TDOA and Angle-of-Arrival measurements. Phase-coherent channels allow interferometric techniques that resolve signal direction as well as timing.

5-channel coherent • TDOA + AoA • Premium rewards

This tiered approach is deliberate. Tier 0 eliminates the cost barrier entirely, turning every Android phone into a passive observer that enriches the radio environment map. Tier 1 enables mass SDR adoption by leveraging hardware many enthusiasts already own, seeding the network with geographic density. Tiers 2 and 3 add precision and capability at the margins, improving the quality of the observation dataset without requiring everyone to invest in specialized equipment. Many Tier 0 contributors convert to Tier 1 when they see the reward differential.

4.3 Positioning Engine

Azimuth computes position through two complementary methods, fused in the aggregation layer:

Time-Difference-of-Arrival (TDOA). When three or more nodes observe the same signal source, the differences in observed arrival times constrain the receiver's position to a set of hyperboloids. The intersection of these hyperboloids yields a position fix. TDOA does not require knowledge of the transmitter's absolute timing — only the relative differences between receivers matter — which eliminates the transmitter synchronization problem that plagues purpose-built networks.

Signal Fingerprinting. Every location has a unique radio signature: the set of observable signal sources, their received power levels, multipath characteristics, and timing relationships. Azimuth builds a continuously-updated radio environment map from crowdsourced observations. A positioning query compares a new observation against this map to estimate location, even when too few signals are available for geometric TDOA.

The fusion of TDOA and fingerprinting provides robustness that neither method achieves alone. TDOA excels in open environments with clear line-of-sight to multiple transmitters. Fingerprinting excels indoors and in dense urban canyons where multipath is severe but the radio signature is highly location-specific. The aggregation layer weights each method dynamically based on observation quality and signal geometry.

A centralized SoOP positioning network could work — but it would face the same scaling challenges as any infrastructure company. Receiver hardware must be purchased, deployed, maintained, and connected at thousands of locations. Site leases, power, internet connectivity, and maintenance staff drive costs per node well above the hardware price.

Azimuth inverts this model through Decentralized Physical Infrastructure. Participants deploy and maintain their own receiver nodes, contributing observations to the network in exchange for token rewards. The network scales with the incentive: as more participants deploy nodes, coverage expands, the radio environment map becomes denser and more accurate, positioning precision improves, and the dataset becomes more valuable to consumers — which in turn funds higher rewards, attracting more participants.

This flywheel is particularly well-suited to SoOP positioning because the marginal value of each new node is high and geographically differentiated. A node in an underserved area fills a coverage gap that cannot be filled by any existing node. Unlike bandwidth-sharing or storage DePINs where nodes are largely fungible, positioning nodes are valuable precisely because of where they are.

The receive-only constraint is a critical advantage for the DePIN model. Because nodes never transmit, there are zero regulatory barriers to deployment in any jurisdiction. A participant in Tokyo, Lagos, São Paulo, or Oslo faces the same regulatory burden: none. This is not true for any transmitting DePIN, where spectrum licensing varies radically across jurisdictions and often requires commercial agreements or government approvals.

06

Tokenomics

The Azimuth token is the unit of value exchange within the network. It flows between three participant classes: node operators who contribute observations, data consumers who query the positioning and mapping services, and governance participants who stake tokens to vote on protocol parameters. The blockchain for the \$AZIMUTH token has not been selected; this decision will be announced before TGE.

6.1 Proof of Observation

Azimuth rewards nodes based on Proof of Observation — cryptographically verifiable evidence that a node received, processed, and reported a specific signal at a specific time. Unlike proof-of-work systems that consume energy for its own sake, Proof of Observation rewards useful work: the generation of positioning-grade radio observations that improve the network's coverage and accuracy.

An observation report includes the signal source identifier (cell ID, transmitter callsign, or satellite PRN), the measured timing parameters (time-of-arrival, carrier phase, Doppler), received signal quality metrics, and a timestamp anchored to the node's timing reference. Reports are signed with

the node's cryptographic identity and submitted to the aggregation layer, which cross-validates observations against reports from neighboring nodes to detect fabrication.

6.2 Reward Factors

Coverage Value

Observations from underserved areas earn higher rewards than redundant observations from well-covered locations. The reward function uses a geographic density coefficient that decreases as node concentration increases in a given cell.

Signal Diversity

Nodes that observe multiple signal classes — LTE and DTV and FM simultaneously — produce richer data for multi-signal fusion and earn a diversity multiplier relative to single-signal observers.

Timing Quality

Higher-quality timing references (GPSDO vs. NTP) produce more precise observations. The reward function applies a precision tier multiplier corresponding to the node's demonstrated timing accuracy.

Uptime & Consistency

Continuous, reliable operation earns an uptime bonus. Intermittent nodes that appear and disappear are less valuable for real-time positioning and earn proportionally less.

6.3 Reward Mechanics

The reward function combines several multiplicative factors that incentivize geographic coverage, discourage over-concentration, and reward hardware investment. All parameters are drawn from the Rewards Architecture v1 specification.

Base Points per Observation

Each tier earns a fixed number of base points per observation, reflecting the hardware investment and data quality contributed:

Tier 0	Tier 1	Tier 2	Tier 3
1	3	8	15

Hex Freshness Multiplier

H3 resolution-8 hexagons are classified by how recently they were first observed. Early arrivals to uncharted hexes earn dramatically more, incentivizing geographic expansion over clustering:

Status	Multiplier
Virgin (never observed)	3.0×
Stale (long since observed)	2.0×
Aging	1.5×
Baseline	1.0×
Recent	0.25×
Saturated	0.10×

Saturation Decay

Network-wide, per-tier logarithmic decay. As more nodes of the same tier come online across the entire network, per-node rewards decay:

$$\text{multiplier} = 1 / (1 + k \cdot \ln(N))$$

where N is the number of active nodes in the tier network-wide, and k is tier-dependent:

Tier 0 (k)	Tier 1 (k)	Tier 2 (k)	Tier 3 (k)
0.50	0.30	0.15	0.10

Higher-tier nodes decay more slowly, reflecting greater hardware investment and data quality.

Collision Detection

When multiple nodes activate in the same H3 res-8 hex within a 30-minute window, latecomers are suppressed for the remainder of that window. This prevents reward sniping and discourages rapid relocation to high-value hexes. The first node to submit valid observations in a hex claims the window; subsequent arrivals within 30 minutes receive zero reward for that observation.

Density Cap

Separate from saturation decay, a per-hex density cap limits same-tier node rewards as $1/\sqrt{N}$ within each H3 res-8 hex. An absolute maximum of 10 same-tier nodes applies per hex — beyond that, additional same-tier nodes earn zero. Cross-tier nodes in the same hex do not penalize each other. This ensures the network grows outward rather than clustering.

RTK Bonus

Nodes with Real-Time Kinematic (RTK) GNSS positioning — providing centimeter-level accuracy in their own location — earn a 1.5× multiplier on all observations. Precise node positioning dramatically improves the accuracy of TDOA calculations, making RTK-equipped nodes disproportionately valuable to the network.

6.4 Data Marketplace

The demand side of the token economy is the positioning and mapping query service. Applications that need GPS-independent positioning, indoor location, radio environment intelligence, or interference detection query the Azimuth network and pay in tokens. Use cases include:

Positioning queries — applications submit a set of signal observations and receive a computed position fix with confidence intervals. **Radio environment maps** — coverage planners, interference analysts, and spectrum regulators access continuously-updated maps of the radio environment built from crowdsourced observations. **Integrity monitoring** — critical infrastructure operators compare GNSS-derived positions against Azimuth SoOP positions to detect spoofing or jamming. **Historical data** — researchers and analysts access archived observation data for propagation studies, interference forensics, and network planning.

Revenue from the data marketplace flows back to node operators through the reward pool, creating a sustainable economic loop: operators generate data, consumers pay for data, and the proceeds fund continued operation and network expansion.

07

Roadmap

Phase 1 — Active

Daemon, Tier 1 Nodes, and Core Network

Release the Azimuth daemon for Windows and Linux with RTL-SDR V4 support. Initial signal acquisition targets: LTE PSS/SSS and FM RDS. Launch the observation aggregation backend and node registration system. Deploy the token reward mechanism and begin Proof of Observation distribution to early node operators.

Phase 2

Multi-Signal Fusion and Positioning API

Add DTV pilot acquisition, LTE CRS/PRS processing, and 5G NR synchronization signal support. Launch the radio environment mapping service and the positioning query API. Begin building the signal fingerprint database from crowdsourced observations. Open the data marketplace for early consumers.

Phase 3

Tier 2 Hardware, GPSDO Timing, and AoA

Release the Tier 2 dedicated node specification with GPS-disciplined timing. Introduce carrier-phase TDOA for sub-meter precision in favorable geometries. Begin Tier 3 coherent array development for angle-of-arrival capability. Expand the positioning engine to fuse TDOA, AoA, and fingerprinting in real time.

Phase 4

LEO Satellites, Governance, and Enterprise

Add LEO satellite downlink acquisition for sky-ground positioning diversity. Launch full on-chain governance for protocol parameters and reward function tuning. Build enterprise integration pathways for critical infrastructure operators, autonomous vehicle platforms, and defense applications. Target 10,000+ active nodes across 50+ countries.

08

Conclusion

The world depends on satellite positioning systems that operate on signals weaker than the cosmic microwave background. Every proposed terrestrial alternative based on purpose-built low-frequency transmitters fails the same test: the physics of antenna efficiency and bandwidth at LF, combined with the regulatory impossibility of harmonizing license-free radiating transmission across jurisdictions, makes decentralized LF positioning a dead end.

Azimuth recognizes that the positioning signals are already everywhere. Cell towers, television stations, FM transmitters, and LEO satellites saturate the radio environment with high-power, precisely timed broadcasts that cover the inhabited world. The missing piece is not the signal infrastructure — it is the receiver infrastructure to exploit it.

By building a decentralized network of passive SDR receivers, Azimuth turns the existing radio environment into a positioning layer. No new transmitters. No spectrum licenses. No regulatory

barriers. No single point of failure. Every node makes the network more accurate, every observation makes the radio environment map more complete, and every participant earns from the value they create.

The signals are already there. Azimuth listens.

References

Regulatory Sources

FCC 47 CFR Part 15 (§ 15.209, § 15.217, § 15.219, § 15.225); Innovation, Science and Economic Development Canada RSS-210 Annex B; Ofcom IR 2030 Table 2; ERC Recommendation 70-03 Annex 9; ETSI EN 300 330; European Commission Decision 2006/771/EC.

Propagation and Positioning

ITU-R P.368 (Ground-wave propagation curves); ITU-R P.372 (Radio noise); Cramér–Rao bound on time-of-arrival estimation; LORAN-C / eLoran positioning accuracy literature (Offermans et al., Johnson et al.); RTI International, “Economic Benefits of the Global Positioning System,” prepared for NIST, June 2019.

Signals of Opportunity

Kassas, Z.Z.M., “Navigation from Low-Earth Orbit,” series of publications 2019–2025; Shamaei, K. et al., “LTE receiver design and multipath analysis for navigation in urban environments,” Navigation, 2018; Khalife, J. et al., “Navigation with differential carrier phase measurements from megaconstellation LEO satellites,” IEEE, 2020; Del Peral-Rosado, J.A. et al., “Survey of cellular mobile radio localization methods,” IEEE Communications Surveys & Tutorials, 2018.

DePIN and Related Networks

GEODNET (GNSS reference station DePIN); Locata Corporation (terrestrial carrier-phase positioning); NextNav (licensed metropolitan pseudolite network); Helium (IoT DePIN precedent).

