

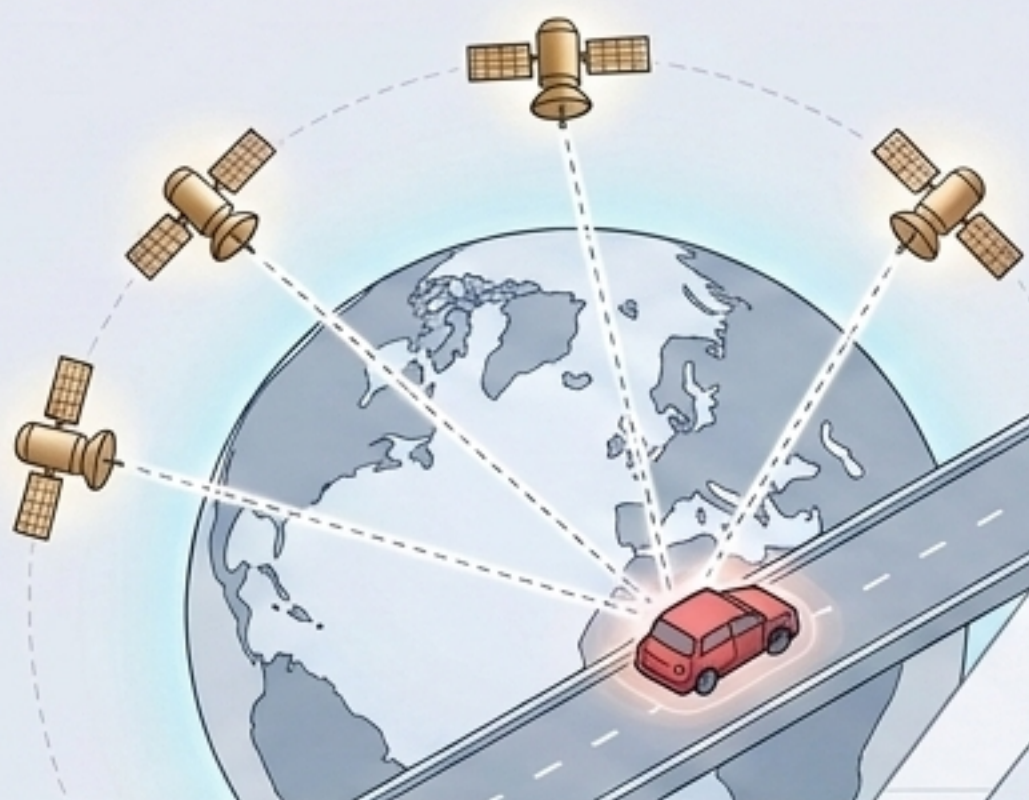
Future of Location Systems

Exploring UWB

MODULE: LOCATION_ENGINE_ARCH

STANDARD: IEEE 802.15.4z

APPLICATION: SPATIAL_AWARENESS & SPORTS_ANALYTICS



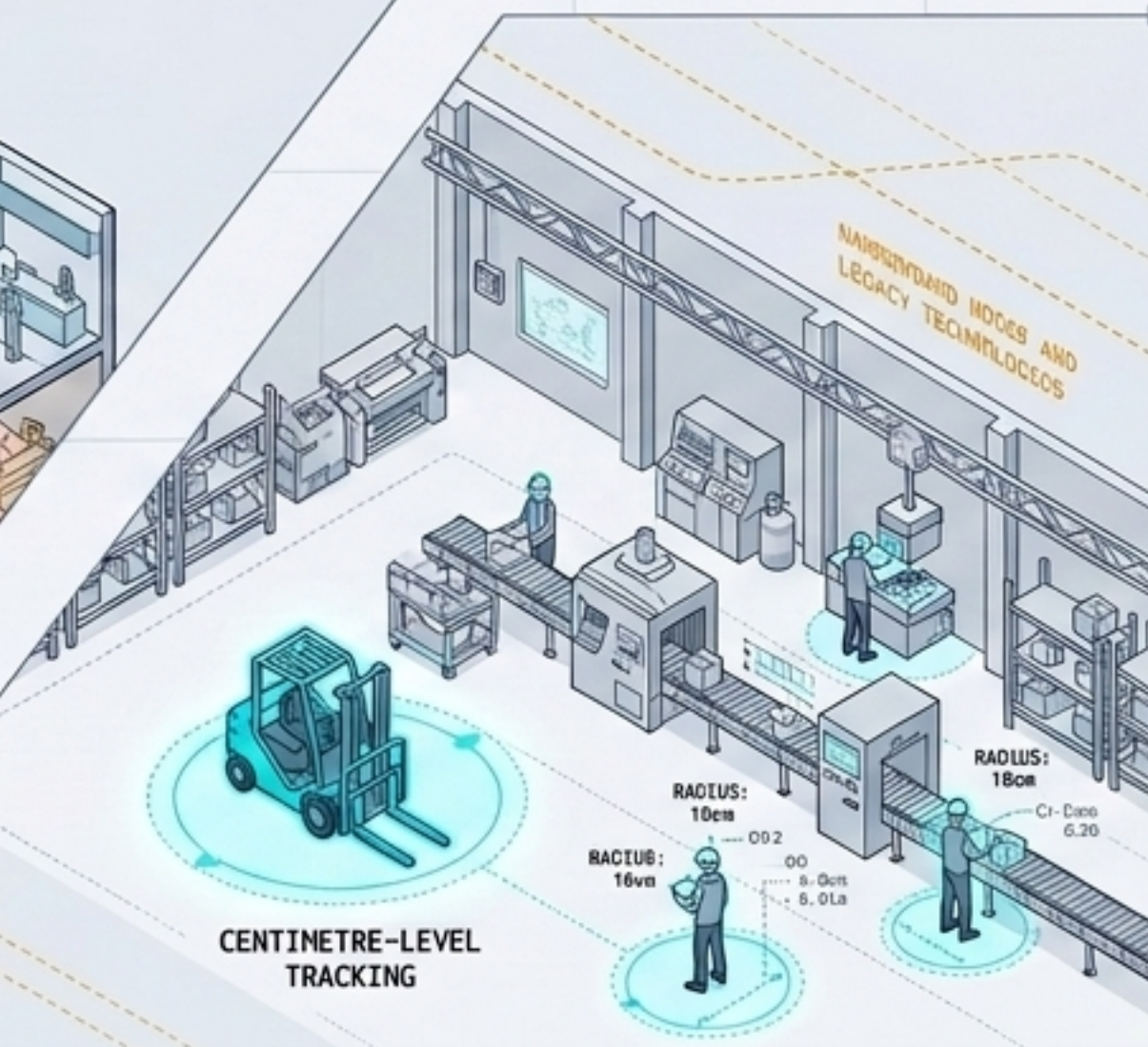
2000-2010: The GPS Revolution

Global outdoor positioning becomes commercially accessible for navigation and logistics.



2010-2015: Start of Indoor Navigation

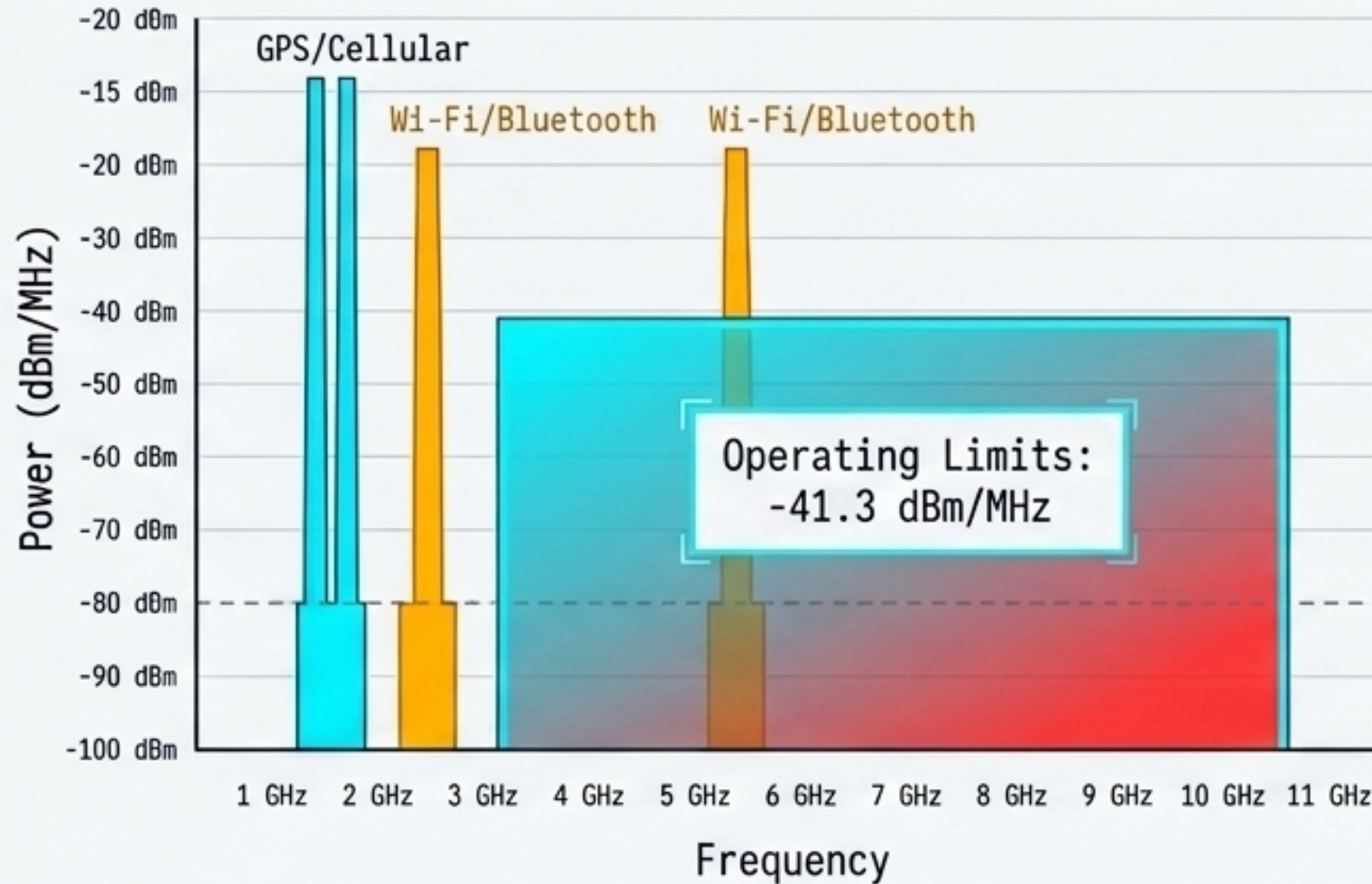
Expansion into complex indoor spaces (malls, airports, commercial facilities).



2015+: Micro-Location Revolution

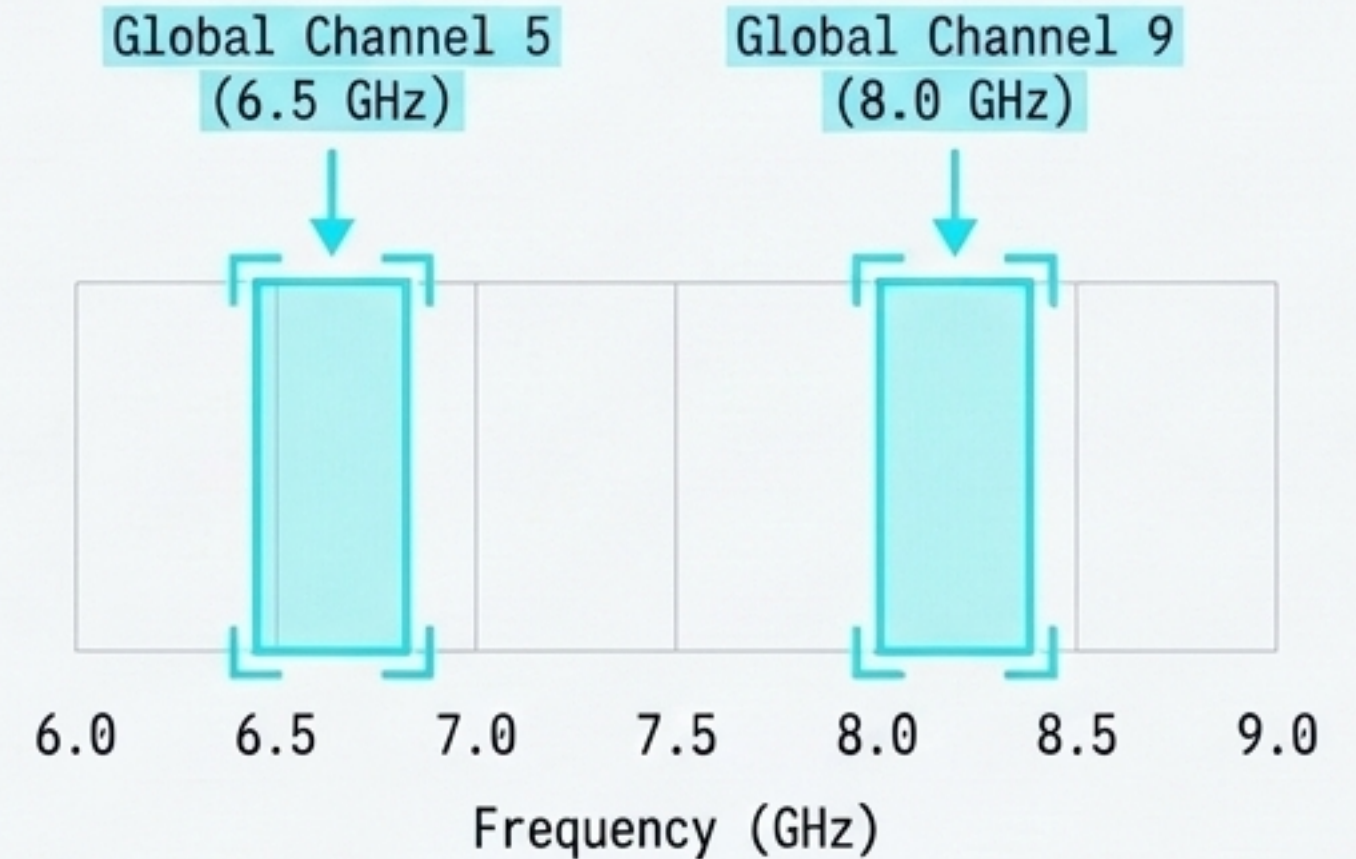
Ultra-precise real-time tracking enabling centimetre-level accuracy for industrial use cases.

Power Spectral Density (PSD)



UWB acts as “engineered noise.” By spreading low power across a massive bandwidth (>500 MHz), it emits up to ~1000x less Electromagnetic Interference (EMI) than narrowband signals.

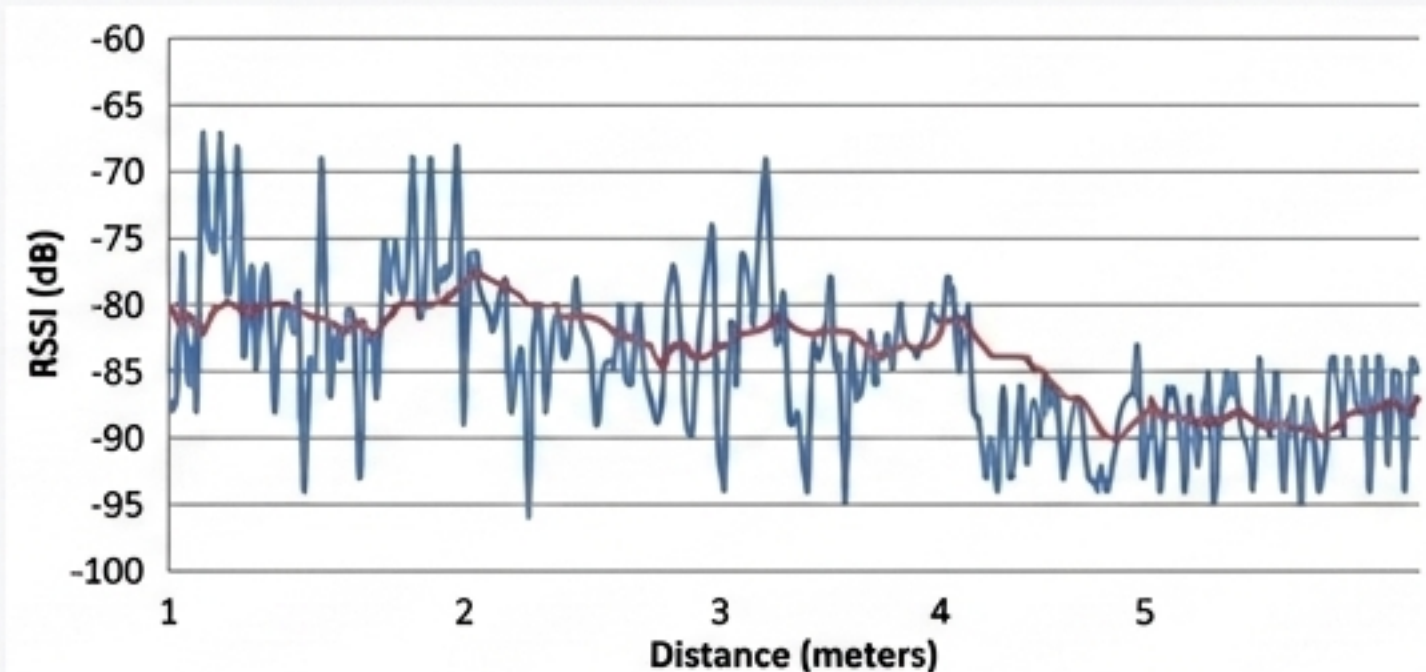
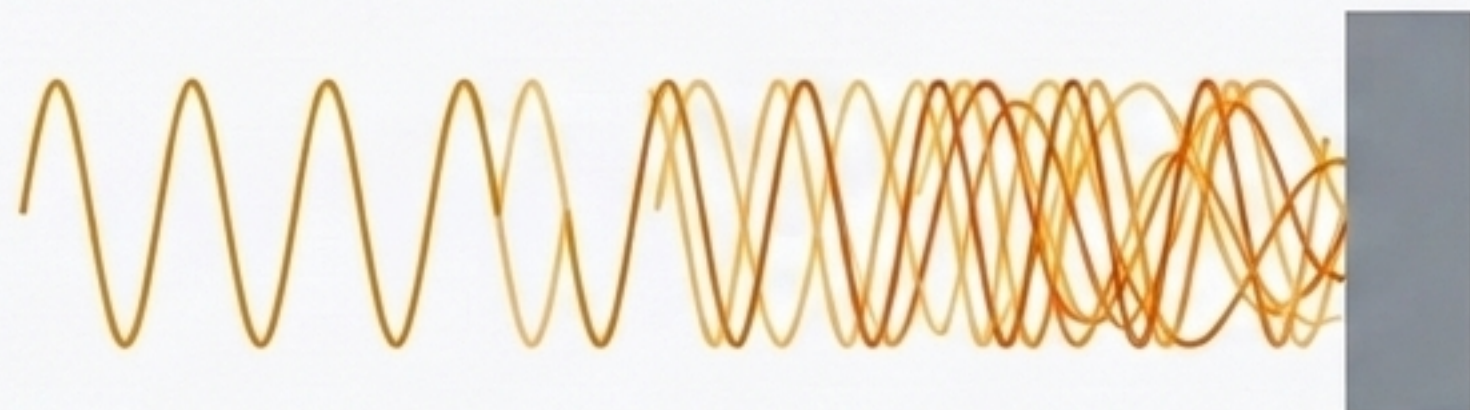
Global Regulations



Low Duty Cycle (LDC) Rules:
Requires an on-time of <50ms per second to prevent spectrum congestion.

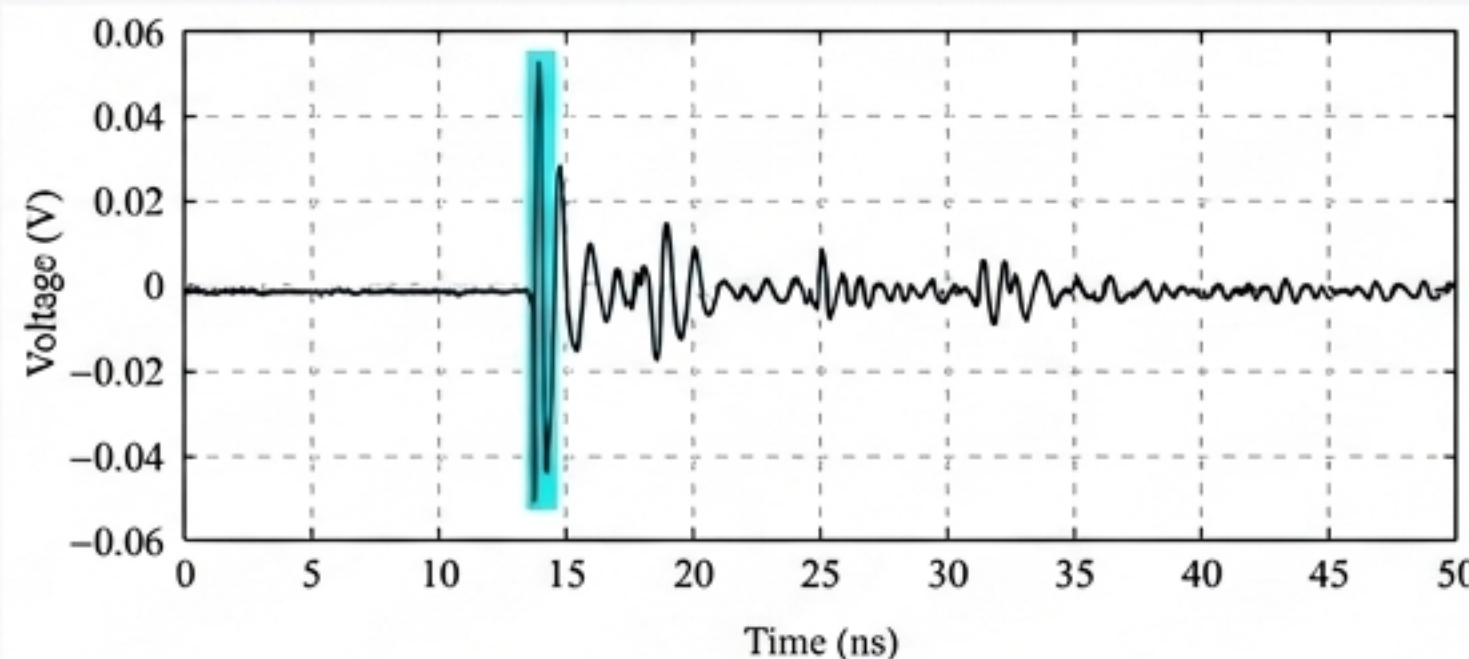
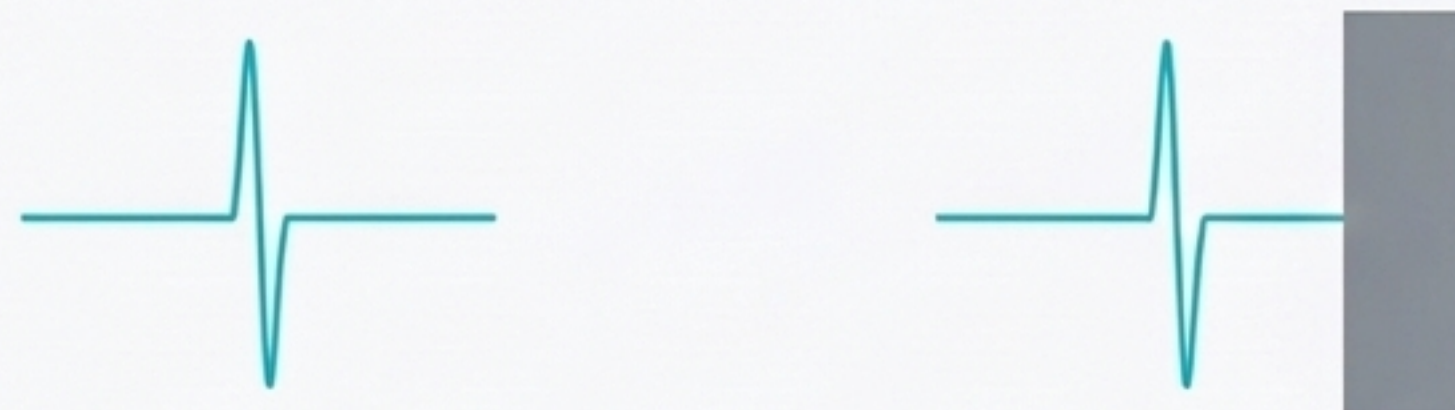
Physics Comparison: Legacy vs. Ultra-Wideband (UWB)

The Problem: RSSI Rayleigh Fading



Constructive and destructive interference causes Wi-Fi/BLE RSSI to fail completely indoors.

The Solution: UWB Pulse

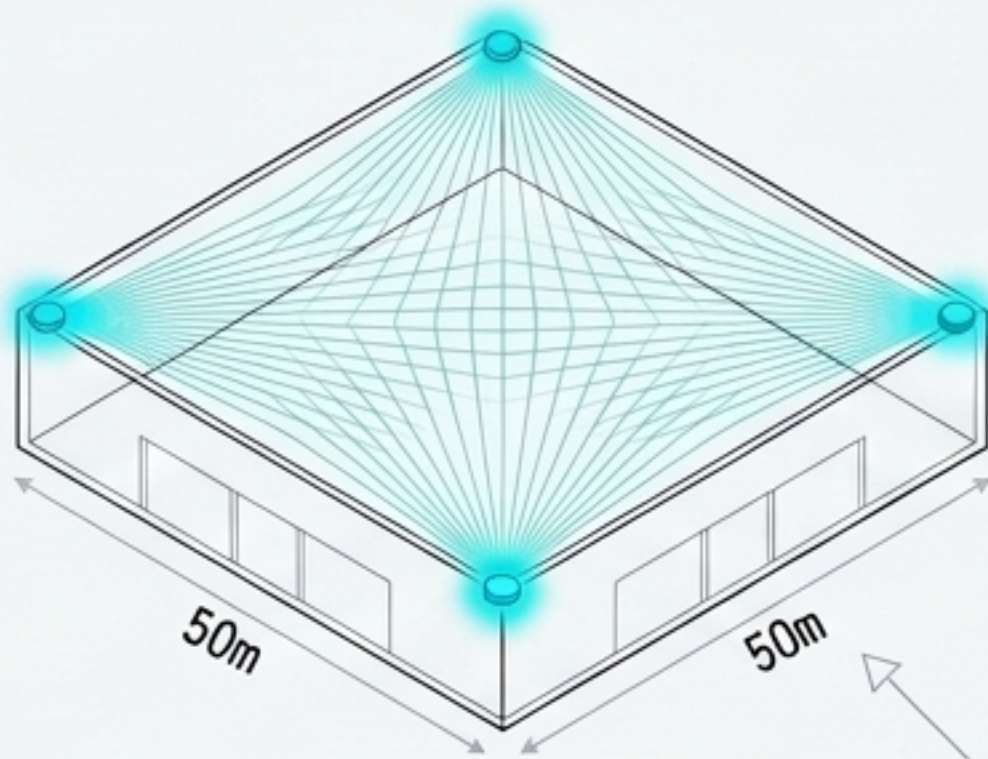


The ultra-short temporal footprint prevents wave overlap. The receiver perfectly isolates the direct path from multipath reflections.

SECURITY: Secured via IEEE 802.15.4z distance bounding protocol to prevent relay attacks.

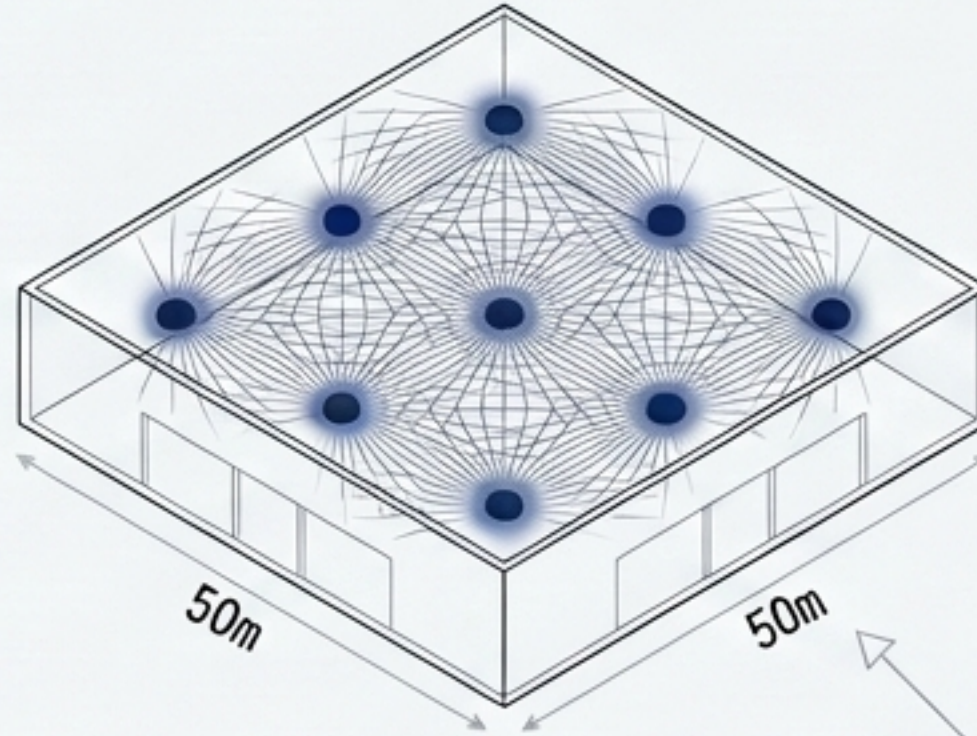
The Infrastructure & Accuracy Matrix

Ultra-Wideband



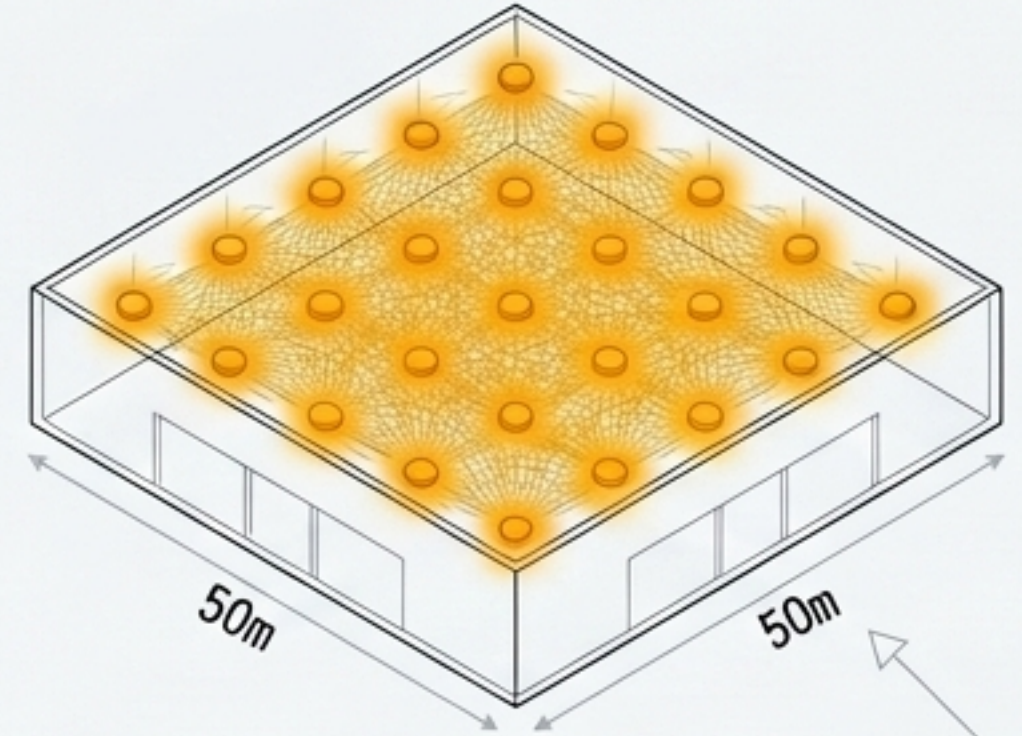
Infrastructure: 4 Anchors
Range: 50-70m
Accuracy: Centimetre-level

Wi-Fi



Infrastructure: 9 Anchors
Range: 40-50m
Accuracy: 5-15m

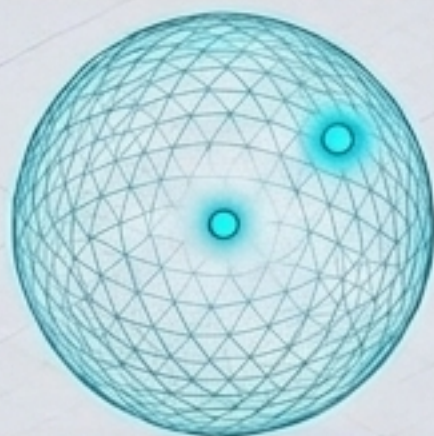
Bluetooth (BLE)



Infrastructure: 25 Anchors
Range: 10-20m
Accuracy: 1-5m

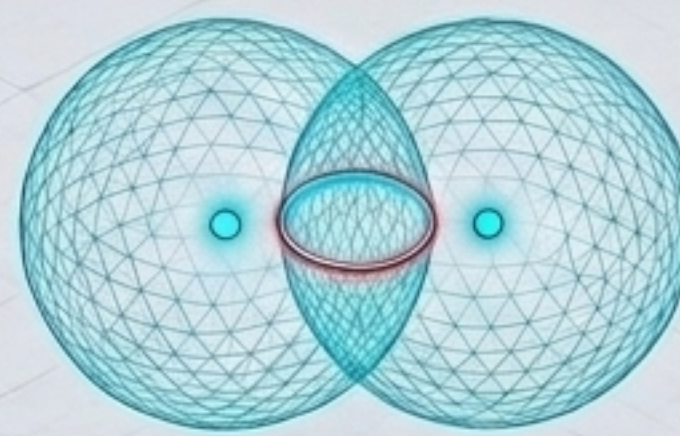
The physical characteristics of the signal (ultrawide vs narrowband) dictate the required infrastructural density for identical spatial coverage.

The First Principles of Multilateration



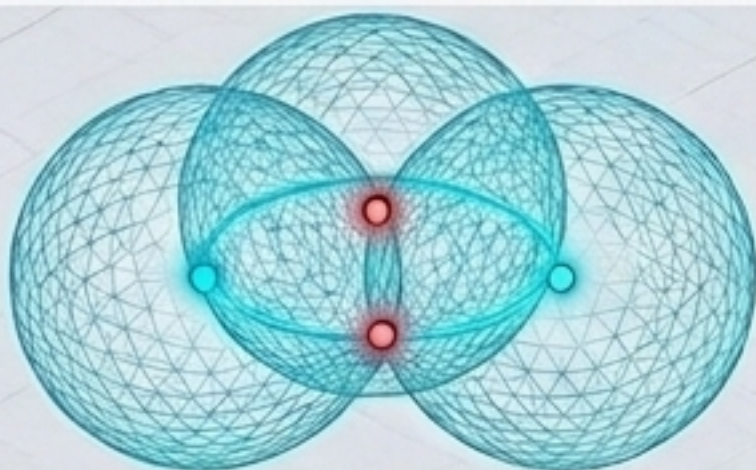
1 Receiver -> Target is located somewhere on the surface of a 3D sphere.

Target Location: Surface Area = $4\pi r^2$



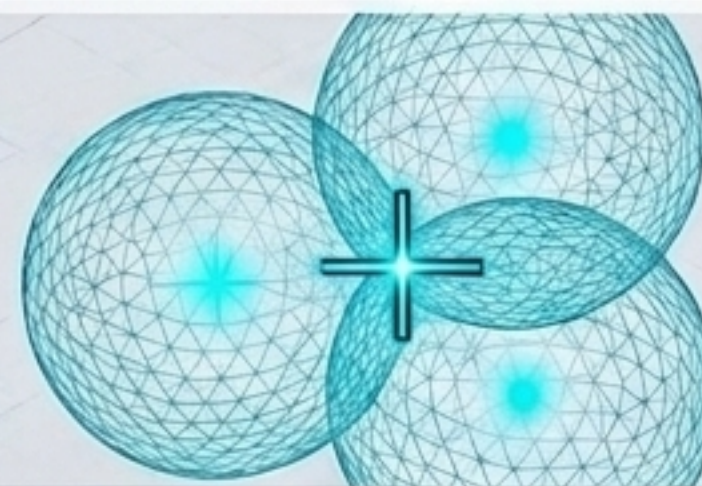
2 Receivers -> Intersecting spheres create a 2D circle. Target is on that circle.

Intersection: Circle = $S_1 \cap S_2$



3 Receivers -> A third sphere intersects the circle, reducing the target to one of 2 distinct points.

Ambiguity Reduction: Points = $S_3 \cap (S_1 \cap S_2)$

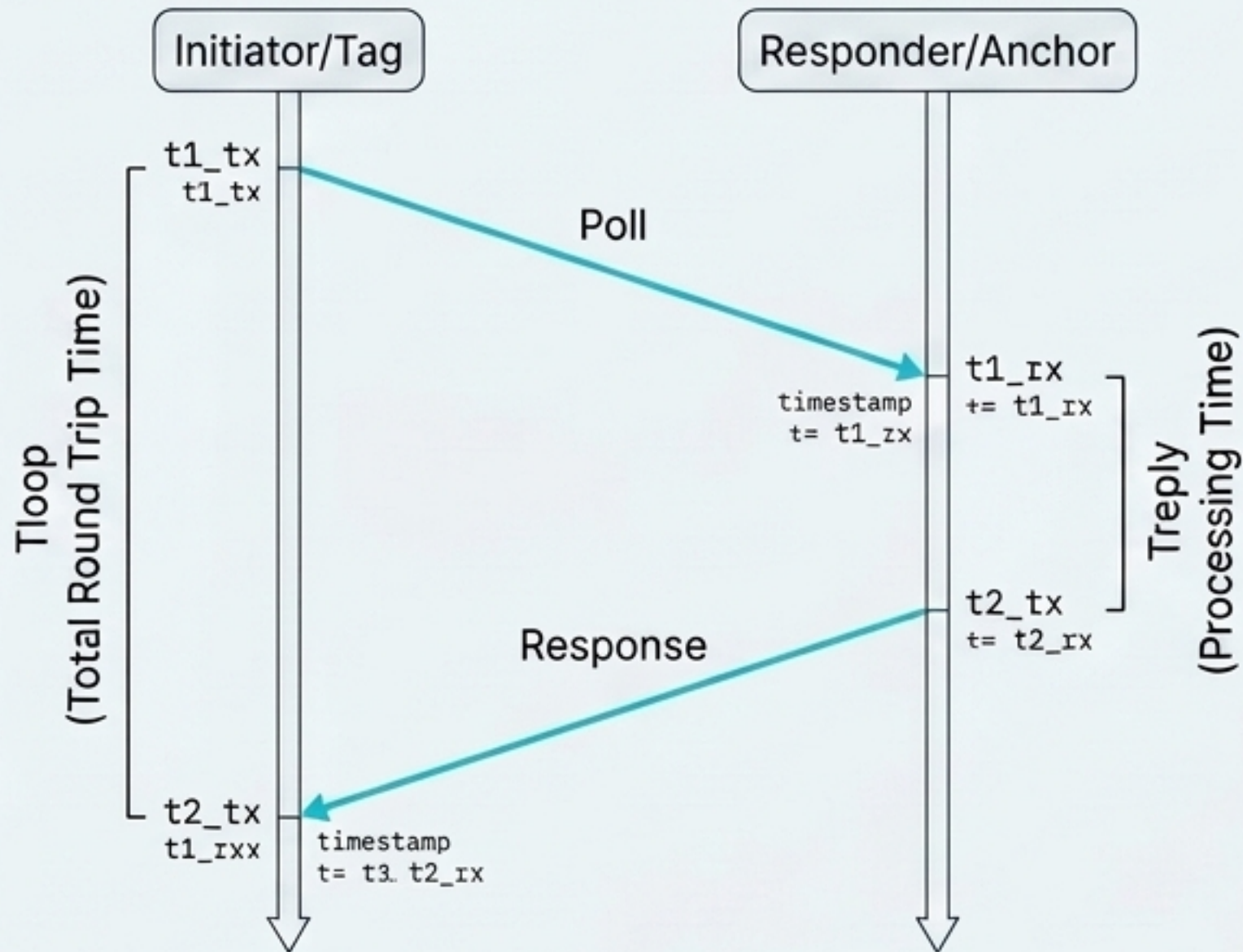


4 Receivers -> A fourth sphere resolves the ambiguity, calculating the exact 3D spatial coordinate (X, Y, Z).

Precise Localization: Point = $S_4 \cap (S_1 \cap S_2 \cap S_3)$

1D Algorithm: Time of Flight (ToF)

Signal Exchange Diagram



Mathematical Engine

$$\text{ToF} = (\text{Tloop} - \text{Treply}) / 2$$

$$\text{distance} = \text{signal speed} * \text{ToF}$$

Engineering Trade-offs

✓ PROS:

- Very high accuracy (<10cm 1D)
- Easy peer-to-peer deployment

⚠ CONS:

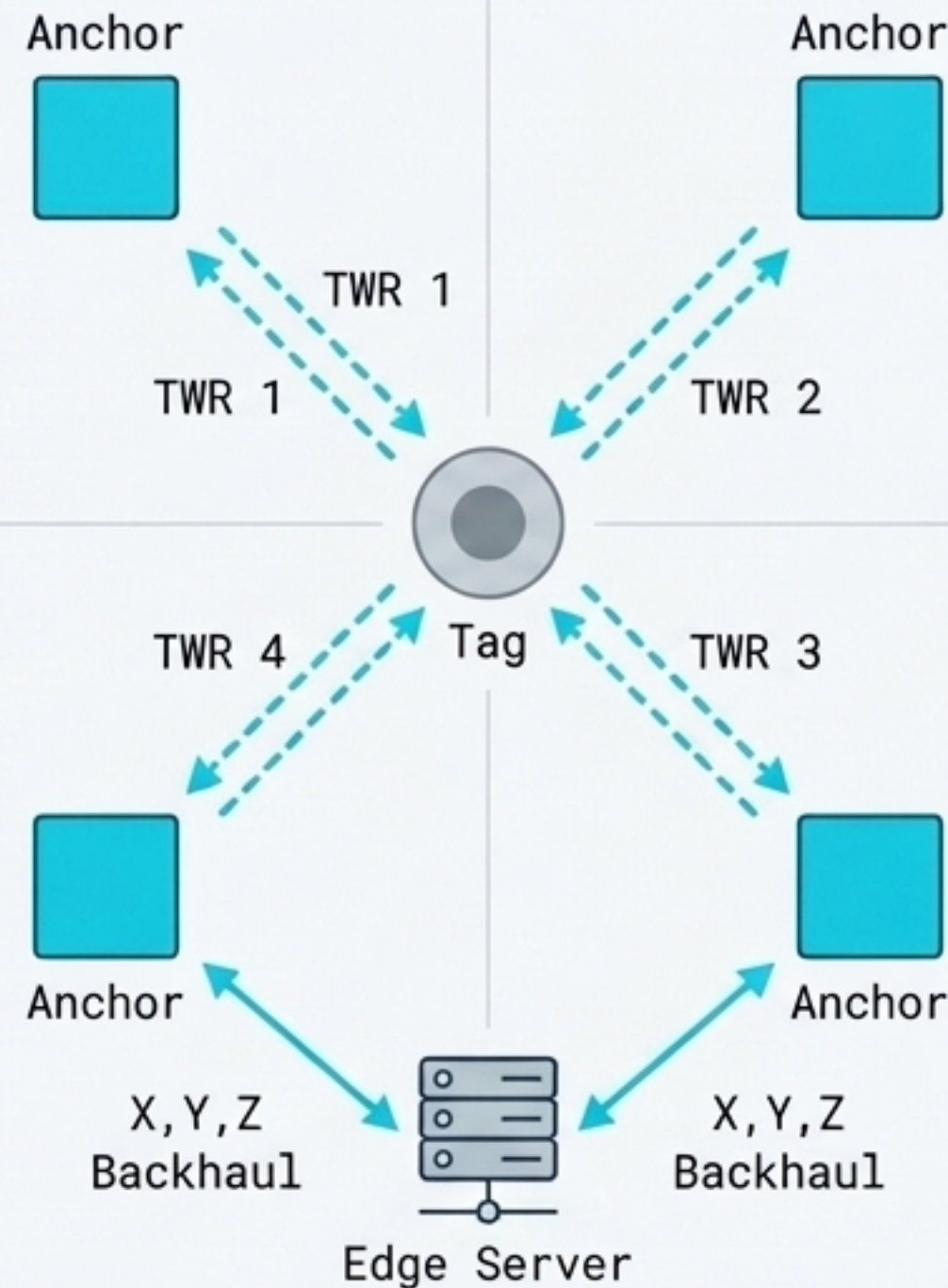
- High power consumption
- Strict capacity limits
- Requires minimum 500ps system synchronisation

2D/3D Algorithm: Two-Way Ranging (TWR)

System Constraints

REQUIREMENT:

- Minimum 3 anchors for 2D location.
- Minimum 4 anchors for 3D location.

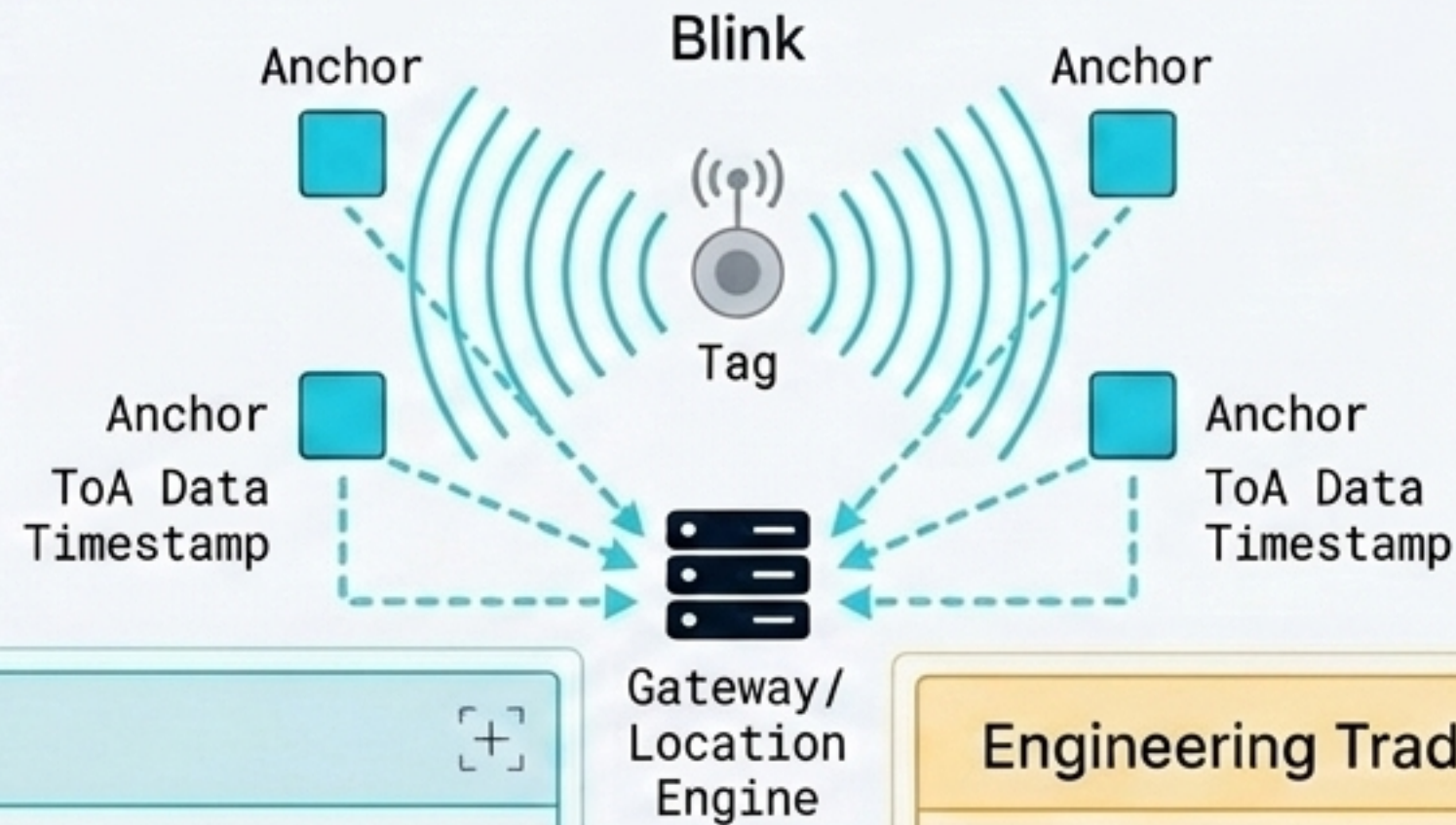


Scalability Limit

THE BOTTLENECK:

Because the Tag must actively complete a full two-way handshake with EVERY anchor, the network mathematically tops out at at **150-200 tags maximum** before radio congestion causes total failure.

Enterprise Scaling: Time Difference of Arrival (TDoA)



Engineering Trade-offs

✓ THE BENEFIT:

- Tag processing burden is **removed**.
- Battery life extends to **7 years** on a standard CR2032 coin cell (@ 0.1Hz).
- Network capacity **explodes** to support **thousands of tags** simultaneously.

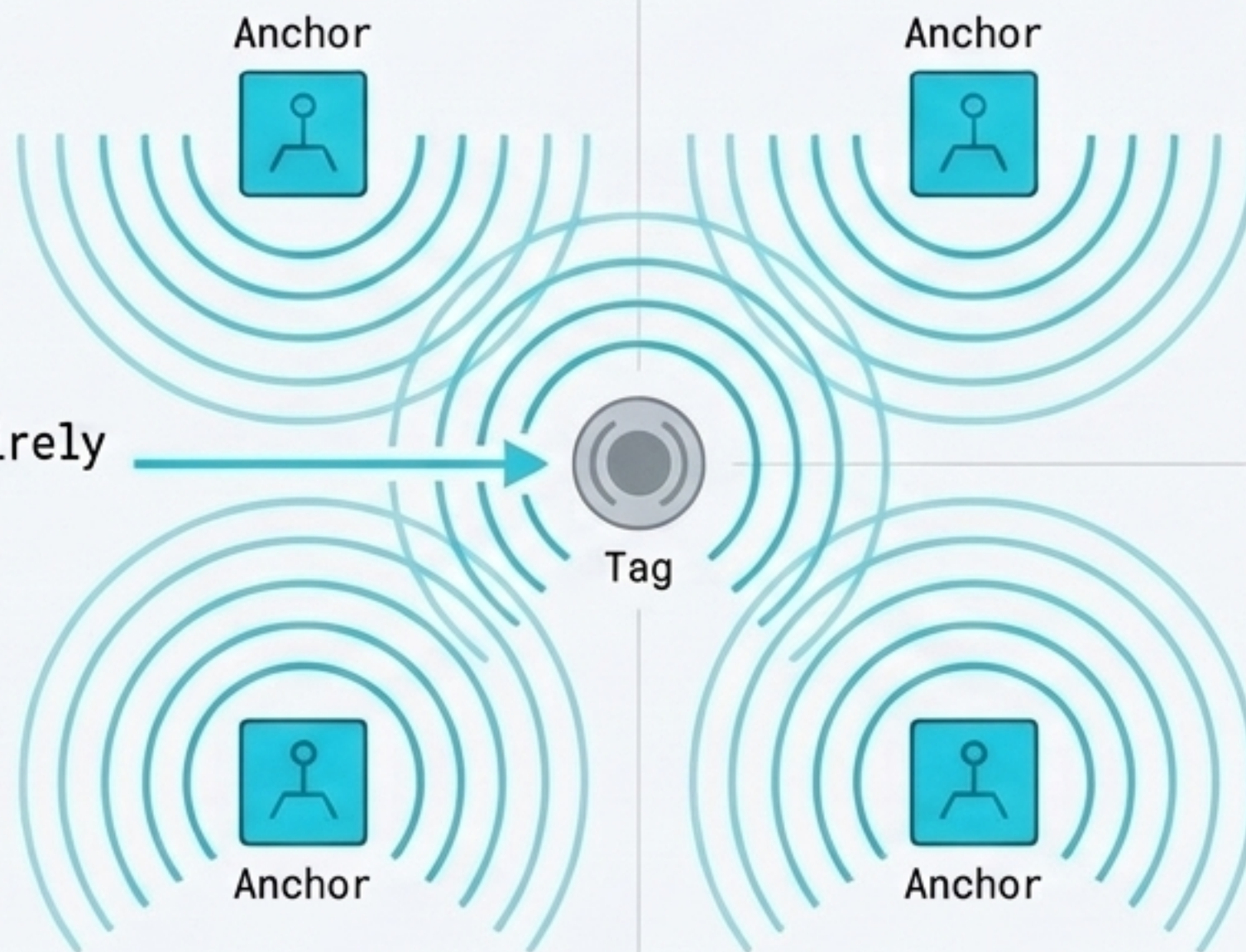
Engineering Trade-offs

⚠ THE COST:

- Extreme infrastructure **complexity**.
- Anchors must maintain perfect, wireless **clock synchronisation** over UWB to accurately calculate microsecond time differences.

Privacy-First Architecture: Reverse TDoA

Position computed entirely
on-device (X, Y, Z).



Architecture Notes

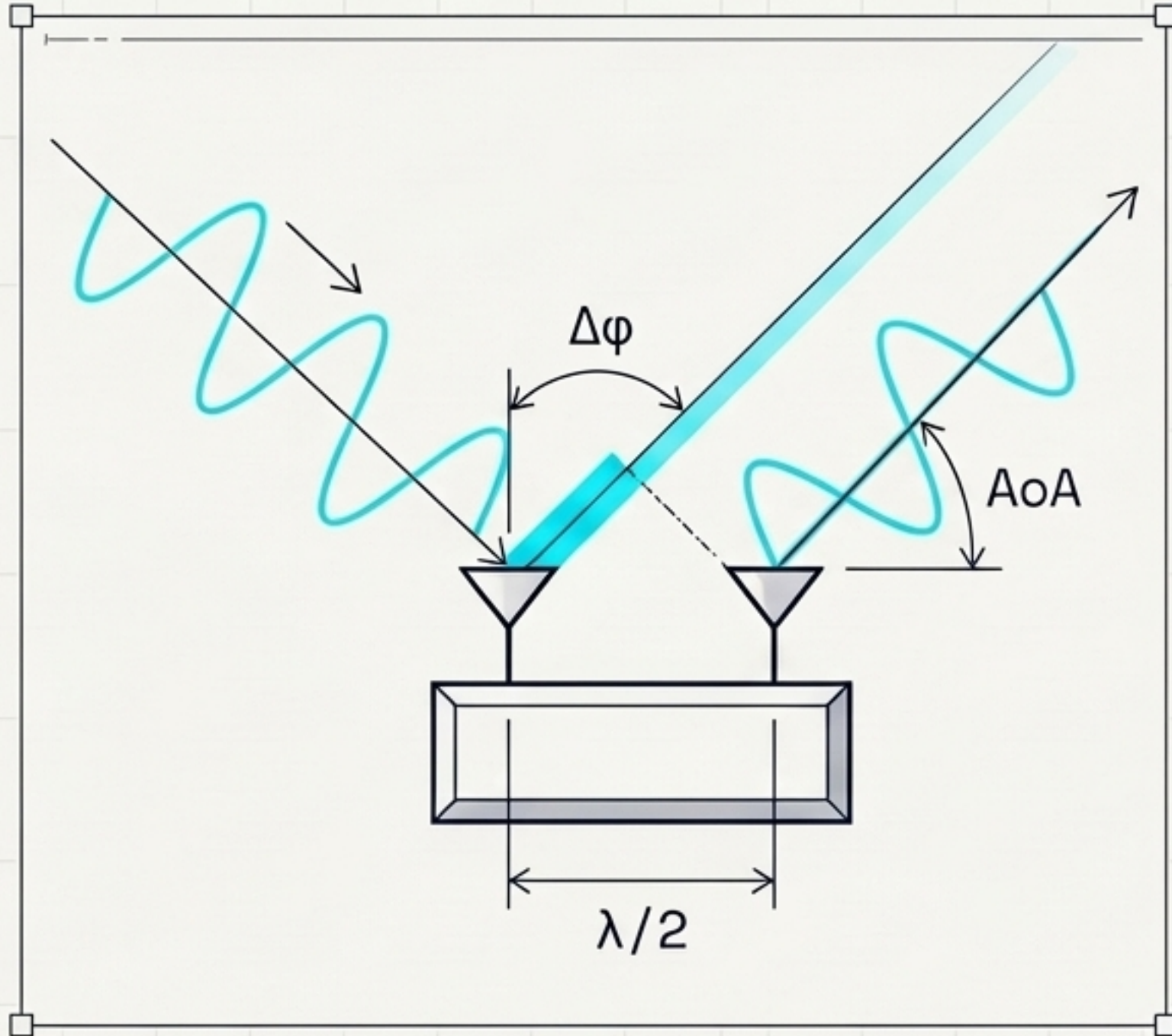
PRIVACY BY DESIGN

The central server never knows where the Tag is unless the Tag actively chooses to backhaul that data via a secondary channel (Wi-Fi/LTE).

INFINITE SCALABILITY

Because tags do not transmit over UWB, the network can theoretically support an infinite number of tags in the same airspace (analogous to infinite cars receiving passive GPS signals).

Spatial Orientation: Phase Difference of Arrival (PDoA)



Mathematical Engine

The location engine measures the phase shift ($\Delta\phi$) between the two antennas to calculate the precise Angle of Arrival (AoA).

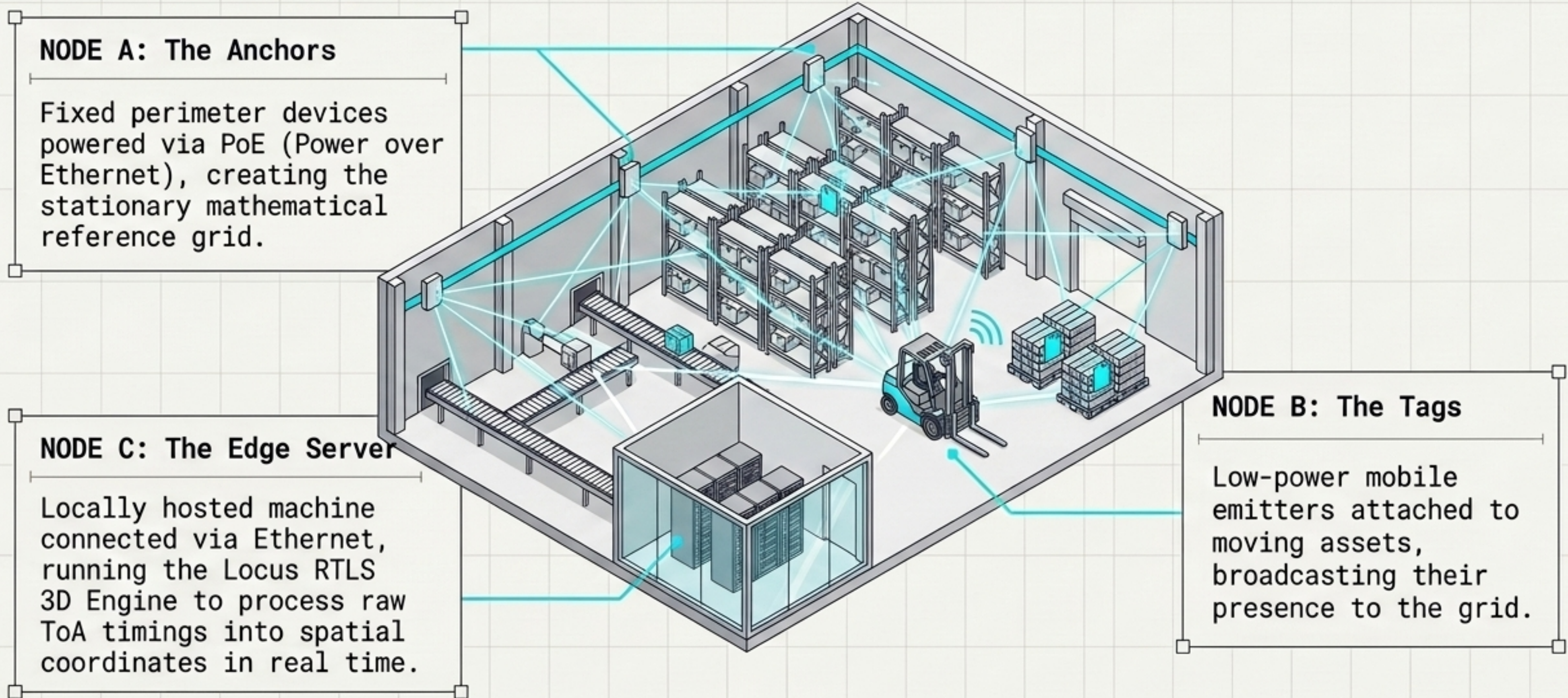
RESULT:

When combined with TWR distance, a single dual-antenna anchor can provide a 2D spatial position relative to itself, drastically reducing the infrastructure required for peer-to-peer tracking.

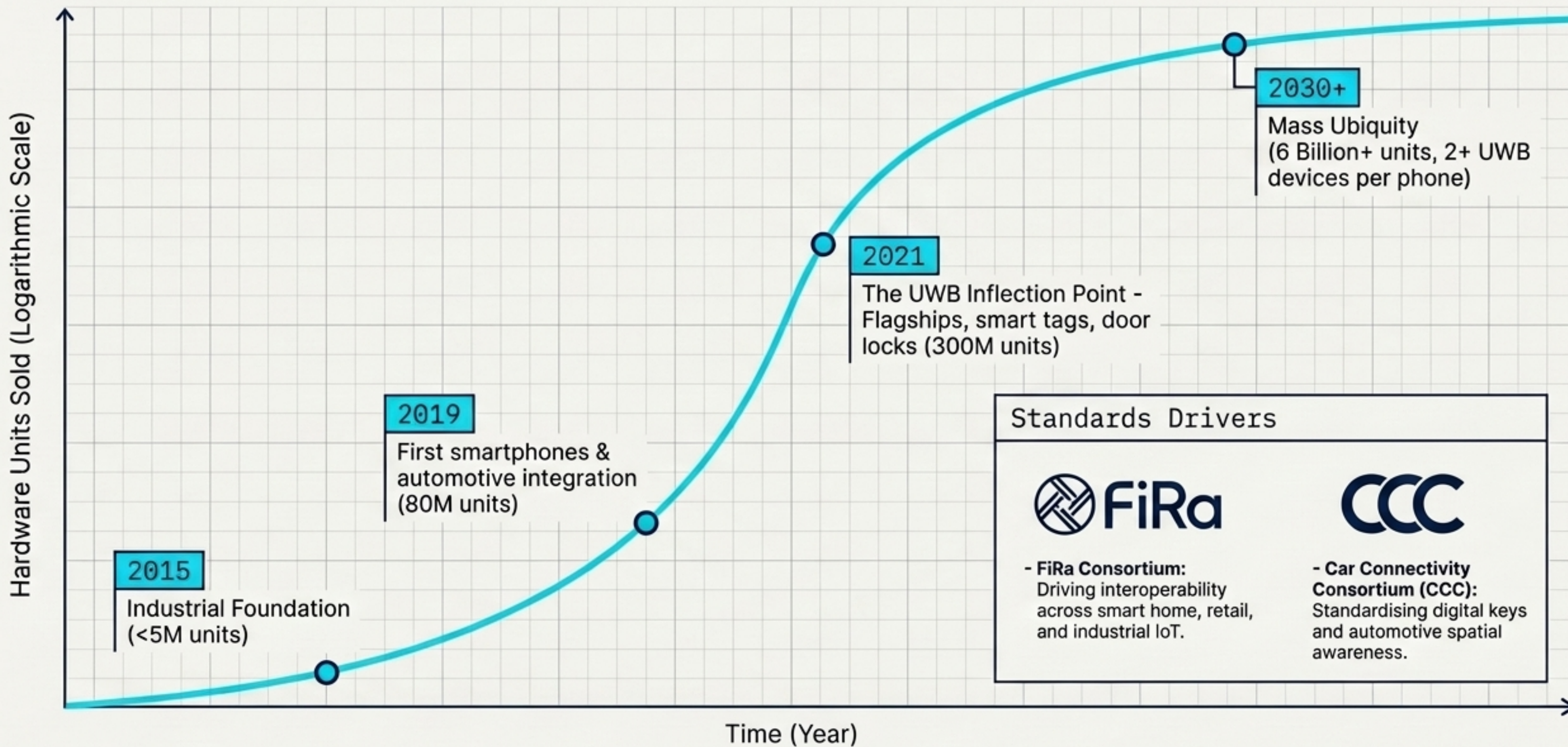
The Algorithmic Trade-off Matrix

Algorithm	Power Consumption	Tag Density Limit	Infrastructure Complexity	Primary Use Case
1D ToF	High	Very Low	Low (2 nodes)	Peer-to-peer ranging
2D/3D TWR	High	Low (150-200)	Medium (Min 4 anchors)	Low-density robotics/drones
TDoA	Ultra-Low (7yr CR2032)	High (2000+)	High (Wireless clock sync)	Mass asset tracking, sports
Reverse TDoA	Medium	Infinite	Medium	Privacy-first navigation
PDoA	Medium	Medium	Very Low (Dual antenna)	Direction finding, spatial awareness

Local Positioning System (LPS) Architecture



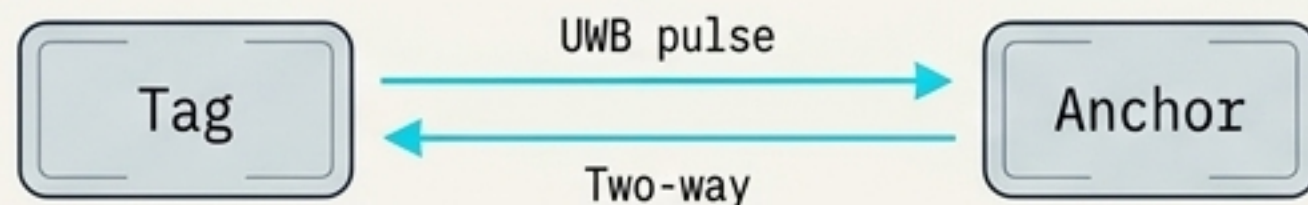
Ecosystem Adoption & Growth Trajectory



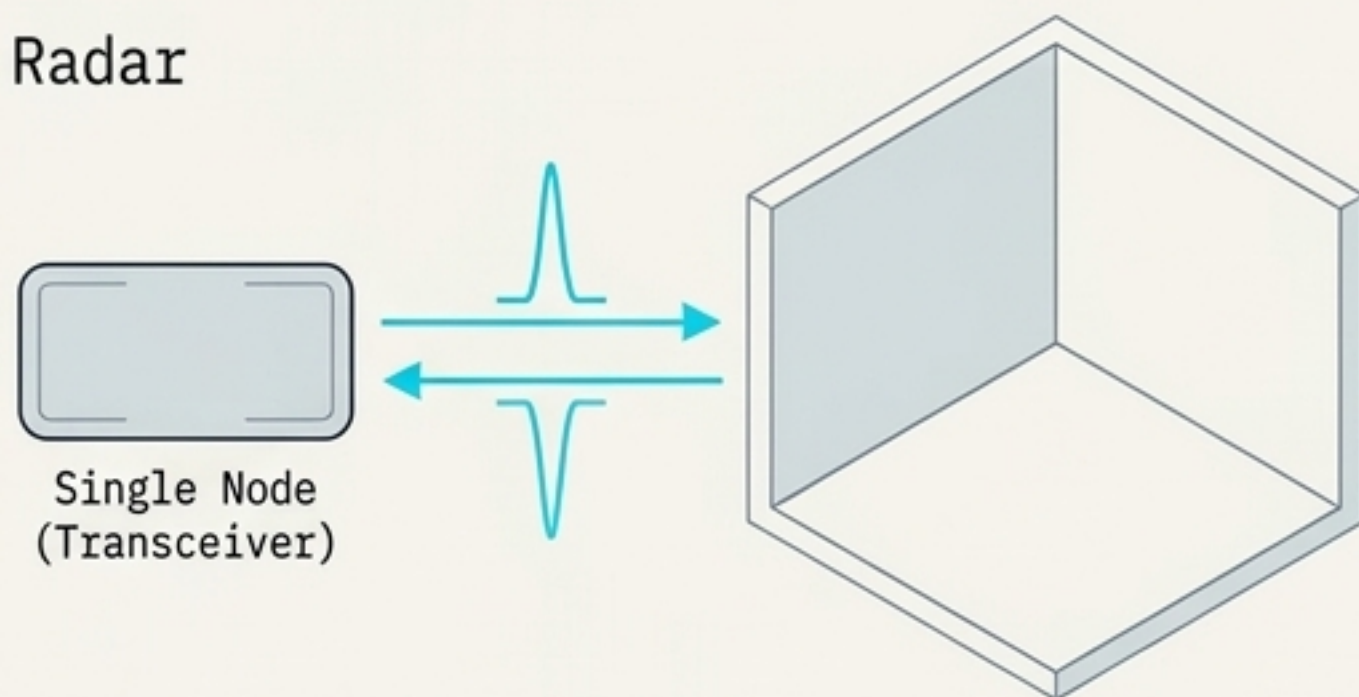
The Radar Frontier: Contactless Sensing

Ranging vs Radar

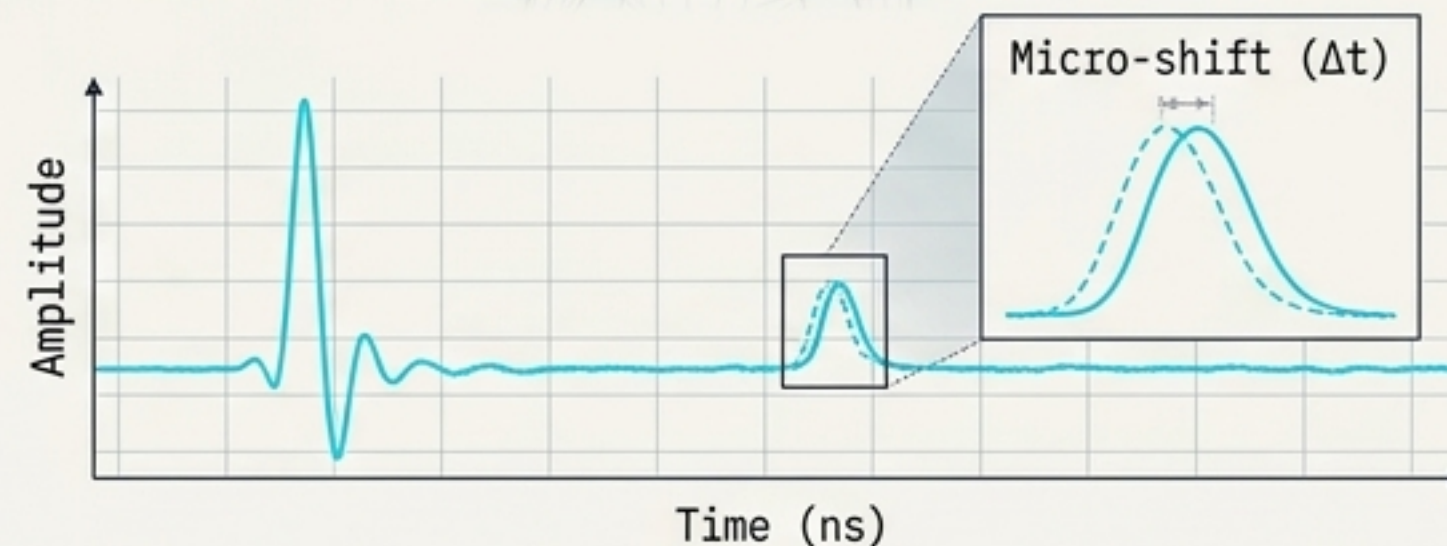
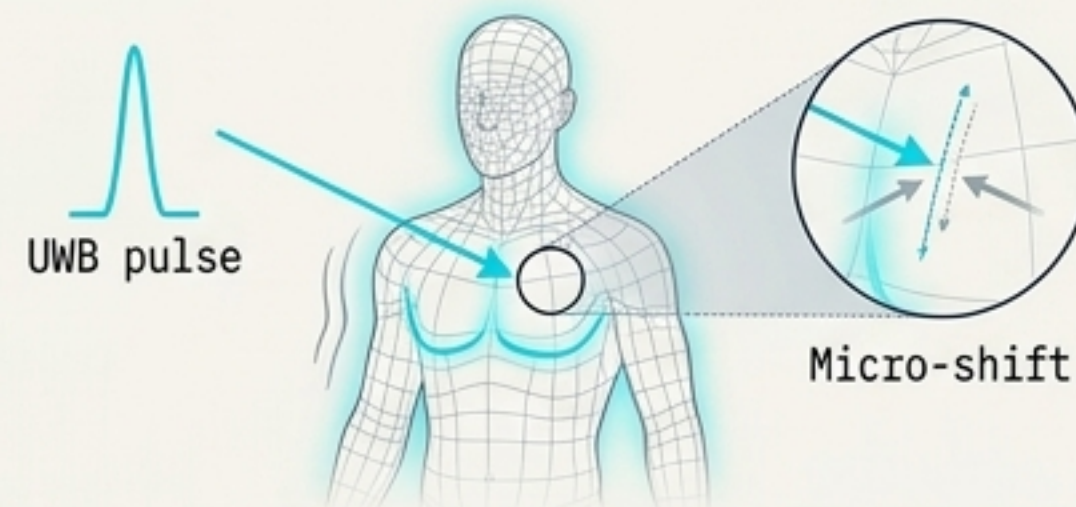
Ranging



Radar



Channel Impulse Response (CIR)



The system isolates micro-shifts in the CIR peak. Mechanical chest displacements of just fractions of a millimetre correlate perfectly to biological respiration rate and heartbeat, requiring zero wearables.

Sensing Modalities Matrix

Benchmarking Table

Modality	Cost / Power	Non-Line-of-Sight (NLOS)	Micro-movements
Passive IR (PIR)	Low Cost / Low Power	Fails at Non-Line-of-Sight (NLOS) ✗	Cannot detect micro-movements ✗
mmWave Radar	High Cost / High Power	Blocked by common materials ✗	Excellent micro-movement detection ✓
UWB Radar	Medium Cost / Ultra-Low Power	Penetrates materials (True NLOS) ✓	Highly sensitive to biological micro-movements ✓

UWB Radar Application Map

Automotive

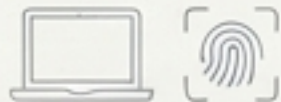


- Driver distraction monitoring
- Infant presence detection.



Secure Computing

- Biological presence detection authorising laptop wake-up protocols.



Why 3D Matters?

- Precise jump height & velocity tracking (Z-axis)
- Accurate vertical load & impact force data
- Better spatial insights and tactical analysis

2D Gameplay Map



2D Gameplay Map
Limited Z-Axis Data

Visual
Difference

3D Digital Twin



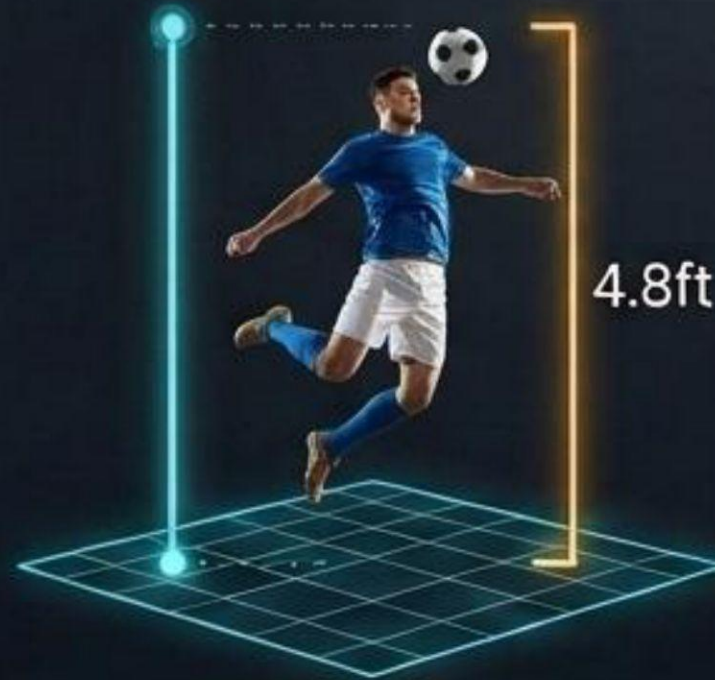
3D Digital Twin
Full Spatial & Z-Axis Tracking

Unleashing the Z-Axis Advantage

The only sensor to enable Z-Axis 3D tracking both indoors and outdoors.
Because the most critical, game-winning moments happen above the ground.



Basketball:
High Jump &
Power Dunks



Football (Soccer):
Leaping Headers &
Aerial Challenges



Volleyball:
Spiking at the Net
& Blocking

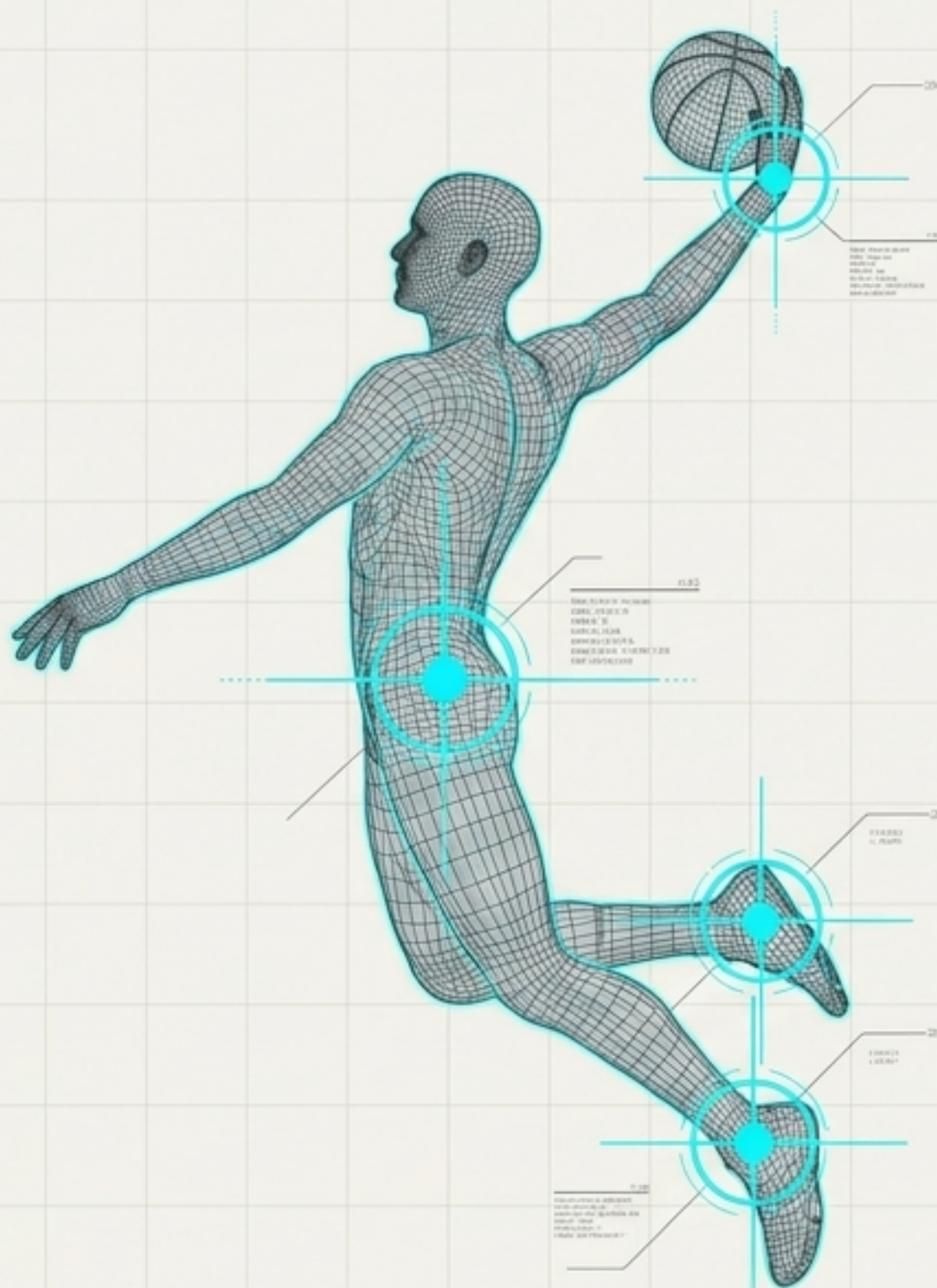


Combat Sports:
Spatial Glove Tracking
& Strike Trajectory

Applied Biomechanics: The 3D Z-Axis Imperative

The Z-Axis Imperative:
2D GPS tracking
completely misses
vertical movement.
**UWB captures the Z-
axis, unlocking
critical biomechanical
data.**

Z-Axis Data:
Vertical acceleration,
Jump Height (Δh),
Landing Force (F_v)



Sport-Specific Kinematic Nodes

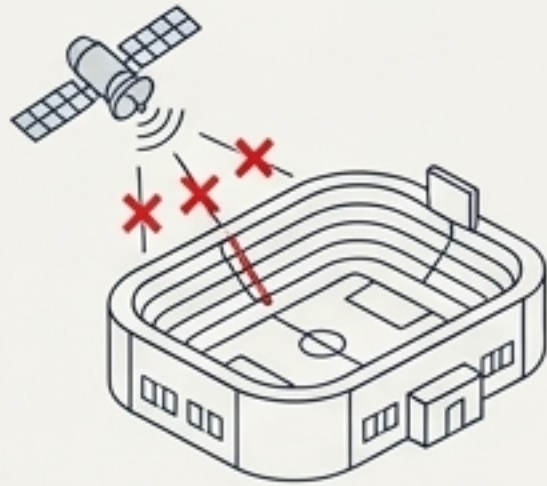
-  - **Basketball & Volleyball:** Vertical jump height, flight time, landing force (vertical load), and exact dunk/spike elevation.
-  - **Soccer:** Leaping header reach mechanics.
-  - **Combat Sports:** 3D glove trajectory mapping and punch speed vectors.

Competitive Teardown: Overcoming Physical Limitations

Catapult (GPS)

⚠ **Constraint:** Satellite dependency.

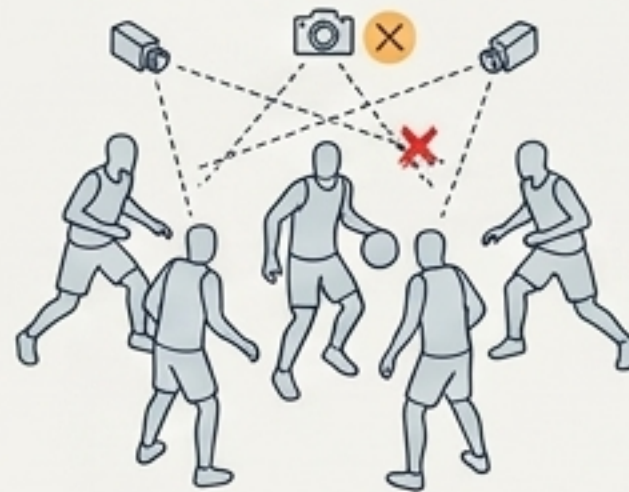
✖ **Failure Point:** Useless indoors (arenas/gyms) and loses accuracy in tight, close-quarters athletic clustering due to signal blocking.



PlaySight (Optical Vision)

⊘ **Constraint:** Camera line-of-sight dependency.

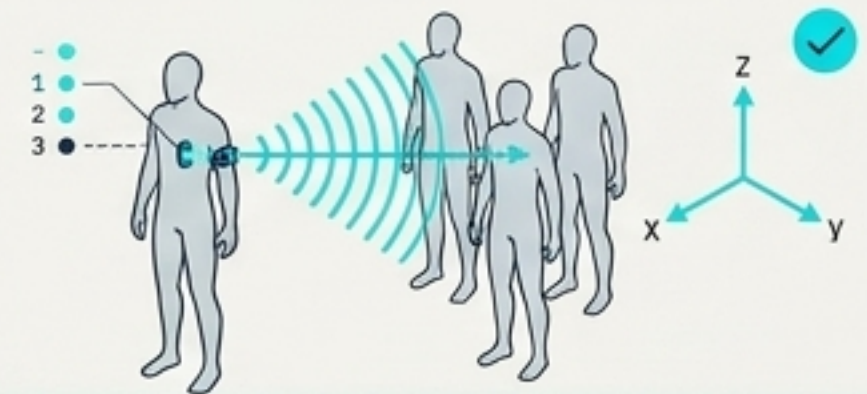
✖ **Failure Point:** Occlusion. When a player is surrounded by defenders, cameras lose the tracking node entirely.



Locus (UWB Sensor Fusion)

🤝 **Advantage:** Wearable unit fuses RF UWB tracking real-time heart rate biosignals.

👤 **Superiority:** Immune to line-of-sight occlusion. Penetrates human bodies to deliver an unbroken 3D telemetry stream indoors, regardless of player clustering.



Ultimate Wearable

10cm High-Accuracy:
Patented spatial positioning system
for micro-movement analytics.

Full 3D Z-Axis Tracking:
Capturing vertical metrics,
not just flat X-Y coordinates.



Integrated Biosignals:
Real-time physiological data
(Heart Rate) without requiring
cumbersome extra straps.

Dual Outdoor + Indoor:
Flawless transition and tracking
support between indoor
arenas and outdoor pitches.

