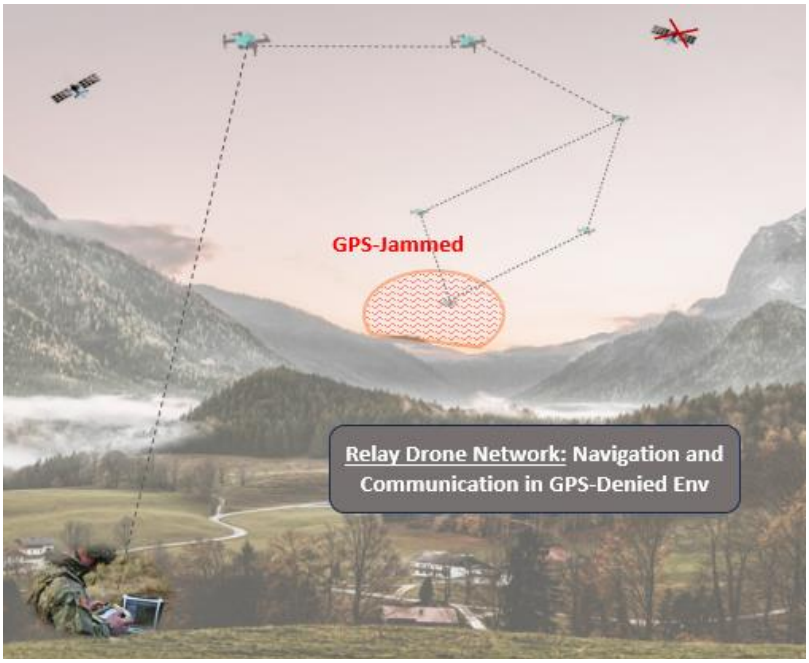
Title: **Next-Gen MANET for GPS-Free UAS Fleet Navigation**

PhasorLab has developed Self-Organizing and Self-Expanding Intelligent Mesh Communication Network based on our novel Hyper Sync Net (HSN) technology, purpose built for multi-domain, autonomous UAS fleet navigation with resilient communication capabilities. Some salient features include:

- Intelligent MANET: Hyper-Synchronized Self-Expanding Mesh with Intelligent Routing for on-demand real-time data and video streaming
- GNSS-free Navigation Capabilities: On-demand A-PNT service
- C3ISR - Command, Control, and Communication platform with flexible network architecture
- Real-time spectrum awareness, frequency agile, multiband anti-jamming capability
- Centralized C3ISR for UAS fleet deployment - UTM technology platform



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Executive Summary:

PhasorLab's Self-Expanding Mesh (SEM) network is built on our proprietary *Hyper Sync Net* (HSN) technology platform. HSN is an ad hoc mobile mesh network (MANET) that provides networkwide sub-nanosecond internode synchronization. Precise sync allows HSN to deliver precision Position, Navigation, and Timing (PNT) services without relying on GNSS assets. The HSN *Self-Expanding Mesh* (SEM) is our ground-breaking, on-demand mobile wireless solution delivering intelligent routing, high bandwidth communication capability, and an advanced Media Access Control (MAC) mechanism.

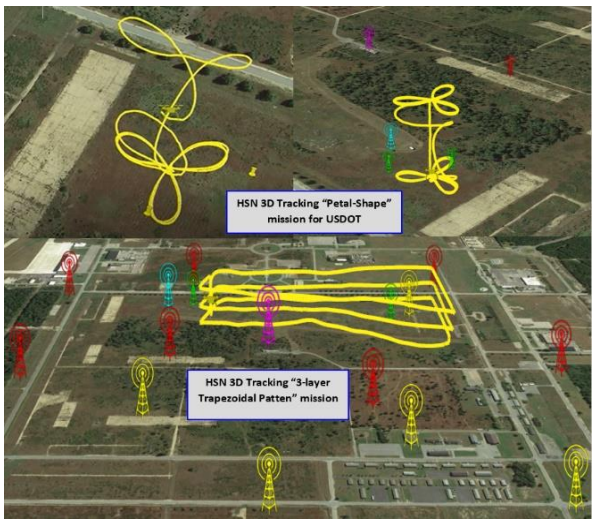


Figure 1: USDOT Drone Tracking demo, March 2021

Quality synchronization enables SEM to form highly reliable and flexible mesh networks, optimizing data throughput and creating a dynamic 3D map of the network in real-time. Leveraging HSN's PNT and SEM's Communications PhasorLab offers a robust and intelligent Alternative-PNT solution independent of GNSS, supporting real-time data, voice, video, and multi-UAS operations. PNT Intelligence makes HSN-SEM ideal for UAS fleet navigation, Intelligence Surveillance and Reconnaissance (ISR) missions as well as UAS Traffic Management (UTM).

PhasorLab's AI-enhanced sensor fusion technology further enables autonomous GPS Free navigation capabilities by combining independent sensors, such as vision, lidar, and IMU with HSN data. Designed for GPS denied or degraded environments, our HSN-based navigation system delivers distributed command and control functions, shared 3D situational awareness, and V2X communications as a mesh network or relay network. HSN-SEM enables single operator fleet deployment as well as required infrastructure for Urban Air Mobility (UAM) and UAS Traffic Management (UTM).

Figure 2: TechConnect Urban Air Mobility Award

PhasorLab has identified "Drone Relay Network for ISR missions in GPS-denied areas as a high-value military application. To address the complexities of such deployments, we're developing a single-operator system for controlling multiple drones from any network location as a unique UAS fleet navigation system. Our solution delivers UAS Command, Control and Communications (C3) data via an anti-jam, frequency-agile channel, enhanced network resiliency, and provides comprehensive situational awareness for efficient UAS fleet operations.

SEM Applications:

HSN is based on over a dozen patented and proprietary innovations with numerous high-value civilian and military applications including:

- Autonomous UAS Navigation for GPS Denied Deployment
- Self-Expanding Mesh for on-demand high bandwidth communications

- 5G precision 3D position tracking for Emergency Services, Enhanced 911 and UAS Location Verification and Redundancy
- Doppler Correction for 5G Base Station and Super Sonic communication
- Precision Wireless Timing (1588 PTP) and Synchronization for critical infrastructure
- UAS Traffic Management solution – CNS capabilities, Autonomous takeoff and landing, V2V and V2I communications

SEM as UAS Fleet/Relay Navigation System:

Figure 3: HSN Enabled (GPS-Denied) Drone Fleet rendition.

PhasorLab's Self-Expanding Mesh (SEM), powered by our Hyper Sync Net (HSN), offers a robust and efficient solution for military drone fleet deployment and control, even into GPS-denied areas. HSN's sub-nanosecond time and frequency synchronization delivers Assured Position, Navigation, and Timing (A-PNT) data, enabling submeter 3D drone position tracking and navigation. HSN's ongoing AI-enhanced sensor fusion algorithm development further improves accuracy, robustness, and reliability. Combined with HSN's low latency, 3D-mapping, space-time awareness, and low Size, Weight, and Power (SWaP), makes SEM ideal for autonomous Unmanned Aerial System (UAS) navigation.

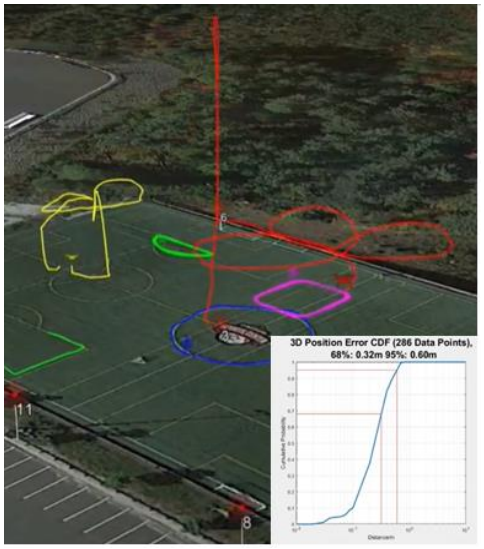


Figure 4: Multi-node tracking demo. GPS-Free UAS tracking. CDF 68%: 0.32m, 95%: 0.62m.

The SEM's advanced routing algorithm, enabled by its quad-vector system, significantly enhances network performance. By maintaining a map of its immediate neighbors, each node updates its routing table in real-time, reducing protocol traffic and minimizing bandwidth limitations. SEM efficiently handles the increased communication demands of military drone operations, including live-streaming video for intelligence, surveillance, and reconnaissance (ISR) missions.

SEM's capabilities are particularly valuable for military drone relay deployments in GPS-denied areas. As a next-generation Mobile Ad-Hoc Network (MANET) solution, SEM can establish an on-demand, self-organizing mesh network to provide reliable communication links between drones and ground stations and enables single-operator drone fleet deployment, simplifying mission planning and execution. Additionally, SEM's drones can detect GPS interference or spoofing events and report the

events geolocation information ensuring accurate navigation and situational awareness even in challenging environments.

SEM as Intelligent MANET incorporating advanced routing algorithm

PhasorLab's Self-Expanding Mesh (SEM) is an advanced Mobile Ad Hoc Network (MANET) built for military, civil and safety-critical applications such as communications among UAVs. SEM protocols are carefully engineered to provide highly reliable and robust real-time internode communication in dynamic and unpredictable environments. By leveraging proprietary high precision time distribution technology, and intelligent routing mechanisms, SEM addresses the unique challenges of MANETs, delivering highly efficient and stable communication with minimal jitter and packet loss in highly mobile, dynamic environments.

Key Features and Components

1. **Advanced TDMA Based Medium Access Control Mechanism**

A low delay and jitter, stable throughput channel access is very important for mission and safety critical MANET systems such as communications among UAVs. To provide deterministic and optimal (low delay and jitter) channel access -- even when the channel is congested, PhasorLab's SEM network utilizes TDMA based channel access mechanisms instead of CSMA. In the design of time slots, we mainly consider supporting real-time voice and video. Also, our TDMA channel access does not require GPS-based external time reference and can operate in challenging environments.

Some Key features of our TDMA based MAC protocols are

- Provides reliable access to the channel for all nodes.
- Achieves high precision clock synchronization for mobile nodes and over multiple hops in a MANET.
- Relays faster timing with minimal overhead
- Optimal time-slot reuse to support large networks

In multi-hop MANET environments, SEM's wireless synchronization algorithms combined with proprietary **Dynamic Time Division Multiple Access (TDMA) protocols** ensure robust synchronization, allowing for precise medium access control across multiple hops. This enhances the reliability of time-sensitive data exchanges, even in dynamic and unpredictable conditions.

SEM employs intelligent **slot reuse algorithm to** optimize the allocation of network resources, allowing multiple nodes to efficiently share bandwidth without causing interference.

2. **Intelligent MANET routing algorithm**

    - SEM incorporates a proprietary **Comprehensive Quad Vector Routing Algorithm (CQVRA)** as its routing engine. CQVRA performs robust and efficient routing between nodes**.** It uses custom quad vector information and link layer packet exchanges to efficiently manage node mobility, reduce routing overhead, reduce protocol traffic and ensure fast route convergence. The algorithm is designed to handle the dynamic nature

of MANETs by continuously updating the routing table based on quad vector real-time changes in the network.

- SEM's integration of the CQVRA routing algorithm significantly improves network efficiency, reliability, and responsiveness compared to state-of-the-art MANET approaches such as Babel. Similar to Babel, CQVRA ensures loop-free and starvation-free routing, but CQVRA's advanced features offer lower overhead and faster convergence. While Babel provides some resilience, CQVRA's hybrid design for the highly synchronized SEM network excels in dynamic environments.
- **Key Benefits**:
    1. **Fast Neighbor Discovery:** CQVRA is integrated into the link layer and leverages RF packet exchanges for faster detection of topology changes and neighbor discovery. This is particularly beneficial in highly mobile networks where frequent updates are required.
    2. **Accelerated convergence:** CQVRA utilizes quad vector information for real-time routing information updates accounting for network topology changes, making it suitable for highly dynamic environments. This mechanism outperforms state of the art Babel protocol's update mechanism.
    3. **Robust route discovery:** CQVRA's composite metric considers link quality, synchronization, and node rank and enables more optimal path selection compared to Babel's hop count-based approach.
    4. **Reduced Protocol Traffic and Bandwidth Optimization:** One of the key issues in traditional MANETs is the high routing protocol traffic that consumes valuable bandwidth. CQVRA reduces protocol traffic by eliminating the need for periodic multicast of entire routing tables. Instead CQVRA exchanges Quad Neighbor Map (QNM) information which is lightweight and is integrated into the link layer. This ensures that most of the available bandwidth is dedicated to mission-critical data transmission rather than control messages.
    5. **Reduced overhead:** What's up here? Is this different from 4 above?
    6. **Reliable Packet Delivery with Hop-by-Hop Acknowledgement**: This feature minimizes packet loss by ensuring each hop confirms receipt of data, creating a more reliable and fault-tolerant network.

3. Self-Healing, Self-Organizing and Self Expanding Network

- SEM protocols are designed around the decentralized architecture with no single point of failure. (this is covered in the bullet below)
- SEM self-healing and self-organization mechanisms are designed to be resilient, avoiding reliance on any central nodes. Its decentralized architecture ensures there is **no single point of failure**, providing enhanced reliability. In the event of node failures, the

network automatically heals and reroutes traffic, maintaining robust communication even in adverse conditions.

4. **Network Security**:
    - The SEM MANET maintains precise clock synchronization allowing for state-of-the-art ani-jamming techniques such as coordinated frequency hopping and spread spectrum techniques
    - SEM packet exchanges are all encrypted in link layers

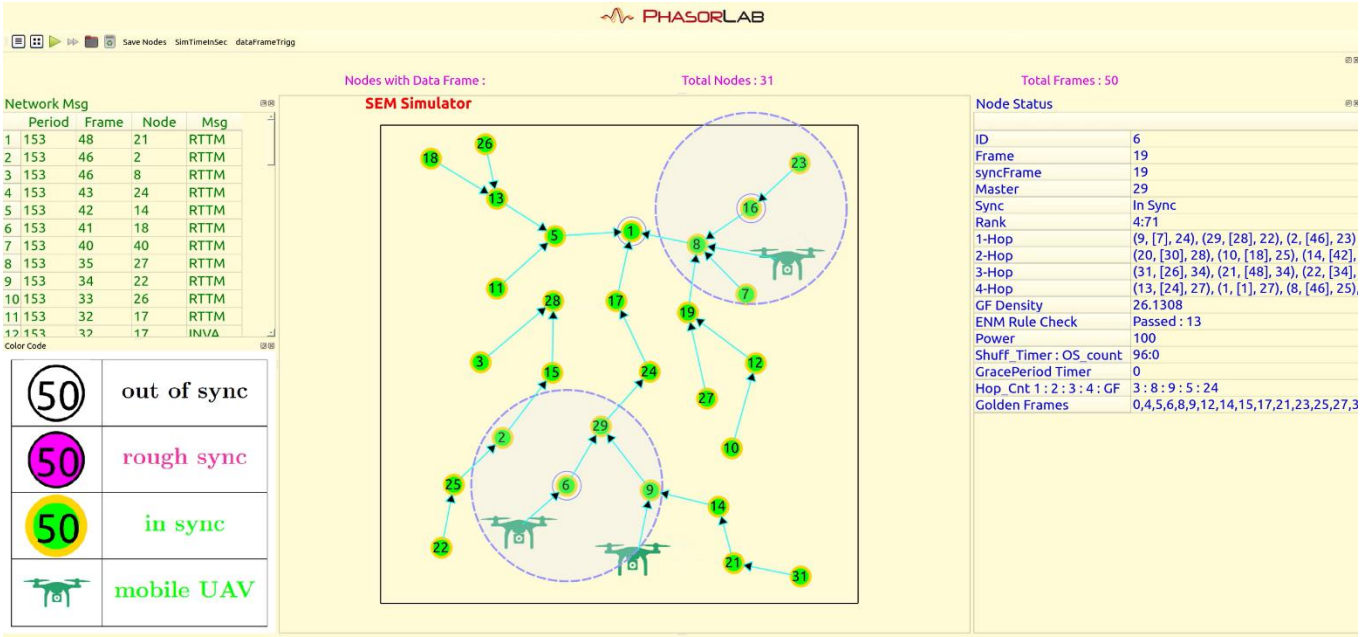


Figure 5: HSN Self-Expanding Mesh event driven simulation tool.

SEM Collaborating with 5G Network

Hyper Sync Net (HSN) is 5G network-compatible for high-precision UE tracking. Deployed as a 5G overlay, HSN delivers 3D position tracking both indoor and outdoor for emergency services, enhanced 911, personnel tracking, asset tracking and IoT applications.

Utilizing the 3GPP Rel 17 Sounding Reference Signal (SRS) scheduling feature, the 5G network configures a common cell phone to send the SRS. HSN, configured as an ad-hoc uplink SRS listen-only device allows HSN nodes to collaborate time-of-flight data and precisely locate the UE.

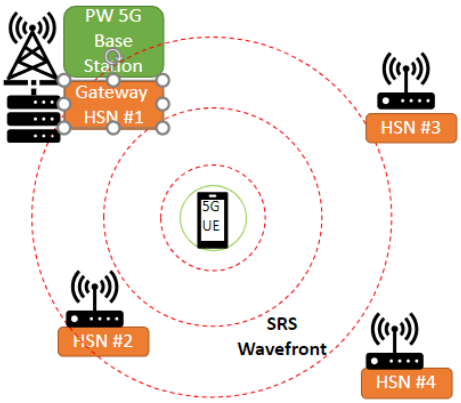


Figure 6: Indoor 5G position tracking demo setup

The high sync quality between HSN nodes, receive RF Band-Stitching and Super Resolution Delay Estimation combine to deliver enhanced position accuracy in multi-path rich environments. Indoor UE tracking results (see below) for our US Navy contract shows submeter accuracy 68% of the time in a multipath rich environment.

How it works:

a) The 5G base station sends an SRS request to the UE
b) The UE replies with SRS message at defined times
c) HSN nodes receive SRS message & measure Time Difference of Arrival (TDOA)
d) HSN network calculates UE position using Super Resolution delay estimation

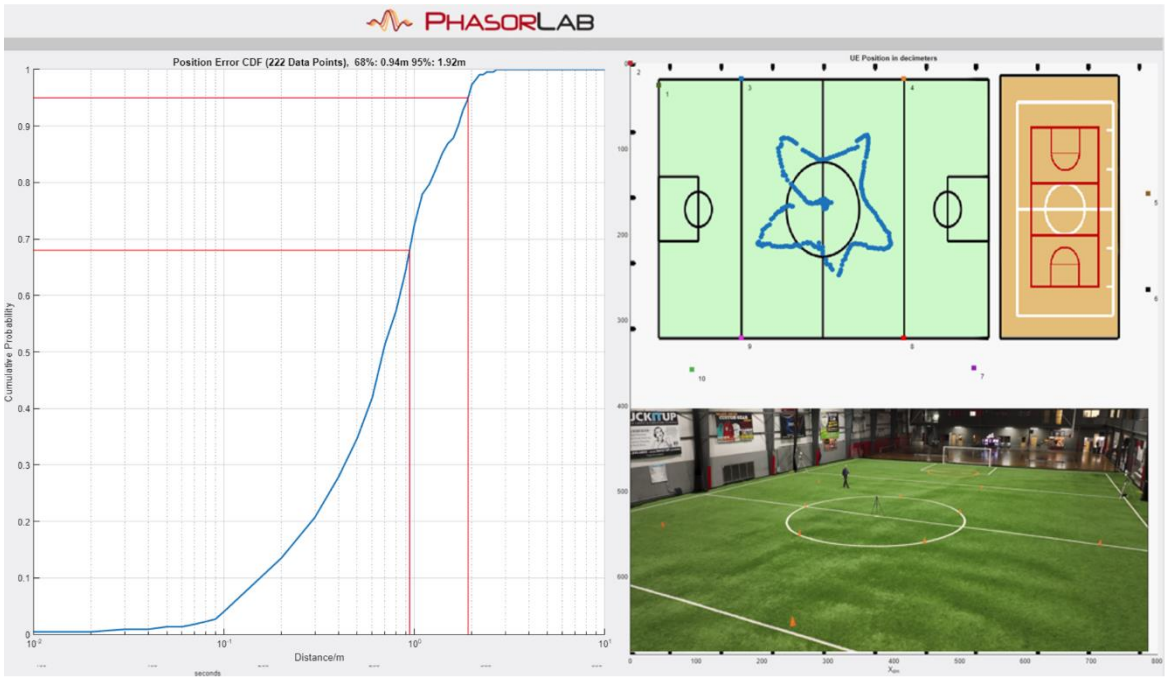


Figure 7: 5G indoor UE position tracking. Cumulative Density Function (CDF) shows 68% 0.94m, 95% 1.92m

SEM as UAS Traffic Management (UTM) Infrastructure platform

The convergence of the FAA and NASA's Unmanned Aerial Systems (UAS) Traffic Management (UTM) and Urban Air Mobility (UAM) initiatives is poised to revolutionize transportation. By addressing urban congestion, expanding accessibility, enhancing emergency response capabilities, and streamlining last-mile delivery, UAM and UTM stand to deliver significant societal and economic benefits. These include job creation, infrastructure development, and a reduction in emissions and noise pollution. The transformative potential of UAM and UTM extends across various sectors, promising a more sustainable and efficient future.

Figure 8: Vertiport rendition of HSN autonomous takeoff and landing.

PhasorLab's Self-Expanding Mesh (SEM) is an ideal vertiport solution facilitating autonomous precision UAS and Air Taxi takeoff and landing capabilities. Additionally, SEM facilitates safe BVLOS UAS and Autonomous Air Taxi operations by providing shared 3D situational awareness, resilient information sharing and data exchange capabilities including Remote ID, operator to operator, vehicle to vehicle and vehicle to infrastructure communications in compliance with both the UTM and UAM ecosystem policy and directives. Our 5G UE tracking will facilitate safe operation of any out-of-network Air Taxi or UAS provided they have 5G connectivity.

Organic PNT data enhanced by AI Enhanced Sensor Fusion (GPS, HSN, IMU, and Vision) adds critical resilience, minimizing risk of airspace conflict and enabling safe reliable UTM and UAM operation when GPS is patchy or unavailable. Advanced signal processing and Super Resolution algorithms enable robust and accurate operation in complex multipath-rich environments (for example, in and around urban vertiports). Combining Assured, Intelligent PNT, 5G position tracking with HSN Self-Expanding Mesh exceed UAM Communication, Navigation and Surveillance (CNS) requirements as well as UTM required data exchange and information architecture and shared 3D situational awareness, autonomous take-off and landing capabilities and can facilitate large-scale automation and autonomy.

PhasorLab's Ingredient Technology Introduction:

PhasorLab's Hyper Sync Net (HSN) technology is a wireless mesh network employing novel synchronization algorithms to wirelessly achieve and maintain sub-nanosecond time and single-digit part per billion (ppb) frequency sync across the entire network. The HSN mesh forms the underlying technology platform in developing our intelligent mobile Self-Expanding Mesh (SEM) network – an intelligent MANET. Our SEM network is a self-organizing, self-healing and self-expanding communication network capable of supporting real-time voice, live streaming video and other high bandwidth applications.

The SEM network architecture enables each node to maintain a *quad vector*, or map of up to its 4th hop neighbors. This dynamically generated *quad-vector* intelligence *at each node* enables real-time routing table updates (critical for mobile networks) greatly reducing protocol traffic issues that plague typical MANET implementations.

High quality synchronization enabled through our HSN technology within our SEM network is the key enabling technology for delivering Assured Position, Navigation and Timing (A-PNT) data independent of GNSS assets with far greater precision than standard space-enabled navigation systems. Some of the fundamental technology ingredients are described individually below:

- ***High Precision Carrier Synchronization Technology (HPCST)***

  High Precision Carrier Synchronization Technology (HPCST) delivers highly accurate Carrier Frequency Offset estimation down to a single-digit part per billion (ppb) from as little as a single data frame. HPCST enhances network performance, reduces Bit Error Rate (BER), and mitigates Inter-Carrier Interference (ICI) in OFDM channels. In addition, our Synchronization Algorithm, leveraging HPCST, can track precise Doppler shift, enabling high-resolution, wide-range velocity tracking between mobile nodes over a common communication channel.

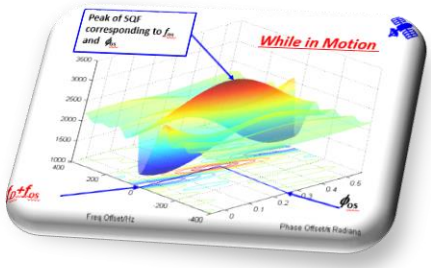


Figure 9: 3D map of the HPCST Sync Quality Function

- ***Wireless Frequency and Phase Locked Loop (WFPLL)***

  HPCST output feeds into the Wireless Frequency and Phase Locked Loop (WFPLL) which tunes the local oscillator to achieve and maintain Atomic-Clock-Level accuracy and network-wide virtual time and frequency lock, providing an alternative to traditional master-clock Hold-Over requirements.

- ***Self-Organizing Self-Expanding On-Demand Deployment***

  The HSN On-Demand capabilities are enabled by dynamic TDMA slot allocation, reuse, and power management algorithms, allowing for unlimited node deployment. Dynamic Resource Block allocation, Intelligent Routing, and dynamic routing table updates support high-bandwidth applications like live-streaming video.

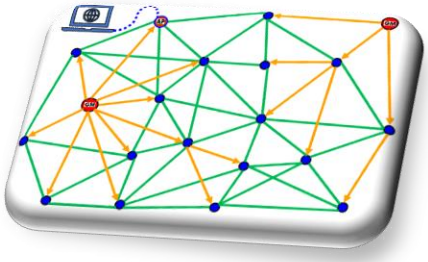


Figure 10: Hyper Sync Net Mesh rendition

- ***Super Resolution Positioning Technology***

  PhasorLab's Super Resolution algorithm employs the frequency-domain Matrix Pencil (MP) algorithm. MP is effective at distinguishing the DLOS path enabling superior TOA estimation in high multipath environments. Adding Spectrum Preprocessing and Statistical Parameter adaptation enable HSN to achieve centimeter-level positioning accuracy both indoor and outdoor.

- ***Synthetic UWB via Synchronous Band Stitching***

  HSN generates synthetic Ultra-Wide Band signal by leveraging high sync quality and frequency hopping to coherently combine or stitch RF signals received at different times on different carrier frequencies. The much wider received RF signal enables far greater positioning accuracy. Adding our frequency-domain Super Resolution algorithm significantly improves time-of-arrival (TOA) estimation accuracy and greatly reduces positioning errors both indoor and outdoor.

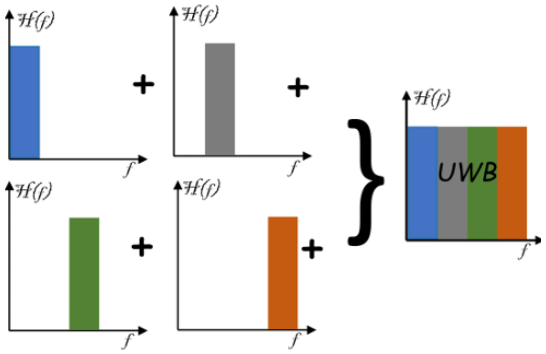
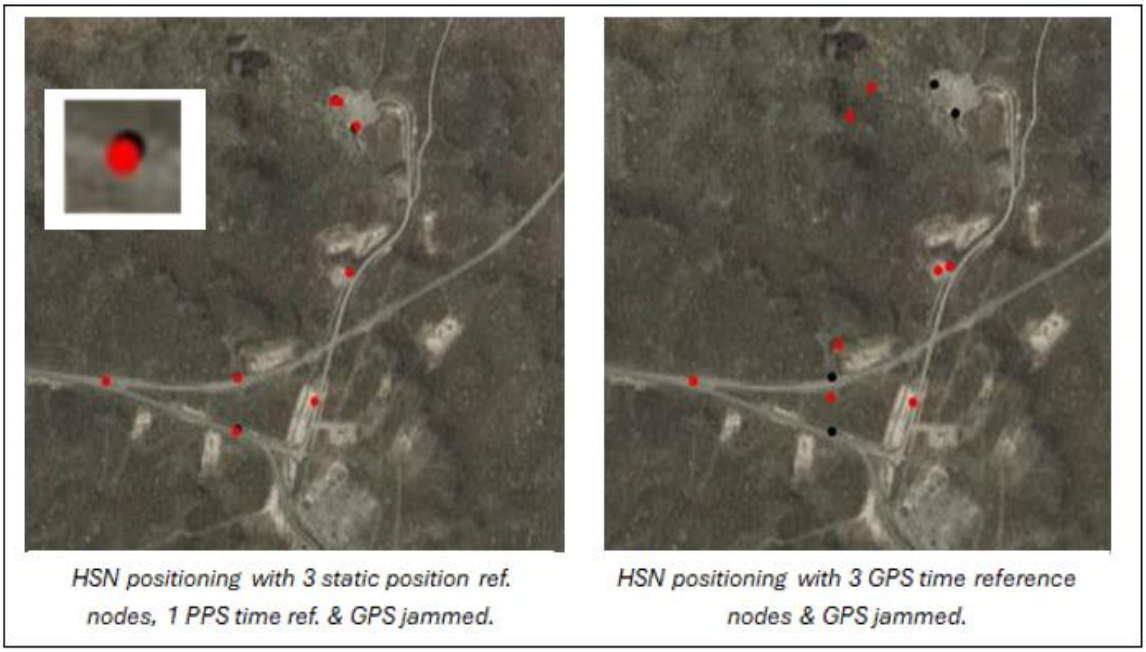


Figure 11: Synthetic Band Stitching functional diagram

Technical Validation & Demonstrations:

PhasorLab has demonstrated the Hyper Sync Net (HSN) capabilities for the past 7 years. Demonstrations include Precision Synchronization, Doppler correction, single node Angle of Arrival UAS tracking, and multimode 2D and 3D position tracking and navigation capabilities. Below are some high-profile functional demo images and summaries from numerous government, industry and military customer demonstrations between 2017 and 2024.

- 2017 DHS First Responder Jamming Exercise JAMX 17 at the Idaho National Lab, where GPS denied HSN position tracking displayed amazingly accurate results (see figure 12).



HSN positioning with 3 static position ref. nodes, 1 PPS time ref. & GPS jammed.

HSN positioning with 3 GPS time reference nodes & GPS jammed.

Figure 12: JAMX-17, Left shows red HSN position tracking of black HSN nodes using HSN internal timing. Right shows red position tracking drift using GPS timing with GPS jammed.

- 2020 USDOT Joint Base Cape Cod (JBCC) where HSN successfully demonstrated 2D and 3D position tracking as detailed in the Complementary PNT and Backup GPS Technology Demonstration Report.

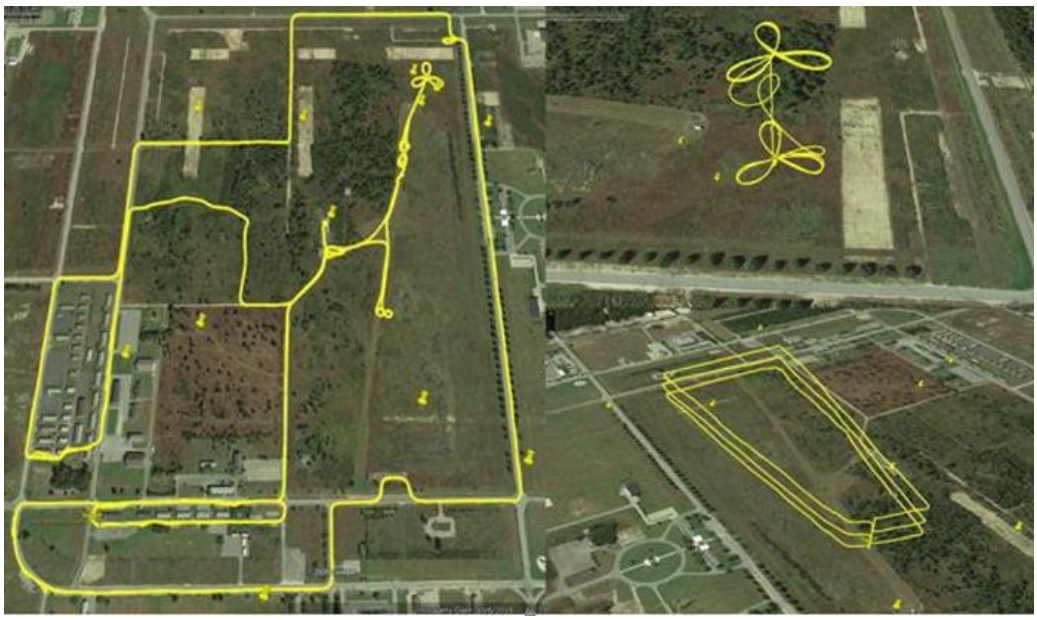


Figure 13: USDOT@JBCC, images above show both 2D and 3D position tracking.

- 2022 Air Force Phase II SBIR contract for Drone Guidance System. Demo shows HSN (red) recording decimeter level accuracy with respect to RTK (green).

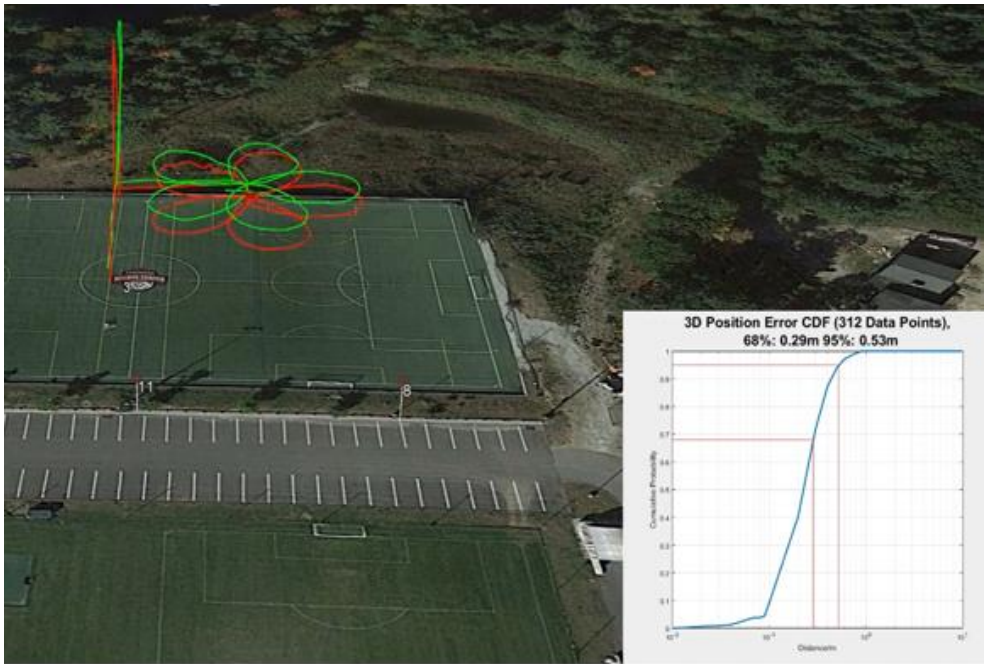


Figure 14: 3D Position-Error Cumulative Density Function (CDF): 68%: 0.29m, 95%: 0.53m. Google Earth plot comparing HSN mesh positioning data (red) and RTK data (green).

- 2022 TechConnect URBAN AIR MOBILITY INNOVATION award winner.

Figure 15: 2022 URBAN AIR MOBILITY INNOVATION award

Other notable demonstrations in recent years include:

- 2021 UK Government and British Telcom, Timing and Outdoor Position Tracking contract.
- 2022 US Navy "5G Network Enhancement Prototype" for indoor 5G UE tracking
- 2024 Phase II AF SBIR of autonomous GPS-Free UAS navigation mission (takeoff, fly, and landing) with decimeter-level accuracy.
- 2024 USSOCOM Technical Experimentation, Avon Park, FL. "Self-Expanding Mesh and Position Tracking"

Conclusion

Combining the Hyper Sync Net (HSN) frequency agile Assured PNT with the Self-Expanding Mesh (SEM) communication capabilities (Smart PNT) will transform military operational effectiveness. PhasorLab's Alt-PNT Intelligence enables:

- GPS denied UAS navigation
- GPS interference and spoofing detect and report
- Live-stream video ISR missions
- Single operator multi-drone deployment
- Anti-Jam UAS Command, Control and Communications (C3)
- CAT-1 Target Tracking
- Tactical Communications

PhasorLab's HSN PNT capabilities have been successfully demonstrated for numerous Commercial, Government, and Military customers over the past seven years. They include, DHS, USDOT, Navy, Air Force, British Telcom, USSOCOM, and the UK Govt. Our development roadmap is clear with critical applications (listed above) in our crosshairs.