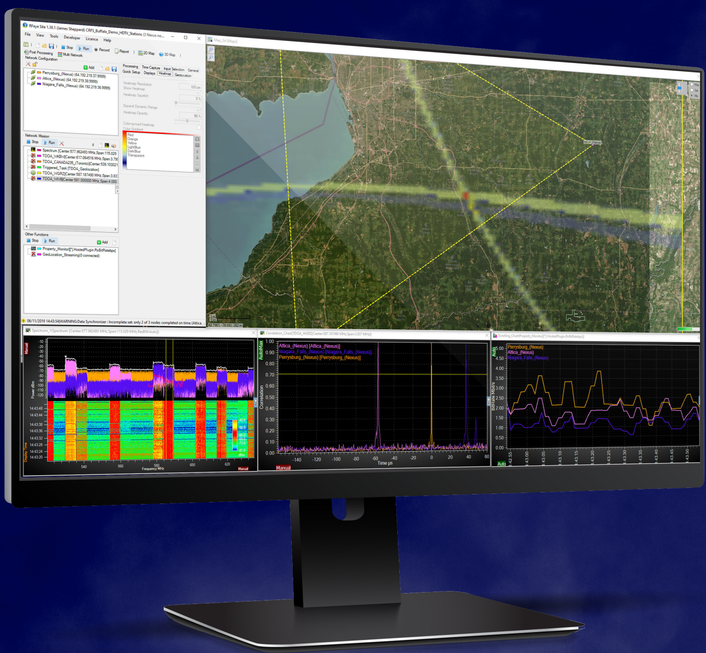
CRFS

EXTRAORDINARY
RF TECHNOLOGY



A CRFS GUIDE TO

AIRBORNE TARGET IDENTIFICATION

Passive air defense using 3D TDoA

CR-006062-MD-02

EXECUTIVE SUMMARY

CRFS' airborne target identification solution leverages cutting-edge passive RF technology to detect and geolocate airborne emitters—including commercial and military aircraft and drones—with a high degree of discrimination and positional accuracy.

By using 3D Time Difference of Arrival (TDoA) geolocation, this solution enhances integrated air defense capabilities without emitting any signals, supporting operations in emission-controlled (EMCON) environments.

The TRL-9 technology fills a critical gap in an integrated air defense 'Find, Fix, Track, Target, Engage, Assess (F2T2EA)' process.

It delivers long- and short-range surveillance, enabling forces to "see without being seen." The system can operate as a standalone capability or integrate seamlessly into broader air defense architectures, such as IADS, GBAD, and SHORAD. It is also ideal for EMCON training ranges where Opposing Forces simulate near-peer threats.

1. INTRODUCTION

Modern air defense demands the ability to detect, identify, and locate airborne threats—quickly, passively, and precisely.

CRFS' airborne target identification solution is built around advanced passive RF sensing and 3D Time Difference of Arrival (TDoA) geolocation software. The TRL-9 technology provides precise, real-time intelligence for airborne target identification, spoofing detection, and signal identification.

It enables long- and short-range detection of aircraft and UAVs without revealing the sensor's position—supporting operations in emission-controlled (EMCON) environments and enhancing survivability.

Detection results can be displayed in multiple formats to visualize signal type, strength, and range. Users can identify specific emitters, track changes over time, and build a comprehensive RF intelligence picture. Data can be viewed in real time and integrated into existing command and control (C2) systems.

This guide outlines the technical capabilities, architecture, and deployment flexibility of CRFS' airborne target identification solution. It demonstrates how passive RF sensing can fill critical gaps in the air defense kill chain—from wide-area detection to precise geolocation—while supporting interoperability with modern defense infrastructure.

2. SYSTEM DESCRIPTION

CRFS' airborne target identification solution includes a minimum of four RFeye Node 100-18 units (frequency range up to 18 GHz), RFeye Site (real-time spectrum monitoring and geolocation software with 'pulse detector' and '3D TDoA' licenses), and RFeye Mission Manager (automated spectrum monitoring and mission management software). This hardware and software combination supports advanced passive detection and geolocation of airborne emitters.

3. CRFS SPECTRUM MANAGEMENT SYSTEM ARCHITECTURE

CRFS' airborne target identification solution provides the following core capabilities as standard:

- **Spectrum monitoring from 10 MHz to 18 GHz:** Users can monitor the RF spectrum to detect emissions from airborne platforms, including COTS UAVs, modified or military drones, and other drones of interest. The system allows users to set up alerts, record I/Q data in high fidelity for post-processing, and geolocate airborne emitters.

- **Passive detection and geolocation of airborne emitters over time:** Users can detect and geolocate an unlimited number of airborne emitters in three dimensions. Generic and pre-set detectors are included for:

  - TACAN/DME
  - ADS-B (decoded information and signal)
  - Tactical data links

- **A user-defined detector for any pulsed signals** emitted from 10MHz to 18 GHz (for example, from a COTS or non-standard UAS (telemetry signal or video downlink signal), DMR, TETRA, dPMR, SSR, SRE, UHF-L Band SAR, Have Quick, AM, FM, etc.)
  - Continuous/static signals
- **ADS-B spoofing detection:** This feature determines the geographic error (X, Y, Z) between the decoded ADS-B position and the geolocated ADS-B position. Large error rates indicate a possible spoofing event or enemy military deception. Users can set error rate limits to help manage false positives.
- **Coverage area:** This depends on the baseline network configuration. In CRFS' 3D TDoA network, RF sensors are spaced 75 km apart, enabling reliable detection of emitters up to 400 km away and at altitudes of up to 30,000 feet. The system provides full azimuth coverage (360 degrees) and elevation coverage from 0 to 90 degrees.
- **Operator Requirements:** Requires 1x operator; however, many functions can be pre-programmed, tasked, and automated.
- **Altitude:** Ground level to 50,000 ft+
- **Airspeed:** Stationary to Mach 1
- **Frequency range:** Spectrum monitoring and 3D passive detection of airborne RF emitters within a frequency range of 10MHz to 18GHz
- **Comprehensive simulation and training system:** The software includes the capability to simulate system performance by incorporating all RFeye Nodes, terrain, and multiple aircraft with configurable emitter geolocation data over time. This allows users to build a comprehensive intelligence picture, such as tracking ground-based movements or airborne flight profiles, including drones and their direction of travel. The feature enables end users to create, store, and repurpose an unlimited number of scenarios.
- **Propagation modeling tools:** The software allows users to determine sensor coverage areas and predict geolocation uncertainties based on location and altitude. Modeling tools support air defense Concept of Operations development and mission planning by simulating the impact of new or relocated RFeye Nodes and identifying optimal locations for additional sensors (to enhance detection and geolocation coverage).
- **Installation support and training:** The proposed solution includes five days of dedicated system integration and support. It also includes a hardware warranty, no-cost software license updates, and online and telephone technical support for 24 months. Further long-term support can be provided within dedicated projects and annual or multi-year support contracts. Additional training is also available.
- **GPS Holdover during GNSS jamming:** All RFeye Node 100-18 sensors can be equipped with GPS Holdover devices that provide accurate timing to within 1.5 μs for over eight hours. There is an automatic switch between GNSS and the Holdover module. Fast track (GNSS fix) is activated within minutes of power-on, achieving Holdover stability after a seven-day training period with an uninterrupted GNSS lock. The system is multi-GNSS and can intake GPS, Galileo, and GLONASS.
- **Easy installation, set-up, and operation:** COTS-optimized RFeye technology is easy to connect and install and does not require recalibration.
- **Networked for multiple users and missions:** Multiple users have multi-mission capabilities and can fully manage central or permission-based airborne target identification operations.
- **Flexible deployment options:** The RFeye Node 100-18 sensors selected in this proposal will be supplied as Mini Outdoor Kits. All RFeye Nodes can be interconnected through a mesh network including fiber, point-to-point datalinks, and 4G+. The RFeye Nodes act as intelligent RF sensors with in-built edge processing and reduced backhaul data bandwidth.

4. **3D TDoA EMITTER GEOLOCATION**

Standard passive RF geolocation uses the 2D TDoA (Time Difference of Arrival) method, requiring a minimum of three RFeye Nodes. When a fourth RFeye Node is added, emitter locations can be determined in three dimensions (longitude, latitude, and altitude). CRFS uses this technique in its airborne target identification (passive air defense) solution.

The solution allows operators to hunt across a wide and congested spectrum (or airspace) with dedicated signal detectors that discriminate specific signals of interest hundreds of kilometers away from the RF sensor network.

Detector-based 3D TDoA achieves airborne target identification with a high degree of discrimination and positional accuracy. The link below provides further information on:

- Passive EW systems and signal detectors
- Key 3D-TDoA principles
- Sample-based TDoA geolocation
- Geolocating aircraft using 3D-TDoA
- Detector-based sensing

Figure 1 (below) is a screenshot from CRFS' Buffalo network (on the US-Canadian border) showing real-time geolocations of commercial aircraft over time. The four RFeye Nodes (75km apart) are located at the points of the triangle. The fourth RFeye Node is located in the center to enable 3D-TDoA.

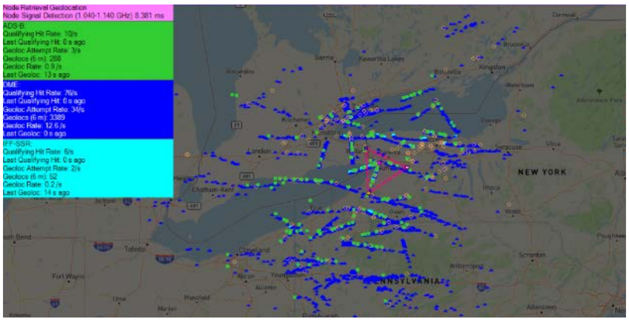


Figure 1: TDoA emitter geolocation in three dimensions

The geolocation uncertainty for a typical TDoA system is affected by RF sensor time reference uncertainty; TDoA RFeye Node network placement; and local geography, emitter altitude, emitter signal strength, and type of emitter signal.

CRFS conducted a trial using is proprietary RFeye Node network located in Buffalo, New York. To assess geolocation accuracy, the trial used commercial aircraft broadcasting 1,090 MHz ADS-B (Automatic Dependent Surveillance Broadcast) transponder signals. Over a 48-hour period, aircraft in the Buffalo airspace were monitored, with RF energy from their transmissions analyzed to gather airborne target identification and geolocation data over time. Ground truth and system accuracy were established by decoding ADS-B signals, which included GPS location, altitude, and airspeed.

The results demonstrate the 3D-TDoA software module's ability to accurately detect, acquire, and geolocate airborne emitters with high positional accuracy and discrimination. The solution provides rapid location updates and can calculate airspeed by analyzing and processing consecutive geolocation fixes over time.

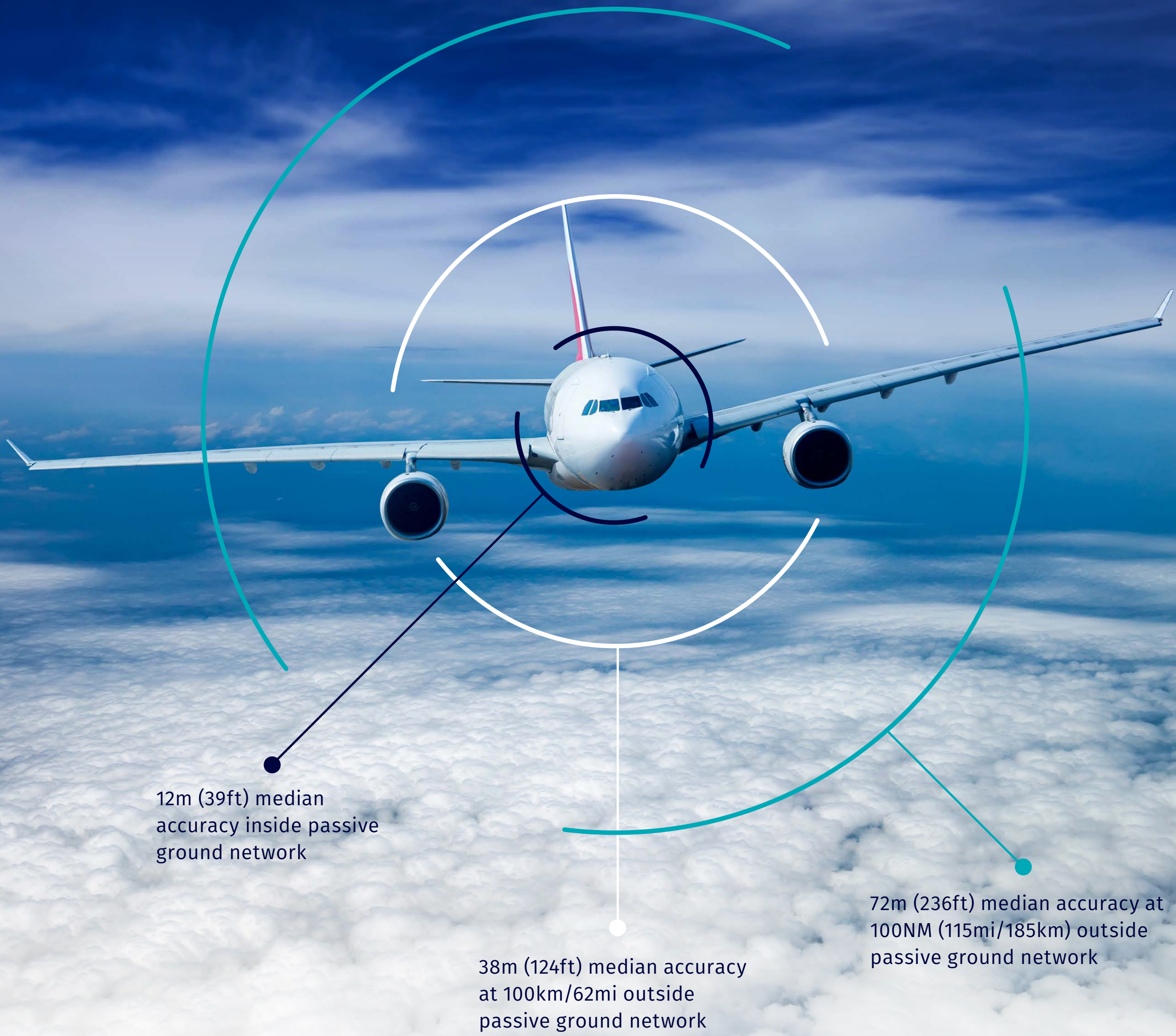
In this test, the 3D-TDoA software demonstrated high accuracy, even when geolocating airborne emitters far beyond the RF sensor's 75 km baseline. As expected, accuracy decreased with distance from the network, but errors remained under 500 meters even outside the network boundary. Notably, aircraft emitters were successfully detected and geolocated up to 400 km from the nearest RFeye Node.

5. CRFS AIRBORNE TARGET IDENTIFICATION ACCURACY

CRFS has demonstrated the capabilities of its Buffalo network in live trials, with detailed accuracy data provided in Section 4 of this document. Through repeated testing, over 100,000 aircraft ADS-B transmissions were captured across New York state and the US-Canadian border airspace. These tests collected real-world airborne target identification data, evaluated system performance, and validated expected accuracy. Based on the Buffalo network's setup, terrain, and operating parameters, the following results were observed:

At a 75 km range, the system demonstrated an accuracy of 16 meters (95% confidence level) in range (roughly equivalent to half a Boeing 747-8 tail span), and 70 meters (95% confidence level) in altitude.

At a 100km range (with a 75km RF sensor baseline), the system achieved an accuracy of 72 meters (95% confidence level) in latitude and longitude, comparable to the fuselage length of a Boeing 747-8 intercontinental aircraft traveling at speed.



6. RFEYE 3D TDOA INTEGRATION INTO INTEGRATED AIR DEFENSE NETWORKS (IADN) AND GROUND-BASED AIR DEFENSE (GBAD)

RFeye Site software controls the deployed RFeye Nodes (RF sensors) and enables data streaming into air defense Common Operating Pictures (COP), Recognized Air Pictures (RAP), and GBAD GUIs. RFeye Site software enables real-time spectrum monitoring and geolocation data streaming output over either TCP or UDP in the following formats:

- ASTERIX (used by Eurocontrol and NATO)
- Google Protocol Buffer

In addition, geolocation data can be saved and exported in the following formats:

- CSV
- KML
- Protocol Buffer structured Data Stream (PBD)

The entire system can be controlled and managed through open-source APIs and integrated into a large IAMD or GBAD system.

CRFS APIs incorporate five key features to enhance usability, efficiency, and effectiveness across integration and communication of RF intelligence (not just data):

RESTful APIs use standard HTTP methods making them easy to understand and use. They are highly flexible for web services and applications.

JSON open data format is universally recognized and understood, allowing interoperability between different systems and platforms.

Event streams for real-time data processing and notifications.

Multi-functional allowing users to request multiple tasks in parallel to meet multiple and complex mission objectives.

Well-documented, clear schemas allow easy integration.

CRFS' synchronous task API (GMP) supports (i) sweeps, (ii) sample-based TDoA and 3D-TDoA, Angle of Arrival (AoA), Power of Arrival (PoA), and detector-based TDoA and 3D-TDoA. It plays a crucial role in managing complex, coordinated efforts vital in advanced spectrum monitoring and real-time geolocations, including 3D-TDoA applications.

7. ELEMENTS COMPRISING THE FULL SOLUTION

RFeye Node 100-18: CRFS' most popular RF sensor is a portable, rugged, high-performance sensor for wideband spectrum monitoring and geolocation of transmitters up to 18 GHz.

The RFeye Node delivers superior RF performance, featuring excellent phase noise, a low noise figure, and exceptional spurious-free dynamic range. With intelligent in-built edge processing, these sensors can sweep up to 390 GHz per second (at 2 MHz resolution bandwidth), enabling the capture and analysis of even short-burst transmissions and transient events.

With advanced signal intercept capabilities, a 100 MHz IBW for wideband RF monitoring, and a high probability of intercept, this sensor is ideally suited for airborne target identification and as a component in 3D-TDoA air defense network subsystems.

Each RFeye Node operates autonomously and is directedly IP addressable without the need for a local computer or any support other than an Ethernet network connection and power.

Multi-stage pre-selection filtering and intelligent AGC support superior signal extraction and processing of very low-power signals. Three RF input ports allow the comparison of signals from different antennas and support direction finding. Timing and synchronization features allow data correlation between multiple modules with a high degree of discrimination and positional accuracy, enabling TDoA and reliable 3D-TDoA.

RFeye Node Plus 100-18: Adding an RFeye Node Plus to a sensor network will significantly enhance the network's capabilities. As the RFeye Node Plus has a next-generation processor, it can run detector missions 3 to 4 times faster than standard RFeye Nodes, meaning there will be a higher POI and an enhanced 3D TDoA result due to the increased computational power.

The RFeye Node Plus can also record and stream I/Q data while the rest of the network continues running real-time signal detectors and TDoA calculations, ensuring uninterrupted RF intelligence operations.

Deployment options: RFeye Nodes can be flexibly deployed, depending on the mission's requirements.

- CRFS' small, compact, and flexible outdoor mounting kit can be used to attach RFeye Nodes to masts, towers, or buildings
- RFeye Nodes can be integrated into manned vehicles
- Unmanned systems (USVs, UGVs, UAVs) can be integrated with an RFeye Node as a payload.

RFeye Site software: Software for real-time spectrum monitoring and geolocation during electromagnetic spectrum operations (EMSO). This advanced desktop application software toolkit provides all the functionality needed for full spectrum operations; it turns data into RF intelligence.

Features include: real-time spectrum visualization, geolocation (PoA, AoA, TDoA, 3D-TDoA, hybrid), airborne target identification monitoring, I/Q data (capture, stream, visualize), propagation modeling, simulation and RF training module, spectrum overlays, measurements, and data streaming.

Operators can customize to their application requirements and run monitoring and geolocation tasks in parallel.

The software includes real-time spectrum sweeps, maps, graphs, and visualization via interactive charts.

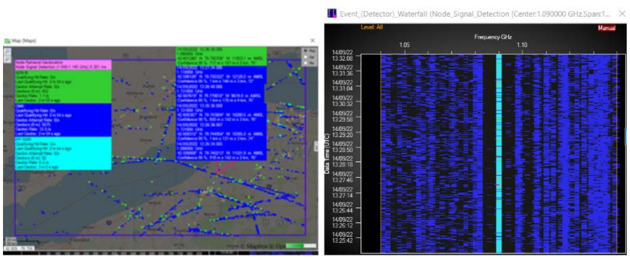


Figure 3: Multiple air target TDoA (including frequency hopping signals), processing, decoding, and display of ADS-B, TACAN, and IFF

Airborne target identification data can be overlaid on GPS-referenced 2D and 3D map views. The software integrates AoA and TDoA geolocation data to refine results and supports importing digital terrain data in various formats, including SRTM and LIDAR. Users can create and customize geofences around Critical Asset List (CAL) and Defended Asset List (DAL) locations or other designated assets, enabling alarms and alerts for specific operating parameters or events. This functionality enhances rapid decision-making and actionable intelligence.

RFeye Site software can geolocate frequency-hopping signals and identify signal characteristics within other signals using advanced filtering, signal interception, detection, and CRFS' "Signal Discovery" tools. Automation enhances these capabilities, enabling efficient signal isolation and analysis.

RFeye Site software provides a powerful and dynamic spectrum analyzer interface for real-time interaction with each RFeye Node and supports advanced geolocation within your monitored airspace.

RFeye Mission Manager software: For automated spectrum management and near-time incident reporting. This software is designed to allow operators to automate tasks, missions, sweeps, and alerts of missions they have set up in RFeye Site.

This desktop application was created for non-technical and non-RF experts, enabling them to easily view, run, and manage complex airborne geolocation missions with automation and efficiency. It supports multi-mission, multi-user, and permission-based operations 24/7/365.

Operators can intuitively plan, schedule, automate, and manage monitoring, detection, and geolocation incidents. The software provides clear views of the RF environment, powerful visualization tools, customizable operating zones, geofencing, and incident configuration. It also includes alerts and alarms tailored to specific mission requirements and operating parameters.

Simulated 3D detection and modeling: Operators conducting airborne target identifications are encouraged to use CRFS' simulation module to optimize RFeye Node placement and modeling. At higher frequencies, RF propagation characteristics can limit the number of RFeye Nodes capable of detecting a distant emitter. Therefore, it is crucial to distribute multiple RFeye Nodes across the detection and geolocation range for effective coverage. Figure 4 (below) shows the results of this type of analysis, which is a recommended component of the consultation, scoping, and setup process outlined in Section 1 of this document.

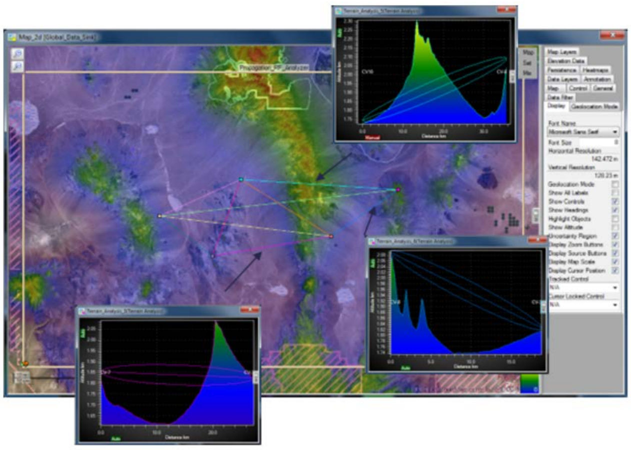


Figure 4: Simulated 3D passive detection and RFeye Node placement modelling

8. CONCLUSION

CRFS airborne target identification solution using 3D TDoA (Time Difference of Arrival) can be tailored to meet a customer's specific operational requirements. Developed through a consultative, mission-tailored process, this solution can operate independently or integrate into broader air defense systems, including Integrated Air Defense Systems (IADS), Ground-Based Air Defense (GBAD), and Short-Range Air Defense (SHORAD). It also supports training and simulation environments where Opposing Forces replicate near-peer threat profiles.

Validated through extensive field trials—including live deployments across the US-Canadian border—the solution has demonstrated high geolocation accuracy even at ranges beyond 100 km. With flexible deployment options, modular architecture, and proven integration with leading defense systems, CRFS' solution offers unmatched capability in passive airborne target identification.

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CRFS is an RF technology specialist for the defense industry, national security agencies, and systems integration partners. We provide advanced capabilities for real-time spectrum monitoring, situational awareness, and electronic warfare support to help our customers understand and exploit the electromagnetic environment.

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