Flight Test Configuration of the Sensor Payload and the Ground Nodes in Distributed Sensing Frameworks

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NASA Ames Research Center (ARC): Intelligent Systems
Autonomous Systems – Distributed Sensing

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Outline

1. Introduction
2. Hardware Architecture
3. Communication Framework
4. Software Architecture
5. Test Setup
6. Conclusion

Objective

- **Objective:** Fulfilling the goal of Urban Air Mobility (UAM) with Distributed Sensing (DS).
- **Functionality:** Environmental sensors as active agents for sensing, processing, and communication, creating a "smart space" for real-time autonomous control.
- **NASA Ames Research Center (ARC):** Conducted indoor and outdoor flight tests to gather data for UAM actualization.
- **Paper Highlights:**
  - Configuration of payload and ground nodes.
  - Sensor node communication framework.
  - Overview of sensor placements.
  - Briefing on different indoor and outdoor tests.

Distributed Sensing

- **Operational Challenges:**
  - Traditional systems are impractical for AAM operations.
  - AAM demands higher accuracy than the current Airspace System.
  - GPS is unreliable in urban areas with tall structures.
- **Distributed Sensing Solutions:**
  - DS ensures real-time monitoring throughout the flight.
  - Establish a framework for diverse sensors and remote observations.
  - Tackle sensor drop-outs effectively.
  - Ensure persistent, high-quality estimates across observations with continuous quality evaluation.

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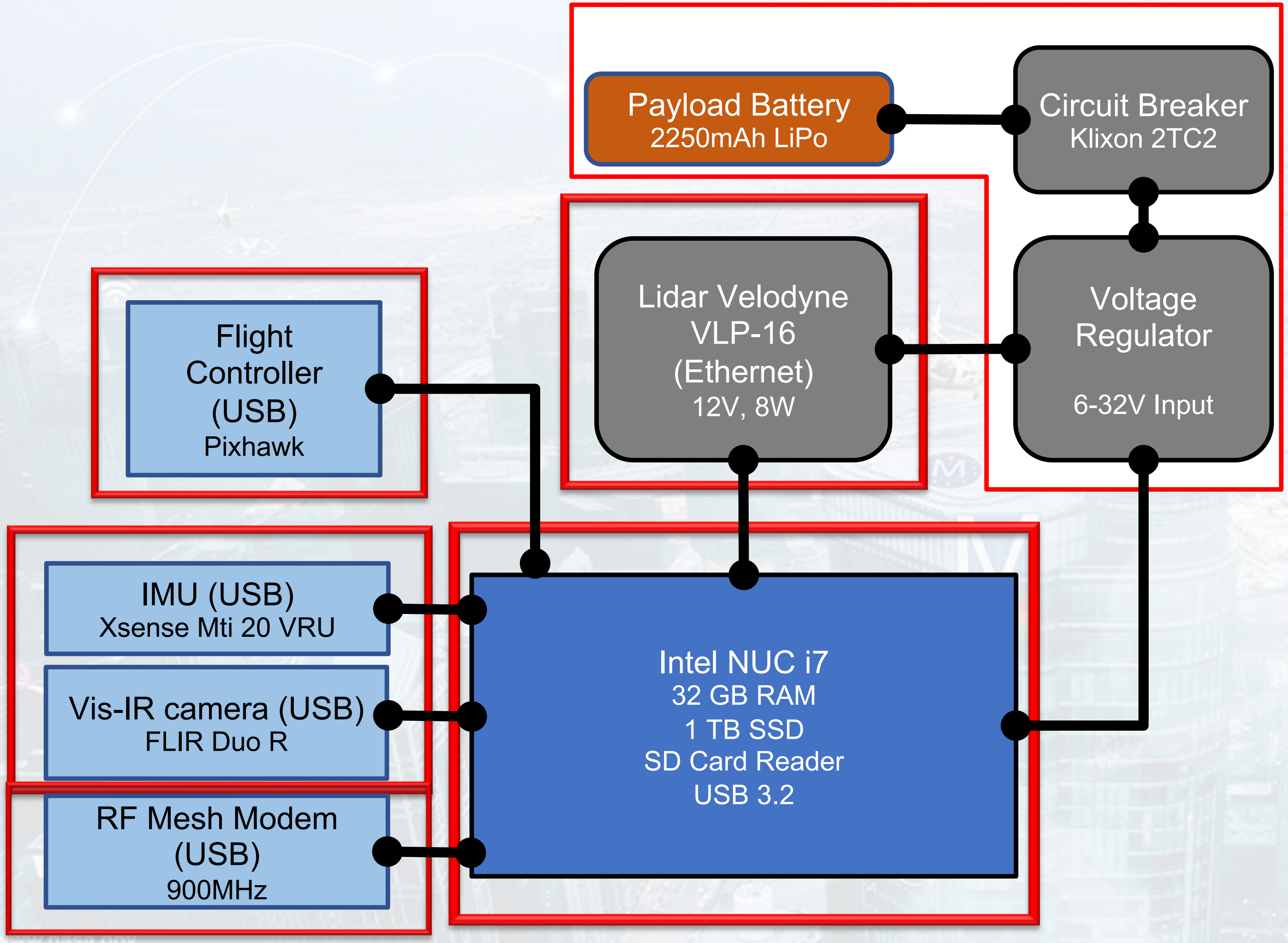
PAYLOAD BLOCK DIAGRAM



AERIAL VEHICLE
FREEFLY ALTAX GEN 2.1

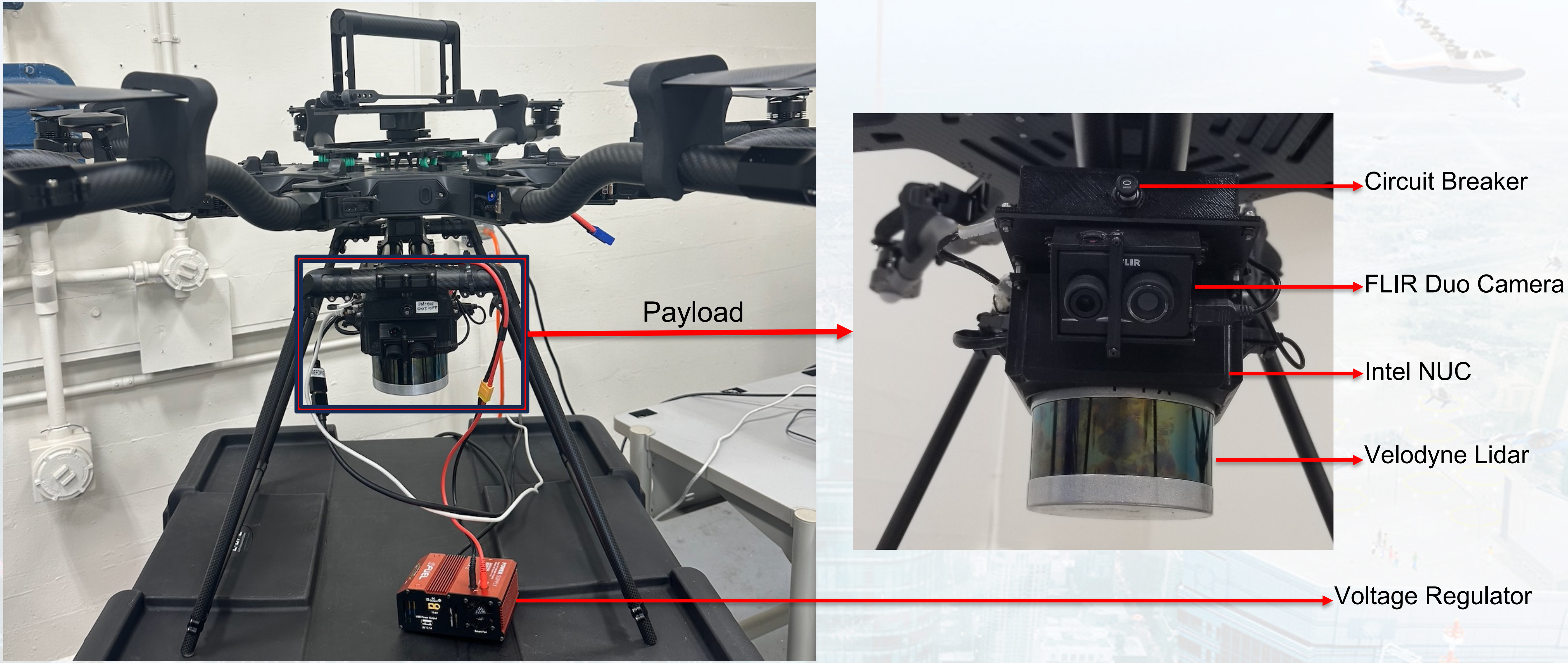
CPU UNIT

SENSORS

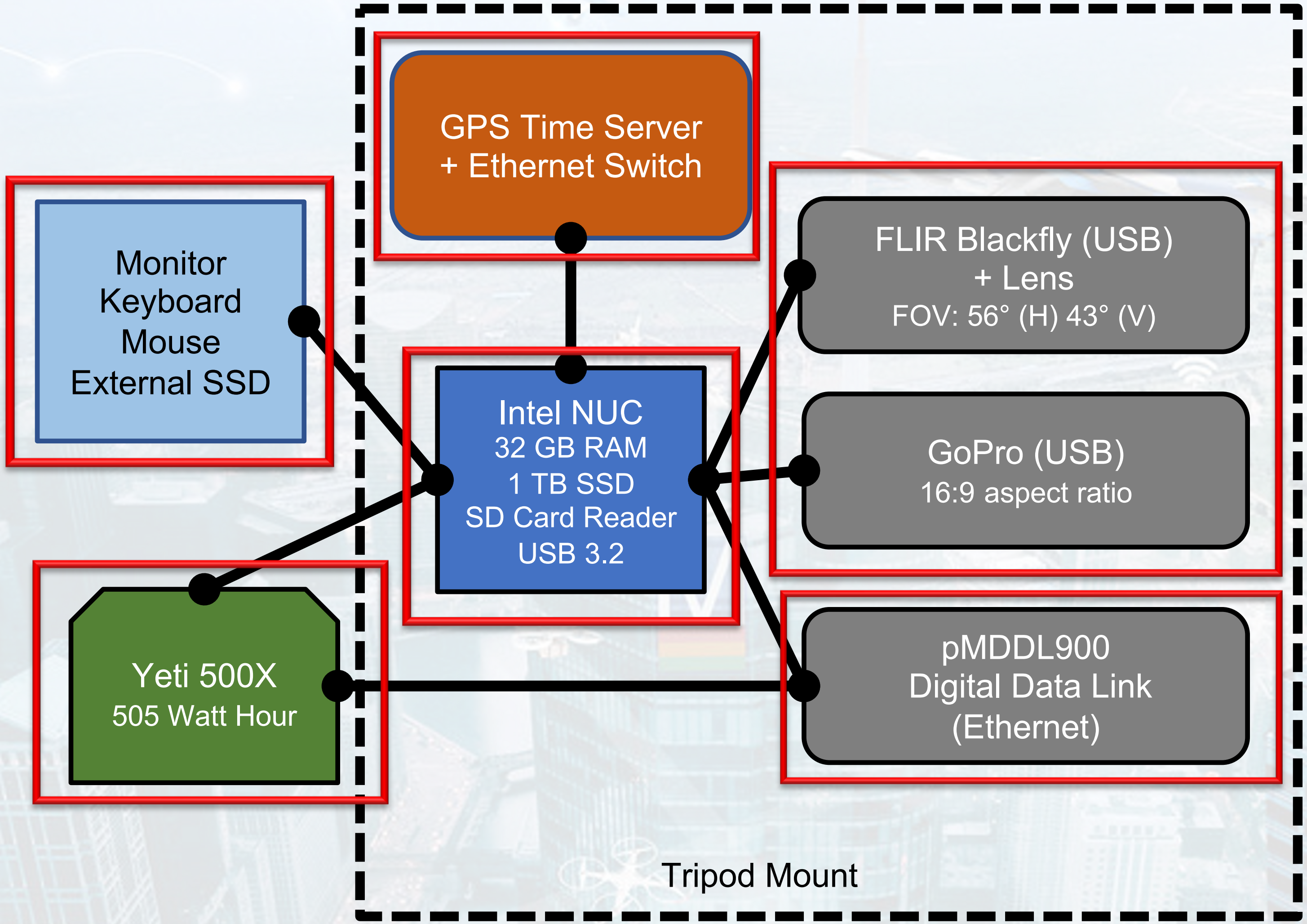
COMMUNICATION LINK

POWER SYSTEM

PAYLOAD


Payload
Circuit Breaker
FLIR Duo Camera
Intel NUC
Velodyne Lidar
Voltage Regulator

BLOCK DIAGRAM – CAMERA GROUND NODE

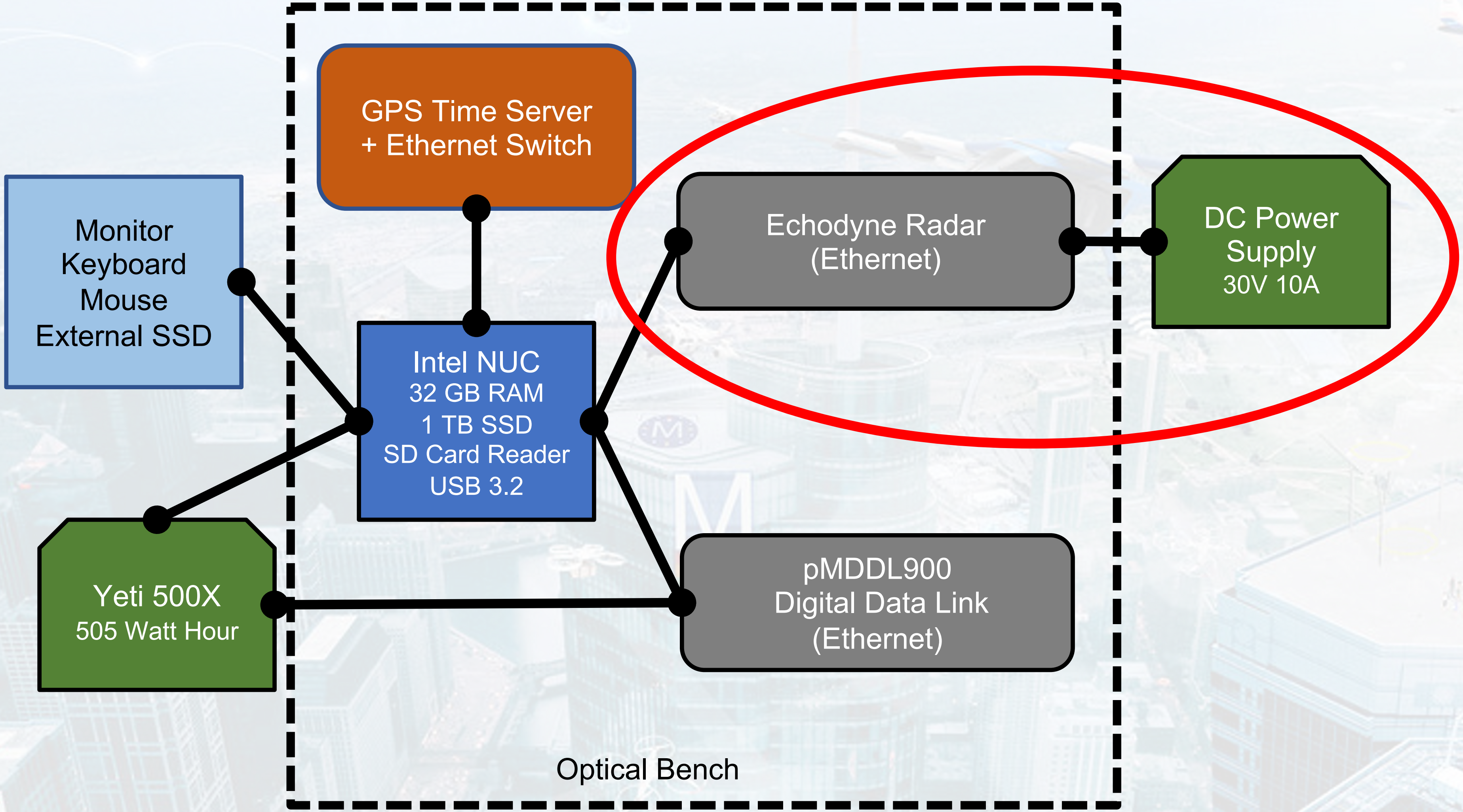


ONGOING INSTALLATION

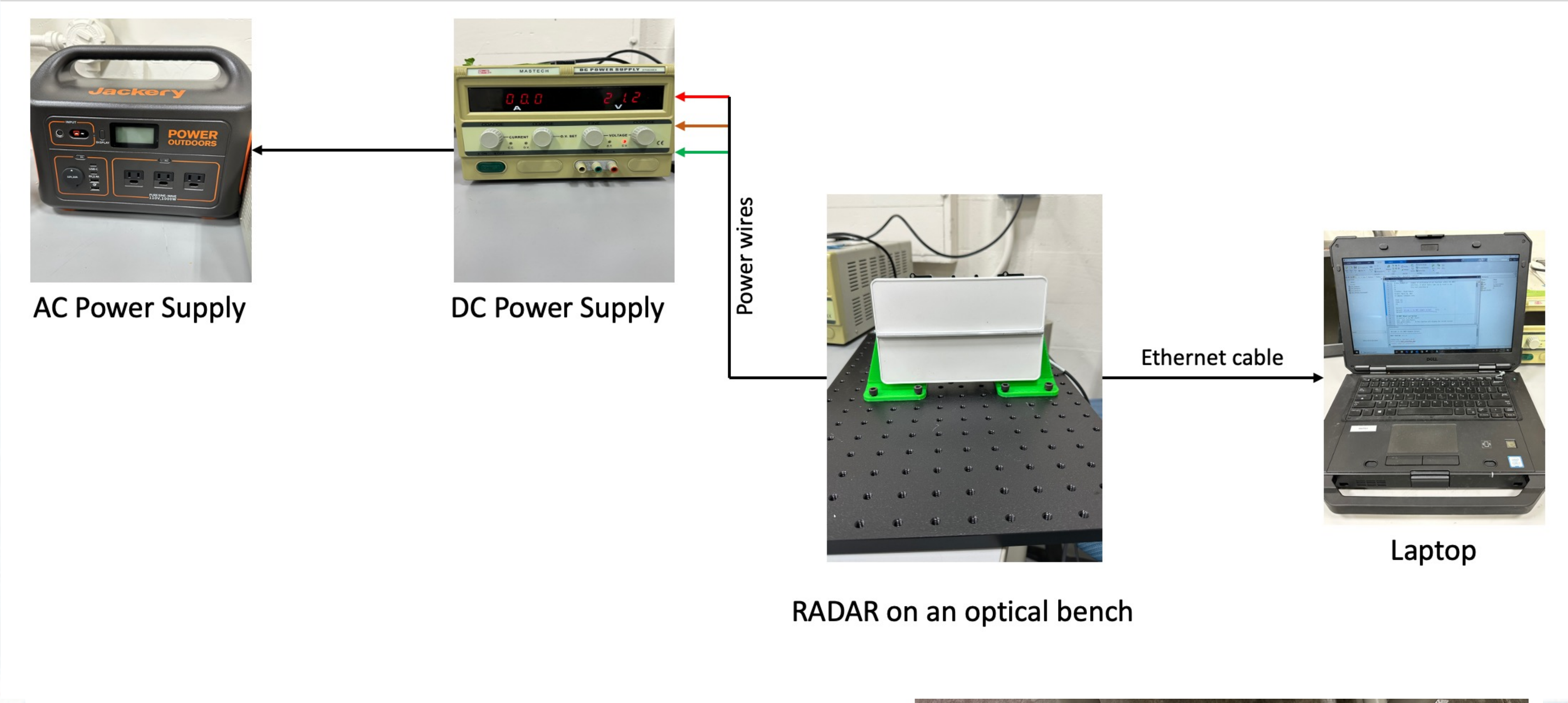
- Inclusion of FLIR Boson 320 IR camera and the MicaDense RedEdge-MX multispectral camera

CAMERA GROUND NODE

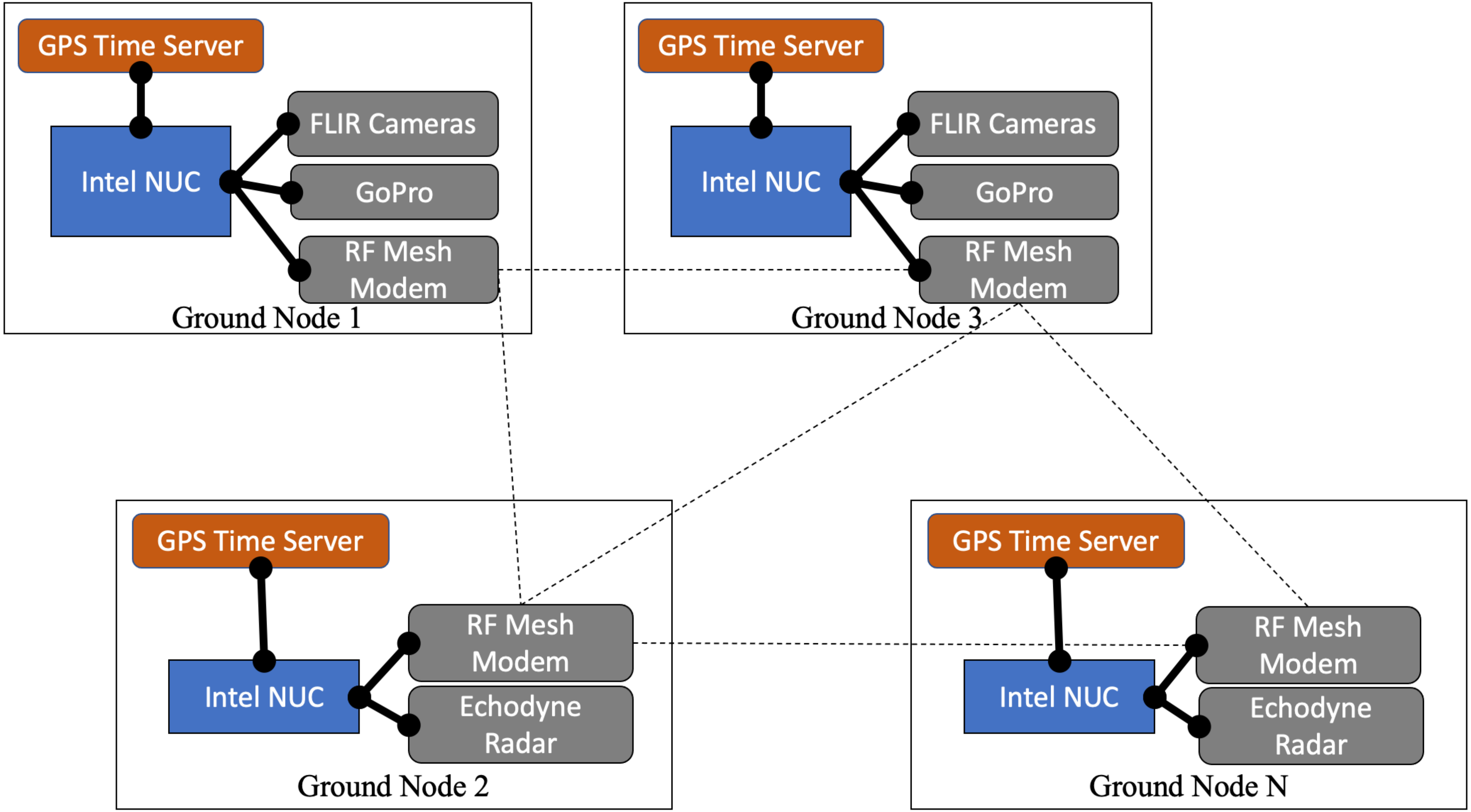
BLOCK DIAGRAM – RADAR GROUND NODE



RADAR GROUND NODE



MULTIPLE GROUND NODES



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MESH ARCHITECTURE

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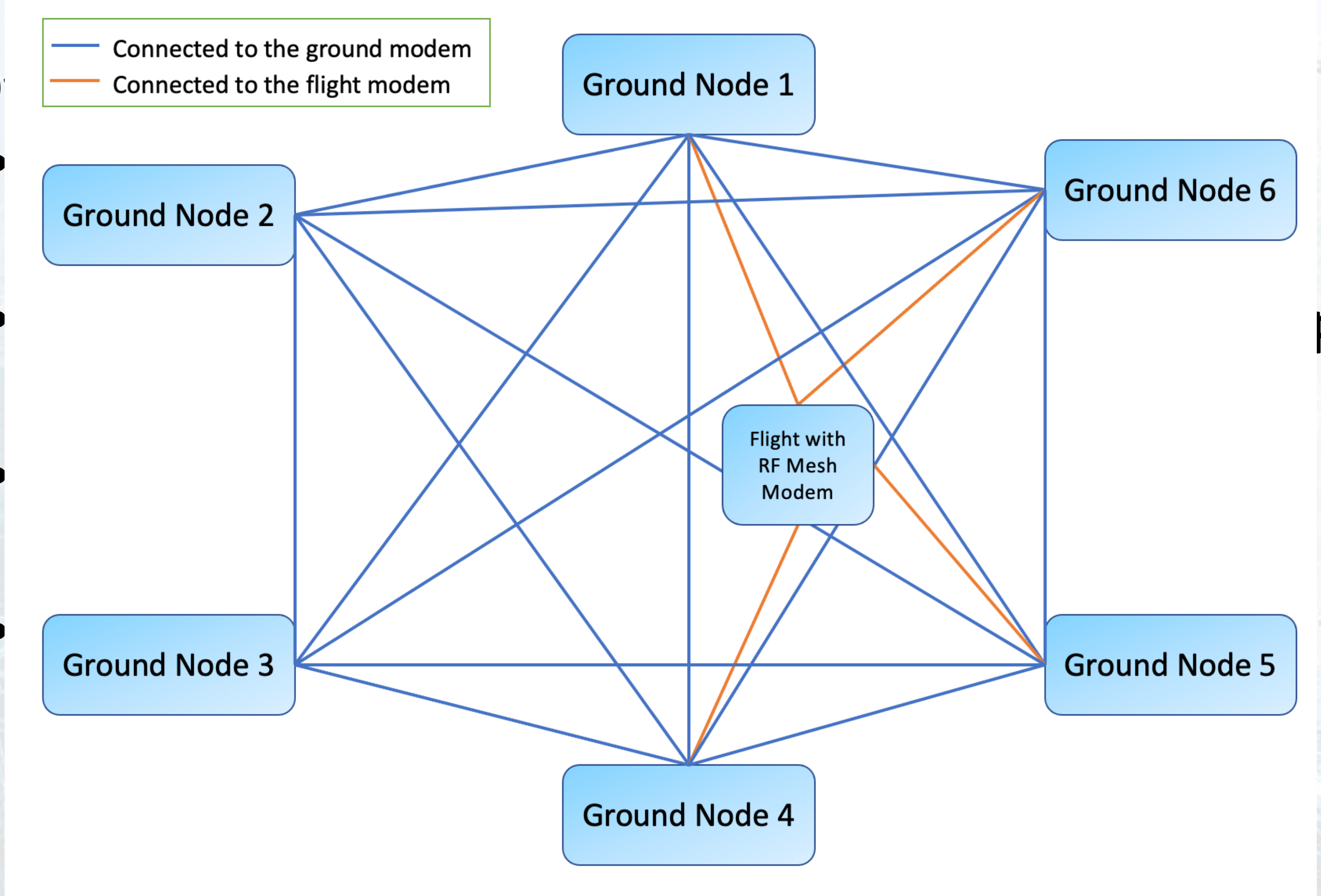
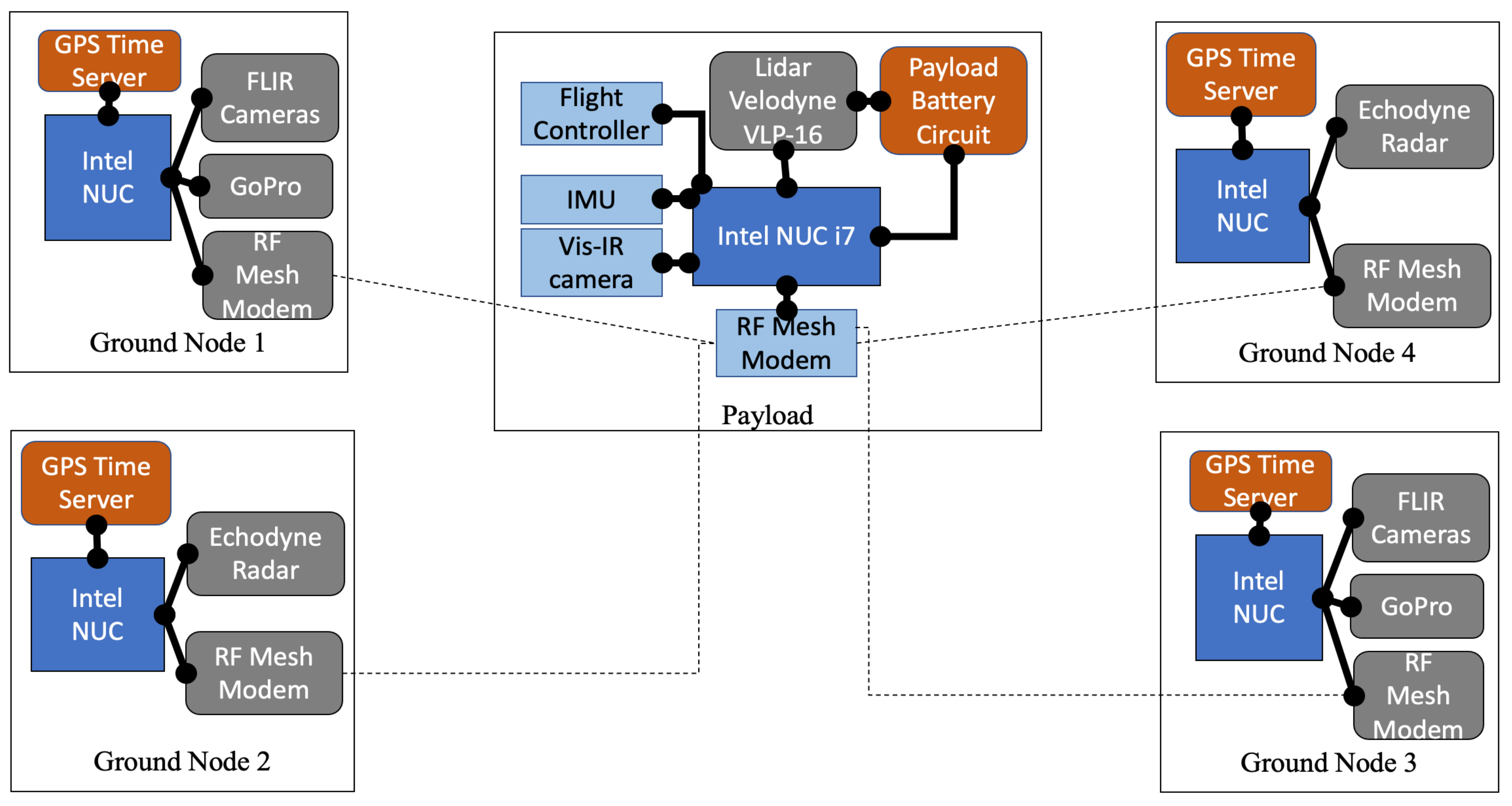


MESH ARCHITECTURE (contd.)



Block diagram overview of the integrated distributed sensing framework.

Modem Configuration: Key Points

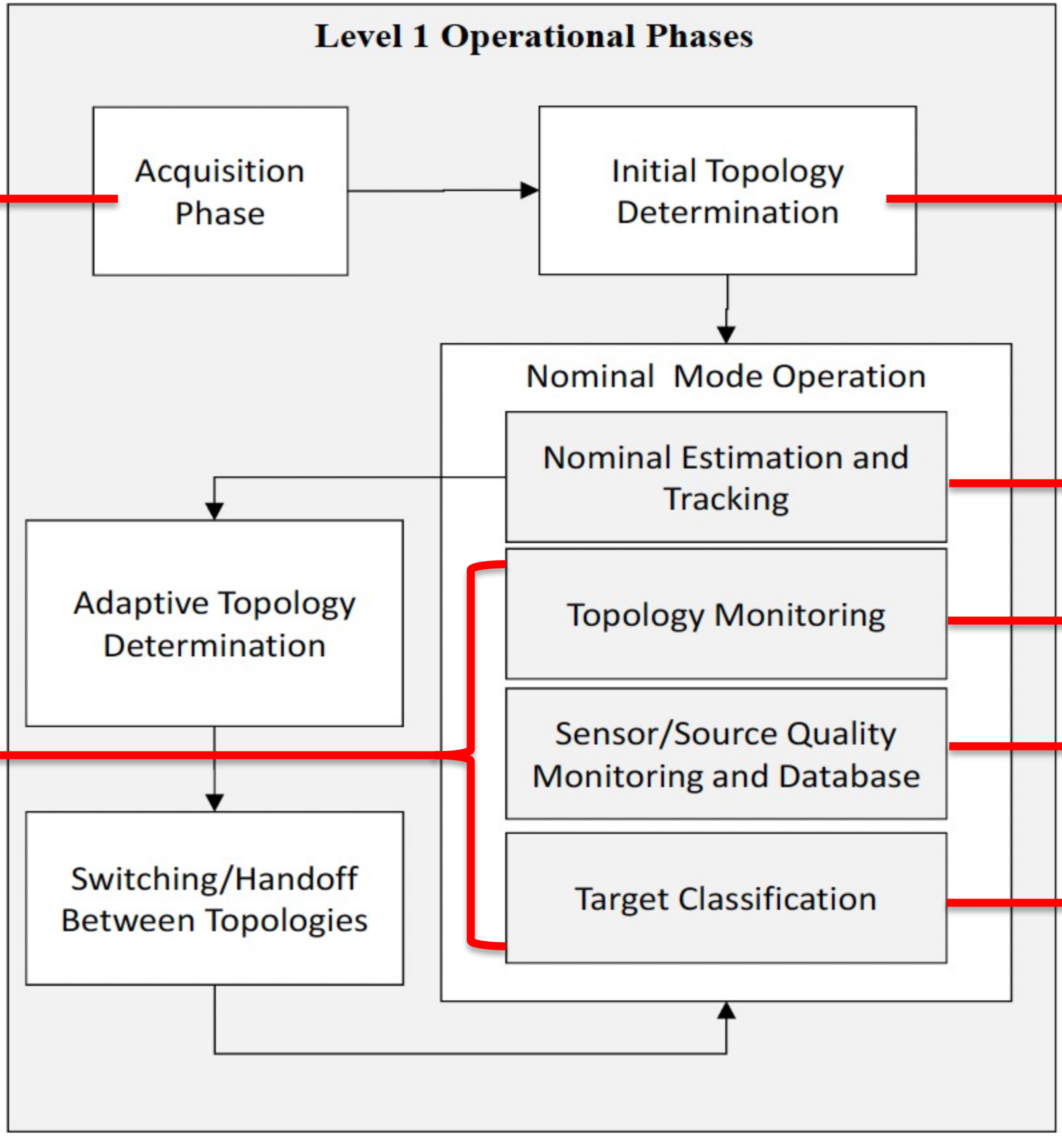
- **Frequency and Bandwidth**
  - Operates in the 900 MHz radio frequency band.
  - 8 MHz channel bandwidth for effective signal transmission.
- **Transmit Power**
  - Meticulously calibrated to 20 dBm for optimal efficacy.
- **Channel Spectrum**
  - Spans from 15 to 917 MHz, providing a broad spectrum for wireless communication.
- **Wireless Distance Capability**
  - Demonstrates an impressive wireless distance capability of 3000 meters.
- **Fundamental Settings**
  - Includes Mesh ID and encryption type for network integration.
  - Static IP addresses assigned to prevent address repetition and maintain network integrity.

Outline

Operational Phases of the Software Framework

potential targets identified in one or more sensors are confirmed as entities to be estimated.

Asynchronous functions



- establishes a distributed sensing network topology
- topology meets requirements, estimation goals, and satisfies constraints in the airspace

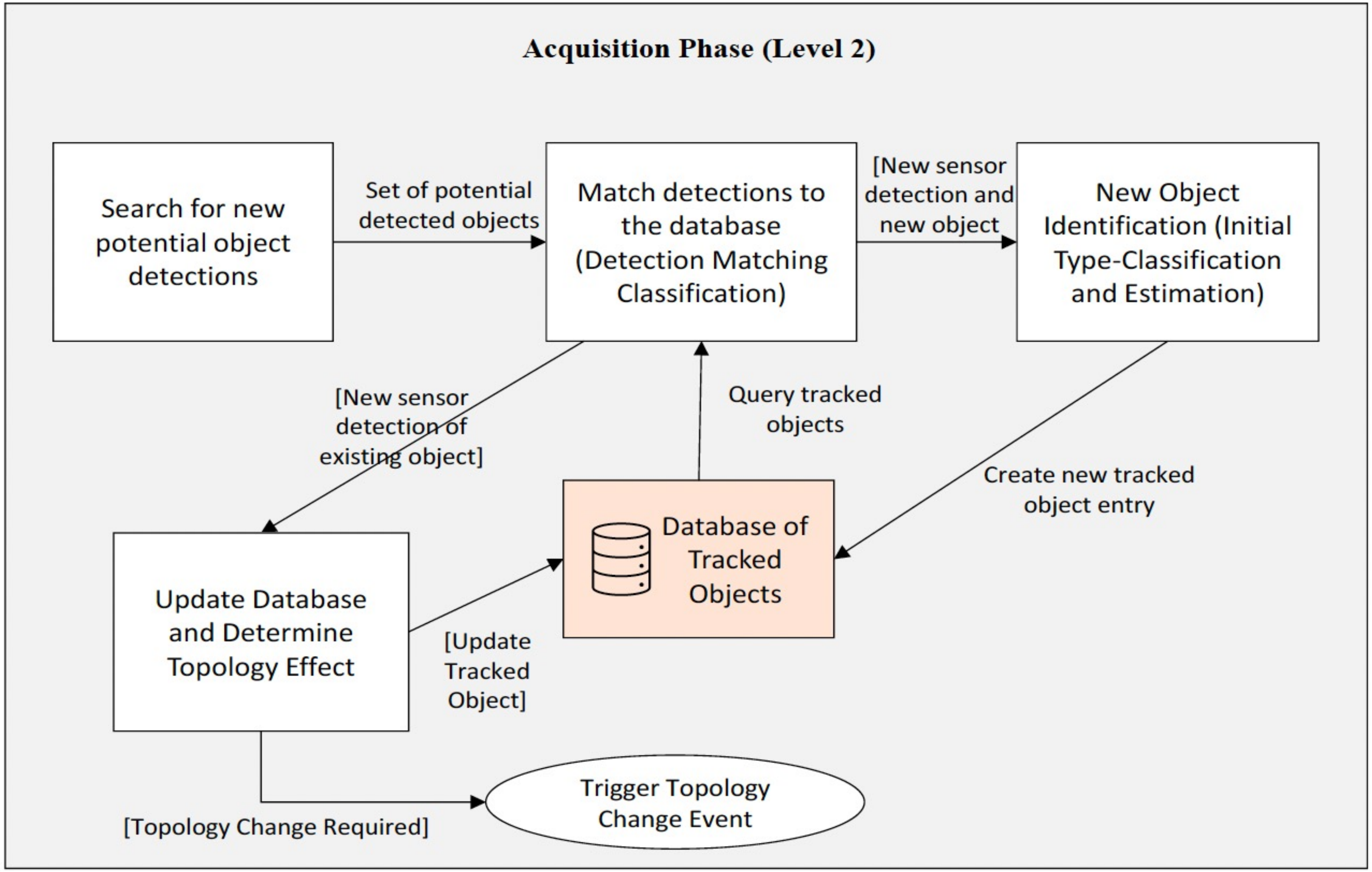
the target state estimate is updated at each time-step based on sensor updates

Monitors the current network topology for events requiring a change

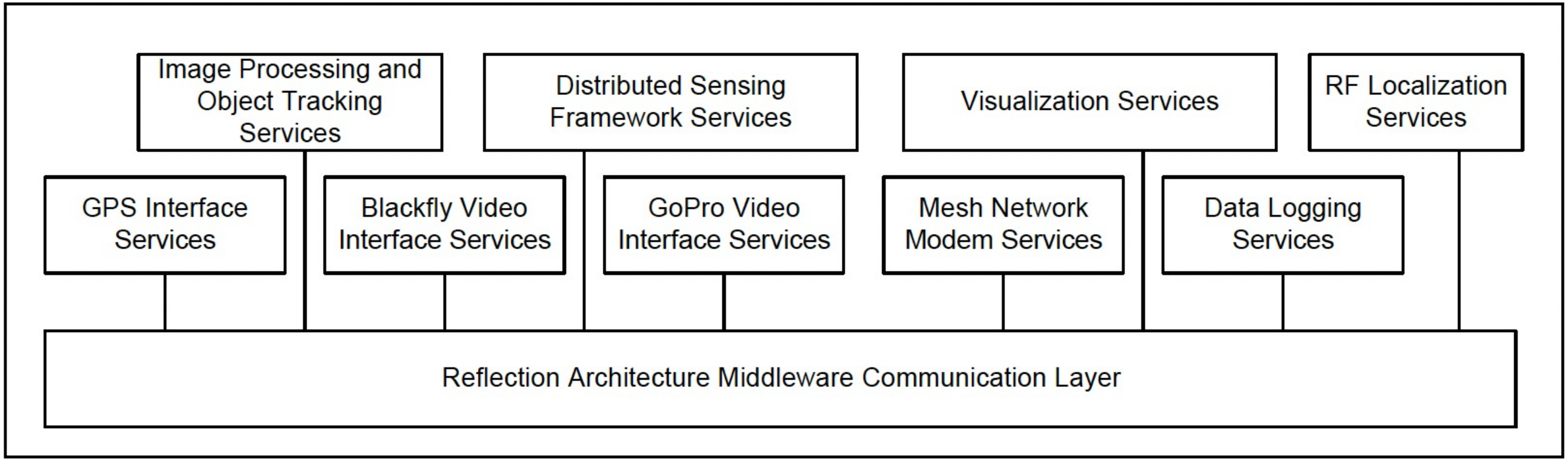
Provides continual quality estimation across all sensors with overlapping observations of the target through cross-validation

Offers valuable information for airspace operators and onboard detect-and-avoid functions

Acquisition Model of the Software Framework



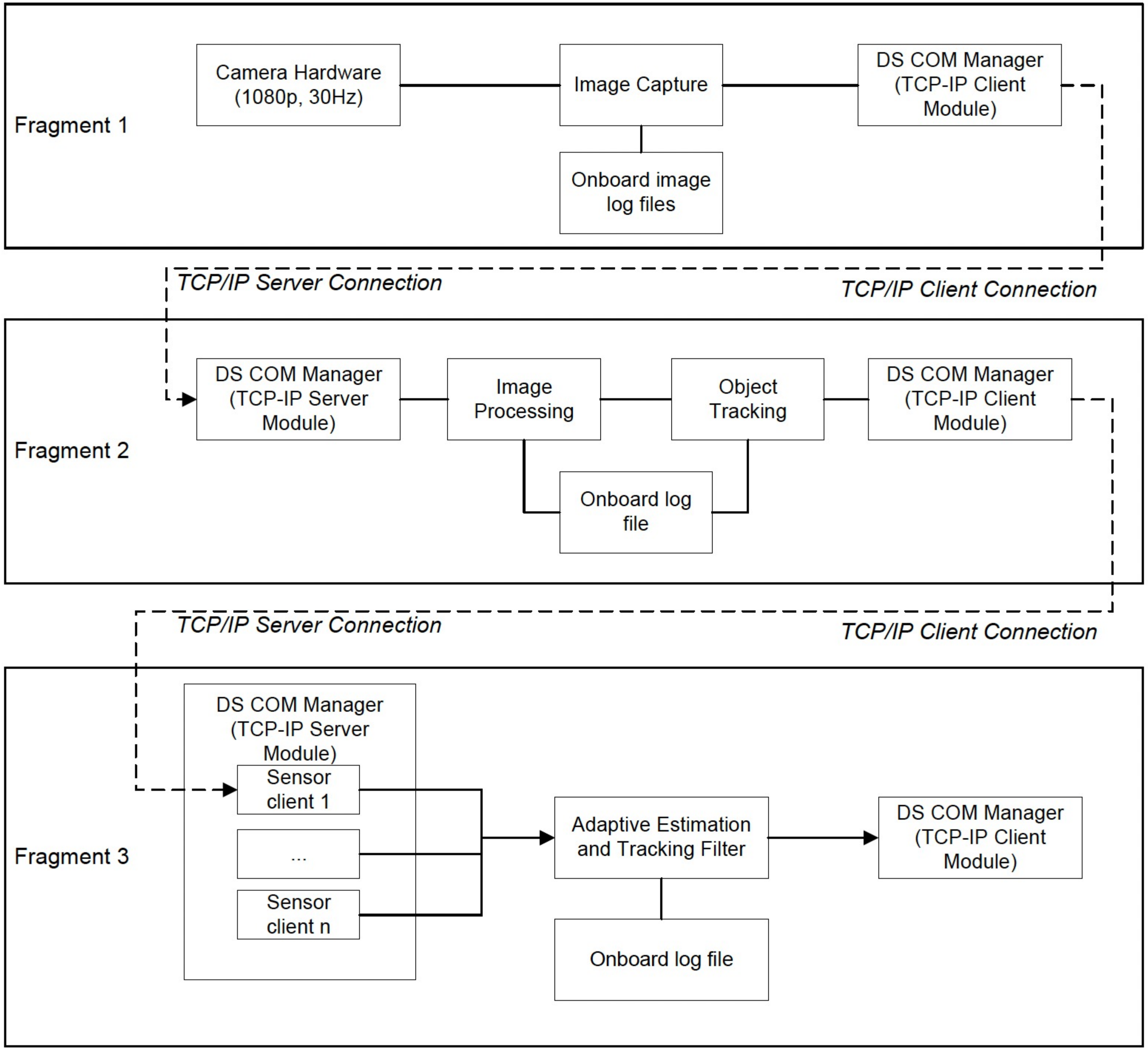
Software Modules and Major Services



- **Hardware Interface Modules:**
  - Responsible for facilitating software-to-hardware communication over hardware-specific connections.
  - Includes modules for the GPS receiver, hardware modems, and cameras.
  - **Camera Modules:** Capture and decode images in real-time from hardware sources.
  - **Modem Module:** Extends the Reflection Architecture's communication system across the network to other instances of airborne and ground-based networks.
- **Data Logging Services:**
  - Responsible for storing data to a file system.
  - Utilized in post-processing for analyzing performance in the experiments.
- **Image Processing and Object Tracking Services:**
  - Process images in real-time to detect and track airborne objects within the sensors' field of view.
- **RF Localization Services:**
  - Determine the position of mesh modems in the network using RF information from the mesh modems.

Adaptive Network and Sensor Processing Pipeline Fragments

- The DS framework requires an adaptive network for continuous operation, necessitating constant reconfiguration and restructuring of the network topology.
- **Fragmented Sensor Processing Pipeline:**
  - Components of the sensor processing pipeline are developed into "fragments" to achieve self-assembling goals.
  - Each fragment is a standalone application with client/server capabilities for inter-fragment communication.
- **Real-time Reassembly:**
  - Fragments can be assembled and re-assembled in real-time to respond dynamically to current system requirements and constraints.
- **Offline Calibration and Registration:**
  - In the initial experiment's implementation, calibration and registration of sensors were performed offline during the pre-process.
  - Future plans include implementing self-calibrating functionality.



Encapsulates camera hardware interfaces responsible for capturing images and communicating them to the next fragment.

- Houses image processing and object tracking pipeline components, operating on a per-sensor basis.
- Sends detection and tracking information to other fragments.

- Adaptive estimation and tracking filter for calculation of target estimation based on correlated signals across the sensor network.
- Handles client connections based on relevant sensor information.

Assembly and Assignment Problem

- **Real-time Topology Determination**
  - The topology determination system module solves the assembly problem during real-time operation.
  - Given the destination node, available hardware, and current sensor state, the system determines the end-to-end topology meeting estimation requirements.
- **Assignment and Allocation System**
  - The processing assignment system allocates software to specific nodes based on communication requirements.
- **Hard-Coded Assignments**
  - In the initial flight tests, assignments were hard-coded into the processing module for evaluation.
  - Per-sensor processing pipelines were allocated to the ground node CPU to manage network bandwidth.
  - Framework components and estimation were assigned to the ground operator's CPU, responsible for real-time result display.
- **Future Development Considerations:**
  - Future experiments will introduce dynamic assignment algorithms as components mature.
  - Experimentation may involve reassignment of framework components and per-object filtering network fragments to dedicated relay CPUs for improved real-time results.

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Lidar Walk-Around Test

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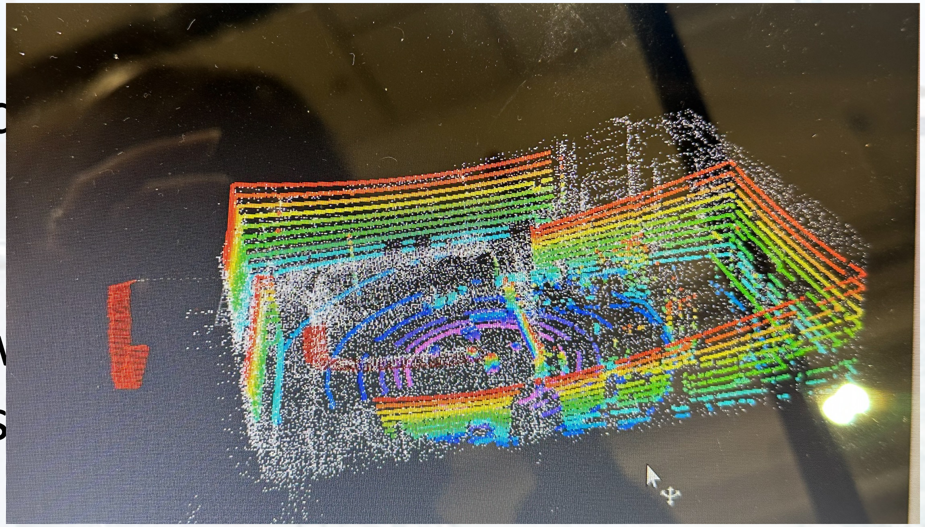

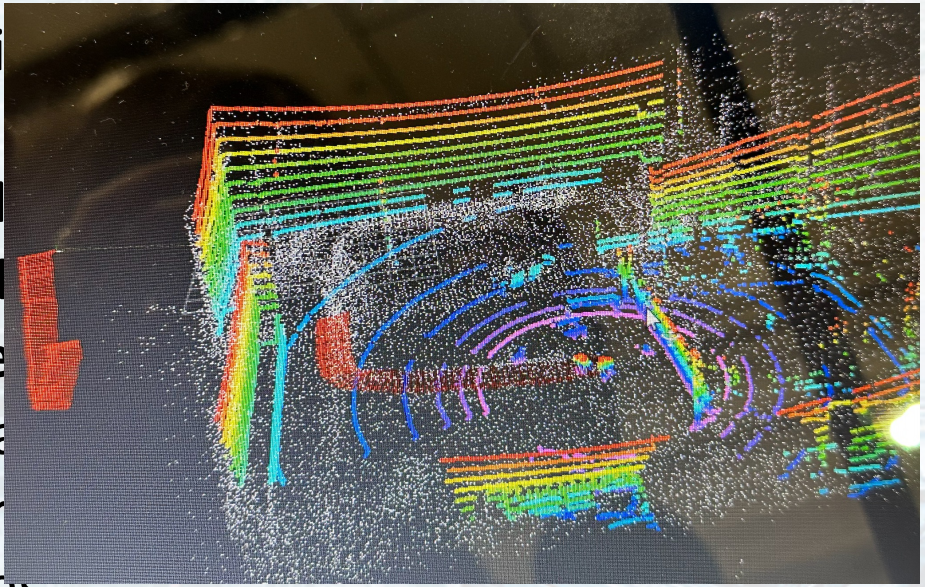

RF Mesh Modem Drive-Around Test

- **Methodology**
  - Payload mobilized on wheels; ground nodes strategically positioned.

  - RSSI readings and GPS log data collected during the test.
  - GPS log data used to create synthetic RSSI readings and calibrate RF antenna.

Flight Test Campaign with Distributed Ground Nodes

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CONCLUSION

- The framework introduces the concept of DS for conducting comprehensive tests in various AAM scenarios.
- It establishes a foundational baseline for future flight tests, incorporating multiple sensor nodes into conceptual and scenario-specific frameworks.
- Precise time synchronization across multiple nodes remains a focal point and requires further attention.

FUTURE WORK

- Extend the distributed sensing network to address the unique challenges posed by outdoor environments.
- Address the difficulties related to time synchronization.
- Execute multiple distributed sensing-based tests, focusing specifically on object detection, tracking, and precision approach & landing scenarios.
- The goal is to enhance the robustness and applicability of the DS framework in the context of AAM operations.

Acknowledgements

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Thank you for listening! Questions?