IT4010 Research Project – 2025 July

Topic Assessment Form

Project ID : 25-26J-010

1. Topic (12 words max)

Autonomous Data Ferrying from a Self-Organizing/Healing WSN in Disconnected Zones

2. Research group the project belongs to

CI - Computing Infrasrtucture

3. Specialization of the project belongs to

Computer Systems and Network Engineering(CSNE)

4. If a continuation of a previous project:

Project ID	-
Year	-

5. Brief description of the research problem including references (200 – 500 words max) – references not included in word count.

In many critical environments such as disaster zones, remote wildlands and military border regions, traditional wireless communication infrastructure is either unavailable, unstable, or actively avoided. Despite these constraints, monitoring such environments using Wireless Sensor Networks (WSNs) remains essential for tasks such as environmental sensing, surveillance, disaster response, and infrastructure assessment.

The key challenges in such disconnected environments are lack of continuous connectivity, limited power availability, dynamic topologies due to node failures, and the need for resilient data delivery without fixed backhaul networks. Standard WSNs fail under these conditions due to reliance on fixed gateways, preconfigured routing, and centralized synchronization.

This research proposes a self-organizing WSN architecture that operates in disconnected environments using a mobile data ferry (UAV equipped with a Raspberry Pi) and a dynamically elected Cluster Head (CH) within each sensor cluster. Each MS (Main Set) continuously senses its environment and locally stores its data. CHs are selected dynamically through coordination among all MS nodes in the cluster, based on metrics such as energy level, trust score, uptime, and sensor availability. This coordination uses a lightweight mesh structure solely for CH election purposes. Once elected, the CH periodically initiates communication with each MS in its cluster to request and collect their stored sensor data. The CH then acts as the cluster's interface to the data ferry, which retrieves buffered data using BLE-triggered ESP32-based wireless communication.

Upon retrieval by the ferry, all data is transmitted to the base station. There, a centralized dashboard system visualizes the sensor network in real time, displaying cluster health, MS battery levels, CH status, data flow direction, sensor values, and alerts. This empowers remote operators to monitor environmental conditions, track data lineage, identify failing nodes, and assess network health, all without live connectivity in the field.

The system is designed to be power-adaptive each MS monitors its battery level and can fall back to passive or deep-sleep modes during critical conditions, broadcasting periodic low-battery alerts. Trust filtering is embedded to avoid accepting corrupt or tampered data from faulty or malicious sensors. The system is designed for rapid deployment using modular sensor packs and can recover from CH failures via self-healing election logic.

Unlike traditional WSNs, this approach avoids the need for live connectivity, backhaul routers, or cloud control, making it uniquely suited for disconnected, high-risk, infrastructure-less environments.

6. Brief description of the nature of the solution including a conceptual diagram (250 words max)

This research proposes a novel Wireless Sensor Network (WSN) architecture that enables autonomous, delay-tolerant data ferrying from a disconnected, self-organizing, and power aware sensor ecosystem.

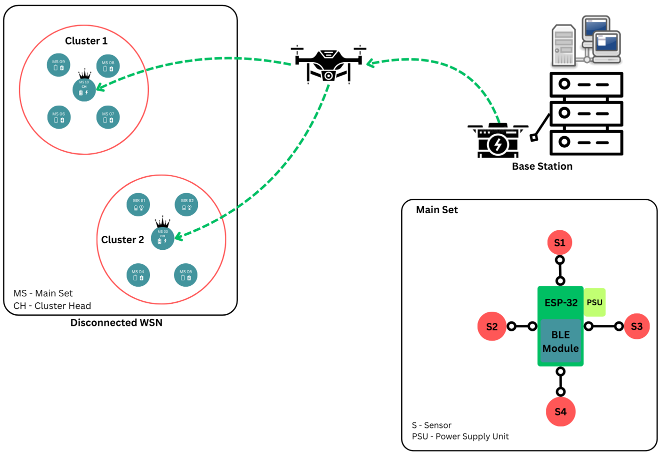
The system is composed of Main set nodes (MS) equipped with ESP32 microcontroller, BLE Module and up to Maximum four sensors (audio, video, image, and other environmental sensors). These MS units are deployed in clusters across a terrain with no existing network infrastructure.

Each cluster autonomously elects a Cluster Head (CH) using a lightweight algorithm that prioritizes battery level, node health, uptime, and trustworthiness. The CH acts as an interface to access data localized to that specific cluster. All MS units continuously sense and store data, regardless of the ferry's presence.

A mobile ferry (UAV or robot) patrols the environment and wirelessly collects data from the CHs when it enters proximity. Detection is triggered using BLE beaconing, which activates the CH's ESP-NOW interface for fast, infrastructure less data exchange. This eliminates the need for permanent gateways or real-time backhaul.

Each MS is power aware, dynamically entering passive or deep-sleep modes depending on its battery status. Low-battery alerts and power state transitions are communicated to the CH and ultimately the dashboard at headquarters via the ferry.

The solution supports modular deployment, dynamic CH reelection, dynamic routing, and energy-aware sensing. The base station dashboard visualizes node health, cluster structure, power modes, and data flow direction, enabling centralized monitoring of a decentralized system.



7. Brief description of specialized domain expertise, knowledge, and data requirements (300 words max)

To build and deploy this system effectively, the project team will require hands-on experience with embedded systems, low-power wireless communication, and sensor network design. The hardware platform is based on ESP32 microcontrollers, which support both Wi-Fi and Bluetooth Low Energy (BLE). Core expertise involves integrating environmental sensors (e.g., temperature, gas, motion) with these microcontrollers, ensuring reliable data acquisition, timestamping, and local storage in memory (SPIFFS or EEPROM).

A solid understanding of BLE and ESP-NOW communication protocols is crucial for this project. BLE is used to help the Cluster Head (CH) detect when the UAV (ferry) is nearby, using low-power proximity signals. Once the ferry is close enough, the CH activates its Wi-Fi radio and uses ESP-NOW to send data. ESP-NOW allows devices to exchange information directly without needing any internet or router, which makes it ideal for this kind of offline, low-power network. The team also needs to manage how sensor readings are collected, stored, and prepared for transmission which involves setting up timers, queues, and logic to trigger communication only when necessary, conserving as much power as possible.

The system also involves power-adaptive behavior. This requires configuring the ESP32 to dynamically switch between active sensing, passive listening, and deep sleep modes based on battery level. Nodes must report their power state and battery warnings to the CH, which queues this data for collection by the UAV. Basic knowledge of solar recharging systems is also beneficial, as sensor units are designed to recover autonomously in the field when sunlight is available.

On the UAV side, the system requires moderate familiarity with Raspberry Pi or similar SBC platforms. The UAV is responsible for scanning, detecting nearby CH nodes, and collecting buffered data wirelessly when in range. Finally, the backend includes a base station dashboard that parses incoming data logs, displays sensor health, node status, and battery trends. Visualization and alerting logic are built using JSON data formats, simple web interfaces, and mapping tools. Test data will be generated during real-world deployment trials in clustered environments to simulate disconnection and ferry-based collection cycles.

8. Objectives and Novelty

Main Objective To design and implement a low-power, autonomous wireless sensor network (WSN) capable of operating in disconnected environments by enabling efficient data collection through a mobile ferry (UAV), using dynamically elected Cluster Heads (CHs), trust-aware data handling, and energy-adaptive behavior without relying on traditional communication infrastructure.			
Member Name with Registration No	Sub Objective	Tasks	Novelty
Bandaranayake K. B. H. M. C. C. IT22069122	UAV Behavior & Routing	• Terrain scanning for known cluster points. • Dynamic route planning per mission. • Fetch & terminate MS clusters. • Cluster Queue Management (priority-based).	• Dynamic routing engine with UAV cluster prioritization. • Drone supports: ○ Predefined routes (e.g., C1 → C3). ○ Priority queue-based decision-making. ○ Mission-mode route behavior (e.g., urgent only / full sweep). ○ Termination via “Kill Command”: UAV → CH → MS broadcast.
Bandara K. B. O. V. IT22564986	WSN Cluster Management	• Automated cluster formation from MS nodes. • CH election algorithm. • Sensor trust metric (used during CH selection).	• Novel cluster formation algorithm combining: Battery level, Uptime history, Sensor health (trust metric). • Enables adaptive CH rotation and resilience in node failure conditions.

Thamasha W. Y. M. G. IT22088000	Cluster Data Communication	• MS ↔ CH communication topology design (star/mesh hybrid). • CH ↔ UAV payload definition, communication methods. • Data framing and exchanging protocols.	• Designed full intra-cluster protocol for ESP-NOW MS → CH polling scheme. • CH → UAV Communication. • Adaptive payload based on ferry proximity & battery level.
Wickrama Arachchi D. R. IT22360496	MS Hardware & Power Design	• ESP32 + BLE embedded design. • Battery + Solar-based PSU integration. • Energy management engine.	• Developed a Power Management Engine (PME) for each MS unit with 3 operational modes: Normal sensing, Passive power-save (BLE beacon only), Critical deep-sleep mode. • Enables longevity and autonomous healing behavior.

9. Individual component description of how it is complied with the specialization.

Member Name with Registration No	Description
Bandaranayake K. B. H. M. C. C. IT22069122	Applied core CSNE principles in routing protocols, UAV path optimization, and priority-based data transmission. Designed a low-latency dynamic routing system between clusters, addressing real-world network constraints in disconnected environments. Integrated mission-specific behavior control for UAVs, showcasing applied systems control and autonomous mobility.
Bandara K. B. O. V. IT22564986	Focused on autonomous network formation and cluster head election algorithms, core topics in distributed systems and network engineering. Implemented a trust aware, adaptive CH rotation system that aligns with CSNE by simulating resilience in decentralized WSNs under node failure.
Thamasha W. Y. M. G. IT22088000	Developed a cluster data communication wrapping protocol using ESP-NOW and hybrid mesh-topology, reflecting deep understanding of low-power wireless protocols and real-time embedded communication. Work complies with CSNE by addressing efficient network data exchange under resource-constrained conditions.
Wickrama Arachchi D. R. IT22360496	Designed embedded hardware using ESP32 and implemented energy-aware software stacks, aligning with embedded systems and low-power computing in CSNE. Created a 3-mode power management engine (PME) for energy sustainability critical in autonomous CSNE systems deployed in the field.

10. Supervisor details

	Title	First Name	Last Name	Signature
Supervisor	Ms.	Dinithi	Pandithage	Dinithi Pandithage
Co-Supervisor	Mr.	Uditha	Dharmakeerthi	
External Supervisor				
Summary of external supervisor's (if any) experience and expertise				

<u>This part is to be filled by the Topic Screening Staff members.</u>

a) Does the chosen research topic possess a comprehensive scope suitable for a final-year project?

Yes	X	No	

b) Does the proposed topic exhibit novelty?

Yes	X	No	

c) Do you believe they have the capability to successfully execute the proposed project?

Yes	X	No	

d) Do the proposed sub-objectives reflect the students' areas of specialization?

Yes	X	No	

e) Supervisor's Evaluation and Recommendation for the Research topic:

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Acceptable: Mark/Select as necessary

Topic Assessment Accepted	
Topic Assessment Accepted with minor changes*	
Topic Assessment to be Resubmitted with major changes*	
Topic Assessment Rejected. Topic must be changed	

* Detailed comments given below

Comments

Staff Member's Name	Signature

*Important:

1. According to the comments given by the evaluator, make the necessary modifications and get the approval by the **Evaluator**.
2. If the project topic is rejected, identify a new topic, and request the RP Team for a new topic assessment.