

Research Title: Adaptive Network Communications Architecture for Sensor Data Transmission with Applications in Beehive Management

Abstract

The global decline in bee populations poses a significant threat to biodiversity, agricultural productivity, and food security. This research report presents an Adaptive Network Communications Architecture (ANCA) for transmission of sensor data in beehive management. Traditional Wireless Sensor Networks (WSNs) face data communication challenges related to network reliability, adaptability, and energy efficiency, particularly in remote areas. Existing single-technology solutions, such as Wireless Fidelity (Wi-Fi), Global System for Mobile Communications (GSM), or Long Range (LoRa), struggle to adapt to changing environmental conditions, limiting their performance.

This study proposes an adaptive network architecture that dynamically selects the optimal communication technology (Wi-Fi, GSM, or LoRa) based on real-time network conditions, data type, and resource availability. The ANCA employs machine learning (ML)-based optimization algorithms, incorporating predictive mobility modeling and congestion-aware routing to enhance decision-making in multi-network environments. It prioritizes sensor data, reduces transmission overhead, and improves end-to-end network efficiency. The architecture integrates algorithms such as Tiny Machine Learning (TinyML) for edge processing, ensuring real-time analysis of key beehive parameters such as temperature, humidity, and acoustic signals from image and audio files.

The research follows a design science methodology, incorporating simulations using Network Simulator 3 (NS-3) and Matrix Laboratory (MATLAB), alongside real-world deployments to validate performance across urban, suburban, and rural environments. Key evaluation metrics include throughput, latency, packet loss, power consumption, and Received Signal Strength Indicator (RSSI). The results demonstrate that the architecture significantly improves data reliability, reduces power consumption, and enhances adaptability compared to conventional single-network solutions.

The study's findings contribute to the advancement of precision beekeeping, providing an adaptable and scalable approach for real-time hive monitoring. Practically, this supports more sustainable apiculture practices, reduces hive losses, and offers a replicable model for low-cost IoT deployment in underserved regions. The proposed ANCA also has broader implications for IoT-based environmental monitoring and can be extended to applications in smart agriculture, wildlife conservation, and disaster response systems.