IoT Homework #1

System Design

Giuliano Crescimbeni, 10712403 - Arimondo Scrivano, 10712429
Politecnico di Milano

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1. System Overview

This solution proposes a low-cost, scalable IoT system for real-time tracking and monitoring of electric forklifts in a warehouse with both indoor (500 m^2) and outdoor (1 km^2) areas. The system aims to compute location, total distance traveled, average and peak speeds, and detect possible impacts.

2. Hardware on Each Forklift

Each forklift is equipped with:

- **ESP32 microcontroller with BLE module:** manages data acquisition and transmission.
- **GPS Module:** for outdoor localization.
- **IMU Module:** for impact detection.
- **LoRa transceiver:** for long-range outdoor communication.

3. Connectivity and Communication

Outdoor Communication

- **Protocol:** GPS + LoRaWAN.
- **Topology:** The GPS module provides real-time outdoor positioning, while data is transmitted via LoRa to a fixed LoRaWAN gateway located at the center of the outdoor yard.
- **Frequency:** A data packet is sent every 5 seconds.

Indoor Communication

- **Protocol:** BLE for short-range tracking.
- **Topology:** Each forklift periodically transmits a BLE beacon. Fixed BLE scanners are distributed throughout the indoor area and are connected via Ethernet to the distribution system.
- **Position Estimation:** The system uses the RSSI of BLE packets received by multiple scanners to estimate the indoor position.

4. Backend Architecture

Each forklift sends its data either via LoRaWAN (outdoor) or via BLE (indoor).

- For outdoor areas, data is collected by the LoRaWAN gateway, positioned at the center of the outdoor yard, and sent via Ethernet to the distribution system.

- For indoor areas, BLE scanners detect the presence and RSSI of nearby forklift beacons. These scanners send the raw RSSI data via LAN to a centralized positioning node which computes the estimated position of each forklift using signal strength analysis and sends them to the distribution system.

The distribution system collects all metrics and positioning data and uploads them to the cloud platform (ThingSpeak) for real-time visualization and historical analysis.

All metrics such as total distance traveled, speed, and impact detection are computed locally on each forklift by the onboard ESP32 microcontroller in the outdoor environment. This offloads processing from the LoRaWAN gateway and improves system scalability.

In the indoor environment, however, GPS data is not available. Therefore, speed and position metrics are computed by the centralized positioning node, based on RSSI data collected from the BLE scanners.

5. Pseudocode on Forklift

```
Initialize all modules and buffers

LOOP:
    current_time ← get current system time

    //=== OUTDOOR LOCATION TRACKING ===
    gps_data = read from GPS
    If gps_data is valid:
        btx = false
        current_location = gps_data.latitude, gps_data.longitude
        current_speed ← gps_data.speed

        // Distance tracking
        If last_location exists:
            delta_distance = calculate_distance()
            total_distance += delta_distance

        // Speed statistics
        max_speed ← max(max_speed, current_speed)
    else:
        btx = true

    //=== IMPACT DETECTION ===
    acceleration_magnitude = calculate_magnitude()
    If acceleration_magnitude  IMPACT_THRESHOLD:
        register_impact

    //=== Transmission phase ===//

    //=== 1. BLE BEACON BROADCAST ===
    if btx:
        broadcast BLE beacon with unique ID, include impact data

    //=== 2. PERIODIC TRANSMISSION (OUTDOOR) ===
    if !btx:
        If 5 seconds have passed since last transmission:
            Send data via LoRa to the gateway
            Reset speed_samples and impact_events
```

6. Graphical System Diagram