**ENERGY EFFICIENT WIRELESS COMMUNICATION USING IoT DEVICES**

**TEAM – 7**

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**Introduction :**

The Internet of Things (IoT) has revolutionized agriculture by enabling remote monitoring and automation of various farming activities. These IoT devices, however, often rely on battery power and are deployed in remote or hard-to-reach locations, making energy efficiency a critical concern. This case study focuses on exploring and simulating power-saving techniques in wireless IoT networks to recommend the most effective strategy for prolonging battery life in agriculture monitoring systems.

**Problem Understanding :**

In traditional agriculture, real-time monitoring of environmental conditions such as soil moisture, temperature, and light intensity requires manual labor and regular field visits. This is both labor-intensive and inefficient. IoT-enabled agriculture provides automated data collection and transmission, reducing human effort and increasing productivity. However, the remote nature of agricultural fields introduces challenges like limited access to power sources, harsh environmental conditions, and the need for long-range communication. Continuous operation of sensors and wireless modules can quickly deplete batteries, especially in expansive fields with many deployed devices. Therefore, to ensure uninterrupted operation, energy-efficient communication strategies must be employed to balance the need for reliable data transmission and prolonged device lifetime.

**Objectives :**

* To simulate different power-saving techniques in IoT networks.
* To measure trade-offs between power consumption and data transmission rate.
* To recommend the most suitable techniques for maximizing battery life in agriculture monitoring applications.

**Application Context - Agriculture Monitoring** **:**

Agriculture monitoring involves the use of various sensors (e.g., soil moisture, temperature, humidity) deployed across a field. These sensors transmit data wirelessly to a central gateway or cloud platform for analysis and decision-making. The effectiveness of this system depends heavily on the longevity and reliability of these sensor nodes.

**Key Components in IoT-based Agriculture Monitoring :**

The following five components play a crucial role in an agriculture monitoring system:

**Soil Moisture Sensor :**

* **Function**: Measures the volumetric water content in soil.
* **Relevance**: Helps in efficient irrigation planning and reduces water usage.

**Temperature and Humidity Sensor :**

* **Function**: Monitors environmental temperature and relative humidity.
* **Relevance**: Essential for climate tracking, plant growth optimization, and disease prediction.

**Wireless Communication Module (e.g., LoRa, Zigbee) :**

* **Function**: Transfers data from sensor nodes to gateways or servers.
* **Relevance**: Enables long-range, low-power wireless communication critical for field-wide deployment.

**Gateway Device :**

* **Function**: Aggregates sensor data and forwards it to cloud services or monitoring systems.
* **Relevance**: Serves as the central node in the network architecture.

**Light Sensor (PAR or LDR) :**

* **Function**: Measures light intensity or photosynthetically active radiation.
* **Relevance**: Assists in crop light exposure analysis and greenhouse management.

**Challenges and Solutions :**

Implementing wireless communication in IoT-based agriculture monitoring systems presents several challenges:

**Challenge: Limited Power Availability**

* **Explanation**: Sensors and communication modules in remote agricultural fields often rely on batteries or solar energy, which can be limited.
* **Solution**: Implement power-saving techniques such as Duty Cycling, Sleep Scheduling, and Low Power Listening (LPL) to reduce the energy usage of sensor nodes.

**Challenge: Communication Range and Coverage**

* **Explanation**: Large agricultural fields require wide coverage, which can strain wireless communication modules.
* **Solution**: Use long-range protocols like LoRa and coordinate communication intervals using sleep scheduling to maintain coverage without constant activity.

**Challenge: Environmental Interference**

* **Explanation**: Weather, foliage, and terrain can interfere with wireless signals.
* **Solution**: Position gateways strategically and use robust, low-frequency communication protocols like LoRa that are less affected by obstacles.

**Challenge: Network Scalability**

* **Explanation**: Adding more devices to the network can lead to congestion and collisions.
* **Solution**: Employ sleep scheduling to reduce simultaneous transmissions and utilize gateway devices to manage data aggregation and traffic scheduling.

**Challenge: Data Synchronization and Timeliness**

* **Explanation**: Ensuring timely and synchronized data reporting from all sensors can be difficult.
* **Solution**: Apply Duty Cycling and LPL with timestamped data packets and coordinated schedules to balance energy saving and data freshness.

**Power-Saving Techniques Analyzed :**

The following power-saving techniques were simulated using the Cooja simulator under the Contiki-NG operating system:

**Duty Cycling**

* **Description**: Nodes periodically wake up to transmit or receive data and then return to sleep.
* **Effect on Components**:

1. Sensors like soil moisture and light sensors are programmed to activate every 30 minutes, collect readings, and go back to sleep.
2. LoRa modules are turned on only during transmission intervals to minimize energy drain.
3. The gateway receives data bursts during scheduled windows and remains in low-power mode otherwise.

* **Example**: A soil moisture sensor wakes up at 6:00 AM, checks the soil's water level, sends data via LoRa to the gateway, and sleeps until the next scheduled time (e.g., 6:30 AM). This reduces the active time to under 10 seconds per cycle.
* **Advantage**: Significant energy savings.
* **Trade-off**: May introduce communication delays.

**7.2 Sleep Scheduling**

* **Description**: Devices follow a scheduled pattern for sleep and wake cycles based on network coordination.
* **Effect on Components**:

1. Temperature/humidity sensors and light sensors sync with a master schedule broadcasted by the gateway.
2. The gateway coordinates the sleep/wake periods of all sensor nodes.
3. Only one node is active at a time to avoid collisions and reduce energy spikes.

* **Example**: The temperature sensor is set to activate every hour at minute 0, while the light sensor activates at minute 10. The gateway is partially awake throughout and fully active during these known periods.
* **Advantage**: Maximizes battery life in static networks.
* **Trade-off**: Less flexible in dynamic or real-time applications.

**Low Power Listening (LPL)**

* **Description**: Nodes remain in a very low power state and periodically check for communication activity.
* **Effect on Components**:

1. LoRa communication modules stay in ultra-low-power mode, waking every 5 seconds to detect signals.
2. Sensors like soil moisture and humidity log data internally and only transmit when queried or triggered.

* **Example**: The temperature sensor stores hourly readings locally. When the gateway sends a request (e.g., at noon), the sensor wakes up, sends the data, and returns to sleep. Meanwhile, the LoRa radio is only briefly active during listening pulses.
* **Advantage**: Lowest energy consumption.
* **Trade-off**: Slightly increased data latency.

**Wireless Technology Comparison**

| **Technology** | **Power Usage** | **Range** | **Data Rate** | **Suitability for Agriculture** |
| --- | --- | --- | --- | --- |
| Wi-Fi | High | Short (~100m) | High | Not suitable (power hungry) |
| Bluetooth | Medium | Short (~10-100m) | Medium | Limited range |
| Zigbee | Low | Medium (~100m) | Medium | Good, but limited range |
| **LoRa** | **Very Low** | **Long (~15km)** | Low | **Best fit for farms** |

**Results and Analysis:**

| **Technique** | **Avg. Power Consumption** | **Packet Delivery Ratio** | **Latency** |
| --- | --- | --- | --- |
| Duty Cycling | Low | High | Moderate |
| Sleep Scheduling | Very Low | Moderate | Low |
| LPL | Lowest | Moderate-High | Slightly High |

* **Duty Cycling** ensures timely transmission from all sensors while conserving energy moderately.
* **Sleep Scheduling** is ideal for fixed-interval data collection, particularly from sensors like soil moisture and light sensors.
* **LPL** provides the best energy savings across all components, with minimal communication overhead.

**Recommendation:**

For agriculture monitoring applications where most sensor data (e.g., soil moisture, temperature, light) can be collected periodically and real-time responsiveness is not critical, **Low Power Listening (LPL)** is recommended. It delivers:

1. **The lowest overall energy consumption across sensors and wireless modules**
2. **Reliable data transmission with acceptable latency**

If the application requires real-time decision-making or rapid data updates (e.g., automated irrigation), then **Duty Cycling** is a better alternative.

**Conclusion:**

Energy-efficient communication is essential in ensuring the long-term operation of IoT-based agriculture monitoring systems. Through simulation, it is evident that while each technique has trade-offs, LPL offers the best energy performance for non-critical latency applications. The use of low-power components such as soil moisture sensors, light sensors, and LoRa modules, when combined with appropriate power-saving strategies like LPL, significantly extends the battery life of devices. Future work can explore adaptive combinations of techniques based on sensor type and field activity.