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IoT-Enabled Wireless Transmission System for Structural Health Monitoring

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Background

Structural health monitoring (SHM) has become increasingly important to ensure public safety. The health of buildings and bridges are observed by collecting sensor data of the target building. Currently, the most common method of obtaining this data is to have inspectors physically interact with sensors and extracting the data using wired connections. This process in not ideal as it could increase costs and may sometimes even be impossible to do.

Project Description

The main objective is to design a wireless transceiver system to be used for structural health monitoring. The operation flow is to place a variety of sensors inside the structure of a building, and these sensors will detect various data such as temperature, vibration, and displacement at a considerable distance. These sensors are able to transmit their measurements through a wireless network so that the data can be easily accessed on a personal device.

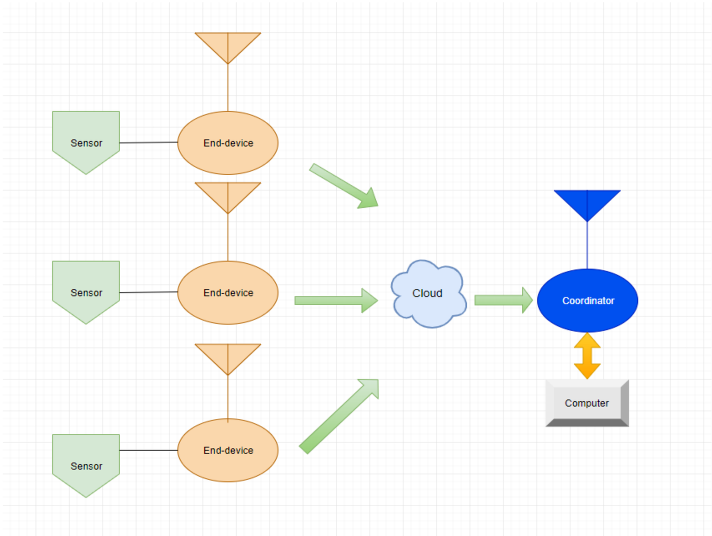

Figure 1. System to be Developed

Theory

Key Technology: **ZigBee**

- It is a communication standard based on IEEE 802.15.4, typically used for wireless personal area networks (WPANs)
- The physical system consists of 3 types of devices: *coordinator, router, end device.*
- The coordinator establishes the communication network and receives data transmitted by the end devices.

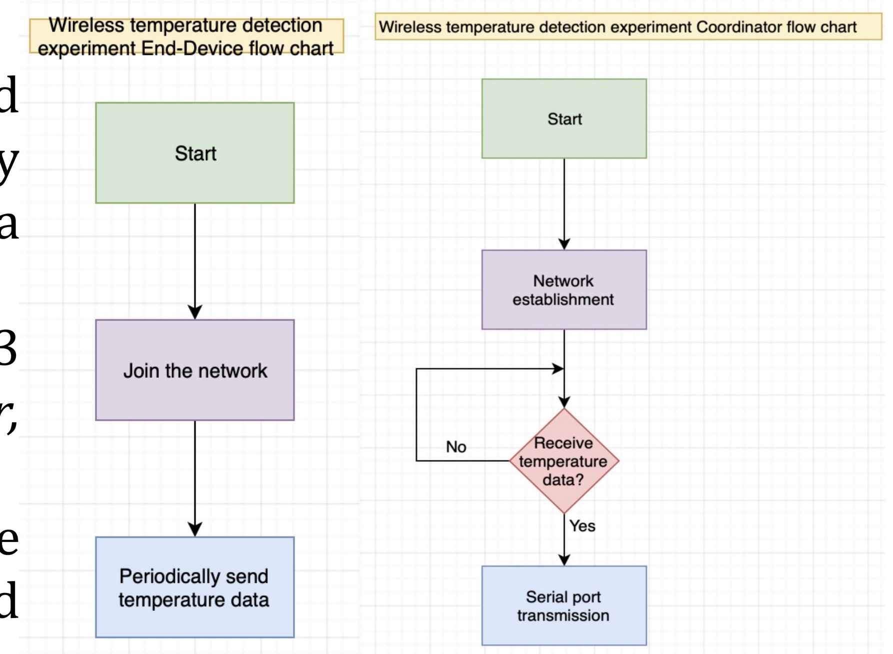

Figure 2. Flow Chart of End Device and Coordinator

- The signal coverage is typically within the range of 10-100m.
- Battery life can be extended as devices can be set to PM2 mode (sleep mode) when not in use.

Properties of ZigBee [1][2]:

- Uses O-QPSK modulation and data bits mapped using DSSS.
- CSMA-CA used to access channel.
- Detects errors using 16-bit CRC.
- Can operate using only 8-bit MCU.
- Encryption using 128-bit AES technology for secure data transfer.

Why ZigBee?
The ZigBee properties ensure that the system developed will have:

- High reliability
- High security
- Low power consumption
- Low costs

Design

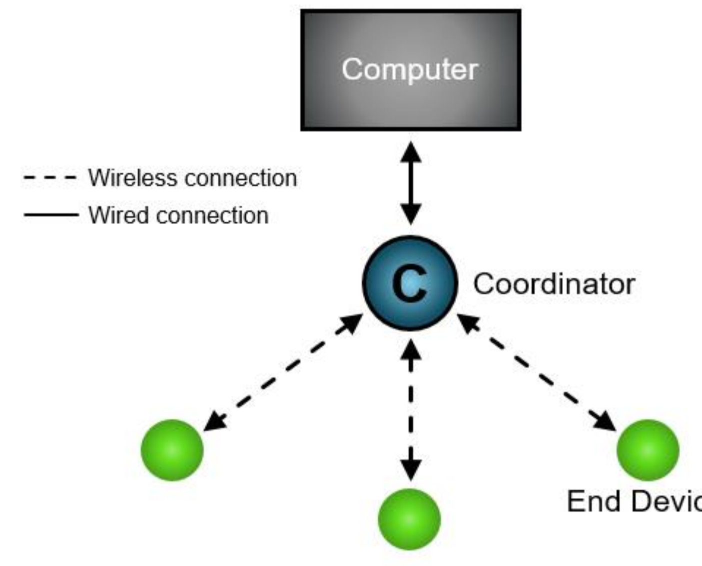

Figure 3. System Design with Star Topology

- The system developed uses the ZigBee standard to establish a wireless sensor network that operates on the 2.4 GHz band.
- It uses a combination of wireless and wired connections.
- The ZigBee network uses the *star network topology:* every end device only communicates with the coordinator and not each other.
- The coordinator is wired to a computer that monitors and manages the received data.
- The end device is composed of a data acquisition unit (temperature sensor), a ZigBee wireless communication module (using CC2530 chip), and a power supply (batteries).

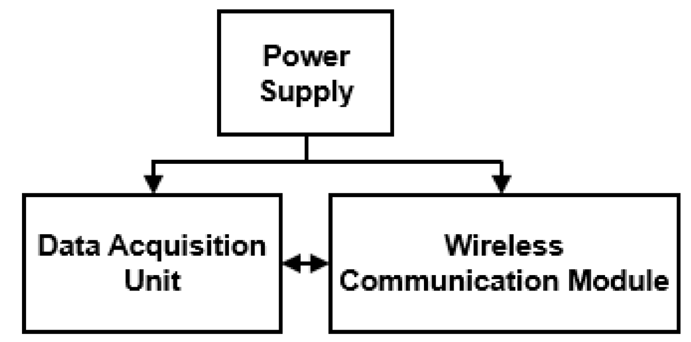

Figure 4. Basic Block Diagram of End Device

- To extend system lifespan, the system can be programmed to enter "sleep mode": end devices only activate when the coordinator requests for data.
- Sleep mode can also reduce risk of interference since system will free up the 2.4 GHz band for other devices using the band.

Testing

Methods

Figure 5. Setup of Physical System

System Operability Test:

1. Ensure that all end devices are working individually. Each is able to collect data and communicate with the coordinator.
2. Activate all three end devices and ensure that they can simultaneously communicate with the coordinator.
3. Measure the limit of the signal coverage of the end devices.
4. Separate the end devices in different rooms to observe the behavior of signal transmission when a physical barrier is present.

System Lifespan Test:

1. Measure the power content of the batteries of a single end device.
2. Measure the power consumption of the device when it is active and also when it is idle.
3. Determine the daily power consumption of the device and calculate its lifespan.

Results

The prototype is able to collect sensor data from the end devices and wirelessly transmit it to the coordinator. Real-time values from each end device are simultaneously displayed to the user through the interface shown in Figure 6.

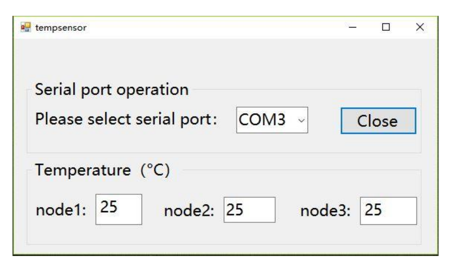

Figure 6. Display for Sensor Data

Final results of prototype:

- 17m is the maximum distance achieved for successful transmission.
- When the coordinator and end devices were placed in different rooms, the performance of the system was largely unaffected – the same maximum distance was achieved.

Conclusion

The final prototype developed is able to wirelessly transmit sensor data from 3 different end devices to a coordinator. Real-time data values are presented on the computer through a user-friendly interface. The transmission range did not meet the initial goal of 30m, but there is potential for improvement.

Future Recommendations:

- Signal coverage can be improved by increasing the power of the transmitted system. However, this would mean greater power consumption of the end device, thus shorter lifespan. A balance must be found between power consumption and signal coverage to obtain optimal results.
- Other topologies (such as tree network) can also help to extend the range of the system.

Budget Summary:
Single board (includes CC2530 chip): 29 CAD
Temperature sensor: 1 CAD
Emulator: 9 CAD

References

[1] Farahani, S. (2008). *ZigBee wireless networks and transceivers* (pp. 1-23). Burlington, Mass.: Newnes/Elsevier.
[2] Gislason, D. (2008). *Zigbee wireless networking*. Oxford: Newnes.