

Poster Abstract: An IoT Mesh Network for a Smart Refrigeration Monitoring System

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Abstract—A major challenge of the next decade is food scarcity and food waste. Smart automation refrigeration systems have emerged, but the devices, methods and outcomes vary significantly. In this work, a smart refrigerator IoT infrastructure is built to investigate system reliability and consistency across heterogeneous data collection devices. The system uses IP-based communications, wireless sensor data, cloud storage and processing, controller actuation, and an mobile app. A temperature report case study provides preliminary results.

I. INTRODUCTION

Food waste contributes significantly to food scarcity. Addressing this problem involves monitoring and analyzing food-related data by many different stakeholders. Refrigerators are a key source of data that may indicate causes and possible solutions [1]. [2] and [3] use sensing, monitoring, and local controllers with a smart phone to send data, and [4] used video sensors with Android App, Raspberry PI, and XiamoMi WiFi adapters. The system was found to need better performance from the sensors and power supply. [5] used an ESP32 to measure and store temperature readings continuously and leakage. Commonly, these systems are limited in terms of the level of network connectivity, lack interoperability, and behave inconsistently as wireless devices.

This work investigates smart automation refrigeration systems' IoT mesh networks by building a representative system infrastructure. The study focuses on the impact of variations in device implementations and lack of interoperability that may lead to unreliable outcomes. An experimental prototype of a smart refrigeration system is presented. A diagram of the refrigerator's devices, manually incorporated into the user interface, will in the future develop a heat map of the system. The resulting smart-refrigerator hosts the ability to indicate leakages, provide faster door-ajar reminders, and assist in greater understanding of refrigerator operations, ultimately preventing harmful bacteria from growing on otherwise edible food.

II. SMART REFRIGERATOR IOT MESH NETWORK

As shown in Figure 1, there are three main levels of connectivity within the deployed mesh network. On the lowest

level, end-devices communicate using both Bluetooth and ZigBee with code from TI Code Composer Studio (CCS). As the 2.4GHz throughput of the becomes heavily loaded by large numbers of BLE devices, Zigbee provides 915MHz and 868MHz frequencies to accomodate more devices or traffic. The next level tests the ESP32, HM-10, TI CC1352 LPSTK and LAUNCHXL, and the Nordic Thingy:52. On the third and highest level is the main aggregator-coordinator, an ESP32 with a MSP432 as a memory cache, offloading the data periodically to the cloud through a local Wi-Fi router. Sensors include DHT11 and DHT22 associated with the ESP32 and Raspberry Pico.

A. Software

Firmware was written in C++, using the Arduino framework on PlatformIO and libraries for WiFi, BLE, and Key-Value storage. PlatformIO allowed for migration from the Arduino IDE, and enabled building from the command line. The nanopb library was used for protobuf support, and NimBLE-Arduino was used for BLE support. The back-end was written in Go, and the display was in Flutter, a cross-platform GUI with built-in support for JSON, Bluetooth and protobuf integration. The built system provides data on a physical interface, serial plot, web-page, and mobile app so the user is not bound by platform or application.

B. Comments on Integration

TI CC1352 is the core processor of both the LPSTK and the LaunchXL, and furthermore the LaunchXL is used as an intermediary to physically flash-program the LPSTK. An ESP32 module is used to establish communication via Wi-Fi to a back-end and inter-device connections. LPSTK, Nordic Thingy52s and Raspberry Picos are incorporated into the wireless network via BLE. The Pico was connected to an HM-10 adapter via UART. The HM-10 adapter is a TI CC254x device with BLE5 support, which can be controlled via AT commands. The Nordic broadcasts the ambient temperature, whereas TI default firmware requires the hub send it a message before it will broadcast ambient temperature. The Pico needs a custom firmware which collects data and sends it via the

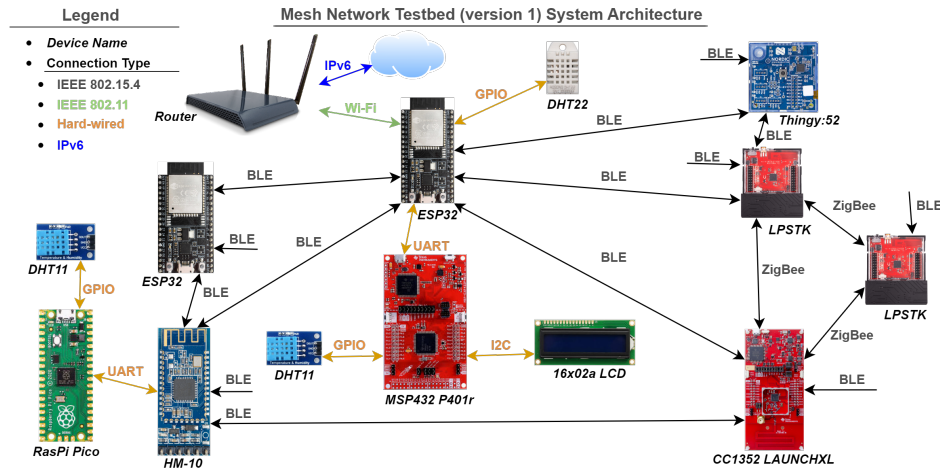


Fig. 1. Mesh Network Test-bed System Architecture

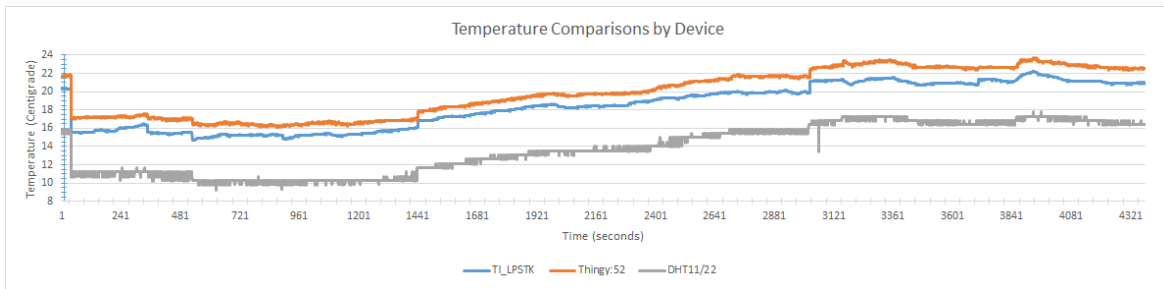


Fig. 2. Comparison of Temperatures between devices over 5000 seconds

HM-10 to a hub. The task of constructing a printed circuit board (PCB) for the backpacking and eventual combination of associated development kits is now much simpler, and the standardization behind typical system-on-chip development kits in general is greatly beneficial to the continuation of the IoT paradigm shift.

Figure 2 shows a case study for measuring outputs of the various temperature sensors. As shown, while there is variation in the values collected, the trends follow fairly closely over the 5000 second data collection time. Additional considerations are slight delay differences in collection, processing, and transmission, power fluctuations, and energy loss at different times. Future work will include an power monitoring system and an energy harvesting infrastructure.

III. CONCLUSIONS

Heterogeneous IoT systems require an unprecedented level of planning for interoperable low-cost wireless communications systems. This work focused on a smart refrigeration system, in communications hardware and software, as a reference for practitioners and to gauge the challenges in deployment.

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REFERENCES

- [1] A. S. Salonen, "Ordinary overflow: Food waste and the ethics of the refrigerator," *Food and Foodways*, vol. 30, no. 3, pp. 145–164, 2022, doi: 10.1080/07409710.2022.2089828. [Online]. Available: <https://doi.org/10.1080/07409710.2022.2089828>
- [2] E. Dekoninck and F. Barbaccia, "Streamlined assessment to assist in the design of internet-of-things (iot) enabled products: A case study of the smart fridge," *Proceedings of the Design Society: International Conference on Engineering Design*, vol. 1, pp. 3721–3730, 2019.
- [3] J. Liegeard and L. Manning, "Use of intelligent applications to reduce household food waste," *Critical Reviews in Food Science and Nutrition*, vol. 60, no. 6, pp. 1048–1061, 2020, doi: 10.1080/10408398.2018.1556580. [Online]. Available: <https://doi.org/10.1080/10408398.2018.1556580>
- [4] H.-H. Wu and Y.-T. Chuang, "Low-cost smart refrigerator," in *IEEE International Conference on Edge Computing (EDGE)*. Hawaii USA: IEEE, 2017, pp. 228–231.
- [5] S. Budijono, "Smart temperature monitoring system using esp32 and ds18b20," *IOP Conference Series: Earth and Environmental Science*, vol. 794, no. 1, pp. 1–7, 2021.