DOI 10.5162/SMSI2025/P06

Comparison of Point-to-Point LPWA Smart Sensors with Low-Power Local Mesh Networking Solutions for Industrial Refrigeration and Operational Parameter Detection

In our presentation, we will outline the expectations for an effective IoT solution in industrial refrigeration, which is an excellent example. We will explore two distinct approaches to meet these requirements: cellular LPWA-based point-to-point solutions and local sub-GHz wireless ad-hoc mesh network-based distributed sensor systems. Our comparison will focus on technical, practical, and economic factors, complemented by application examples for both technologies.

We will discuss the challenges involved in parameter detection that support predictive maintenance, data collection for marketing purposes, and geolocation. Additionally, we will demonstrate how our E-IoT ecosystem addresses the needs of this industry by describing the complete asset chain, from sensors to the Cloud, encompassing wireless communication, Cloud services, and dashboard software.

Our presentation will provide insights into our hardware solutions for smart sensors, as well as our battery-operated local sensor networks and their gateways, which are designed for long service life.

We will include details on connectivity techniques, solution reliability, and data security protocols. On the hardware side, we will give an overview of the battery and circuit protection solutions that support operation in harsh environments.

The presentation offers best practices for engineers and data scientists active in the field of parameter detection, and data processing to be able to use the best smart sensor configuration to gather data for their analysis.

Endrich is committed to helping its customers leverage IoT technology to connect their traditional devices to networks and gather valuable data. This data can be utilized in a range of applications, including marketing, predictive maintenance, and remote monitoring. Our goal is simple: "We make your device smart."
In this summary, we'll showcase how we applied this approach to transform industrial refrigerators.

Advanced Collection of Refrigerator Data

Integrating traditional devices with the Internet opens a wide array of possibilities for collecting operational data and ensuring the appliance functions efficiently. By connecting for example a fridge or freezer to a cloud-based database, we can not only monitor its performance but also process and display this data in real time. This requires equipping the refrigerator **with various sensors** and a **reliable communication** channel, enabled by the hardware and software elements of the E-IoT (Endrich's own Internet of Things ecosystem) concept. The primary goal is to gather data that helps maintain optimal operating conditions, thus ensuring that the refrigerator operates effectively while providing valuable insights into its usage patterns. Of course, this system applies to any devices that need additional IoT functions.

Through continuous monitoring of critical parameters such as temperature and humidity, users can be assured that their refrigerator maintains the appropriate cooling environment for food storage. Additionally, these systems help to prevent mishaps such as the door being left open accidentally or detecting potential defrosting due to power cuts. The sensors can send alerts if such conditions arise, ensuring timely action to avoid food spoilage. This is particularly useful in cases where users are away from home for extended periods but still want to ensure that their stored food is safe.

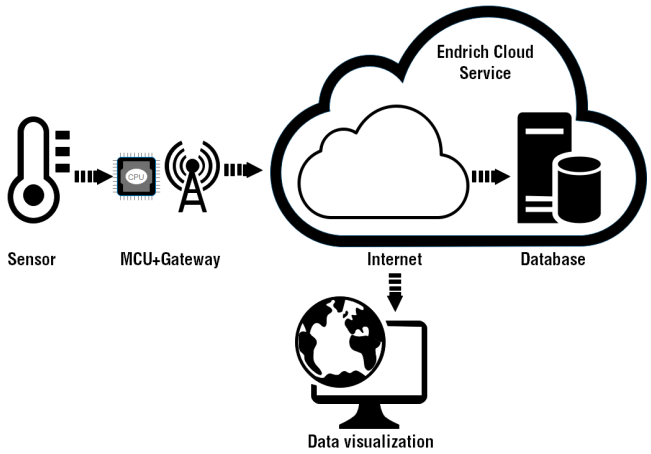
The telemetry unit installed in these refrigerators offers a level of predictive maintenance that was previously unavailable in traditional appliances. By analyzing data related to power consumption, noise levels, and vibrations, the system can detect early signs of wear and tear or impending failures. This preemptive approach allows for repairs or maintenance to be performed before the refrigerator breaks down entirely, potentially saving significant costs and inconvenience for the user.

In terms of safety, the system plays a dual role. First, it monitors basic operational conditions, such as increasing internal temperatures, and can raise alarms if defrosting is imminent due to power failure or the door being left open. Second, it addresses the physical security of the appliance itself. For instance, built-in acceleration sensors or GPS-based tracking devices can alert the owner to unauthorized movement of the fridge, particularly in commercial or public spaces where theft or vandalism might be a concern. This ensures both operational and material safety are prioritized.

The ability to control and monitor the temperature of the refrigerator, as well as track energy consumption, also contributes significantly to more economical operation. Businesses can use this data to optimize cooling cycles, reducing energy costs without compromising food safety. In commercial environments, such as grocery stores or convenience shops, monitoring door openings provides valuable insights. The frequency and duration of door openings can help businesses understand customer behavior, track inventory flow, and calculate sales patterns. This data-driven approach can optimize store operations, minimize waste, and enhance marketing strategies.

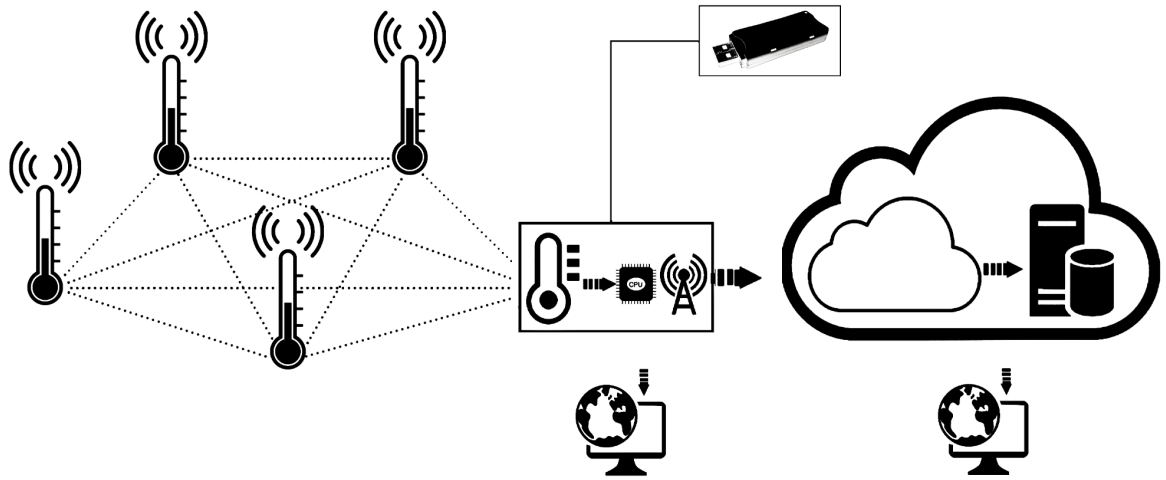
The Endrich smart refrigerator concept offers several hardware solutions, all built around easy-to-install sensor modules. These sensors collect data on various parameters and wirelessly transmit this information to a dedicated cloud database. Transmission is achieved either directly through a mobile phone network or via a local mesh WLAN (Wireless Local Area Network) using a GSM gateway. Temperature and humidity sensors, light intensity detectors, and mechanical sensors such as acceleration sensors and MEMS microphones are strategically placed inside the refrigerator compartment to monitor key metrics.

For monitoring door status, the system offers flexibility. A magnetic sensor activated by the door magnet can detect when the door is opened or closed. Alternatively, a six-axis acceleration sensor can be used to measure the angle of the door opening, providing more detailed insights into



how the appliance is being used. Most of these sensor units are equipped with a backup battery offering seamless operation even in power failure situations. In freezers, where the harsh environment does not enable of using rechargeable batteries, special long-life disposable batteries are used. Depending on the frequency of data transmission, these low-power devices can operate for a long time and can report power failures as well thanks to the backup power solutions.

Communication between the sensors and the central system operates on the sub-GHz (868/915 MHz ISM) band, a low-power wireless communication channel that supports the installation of individual sensors in various locations inside the refrigerator. This approach allows for more flexible sensor placement, enhancing the system's ability to monitor different aspects of the appliance simultaneously. All sensor units form a local mesh network, which is connected to a WLAN-LPWA or LTE (Low Power Wide Area or 4G) gateway. This gateway is usually integrated into a power consumption monitoring device, enabling it to transmit all collected data to the cloud via a specialized NB-IoT/LTE-M/2G or LTE GSM modem.



The advantage of this setup is clear: it not only monitors a single refrigerator but can also handle multiple units located in the same commercial building. For instance, a chain of refrigerators in a grocery store or gas station can all be connected to the cloud using the same system. Since the gateway operates on mains voltage, there are no concerns about power consumption during frequent data transmissions. In case of a power outage, an integrated supercapacitor provides enough reserve energy to send out one or two final status messages, alerting the user to the power failure and triggering preventive actions.

The LPWA communication technology (specifically NB-IoT) and the low-power ARM-M0+ microcontroller are designed to ensure long battery life for the sensors, minimizing the need for frequent recharging. This, combined with extremely low telecommunication costs—prepaid SIM cards can be purchased for just EUR 10, with 500 MB of data valid for 10 years—makes this an affordable and efficient solution for both consumers and businesses alike.

In terms of data utilization, several software services are available. Standard options include a smartphone app for real-time monitoring, a Data Access API for developers to integrate the system with other platforms, and a web-based interface for administration and data visualization. Custom software solutions can also be developed to meet specific customer needs, allowing businesses to leverage this data for unique applications.

In summary, by integrating our various sensors and IoT technologies into traditional refrigerators, we can transform them into smart appliances that offer a range of benefits. From improved energy efficiency and predictive maintenance to enhanced security and valuable business insights, these advanced systems represent the future of refrigeration in both residential and commercial settings. The ease of installation, combined with long-lasting, low-power operation, makes these solutions accessible and practical for various users, ensuring that refrigeration technology continues to evolve in line with the demands of modern life.