IT UNIVERSITY OF COPENHAGEN

Internet Of Things Report

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1 Q1 — Networked Sensor Device for tracking

We need a sensor device to track assets (vehicles and animals) in two wildlife parks:

- **Knuthenborg Safari Park**, Denmark
- **Mpala Research Center**, Kenya

The parks are large, and the devices must be able to track the location of the assets with a high degree of accuracy. The devices will be used to monitor the animals' movements and behavior, as well as to track the vehicles used for research and conservation efforts. The parks are located in different parts of the world, and the devices must be able to operate in different environments. The devices must be able to withstand harsh weather conditions, including extreme temperatures, rain, and dust. The devices must also be able to operate in remote areas with limited access to power and communication networks.

1.1 Functional requirements

- Location tracking (GPS)
- Measure acceleration (motion state)
- Measure particulate matter concentration
- Record data every hour (preferably real-time reporting)

1.2 Non-functional requirements

The devices must have an accuracy of at least 500 meters. Apart from that we need to consider environmental conditions, battery life, size, and cost.

Given that the devices will be used in wildlife parks, they must be able to withstand extreme temperatures, rain, and dust. Knuthenborg Safari Park is located in Denmark, where temperatures in worst case can drop to -20 degrees Celsius in winter and have hot humid summers. Mpala Research Center is located in Kenya, where temperatures can reach close to 40 degrees Celsius in summer.

Because the device needs to be able to track animals as many types of animals are present in the parks, the size of the device must be small enough to be attached to the animals without causing discomfort.

- Accuracy: $\geq$500 m or more
- Withstand extreme temperatures (e.g., -20 to 40 degrees Celsius)
- Withstand rain and dust (IP67 or better)
- Battery life: 0.5 years or more
- Track animals and vehicles
- Size has to be Small
- Cost: $100 or less

1.3 Device selection

1.4 Acceleration

For the acceleration we can would want to use a accelerometer. An example of a sensor could be the ADXL345, which measures at 3mm x 5mm x 1mm, has a range of up to +/-16g, and can operate in temperatures from -40 to +85 degrees Celsius. ADXL345 can measure the acceleration of the device in three dimensions so vertical movement of birds can be detected too if needed. It has a startup of 1.4ms, with a resolution of 13 bits, typically operates at 2.5V, and has a draw of 23μA in normal operation and 0.1μA in standby mode.

1.5 Particulate matter concentration

For the particulate matter concentration we can use a laser particle counter. The laser particle counter is a small device that can measure the concentration of particulate matter in the air. It uses a laser to detect particles in the air and can provide real-time data on the concentration of particulate matter.

1.6 Location tracking

For the location tracking, we can use a GPS module. The GPS module is a small device that provides real-time location data by using satellite signals to determine the device's position. It offers accurate tracking even in remote areas like Mpala. An example of such a module is the u-blox MIA-M10, which measures just 4.5 mm x 4.5 mm x 1 mm. It supports our needs with a temperature range from -40°C to +85°C, has a cold start time of about 30 seconds, and has a positional accuracy of up to 2.5 meters. It has power consumption, drawing approximately 22mA at 3.3V during continuous tracking. However, with power supplied to the VBAT pin, it can retain satellite data and significantly reduce startup time to 1-10 seconds, using less energy per fix. In deep sleep mode with VBAT maintained, the module draws as little as 1μA.

1.6.1 Microcontroller and communication

Given that we want to send data over a long distance, we can use LoRaWAN for communication. An example of a microcontroller that supports LoRaWAN is a STM32WLE5 module like the RAK3172 STM32WLE5. The module

1.6.2 Power supply

The device will be powered by a rechargeable lithium-ion battery. The battery should be able to provide power for at least 0.5 years of operation.

To know how much power we need, we can calculate the power consumption of the device. This will be a naive calculation, as we have not yet tested real-world power consumption, but it will give us an idea of the power requirements.

We know we need to send data every hour, and we can assume that the device will be in sleep mode most of the time to conserve power. We assume that the GPS module will be active for 10 seconds every hour to get a location fix, the accelerometer will be active for 1 second every hour to measure acceleration, and the particulate matter sensor will be active for 1 second every hour to measure particulate matter concentration. Assuming the following power consumption:

- GPS module: 22mA for 10 seconds every hour
- Accelerometer: 23μA for 1 second every hour
- Particulate matter sensor: 68mA for 1 second every hour
- Microcontroller: 10mA for 1 second every hour
- LoRaWAN transmission: 20mA for 1 second every hour
- Sleep mode: 1μA for $(60 * 60) - 10 - (1 * 4) \simeq 3586$ seconds every hour

For additional power supply, we can consider energy harvesting. A common source would be using a solar panel. A possible issue would be that the device is not always exposed to sunlight, especially in the case of animals that might cover the cell from the sun with their body, fur or dirt.

The device will also have a solar panel to recharge the battery when it is exposed to sunlight. The solar panel will be able to provide enough power to keep the battery charged even in low-light conditions.

2 Question 2

3 Describe the system architecture and motivate your design choices

4 Question 3

5 Sensor precision VS sensor accuracy

Sensor **precision** refers to the degree to which repeated measurements under unchanged conditions show the same results. In other words, it indicates how consistent the measurements are. For example, in dart if all darts land in the same area, even if that area is far from the bullseye, the sensor is precise. Precision does not imply correctness; it only indicates that the measurements are repeatable and consistent.

Sensor **accuracy**, on the other hand, refers to how close a measured value is to the true value. A sensor can be precise but not accurate if it consistently gives the same incorrect measurement. Conversely, a sensor can be accurate but not precise if it gives varying measurements that are close to the true value. For example, if all darts land close to the bullseye, the sensor is accurate. Accuracy indicates correctness and reliability of the measurements.

5.1 MQTT and it's role in IoT

MQTT (Message Queuing Telemetry Transport) is a lightweight messaging protocol designed for low-bandwidth, high-latency, on unreliable networks[4]. It is a publish-subscribe messaging protocol that theoretically can run over any transport protocol that ensures ordered, lossless, bi-directional connections. However, it is most commonly used over TCP/IP.

MQTT plays a crucial role in IoT by providing efficient communication for resource-constrained devices. With MQTT devices can send data to a central server (broker) without needing to establish a two way connection or wait for a response. This is particularly beneficial for battery-powered devices, as they can send their data and then enter a low-power sleep mode, conserving energy while still maintaining connectivity.

Its lightweight design minimizes bandwidth usage and power consumption, making it ideal for battery-operated devices. The protocol's small packet size and minimal overhead allow for efficient operation on bandwidth-constrained networks. MQTT's quality of service levels ensure reliable message delivery according to application needs, while its last will feature helps detect unexpected device disconnections.

MQTT is particularly valuable in IoT applications because devices can publish their data to a broker without maintaining persistent connections. This publish-subscribe model enables devices to send data and then enter low-power sleep modes, significantly extending battery life while maintaining effective communication.

5.2 All relevant layers of Wi-Fi, Bluetooth, LoRa and LoRaWan and their use in IoT

WiFi and Bluetooth are relevant for the OSI model layers 1 (physical) and 2 (data link), while LoRa and LoRaWAN are relevant for the OSI model layers 1, 2, and 3 (network).

WiFi and Bluetooth physical layer operate in the 2.4 GHz radio frequency band. The data link layer is responsible for the MAC protocol, which is used to control access to the transmission channel. Bluetooth uses a frequency-hopping spread spectrum (FHSS) which also belongs to the data link layer[2, 1]. These technologies are typically used for short-range communication, such as connecting devices within a home or office network. The technologies are designed for high-bandwidth applications, such as video streaming and file transfer. WiFi has a range of up to 100 meters, while Bluetooth has a range of up to 10 meters. For IoT applications, WiFi and Bluetooth are often used for local communication with cameras, sensors, and other devices that require high data rates and low latency.

LoRa is a physical layer technology that uses Chirp Spread Spectrum (CSS) modulation to achieve long-range, low-power communication. It operates in the sub-GHz frequency bands (e.g., 433 MHz, 868 MHz, 915 MHz). LoRaWAN is built on top of LoRa and adds network layer functionality. It defines the communication protocol and system architecture for the network, handling critical functions such as device authentication, data encryption, adaptive data rates, and end-to-end security[3]. While LoRa enables the long-distance link between devices, LoRaWAN provides the networking framework that allows multiple devices to communicate with gateways connected to the internet. With LoRaWAN, devices can send small amounts of data over long distances (up to 15 km in rural areas) while consuming very little power, making it ideal for remote battery-operated IoT devices.

5.3 Security features of the LoRaWAN protocol

LoRaWAN has AES-128 encryption, which is a symmetric encryption algorithm that uses a 128-bit key to encrypt and decrypt data. This ensures that only authorized devices can access the data transmitted over the network/in the air.

LoRaWAN also has a unique device identifier (DevEUI) and application identifier (AppEUI) for each device, which helps to identify and authenticate devices on the network. The DevEUI is a globally unique identifier assigned to each device, while the AppEUI is used to identify the application that the device is associated with.

6 Bibliography

[1] Control Engineering. *Wi-Fi and the OSI model*. https://www.controleng.com/wi-fi-and-the-osi-model/. Accessed: May 16, 2025. 2014.

[2] GeeksforGeeks. *What is Bluetooth?* https://www.geeksforgeeks.org/bluetooth/. Accessed: May 16, 2025. 2024.

[3] LoRa Alliance. *What is LoRaWAN®?* https://lora-alliance.org/about-lorawan/. Accessed: May 16, 2025.

[4] MQTT.org. *MQTT: The Standard for IoT Messaging*. https://mqtt.org/. Accessed: May 16, 2025.