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# Internet Of Things Report

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**Author**

Patrick Bohn Matthiesen

**Email**

pmat@itu.dk

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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. tun

## 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 23 $\mu$ A in normal operation and 0.1 $\mu$ A in standby mode[1].

### 1.5 Particulate matter concentration

For the particulate matter concentration, we can use the Bosch BMV080 laser particle sensor. This compact sensor measures only 4.2 mm x 3 mm x 3.5 mm, making it ideal for our size constraints. A key advantage of the BMV080 is its fan-less. Unlike traditional particulate matter sensors that require fans to draw air through the sensing chamber, the BMV080 is able to measure particulate matter concentration without a fan. This is would be beneficial for our use case, as it reduces the risk of dust buildup on the sensor. Dust is especially problematic in wildlife environments like the parks that we want to deploy the devices in, as it can clog the fan and affect the sensor's performance. The sensor operates with a supply voltage of 1.8 to 3.3 V and has a quick start-up time of 1.2 seconds. It can function in temperatures ranging from -15°C to +65°C, which covers our operational requirements. The BMV080 is has a sleep current of less than 3 $\mu$ A and an average total current of less than 68mA at 0.97Hz output data rate. The

datasheet conveniently also specifies that in duty cycling mode that we will use, then the sensor will use about 0.6mW each hour.

## 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 1 $\mu$ A.

### 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 the RAK3172 module based on the STM32WLE5 chip[6]. The module has an ARM Cortex-M4 core, which fits the host requirement for the Bosch BMV080 sensor. The RAK3172 measuring only 15 mm x 15.5 mm x 3.5 mm, making it suitable for our small-size requirements.

The module supports a temperature range from -40 °C to +85 °C, which is ideal for the extreme conditions in both wildlife parks. It operates with a supply voltage of 2.0 to 3.6 V, compatible with our other components. The module provides multiple I/O ports including UART, SPI, ADC, GPIO and most notably I2C which many of the sensors require.

For communication, the RAK3172 supports frequency ranges from 150 MHz to 960 MHz with a bandwidth from 7.8 kHz to 500 kHz, appropriate for long-distance, low-power transmission required in large wildlife parks. It supports multiple regional bands including EU433, CN470, RU864, IN865, EU868, AU915, US915, KR920, and AS923, making it deployable in both Denmark and Kenya with the appropriate regional settings.

A plus for the RAK3172 is the low power consumption of just 1.69  $\mu$ A in sleep mode, which is critical for our battery life requirements. In operation i would assume it would draw around 10 mA for processing and communication tasks, which is manageable within our power budget. The module includes

256 KB flash memory with ECC (Error Correction Code) and 64 KB RAM, providing sufficient storage for our sensor data and communication protocols.

For our application, we would use this microcontroller to collect data from the sensors (GPS, accelerometer, and particulate matter sensor), process the data, and transmit it over LoRaWAN to a base station.

As we want to at least be sure we can send data 1km, we will set the LoRa transmission power to 14 dBm, which is the maximum allowed in the EU868 band. This will allow us to achieve a range of up to 10 km in open areas, which is more than sufficient for our needs in both wildlife parks.

### 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 =  $220\text{mA} \cdot \text{s}$
- Accelerometer:  $23\mu\text{A}$  for 1 second every hour =  $0.023\text{mA} \cdot \text{s}$
- Particulate matter sensor: 68mA for 1 second every hour =  $68\text{mA} \cdot \text{s}$
- Microcontroller (active processing): 10mA for 13 seconds every hour =  $130\text{mA} \cdot \text{s}$
- LoRaWAN transmission: 20mA for 1 second every hour =  $20\text{mA} \cdot \text{s}$
- Sleep mode:  $1.69\mu\text{A}$  for  $(60 * 60) - 10 - 13 - 1 \simeq 3576$  seconds every hour =  $6.044\text{mA} \cdot \text{s}$

Based on these values, we can calculate the total power consumption per hour. We need to use the formula for power consumption  $P = I \cdot t$ , where  $I$  is the current in milliamperes (mA) and  $t$  is the time in seconds (s). The

total power consumption per hour will be the sum of the power consumption of each component. The power consumption will be given in milliampere-seconds ( $\text{mA} \cdot \text{s}$ ) and then converted to milliampere-hours ( $\text{mAh}$ ) by dividing by 3600 seconds per hour.

$$\begin{aligned}\text{Total per hour} &= 220\text{mA} \cdot \text{s} + 0.023\text{mA} \cdot \text{s} + 68\text{mA} \cdot \text{s} + 130\text{mA} \cdot \text{s} + 20\text{mA} \cdot \text{s} + 6.044\text{mA} \cdot \text{s} \\ &= 444.067\text{mA} \cdot \text{s} \approx 0.1234\text{mAh per hour}\end{aligned}$$

For a 6-month (0.5 year) deployment, we can calculate the total battery capacity required:

$$\begin{aligned}\text{Total capacity} &= 0.1234\text{mAh} \times 24\text{h} \times 365.25\text{days} \times 0.5\text{year} \\ &= 0.1234\text{mAh} \times 24\text{h} \times 182.625\text{days} \\ &= 0.1234\text{mAh} \times 4,383\text{h} \\ &= 540.86\text{mAh}\end{aligned}$$

To account for battery self-discharge, temperature effects, and capacity degradation over time, we should include a safety factor of at least 1.5:

$$\begin{aligned}\text{Required capacity} &= 540.86\text{mAh} \times 1.5 \\ &= 811.29\text{mAh} \approx 800\text{mAh}\end{aligned}$$

Therefore, a 600mAh lithium-ion battery would be sufficient for our application. However, to provide additional reliability and to account for potential harsh operating conditions in wildlife environments, we would recommend using a 1000mAh battery, which provides extra margin while still maintaining a reasonable size and weight.

For additional power supply, we can consider energy harvesting. A small solar panel rated at approximately 0.5W (measuring around  $50\text{mm} \times 50\text{mm}$ ) would be sufficient to recharge the battery during daylight hours. With an average of just 1-2 hours of effective sunlight per day, this would provide enough additional energy to significantly extend the battery life beyond the required 6 months.

A potential 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. However, the generously-sized battery should compensate for periods without solar charging. The combination of a 1000mAh battery with solar recharging would likely enable the device to operate for well over a year in most deployment scenarios, and potentially indefinitely in locations with good sun exposure.

## 1.7 Device enclosure

To protect the device from environmental conditions, we can use an enclosure that is rated at least IP67. This means that the enclosure is dust-tight and can withstand immersion in water up to 1 meter for 30 minutes. The enclosure should also be able to withstand extreme temperatures, so we can use a material that can withstand temperatures from -40 to +85 degrees Celsius. We still need to allow air to get through the enclosure to allow the particulate matter sensor to do its work. A suitable material for the enclosure could be polycarbonate or ABS plastic, which are both durable and can withstand extreme temperatures. The enclosure should also be small enough to be attached to the animals without causing discomfort.

All the components we have selected would cover an area of about:

- ADXL345: 3mm x 5mm x 1mm
- BMV080: 4.2mm x 3mm x 3.5mm
- u-blox MIA-M10: 4.5mm x 4.5mm x 1mm
- RAK3172: 15mm x 15.5mm x 3.5mm
- Battery: 30mm x 20mm x 5mm (assuming a small lithium-ion battery)
- Solar panel: 50mm x 50mm x 2mm (assuming a small solar panel)

The total area of the components would be approximately:

$$\begin{aligned}\text{Total area} &= (3 \times 5 \times 1) + (4.2 \times 3 \times 3.5) + (4.5 \times 4.5 \times 1) + (15 \times 15.5 \times 3.5) + (30 \times 20 \times 5) + \\ &= 15 + 44.1 + 20.25 + 817.5 + 3000 + 5000 \\ &= 8856.85 \text{ mm}^3\end{aligned}$$



## 2 Question 2 — Wildlife Monitoring System

Building on the sensor device designed in Question 1, we now develop a monitoring system for tracking wildlife and vehicles in the two parks. This system will collect and analyze data from our hourly measurements to support wildlife research and park management.

### 2.1 System Architecture and Data Flow

The system uses a practical three-tier architecture that efficiently handles data from sensor devices. We want all the nodes to be independent and be able to just send data. So we want to have gateways placed strategically in the parks accounting for things like trees, buildings, and other obstacles that might block the signal. Each gateway will be connected to a LoRaWAN network server, which will then forward the data to central servers for storage and analysis.

I am not sure what the best option would be for sending data from gateways to the central servers, but I will assume that we can use a cellular network, satellite uplink, or fixed wireless connection depending on the local infrastructure. I have been able to see on maps that each park has a few buildings around the parks that might be suitable for placing the gateways. Given the size of Knuthenborg we might only need 3-5 gateways, but given the bigger size of Mpala we might need more.

The idea of the central servers is to have a place to process and store the data collected from the sensor devices. With the servers having processed the data it will also be easier to create user applications that can visualize the data and provide insights for researchers and park managers. Data flowing in from the sensor devices will be stored in a time-series database, which is well-suited for handling the hourly data from multiple devices. The results from analytics on the servers will be stored in a separate relational database. The system architecture is illustrated in Figure1.

#### 2.1.1 Scalability and Flexibility

Setting the system up in layers like this allows us to just add more devices, gateways and servers as needed. Given that each node only sends a message once per hour, the system should be able to handle a large number of devices without any issues. The bigger issue might come down to the gateways depending on how many devices we end up having to support. In a place like Mpala we might not be able to just add more gateways. Servers on the other hand shouldn't be a problem as most applications for analysis would be able

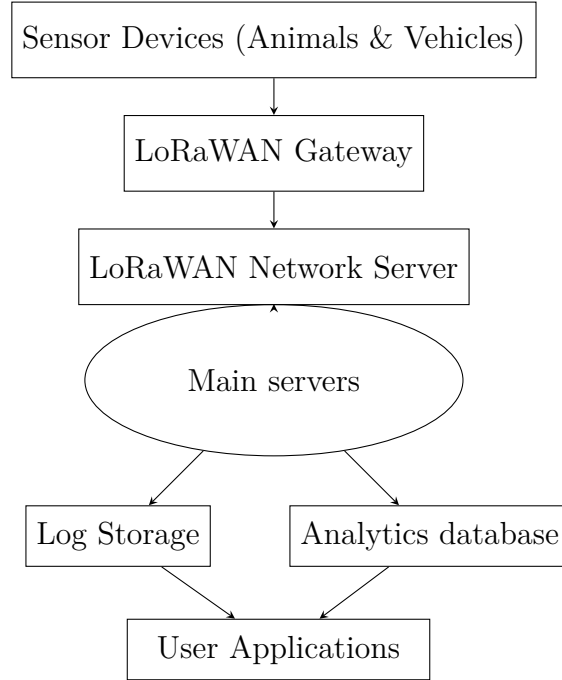


Figure 1: System Architecture for Wildlife Monitoring

to scale horizontally. We can just add more servers to handle the increased load.

## 2.2 Analytics and Data Processing

The key parts of the system is the sensor devices and the servers that allow us to make data analysis on the data collected from the sensor devices. But we don't want to do all the processing on the servers, which would require us to send a lot of data which can be expensive for the devices. So we want to do some of the processing on the devices themselves, which will allow us to save power and bandwidth.

The idea is to use TinyML models on the devices to do some basic processing of the data. The models will be trained to detect changes in the data, which will allow us to filter out meaningless data. For example we might not need to send the animals coordinates, if it has only moved up to 5 meters since the last measurement. This will allow us to save power and bandwidth, while still getting valuable insights from the data.

On the servers we will do more advanced processing of the combined data from all devices. The combination of data from multiple devices will allow us to do flock analysis, which will allow us to see how animals move in relation

to each other. We can also do more advanced analysis of the particulate matter data, which will allow us to see how the air quality changes over time and how it relates to the animals movement. The servers will also be able to draw in things like weather data to see how the weather affects things like the animals movement patterns and the air quality.

Interesting insights that we can get from the data include:

- **Movement Patterns:** How far animals travel, areas they visit, and rest periods.
- **Territory Mapping:** Home ranges and territories for different species.
- **Seasonal Migration:** Patterns in movement across months and years.
- **Air Quality Maps:** Spatial maps of particulate matter concentration.
- **Vehicle Impact Assessment:** Correlation between vehicle locations and pollution patterns.
- **Health Indicators:** Activity levels and potential health issues based on movement patterns.

With the insights the staff in the parks will be able to see how the animals are doing and if there are any issues that need to be addressed. The insights can also be used to see how the air quality is doing in the parks, which can be used to see if there are any issues with pollution or other environmental factors.

Based on the insights we can decide on some ratings for the parks. We could use the data to build a health score based on movement patterns and air quality. The health score could be used to tell the park staff if they need to do a more thorough health check on specific animals or if they need to take action to improve the air quality in the park. We could build a risk assessment based on predictive health analytics. By analyzing historical data, we can identify patterns that precede health issues, allowing us to proactively monitor at-risk animals before they show symptoms.

## 2.3 Conclusion

The proposed monitoring system leverages hourly data collection to create a practical, energy-efficient solution for wildlife tracking. By focusing on what's achievable with periodic rather than continuous monitoring, we create a system that's both feasible to deploy in remote environments and capable of generating valuable insights for research and park management.

### 3 Question 3

## 4 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.

### 4.1 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[5]. 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.

## **4.2 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[3, 2]. 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[4]. 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.

## **4.3 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.

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