LoRaWAN and MIOTY: A Study on Packet Reception and Energy Consumption in the Industrial Internet of Things

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1 Introduction

We report on experiments comparing LoRaWAN and MIOTY LPWAN communication protocols regarding their **range** and **energy consumption**. Experiments were conducted at *ifm electronic GmbH, Tettnang, Germany*, a shared R&D and manufacturing campus. We deployed LoRaWAN and MIOTY devices at various locations on the campus and send a predefined number of packets to a gateway/base station (BS) mounted on the roof at a fixed location. We metered packet loss and energy consumption. To ensure the comparability of the results for LoRaWAN and MIOTY we utilized completely identical hardware for LoRaWAN and MIOTY devices as well as a shared gateway/based station and communications path to the cloud. Section 2 details the design and procedure of the experiments. In Section 3, we present and discuss the results. Section 4 concludes this report.

Key words: IIoT, industry, LPWAN, LoRa, LoRaWAN, MIOTY, benchmarking, network architecture.

2 Experiment Design

Architecture For the experiments, we use the setup shown in Figure 1. Hardware and software components used are listed in the corresponding Table 1. **LoRaWAN/MIOTY** devices send data to a base station **(BS)**, which can receive and forward both LoRaWAN and MIOTY packets [1] .

[1] MIOTY uses the terms *end point* and *base station* while LoRaWAN calls the equivalent devices *end node* and *gateway*. For easier legibility, we will use the terms *device* for the end nodes/end points and *base station* BS for the base station/gateway.

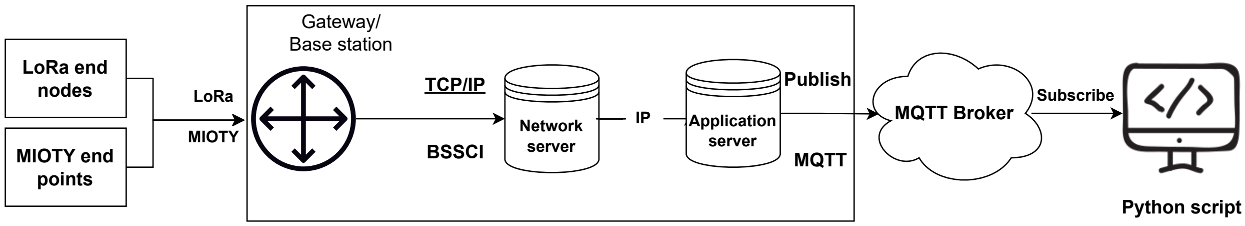

Figure 1: Network architecture used in the experiments

Table 1: Hardware and software used in the experiments

Component	**Description**
LoRaWAN/MIOTY devices	Customized devices (shown in Figure 2 and Figure 3)
Base Station BS	AST-X VIORYTI BS
Network Server	AST-X VIORYTI BS
Application Server	AST-X VIORYTI BS
MQTT Broker	Mosquitto broker, runs on Raspberry Pi 4
Lenovo laptop	Python script: Subscribes to MQTT topic, plots data

The BS checks the integrity of incoming packets and in case of success forwards the packets to the **network server**, which in turn forwards data to the **application server**.

The application server publishes received messages to a **MQTT Broker** to which we subscribe with a script which also analyzes and plots received data.

Metrics We meter the packet reception rate (PRR) at the BS for selected LoRaWAN/MIOTY device locations by calculating the number N of lost packets:

$$N = (1 - \frac{packets\_received}{packets\_sent}) \times 100\% \tag{1}$$

$packets\_sent$ is known, while $packets\_received$ is the number of packets received by the script. Packet loss occurs if the signal strength P_{Signal} at the receiving BS is lower than the sensitivity S of the BS. P_{Signal} is reduced with increasing distance d between sender and receiver. It is also subject to fading, shadowing, reflection, scattering, refraction, diffraction and multipath propagation. Additionally, interference degrades the signal-to-noise ratio (SNR), where $SNR = \frac{P_{Signal}}{P_{Noise}}$. If the SNR is too low, the BS can not separate the signal from the noise floor anymore and thus can not decode packets.

In our industrial setting it is not feasible to quantify those influencing factors, as it requires elaborate measurements and the influencing factors might change over time. Instead our results shall guide the following practical approach: if LoRaWAN/MIOTY devices are deployed at a particular

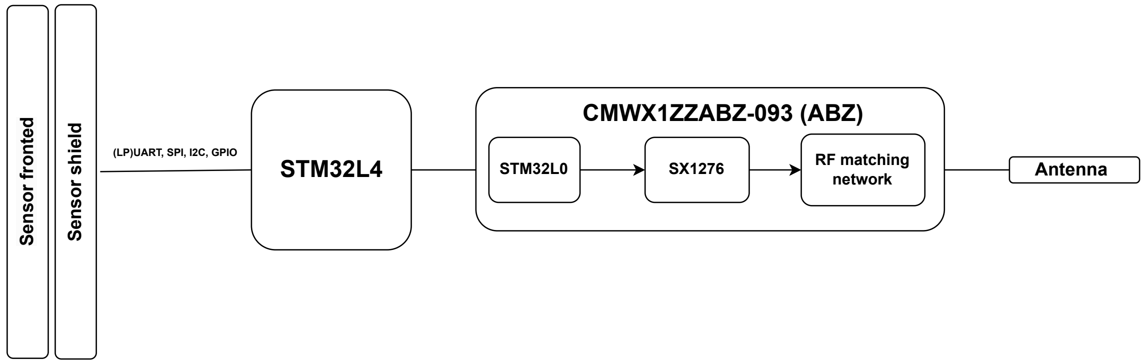

Figure 2: LoRaWAN/MIOTY device block diagram

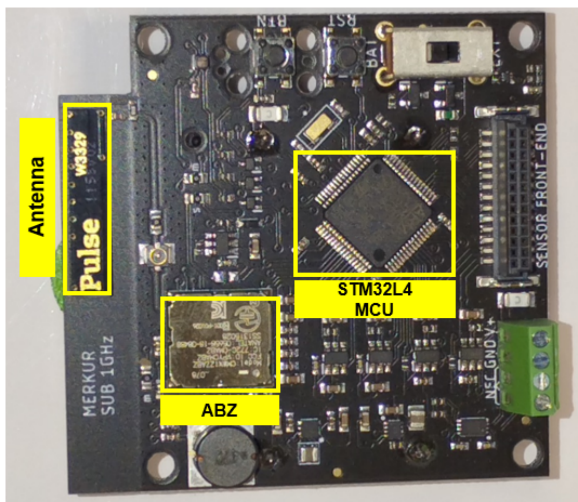

Figure 3: LoRaWAN/MIOTY device

location and packet loss metered at this location is too high (were "too high" is defined by the intended application of the devices), then the BS will either be moved closer to the devices, or an additional BS might be installed.

Implementation Our implementation ensures a fair comparison between the two protocols by the following means: We use identical hardware for both LoRaWAN and MIOTY devices, which is shown in Figure 2 and Figure 3. The STM32L4 host microcontroller, to which we have full access, interfaces the CMWX1ZZABZ-093 ("ABZ") wireless module by *muRata Manufacturing* using the Universal Asynchronous Receiver-Transmitter (UART) interface and a set of defined AT Commands [6]. The ABZ module includes the SX1276 transceiver by *Semtech* which supports both LoRa modulation and Frequency-Shift-Keying (FSK) which is used by MIOTY [9]. The RF matching network of the ABZ module feeds the signal into an antenna W3329 by *Pulse Electronics* [7].

The ABZ module also contains communication stacks for both LoRaWAN and MIOTY. By sending the appropriate AT Commands we can configure it to either send data using LoRaWAN or MIOTY and can configure those protocols.

For the BS we use the *VIORITY* BS manufactured by *AST-X*, which can receive both LoRaWAN and MIOTY packets and includes a network and an application server [1]. We used a single rod antenna [3] whose signal was split by a passive splitter [2] and fed into both the LoRaWAN and the MIOTY receive chains. This results an attenuation of 3 dB for every receive chain which reduces the signal to noise ratio (SNR). However, as it affects both LoRaWAN and MIOTY the same, this does not impact the comparison. The included network and application servers handle incoming LoRaWAN/MIOTY packets and the application server forwards the packets to an MQTT broker. This MQTT broker *Mosquitto* is installed on a *Raspberry Pi Model 4* [5]. On a *Lenovo Thinkpad* laptop, a Python script subscribes to the MQTT broker. There, we calculate the number N of lost packets according to Equation 1.

Discussion of the Implementation In our experiments we are only interested in the range and robustness of the *wireless link*, i.e., from the LoRaWAN/MIOTY devices to the BS. Thus it would have been preferred to read received packets directly from the BS after the BS has confirmed their integrity. However, we were unable to tap into the BS to extract received packets there, hence we chose the experimental setup described above. While this introduces additional transmissions, which might be subject to packet loss, we consider the chance of packet loss on those links negligible: Firstly, the Network Server and the application Server both run on the VIORITY BS. Secondly, the BS, the Raspberry Pi with the MQTT broker and the laptop are part of the same local network and are connected by wired Ethernet. Thus, no communications take place over the Internet. Lastly, communications between BS, the Raspberry Pi and the laptop use the TCP/IP communications protocol, which uses acknowledgments and retransmissions to increase robustness. Hence we conclude that our setup is suitable, as it is much more likely to experience packet loss on the wireless link than wired links.

Setup As stated before, LoRaWAN/MIOTY devices are implemented using the same hardware and we can configure the communication protocol stacks using AT Commands. To ensure a fair comparison we configured the devices such that differences between the protocols are minimized. For this, we deactivated re-transmissions in LoRaWAN. This means, that the LoRaWAN device will not expect acknowledgment messages from the BS and will not re-transmit messages. While the LoRaWAN device will still open two downlink windows, during which it listens for messages from the BS, this is the closest we can get to the "fire and forget"-approach utilized by MIOTY.

Figure 4: VIORYTI BS mounted on the roof

We configured LoRaWAN devices to use the highest *Spreading Factor (SF)* 12. This lowers the effective data rate, increases the air time and hence power consumption but increases the effective transmission range.

Both LoRaWAN and MIOTY devices used a transmission power $P_{TX} = +14dBm$ and sent a packet with a payload length 10 bytes every 10 min.

Firstly, we verified that the four LoRaWAN/MIOTY devices to be used in the experiments are operational. For this, we used two BS which had been in use at ifm for over two years and which were known to operate reliably. We ran a direct line-of-sight test and obtained 100 % packet reception in the Python script as expected. This assured that our LoRaWAN/MIOTY devices were working as intended.

Then, we placed the VIORITY BS in a weatherproof enclosure and attached it to a post, the rod antenna being mounted above the enclosure (Figure 4). The post was mounted on the roof of the highest building on our campus, which is also located roughly in the center of the campus (Figure 5). This position moves the BS well away from interferes such as wireless communications infrastructure and machines.

In Scenario ① we verified that the BS is operational. We placed the four LoRaWAN/MIOTY devices on the roof at position ① in a distance of about 5 m in line of sight to the BS. We achieved 100 % packet reception rate in the Python script and were assured that the BS is also operational.

In Scenario ② we placed the devices in the basement, which is about 72 m away from the BS in the horizontal axis and about 24 m in the vertical axis. Between device position ② and the BS is office building with three floors and a dense Wi-Fi infrastructure. In addition, concrete ceilings must be passed.

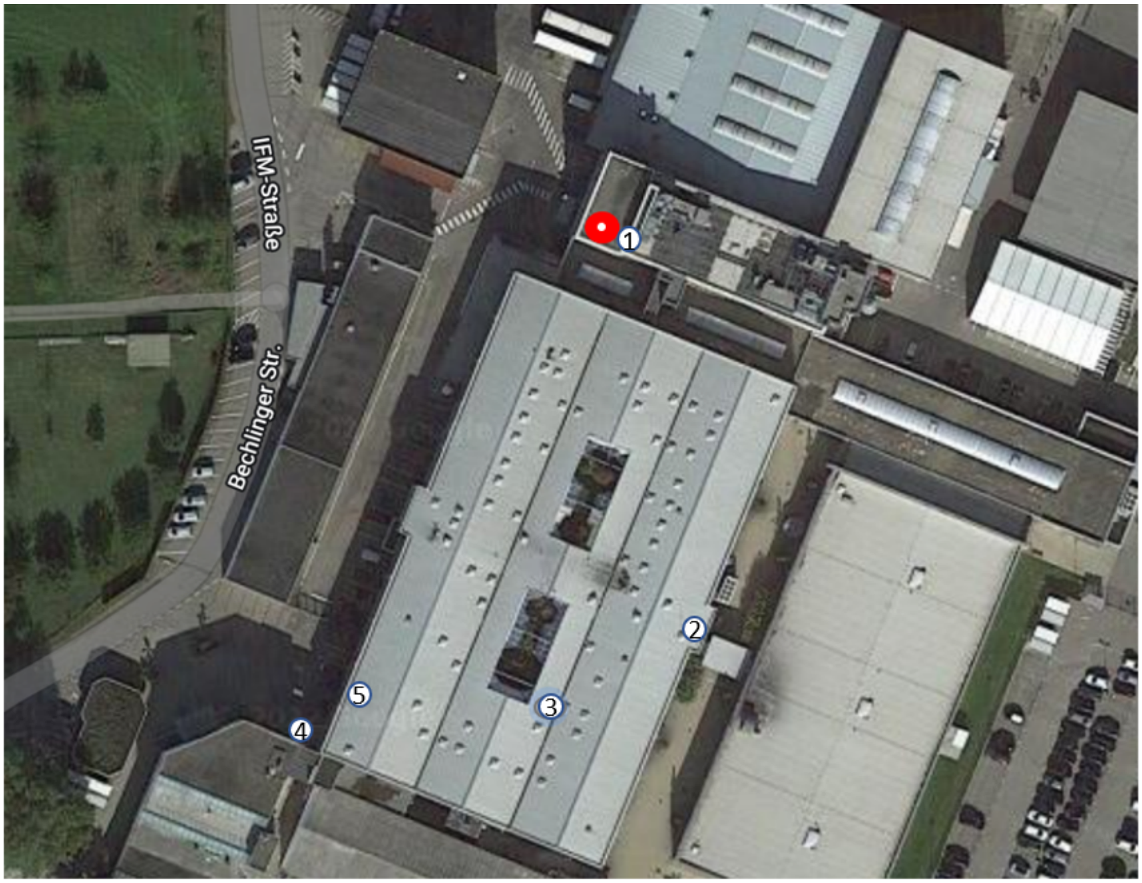

Figure 5: Aerial view of *ifm* campus, Tettnang. The BS is highlighted by the red dot. Locations of measurement scenarios are denoted ① to ⑤ and correspond to the scenario numbering in the main text.

In Scenario ③, we placed the devices indoors in an office space, which is about 85 m away from the BS in the horizontal axis and about 12 m in the vertical axis. In this office, the LoRaWAN/MIOTY device is subject to wireless interference from Wi-Fi networks and other LoRaWAN/MIOTY testbeds. Thus, downlink messages from the BS to the device will be affected, likely resulting in lower packet reception at the device. Packet reception at the BS will be affected less by the interference, as the BS is spaced apart from the office. As we are only concerned with PRR at the BS, the interference will most likely not impact our results.

Scenario ④ is outdoors at the main entrance which is about 107 m away from the BS in the horizontal axis and 18 m in the vertical axis.

Scenario ⑤ is indoors in the production site on the ground floor which is spaced about 99 m from the BS in the horizontal plane and in a vertical distance of 18 m.

Table 2: Summary of Scenarios ① to ⑤

Scenario	Distance device to BS horizontal/vertical [m]	Number of sent packets	PRR of LoRaWAN (SF12) [%]	PRR of MIOTY [%]
①	5/1	13	100	100
②	72/24	696	0	**14.3**
③	85/12	3508	58.9	**75.3**
④	107/18	601	69.7	**72**
⑤	99/18	265	61.9	**86.8**

Measuring Energy Consumption To meter the energy consumption of the LoRaWAN/MIOTY devices, we used the *Otii Arc* combined power supply and power meter by *Qoitech* [8]. We placed the devices at the same location as Scenario ③ and powered the devices with the *Otii Arc*. Then we metered and plotted the energy consumed.

We differentiate between *active mode (AM)* and *sleep mode (SM)*. In active mode, LoRaWAN/MIOTY devices sent sensor readings to the BS. Then, devices sleep for 10 min before going into active mode again. Based on the metered power consumption and a reference battery CR123A by *VARTA* with a capacity of 1600 mAh [4], the *Otii Arc* can estimate battery lifetime.

3 Results and Discussion

3.1 Packet Reception Rate

Table 2 summarizes the results of the scenarios ① to ⑤. In every scenario, MIOTY showed a higher PRR than LoRaWAN despite the latter using SF12 and the highest transmission power possible (+14 dBm). As stated before, to provide a fair comparison on a per-packet basis, the re-transmission feature of LoRaWAN had been deactivated. In future experiments we are going to study the impact of this feature on PRR.

Especially Scenarios ②, ③ and ⑤, where devices were placed in the basement, the office space and the production site, MIOTY PRR was between 14.3 to 24.9 % higher. Thus, although MIOTY also experienced packet loss, this indicates that MIOTY is more robust and thus well suited in obstructed environments.

3.2 Energy Consumption

Table 3 presents the battery life estimation for LoRaWAN and MIOTY devices. A higher SF results in higher energy consumption. Interestingly, SF12 shows a similar energy consumption as ADR and thus a similar battery life estimation (± one day). Hence we assume that either the SF chosen by ADR was SF12 or the downlink messages from the BS instructing the device to switch to a SF other than the default SF12 did never reach the device.

Table 3: Battery life estimation for LoRaWAN/MIOTY devices

Node	ADR	SF12	SF10	SF9	SF7	MIOTY
Energy consumed in AM μWh	166	167	121	115	109	**107**
Energy consumed in SM μWh	12,2	12,2	12,1	12,2	12,2	**11,2**
Battery life estimation in months	6.8	6.7	9.1	9.5	9.9	**10,2**

MIOTY has less energy consumption in AM compared to LoRaWAN despite using the same hardware. Thus MIOTY shows a battery life estimation of 10,2 months, which is higher than LoRaWAN in SF7. How can the difference in energy consumption be explained despite both LoRaWAN and MIOTY using the same hardware? The reason is the Over The Air Activation (OTAA) procedure used by LoRaWAN. With this, in our device hardware, keys and session related information are stored in the Random Access Memory (RAM) which must be retained. Hence, when used with LoRaWAN, our device can not enter the deepest sleep mode between two transmissions. This is different than if the device were used for MIOTY.

4 Conclusion

We compared the packet reception rate (PRR) and energy consumption of MIOTY and LoRaWAN using a unified test setup in different scenarios in an industrial facility. Our results show how MIOTY shows higher PRR per packet and lower energy consumption than LoRaWAN configured for maximum reliability, i.e., SF12.

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