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Application of LoRaWAN for Smart Metering: An Experimental Verification

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Abstract

The emerging Internet of Things (IoT) market is generating a lot of buzz, and different Low Power Wide Area Network (LPWAN) technologies such as Sigfox, Ingenu or LoRaWAN are making waves in the industry. The speed at which nation-wide networks based on these technologies are being rolled out is among the fastest ever seen on the European continent.

In this paper we discuss the aptitude of a LoRaWAN network to capture data from smart energy meters. Special attention is given to the communication requirements of different uses cases for smart metering, and the benefits and drawbacks of LoRaWAN are illustrated. Additionally, a brief overview of the most prominent LPWAN technologies is presented and a small field test is conducted.

Keywords:	Smart metering; Internet of things; LoRaWAN; Smart grids; Energy management		

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1. Introduction

In many Western and most West-European countries, smart metering is being rolled out as a replacement for traditional electromechanical consumption meters at the customer's premises [1-2]. These smart meters are intended as a cornerstone in tomorrow's smart grids, as they provide new services impossible or difficult to implement on the former metering devices [3]. When well implemented, smart metering offers potential benefits to customers and certain benefits to the Distribution System Operator (DSO).

One of the main benefits for customers, and also one of the main regulatory drivers for smart metering, is the ability to receive accurate and timely statements of energy use. No longer do provisional statements have to be made based on energy consumption estimates, possibly leading to unpleasant surprises when a customer receives a final settlement after a manual meter reading by the DSO. With smart metering the intermediate statements are based on the real meter readings communicated through a digital network to the DSO.

Smart metering offers additional benefits to customer and society as a whole, such as real-time feedback about their energy use. This leads to higher energy awareness and potentially energy savings. Connecting the smart meter to home automation systems can automate this process significantly.

The main benefits of smart metering are arguably reserved for the DSO [4]. The automation of meter reading releases them form the time-consuming process of manual meter reading and simplifies administration, e.g. disputes about the settlement. It also gives the DSO an intricate and quasi real-time view of the distribution grid, enabling quick problem identification and resolving or even pro-active maintenance.

To make smart meter reading a technical and commercial success, achieving reliable and scalable communication at low cost is key. This has resulted in many DSOs experimenting with different communication technologies or even developing their own, trying to find the optimum combination of parameters mentioned above [5-6].

Recently, a new form of wireless communication networks known as Low Power Wide Area Networks (LPWAN) have emerged, promising reliable long range communication at low cost at the expense of data throughput [7-8]. Because of the apparent benefits numerous telecom operators and communal initiatives have already began rolling out nation covering LPWAN networks, even though the individual technologies that make up LPWAN have not always been finalised.

LoRaWAN is one example of a LPWAN technology that appears to be very suitable for smart metering [9]. In this article we investigate if this is the case. We start by examining the communication needs of smart metering and smart grids in general in Section 2. In Section 3 we present a brief overview of different LPWAN technologies. This is followed by a more detailed description of a LoRaWAN network setup in Section 4. Section 5 shows the results of some experimental field testing. Finally, conclusions and future work are presented in Section 6.

2. Smart metering communication requirements

In order to assess the usability of the LPWAN communication technologies discussed in Sections 3 and further, the communication requirements of smart metering must be established. There are several types of data that smart meters can communicate, but the most important are meter readings, instantaneous values and states.

We define a *meter reading* as a snapshot of the current total consumption value, and it is considered to fit in a 32 byte unsigned integer, yielding a maximum value of 4,294,967,295 ($2^{32} - 1$). This is more than sufficient because most residential consumption meters do not have more than 8 digits of precision.

An *instantaneous value* is defined as the current value of a certain measured parameter such as instantaneous active power, voltage, current etc. It is considered to fit in a 16 byte signed integer, yielding a usable range of -32,768 to 32,767 ($\pm 2^{15} - 1$). Floating point values can be multiplied to include the added precision in the integer value, likewise larger values can be scaled down. Most relevant residential measurement values should not be required to be scaled down.

A *state* is defined as a yes/no condition, and considered to be one byte.

Furthermore, the direction of communication must be defined. An *uplink* is defined as a message transmitted from the smart meter to the network. A *downlink* is defined as a message transmitted from the network to the smart meter.

In this article, four typical uses cases for smart metering are taken into account [6], as summarised in Table 1. *Automated Meter Reading* (AMR) is the most basic functionality a smart meter should be able to perform. A smart meter should at least be able to send one meter reading per day to the DSO, and optionally one meter reading every 15 minutes. This way the DSO has access to the total consumption value of each day, and optionally the standard load profile of the energy consumer. AMR would require a maximum throughput of 32 bytes per hour. Latency, the delay between making the meter reading and the DSO receiving it, is not strict.

Time Of Use (TOU) is the practice of deferring energy consumption to periods with lower energy prices. To do this, the smart meter should be able to at least receive four different states through downlink each day. With this information the meter can switch between three tariff periods (low price, normal price and peak price) and back again. Optionally this should be able to happen every 15 minutes. TOU requires a maximum of 4 bytes per hour. Latency is not strict.

Outage Monitoring (OM) is sending information about the grid state to the DSO. Normally the DSO is notified of a power outage by its clients through phone calls. A smart meter can communicate power failures automatically. This requires very little data, only one

Table 1: Throughput and latency of different smart metering use cases

Use case	Minimum throughput	Maximum throughput	Latency
Automated meter reading	32 bytes/hour	4 bytes/day	1 day
Time Of Use	4 bytes/hour	4 bytes/day	15 min
Outage Monitoring	1 byte/day	1 byte/day	1 min
Quasi Real-time Monitoring	200 bytes/min	2.4 kbyte/day	5 min

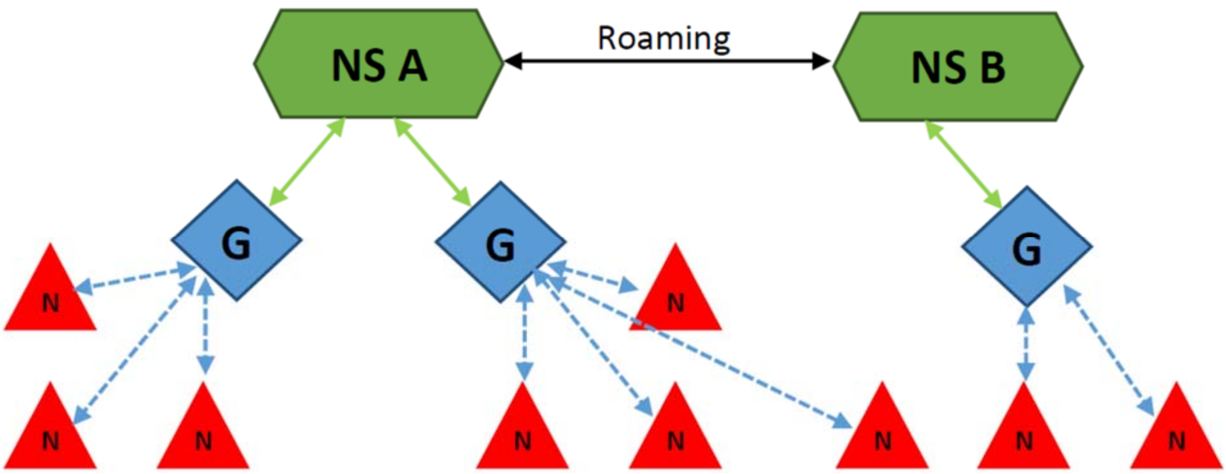

Figure 1. LoRaWAN network topology

state message, but must be done while the smart meter has no power. Latency is more strict.

Quasi Real-time Monitoring (QRM) is the more timely reporting of energy measurements. Not only meter readings but also instantaneous values need to be communicated at least every five minutes. Starting from the idea that at least grid voltage, active power, power factor and the total meter reading should be logged every minute, this results in message payloads of up to 2.4 kB per hour for three phase energy meters.

3. Overview of LPWAN technologies

Several LPWAN technologies have been introduced in the last 5 years which make use of novel radio frequency (RF) modulation techniques and/or occupy parts of the RF spectrum that were only recently been designated available for data communication. We discuss some technologies that are already seeing commercial adoption, by no means is this an exhaustive list of all emerging LPWAN technologies.

Ingenu is a proprietary LPWAN technology developed by the eponymous company, formerly called On-Ramp Wireless, and is based on Random Phase Multiple Access (RPMA) [10], a Direct-Sequence Spread Spectrum modulation with multiple access. It uses the license-free 2.4 GHz RF band, commonly known because of its other famous user WiFi. Because of this high band it is able to offer significant data rates up to 624 kbps, but the range is rather limited and the energy consumption somewhat higher. It supports uplink and downlink messages. It has some popularity in the USA and parts of the EU. Ingenu is owner and operator of the network.

A similar business strategy is adopted by SigFox and its similar eponymous LPWAN technology. SigFox uses a proprietary, extremely narrow band solution based on Random Frequency and Time Division Multiple Access [11] and operates in the license-free 868 MHz (EU) and 915 MHz (North-America, Oceania) band. Because of the limited 100 Hz bandwidth it only achieves 100 bps data rate, and end-devices are limited to 140 uplink messages of 12 bytes each and 4 downlink messages of 8 bytes each per day. It is mainly used in the EU.

Semtech uses a different approach with its LoRaWAN technology. LoRaWAN is a network protocol stack on top of the Lora modulation technique. This modulation employs Chirp Spread Spectrum (CSS), making it very resilient against interference, multipath propagation and Doppler effect [9]. Like SigFox it occupies the 868 MHz (EU) and 915 MHZ (North-America, Oceania) bands, defining at least 3 channels with minimum 125KHz bandwidth each. As such it offers data rates up to 27 kbps and maximum message lengths of 222 bytes, both for uplink and downlink messages. In contrast to the former companies, Semtech only provides the RF hardware and lets its clients setup and operate their own LPWAN network.

Based on the specifications, both Ingenu and LoRaWAN should be able to support all use cases from Section 2. SigFox is not able to support QRM and only partially supports TOU. Based on the specifications and the semi-open nature of the technology, we will examine LoRaWAN further in this article.

4. LoRaWAN network setup

While the LoRaWAN specification only covers the media access (OSI layers 2 and 3), a general network topology as depicted in Figure 1 is implied. The network is typically set up in a *star-of-stars* topology, where gateways (**G**) pick up the messages broadcast by the end-devices or *nodes* (**N**) and forward them over an Internet Protocol (IP) based network to a *network server*

(**NS**). The network server is a software application running on one or more physical servers that possess a register of nodes and their associated owners. It forwards the message to its owner. The message payload was encrypted by the node with a key only known to the owner of the node. When the message arrives from the network server, the owner can decrypt and extract this payload.

This specific topology has some very interesting benefits. In a sufficiently dense LoRaWAN network, a message transmitted by a node can be picked up by multiple gateways and forwarded to the network server. The network server only forwards the first received valid message to its owner, but it also calculates the signal strength of the node for each gateway that has picked up the message. This allows the network server to select the best gateway in reach for a possible downlink to the node.

When a received message originates from a node whose owner is not registered in the network server, the message is generally discarded. It is however possible to forward the message to the network server of another LoRaWAN network operator under a so-called roaming agreement. This other network operator can then check the node against its own register. With these roaming agreements the density of LoRaWAN coverage can be extended greatly, because the network coverage of different operators and their gateways are joined. Message integrity is never compromised because the payload of the message can only be decrypted by the owner.

For smart metering applications this kind of flexibility offers many benefits [12]. The DSO can choose to rely on commercial LoRaWAN networks where available, but roll its own network in areas with no reliable coverage. By accepting roaming agreements with the commercial operators, messages will be routed transparently to the owner or operator of the nodes. The network server can be outsourced, e.g. to the commercial network operator, keeping technical and administrative overhead for the DSO to a minimum. The DSO only needs to maintain the register of nodes and their associated operators, which in the case of AMR will be the energy suppliers.

The LoRaWAN specification defines three types of operation the nodes and network can support: Class A (mandatory), Class B and Class 2 (both optional). A Class A node transmits uplink messages according to its own schedule, and after the transmission opens two receive windows to await downlink messages. All other times, the node can be in a low-power sleep mode conserving battery. Class B devices open additional receive windows at specified intervals. Nodes implementing Class B require exceptional time synchronisation with the network, and are therefore regularly synchronised with the network through beacons (synchronisation messages) broadcasted by the gateways. Finally, Class C devices always have an open receive window, unless they are transmitting themselves. These type of nodes provide the lowest latency downlink, but also use the most power.

For smart metering applications, all three classes offer possibilities. All classes are suited for AMR. Class C is most suited for TOU applications because of the low latency in downlink messages. Class A is best fit for OM because of the low power requirements, making it possible for the node to keep functioning during power outages, e.g. on a small integrated supercapacitor. Although this is not yet supported at the time of writing, the LoRaWAN specification allows nodes to change classes on the fly. This offers additional flexibility, e.g. a node could operate normally in Class C and switch to the power saving Class A during an outage.

In the EU, LoRaWAN operates in the 863-870 MHz RF band. The LoRaWAN specification defines three mandatory RF subbands or channels (868.1, 868.3 and 868.5 MHz), but additional channels can be negotiated between the network and node, depending on the capacity of the gateway. Current gateways support a total of at least 8 channels, and nodes use pseudo-random channel hopping to avoid consecutive use of the same channel.

Messages are transmitted on these channels using a specific Spread Factor (SF). SF is defined as $= log_2 \frac{R_C}{R_S}$, with R_s being the symbol rate and R_c the chirp rate of the CSS modulation. The SF illustrates the ratio between communication speed and range. Messages transmitted with a high SF will be less susceptible to path losses such as fading, but will take more airtime to transmit. Similar, a low SF will improve transmission speed but make the transmission more susceptible to interference, lowering the usable range. The symbol encoding is orthogonal, allowing messages using different SF to be transmitted on the same channel simultaneously. The LoRaWAN specification defines six different SFs (SF7 to SF12). Together with two possible channel bandwidths of 125 kHz and 250 kHz, this results in Data Rates (DR) of 0 to 6 and accompanying raw bit rates of 250 bps to 11 kbps.

LoRaWAN nodes are able to use Adaptive Data Rate (ADR), changing their SF and channel bandwidth between messages. This is particularly interesting for smart metering, because many utility meters are often installed in cellars or other places with bad RF reception. The node can select the suitable DR without intervention of the DSO.

While the 863-870 MHz RF band is a license free band, users must adhere to a duty cycle of 1%. This means that no single user can occupy a certain frequency channel for more than 1% of the time. To avoid collisions, e.g. two nodes trying to transmit on the same channel using the same SF, no single node should occupy the channel too long [13]. The LoRaWAN specification therefore limits the maximum payload of the message. On DR6 the payload may contain 242 bytes, on DR0 it is limited to 51 bytes. A summary is given in Table 2.

For smart metering applications, it is therefore good practice to limit the payload to 51 bytes to avoid transmission problems on lower DR. As discussed in Section 2, this should still be more than enough for all use cases.

The duty cycle limitations prevent a single LoRaWAN cell, which is the area and nodes covered by a single gateway, from scaling too big. [14] shows that maximum throughput per node (packets/hour) falls drastically as the amount of nodes increase, resulting in only 7.3 50-byte packets per hour if a cell contains 5000 nodes and uses only the default three channels. This is still sufficient for AMR, TOU and OM, but not for RTM. For smart metering, cell sizes should be kept reasonable. This requires suitable siting practice. It makes little sense installing gateways at very high locations, which are typically used as RF broadcast sites, because the amount of nodes the gateway will pick up will be too large. It is better siting practice to place more local gateways, each covering a sector of the area where LoRaWAN coverage is needed.

5. Experimental verification

In order to obtain perform an experimental verification of a LoRaWAN network, a small field test was deployed at the Technology Park campus of Ghent University. A gateway was placed on the roof of a 7m high building. This building is around the medium height of other surrounding buildings, which would be a good practical gateway site in order to limit the maximum cell size. A standard ground plane antenna with a gain of 2.15 dBi was used as aerial.

A node was built using a Microchip RN2483 LoRaWAN transceiver and a GPS receiver. The node transmits its location every 30 second to the gateway. A fixed SF of 7 was used.

The free and open source The Things Network (TTN) was used as a network server [15]. A software application was developed which interfaces with TTN and parses the received node location data together with the Received Signal Strength Indication (RSSI) as reported by the gateway. The RSSI is a general indication of the signal strength the gateway measured when receiving the message. This combined information was then visualised on a geographical map (Figure 2).

The results show that almost the entirety of the campus (1 km^2) had usable coverage of this single gateway, even in the absence of a line-of-sight between the node and the gateway. A RSSI of -120 dB was shown to be the limit after which the gateway would no longer be able to pick up the messages. The maximum usable outdoor range proved to be 5 km.

To test a typical smart metering scenario, a mapping of the basement of a building on campus was done (Figure 3). This showed consistent usable RSSI of -102 dBi to -117 dBi.

Note that these are worst case results because of the use of a fixed SF of 7 so the node could be used for QRM. As discussed in Section 4, a higher SF will improve the reception of the LoRaWAN signal, at the expense of a lower datarate and smaller payload.

6. Conclusions and further research

In this article, we discussed the suitability of a LoRaWAN network for different smart metering use cases. We first gave an overview of these use cases and their communication requirements. Most use cases do not require high speed, low latency communication, making LPWAN technologies in general a good communication for these applications. We presented some of the currently popular LPWAN technologies before examining LoRaWAN more in depth.

LoRaWAN has the potential to offer speed and latency acceptable for most smart metering use cases such as

Table 2: Achievable bit rates and payload sizes in LoRaWAN

Data rate	Spreading factor	Channel bandwidth	Bit rate	Maximum payload size
0	SF12	125 kHz	250 bps	51 bytes
1	SF11	125 kHz	440 bps	51 bytes
2	SF10	125 kHz	980 bps	51 bytes
3	SF9	125 kHz	1.76 kbps	115 bytes
4	SF8	125 kHz	3.13 kbps	242 bytes
5	SF7	125 kHz	5.47 kbps	242 bytes
6	SF7	250 kHz	11 kbps	242 bytes

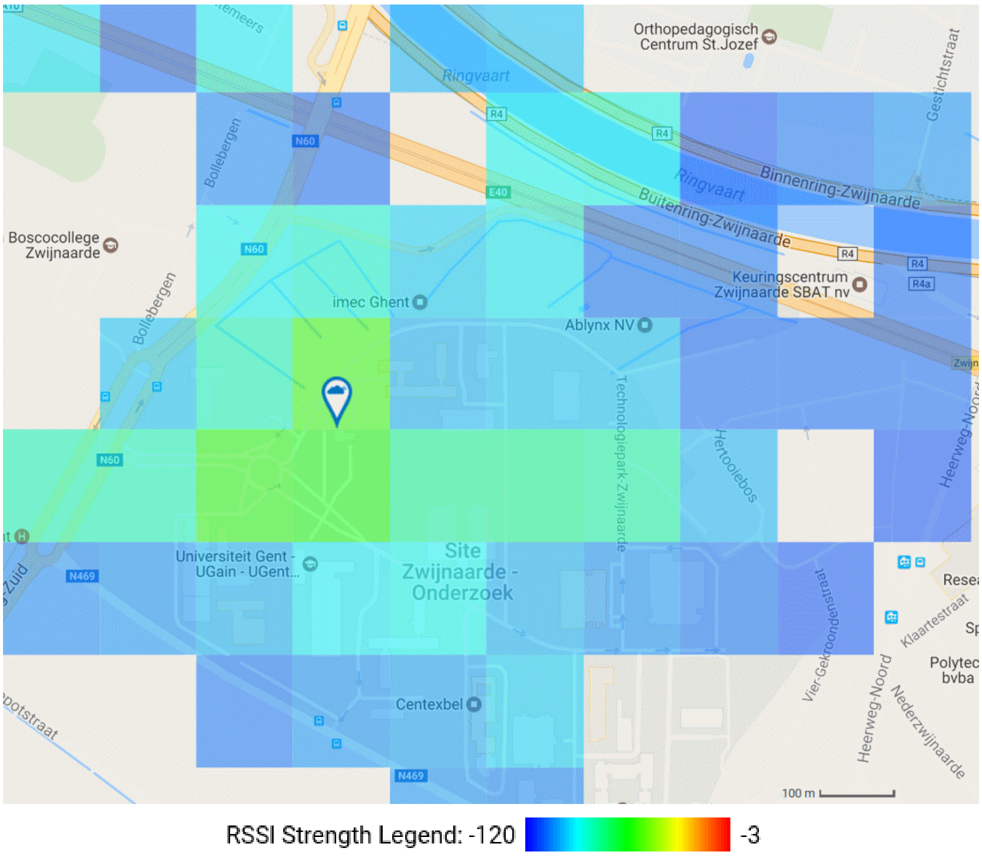

Figure 2. LoRaWAN coverage map of UGhent campus Technology Park

Figure 3. LoRaWAN coverage of the basement floor of a campus building

Automated Meter Reading, Time Of Use and Outage Monitoring, but is not particularly suited for Real Time Monitoring. The LoRaWAN star-of-stars network topology is shown to be interesting for Distribution System Operators wishing to roll out smart metering. By implementing roaming agreements between LoRaWAN network operators, transparent and reliable communication can be achieved. The way the network handles communication also reduces administrative overhead. The maximum message payload and cell site must however be limited in order to sustain many smart metering nodes. Gateways must also offer as much additional channels as possible.

A small experimental verification proved that LoRaWAN operates reliably in a cell site of limited size, even under the difficult radio reception conditions smart metering use cases may encounter.

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