CONSIDERATIONS FOR LOW-POWER COMMUNICATION IN INDUSTRIAL IOT APPLICATIONS

DASH7 ALLIANCE

September 2019 - v1.0

Contents

INTRODUCTION

Of all the unlicensed spectrum LPWAN technologies it would appear that the LoRaWAN standard seems to be gaining the most market traction. The most cited reasons for choosing LoRaWAN is the large communication range and the wide ecosystem of compatible sensors and gateway equipment. By standardizing on a LoRaWAN network deployment, industrial customers hope to cover a large number of use cases with only a limited investment in shared infrastructure.

However, as always, there is no silver bullet technology, and this is certainly true in industrial IoT. In this document we will look into different application trade-offs and the underlying aspects responsible for these limitations. For instance, for meter reading type of applications (a reading being taken every hour) it might be acceptable to miss some messages, but other industrial use cases require better reliability, especially for control systems or safety related use cases. In addition to reliability we will also explore aspects like latency, scalability, bidirectional communication, multi-cast communication and legislation. We will be comparing (private) LoRaWAN and the DASH7 Alliance Protocol mainly in industrial IoT use cases.

BACKGROUND

This section explains some background concepts which are needed to understand the trade-offs, without going too much into details.

2.1 Specification

The DASH7 Alliance (D7A) Specification is managed by the DASH7 Alliance (dash7-alliance.org), a non-profit organization, based in Belgium. The D7A Specification is open and freely downloadable. The DASH7 Alliance promotes open technology, free of any royalties and IPR claims. The LoRaWAN specification is managed by the LoRa Alliance, a non-profit association promoting it as an open standard. Its physical layer is based Semtech proprietary technology (LoRa).

2.2 Physical layer

If we look at the physical layer (PHY) there a few important aspects which have an impact:

- Frequency: radio waves with a lower frequency propagate further than those using a higher frequency. Both LoRa and DASH7 are using the 868 MHz band in the EU (CEPT). This means both technologies use the same unlicensed spectrum and thus the same legislation applies.
- Modulation: modulation defines how the data is coded on the radio wave. DASH7 uses Gaussian Frequency-Shift Keying (GFSK) modulation, a standard frequency modulation implemented by all low-cost RF chips. LoRa uses a proprietary spread spectrum modulation owned by the company Semtech, which is the only licensee producing LoRa capable chips. Put simply, LoRa modulation transforms each bit into multiple symbols which it transmits over a bigger bandwidth in a clever way. For the receiver it is easier to distinguish this signal from background noise, hence the receivers' sensitivity increases and thus the range. The spreading factor (SF) is a modulation parameter: SF12 (the highest) yields the biggest range but also the longest transmission time.
- Data-rate and coding.
- Sensitivity and link budget.
- Interference tolerance and co-existence.
- Spectrum usage and scalability.

2.3 Range

The PHY modulation of LoRa allows increased link budget (and thus, range) compared to most conventional modulation types. The modulation allows trading-off between range and data rate. The higher the spreading factor (SF) the higher the range which can be achieved. In DASH7 the maximum range will be lower compared to the maximum range for LoRa, although a single hop using a sub-controller could be used to extend the range. Empirical tests using both technologies on industrial sites are required to determine which ranges are achievable and reliable for the specific application. As will be explained later, the maximum range achievable on the PHY layer does not make it possible to reliably run all applications over this range, however, there are trade-offs to be considered. Next to the wide band spread spectrum approach of LoRa modulation a narrow-band approach based on non-proprietary FSK modulation can also result in larger ranges while performing better in terms of spectrum efficiency and co-existence (scalability) as explained in [17]. The DASH7 Alliance is working on adding a new PHY mode supporting a lower data rate, more narrow-band approach, for applications requiring more range.

2.4 LoRa vs LoRaWAN

LoRa defines only the physical layer. LoRaWAN is a Medium Access Control (MAC) layer protocol building on top of LoRa. LoRaWAN defines how the network operates and how devices communicate with each other. Other MAC layers on top of LoRa are possible as well, for instance Symphony Link [18] or DASH7-over-LoRa. The LoRaWAN Alliance manages this specification and the certification of devices.

2.5 Network architecture and deployment

Both DASH7 and LoRaWAN are deployed in a stars-of-stars topologies where multiple devices can be received by multiple gateways. The DASH7 channel plan is not standardized by the specification with the only restriction to comply with the local area regulations. It is based on the concept of access profiles, which are full sets of wireless access parameters that are statically shared by the devices in the network. They are referred to through one byte identifiers (access classes). The access profiles define the channels scanned by the receiving device, the scan period, the channel coding, the data rate, the local duty limits, etc. This modular approach is very convenient for adapting the communication plan to the use case constraints - regulations, power consumption, access delays, channel diversity, etc. As such there is no conceptual difference between tag-to-gateway and tag-to-tag communication. In practice, gateways will use access profiles with more channels and shorter scan periods than remote devices, at the expense of higher power consumption. Compared to DASH7 a new server is introduced: the LoRaWAN network server. This server is required by LoRaWAN to manage the gateways and devices. It can either be deployed on-premise, in a public / private cloud or hosted externally by a 3rd party network operator. The LoRaWAN network server and its behavior are not standardized by the LoRaWAN Alliance. Different LoRaWAN network server implementations exist, with various advantages and disadvantages. This goes from open source solutions embedded in a single gateway for small networks to nationwide solutions, as deployed for instance by KPN (NL) or Proximus (BE). The choice of network server can be linked to the choice of gateway, i.e., the gateway software may have to be adapted to the network servers' needs. Pricing will vary, as will features and performance. As will be discussed later, the network server has a large impact on the behavior and performance of the network in terms of scalability, reliability and power consumption. Although performance is important, not much information is available for different network servers.

2.6 Legislation

The EU legislation is defined in RED 2014/53/EU and 2017/1483 and on the national level. ETSI EN 300 220 [10][11] together with CEPT REC 70-03 [8] provides practical information on how to conform to the legislation taking into account technical parameters and test methods and lists the implementation status of member states. For now, we assume the system falls under the category of "non-specific short-range devices" and uses the channel definitions from REC 70-03. The relevant sub-bands defined in [8] are shown in figure 2.1.

Important aspect are the duty cycle (DC) regulation, defining the percentage of time a device may transmit on the channel and Listen-Before-Talk and Adaptive-Frequency-

Agility (LBT+AFA), also referred to as 'polite access'. The LoRaWAN Alliance specifies regional parameters [4] based on this legislation, where EU863-870 is the most relevant for us now. LoRaWAN does not use LBT+AFA so it must comply with the duty cycle limit per sub-band. The LoRaWAN specification requires that every device must implement three uplink channels, i.e., the default channels. These channels fall within (and totally occupy) the h1.4 sub-band and are mostly used for uplink communication. Usually one downlink channel in the h1.6 sub-band is used.

Assuming a device uses the three default channels in h1.4, each device is limited to a duty cycle of 1% summed over all 3 channels, i.e., the end node may transmit only 1% of total time, which is the main limiting factor on throughput for a LoRaWAN end node. Using channels from other sub-bands allows to increasing the total duty cycle but only marginally since bands h1.2, h1.3 and h1.5 are limited to 0.1%. Band h1.6 allows a duty cycle of 10% however in most implementations this band is reserved for downlink communication (from gateway to a device) precisely because of the higher duty cycle (the DC restriction is even more problematic for a gateway).

In LoRaWAN the duty cycle limits are enforced by a minimum off-time between subsequent packets, i.e., wait for a certain period for the next transmission. In practice this means that after transmitting a packet of 20 bytes on SF12 on a 1% DC channel, a minimum off-time of 180 seconds should be respected with a transmission time in this case of 1.8 seconds. The same packet transmitted using SF9 would require a minimum off-time of 25 seconds. Note that the 20 bytes in this example refers to application payload. Adding the LoRaWAN header of 13 bytes makes a total packet length of 33 bytes.

h1.2	863-870 MHz (notes 3 and 4)	25 mW e.r.p. Power density: -4.5 dBm/100 kHz (note 7)	≤ 0.1% duty cycle or LBT+AFA (notes 1, 5 and 6)	Not specified		DSSS and other wideband techniques other than FHSS. Parts of the frequency band are also identified in Annexes 2 and 3
h1.3	863-870 MHz (notes 3 and 4)	25 mW e.r.p.	≤ 0.1% duty cycle or LBT + AFA (notes 1 and 5)	≤ 100 kHz, for 1 or more channels modulation bandwidth ≤ 300 kHz (note 2)		Narrowband / wideband modulation. Parts of the frequency band are also identified in Annexes 2 and 3
h1.4	868-868.6 MHz (note 4)	25 mW e.r.p.	≤ 1% duty cycle or LBT +AFA (note 1)	Not specified for 1 or more channels (note 2)		Narrowband / wideband modulation. No channel spacing, however the whole stated frequency band may be used
h1.5	868.7-869.2 MHz (note 4)	25 mW e.r.p.	≤ 0.1% duty cycle or LBT+AFA (note 1)	Not specified for 1 or more channels (note 2)		Narrowband / wideband modulation. No channel spacing, however the whole stated frequency band may be used
h1.6	869.4-869.65 MHz	500 mW e.r.p.	≤ 10% duty cycle or LBT+AFA (note 1)	Not specified for 1 or more channels		Narrowband / wideband modulation. The whole stated frequency band may be used as 1 channel for high speed data transmission

Figure 2.1: 868 sub-bands

In the case of DASH7 the duty cycle limits listed in the table do not apply since LBT+AFA is used; the transmitting device will first listen to the channel before sending its packet (when the channel is deemed free). In this case the main restriction in terms of transmission duration is that a device cannot transmit more than 100 seconds accumulated in 1 hour per 200 kHz of spectrum, irrespective of the sub-band. Also, a device needs to respect an off-time of 100 ms on the same channel after a transmission. In practice this means a duty cycle limit of nearly 3% per channel. If we assume the device uses three channels, this would result in a duty cycle limit of 9%.

It is important to know that the legislation is not applicable worldwide, there are changes per country which can have a significant impact. The rest of this document assumes EU legislation, further analysis of US legislation (FCC) needs to be done. As shown by [7] however, even within one technology like LoRaWAN deploying in the US and the EU imposes different limitations because of legislation differences which may have a large impact on the application and network deployment required. At the EU level efforts are made for further harmonization (see harmonized approach initiative for SRD in the bands 870-876 and 915-921 MHz [9][12]).

2.7 Power consumption and battery capacity

In relation to RF protocols, power consumption is determined by the amount of time the radio is in transmit or receive-mode and the transmission power. A lower data-rate increases power consumption compared to a higher data-rate. In the case of LoRaWAN, a spreading factor of SF7 up to SF12 is used, where each step in spreading factor doubles the transmission time. Similarly, a higher transmission power will logically increase the power consumption. The table below shows the equivalent bitrate (which is proportionate to transmission timing) for the LoRa SFs and DASH7 datarates.

Modulation	Equivalent bitrate (kb/s)
LoRa SF12	0.293
LoRa SF11	0.537
LoRa SF10	0.976
LoRa SF9	1.757
LoRa SF8	3.125
LoRa SF7	5.468
DASH7 low rate	9.6
DASH7 normal rate	55.555
DASH7 high rate	166.667

Besides the power consumption, it is important to note that batteries do not exhibit ideal behavior. The battery capacity given in the datasheet is typically valid only for constant (and low) currents. For RF communications we use much higher currents for short periods, for instance during transmission. Most batteries can deliver peak currents and sustain this for short periods, however doing so reduces the total net capacity of the battery. The battery can recover to some extent, given enough time between peak loads, so the interval is also important. Therefore, it is important to limit the duration of these periods, and thus limit the transmission duration.

2.8 Reliability, latency and scalability

Latency is non-deterministic for both DASH7 and LoRaWAN. Both protocols are asynchronous (not synchronized) and cannot guarantee hard real-time restrictions, as opposed to synchronized protocols like WirelessHART. In case of LoRaWAN the channel access is random, i.e., a message will be transmitted whenever it is ready and is only limited by the off-time imposed by the duty cycle limit. This is called 'ALOHA'. In case of DASH7, channel access is done using CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance) where before transmission the node will first listen on the channel to detect if there is energy on the channel in order to avoid collisions. When the channel is deemed in use a random back-off slot will be selected to retry. The maximum window in which this slot is selected is deterministic. It is important to note that multiple channels can be used, reducing the chances of a node being blocked by a (3rd party) interferer. When the node fails to insert the packet, the application is aware of this and can respond to this event (i.e. retry, alert the user, ...), while in case of LoRaWAN the node does not know this unless it requests, and receives, an acknowledgement (ACK) message from the gateway. Due to CSMA/CA being used, DASH7 does not have to adhere to the duty cycle limit of 1% but can use about 3% per channel (i.e., 9% for 3 channels) over a one-hour interval (see section 2.6). This means the latency will be lower in scenario's where the duty cycle budget is used, especially taking into consideration the much lower transmission time. For LoRaWAN SF12, the worst-case latency before a new packet can be transmitted is about 3 minutes, for DASH7 lo-rate this is 100 ms even in case of only one channel (worst case).

Reliability is also an important aspect: how certain are we that the transmitted packet is received by the gateway. The amount of traffic (both originating from the system itself as from 3rd party interference – which is not unlikely since we are operating in unlicensed bands) has an impact on the number of collisions and thus the number of packets which are not received correctly by the gateway. The longer transmission times as well as the ALOHA channel access without collision avoidance increase the likelihood of interference for LoRaWAN transmissions. In LoRaWAN, collisions can be avoided to a certain extent by making sure the SF levels used by the nodes are distributed in an intelligent way since packets using a different SF are less likely to interfere. Another way to limit the interference is to dynamically adjust the transmission power of each node based on the signal to noise ratio (SNR) for instance. Keeping this transmission power lower (while still ensuring good enough SNR) allows to save energy and reduces the interference domain (area). Both parameters can be tuned by the central LoRaWAN network server. The way how the network server does this is not defined by the LoRaWAN alliance and is implementation specific.

An often suggested way of improving reliability in a LoRaWAN network is to retransmit each packet x times, thereby improving the chances of this packet being received. Naturally this method has an impact on battery life. Also, this is not necessarily an improvement, for instance as stated in [5]: "The current LoRaWAN specification does not have any means to enforce quality of service, and thus, it should not be used for critical applications or applications where the delay between the first time at which the device tries to send a message and the time at which it is received is important. Adjusting the number of times a device sends its packets may increase the chance of these packets going through, but it does so at the expense of more collisions with transmissions from other nodes and does not provide any hard guarantee.". Similarly, [6] observes that retransmissions may improve the packet delivery ratio for light traffic conditions, while only making performance worse in more congested scenarios.

In LoRaWAN, reliability can be enforced by a node by asking for an acknowledgement (ACK) from a gateway. After transmission, the node opens two receive windows within which the gateway can respond. When receiving the ACK, the node is certain the message was correctly received. If not, the node can decide to retransmit. At first sight this seems to be the best solution to enforce quality of service for a LoRaWAN network. However, it is important to take scalability in terms of number of nodes, messages and gateways into account. Recent research (in [21][20][14][1][6][19]) shows that requiring ACKs has a large impact on the scalability and performance of a LoRaWAN network. For practical reasons most research uses simulations to research the scalability of LoRaWAN networks. For instance, in [21] the authors simulate the reliability when scaling a LoRaWAN network. Figure 2.2 (from [21]) shows the Packet Delivery Ratio (PDR) in function of the number of devices, for different transmission intervals and for both confirmed (CON), thus with acknowledgements, and unconfirmed (UNC) messages. As shown in the graph, the PDR drops when the number of devices increase. For instance, in case of UNC 600s (meaning nodes are sending every 10 minutes, without requesting an ACK) already 30% of the messages are not delivered for a network of 1000 nodes. Using the same interval but with ACKs more than 90% of messages are lost. Contrary to what we would expect requesting ACKs seems to decrease the reliability; only for a small number of devices the contrary is true. The main reason why is that the gateway is unable to respond to the nodes due to duty cycle limitations, which causes the nodes to think their transmitted messages were not correctly received, which triggers retransmissions and thus increases the load on the network even more. In addition, when transmitting ACKs,

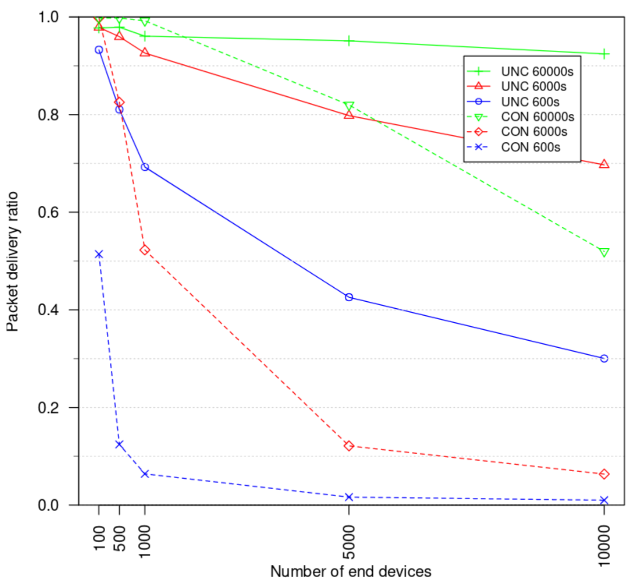

Figure 2.2: LoRaWAN packet delivery ratio

the gateway is unable to receive other messages, causing greater message loss.

This simulation was done using a single gateway. The authors observed that adding more gateways gives better results but does not completely solve the problem. For instance, using four gateways for the same scenario the PDR would increase to 35% (instead of 15%), resulting in a loss of 65% of messages.

A similar study in [20] shows that for larger networks throughput is significantly reduced even when only 5% of the packets require downlink response. A downlink response can be because of an ACK request, because of downlink application data or because of network management commands (change SF, change TX power, etc.) originating from the network server.

Periodic heartbeat messages transmitted by the devices are a tool which allows measuring the reliability and the health of the network. Network problems or device malfunction can be identified on the backend in the timeframe of a heartbeat interval of for example, 30 minutes. A device which does not use heartbeats but only transmits a message based on a certain sensor threshold for instance might only send a message after a few days or weeks, which would make automatic device health monitoring rather unpredictable. The customer might also require functional safety guarantees from the sensors, certainly in an industrial context. For example, to comply with a certain Safety Integrity Level as defined in the IEC 61508 standard, the sensor will need to ensure a maximum heartbeat period to be able to detect faults timely. Apart from better monitoring of the network health at the backend side, periodic heartbeats can also be used to improve quality of service by requesting acknowledgements. When an end node suddenly fails to receive an ack on a transmitted heartbeat it knows the link is currently broken (for example due to a change in the environment) and can take corrective actions (for example increase SF or TX power) until communication is established again. In this way, requesting the acknowledgements for periodic heartbeats as well increases the quality of service of normal (more important) messages.

A final factor which might impact scalability is the LoRaWAN network server. First, because the network server is a central entity, it can become a bottleneck. There is not much information publicly available about the scalability of the different implementations, but if the architecture is designed correctly, it seems feasible to scale this on a cluster of servers. Secondly, the network server is instrumental in the general performance and scalability of the whole network itself, since the network server will be able to assign the SF and transmission power of the nodes.

BACKGROUND

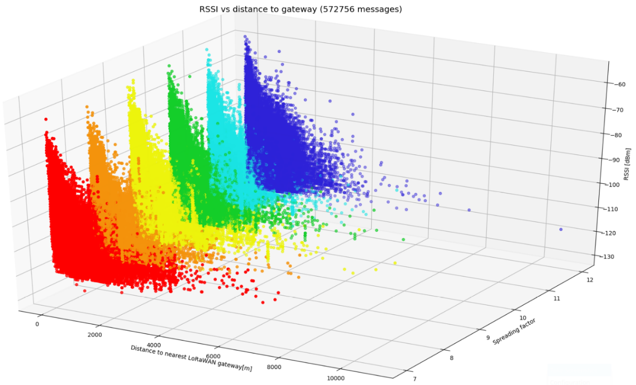

Figure 2.3: LoRaWAN spreading factor in function of distance

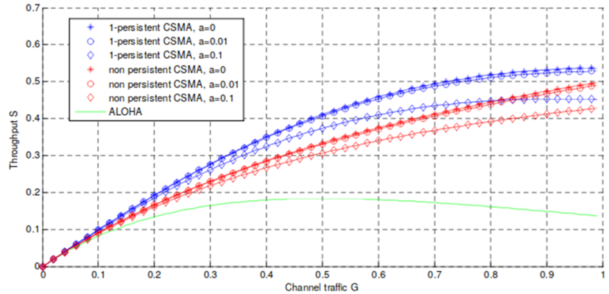

Figure 2.4: Channel throughput of CSMA vs ALOHA

There is little public information on how each implementation performs in this regard. Recent large-scale measurements in [2] using 70 gateways, 20 mobile nodes and 527k messages covering the city of Antwerp suggest that the network server aims to balance the SF used over all nodes, as can be seen in figure 2.3. Even for small distances between device and gateway, SF12 is used as much as SF8, so there seems to be no relation between distance and SF (in case of mobile nodes, the network server might react differently in a more static environment).

For DASH7 no simulations have been performed yet for large scale environments in terms of reliability and scalability. There are however a few differences which will improve the performance. Firstly, as already discussed, the channel access is not using random ALOHA but CSMA with collision avoidance. As shown in figure 2.4 from [14] the throughput when using ALOHA will decrease when the traffic on the channels increases, while in case of CSMA the total throughput is higher. This is of course still limited (for instance by the hidden node problem) but it is a clear improvement.

The lower transmission duration of DASH7 (as explained before) will be beneficial for reliability and scalability as well, as the chances of a collision are lower and the lower pressure on duty cycle for downlink messages allows for more ACK's, thus increasing reliability. A DASH7 node will also pick a preferred gateway (the one reachable with the lowest link budget) and will unicast to that gateway by default. This lowers the pressure on other gateways (which can discard the packet sooner) and allows to lower the transmission power so that the collision domain decreases. Finally, in case of DASH7, there is no central network server which can become a bottleneck. Gateways can respond immediately to an incoming packet without having to wait for a response from a network server, which lowers the total transaction time. Features like TX autoscaling are implemented on the end nodes, instead of on the central network server like in the case of LoRaWAN, which means there is no signaling overhead (in terms of downlink packets) required for this.

The survey paper [16] provides a good overview of all recent LoRaWAN research about scalability and other topics like security. It also lists recent ongoing research focus-

Strengths	**Weaknesses**
- Large coverage in outdoor environments - Low power usage of end nodes - Low complexity of end nodes - Cheap end devices - Private network deployment opportunity - Suitable for monitoring applications	- Security issues - Reply and DoS attacks possible - Ntw security and App security terminates at different points in the network - ADR mechanism performs badly under heavy network load (increase power consumption of end-nodes, and collision rate in network) - Low scalability in DL due to duty cycle.
Opportunities	**Threats**
- Power usage can decrease further by modifying DL communication scheme - Low-power traffic synchronization possibilities. - Low-power traffic scheduling possibilities - CSMA schemes to avoid duty cycling in DL.	- Scalability issues in UL under heavy network load. - Interference from other technologies. - Not-suitable for two-way communication.

Figure 2.5: LoRaWAN SWOT analysis

ing on improving the reliability for large scale deployments. The main conclusions are listed in the SWOT analysis in figure 2.5.

There are also existing commercial solutions built on top of LoRa but avoiding the limitations of LoRaWAN like [18].

The conclusion in [1] summarizes the limits of LoRaWAN as follows: "In the low-power M2M fragmented connectivity space there is not a single solution for all the possible connectivity needs and LoRaWAN is not an exception. ... For instance, we have seen that deterministic monitoring and real-time operation cannot be guaranteed with current LoRaWAN state of the art."

APPLICATION TRADE-OFFS

Before implementing a LoRaWAN network it is crucial to take the functional and non-functional requirements for all applications which will be using the network into account. While basic monitoring use cases might be feasible using one LoRaWAN gateway on site, other applications requiring better quality of service, compliance with functional safety standards or battery life pose more stringent requirements on the network infrastructure. The performance of the network can be improved by adding more gateways and by lowering the SF parameters of the devices (and thus the range), however the throughput will still be limited by the ALOHA channel access and the downlink duty cycle. While it may be possible to install one gateway and fully cover a plant to get hourly temperature measurements of a few devices it is much harder to implement a network which can do reliable bidirectional communication with 500+ devices. It is also important to have a complete view of all applications that will run on the (shared) LoRaWAN infrastructure. This will require careful network planning and tuning of the network parameters by the network server. It is unclear how the various LoRaWAN network servers perform in optimizing this network which is an uncertainty that you would want to be controlled in an industrial setting. A similar conclusion is reached by [19]: "Overall, however, the interplay among the different system's tuneable knobs is often subtle and difficult to predict, calling for the development of efficient system design/configuration tools.". The remainder of this section lists some aspects which are important to keep in mind when implementing a LPWAN network given the use case(s).

3.1 Quality of Service

As explained in more detail in chapter 2 there are trade-offs to be made in terms of battery life, scalability, reliability, latency and range. Scaling these requirements in a LoRaWAN network can be covered only to a certain extent, by scaling the network infrastructure (increasing the density of the gateways) and careful tuning of the network parameters, after which legislation and protocol design choices will be the main limiting factors. Section 2.8 describes in more detailthe limitations on the QoS in a LoRaWAN network and the main differences with DASH7 in this regard.

3.2 Low-latency downlink

Any use case where a low-latency downlink is required is not possible with LoRaWAN, since battery powered LoRaWAN devices can only receive downlink messages after each transmission so this is limited to the (heartbeat) message rate (in the best case; assuming there is enough downlink duty cycle). In DASH7 the nodes perform low power listening where they sample the channel for possible downlink commands once per second and thus resulting in a downlink latency of one second.

3.3 Flexible communication schemes

In DASH7 it is possible to communicate with multiple device at once, based on device properties (queries aka Smart Addressing), instead of only based on the device ID. For instance, it is possible to enable the LEDs on all devices which are monitoring the same pipe (or any other logical subset of devices, based on a device property). Similarly, this can be used to select a subset of devices for a firmware update (for example: update all devices in unit A, since this unit is now not operational). DASH7 also allows device to device(s) communication, enabling more communication schemes than the device to gateway communication as used by LoRaWAN.

3.4 Localization accuracy

If we look at use cases like on site asset or people tracking, localization accuracy becomes more important. Using a denser gateway network (as required for DASH7) is beneficial for accuracy compared to only one or two LoRaWAN gateways.

3.5 OTA updates

Over-the-air updates of the firmware (FUOTA) on the devices is crucial. In case of LoRaWAN over-the-air upgrades are cumbersome because of the impact on the gateways' duty cycle and the energy impact of the large number of messages which have to be received. To give an idea: transmitting 80k of code for an upgrade would take 60 hours using SF12 given the duty cycle limitations. For lower SFs this decreases but it still too slow for practical purposes. By some LoRaWAN providers, it is proposed to use mobile additional gateways only for FUOTA, which limits the dynamic character of a network and increases cost. Of course you can decrease the necessary pay load by sending incremental or partial updates. Besides the duty cycle impact, the gateway is not available for incoming messages during this period. In the case of DASH7 firstly the data rate is much higher and secondly, we can switch to other frequency bands which will not impact the 100 seconds per hour limitation of the frequency band which is used for normal communication.

3.6 Battery lifetime

The most important aspects determining the net capacity of the battery are: peak current level, peak duration, sleep current level, recovery time between peaks and ambient temperature. The peak level and duration are influenced by the choice of network technology and the network deployment/tuning. For example, a denser gateway deployment allows the use of a faster data rate (by decreasing LoRaWAN SF or using DASH7) which is beneficial for the peak duration. Also, a denser gateway deployment allows downscaling the TX power, which in turn impacts the peak height. Frequency of the peaks are partly determined by the application and/or environment. The impact of these peak loads result in a decrease of the net battery capacity compared to the nominal capacity, and the impact is typically not linear. This can be significant, for example 50% loss in capacity. This can be improved by integrating a supercapacitor in the design which can for a large part take the burden of the peak loads from the batteries, which allows to raise the net capacity, and thus the lifetime significantly, at the expense of device size and cost. In many scenarios it is more cost efficient to deploy a denser gateway network, when comparing to the cost of more frequent sensor device or battery replacements in the field.

3.7 Multimodality

As shown in the rest of this document there is no "one size fits all" technology for industrial IoT. This is now acknowledged by the LoRaWAN Alliance as well in a recent whitepaper on combining Wi-Fi and LoRaWAN [15]: "The reality is that no one single technology is going to fit the billions of IoT use cases" said Donna Moore, CEO and Chairwoman of the LoRa Alliance [3]. It may however be possible to support multiple technologies on the same hardware. For instance, if the device is based on a Semtech sx127x LoRa radio it is possible to use multimodal firmware which can use both LoRaWAN and DASH7. This allows, for instance, DASH7 to be used while on-premise and switching to public LoRaWAN for off-premise monitoring as shown in [13]. Similarly, it is possible to equip

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gateways on site with both radios which allows the use of the most efficient technology for each application while preventing having to deploy more gateway infrastructure. Multimodal LoRaWAN and DASH7 network infrastructure would enable to expand the number of possible use cases or QoS, while it does not require installing separate network infrastructure.

CONCLUSION

In this document we have tried to give some of the background required to compare RF technologies and some limitations of both technologies. LoRaWAN is certainly a very interesting LPWAN technology, especially for uplink only, infrequent sensor data and with a low density of nodes and gateways deployed over a large range. This is also the main use case of the public LoRaWAN networks. Recently more and more private LoRaWAN deployments are being installed as well. While a private deployment allows more flexibility, there is still a limitation on scalability and reliability which may or not be compatible with the specific application requirements. Range alone is a poor metric to plan a network deployment. For reliable LoRaWAN operation the gateway density should be increased compared to the case where one gateway can cover an area to receive sporadic uplink messages. If the maximum range using SF12 is 2 km this is irrelevant when this means that the that battery lifetime or the wanted QoS level for a specific use case is not reached, in which case the practical range might need to be limited to 300 m for example.

We discussed the trade-offs to take into account when implementing a private LPWAN network, and can conclude there is no silver bullet technology which can cover most industrial IoT use cases. The trade-offs are discussed in this document and the main differences with DASH7 are highlighted. Finally, the advantages of coexistence of both technologies are listed.

DASH7 ALLIANCE

The DASH7 Alliance is a non-profit mutual benefit organization formed to foster the existence and the further development of the DASH7 protocol specification (D7A protocol) (based on ISO 18000-7). It is the intent of the Alliance to enhance the technology beyond its current capabilities and physical boundaries to enable security, automation and control systems for a multitude of environments.

LEGAL NOTICE

PARTICIPANTS

Following persons where involved in the creation of this document:

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