LoRa and LoRaWAN Testbeds: a Review

Jaco M. Marais and Reza Malekian
Electrical, Electronic and Computer Engineering,
University of Pretoria, Pretoria, 0002, South Africa

Adnan M. Abu-Mahfouz
Meraka Institute, CSIR
Pretoria, 0184, South Africa

***Abstract*—The Internet of Things (IoT) is a fast-growing movement turning devices into always-connected smart devices through the use of communication technologies. This facilitates the creation of smart strategies allowing monitoring and optimization as well as many other new use cases for various sectors. Low Power Wide Area Networks (LPWANs) have enormous potential as they are suited for various IoT applications and each LPWAN technology has certain features, capabilities and limitations. One of these technologies, namely LoRa/LoRaWAN has several promising features and private and public LoRaWANs are increasing worldwide. Similarly, researchers are also starting to study the potential of LoRa and LoRaWANs. This paper examines the work that has already been done and identifies flaws and strengths by performing a comparison of created testbeds. Limitations of LoRaWANs are also identified.**

***Keywords*—LoRa, LoRaWAN, LPWAN, Internet of things.**

I. Introduction

The IoT bring the promise of a world filled with smart cities, constant tracking of objects and everyday life filled with wireless devices to improve every aspect of our existence. The IoT movement creates the need for new wireless technologies, capable of supporting the large numbers of devices found in the IoT space [1]. These low-cost devices can be considered to form a Low Power Wide Area Network (LPWAN) and require a multiyear lifespan and are deployed in large amounts. Furthermore, these devices may be located underground, underwater or deep inside buildings [2]. New wireless technologies must therefore have sufficient penetration and range capabilities. Security of these devices and networks are also a major concern as more and more critical infrastructure are added to the IoT. Most of these sensors are battery powered. Therefore, energy efficiency and low power consumption is also a major concern.

Previously Machine to Machine (M2M) networks operated on cellular networks in the form of 2G but 2G is now being phased out by some cellular operators to make room for newer technologies (Long-Term Evolution (LTE)) [1]. These new technologies offer significantly increased Bandwidth (BW) but come at a cost of higher power consumption. For the M2M use case the higher bandwidth capabilities are unnecessary and the increase in power consumption renders these technologies unsuitable. To fill this gap several competitors such as SigFox, Random Phase Multiple Access (RPMA), NB-Fi, Weightless, DASH7 and Long Range (LoRa) now compete for market share in the LPWAN domain. The cellular industry is also developing their own products, for example NB-IoT, eMTC and EC-GSM which will use licensed cellular frequencies.

Currently some communication standards, those based on IEEE 802.15.4 such as ZigBee, use a mesh network topology to extend their network coverage, as links between nodes are limited to approximately 100 meters [3]. The technologies competing in the LPWAN market however, use a star topology as greater receiver sensitivities allow for coverage in the kilometres range. This increased coverage comes however at the cost of reduced data rates. Using the star topology greatly simplifies network management and reduces the required networking firmware for end devices [3].

All of the LPWAN competitors claim that their approach is the optimum solution for this new generation of IoT. Depending on the use case some connectivity options will be more suited than others but an in-depth analysis is required to ensure that the correct design choices are made. An evaluation of LoRa and LoRa Wireless Area Network (LoRaWAN) will provide insight into the advantages and disadvantages of this technology.

II. LoRa and LoRaWAN

Some of the LPWAN offerings are mainly proprietary but the LoRa Alliance develops LoRaWAN as an open standard. The physical layer (LoRa) was however developed by Semtech which remain the sole LoRa integrated circuit producer [4]. LoRaWAN is the communication protocol (ALOHA-based) [5] and system architecture for a network using the LoRa physical layer [6]. LoRaWAN is not the only communication protocol that uses LoRa as the physical layer: Symphony Link™ and LoRaBlink are other examples. LoRaBlink [7] adds multi-hop support while Symphony Link offers guaranteed Acknowledgements (ACKs), over the air firmware updates and many other features. The DASH7 stack can also be configured to use LoRa as its physical layer and can potentially run side-by-side with a LoRaWAN stack [8].

A. Physical layer (LoRa)

LoRa is a derivative of Chirp Spread Spectrum (CSS) modulation with integrated Forward Error Correction (FEC) [9]. LoRa uses sub one GHz ISM bands in Europe and North America and its wide band nature allows LoRa to better compensate for a low Signal to Noise Ratio (SNR) [10]. This allows LoRa to demodulate signals even when they are 19.5 dB below the noise floor [11]. CSS allows for a longer communication range than Frequency-Shift Keying (FSK) without an increase in power consumption [5].

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Transmitting at higher power levels will increase a LoRa node's range. Nodes can adjust their output power to meet regulatory requirements. In Europe +14 dBm is the maximum transmit power except in the G3 band (+27 dBm) [5].

LoRaWANs deployed in Europe have channel bandwidths of either 125 kHz or 250 kHz and a single FSK transmission channel providing a higher data rate is also available [6]. Data rates are region (regulatory restrictions) as well as Spreading Factor (SF) dependent. Increasing the spreading factor improves the SNR but results in longer transmission times [7]. Using a higher bandwidth shortens the transmission times but reduces the maximum receiver sensitivity [11]. Capacity calculations performed in [12] revealed that when a single gateway must serve many devices the majority of them should be close to the gateway (SF = 7) as only a few nodes with the maximum SF can be supported given their long transmission times.

LoRa uses FEC to allow the recovery from transmission errors due to bursts of interference, but the use of FEC adds some encoding overhead [13]. LoRa's coding rates are $4/(CR+4)$ with $CR \in \{1, 2, 3, 4\}$. A LoRa packet's header and its Cyclic Redundancy Check (CRC) will always be transmitted using a CR of 4/8 and the payload with its optional CRC at the chosen coding rate [13].

When LoRa is transmitting with a BW of 125 kHz and a SF of 11 or 12 a low data rate optimization can be enabled. This reduces the impact on transmission due to drift in the reference frequency of the oscillator, but does add additional data overhead [13].

LoRa can detect channel activity using Carrier Activity Detection (CAD) [7]. This is faster than Received Signal Strength Indicator (RSSI) identification and can differentiate between noise or a desired LoRa signal [10].

B. LoRaWAN

LoRaWANs in Europe are limited to 10 channels, has duty cycle restrictions but no channel dwell time limitations. LoRaWANs in North America have 64 channels, also have duty cycle restrictions but no channel dwell time limitations [5]. LoRaWAN has 3 common 125 kHz channels for the 868 MHz band namely 868.10, 868.30 and 868.50 MHz that devices use to join the network [14]. Once a node has joined the network, the network server can provide additional channels to the device. In Europe, the same channels are used for uplink and downlink.

The network architecture is a star of stars topology in which end nodes connect directly communicate with gateways which in turn connect to a central network server [4]. Gateways are always on devices and have LoRa capabilities and potentially Ethernet or cellular capabilities to connect to the network server.

In a LoRaWAN transmissions are received by any nearby gateway(s). This allows mobile nodes to transmit to any gateway without any handover. The network server drops any copies of a message and replies using the optimum gateway [5], [6].

LoRaWAN uses Adaptive Data Rate (ADR) and a multichannel multi-modem transceiver in gateways. This allows for simultaneous message capturing on multiple channels [6]. Different spreading factors allows multiple different data rates on the same channel simultaneously [5]. Nodes with good link capabilities should use higher data rates to decrease their transmit times, allowing other nodes to use larger spreading factors.

LoRaWAN defines three device classes (A, B, C). All end devices must support Class A but the other classes are optional [14], [15]. Class A devices transmit as needed and create two downlink windows shortly after transmission. Class B devices are similar to class A devices but add scheduled receive slots (scheduling is enabled by beacon broadcast from gateways). Class C devices continuously listen when they are not transmitting. Choosing the optimal class is vital for applications with response time or minimum power consumption requirements.

III. Testbed evaluation metrics

When deciding if a LoRaWAN will be the most suitable solution the capabilities of this technology should be understood. These capabilities can be found through simulation or through testbeds. Before this can commence a clear definition of evaluation metrics is required to accurately compare results.

Suggested LoRa and LoRaWAN testbed evaluation metrics can be viewed in Table I . Furthermore, the following should be kept in mind: the SNR at a node will have an impact of the Bit Error Rate (BER) of the node which in turn impacts the Packet Error Rate (PER) [16]. A chosen SF will have an impact on the maximum bit rate, maximum payload size and the amount of time a node is required to be off air before transmitting again [14].

In addition to these metrics there are additional metrics that are implementation or use case specific. These are listed in Table II.

IV. LoRaWAN testbeds

A. Outdoor

Free space measurements with a BW of 250 kHz took place in Germany and recorded RSSI, SNR and PER for various distances and payload lengths of 10, 50 and 100 bytes [16]. With the SF fixed at 10 the results showed that for a 10 byte payload the PER remained zero up till 8 km. The 50 byte payload resulted in invalid packets from 2.3 km with the PER changing inconsistently as the distance increased. In contrast with the 50 byte payload the 100 byte payload had a near zero PER up until 6.6 km. The chosen bandwidth value of 250 kHz differs from the LoRaWAN specifications (LoRaWAN mainly uses 125 kHz for these channels) [14].

The water level of troughs is monitored using a 915 MHz LoRaWAN [17]. The troughs are placed on the ground and connectivity with the gateway is negatively affected by objects in the Fressnel zone. Therefore, distance tests were conducted in which RSSI levels for various hub and node heights and antenna polarization were recorded. A 100 node network was simulated in a lab environment by increasing the data

TABLE I
TESTBED EVALUATION METRICS.

Metric	Explanation
Number of gateways	A LoRaWAN with only one sink will operate differently than one with multiple sinks.
Number of nodes	Increasing the number of nodes demands higher performance of the LoRaWAN.
RSSI	The RSSI measured by a node provides an indication of the coverage range of the gateway and how reliable communication will be.
SNR	The SNR experienced by a node also provides an indication of how reliable communication will be.
Distance from gateway	Distance measurements can be combined with connectivity measurements (RSSI, SNR, PER) to determine a gateway's effective range.
Payload size	Ideally network performance was evaluated for multiple payload sizes as these impacts transmission times.
Transmit power	Transmitting at higher power levels (dBm) can achieve greater range but regulatory restrictions apply.
Network reliability	Network reliability can be defined in several ways: number of packets received successfully, the number of valid received packets or examining the PER.
Power consumption	Power consumption values for the motes can be used to estimate the network's lifetime.

TABLE II
OTHER SITUATIONAL EVALUATION METRICS.

Metric	Explanation
Number of floors or walls between gateway and node.	For indoor LoRaWANs this provides an indication of the penetration capabilities of the network when combined with e.g. RSSI.
Single or multi-hop network	LoRaWAN is by default a single hop network but multi-hop features can be added (see [7]).
LoRaWAN class	Options are A, B or C. The class used defines how communication takes place. By default, LoRaWANs are class A.
Are nodes set to use a specific channel or can they choose.	When nodes can choose less congested channels, the amount of nodes supported increase.

transmission rate of 5 nodes, resulting in a 17 % drop of valid packets (payload was 26 bytes) [17]. Care should be taken when comparing their results with others as the regulatory requirements for US and Europe ISM bands differ (no duty cycle restrictions in the US band).

An outdoor evaluation of LoRa and LoRaWAN using 3 gateways was performed in Glasgow [6]. Outdoor testing recorded GPS location, RSSI and reliability of receiving an Acknowledgement (ACK) after transmitting. Reliability testing revealed that the gateway's cellular network connections experience periods of disconnect, due to the cellular network's inactivity policies. Continuously pinging the gateways raised the LoRaWAN connectivity rate from 70 % to 95.5 % [6]. In 2.5 % of attempts the data was received but the LoRa node did not receive an ACK.

A range test with 2 LoRa transceivers was also conducted. Connectivity tests was successful up to 2.2 km in one direction but only 1.6 km in another due to a hill [6].

In Finland LoRa's long rage capabilities was tested using a mobile node (car and boat trips) with a PCB antenna [18]. The received signal strength, GPS coordinates and resultant packet loss was recorded for locations up to 30 km. The node had a SF of 12 and randomly chose between 6 channels when transmitting and transmit power was limited to 14 dBm. Measurements by car showed that even close to the gateway ($\leq$ 2 km) a 12 % packet loss ratio as experienced. Path loss exponents was also calculated from the resulting data.

Outdoor testing of 6 LoRa nodes in a 1.5 ha area showed a potential lifespan of 2 years on 2 AA batteries [7]. The authors implemented their own Media Access Layer (MAC) protocol (LoRaBlink) to enhance LoRa by adding multi-hop capabilities. Evaluations revealed a relatively high packet loss of 20 % for their now short range multihop LoRa network.

Transmissions can be sent on different frequency channels and on different spreading factors. Transmissions with different spreading factors are mostly orthogonal and can still be decoded successfully [7]. This allows gateways to receive multiple transmissions from end devices simultaneously. An investigation into LoRa's CAD found that the detection probabilities are more than 97 %. Furthermore, if two transmissions sent with the same parameters are received, the strongest of the two will with a strong probability still be recovered [7]. However, false positives increase when different LoRa networks are active on different SF/BW combinations [7].

In Padova (Italy) LoRa's coverage distance for various SF levels was evaluated [3]. The gateway was placed in a worst-case scenario of no antenna gain, antenna elevation and taller buildings surrounding the gateway. Up to 2 km range was achieved (SF = 12) but the researchers felt that 1.2 km should be considered as the coverage value to compensate for any link budget variations. Calculating the achievable theoretical amount of LoRa nodes per person in Padova revealed 2 nodes per person when 30 gateways was used (gateway capacity was set to 15 thousand nodes per gateway) [3].

LoRa mobile connectivity tests was conducted on a university campus [19]. A researcher with a PCB antenna LoRa node navigated his daily routes on campus. Apart from entering an anechoic chamber the LoRa node had 96.7 % connectivity (95 % when moving). A spreading factor of 12 was used and the node randomly chose between six channels when transmitting [19]. Acknowledgements were not required for uplink messages and no retries were made when transmissions were unsuccessful. The average path loss for different areas on campus was calculated. One limitation of this test was that one node was used and the coverage results may differ when using multiple or different manufacturer's nodes. The researchers point out that using the maximum spreading factor results in long transmission times, leading to limited link availability and scalability issues.

Line of sight measurements (9.75 km) for a 2.45 GHz LoRa system resulted in 81.58 % correctly received packets [20]. The SF was set to 12 and when the antennas were misaligned 50 % of packets were still received correctly. The penetration of LoRa through a salty water mixture (0.77 % salt) was also tested and 94.5 % of packets was correctly received through a 10-12 cm water layer. When the width of the water layer was increased all communication promptly stopped. The potential of LoRa's use in safety systems was evaluated in which LoRa provides redundant links via 868 MHz and 2.45 GHz LoRa modules [20].

LoRa's network coverage in urban environments (Paris) was tested using SFs of 7, 9, 12 and a transmission power of 14 dBm [21]. Coverage was achieved for distances of up to 3.4 km and at 3.4 km a SF of 12 resulted in a $\approx$ 38 % packet delivery ratio. The closest test point (650 m) revealed that 100 % delivery can be achieved with a SF of 12 and this ratio drops down to $\approx$ 84 % when a SF of 7 is used. As acknowledgements and retransmission were disabled, higher success rates are possible when these are enabled.

B. Indoor

An indoor LoRaWAN deployment [14] evaluates LoRa's data throughput capabilities when considering the European 1 % duty cycle limitation. In maximum interference conditions (SF of 12) end devices must wait two and a half minutes before two consecutive transmissions even when sending an empty payload packet. Using data rate 6 for this empty packet reduces the required off air time to 2 seconds [14]. The indoor network also measured RSSI and SNR levels to evaluate building coverage for a single gateway scenario.

Tests show RSSI levels are not influenced by the data rate but that the SNR is however influenced [14]. Repeated transmission tests at date rate 2 found that nodes close to the gateway had frame duplications and received packets with bad CRCs. Packet loss versus data rates comparisons shows big differences between the rates and decreases in error with increases in distance. Therefore, special attention should be taken when nodes are in basements to ensure they have sufficient coverage [14].

An indoor evaluation of LoRa and LoRaWAN was performed in Glasgow in Scotland [6]. Brief indoor testing evaluated RSSI by noting the quality of reception in stairwells and central corridors, as well as number of floors between the node and the gateway.

LoRa's indoor penetration abilities was tested in Prague [2]. LoRa's reach inside the building was measured by recording a node's RSSI levels for various locations and floors in the building. The impact of placing the gateway on the roof versus in the basement was also explored. Ten messages was send from each test location and messages had a large payload containing info such as identification information, RSSI, SNR and the data rate to name a few. Tests were conducted using a IMST iU880A USB adapter LoRa node which does not feature an external antenna. The output power was reported to be fixed at 20 dBm but IMST indicates that the maximum output power for this product is 18 dBm. An analysis of the recorded RSSI levels showed that placing the gateway on the roof provides significantly more coverage than in the basement [2].

A private LoRa network consisting of 1 gateway and 32 nodes are part of an energy saving program for a building [3]. Switching to a LoRa network removed the need for repeaters and allowed a single gateway on floor 9 to provide coverage for all 19 floors of the building. This installation demonstrates LoRa's penetration abilities as the researchers noted that some nodes could be placed in areas where connectivity had previously been poor [3].

LoRa's power consumption as well as penetration capabilities were evaluated by varying the spreading factor [20]. Lower SFs are better for single reinforced concrete wall penetration, but a SF of 12 enabled transmissions to penetrate 3 walls with 33 % of packets received.

The RSSI levels for packets being transmitted from an outdoor end device to an indoor gateway was recorded [21]. The experiment used a transmit power of 2 dBm which resulted in a maximum range of 100 m and RSSI levels did not decrease as the SF was increased. It was noted that lower RSSI level packets had a large Signal-To-Interference-plus-Noise Ratio (SINR) [21].

C. Simulations

As LoRa and LoRaWANs are new technologies a demand exists for suitable network simulation programs to better predict network coverage before a network is deployed. A LoRa simulator was created named LoRaSim to attempt to address this problem [11]. This simulator can evaluate the ratio of received to transmitted messages for a period and can evaluate a network's energy consumption (estimation). It also has support for single and multiple sink scenarios. The creators found that only 120 nodes can be supported by a single sink (gateway) when a SF of 12 is used with nodes sending 20 bytes every 16.7 minutes [11].

The collision rate in a LoRaWAN under load was simulated for different packet sizes [21]. A collision was defined as two packets having overlapping transmission times. Experiments performed in [7] show however that LoRa can receive concurrent transmissions (to a degree). Simulations showed results similar to those of pure ALOHA with a maximum capacity use of 18 % for a link load of 0.48. However 60 % of packets are dropped resulting in retransmissions for any messages requiring acknowledgements [21].

D. Comparison of testbeds

The LoRa and LoRaWAN based testbeds discussed above are compared in Table III. For the gateway column only true gateways were considered, using an end nodes as a single channel gateway was counted as another node. The table shows that care should be taken when comparing the work presented in one paper with the work in another. Directly comparing the results are made difficult by some researchers publishing incomplete setup information and the many ways reliability was measured.

Most of the presented work used only a single gateway and very few nodes. In all the studies the only LoRa network present was the one created for the study and no interference from other LoRa networks were present. Most of the testbeds evaluated LoRa by only varying one parameter such as distance, SF or payload size instead of varying multiple aspects. Some researchers consider the validity of received packets while others only look at the number of packets received (or lost). Payload size has a substantial impact on performance but many testbeds don't fully define their payloads. Most testbeds fixed the transmission power to the maximum value allowed by regulations. However, this can be varied and nodes closer to the gateway can use less transmission power to improve battery life.

V. Limitations of LoRaWAN and future work

Examining LoRaWAN from an Open Systems Interconnection (OSI) model perspective reveals that LoRaWAN is mainly a MAC layer protocol with a set network architecture and the rest of the stack is left up to the developer [5], [21]. Advanced features such as a mechanism to auto-fragment payloads that is larger than the maximum size will have to be developed. Gateways can use ADR to control data rates of end devices but the optimal manner to execute ADR is still unknown [4].

Class A devices establish two receiver windows only after a message is transmitted. By default window two is fixed to use 869.525 MHz and a SF of 12 in Europe [22]. A potential scenario could arise where a busy gateway is forced to use the second window to reply to devices, resulting in very long transmit times during which a channel is occupied [4]. Furthermore, in Europe several of the channels are limited to a maximum of 1% duty cycle also restricting the time on air for devices. There is a delay window between when a gateway has received a message and when the first receive window of the sender node opens. During this time, the gateway could keep listening to the channel and start receiving a message from another node [4].

LoRa uses different sub 1 GHz bands depending on your region. This results in region-specific configuration problems as end devices must be re-configured or detect their region. The LoRaWAN specification suggests methods for end devices to determine their region. Suggestions include adding GPS hardware to end devices, equipping beacons with GPS and transmitting their coordinates or instructing beacons to transmit a list of join frequencies. Programming beacons to transmit a list of join frequencies avoids the cost of GPS hardware but requires that beacon nodes be present [15].

The long-term viability of LoRaWANs remains in question. Presently there is only one LoRa manufacturer (Semtech) and as the unlicensed bands become more and more congested a network may no longer provide the performance it originally did. Public and private LoRa networks will interfere with one another as especially in urban environments all the end devices will be in close proximity. This is a widespread problem for all wireless solutions using the unlicensed bands. Usage of protected licenced bands will always have an advantage. This problem is alleviated to a degree by LoRa's configurability of SF, BW and transmit power as well as CAD [7]. LoRa's CAD does however suffer from false positives when multiple SF/BW combinations are present (multiple networks in an area) [7].

Support for over the air firmware upgrades appear to be limited if not completely unfeasible. Firmware updates are restricted by the 1 % duty cycle restriction and class A nodes are unicast messaging only. The LoRa specifications for class B devices leaves setting up multicast groups to the application layer or as part of node personalization [15]. The Multicast message format requires that no acknowledgement be requested for multicast messages. Similarly support for over the air security updates are lacking, this is a major concern for security sensitive applications such as critical infrastructure.

Semtech announced in a June 2016 press release that native geolocation has now been added to LoRa. Limited information on this feature is available but the press release states version 2 LoRaWAN gateways are required. LoRa supports geolocation by using timestamps and differential time of arrival algorithms [1]. Mobile nodes attempting geolocation will receive inaccurate results as especially in Europe the 1 % duty cycle limitation will restrict the frequency of geolocation attempts. Geolocation features will increase the amount of supported use cases but secure localisation algorithms are required to preventing fraudulent or malicious nodes from disrupting the network.

When devices re-join a network, they revert back to the default MAC settings [22]. The network server will then have to re-adjust any changes to these settings on every join procedure. As a result, a major traffic spike for the network server will occur if a large amount of devices suddenly have to re-join/join a network. This could occur when a gateway lost power and it served as the only gateway for all nodes in its coverage area.

The LoRaWAN protocol allows end devices (Class A) to decide when to send ACKs for received messages and when to receive pending messages [22]. This allows end devices to ensure they stay within duty cycle limits. However, gateways don't have an upper bound on when messages will be acknowledged or when devices will receive any pending message(s). Applications with time critical requirements will need to either carefully design their end node firmware, choose a different LoRaWAN class or opt for a different LPWAN technology.

VI. Conclusion

There are many challenges and factors to consider when implementing a LPWAN. Not only are there several technologies and protocols to choose from, comparing these options can be difficult. The long-term performance of a network isn't only impacted by the logical and geographical layout of the network but also by interference from other networks, the ability to perform firmware upgrades and regulatory restrictions (which could change).

LoRa and LoRaWAN has the potential to create viable LPWANs but only when this option's strengths and weakness are considered. The major advantage is the variety of state of the art performance improvement mechanisms included which enables optimisation for different use cases and contexts. The open nature of the LoRaWAN specifications enables designing

TABLE III
TESTBEDS FOUND IN LITERATURE.

Ref.	Gate-ways	Nodes	Tx (dBm)	SF	BW (kHz)	ISM band (MHz)	RSSI mea-sured?	SNR mea-sured?	Distances covered (km)	Payload (bytes)	How was reliability measured?
Conc building [2]	1	1	20	12	125	-	Yes	-	7 floors	large	RSSI values
Glasgow CBD [6]	3	2	14	varied	-	868	Yes	-	2.2	seq. number	Record ACKs
LoRaBlink [7]	0	6	17	varied	varied	-	-	-	0.342	varied	Packet reception rate
Urban coverage [3]	1	1	-	varied	-	-	-	-	2	-	SF needed for coverage
Indoor [14]	1	1	14	varied	125	868	Yes	Yes	0.5 m to 60 m	varied	Number of lost packets and packet error
Outdoor [16]	1	1	-	10	250	868	Yes	Yes	0.276 to 8.52	10, 50 and 100	PER
Water troughs [17]	0	7	-	-	-	915	Yes	-	0.5 to 2.7	26	% valid packets received
Car and boat [18]	1	1	14	12	125	868	Yes	-	15	seq. number, status	% packets lost.
Campus eval [19]	1	1	14	12	125	868	-	-	65 m to 195 m	-	% received packets
2.45 GHz LoRa [20]	0	2	3	varied	-	2450	-	-	9.75 outdoor, 30 m indoor	21	% valid packets
Paris testbed [21]	1	1	2/14	several	125	-	Yes	-	3.4 outdoor, 100 m indoor	1, 25, 51	% packets received and avg. throughput (bytes/s)

your application around LoRaWAN's strengths. At the same time care must be taken before choosing to opt for LoRa and LoRaWAN as not all use cases are best supported by this technology.

Further research into the capabilities, limitations and optimal use cases for LoRa and LoRaWAN is required. Creating better simulation tools will provide a better understanding of the true performance of a potential network. Additionally, more comprehensive evaluations using larger testbeds are required to better understand the role of LoRa/LoRaWAN in the bigger LPWAN space.

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