QoS Metrics Measurement in Long Range IoT Networks

An experimental study of LoRaWAN metrics for the low-rate overlay scenario

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***Abstract*—Low Power Wide Area Networks (LPWAN) is a new solution for the Internet of Things (IoT). This type of networks already has several specific implementations like LoRa, Sigfox, Weightless, RPMA and others. Due to long wireless range, low power consumption and numerous nodes low speed overlay networks can be organized on top of LPWAN. Small pieces of data like text messages, low-quality photographs, etc. can be sent over these overlays and can be of significant importance for emergency services. When organizing an overlay network over LPWAN it is important to meet the Quality of Service (QoS) requirements present in the base network to prevent malfunction of its services. This paper presents the results of experimental study of QoS metrics measurement in LoRaWAN networks.**

Keywords—LPWAN; LoRa; LoRaWAN; QoS; IoT; overlay networks; mesh networks; QoS metrics

I. INTRODUCTION

LPWAN refers to a new type of networks that aim to provide long distance communications using low-power transceivers, making them a solid solution for building IoT systems, in which wireless nodes cover large areas. Low data rates in LPWAN make traditional overlay networks meaningless, however a developed network infrastructure with numerous nodes, stand-alone power supplies and high level of network isolation enable low-rate overlays, e.g. for emergency situations when communication backbones can become unavailable. It is possible to send text information, coordinates and small to medium size photographs over these low-rate overlay networks.

One of the key tasks in the overlay scenario relates to keeping the quality of LPWAN services in a good condition while the overlay network serves requests of an external client. We previously proposed an approach that takes into consideration QoS requirements of both networks [1]. To show QoS feasibility in LPWAN networks we conduct the present experimental study for LoRaWAN, which today seems to be the number one choice in the field of LPWAN. The following core metrics are normally considered in QoS: bandwidth, packet error rate, packet delay, delay jitter. In this experimental study, we measure Received Signal Strength Indicator (RSSI), Signal to Noise ratio (SNR) and packet delay. The packet delay is an important QoS metric, which is neccessary even for a simple overlay traffic type, such as text messaging. It is however a complex metric, which differs from the commonly measured Packet Time on Air / Time of Flight (ToF), as it includes all delays (both hardware and software) that happen between network nodes. Still, RSSI and SNR can be retrieved directly from the LoRaWAN layer. In this work we use these metrics as markers to verify that the experimental results are correct and correlate with previous studies.

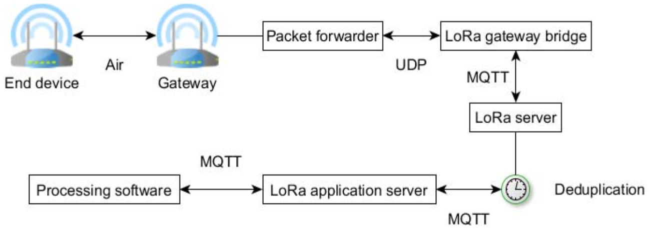

Figure 1. Packet processing schematic.

To understand, which elements add up to the total delay the packet processing schematic is presented (Fig. 1). Packets are transferred from the end device to the processing software and vice versa. All software components including the packet forwarder, the LoRa gateway bridge, the LoRa server, the LoRa application server and the end software introduce their own processing delays. It is impossible to retrieve the packet delay metric directly from LoRaWAN, we later describe a specialized protocol we use to measure this metric.

Our contributions can be summarized as follows. We first discuss an approach for organizing low-rate overlay networks over LoRa. Today LoRaWAN allows to build a star topology around a gateway [2]. Still, it is possible to implement a custom MAC-layer over LoRa to achieve a more complex topology [3] [4]. We hence briefly overview the possibilities of building a LPWAN mesh network. Then in sections V and VI we present results of our experimental study aimed at determining correlation between key QoS metrics in LoRaWAN and distance between an end device and a gateway. Our primary focus is the delay metric.

II. LORAWAN

At the moment one the most adopted solutions for LPWAN networks is Semtech LoRa. It declares a PHY layer for long-

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distance low-power communications [2]. LoRa networks can achieve up to 15 km range with maximum bandwidth up to 290 bps with CSS modulation [5]. For lower distances maximum data rates can get up to 50 kbps with FSK modulation, CSS modulation having slightly lower numbers. There is information about farther ranges up to 37 km in the experimental study [6].

Most LoRa solutions are based on the LoRaWAN stack provided by the LoRa Alliance [2]. LoRaWAN allows to build a star-of-stars network, in which every gateway listens a node uplink and only the nearest gateway provides downlink to the node [7]. Duplicate frames are removed by the LoRaWAN server side. Direct node to node communication is not supported. Reliability of the network increases with more active LoRaWAN gateways.

LoRaWAN gateway deployment is not anyhow restricted for personal applications and is legally unregulated at the moment. Community LoRa servers, e.g. The Things Network [8], enable networks consisting of personal gateways, in which every user shares his/her own gateways with other participants.

III. RELATED WORKS

An experimental study of QoS in the LoRa FABIAN network is conducted in [9]. In particular, the authors measured packet error rate (PER), Received Signal Strength Indicator (RSSI) and Signal to Noise Ratio (SNR). Experimental equipment was located in Rennes (France) and was set up for EU LoRa radio regulations. The equipment contained IoT objects built on an Arduino platform and a FroggyFactory LoRa Shield controlled by a modified version of Contiki OS, LoRa IoT station based on the Kerlink LoRa station. During the experimental study correlation between elevation and performance was evaluated.

C.Pham carried out research of QoS in LoRa networks under duty-cycle regulations [10], described a solution for LoRaWAN networks using shared activity time approach and provided an example for a surveillance application that uses 128×128 8-bbp grayscale images. The author conducted an experiment with a long-range image sensor platform for visual surveillance. The equipment contained nodes based on the Arduino Duo platform with a XBee 802.15.4 module, SX1272 LoRa module, uCamII camera module. The author took into account synchronization for network start-up, support for sleep period, a CSMA-like channel access mechanism, a cumulative behaviour for updates and dynamic insertion of new devices.

Krupka et al. provided a study of LPWAN network coexistence [11]. In their work the authors observed LoRa, Sigfox and IQRF LPWANs. They argued that a maximum number of devices on the channel was important for QoS in LPWAN networks concluding that there are certain risks in coexistence of LoRa and Sigfox LPWANs, which is not that critical at the moment with the small amount of active LPWAN nodes, however it may be an issue in the future as the number of deployed devices grows.

An experimental study of LoRa behaviour in different types of areas can be found in [12]. The authors varied a number of parameters including channel bandwidth, spreading factor, coding rate, antenna type and measured the following metrics: Packet Delivery Ratio (PDR), RSSI, SNR, connectivity range and packet time on the air. The experimental equipment contained two portable SX1272 devices from the Semtech development kit. The experimental study was conducted in different locations: Mattarello airport, long bike lane outside in the Adige valley, mountain forest in Maso Ariol. For the antenna experiment a set of different antennas was used: PC81, FXP280, Laird omnidirectional flexible antenna. The results showed that in mountainous environments communication range dropped by an order of magnitude, high temperatures deteriorated signal quality and the right antenna was necessary for a successful deployment.

A group of researchers from the University of Oulu (Finland) and Nokia (Finland) provided a set of experimental studies to determine PER and RSSI dependency on angular velocity (conducted in the laboratory of University of Oulu), PER dependency on linear speed (conducted on the city of Oulu motorway) and outdoor coverage test (conducted in the city of Oulu and Baltic Sea near the shore) [13]. The experimental equipment contained Kerlink's LoRa IoT gateway and end devices, based on Semtech SX1272 transmitter. The authors' findings included the 60% packet delivery rate on the ground at distances up to 10 km, with transmit power set to 14 dBm and LoRa spreading factor to the value of 12.

Nolan et al. from Intel Labs Europe (Ireland) conducted an experiment to determine coverage areas of SigFox and LoRa LPWANs [6], which included measurement of RSSI and SNR metrics. Carried out on the eastern seaboard of Ireland the experiment revealed the possible coverage area of 1380 km^2 for LoRa and the 25 km direct connection for SigFox.

In the related works listed above the following characteristics were measured for LPWAN: RSSI, SNR, PER, PDR, connectivity range, packet time on air. These are all important metrics used for QoS. Still, to the best of our knowledge there is no experimental study that provides measurement of the packet delay in LoRa/LoRaWAN. We understand the packet delay metric as a total delay that results from a packet being processed by the LoRaWAN infrastructure including its hardware and software parts, not just the time on air. Our present paper aims to provide an experimental study that includes measurement of this total delay metric.

IV. OVERLAY NETWORKS OVER LORA

An overlay network is a popular approach in traditional telecommunication networks used for different applications, like Virtual Private Networks (VPN) or special ad-hoc networks (XMPP, BitTorrent, etc.) to achieve network layer transparency, extra security and other profits for the user application [14] [15].

It is equally possible to build an overlay on top of a low-rate network to provide external clients with a telecommunication service they need. There are certain types of traffic that low data rate networks can handle: text messages, low-quality photographs, GPS/GNSS coordinates, alarm signals, etc. High LoRaWAN reliability [2], large network coverage [2], network isolation and autonomous power supplies - all make it possible for LoRaWAN networks to survive a possible disaster and provide, for example, telecommunication resources for emergency services.

However it is important to keep guaranteed QoS for both LoRaWAN and the overlay network [16] [17] to prevent malfunction of any of the two. In one of our previous works we proposed a method for converting overlay networks QoS quotas to WSN QoS quotas. Still, the issue of QoS in LoRaWAN lacks a more in-depth research.

To access a low-rate overlay network external clients can also use a different standard, like IEEE 802.15.1 (Bluetooth). There are LoRa modules in the market, that support IEEE 802.15.1 connection for short-distance communication [18]. One of the reasons for switching to a different standard would be improving the number of potential client devices.

A mesh network allows to send data through different paths depending on desired network characteristics and its current state [19]. Advantages of mesh networks include the ability to “self-heal” and reconfigure in the event of connectivity loss on a single node or on a group of nodes [20]. A disadvantage of this topology is the relatively increased complexity over traditional star networks and an increase in network traffic due to the inherent redundancy of the network and the necessity to maintain a more complex routing infrastructure. In addition, the increased traffic that each node has to handle means that mesh networks are typically implemented when nodes are not energy constrained.

LoRa as a physical layer technology (PHY) does not define any network topologies. It is then theoretically possible to build a mesh topology on LoRa, in this case an existing mesh protocol shall be adjusted to support the modulation format and other physical level characteristics of LoRa. This would be a significant engineering task especially for the scenario of fully autonomous networks as some of LoRa's specific characteristics like floating bit rates and long preambles need to be considered.

To provide a mesh solution over LoRa the MAC and network layers need to be provided. One of the possible solutions for the MAC layer is to integrate a CSMA-like mechanism, however in this case there are certain issues like the duty cycle limitation that would prevent a network node from sending messages too frequently; another is the potential non-transitivity of the channel. If the current LoRa architecture is retained, the CSMA-like mechanism would have to be controlled by the network server, which would put even more load on it.

The LoRa PHY level restricts the potential mesh protocol in some parameters like bitrate and activity period, but it also brings profit such as channel reliability and communication range. Hence, a LoRa mesh network in theory could provide long range communication with small bitrate and large sleep period. We believe that a LoRa mesh network would provide an even better solution for low-rate overlays increasing their efficiency and reliability, however a complete implementation is still to be proposed.

V. EXPERIMENTAL SETUP

We measure QoS metrics using the following LoRaWAN equipment: an end device based on the Laird DVK-RM186-SM-01 development kit, a gateway based on RaspberryPi 2 with a Raspberry Pi iC880A Shield. All devices are hardware configured for EU LoRa specifications and limited to the RU 864-869MHz ISM Band LoRa Alliance specifications [21]. Both devices are fitted with omnidirectional antennas. The gateway software is based on the Open Source loraserver project [22] and uses default or recommended settings for its configuration. Interserver communication uses the MQTT protocol. We use mosquito server to provide MQTT support and postresql server to provide nonvolatile server storage.

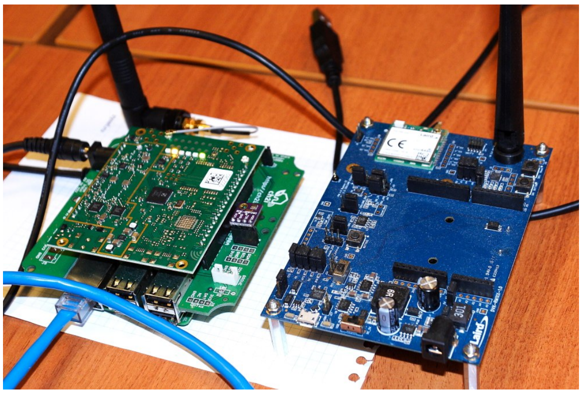
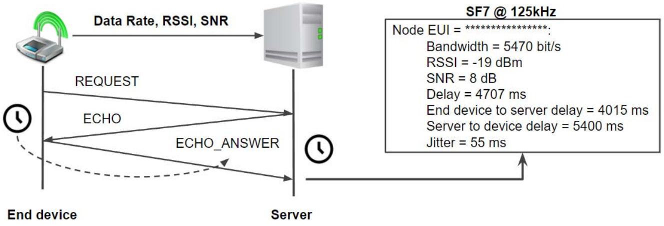


Figure 2. Experimental equipment: LoRaWAN gateway on the left and LoRaWAN end device on the right

The equipment (Fig. 2) allows to measure bandwidth, Received Signal Strength Indicator (RSSI), Signal to Noise ratio (SNR), packet delay and its jitter. Packet delay and jitter are impossible to measure directly. We use a special three-stage echo protocol to determine these metrics (Fig. 3).



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Node EUI = ****************:
        Bandwidth = 5470 bit/s
        RSSI = -19 dBm
        SNR = 8 dB
        Delay = 4707 ms
        End device to server delay = 4015 ms
        Server to device delay = 5400 ms
        Jitter = 55 ms
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Figure 3. Delay and jitter measurement protocol diagram.

The protocol contains the following stages: REQUEST (an end device initiates a measurement process and requests a server to start measurement), ECHO (the server initiates the measurement process and asks the end device to finish measurement), ECHO_ANSWER (the end device finishes the measurement process, requests the server to finish measurement on its side). The end device measures delay between steps REQUEST and ECHO, the gateway in turn measures its own delay between steps ECHO and ECHO_ANSWER. The end device includes its results into ECHO_ANSWER packet for further processing on the gateway. The gateway calculates the final delay as an average value of delays measured on two communicating sides. From the second measurement iteration, the gateway calculates jitter as a mean difference between previously measured delay. An example of the metrics output from the experimental software is presented on figure 3 (see box on the right).

Our experiment, conducted in Moscow (Russia) near Stroginskaja pojma, aimed to study QoS metrics change with distance between the stationary LoRaWAN gateway and the mobile LoRaWAN end device. The chosen area is within the city borders and is moderately built-up, it has a wide open area of the floodplain and the neighbouring forest as well as several sparsely spaced multi-storey buildings, all this forming a semi-urban environment.

For the experimental study, the end device was configured for a fixed data rate with a channel bandwidth of 125 kHz and a spreading factor of 7. Channel selection was set to automatic mode.

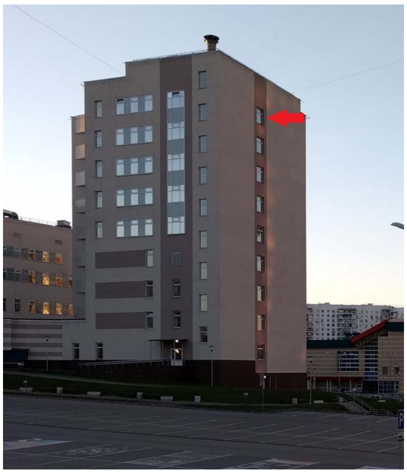

Figure 4. The LoRaWAN gateway location

The gateway equipment was placed by the window on the upper floor (about 29 m above ground level) of the administrative building at our University's MIEM campus (Fig. 4) (marked with a red arrow). The antenna position was selected to achieve the best direct line of sight for the planned measurement points. Still, some small objects like tree branches could block direct line of sight from different measurement points slightly affecting experimental results.

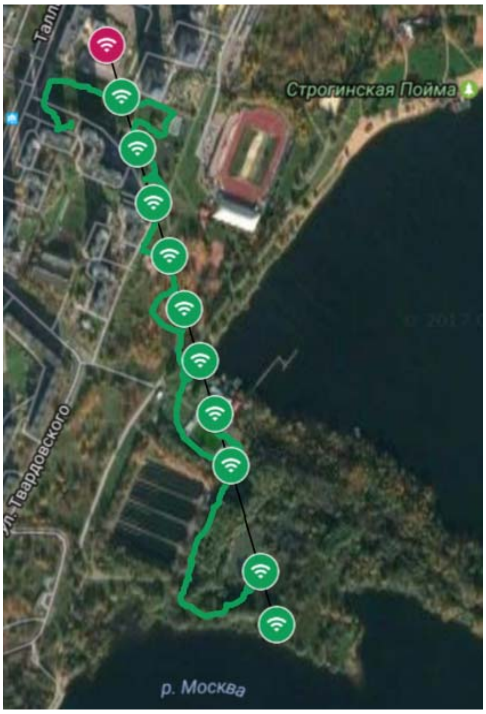

Figure 5. Experimental study map.

On the experimental study map the gateway is marked as a red point (Fig. 5). We selected a track with the longest clear line of sight for metrics measurement in relation to the campus building. The track with a total length of 1150 m was divided into steps of about 100 m long, after each step a new measurement was made, so in the end we finished with 10 checkpoints. Measurement points are marked as green circles on the map (Fig. 5). Point number 9 has a shift of about 200 m because of a swamp on the route. Every metric was measured three times per point and is averaged in the presented results.

The actual movement path was recorded with a GPS tracker to verify placement of measurement points and is marked as a green line on the map (Fig. 5).

VI. EXPERIMENTAL RESULTS AND DISCUSSION

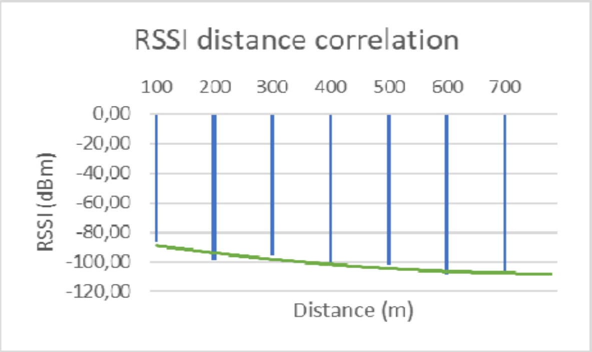

Figure 6. Decrease of RSSI with distance.

The change of the RSSI metric with distance is shown in fig. 6. The acquired data confirms the obvious decrease of RSSI as the end device was moved away from the gateway, we recorded the loss of readings at RSSI value lower than -107 dBm (point #8). Point #9 was additionally checked and no communication was recorded.

The maximal distance for the LoRaWAN connection in our experiment was about 700 meters. However, even at 1 km the network registration phase that is performed at 125 kHz bandwidth with a spreading factor of 12 still succeeded. Spreading factor directly affects the maximum distance, so a further study with a larger spreading factor can be implemented. In our study, we selected a data rate with the highest bandwidth that is the best condition for the low-rate overlays approach. We hence had to keep the spreading factor as low as possible.

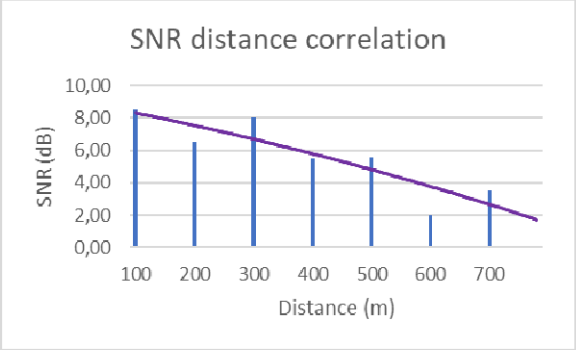

Figure 7. Decrease of SNR with distance.

The change of SNR with distance is presented on fig. 7. The readings have stopped at the SNR value lower than 2 dB.

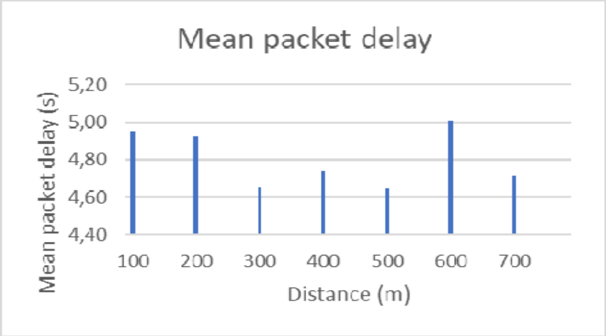

Figure 8. Correlation between mean packet delay and distance.

The mean packet delay (average between the end device to server delay and server to end device delay) as a function of distance is presented in fig. 8. We believe the change in delay is likely a random fluctuation caused by a sum of delays in the complex LoRaWAN gateway software infrastructure. The mean delay is about 4,81 s for our equipment and software setup and the changes with distance aren't very significant.

The resulting delay can be decreased using additional configuration steps for the server components. Unconfigurable parts in our scenario are the end device's LoRaWAN driver, LoRa transceiver and the gateway's LoRa transceiver. As we found out, MQTT packet transactions formed the most significant part of the packet delay. However, the exact reasons require further investigation.

In general, our experimental study proves the idea that QoS metrics measurement is feasible in LoRaWAN networks and can be used for building low-rate overlay networks over LPWANs.

CONCLUSION AND FUTURE WORK

In this paper, we described an approach to building low-rate overlay networks in LoRaWAN. An experimental study allowed to find correlation between key QoS metrics and the distance between a LoRaWAN node and a LoRaWAN gateway. Taking off-the-shelf components and online services with their initial settings we built a prototype and measured changes in RSSI, SNR, packet delay and jitter with distance between an end device and a gateway.

The full delay of a packet going through the LoRaWAN infrastructure turned out to be significant in value, remaining independent of the distance. In our future work, we plan to fine-tune the experimental equipment to see if we can drastically decrease packet delay times, which may be required by certain type of overlay applications.

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