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LoRaWAN Network Capacity for Practical Network Planning in India

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Abstract

LoRaWAN is a promising technology for IoT applications in the Low Power Wide Area Network (LPWAN) space and has seen rapid deployment in several parts of the world. It can also potentially serve as an alternative communication media in post-disaster scenarios when conventional networks are down. However, in such scenarios, the communication needs are much higher than in typical IoT use cases due to high density of devices and frequent exchange of large messages. Hence, it is important to conduct pre-deployment studies to understand the limitations of the network. In this paper, we present a MATLAB analysis of the number of end-devices that can be supported per LoRaWAN gateway. The dependence of gateway capacity on the length and rate of generation of new messages for different kinds of applications is shown. This paper also highlights the limitations of the hardware architecture of the currently available LoRaWAN gateway technology, which further limits the capacity of the network. Presented results demonstrate that practically achievable capacity is significantly reduced from the theoretical estimate. Upper and lower bounds on the capacity of the LoRaWAN gateway are obtained for different payloads. This analysis can be useful for network service providers and application providers in finalizing network requirements and deployment scenarios especially for post-disaster ad-hoc networks.

1. Introduction

Internet of Things (IoT) is a growing network of a large number of devices. Each device has a different bandwidth, power and range requirement depending upon the application. Several LPWAN technologies have been developed over the years to cater to IoT applications with end-devices spread over large geographical areas and requiring infrequent communication at low data rates. Hence, both device densities and application payloads are generally small. LoRaWAN, based on LoRa – a proprietary technology developed by M/s Semtech Corporation, is a front-runner in LPWAN technologies. LoRaWAN network has been successfully deployed in several countries of the world including parts of India. LoRaWAN can support a large variety of IoT applications such as smart street lighting, agricultural crop monitoring, and air pollution monitoring.

C-DOT has been working on developing an ITU-T X.1303 [1] CAP compliant platform for disaster warning and management. While working with disaster management authorities during the recent floods in Kerala and Cyclone Titli in Orissa it was observed that there was no electricity supply, roads were damaged and telecom networks were down for several days in many of the affected areas. Being a long range and low power technology, LoRaWAN can be useful in saving lives by providing alternative mode of communicating emergency messages in the form of text, voice, image etc. during disaster recovery operations while conventional cellular networks are being restored. However, in such a scenario, device density and application payload size are very much higher as compared to IoT applications. Hence, for network deployment and application deployment in post-disaster scenario, insight is required into the capacity of the network to develop a suitable deployment strategy for high density of devices. In this paper, MATLAB is used to obtain the performance of LoRaWAN network in terms of the number of end-devices that can be supported per LoRaWAN gateway considering unacknowledged uplink messages. The analysis shows how the capacity of a single gateway varies with the size of messages from the end-device and also the rate of generation of new messages. It is also shown that practically achievable LoRaWAN network capacity is much lower than theoretically calculated values because of the hardware architecture of the LoRa chipsets which has not been considered in previous works [2], [3] and [4]. The results are presented in the coming sections.

2. Background

LoRa [5] is a radio modulation technique and constitutes the PHY layer. It is based on Chirp Spread Spectrum (CSS) and supports several spreading factors (SFs). It is used in the unlicensed frequency band (865-867MHz in India) and has a range of around 15km kilometers LOS. It supports maximum data rate of about 38.4kbps. LoRa being proprietary technology of Semtech, Semtech is the only manufacturer of transceiver ICs for end-devices and baseband processors for the gateway. For the gateway, Semtech provides SX1301 [6] chips for baseband processing and simultaneous reception of multiple LoRa packets to cater to large number of devices.

LoRaWAN [7] is an open standard MAC layer protocol developed by the LoRa alliance for LoRa. It has a star topology based network architecture and specifies the communication protocol between end-devices, gateway and network server. LoRaWAN allows spreading factor from 7 to 12; higher the SF, higher the range, higher the time on air (TOA) and lower the data rate. It also specifies region wise parameters for Europe, China, North America etc. This paper focuses on the analysis based on India region parameters. LoRaWAN defines three classes of devices, Class A, B and C of which Class A is based on pure ALOHA and is most suitable for battery powered devices. Such devices can transmit randomly at any time, at any frequency supported in the region, and at any SF under the duty cycle constraints of the region.

To understand the payload requirements for different applications, C-DOT developed devices for some of the use cases in post-disaster scenarios. Figure 1 shows the device developed for voice messaging. These payload sizes provide basis for the analysis in the coming sections.

Figure 1. Device with microphone developed for voice messaging

Table 1: Average payload size for different applications

Application	**Length of message (byte)**
Health Monitoring Sensors	100
Text messaging	250
Voice messaging	1200
Low Resolution Image	2000

3. Theoretical Analysis of LoRaWAN Gateway Capacity

To analyze the number of devices that can be supported by a single LoRaWAN gateway considering only unacknowledged uplink messages, we first find the maximum throughput under the condition of no collision. Packets arriving at the same time at the gateway and occupying the same frequency channel and using the same SF collide and lead to packet loss. Hence, to avoid collision, the time on air needs to be reserved for the packet, which limits the capacity due to large time on air of spread spectrum technology. Time on air depends on various parameters such as spreading factor, PHY payload, preamble length and other parameters as defined by Semtech in the LoRa transceiver datasheet [8]. On the other hand LoRaWAN payload size is defined by the LoRaWAN specifications [9]. The table below shows the minimum and maximum payload size for 125 kHz bandwidth.

Table 1: Maximum allowed application payload for different SF for multi-SF channels with 125 kHz BW as per regional parameter specification for India region [10]

SF	Max. application payload (bytes)
7	242
8	242
9	115
10	51
11	51
12	51

This is added with the 13 byte LoRaWAN header to get the total PHY payload for the LoRa packet. Based on frame sizes defined by LoRaWAN for different SF and using LoRaWAN frame as PHY payload, the variation of time on air with SF and frame size is plotted in Figure 2. For message size greater than the maximum payload size, fragmentation has been employed. Since, there is no inherent provision for message fragmentation in LoRaWAN, hence, the headers need to be retransmitted along with each fragment. Also as there are no duty cycle constraints in India, it is assumed that packets with fragmented message can be sent one after the other without restriction.

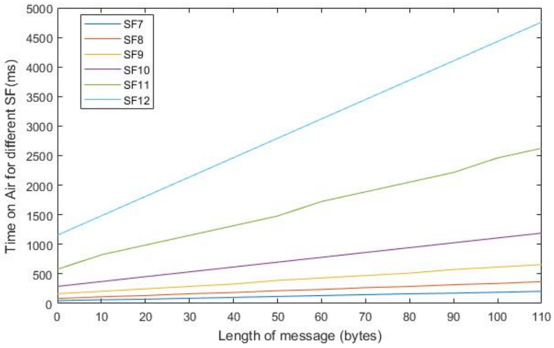

Figure 2. TOA vs message size for different SF. As expected, TOA is smaller for smaller SFs.

To calculate capacity, we have considered the case of 6 enabled frequency channels and 6 spreading factors. As the SF are orthogonal to each other, under time synchronization between packets, collision does not occur as along as either frequency channel or SF are different. Treating this condition as the unordered pair (SF, channel) we have $^6C_1 x ^6C_1=36$ paths. These paths can be considered independent of each other as discussed in some previous works [2], [3] and [4]. However, LoRaWAN Class A is based on ALOHA, where any node can transmit at any time with any SF and enabled channel frequency. Hence, using this fact the actual throughput of ALOHA due to collisions is reduced to

$$\max(Ge^{-G}) = 0.18$$

or 18% from the synchronization scenario [11]. Based on above, LoRaWAN gateway as a function of message size and rate of generation of new messages are plotted in Figure 3 and 4 respectively. In Figure 3, we show the number of end devices feasible for different kinds of applications sending different amounts of information to their application server in an interval of 60 min.

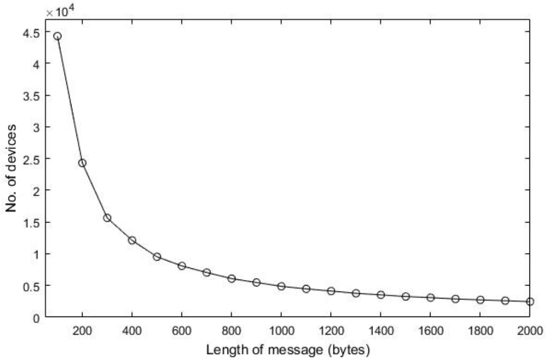

Figure 3. No. of devices vs length of message in bytes.

Initially the curve is quite steep, because the overhead of retransmitting header for fragments is significant compared to the payload size.

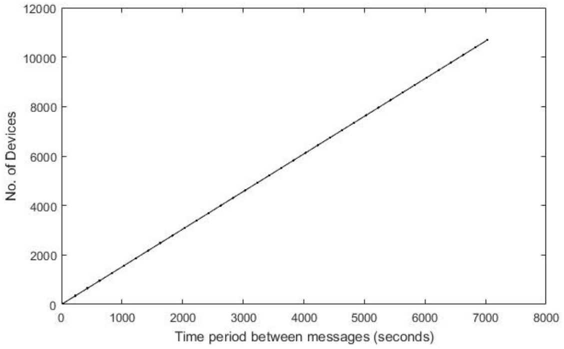

Figure 4. No. of devices vs time interval between two messages for message size of 900 bytes.

In Figure 4, we show that that larger the time interval between new messages, larger the number of devices that can be supported. Hence, applications that report data infrequently allow a larger network size. These plots are based on the time on air calculation presented in Figure 2.

4. Practical Hardware Limitation in LoRaWAN Network Capacity

The baseband processor for gateway, SX1301 [12] supports 8 multi-SF channels such that all SF can be simultaneously detected on each channel frequency without prior information on the configuration of the incoming packet. As SFs are orthogonal, multiple packets on same channel with different SF can be demodulated. Although, the SX1301 chip can detect preambles of 8 frequency channels x 6 SF = 48 packets in parallel, only 8 packets will be simultaneously demodulated due to its architecture, and rest of the packets will be dropped. Hence, SX1301 presents a bottleneck on the reception of all possible combination of (SF, channel) that is used in the theoretical analysis. The capacity of the LoRaWAN network calculated on the basis of 36 independent paths as in the previous section cannot be practically implemented and we need to consider the demodulation capability of a practical gateway for capacity estimation. Taking into account the above argument, only 8 packets can be demodulated at any given time. Under the assumption of perfect synchronization, we can only consider 8 independent (SF, channel) pairs, from which the capacity in ALOHA case can be derived as in previous section. The different frequencies of reception have no impact on the capacity as they are independent of the time on air. However, as the time on air is heavily dependent on the SF, hence, which SF is used by the devices causes major variation in the number of end devices that can be supported. Hence, in this paper we have evaluated the best case and the worst case scenario to obtain upper and lower bounds on the number of devices that can be supported per gateway.

a. Best Case Network Capacity Results

The best case is obtained when the SF is chosen such that the time on air is minimum so that maximum devices can be accommodated. Hence, we should have SF7 for all the channels. However, as we have taken 6 enabled channels, all 8 packets of the same SF cannot be demodulated. Hence, for the best case, we have taken 6 out of the 8 paths as SF7 and rest as SF8. Figure 5 shows the best case plot of number of end-devices vs message size for a rate of generation of 1 packet per hour per device.

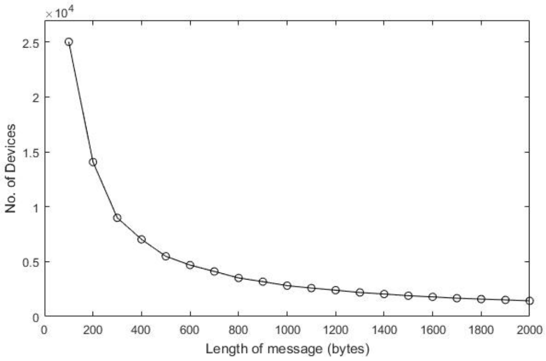

Figure 5. Best case results for no. of devices vs length of message in bytes with gateway architecture limitations.

b. Worst Case Network Capacity Results

The worst performance is obtained when the end-devices are farthest from the gateway, and are using the largest SF. The numbers of devices as a function of message size for 1 packet per hour per device are plotted in Figure 6.

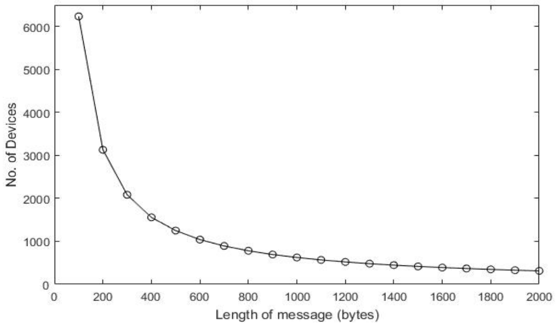

Figure 6. Worst case results with hardware limitations.

Figure 7 shows a comparison of the best case, worst case with 8 demodulation paths and the assumption of 36 paths as explained in Section 3 for 60 min duration between messages from an end-device. The impact of gateway architecture limitation can be seen as the no. of devices for a particular message size has greatly reduced even when the best case is considered. For example, for post-disaster hourly text update of 250 bytes, no. of devices is reduced from approx. 18,000 to 2,500 in the worst case.

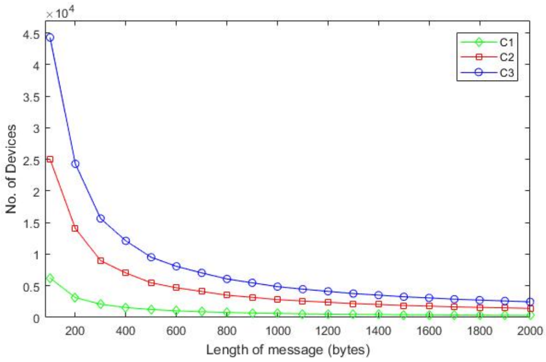

Figure 7. Comparison of theoretical and practically achievable results. C1 and C2: Worst Case and Best Case considering practical limitations, C3: Theoretical Analysis

5. Analysis of Results

In Section 3 it was shown that gateway capacity depends on payload size of the application and the rate at which the application end-device generates new messages.

Section 4 showed that incorporating limitation of the only available baseband processor for the gateway provides a tighter bound on the capacity of the network compared to the theoretical analysis. For example, for health monitoring sensor payload of 100 bytes and rate of generation of 60 min, the practically achievable supported number of end-devices is of the order of 25,000 in the best case compared to 44,000 from the theoretical analysis. Also, maximum capacity can be achieved when the devices are close to the gateway whereas capacity is reduced when devices are far and resort to higher SF with larger air times to increase range.

6. Conclusion

The capacity of a LoRaWAN gateway in terms of number of end-devices considering unacknowledged uplink messages was analyzed theoretically and plotted using MATLAB for India region. The results demonstrated that capacity for different applications e.g. health monitoring sensors, text messaging, voice communication, image transfer etc. depends on payload size of the application and the rate at which the application end-devices generate new messages. Upper and lower bounds on the practical capacity of LoRaWAN network were obtained after incorporating the limitations imposed by the hardware architecture of the LoRaWAN multi-channel gateway on high density networks. This analysis can be used for network planning and finalizing deployment strategies for LoRaWAN based emergency communication in post-disaster ad-hoc networks.

6. Future Scope

The impact of downlink and acknowledged messages on the network capacity needs to be studied. FPGA based hardware modification can be implemented for high density post-disaster ad-hoc network.

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