Delay Analysis for P2P Systems Using LPWAN

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Abstract. LPWAN technologies such as-LoRa, Sigfox, and NB-IoT has been the key enabler in the advancement of Internet-of-things and Industry 4.0. LPWAN technologies known for long distances communication in low power devices at low operation cost for battery powered things. In this paper we have studied the performance of LPWAN in peer-peer (P2P) models for IoT-applications. We present a comparative analysis with respect to minimum data distribution delay for P2P system among LoRa, Sigfox, and Nb-IoT technologies, which shows that NB-IoT is best in LPWAN.

Keywords: Distribution delay · IoT · Latency · LPWAN · Long range connectivity · P2P

1 Introduction

Internet of thing (IoT) is based on billions or trillions of intelligent, vast processing power, and low power consuming sensors, actuators, and energy efficient appropriate connectivity medium. Connectivity is important for effective communication among sensors, actuators, and end users of IoT based /driven system. These systems use wired, wireless or combination of both medium for the connectivity. Wired connectivity mostly uses Ethernet technology but for wireless connectivity one can use Bluetooth, NFC, Wi-Fi, RFID, ZigBee, Wireless HART, IEEE 802.15.4, 6LowPan, Cellular based technology (2G-5G), LPWAN (Low-Power Wide Area Network) [1].

Wireless connectivity technology like Bluetooth, WI-Fi, RFID, NFC, and ZigBee mostly are used in short range communication, while Cellular communication (2G-5G), and LPWAN are extensively used for large range communication. As Cellular based technology provides larger coverage with extreme power consumption so IoT based /driven system mostly rely on LPWAN technologies which include LoRa, Sigfox, NB-IoT, Weightless, Telensa, Ingenu, and Dash7. LPWAN technologies fulfill specific design requirements such as long range connectivity (rural zones: 1040 km and urban zones: 15 km via low inference Sub 1GHz band and modulation schemes (Narrowband and Wideband)), low data rate, low energy consumption (via suitable topology (mostly star topology),

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shorten device complexity, random access MAC protocol like ALOHA (some are using TDMA), and effective duty cycle), scalability (via exploiting the assortment in channel, time, space, hardware, adaptive channels selection and data rate), and cost effectiveness (via shorten the device complexity, license free band (ISM band), and sharing other network band (some of them using licensed band)) [2–4].

1.1 Road Map

The road map of the paper is as follows: Sect. 2, describes related works, Sect. 3, describes various LPWAN technologies, Sect. 4, describes minimum data distribution delay formulation, Sect. 5, describes comparative analysis of minimum data distribution delay in P2P system using LPWAN technologies (LoRa, Sigfox, and NB-IoT), Finally, the conclusions are given in Sect. 6.

2 Related Work

There are many works in literature on the analysis of LPWAN technologies. R.B. et al. [13] described analytical model to examine the performance of LoRaWAN in terms of latency, collision rate and throughput. Yousuf, A.M. et al. [24] described throughput, coverage and scalability of live LoRa networks using simulation. Rizzi et al. [14] assess physical and data link layers capability of LoRa link directly on the transceiver hardware. Pötsch et al. [15] presents experimental analysis of the end-to-end latency and jitter of a real-world LoRaWAN transmission. The authors in [5,10,11] have investigated the number of nodes support on a typical LoRaWAN, and some of the authors look on the scalability analysis of LoRa gateway [12,16,17]. Further, The authors in [18,19] uses LPWAN in P2P IoT based applications. However, as per the knowledge none of the studies discussed about minimum data distribution delay analysis of LPWAN for P2P system in the literature. In this paper, We describes the formulation of minimum data distribution delay in P2P IoT system and compares LPWAN technologies based on the formulation.

3 LPWAN Technologies

LPWAN is progressively more ahead attractiveness in industrial and among research communities because of its design features. LPWAN technologies used in IoT applications like LoRa and Sigfox worked in unlicensed (free) frequency band. However, NB-IoT, Weightless, Telensa, Ingenu, and Dash7 worked in licensed (paid) frequency band. In this section, We look at the key LPWAN technology with their diverse role, technical aspect and explicit distinctiveness.

3.1 LoRa

LoRa means Long Range, is at present one of the most common LPWAN technology uses unlicensed frequency band (India: ISM band 865–867 MHz, Europe: 868 MHz, North America: 915 MHz, and Asia: 433 MHz). LoRa was developed by the founding member of the LoRa Alliance Cycleo of Grenoble, France, and later acquired by Semtech corporation. LoRa has six spreading factors (SF7 to SF12). The higher spreading factor permits longer communication range at the cost of lower data rate, and vice versa. In addition, LoRa technology have up to 20 km of coverage range, effective connectivity of up to millions of nodes, more than 15 years of battery life, and at max 50 kbps data rate. Further, basically, LoRa is a physical layer technology with maximum payload length for each message is 243 bytes. LoRa uses LoRaWAN protocol to defines the communication protocol and system architecture for the network. Additionally, LoRa uses the chirp spread spectrum (CSS) modulation to provides bidirectional communication, minimize signals noise levels, and enabling high interference resilience [6,7].

LoRaWAN networks have usually three types of device classes, namely Class A, Class B, and Class C. Class A is a type of lowest power consumption device as it spending most of the time in sleep mode and is only waked up on a scheduled time or when it needs to transmit data. Class B type extended from Class A type, it opens additional receive windows at programmed time to determine the time of receiving data. Finally, Class C type is always listening to receive the data at any time except when transmitting data hence has the minimum latency among other types.

3.2 Sigfox

SigFox is developed by France Company Sigfox in 2009. It is working on non-licensed spectrum with the aims to create wireless networks for IoT devices with long range (rural areas: 20–50 km and urban areas: 3–10 km) connectivity, low power consumption, and low costs. SigFox has been quickly commercialized and provides network devices with ultra-narrow-band technology. The users of Sigfox are need to purchase end devices and subscription of Sigfox network providers to connect to regional Sigfox networks. Further, Sigfox also operates on unlicensed sub 1 GHz bands and utilizes a cloud server to receive, process the sensed data, and after processing sends it to a back-end server. The data rate of Sigfox is 100 bps with maximum payload length of 12 bytes for each uplink message with 140 messages per day over the uplink, and four messages per day over the downlink. In addition, the maximum payload length for each downlink message is eight bytes. Moreover, In Sigfox downlink communication only precedes uplink communication. In addition, uplink communication adapt binary phase shift keying (BPSK) and gaussian frequency shift keying (GFSK) adapted in downlink communication) [8].

3.3 NB-IoT

NB-IoT is developed as a fusion of NB-CIoT and NB-LTE by 3rd Generation Partnership Project (3GPP). NB-IoT utilizes the licensed frequency bands as LTE with three different deployment set-up, namely stand-alone (separate 200 kHz of spectrum), guard band (NB-IoT and LTE are co-located), and in-band (NB-IoT deployed within an LTE wide-band). Further, NB-IoT uses single-carrier frequency division multiple access (FDMA), orthogonal FDMA (OFDMA), and quadrature phase shift keying modulation (QPSK). Moreover, NB-IoT aim to provide a low cost, low power consumption (10 years of battery lifetime), highly scalable (up to 50,000 connections per sector), and wide range (1-10Km) of communication with low data rate (uplink: 20 kbps, and downlink: 200 kbps). Additionally, NB-IoT has support maximum 1600 bytes per message payload size, transmission bandwidth of 200 kHz, suitable in non-latency-sensitive (up to 10s) and low-bit rate applications [9].

3.4 Weightless

Weightless consist of a set of three LPWAN technology namely Weightless-W, Weightless-N, Weightless-P. Weightless developed by Weightless-SIG (Special Interest Group), a non-profit organization in 2008. The entire three Weightless technology is also operates in unlicensed sub 1 GHz spectrum with each of them has own unique features. Weightless-W uses TV whitespace spectrum, has a low overhead communication, high date rates (1 kbps to 10 Mbps), low battery life (up to 3 years), communication range (up to 5 km), and high deployment cost. In addition, the communication range of Weightless-W depends on the factors like obstacles, weather, etc.

Weightless-N is similar to Sigfox technology it adopts ultra-narrowband modulation scheme. Weightless-N has low cost (communication and deployment), low data rate (up to 100 bps) (Nwave, 2019), high battery life (up to 10 years), and the communication range of up to 5 km. Weightless-P uses ultra-narrowband modulation schemes (GMSK and offset-QPSK) and operates on the 12.5 kHz channels. Weightless-P is mainly developed for the industrial sector, has data rates ranging from 200 bps to 100 kbps, communication range of up to 2 km, battery life maximum 3 years, and provides a reliable bidirectional communication [20].

3.5 Telensa

Telensa is a proprietary LPWAN network developed in 2005 by electronic design consultancy Plextek. Typically, Telensa is also operates in unlicensed sub 1 GHz spectrum, can support bidirectional communication of maximum 5000 nodes, coverage range in urban areas of 2–3 km and in rural areas 5–8 km [22].

3.6 Ingenu

Ingenu is also operates in unlicensed sub 1 GHz band, developed in 2008 with the name On-Ramp Wireless and later in 2015 renamed as Ingenu. Typically, Ingenu is based on random phase multiple access (RPMA) technology. Ingenu have a long coverage range (up to 6 km), low-power consumption (10+ years battery life), and guarantee for secure wireless connectivity [21].

3.7 Dash7

Dash7 LPWAN technology developed by Dash7 Alliance, an open source protocol basically designed for wireless sensor network applications. Dash7 also operates in unlicensed sub 1 GHz band (433 MHz, 868 MHz and 915 MHz, can provide a long battery life, long communication range (up to 2 km), low latency, and low data rate (up to 167 kbit/s). Further, Dash7 support AES 128-bit shared key encryption (Dash7, 2019), consists of endpoints, sub-controllers, and gateways [23].

In summary, The following Table 1 shows technical aspect and explicit distinctiveness of the LPWAN technology's based on main features like range (communication), frequency band, data rate, battery life, and cost [2,3].

Table 1. Comparative technical aspect and explicit distinctiveness of the LPWAN.

LPWAN	Range	Frequency band	Data Rate	Battery Life	Cost
LoRa/LoRaWAN	5–20 km	868/780/915 MHZ	50 kbps	15 yrs	High
Sigfox	10–50 km	868/915 MHZ	100 bps	15 yrs	High
NB-IoT	1–10 km	LTE and GSM	200 kbps	10 yrs	Very High
Weightless-N	2–4 km	Sub 1 GHZ	100 kbps	10 yrs	High
Telensa	2–8 km	Sub 1 GHZ	50 kbps	5 yrs	Medium
Ingenu	3–6 km	2.4 GHZ	8 kbps	10 yrs	High
Dash7	1–2 km	Sub 1 GHZ	167 kbps	10 yrs	Medium

4 Minimum Data Distribution Delay Formulation

Data distribution delay is the time taken to get a copy of data/information by all the end devices. Data/information distribution is mostly performed in IoT based /driven system to extracts and transmit sensor data for making smarter decision. Data distribution is mainly performed by wireless connectivity in either client server model or peer-2-peer model. In this section, We have described the formulation of minimum data distribution delay taken by LPWAN technologies in P2P system using LPWAN system model shown in Fig. 1.

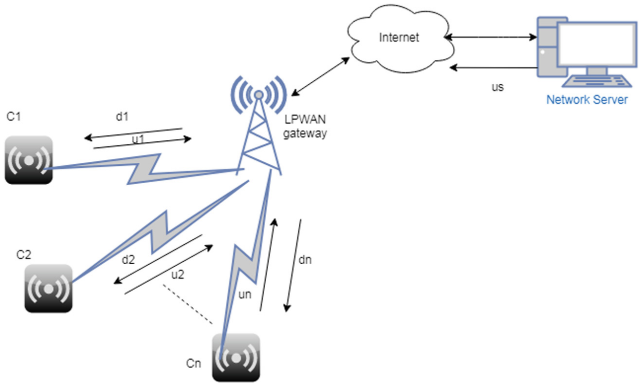

Fig. 1. LPWAN system model for delay analysis

4.1 LPWAN System Model

let us assume there are n end nodes $\{c_1, c_2, ..., c_n\}$ connected to the network servers through LPWAN gateways with the downlink rate of end nodes i is D_{Li}, and uplink rate of end node i is U_{Li}. Moreover, Also assume that $D_{L_{min}}$ denotes downlink rate of end nodes with minimum value among others. Further, the data size is to be distributed is m, and server uplink is U_s. Now with respect to explained LPWAN system model in Fig. 1, the formulation of minimum data distribution delay of m size data for the case of P2P system is given in the subsequent subsection.

4.2 Minimum Data Distribution in P2P System

In this type of system the end nodes assist the server in distributing the data. i.e. after receiving the data, end nodes uses own upload link data rate to further distribute the data, and this process is repeated by other end nodes too so that after some times all end nodes in the system have the same information as the server. The following facts arises for P2P case in minimum data distribution delay:

- In the start, only server have the data of size m so must be upload by server once into the network. This uploading by server takes the minimum time $\{m/U_s\}$.
- The end nodes with minimum downlink rate $\{D_{L_{min}}\}$ takes at least $\{m/D_{L_{min}}\}$ time to download this m size file.
- Now as in P2P system server and all end nodes participates in the data distribution. Hence, the total data size $\{m.n\}$ is distributed collectively with say total upload link $U_t = U_s + U_{L_1} + U_{L_2} + \ldots + U_{L_n}$ so the distribution delay is at least $n.m/U_t$

Thus using above observation distribution delay for transforming m size data into P2P case say T_{p2p} is given by the following equation:

$$T_{p2p} \geqslant \max\{m/D_{L_{min}}, \{m/U_s\}, \{m.n/U_t\}\} \tag{1}$$

Further, for simplicity let us consider the uplink and downlink of each end nodes is same and say it is u so $U_t = \{U_s + n.u\}$ and $D_{L_{min}} = u$. Now when number of end nodes n is very large then $m.n/U_t = m.n/\{U_s + n.u\} = m/u$, hence the distribution time is written by the following:

$$T_{p2p} \geqslant \max\{m/u, \{m/U_s\}, \{m/u\}\} \tag{2}$$

Again as U_s is more and more greater than u. Hence, We can write minimum distribution delay for P2P case as follows:

$$T_{p2p_{min}} = m/u \tag{3}$$

5 Comparative Analysis of Data Distribution Delay

In this section, We have compared minimum data distribution delay for P2P system only for loRa, sigfox, and NB-IoT communication technologies as these technologies are mostly used in IoT system in compared from others existing technologies. We have considered packet size in bytes (200B–1000B), minimum data distribution delay in milliseconds, and data rate of LoRa 50 kbps, Sigfox 100 bps, and NB-IoT 200 kbps respectively.

The following Fig. 2, and Fig. 3 obtained for data distributed in P2P case by applying the above data on the formula given in Eq. 3. The obtained Fig. 2, and Fig. 3 shows that in P2P case minimum data distribution delay is obtain lower in NB-IoT technology.

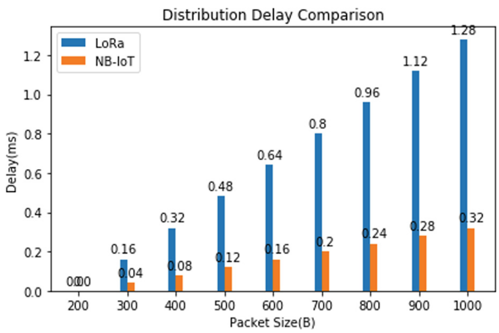

Fig. 2. LoRa vs NB-IoT minimum data distribution delay

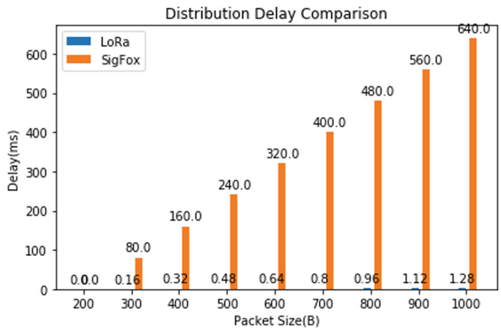

Fig. 3. LoRa vs Sigfox minimum data distribution delay

6 Conclusions

An important performance aspect for LPWAN technologies in peer-to-peer system is thepr minimum data distribution delay, which is the time taken to get a copy of data/information by all the end devices (peers). In this paper for P2P IoT systems, The formulation of minimum data distribution delay for LPWAN technologies have described. Moreover, comparative analysis of minimum data distribution delay among Lora, Sigfox, and NB-IoT based on the proposed formulation have also described. The comparative analysis shows that NB-IoT technology perform best in P2P case with respect to minimum data distribution delay.

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