A Study on Key LPWAN Technologies

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Abstract. In the ever-changing world of technology, various communication technologies have penetrated people's daily lives, which has greatly improved people's work efficiency and quality of life. By means of the Internet and various LAN technologies, users can remotely control their smart home appliances. In addition, the commercial use of 5G networks has contributed to the integration of communication technologies with people's work and life. Meanwhile, each communication technology has its own advantages and disadvantages. For wireless network technologies, distance and power consumption are always contradictory. LPWAN (Low-Power Wide-Area Network) is a wireless network technology designed to allow long-range communication with low power consumption. Therefore, this paper studied key LPWAN technologies with a focus on the LoRa technology.

1. Introduction
Under policy and platform support, the Internet of Things (IoT) technology is rapidly developing with growing types of technology. For some short-range communication scenarios, such as industrial data collection, smart home appliances, short-range wireless technologies are generally applied, such as Zigbee, WIFI, Bluetooth, and Z-wave, which have been widely used in recent years. However, with the rapid development of information technology, individual communication needs have increased dramatically. As a result, low-power, wide-area, and long-range IoT communication connections have become a trend. Although the IoT technology can be developed based on the mobile cellular networks that telecom operators have built worldwide, the development of IoT devices based on cellular mobile communication technology has the disadvantages of high cost and power consumption. With regard to it, the main application scenario of the communication network is still human-to-human communication. In order to meet the need for long-range IoT communication connections, LPWAN (low-power Wide-Area Network) technology has emerged. LPWAN has the characteristics of low bandwidth, long range, low power consumption, and a large number of connections. According to the operating frequency band, the applied communication technologies can be divided into two types: one is the technologies operating in an unlicensed spectrum such as LoRa and SigFox, and the other is LPWAN communication technologies supported by 3GPP protocol and operating in a licensed spectrum authorized by operators such as EC-GSM and NB-IoT, which are constructed based on mobile communication networks. Therefore, this paper studied key LPWAN technologies with a focus on the LoRa technology[1].
2. LPWAN Technologies

The technologies applied in LPWAN are mainly divided into two types. One is the communication technologies operating in a licensed frequency band, such as NB-IoT, and the other is the communication technologies operating in an unlicensed frequency band, such as LoRa. In recent years, the two types of communication technologies have also become the mainstream technologies in the low-power-consumption and long-range IoT industry, which have broad application prospects [2].

2.1 Operating Frequency Band

NB-IoT uses licensed ISM bands with the band number defined by LTE. Release 13 specifies 14 bands for NB-IoT to use. Currently, the mainstream NB-IoT bands worldwide are the 868 MHz and 915 MHz ISM bands.

LoRa uses license-free ISM bands, but different ISM bands are used in different countries and regions. In the Chinese market, the China LoRa Application Alliance (CLAA), led by ZTE, generally recommends the use of the 470-518 MHz band but the use of the 470-510 MHz band for radiometers. Since LoRa operates in license-free bands, no application is required for network construction, and the network architecture is simple and the operating cost is also low[3].

2.2 Network Technology and Communication Performance

LoRa uses linear spread-spectrum modulation techniques, which not only maintains the characteristic of low power consumption but also significantly increases the communication distance. Owing to it, end devices with different spread spectrum sequences will not interfere with each other even if they transmit using the same frequency at the same time. Therefore, the devices developed on this basis can receive and process data from multiple nodes in parallel, which can greatly expand the system capacity. The LoRa gateway can provide more than 20,000 end devices connections. The coverage distance of a single LoRa gateway is usually 3 to 5km, which can exceed that of traditional cellular networks in complex urban environments. In open areas, its coverage distance can be even up to 15km. Under certain conditions, the LoRa gateway can even operate at a distance of 100km.

Since NB-IoT is built on cellular networks and occupies only about 180KHz of bandwidth, it can be deployed directly in the various communication networks that telecom operators have established. With the same base station, NB-IoT can increase the number of accesses by 50-100 times compared with existing communication technologies, and a sector can support 100,000 connections. Also, NB-IoT has strong indoor coverage capability, which is about 20dB higher than LTE, equivalent to 100 times higher in terms of coverage capability. It can not only meet the demand for wide coverage like rural areas, but also apply to deep coverage applications such as factories, underground garages, and manhole covers, with the transmission distance usually greater than or equal to 10km[4].

2.3 Protocol Operating Modes

LoRa has three modes of operation:

- **Class A:** The end device sends an uplink and then opens a receive window for a period of time after sending, and the end device can receive only after sending. That is to say, there is no restriction on the uplink, and the downlink data can only be received by the end device when the uplink packet is sent up. (Lowest power consumption)
- **Class B:** The end device negotiates with the server about the time when the receive window is opened, and then receives at the agreed time. Multiple packets can be received at one time. (Second lowest power consumption)
- **Class C:** The end device opens the receive window at all times other than when it sends. It’s more energy-consuming but has the lowest communication delay. (Highest power consumption)

NB-IoT supports three modes: DRX, eDRX, PSM.
- **DRX:** discontinuous reception. The module listens to the paging channel once every DRX cycle, and the power consumption is relatively higher compared to eDRX and PSM.
eDRX: extended discontinuous reception. The module continuously turns on and off the receiver. When the receiver is turned on, it can receive data, but when the receiver is turned off, it cannot receive data. eDRX cycle consists of two complete periods, that is, turning off the receiver and turning on the receiver, and the supported configuration time is 20.48s to 2.92h. eDRX is lower than DRX in terms of power consumption.

PSM: power saving mode. Compared to eDRX, PSM turns on and off the receiver less frequently, as low as once every few days. Within the PSM cycle, the module can only receive data when the receiver is turned on, and the downlink data will not be received when the receiver is turned off. For the PSM, power consumption is only microamp level, resulting in very low power consumption of the end device in this mode of operation[5].

3. LoRaWAN Network Architecture
LoRaWAN is a set of communication protocols and system architecture designed based on LoRa long-range communication network, which can provide regional, national, or global network connections for various battery-powered wireless devices. Owing to its high scalability and compatibility for the development of embedded applications, seamless connections can be achieved without too complex configuration. According to the classes of protocols, LoRaWAN is the MAC layer and LoRa is the physical layer. Because of this, LoRaWAN is originally called LoRaMAC. The LoRaWAN protocol has been optimized for low-power-consumption and battery-powered sensors. By covering different levels of nodes of end devices, the balance between network latency and battery life has been optimized. As a complete set of basic protocol framework has been built in LoRaWAN, global manufacturers in the IoT field can develop, produce, and manufacture products based on it, and it is more cost-efficient compared with other networks. The LoRa Alliance specified the communication protocol of the MAC layer. Only on the premise of the MAC layer protocol that the devices (Gateway, Node) jointly comply with can devices from different hardware manufacturers access each other. Although the protocols of Gateway to Server and Server to User were regulated by the LoRa Alliance, different manufacturers may vary. In LoRaWAN, nodes are generally connected to sensors. They are used to collect sensor data and transmit the data to Gateway through the LoRaMAC protocol. Gateway is concentrator, which is mainly used to transmit the data from the nodes to the server, that is, convert the data from the LoRa form to the network form. In the process, Gateway does not process data but only pack and encapsulate the data, and then transmit it to the server. According to the regulations of LoRaWAN, the protocol is divided into four parts: NS (Network server), AS (Application server), CS (Customer server), and NC (Network controller). The transmission of the LoRaWAN protocol is mainly divided into three modes, which are Class A, Class B, and Class C. All end devices in the LoRaWAN protocol must support Class A communications.

LoRaWAN networks are deployed in a star topology so as to support different sizes of networks. In this architecture, the LoRa gateway acts as a transparent bridge relaying messages between end devices in use and the back-end server. The gateway and the server are connected through a standard IP network. Since the gateway acts as a transparent bridge relaying messages, end devices can communicate with multiple gateways, and all nodes can communicate in both directions. When end devices communicate with gateways, the carrier frequencies and data transmission rates of different nodes are not necessarily the same, and the data transmission rates need to make a balanced choice between transmission distance and message delay. Due to the application of spread spectrum modulation techniques, the data communication of the devices with different data transmission rates will not interfere with each other and the anti-interference capability of the devices can be improved. In the LoRaWAN network, the data transmission rate ranges from 0.3 kbps to 50 kbps. To ensure reliable packet transmission and optimize network performance and node capacity of end devices, the LoRaWAN server adopts the Adaptive Data Rate (ADR) algorithm to control the data transmission rate.

Currently, many deployed networks adopt a mesh architecture, in which each node of end devices can forward information from other nodes, acting as a routing role. By doing so, the network
communication distance and range are increased. But on the flip side, the mesh architecture increases
the complexity of the system and reduces network capacity. Besides, to receive and process these
messages, the battery has high power consumption, which shall shorten the battery life. And of these
messages, only a small part is related to the node, which means that most of the time and power of the
node is wasted on processing irrelevant messages. As for LoRaWAN, a long-range star structure is
adopted, which can not only enable long-range connection but also well extend the battery usage time,
thereby saving cost.

4. LoRa Packet Format
The packet format of LoRa signals is shown in Figure 1. It includes two different formats of wireless
packets, that is, explicit packet and implicit packet. The explicit packet includes n-bit preamble
symbols, n-bit header symbols, payload, and payload cyclic redundancy check (CRC), and the implicit
packet includes n-bit preamble symbols, payload, and payload CRC without the header. The header
mainly includes payload length, coding rate (CR), and whether there is CRC or not.

| nPreamble Symbols | nHeader Symbols |
|-------------------|-----------------|
| Preamble           | Header          |
| explicit           | mode only       |
| C/R=4/8            | C/R=CodingRate  |

Figure 1. LoRa packet format

5. LoRa Frequency Hopping
Frequency-hopping spread spectrum (FHSS) refers to both transmitter and receiver performing
communication frequency hopping in a simultaneous and synchronized manner according to the
pre-arranged frequency hopping pattern. External interference and multi-path fading are two major
factors influencing the robustness of wireless communication. External interference mainly results
from the frequent use of wireless communication in life such as cell phones, wireless routing, radio,
and remote control toys. Multi-path fading is more complex, and it is almost impossible to analyze all
its influencing factors. In the actual environment, walls, doors, trees, buildings, and walking persons
all may cause signal reflection, so the transmitter and receiver still have multiple reflection paths in
addition to the wireless signal straight transmission path. These signals mixed may cause a lot of
interference. The solution to the external interference and multi-path reflection is frequency hopping
technology, which avoids the interference and signal reflection in a certain frequency band by hopping
the communication frequency.

The LoRa frequency hopping principle is as follows. Both frequency-hopping transmitting and
receiving start at channel 0. The transmitter sends the preamble and the header in channel 0 first. After
that, the first frequency hopping is conducted to interrupt the signals. Then the MCU responds to the
interrupt and jumps to channel 1 according to the agreed frequency. The first hopping is completed.
Meanwhile, the channel counter starts counting. When the count reaches one hopping cycle, frequency
hopping is conducted to interrupt the signals. Then the MCU responds to the interrupt and jumps to
channel 2, repeat the above process. The receiver starts from channel 0. After receiving the valid
preamble and header, the receiver executes the frequency hopping process as the transmitter above.
The channel residence time is an integer multiple of the transmission time of a single symbol, which
can be set through registers and must be greater than the time required for frequency hopping
implementation. Only in this way can the data be sent within the remaining time of each channel. The
preamble and header need to be sent and received in channel 0 before frequency hopping, and the
payload is sent and received in multiple channels in segments.

6. Conclusion
Based on the study of LPWAN, LoRa, and NB-IoT, this paper further compared the technical
performance and communication modes of LoRa and NB-IoT from several aspects. In terms of technical performance, the advantages and disadvantages of NB-IoT and LoRa are studied from the perspectives of the operating frequency band, network technology and communication performance, and battery life. In terms of communication modes, the differences between NB-IoT and LoRa communication methods are studied from the perspective of protocol operating modes. Based on this study, we can conclude that LoRa has greater advantages in ad hoc networks. The LoRa uses unlicensed frequency bands, so any additional communication cost is not required. Also, it has a wider coverage range and star topology, making it easier to build systems. For the nodes of end devices, LoRa is not only simpler and easier to develop than NB-IoT but also better applicable to and compatible with microprocessors.

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