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Research on Application of LPWAN in State Monitoring of Distribution Network

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Abstract. Technology of IoT plays an important role in the application of power information collection and fault warning of distribution network equipment. However, the communication technology used in the previous smart grid IoT demonstration application project generally has short coverage distance, high power consumption of terminals and other defects. In this paper, the requirements of typical state monitoring service in distribution network are analysed. The number of potential monitoring terminals is huge, and the service data have the characteristic of “small data”. Traditional technologies such as wireless private network or Zigbee are not suitable for this communication requirement. LPWAN such as NB-IoT and LoRa is very suitable for transmitting a small amount of information over a long distance, which provides a new support for the communication in distribution network.

1. Introduction

As an important part of smart grid construction, distribution network is a direct power network for users, which plays an important role in the power system. Using the technology of Internet of Things(IoT), the power interference and power outage caused by equipment failure and capacity limitation can be largely avoided by on-line monitoring, diagnosis and protection of the power system. Up to now, there are many technologies that can meet the communication requirements of smart grid. For example, wired communication technologies, such as fiber optics, power line carriers, and wireless communication like Zigbee, wireless private networks, GPRS, etc[1]. Although these solutions allow the interconnection of IoT devices in distribution system, they usually have the disadvantages of high cost, poor scalability, short battery life, high complexity and low reliability.

Low power wide area network(LPWAN)[2] is a general term for a series of IoT technologies supporting wide area communication, which is suitable for application of transmitting a small amount of data over a long distance. Narrowband IoT(NB-IoT) and LoRa[3] are two leading LPWAN technologies, and they have their own advantages in wide and deep coverage, power saving and other aspects, which can make up for the deficiency of present communication technologies in distribution network[4-5]. In this paper, the state monitoring service of distribution network is analyzed in detail. Through modeling the service and further analyzing bandwidth, latency and other communication requirements for state monitoring in distribution network, the technical characteristics of NB-IoT and LoRa in the application of power grid state monitoring are analyzed and compared, which provides a theoretical support for the application of LPWAN in intelligent power distribution network.



2. Service Requirements of State Monitoring in Distribution Network

2.1. Service model

The power distribution network service includes basic service and state monitoring service. At present, the basic service mainly includes power distribution automation, power consumption information collection, electric vehicle charging and distributed energy resources[6]. And the state monitoring service is mainly divided into the following two types:

(1) Equipment state monitoring

Based on the components of distribution network, the equipment should be monitored mainly includes the pole-type transformer, box-type transformer, pole-type circuit breaker, Cable branch box, etc. The main monitoring services are the inlet/outlet interface temperature of equipment, the angle of the pole tower tilt, line failure state, leakage current of line arrester, door switch state of cabinet or room, etc.

(2) Environmental state monitoring

Environmental state monitoring services mainly include noise decibels of equipment, the temperature and humidity state, flooding state, cable branch box, ring main unit and so on.

2.2. Communication requirements

In order to understand the data flow and the communication requirements of services more intuitively, the communication model can be illustrated as shown in Figure 1. According to the service model, the state monitoring data is collected through the sensor terminal (represented by ED in the Figure 1) and transmitted to the communication gateway via wireless communication, and then transmitted to the main station of city through the power backbone communication network. To discuss wireless communication technology from terminal to gateway, the following aspects should be considered.

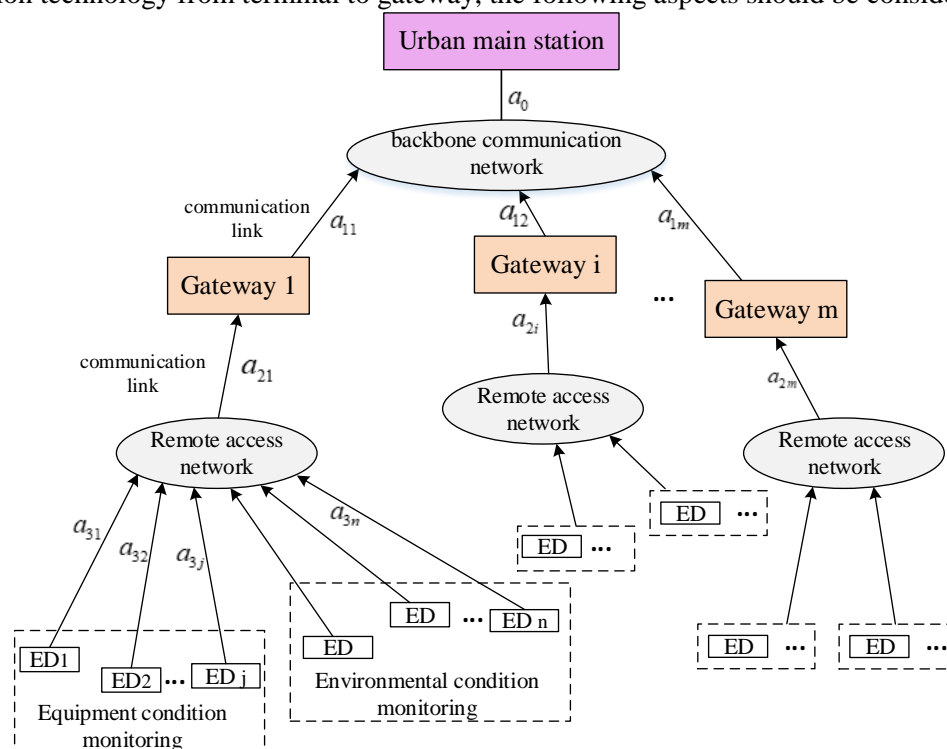


Figure 1. Communication model of state monitoring of distribution network

(1) Band width

In Figure 1, a_{3j} is the data flow from a class of sensor terminal j ($j=1,2,\dots,n$) to the communication gateway i ($i=1,2,\dots,m$), and a_{1i} is the data flow from the communication gateway i

to the main station of city. Within the coverage of one communication gateway, the required bandwidth $B_{a_{2i}}$ of the cross-section between terminals and the gateway is the sum of the bandwidth required $B_{a_{3j}}$ from each type of terminal to the gateway, therefore, the bandwidth B_{a_0} for the entire system is the sum of the bandwidth from each gateway to the main station.

The bandwidth B_{a_0} can be calculated by the flowing formula:

$$B_{a_0} = \sum_{i=1}^m \sum_{j=1}^n \left(N_j \times B_{a_{3j}} \right) \times \varphi_1 \times \varphi_2 \times \theta$$

Where, N_j is the number of j sensor terminal, for example, if there are k temperatures sensors and temperature sensor is numbered as 5, then $j = 5$, $N_j = k$. $B_{a_{3j}}$ represents the required bandwidth for data transmitted from single terminal to gateway. φ_1 is the network redundancy coefficient, φ_2 is the reliability coefficient, and θ is coincidence coefficient.

According to the above calculation method, the data size of every interaction between the terminal and gateway is about 50 bytes, and assuming $\varphi_1=1$, $\varphi_2=1.5$, $\theta=100\%$, so the required bandwidth of the state monitoring service in the distribution network is about 100 kbit/s.

(2) Communication distance

The data transmission path from terminal to the city main station includes two parts, from communication gateway to the main station and from terminal to gateway, wherein the data transmitted from the gateway to the main station through city backbone network, and if the wireless communication were adopted when the data transmitted from the terminal to communication gateway, it is required that the coverage distance of wireless communication should reach 10-20 km.

(3) Reliability

The correct rate of receiving data should be more than 98 percent, and the correct rate of receiving the alarm for the emergency incident should be more than 99.9 percent.

(4) Real time

The transmission delay of monitoring service data which need to upload periodically should be in the second order, and the transmission time of the alarm service should be less than 10s for the sudden events.

(5) Safety

Key information such as identification data, data type and so on should transmitted from terminal to main station, and encrypted channel transmission and certain physical isolation of communication channels should be adopted in the data transmission process.

3. Comparison of Wireless Communication in Distribution Network

At present, Zigbee, GPRS, TD-LTE wireless private networks and other wireless communication technologies are widely used in power distribution network. Table 1 shows the comparison of these communication technologies parameters.

Zigbee technology has been put into use in early stage of IoT application demonstration project and has made corresponding progress. However, Zigbee is a kind of self-organizing network, and the communication distance is short, so a large number of optical fiber cables need to be laid among the converging nodes to increase the transmission distance, which causes difficulties of fault localization and maintenance. Wireless public network like GPRS is a kind of rented network, which has a blind area in coverage and seriously affects the real-time online rate of terminals. In addition, its inherent openness makes it more vulnerable to security threats such as monitoring, abuse and other security threats. The TD-LTE wireless private network[7] can be divided into 230MHz and 1.8GHz according to the working spectrum, its transmission distance and reliability are higher than wireless public network, but its transmission bandwidth is much higher than required bandwidth of state monitoring in distribution network, so it is not suitable for small packet transmission.

Table 1. Comparison of wireless communication in distribution network

Technology	Frequency	Data rate	Latency	Range	Cost	Shortage
Zigbee	2.4GHz	250kbps	15ms	75m	Low	Short coverage distance
GPRS	900/1800/1900 MHz	114kbps	1.8s	>2km	Low	Transparent transmission, with security risk
TD-LTE230MHz	230MHz	0.5-1.76Mbps	100-300ms	5-20km	High	Limited bandwidth and the difficult development of technology
TD-LTE1800MHz	1800MHz	50-100Mbps	30-100ms	3-10km	High	Existing high loss and the problem of interference
NB-IoT	800-1800MHz	200-230 kbps	<10s	<35km	Low	High transmission delay
LoRa	868 (EU)/915 (US)/490(CH)MHz	0.3-50kbps	2s	<15km	Low	Low data rate

NB-IoT and LoRa are mainstream LPWAN technologies, which meet the requirements of state monitoring service in terms of terminal power consumption and data transmission, and provide a new solution for wireless communication in power system.

4. Network Performance Comparison of NB-IoT and LoRa

In power network service, the characteristics of high reliability and short delay time have strict requirements for communication technology. Although both of the NB-IoT and the LoRa meet the demand of the state monitoring service in the communication distance, network capacity and the application to the service, etc. However, the access control mechanism adopted by LoRaWAN[8] is too simple. When a large number of terminals are connected to the network at the same time, it is easy to cause network congestion or even lose packets. In contrast, NB-IoT is more suitable for the communication requirements of state monitoring services. Nevertheless, considering the terminal power consumption and the different latency requirements of different services, NB-IoT should make changes in simplifying the terminal and designing communication protocols suitable for small data transmission. This section compares the two technologies in the following ways.

4.1. Network deployment

The advantage of NB-IoT is that it can be deployed with the existing infrastructure (LTE base station), saving deployment costs to a certain extent, but NB-IoT is not for rural or suburban areas without 4G network deployment.

The LoRa physical layer adopts CSS spread spectrum modulation[9-10] that make the network deployment relatively flexible, and its module components and network technology are mature, many large enterprises can adopt the mixed network mode of private network and public network. NB-IoT deployment is limited to the cellular network model.

4.2. Spectrum support

NB-IoT is based on the authorized spectrum, the network deployment can select the in-band mode, the guard band mode and the single band mode[11] on the assigned frequency band of GSM or LTE system according to the requirements.

The working spectrum of LoRa in China is 470-510MHz. However, according to the ratio management policy of the Ministry of Industry and Information Technology, the 470-510MHz frequency band will be used for civil ratio metering instruments, and it will only be used at single frequency points and cannot be used in networking. Furthermore, in practical application, the bandwidth must not exceed 200 kHz and the transmission power must not exceed 50mW, which makes large-scale deployment of LoRa network relatively difficult.

4.3. Network cost

As shown in table 2, the cost of network deployment should take into account terminal cost, spectrum cost and network deployment cost. LoRaWAN network deployment adopts tower, industrial gateway and home piconet network. Moreover, the high integration of terminal devices and free unauthorized spectrum make the deployment cost of LoRaWAN network relatively low.

Table 2. Comparison of network cost

	Terminal module	Spectrum cost	Network deployment cost
NB-IoT	\$20	>\$0.5billion/MHz	\$15000 per base station
LoRaWAN	\$7-10	free	\$100-\$1000 per gateway

4.4. Terminal power consumption

The terminal battery life needs to consider two aspects: terminal current consumption and MAC communication protocol. LoRaWAN adopts asynchronous MAC protocol based on ALOHA. LoRa terminals can sleep when there is no data need to be transmitted. In cellular-based synchronization protocols, terminals need to stay in synchronous with the network and check connectivity. Although the NB-IoT uses power saving model(PSM) and enhanced discontinuous reception(eDRX) mechanism to reduce the frequency of network synchronization, it is still regular, which increases the additional energy consumption of the battery. In addition, the physical layer of NB-IoT adopts OFDM modulation, which requires higher peak currents for linear emitters[12] (as shown in Table 3) and depletes battery life quickly.

Table 3. Comparison of terminal power consumption

	Peak current	Sleep current	Delay sensitivity
NB-IoT	120/130mA	5 μ A	<10s
LoRa	32mA	1 μ A	delay insensitive

4.5. Information safety

NB-IoT relies on cellular networks and its security mechanisms are based on identification modules attached to terminal devices, benefiting from all the security and privacy features of the cellular network that support device authentication, confidentiality, data integrity and mobile device identification[13].

The LoRaWAN works in the ISM unlicensed frequency band, and its protocol specification is public[14], which makes it vulnerable to malicious attacks such as forged packets, malicious congestion and so on. Secondly the network authentication credentials of terminal in LoRaWAN have no secure storage medium similar to SIM card and need to rely on the physical protection from the terminal itself, which has a great risk of information leakage to the terminal.

5. Conclusion

In this paper, two low power wide area network technologies, NB-IoT and LoRa, are considered from the point of view of service requirements of distribution network state monitoring, and their advantages and disadvantages in distribution communication application are analyzed. By comparison, NB-IoT is more suitable for power network monitoring services. However, there are still problems such as power consumption, cost and latency in practical applications that need to be perfected. This paper provides theoretical support for the study of the application of IoT in distribution network state monitoring and points out the working direction in the future.

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