Channel Virtual Widening for Electric Information Acquisition System Based on LoRa and Edge Computing

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Abstract. Limited by the channel bandwidth of the terminal communication network in the power system electric information acquisition system, the energy user data at the end of the power system lack proper access mode. In this paper, based on the analysis and comparison of PLC technology, small wireless technology and GPRS technology, a new method of access communication based on LoRa technology and edge computing is proposed. The technology can take into account the advantages of low cost, strong coverage and anti-jamming, and can also improve the virtual bandwidth of the channel, and provide a solid foundation for high frequency data acquisition and mass delivery.

1. Introduction
In recent years, with the in-depth advancement and rapid development of the energy Internet and smart grid, the basic logic of data-driven decision-making is gradually becoming the consensus of many experts and scholars. As data from various links of "source, network, load, and storage" in the energy industry chain becomes more detailed, there are more information value able to be tapped, and the degree of intelligence for the decision-making and control system gets higher. Collection and utilization of massive energy data is of great significance for optimizing resource allocation, promoting energy conservation and emission reduction, leading technological innovation, and driving industrial upgrade.

However, since the energy industries such as coal, oil, and natural gas are widely distributed, and energy corridors stretch for thousands of kilometres, it is extremely difficult to digitalize every dead end of the chain. Even for the power system representing the highest level of informatization in the energy industry, there are still cases where the end node has a low communication rate or is even impossible to cover[1].

The electric information acquisition system ("EIAS") deployed by State Grid Corporation of China ("SGCC") for end users is a good example[2-3]. This system functions as an important means for SGCC to build the "big marketing" system and smart grid, and realize two transformations, so as to improve the automation level of marketing operations, such as electric energy measuring, automatic meter reading and intelligent charge control, to meet the requirements of "SG186" system for deepening operational application, and to support the new energy development, implementation of tiered pricing for electricity and two-way interactive services.

At present, the electric information acquisition system is divided into three levels, i.e. master station, communication channel and acquisition device in logic. The field acquisition equipment is composed of electric energy meter (collector) and concentrator, where one concentrator exchanges
information with a number of electric energy meters in the area, and the local channel is usually achieved by such means as low voltage power line carrier (LV PLC), RS 485 and the micro power wireless communication[4]. The remote channel between the concentrator and the master station is usually realized by optical fiber special network, GPRS/CDMA wireless public network, 230M wireless special network, medium voltage power line carrier (medium voltage PLC) and so on. Efficient and reliable data communication is an important prerequisite for the electric information acquisition system to implement two-way interconnection between the power grid and users. However, in actual operation and maintenance of EIAS, due to numerous equipment tiers and uplink/downlink communication links, the rate of successful acquisition is affected by many factors, such as in following cases: (1) EIAS used in most provinces still uses the power line carrier (PLC) communication mode, which has such demerits as inferior anti-jamming ability, low efficiency, and close to saturation. Therefore, it is difficult to meet higher communication interaction demands; (2) The micro-power wireless communication technology used in Beijing and some other regions also have shortcomings, such as small coverage radius, weak penetration, excessive relay nodes, low data transmission efficiency, and complicated and fragile network architecture. It is hard to realize wide-area coverage and in-depth sinking; (3) The GPRS communication technology used in the Yangtze River Delta is relatively stable and reliable, but with a high cost. It needs to pay huge data fees to telecom operators, and the signal quality depends heavily on the coverage ability of operators' base stations. Furthermore, the data channel uses the public network, hard to guarantee data security and stability.

In summary, the existing EIAS urgently needs a new communication technology to break through in all aspects of carrying capacity, communication quality, data security, and cost, which supports a new generation of energy systems centering on the smart grid. In recent years, the low-power wide-area network (LPWAN) IoT wireless communication technology represented by LoRa and NB-IoT has demonstrated many advantages, including low power consumption, wide coverage, high reliability, and large access capacity, and meets grid demands[5-7].

This paper proposes an EIAS communication solution based on the LoRa technology and edge computing, which not only fully utilizes the wide coverage characteristics realized by spread spectrum communication (SSC) of LoRa[8-10], but also optimizes the protocol efficiency based on edge computing. This greatly improves the virtual bandwidth of the channel, and provides effective support for massive upload of end users' energy consumption data. In addition to serving transformer-range topological identification for "operation, distribution and link-up" of the State Grid, this solution also provides data support for advanced applications, such as line loss analysis, three-phase unbalance analysis, fault locating, and user portrait[11-12]. It is of great significance for construction of the smart grid.

2. Technical Principles and Coverage Performance of LoRa Technology

2.1. Technical Principles of LoRa Technology

The debugging method of LoRa technology incorporates Spread Spectrum Modulation, and its theoretical basis is the Shannon (C·E·Shannon) channel capacity formula in the information theory:

$$C = B \log 2(1 + S / N)$$  \hspace{1cm} (1)

Where $C$ is the channel capacity (unit b/s); $B$ is the channel bandwidth (unit Hz); $S$ is the signal power (unit W); and $N$ is the noise power (unit W).

According to Shannon Theorem, the communication capability under harsh conditions (with low signal-to-noise ratio) can be improved by increasing the signal bandwidth $B$. Therefore, spread spectrum coding over elements of digital signals increases their bandwidth in the frequency domain and further enables them to resist the harsh channel environment. The mechanism is as follows:
The pseudo-random code, since having a spectral characteristic very similar to that of the white Gaussian noise in the frequency domain, is used for spread spectrum coding during the modulation process of the LoRa signal. This is also one of the important reasons for the LoRa signal's strong ability to resist multipath interference.

LoRa also incorporates the forward error correction (FEC) technology, which adds some redundant information to the data sequence to be transmitted, so that the error elements injected in the data transmission process will be corrected in time at the receiving end. This technology reduces the demand of retransmission by creating "self-healing" packets in the past and performs well in solving sudden error codes caused by multipath fading.
Once the packet grouping is established and FEC is injected to ensure reliability, these packets will be sent to a digital spread spectrum modulator. This modulator feeds each bit of the grouped packets into a "spreader", which divides each bit of time into a number of chips. After configuration, the LoRa modem can be divided into a range of 64-4096 chips/bit.

With high spread spectrum factors, LoRa technology can transmit small-capacity data through a wide range of radio spectrum, even below the noise level, but since the data is correlated but the noise is not, the data can be extracted from the noise.

2.2. Test of Coverage Performance
To test the communication effect of LoRa technology in EIAS, we have developed the local modules for the concentrator and smart meter that meet the EIAS standard, according to LoRa module design. Two typical scenarios (one at urban intensive building area and the other at suburb industrial park) are selected to carry out the test. Figure 2 shows the local communication modules of the concentrator and smart meter that incorporate the LoRa modules. Their electrical parameters and RF parameters are listed in Table 1.

![Local communication module of electricity meter and concentrator based on LoRa](image)

**Fig.2 Local communication module of electricity meter and concentrator based on LoRa**

| Table 1 Main parameters of communication module |
|-----------------------------------------------|
| Number | Parameter name             | Value and unit    |
|--------|----------------------------|-------------------|
| 1      | Power supply              | 12V DC            |
| 2      | Transmit power            | 17dBm(50mW)       |
| 3      | Received power            | <19mA@3.3VDC      |
| 4      | Operating frequency band  | 470~510MHz        |
| 5      | Antenna gain              | 0 dBi             |
| 6      | Spread factor             | SF=12             |
| 7      | Modulation bandwidth      | 125kHz            |
The communication module follows the following technical standards: Technical Specification for Single Phase Smart Electricity Meters (Q/GDW 1364-2013), Interface Protocol for Local Communication Module of Concentrator (Q/GDW 1376.2-2013), and Multi-function Watt-hour Meter Communication Protocol (DL/T 645–2007).

The test includes following items about the master station: call power, remote operation, issuing of power fees, search and issuing of tiered pricing for electricity, search and issuing of rate. Communication succeeds if continuous three attempts are successful, or is determined to be unstable if at least one attempt fails, or fails if all the three attempts are unsuccessful. The test results are shown in the following figures:

According to the results of the coverage performance test, in the urban intensive building area, the LoRa-based EIAS end-to-end communication can only effectively cover a radius about 1 km, due to serious signal attenuation caused by densely distributed high-rise buildings, which can be solved by relay networking. In the suburb industrial park, the coverage radius is up to 5.5 km. The worst signal-
to-noise ratio (SNR) for the signal is -20dB, and the signal strength is at least -138dBm. We can conclude that, thanks to the technical principles of spread spectrum communication, LoRa do outperforms current micro-power wireless technologies in coverage performance.

3. Protocol Optimization based on Edge Computing

According to Shannon’s Theorem, LoRa technology’s coverage performance boosts enormously at the cost of occupying high bandwidth and sacrificing data rate. When the spread factor (SF) is 12, LoRa technology has the strongest coverage capability. At this time, the communication rate has dropped to 0.3 kbps. It is necessary to study the channel virtual widening technology considering efficiency of the protocol itself, to effectively utilize communication bandwidth.

Currently, in EIAS of the State Grid, the standard followed to interact with the smart grid is Multi-function Watt-hour Meter Communication Protocol (DL/T 645–2007), which has complex considerations on security, reliability, and system capacity, thus to cause cumbersome protocol content. For example, the command for reading the voltage of a single-phase power meter is as follows:

![Fig.5 Voltage reading instruction of single-phase electric meter](image)

The message contains a total of 20 bytes, including the preamble, spacer, MAC address, control word, message length, message body, parity bit, and terminator. However, there are only 4 core fields that really work, making the message efficiency as low as 20%. The message returned from the power meter is as follows:

![Fig.6 Voltage response instruction of single-phase electric meter](image)

This message has a total of 22 bytes. However, the voltage value only occupies 2 bytes, and the message efficiency has dropped below 10%. Therefore, if the communication module incorporates the transparent transmission mode, the protocol efficiency will be further reduced due to the frame header and trailer of the LoRa message.

The core concept of the protocol optimization algorithm proposed in this paper is to adopt the "fast acquisition and slow transmission" strategy to fully improve the protocol efficiency of each packet. N packets collected in a certain period are subject to frame header filtering and kernel reassembly, to be re-encapsulated into a relatively saturated protocol message before being sent out through the wireless port. The specific message architecture is as follows:

![Fig.7 Optimized protocol message structure](image)

To compare with the effect after protocol optimization, we define the equivalent bandwidth $B_{eq}$ as the total number of bits transmitted for completing a single valid data read operation divided by the elapsed time, in bps (bit per second). It is easy to know that with this definition, the equivalent bandwidth without protocol optimization $B_{eq}=0.3$ kbps.

In view of the reliability of LoRa signals in air transmission, when the spread factor SF=12, the number of bytes per packet is limited to 128. Therefore, N=10, 20, and 40 are selected for comparison. The result is listed in the following table:
Table 2 Comparison of the effect of protocol optimization

| Parameter name      | N=10   | N=20   | N=40   |
|---------------------|--------|--------|--------|
| Protocol efficiency | 50%    | 66.7%  | 80%    |
| Equivalent bandwidth| 1.65kbps | 2.2kbps | 2.64kbps |
| Widening times      | 5.5 times | 7.3 times | 8.8 times |

From the above table, as the packet number N increases, both the protocol efficiency and equivalent bandwidth grow. This indicates that the channel virtual widening strategy proposed in this paper is effective.

4. Summary
This paper proposes a channel virtual widening strategy incorporating the LoRa communication technology, to solve problems faced by the end communication network of EIAS, such as insufficient channel bandwidth, poor anti-jamming ability, and narrow coverage. This strategy utilizes the idle embedded computing resources in the communication module of smart meter, incorporates a protocol optimization method with the core concept of "fast acquisition and slow transmission", and widens the equivalent bandwidth 5–9 times compared with that before optimization through such steps as frame header filtering, kernel reassembly, and packet encapsulation, to provide effective support for end users to upload massive data.

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