Research on Dedicated Network of Distribution Electric Power IoT Based on LoRa Technology and Multi-fork tree Model

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Abstract: With the development of ubiquitous electric power Internet of things, the construction of Distribution Electric Power Grid IoT is becoming imperative. Because of the data producer’s characteristics of weak communication conditions, wide-area characteristics, strong discreteness and unstandardized data types and interfaces, the construction of the DEPN-IoT pushes on difficulty. In order to compensate for the LTE-230 and LTE-1800’s shortcomings, the paper proposes a dedicated network of DEPN-IoT based on LoRa technology and multi-fork tree model. Firstly, the paper introduces the advantages of LoRa technology, then proposes the architecture of the dedicated network. In addition, the paper proposes the networking method between the data transmission and data producer. At last, the paper provides the test method of the network.

1. Introduction

Under the requirements of Energiewende, Distribution Electric Power Grid (DEPG) integrates more and more new generation of information and communication technology[1]. The IoT of Distribution Electric Power Grid (DEPN-IoT) is becoming a new development form. In 2019’s State Grid Two sessions(NPC and CPPCC), the State Grid proposed to build “three-type and two-grid” enterprises, where ubiquitous electric power Internet of things(UEP-IoT) has become an important connotation[2-3]. It means that everything in the electric power system is interconnected and human-computer interaction, and it also represents comprehensive state perception, efficient information processing, convenient and flexible application[2-3].

DEPN-IoT need to obtain real-time data or operation status information of all kinds of sensors. And, it will face several key difficulties during the construction of DEPN-IoT[4-6]. That is: 1) Establishing reliable communication network, realizing free networking, interconnection and plug-and-play of multi-type sensors. 2) Standardizing information model of multi-type sensors and multi-data exchange model, realizing the interconnection and interoperability among multi-type sensors. 3) Formulating the architecture of communication module, considering the principles of miniaturization, low power consumption, abundant interfaces and easy access to electricity.

However, because of the data producer’s characteristics of weak communication conditions, wide-area, strong discreteness and unstandardized data types and interfaces, the construction of the DEPN-IoT becomes more difficult[4-6]. In order to solve these problems, LTE-230 and LTE-1800 technology have been tried[7-9], but the results are not satisfactory. The main reasons are as follows: 1) Non-
dedicated frequency points are limited in use for LTE-1800. 2) Weak technology industry ecology for TD-LTE230.[9-11]

In order to compensate for the above shortcomings, this paper proposes a dedicated network of DEPN-IoT based on LoRa technology and multi-fork tree model.

2. LoRa Introduction

2.1 LoRa Advantage Analysis

LoRa is a kind of LPWAN communication technology. It is a long-distance wireless communication transmission scheme based on spread spectrum technology promoted by Semtech Company in the United States. It’s theoretical basis is Shannon's theorem \( C = B \cdot \log 2(1 + S / N) \), in which C is channel capacity, unit b/s; B is channel bandwidth, unit Hz; S/N is signal ratio, unit dB. It can be seen that under the same channel capacity C, the higher the signal bandwidth B, the lower the S/N signal-to-noise ratio of the received signal, that is, the higher the sensitivity. At the same time, LoRa also uses forward error correction technology to further enhance its anti-jamming ability. The limit receiving sensitivity reaches -148 dBm, which is about 27 dB higher than that of small wireless FSK[12-16].

Comparing to LTE-1.8G, LoRa works at in the public frequency band, there is no need to apply for dedicated frequency, which is generally not allowed. Comparing to LTE-230MHz, LoRa has abundant and sound industrial ecology. Whether from chips to modules, or from modules to communication terminals, there are a large number of products and applications. In addition, LoRa Gateway has the advantages of long range, small size, low power and cost. Therefore, LoRa technology is one of the suitable technology for the construction of DEPN-IoT.

2.2 Composition of DEPN-IoT’s Dedicated LoRa Network

DEPN-IoT’s dedicated LoRa network is designed to provide services to distribution automation system, electricity information acquisition system, electric vehicle charging pile and integrated energy services, etc. The architecture of DEPN-IoT’s dedicated LoRa network is shown below, including data producers, data transmitter, data manager and data consumer.

![Diagram of DEPN-IoT’s Dedicated LoRa Network]

Figure 1. Composition of DEPN-IoT’s Dedicated LoRa Network

(1) Data Producers
The sensors in DEPN-IoT, such as discharge, temperature in power ring cabinet, fault indicator in transmission line, and electric meter in energy consume acquisition, etc.

(2) Data Transmitter: Wireless Internet of Things Gateway
Wireless Internet of Things gateway (IWG) is the first level of pan-sensing connection, which realizes the physical layer wireless connection function of massive pan-sensing small data. IWG is a wireless micro-base station of the Internet of Things, which is different from the traditional public network macro-base station in terms of high power consumption and high investment. The micro-base station of the Internet of Things should have the characteristics of ready-to-use and deployment anytime and anywhere, so as to facilitate the "sparkling" expansion of the Internet of Things network.

(3) Data Manager: Multi-service Platform

MSP (multi-service platform) is the core management system of the Internet of Things private network. The massive and small data connected by the Internet of Things pan-perception are collected into MSP for data management. MSP needs to implement the Internet of Things wireless communication underlying protocol and expansion, wireless network optimization management, data encryption and decryption and decompression, application data upstream and downstream distribution and third-party application server interface and other functions.

(4) Data Consumer: Applications

Operational-level energy and power Internet of Things network needs operational business support system, including user management, flow management, billing management, billing system, customer management system, etc. Implementing the operation function of the Internet of Things business and serving the users of the whole industry.

3. LoRa multi-fork tree network topology

The LoRa dedicated network is between IWG and sensors. Limited to space, the next paper will focus on this part.

3.1 LoRa multi-fork tree network topology

Every sensor in data producer is a slave node, such as B–K in figure 2. In order to maintain network reliability, this paper studies the DEPN-IoT dedicated network based on "multi-fork tree". Among them, A is the main node (i.e. IWG), B, C, D, E is the first-level slave node, F, G, H, I is the second-level slave node, J, K is the third-level slave node. The master node carries the scheduling task of downlink communication network. Multi-fork tree has growth characteristics, and when the slave node is expanded, the network will grow orderly fourth or fifth level slave nodes.

![LoRa multi-fork tree network topology](image)

Figure 2. LoRa multi-fork tree network topology

To describe the growth process of "multi-fork tree", the following terms are defined:

1) Slave node set \( \{S\} \): The set of known slave nodes in the network, such as the first-level slave nodes B, C, D, E as shown in Figure 2, and the second-level slave nodes F, G, H, I, etc.
2) Si: Nodes not connected to the network in \( \{S\} \).
3) Slink: The communication link of Si. The path that the master node can establish the communication link with Si, as shown in Figure 2, A-B-I-J is a communication link of the slave node J.
4) Slink(SNR_S, SNR_M): Communication quality of Slink, where SNR_S is the received SNR of the communication that Si correctly receives the network request frame from the parent node and
SNR_M is the received SNR of the communication that Si’s parent node correctly receives the network confirmation frame from Si. As shown in Figure 2, for (B, I), B is the parent node, denoted as ‘M’, I is the child node, denoted as ‘S’.

3.2 Growth Strategy of LoRa Multi-fork tree Network

A) Best Route Network, BRN

In the process of multi-fork tree growth, the nodes in the network need to search the better path continuously through the optimization algorithm until the path traversal is completed. Specifically: Note that the previous link of the networking node S is SLink'(SNR_S', SNR_M'), current link is SLink(SNR_S, SNR_M). When it is satisfied with SNR_M + SNR_S >= SNR_M' + SNR_S' and min(SNR_S, SNR_M) >= min(SNR_M', SNR_S''), Link of nodes to be networked is replaced by SLink(SNR_S, SNR_M), Otherwise, it will remain unchanged.

B) Max Reliable Route Network, MRRN

In the process of multi-fork tree growth, the nodes in the network are searching for better paths through the optimization algorithm in A. When the SLink(SNR_S, SNR_M) communication quality is good or above, the node stops growing, otherwise, the process goes on until the path traversal is completed. Specifically: The threshold of excellent and good communication quality is defined as W and G. When SNR_S > W and SNR_M > W, the communication quality is excellent, when SNR_S > G and SNR_M > G, the communication quality is good, otherwise, it is bad.

3.3 LoRa Multi-fork tree Growth Algorithms

3.3.1 First-level Node Growth Algorithms

Step 1: Sending networking request to Si

The master node sends networking request frame to one of the unconnected slave node Si, and enables timeout monitoring. If the receiving time-out occurs, this Si fails to connect to the network. Then the process goes to Step 4, otherwise Step 2.

Step 2: Analyzing Received Message

If the received message is not valid, this networking of Si fails too, then the process goes to Step 4, otherwise Step 3.

Step 3: Rating Link Quality

The slave node Si is marked connected and as a level-1st slave node. And, the communication quality will be rated as W or G according to Slink (SNR_S, SNR_M). Then, the process goes to Step 4.

Step 4: Traversing the unconnected nodes

Searching the next node in {S} and repeating Step 1 to Step 4. if {S} is traversed completely, the first-level networking process ends and the process goes to Step 5.

Step 5: Cleaning up networking results

The node which is level-1st slave node and the communication quality is good or above will be set to {L1}, others will be set to {U1}. If {U1} is empty, all nodes have connected to the network and the growth process ends. Otherwise, the process goes to the secondary nodes growth process.

3.3.2 Multistage Node Growth Process

Multilevel node growth is based on the result of the previous growth level. Here, the paper takes the growth process of secondary nodes as an example to illustrate the growth process of multilevel nodes.

Step 1: Sending growth request to L1i

Step 2: Sending networking request to U1i

L1i sends networking request frame to one of the unconnected slave node U1i, and enables timeout monitoring. If the receiving time-out occurs, this U1i fails to connect to the network. Then the process goes to Step 5, otherwise Step 3.

Step 3: Analyzing Received Message
If the received message is not valid, this networking of U1i fails too, then the process goes to Step5, otherwise Step4.

Step4: Rating Link Quality
The communication quality will be rated as W or G according to Slink (SNR_S, SNR_M). If the Slink (SNR_S, SNR_M) is satisfied to the growth strategy, the slave node U1i is marked connected and as a level-2st slave node, otherwise unconnected. Then, the process goes to Step5.

Step5: Traversing the unconnected nodes
Searching the next node in {U1} and repeating Step2 to Step5. If {U1} is traversed completely and all the U1s are connected, the process ends, otherwise, the process goes to the third nodes growth process.

4. DEPN-IoT Dedicated Network Test
In order to test the coverage of DEPN-IoT dedicated network, this paper develops a LoRa network test system, which includes two parts: APP and LoRa transceiver. The APP and LoRa transceiver are connected by USB OTG.

![network test system](image)

Figure 3. network test system

The testing process is as follows:
1) APP sends broadcast test frames to LoRa transceiver through USB OTG regularly, which is defined as P frame. P frame format is as follows: AT+N=1, AAAAAAAAAAAA;
2) When LoRa correctly receives P frame from the node, it returns to the test confirmation frame, which is defined as Q frame, and Q frame contains the received SNR_S from the node.
3) After receiving Q frame, LoRa transceiver calculates the received SNR_M.
4) LoRa transceiver transmits test results to APP, which is defined as R frame. R frame format is as follows: AT+N=SNR_S,SNR_M.

5. Conclusion
With the development of ubiquitous electric power Internet of things, the construction of Distribution Electric Power Grid IoT is becoming imperative. Because of the data producer’s characteristics of weak communication conditions, wide-area characteristics, strong discreteness and unstandardized data types and interfaces, the construction of the DEPN-IoT pushes on difficulty. In order to compensate for the LTE-230 and LTE-1800’s shortcomings, the paper proposes a dedicated network of DEPN-IoT based on LoRa technology and multi-fork tree model. Firstly, the paper introduces the advantages of LoRa technology, then proposes the architecture of the dedicated network. In addition, the paper proposes the networking method between the data transmission and data producer. At last, the paper provides the test method of the network.

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