Two Networking Algorithms Based on LoRa Communication Used for Private Network Construction in Energy Acquisition System

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Abstract: With the continuous improvement of acquisition quality, service quality, maintenance cost of energy acquisition system, downlink communication still lacks systematic solutions to the complex, changeable, new and weak planning application scenarios of underground garage charging pile, coal-to-electricity conversion, etc. This paper proposed two networking algorithms, BRN and MCN, based on LoRa communication used to construct the private network in energy acquisition system. With the long-distance characteristics of LoRa technology, a larger private network can be built quickly.

1. Introduction

The integration of energy revolution and digital revolution is the trend and characteristic of the fourth industrial revolution. For this reason, in the work report of State Grid Co., Ltd. in 2019, the goal of promoting the construction of "three-type, two-network, world-class" energy internet enterprises was put forward, and proposed the requirements of building "ubiquitous power Internet of things", that is to say, building a comprehensive state awareness, efficient information processing, convenient and flexible application of ubiquitous power internet of things [1].

Electric energy is an important source for the national economic development and social stability. With the continuous increase of population and the expansion of electricity consumption, power management organizations such as state grid, are facing major difficulties in energy metering work. In addition, the rapid increase of the number of residential users in buildings, the requirement of wireless communication functional watt-hour meter and wireless meter reading equipment is getting stricter and stricter. The traditional short-distance wireless data transmission mode will not meet the distance requirements of future wireless meter reading equipment.

On the other hand, the number of cities that are currently creating smart cities is increasing. The construction of wireless meter reading, remote monitoring of firefighting equipment and other projects in cities cannot meet the needs of the existing 3G/4G GSM network. Therefore, the construction of urban information infrastructure needs a low-power WAN technology to achieve intelligent monitoring and measurement.

In recent years, the emergence of a new low power wide area network (LPWAN) has developed rapidly because of its low power consumption, wide coverage and strong penetration. It makes up for the shortcomings of WiFi and Zigbee protocols in cellular networks, and has been applied in many...
industries. One of them, long range communication technology (LoRa) is a proprietary spread spectrum modulation scheme, which extends the signal to wider bandwidth noise by spread spectrum to obtain spread spectrum gain. It is a derivative of chirp spread spectrum modulation [2-3].

LoRa has the characteristics of long-distance transmission, low power consumption and low cost. The radio module based on LoRa technology uses high-frequency amplification in the front part of the radio frequency and it can transmit five kilometers. It is suitable for places that require high transmission distance and penetration ability, especially, for complex, changeable and new scenarios such as underground garage charging pile, coal to electricity conversion, etc.

Some scholars have studied the application of LoRa technology such as overview of LoRa and an in-depth analysis of its functional components [4], the coverage of LoRa LPWAN technology via real-life measurements [5], interleaved chirp spreading LoRa-based modulation [6], campus-scale monitoring [7] and smart building [8]. Most of them are based on point-to-point communication, but there is no single hop communication network research, especially in the private network of energy acquisition system.

This paper presents two networking methods based on LoRa single hop communication, namely, the best route net (BRN) and the maximum connect net (MCN). BRN network can guarantee the best channel quality of the LoRa network, while MCN network is based on the construction of the maximum coverage network. The networking strategy is discussed in detail in this paper.

2. Private Network in Energy Acquisition System of Smart Grid

Figure 1 shows the schematic diagram of smart grid meter reading architecture. Smart electric concentrator and meter are both consists of local communication modules and host. Those communication modules have communication components, which generally adopt PLC, wireless communication or both of them. In order to achieve the goal of reading smart meter by the concentrator, the local module of concentrator is used as the middle layer to establish the data transmission channel between concentrator and electric meter. The concentrator local module is installed in the concentrator ontology, and data communication is conducted through serial ports with protocol of Q-GDW1376.2. The concentrator sends messages which met DLT645 standard requirements to the concentrator local module when it reads a meter. Local module of smart meter analyzes those messages to read meter data according to the received commands. Therefore, if the distribution of concentrator meter reading files can be completed, and single-phase or three-phase meters reading operations can be achieved, then the concentrator local module and the meter local module meet the requirements of Q-GDW1376.2 and DLT645 protocols [9-11].
According to our findings, the communication link only judges whether it is networking by receiving the corresponding reply data in some LoRa networking modes of energy acquisition system. It could not judge the channel quality of the communication link. In the process of searching nodes sequentially, the network is usually organized in the order of archives. Once the communication link with lower channel quality is successfully networked, the current node's networking process will be terminated immediately. In addition, the network is searched according to breadth-first mode. When the network scale is larger and the network depth is deeper, the process of networking is extremely complex and time-consuming. Sometimes, the relay nodes will be traversed in turn until the communication is successful (single point repeats many times), which leads to frequent networking and further reduces the efficiency of networking process. Therefore, a LoRa networking algorithm based on SNR signal-to-noise ratio is proposed to solve the unreliable and inefficient problems of existing large-scale networking schemes.

Moreover, for deployed large-scale networks, the process of networking can be intervened. Because the topological relationship of each cluster is known in advance, the networking process can actively search path information in the set relay nodes by setting relay nodes which need to be networked. It avoids blindly traversing and traversing links with poor communication quality in breadth-first search, thus guaranteeing the reliable communication of terminal measurement points. In addition, a new judgment index is introduced to confirm the communication link. The received noise ratio (SNR) is used to calculate the link channel quality and to assist in judging whether the network is built or not.

3. Networking algorithm

Signal-to-Noise Ratio (SNR) in multi-level networking schematic is shown in Figure 2. In order to introduce the networking method of meter reading based on SNR, here are some key terms to describe as follows.

**Slave Node**: The meter communication module nodes which are waiting for networking, represented by $S$. See DB1 in 1-level, DB2 in 2-level and DB3 in 3-level respectively.

**Master Node**: It is the last node on the communication link to communicate with the node to be networked, namely, the superior node of the node to be networked and represented by $M$. See JZQ in 1-level, DB1 in 2-level and DB2 in 3-level respectively.
**SNR of Master Node**: SNR computed by slave node after receiving data correctly, represented by SNR1.

**SNR of Slave Node**: SNR computed by master node after receiving data correctly, represented by SNR2.

**Single-hop**: Point-to-point communication between smart concentrators and meter’s node.

![Schematic diagram of multi-level networking](image)

Figure 2. SNR in multi-level networking schematic

LoRa communication network used to reading meter is mainly based on single-hop technology. In the process of networking, different link channel quality criteria can be used to determine the networking modes with different networking characteristics. One of the advantages of LoRa communication technology is that it can easily calculate SNR of signal transmission process. Therefore, two kinds of easy-to-implement networking are proposed as described below. First, by using SNR threshold as rigid quotas, the best route net (BRN) with the strongest connection attribute can be obtained. That is, if the channel quality meets the set requirements, communication success can be guaranteed. Second, maximum connect net (MCN) can be obtained by using SNR channel quality classification (better, good, well, bad, worse) as a flexible index. The MCN networking method ensures the completion of networking and success of communication as far as possible.

### 3.1 The Best Route Net BRN

SNR1 is added at the end of the message to assist the network reliability judgment without changing the header of the original network message. Multi-level networking is based on single-hop method. If the link of each single hop is reliable, the whole network is reliable. The core of BRN method lies in 3 aspects, 1) judging whether the current communication link channel quality SNR1 and SNR2 meet the set threshold requirements; 2) whether the optimal single hop path of current node needs to be updated; and 3) traversing M in turn from all the candidate master sending nodes. Table I shows the BRN networking algorithm. The detailed steps of BRN algorithm are as follows.

| First-level networking process | Multi-level networking process |
|--------------------------------|--------------------------------|
| **Input**: JZQ file, All Master node and standby Slave node S_i | **Input**: M, (M_i e M-table), j = 0 (S_j e S-table(connected = 0)) |
| **Output**: S_i.connect and S_i.Netflag | **FOR** L ← 2 to maximum networking level |
| **FOR** i ← 1 to num. of Slave node |
| ↓ JZQ send netting message to S_i ; |
| **Init** S_i.connect = 0, S_i.Netflag = 1 | **FOR** i = i + 1 from M-table |
| **IF** (time no out and parse message success) | **FOR** j = j + 1 from S-table |
| Judging link channel quality by Equation (1): | M_i send netting message to S_j ; |
| **IF** (SNR1 > -15 dB && SNR2 > -15 dB) | **IF**((SNR1 > -15 dB && SNR2 > -15 dB) |
| S_i.connect = 1, S_i.Netflag = 1 | **AND** (SNR1 + SNR2 >= SNR1’ + SNR2’) |
| **CONTINUE**; | **AND** (min(SNR1, SNR2) >= min(SNR1’, SNR2’)) |
| **ELSE** | **THEN** |
| S_i.connect = 0, S_i.Netflag = 1 | |
| END IF | SNR1' = SNR1;  
| ELSE | SNR2' = SNR2;  
| END IF | LinkSj = Mj;  
| END FOR | Sj.connect = 1; Sj.Netflag = L; Sj.relay =LinkSj.MAC;  
| END FOR | END FOR |

### A. First-level Networking Process

**Step1:** In first-level networking process, JZQ serves as the master sending node, M = JZQ. Firstly, the networking process will initiate networking requests. JZQ sends requests for networking information to the standby node S normally, and enables timeout waiting to receive retaliation messages. If the timeout is received, the node currently waiting to be networked fails to enter **Step4**, otherwise it goes to **Step2**.

**Step2:** Analysis of receiving network messages. If the retaliation message is received within the timeout period and the parsing of the retaliation message is successful, the algorithm enters **Step3**. If the parsing message is unsuccessful, the current node to be networked failure and enters **Step4**.

**Step3:** Judging link channel quality. The SNR1 of the message is obtained and the SNR2 of the current message is calculated to determine whether the channel quality of the current communication link meets the requirements of stable communication as expressed in Equation (1). If the requirement is satisfied, the first-level network is successfully formed, the first-level network entry success marks $S_{i}.connect = 1$, $S_{j}.Netflag = 0$ and enter **Step4**; if not, the current network node will fail to form and enter **Step4**.

\[
\text{LoRa\_Linked} = (\text{SNR1} > -15 \text{ dB} \&\& \text{SNR2} > -15 \text{ dB})
\]

(Equation 1)

**Step4:** Traversing the nodes to be networked. From the current file, the process will search other nodes which are not netted and traverse $S_i$ in turn. If the traversal go to end, the first-level networking process will be finished, and the networking level $L = 1$ is about to enter the multi-level networking process; otherwise, it would still entry **Step1**.

### B. Multi-level Networking Process

Multi-level networking is based on the completion of previous networking, that is to say, secondary networking requires primary networking, using primary networking nodes as relay of secondary networking; tertiary networking requires secondary networking, relay of secondary networking nodes. After the JZQ networking information reaches the previous networking node, the previous networking node (DB) acts as the main sending node, M = DB, and the networking process is regarded as the initiative of M to initiate networking requests. The multi-level networking steps are as follows.

**Step5:** Record the current networking level $L = L + 1$ and select a master sending node $M_i$ form M-table. $M_i$ sends requests for networking information to the $S_j$ node to be networked normally, and enables timeout waiting for receiving reply messages. If the parsing of retaliation message is successful, the process goes to step 6; otherwise, $M_i$ sends requests for networking information to the $S_{i+1}$.

**Step6:** Judging link quality and choosing optimal link. By Obtaining the SNR1 of the message and calculating the SNR2 of the current message, the networking process determine whether the channel quality of the current communication link meets the requirements of stable communication according to Equation 2. Then, for the current network node $S_j$, the networking process needs to compare the current link (SNR1, SNR2) with the previous link (SNR1', SNR2'), select and record the link with better channel quality, that is, record the best master sending node $M_i$ and the corresponding SNR1M, SNR2M. The criteria for LoRa link quality selection are as follows.
if((SNR1 + SNR2 >= SNR1’ + SNR2’) && (min(SNR1, SNR2) >= min(SNR1’, SNR2’)))
{
    SNR1’ = SNR1;
    SNR2’ = SNR2;
    LinkSj = Mi;
    LinkQSj’ = LinkQSj;
}

**Step7:** Recording Optimal Link. For the current network node Sj, a new sending node Mi is selected in the alternative master sending node from M-table and \(i = i + 1\). If Mi traversal ends, Sj optimal networking links are recorded. If there is no Sj optimal single-hop communication link after searching all Sj optimal link, the Sj node is not networked and directly enters **Step8**. Therefore, if there exists an optimal single-hop communication link, the best single-hop LinkSj is communication link for Sj.

**Step8:** Traverse all nodes Sj from Sj table. If the Sj traversal ends, the current networking level process is finished. The level of networking will be further increased with \(L = L + 1\) until it reaches the maximum level.

### 3.2 The Maximum Connect Net MCN

Because the communication link of the network slave node is to search the best channel quality path of all possible links, BRN can ensure the stable and reliable communication. However, it deliberately seek the strongest path and ignores the links that can communicate, which may cause a large number of nodes with low SNR to be disconnected, resulting in a low success rate of networking.

The success rate of BRN network is related to its channel quality judgment method. Its judgment index is SNR1 > -15 dB and SNR2 > -15 dB. In fact, although its communication quality is low, LoRa can communicate successfully if SNR in [-20, -15]. For some networks with poor channel quality, or some of them can barely communicate with extreme location nodes, it doesn’t have to be off-line after BRN networking. Therefore, those nodes with low signal quality but still communicating should also be considered as successful networking.

Specifically, it only needs to modify the BRN judgment flag and the selecting strategy of the optimal communication link, and the code segment is expressed as follows.

| Channel Quality Classification | Strategy of the Optimal Communication Link |
|-------------------------------|-------------------------------------------|
| if (SNR1 > 0 & SNR2 > 0)     | if (SNR1 + SNR2 >= SNR1’ + SNR2’) && (min(SNR1, SNR2) >= min(SNR1’, SNR2’)) |
| else if (SNR1 > -10 & SNR2 > -10) | {                     |
| else if (SNR1 > -15 & SNR2 > -15) | SNR1’ = SNR1; |
| else if (SNR1 > -18 & SNR2 > -18) | SNR2’ = SNR2; |
| else LinkQSj = Worse;    | LinkSj = Mi; |
|                            | LinkQSj’ = LinkQSj; |

### 4. Conclusion

With the proposal of ubiquitous power internet of things, smart watt-hour meter is an important sensing device at the end of perception layer of power Internet of things. It is of great significance to improve the service quality of energy acquisition system by constructing a special network for meter reading. LoRa technology is very suitable for building local area networks for residential areas, villages and some new electricity scenarios. The two networking methods proposed in this paper construct are used to build LoRa private network from two aspects of reliability and wide coverage. By introducing new criteria into communication links and using SNR to calculate link channel quality, network reliability is improved.
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