A Dual-mode Communication Power Internet of Things Routing Algorithm Based on RPL Protocol

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Abstract. Medium frequency (less than 12 MHz) Power Line Communication (PLC) and micro-power wireless Radio Frequency (RF) communication dual-mode communication technology can realize the depth and breadth coverage of the power Internet of Things (IoT) and enhance the robustness of the network. But dual-mode communication also brings difficulties to the application of the RPL protocol. According to the characteristics of PLC and RF dual-mode communication technology, the routing communication delay is the optimization objective function, and a routing metric algorithm of RPL routing protocol is proposed. The RPL protocol is applied to the dual-mode communication in power Internet of Things. Experiments show that the proposed algorithm has higher communication efficiency and can meet the needs of dual-mode communication hybrid networking and operation. It is a feasible method.

1. Introduction

The Field Area Network (FAN) based on Medium Frequency (less than 12 MHz) Power Line Communication (PLC) technology and micro-power wireless Radio Frequency (RF) communication technology has been widely used in the power Internet of Things. They have become the main communication mode of FAN. PLC has the characteristics of transmitting along the physical topology of the power line in the power supply station area; while the RF transmits data through radio frequency airborne propagation, and has no direct connection with the physical topology of the power line. Due to the difference in bandwidth, the communication speed of the PLC is higher than that of the RF generally. However, there are problems such as the failure of the PLC to report the power outage event and the non-AC power supply sensor cannot be accessed. PLC uses power line for communication, which is susceptible to noise interference and has strong time-varying characteristics. The RF channel has good stability and coverage. The access devices of the power Internet of Things have the characteristics of fixed installation location and non-movability. Therefore, the existing power Internet of Things based on PLC or RF communication technology has their own communication coverage blind spots, which cannot meet the needs of the power Internet of Things. Application requirements for device access and multi-category data collection as well as high-frequency data collection cannot be met.

The dual-mode communication technology combining PLC and RF can achieve complementary advantages, realize the depth and breadth coverage of the network, enhance the robustness of the network, and meet the requirements of high-frequency data acquisition and new services of power Internet of Things. The dual-mode communication technology means that each node has both PLC and RF channels, which provides a richer network connection between the nodes of FAN, and also makes the routing algorithm more complicated. How to better utilize the advantages of dual-mode...
communication, and to study the dual-mode routing algorithm with high communication efficiency and good robustness under the premise of ensuring coverage becomes a challenge.

IPv6 is a new generation Internet protocol, providing a large number of IP address resources. IPv6 can realize end-to-end direct communication access, and lays a foundation for the IoT to realize functions such as plug-and-play, network security communication and network device management for network devices and sensors. In order to introduce IPv6 into the Internet of Things of Low-power and Lossy Networks (LLN), the Internet Engineering Task Force (IETF) ROLL (Routing over LLN) working group standardized the routing architecture for LLN called RPL\cite{2}. RPL uses the concept of Destination Oriented Directed Acyclic Graph (DODAG). RPL can be applied to the wireless power Internet of Things\cite{3}. The comprehensive performance of the RPL objective function was analysed in \cite{4}.

Aiming at the characteristics of PLC and RF dual-mode communication, this paper proposes a routing metric algorithm for RPL protocol with the lowest communication delay of routing as the optimization objective function. The RPL protocol is applied to the dual-mode communication in power Internet of Things to realize PLC and RF dual-mode communication hybrid networking.

2. RPL Protocol Overview

The RPL protocol establishes a target-oriented DODAG through an objective function (OF) and a route metric. The nodes in each DODAG (except the root node) select a parent node as the default route to the root node along the DODAG. IPv6 packets are forwarded from a source node up the DODAG to the root using next hop routing. Packets are forwarded down the DODAG to a destination node using source routing determined by the root. The OF uses some sort of routing metric to choose the default route. There are many combinations of objective functions and routing metrics to suit the needs of different application scenarios. Some application scenarios require the expected transmission Count (ETX) as the routing metric; while other application environments may choose the hop count or transmission delay of the root node as the routing metric.

The RPL protocol defines a number of ICMPv6 \cite{5} (Internet Control Message Protocol for the Internet Protocol version 6) type control messages for DODAG establishment and maintenance. The RPL supports nodes for data routing in both the up direction (the child node points to the root node) and the down direction (the root node points to the child node). Figure 1 shows the process of data routing on the network using the RPL routing protocol.

![Figure 1. RPL and network layering structure](image)

The RPL implements the networking process as shown in Figure 2.

First, the root node broadcasts a DIO (DODAG Information Object) message. The DIO messages contain various DODAG metadata and the rank (relative position within the DODAG) of the transmitting candidate. A set of routable parents is selected from the candidate set, one of which is determined to be the preferred parent, providing the default upward route from the child node. The child node itself calculates its rank within the DODAG, then transmits its version of DIO messages to listening neighbors.

After receiving the DIO message, the Node A replies with a DAO (Destination Advertisement Object) message and forwards the modified DIO message; after receiving the message, the Node B repeats the process of the node A. The Node C that receives the DIO message for a long time, as an
isolated node, can actively multicast a DIS (DODAG Information Solicitation) message. After receiving the DIS message, the Node B repeats the process of the node A. Then all nodes are added to the same network.

The ROLL Working Group has developed OF0 (Objective Function Zero) \([6]\) and MRHOF (Minimum Rank with Hysteresis Objective Function) \([7]\). OF0 only uses the minimum hop count as the basis for establishing a route; MRHOF uses the route metric as the basis for establishing a route.

![Diagram](image.png)

**Figure 2.** DODAG establishment and maintenance

### 3. Application of RPL Protocol in Dual-mode IoT

In a dual-mode communication network, a central node and N sub-nodes form a graph, based on the received signal strength indication (RSSI) and Signal-to-Noise Ratio (SNR) between two nodes \(i, j\) in PLC channel or RF channel. If RSSI and SNR between nodes \(i, j\) are greater than the thresholds, which means they can communicate with each other, then they are called adjacent. There are three cases of channels between two adjacent nodes: (1) only PLC channel, no RF channel; (2) only RF channel, no PLC channel; (3) both PLC and RF channels exist. The adjacency relationship matrix is \(E = [e_{ij}], i,j=0,1,\ldots, N\), here

\[
e_{ij} = \begin{cases} 
0, & \text{if Nodes } i \text{ and } j \text{ are not adjacent;} \\
1, & \text{if Nodes } i \text{ and } j \text{ are adjacent only by PLC channel;} \\
2, & \text{if Nodes } i \text{ and } j \text{ are adjacent only by RF channel;} \\
3, & \text{if Nodes } i \text{ and } j \text{ are adjacent by both channels.}
\end{cases}
\]

Assuming that the communication rates of PLC and RF are \(v_p\) and \(v_R\) respectively, the Communication delay matrix of the graph is \(W = [w_{ij}], i,j=0,1,\ldots, N\), here

\[
w_{ij} = \begin{cases} 
0, & \text{if } e_{ij} = 0 \\
\frac{1}{v_p}, & \text{if } e_{ij} = 1 \\
\frac{1}{v_R}, & \text{if } e_{ij} = 2 \\
\frac{1}{\max(v_p,v_R)}, & \text{if } e_{ij} = 3.
\end{cases}
\]
The measure of a route is the sum of $w_{ij}$ in a link. Taking the fastest transmission rate of a route as the optimization goal is to select the minimum of the sum $w_{ij}$ of any node to the root node. Using this objective function, the RPL protocol can be applied to a dual-mode communication network.

4. Experimental Results

Set $N=9$. Figure 3 shows the adjacencies between nodes. The solid line indicates that there is a PLC connection in the adjacent node; the dotted line indicates that there is an RF connection in the adjacent node.

![Figure 3. The adjacencies between nodes](image)

The adjacency relationship matrix $E$ that can be obtained according to the neighbor relationship of the nodes:

$$
\begin{array}{cccccccccc}
0 & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 \\
0 & 3 & 2 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 3 & 3 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
2 & 2 & 3 & 2 & 0 & 2 & 1 & 0 & 0 & 0 \\
3 & 1 & 0 & 2 & 0 & 0 & 0 & 0 & 3 & 0 \\
4 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
5 & 0 & 0 & 2 & 0 & 0 & 2 & 0 & 0 & 2 \\
6 & 0 & 0 & 1 & 0 & 0 & 2 & 0 & 0 & 2 \\
7 & 0 & 0 & 0 & 0 & 0 & 0 & 2 & 2 & 0 \\
8 & 0 & 0 & 0 & 3 & 0 & 0 & 0 & 2 & 0 \\
9 & 0 & 0 & 0 & 0 & 0 & 2 & 2 & 2 & 0 \\
\end{array}
$$

If only PLC single mode communication is used for networking, the network topology is shown in Figure 4. Node 5, 7, 9 cannot be covered by the network.

If only RF single mode communication is used for networking, the network topology is shown in Figure 5. Node 4 cannot be covered by the network.
If PLC and RF dual-mode communication are used for networking, all nodes can be covered by network. Set $v_p = 625\text{kbps}$, $v_R = 500\text{kbps}$, then the communication delay matrix $W$ (unit: $\mu$s) is

|    | 0  | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
|----|----|----|----|----|----|----|----|----|----|----|
| 0  | 1.6| 2  | 1.6|    |    |    |    |    |    |    |
| 1  | 1.6| 1.6| 1.6|    |    |    |    |    |    |    |
| 2  | 2  | 1.6| 2  | 2  | 1.6|    |    |    |    |    |
| 3  | 1.6| 2  | 1.6|    |    |    |    |    |    |    |
| 4  | 1.6|    |    |    |    |    |    |    |    |    |
| 5  | 2  | 2  | 2  | 2  |    |    |    |    |    |    |
| 6  | 1.6| 2  | 2  | 2  |    |    |    |    |    |    |
| 7  | 2  | 2  | 2  |    |    |    |    |    |    |    |
| 8  | 1.6| 2  | 2  | 2  |    |    |    |    |    |    |
| 9  | 2  | 2  | 2  | 2  |    |    |    |    |    |    |

With the minimum communication delay of the route as the optimization objective function, the network route instance 1 in Figure 6 can be obtained.
In the calculation process, the time taken by the routing node to forward data is ignored. In practical applications, it needs to be considered according to the processing capability of the node.

Similarly, set $v_p = 500$kbps, $v_R = 625$kbps, then the communication delay matrix $W$ (unit: $\mu$s) is

|   | 0   | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0 | 2   | 1.6 | 2   |     |     |     |     |     |     |     |
| 1 | 2   | 2   | 2   |     |     |     |     |     |     |     |
| 2 | 1.6 | 2   | 1.6 | 1.6 | 2   |     |     |     |     |     |
| 3 | 2   | 1.6 |     | 2   |     |     |     |     |     |     |
| 4 | 2   |     |     |     |     |     |     |     |     |     |
| 5 | 1.6 |     | 1.6 | 1.6 |     |     |     |     |     |     |
| 6 | 2   |     | 1.6 |     | 1.6 |     |     |     |     |     |
| 7 |     |     | 1.6 | 1.6 |     |     |     |     |     |     |
| 8 | 2   |     |     | 1.6 |     |     |     |     |     |     |
| 9 |     |     |     |     | 1.6 | 1.6 | 1.6 |     |     |     |

The network route instance 2 in Figure 7 can be obtained. Instance 1 and instance 2 have the same route structure, but the channels between nodes are different. In instance 2 ($v_R > v_p$), then more RF channels are selected; In instance 1 ($v_p > v_R$), then more PLC channels are selected.
5. Conclusion

PLC and RF dual-mode communication have different characteristics, which can complement each other and realize the depth and breadth coverage of power Internet of Things. According to the characteristics of PLC and RF dual-mode communication, the routing communication delay is the optimization objective function, and a routing metric algorithm of RPL routing protocol is proposed. The RPL protocol is applied to the dual-mode communication power Internet of Things. Experiments show that the proposed method has higher communication efficiency and can meet the needs of dual-mode communication hybrid networking and operation. The method proposed in this paper can apply IPv6 to PLC and RF dual-mode communication in power Internet of Things, which has high application value.

6. Acknowledgments

This research was supported by State Grid Headquarters Technology Project (No. 1100-201919158A-0-0-00).

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