The traffic performance analysis of wireless broadband communication in electricity system

Xiaoke Tang1, Rui Wang1, Yubo Wang1, Dongyan Zhao1, Xu Zhao1, Yubing Zhang1

1 State Grid Laboratory of Power Industrial Chip Design and Analysis Technology
Beijing Smart-Chip Microelectronics Technology Co., Ltd
Beijing 100192, China

E-mail: tangxiaoke@sgitg.sgcc.com.cn

Abstract. HPLC (high speed power line carrier) is widely used in electricity information collection, but because of the large variation of attenuation of power line channel, in some environment, it needs wireless communication as supplement router, the current wireless technology, such as LORA, NB-IOT are for narrowband and can’t be used to form a hybrid network with HPLC. So wireless broadband communication in electric system need to be studied. In this paper, we evaluate three types of electric traffic under wireless broadband communication with the reference of HPLC standard because there is not an approved standard about wireless broadband communication for electric system currently.

1. Introduction
HPLC is a standard for high data rate power line carrier system which can bear traffic with high data rate, but in some scene, it can’t work because of the large variation of attenuation of power line channel which is obviously affected by the wiring environment of power line.

Wireless broadband communication can be used as a supplementary router for HPLC and form a hybrid network with HPLC. But, at present, there is not an approved standard about wireless broadband communication in electric system, so we can make some performance evaluation of wireless system with the reference of HPLC standard, the frame format and the processing of data transmitting and receiving can employ the HPLC standard, the frequency, bandwidth, transmitting power and data rate need to be changed according to the wireless system.

In this paper, first, we introduce the MAC layer of HPLC standard, it mainly includes the processing of data transmitting and receiving and the algorithm of CSMA-CA (carrier sensing multiple access-collision avoidance). Then, we give the modelling method of wireless broadband communication system with network simulation software Ns3. We make some simplification and modification of the HPLC standard in order to evaluate wireless system. A beacon period is only composed of beacon slots and CSMA-CA slots, the beacon slot number is reserved according to the node number of the network. We evaluate three kinds of electric traffic and the performance, such as drop data rate and average time delay are analysed.

2. Related works
The beacon frame format and the processing of data transmitting and receiving of HPLC standard is based on IEEE 802.15.4, IEEE 802.15.4 is the most popular and widely used technology of WSN (wireless sensor network). The performance analysis of IEEE 802.15.4 MAC protocol has been
studied by many researchers. In [1], the studies show that choosing an optimum packet size helps to improve the performance of the network by increasing the PDR and reducing the latency, but the nodes were regularly placed in a rectangle with fixed space between columns and rows, the source nodes and proxy nodes were set beforehand, the source nodes will generate traffic and the proxy nodes only forward traffic, which may not be the case in practical scenarios. In [2], the purpose of distinguishing QoS is achieved by setting different BE (binary exponent) parameters of CSMA-CA, but, in HPLC, the TDMA slot and the binding CSMA-CA slot is dedicated to those traffic with higher priority. And there are only two nodes in this simulation, it’s not a typical scenario. In [4], the studies show the data frame received with the variation of transmitting nodes number and packet size and the parameters of CSMA-CA, but the topology of the simulation is star topology.

In this paper, we simulate the cluster topology of electric network, the nodes in the network is randomly placed, parent-to-child relation is set during the formation of network before traffic starts, we analyse three typical traffic model in electric network: electricity information collection, active report of blackout event, control signaling of network maintenance.

3. CSMA-CA Overview

In the HPLC standard, a beacon period is divided into four parts, beacon slots which is used for the transmission of beacon, TDMA slots which is reserved for traffic with lower end to end time delay requirement, CSMA-CA slots can be occupied by nodes contention (including binding CSMA slots).

![Beacon period diagram](image)

Packet collision means that more than one nodes want to transmit data simultaneously, and they choose the same backoff time. After collision, the node will retransmit the packet until the transmission is successful. The data transmitted in CSMA slots can’t across the CSMA slots boundary.

VCS (virtual carrier sensing) mechanism is implemented in HPLC standard, which is an important part of the CSMA-CA. The VCS timer can be considered as a counter that counts down to zero. The maximum counter value is the transmission time required by a MPDU, which is the time the channel will be busy. At the start of transmission of a MPDU, the counter value is set to MPDU length. A non-zero value indicates that the channel is busy, and so no node contends for it. When the counter value decreases to 0, it indicates that the channel is free and the other nodes can contend for it.

Without VCS counter, the nodes need to repeatedly check whether the channel is free, a task that consumes considerable power. However, when VCS counter is used, in the period with non-zero counter value, no carrier sensing is done by any of the nodes in the network. Thus, energy conservation is achieved.
Figure 2 The flow of CSMA-CA in HPLC.

The processing of CSMA-CA is implemented as follows:

a) When the traffic starts, first, the nodes will check whether the channel is idle or busy, if the channel is idle, in order to avoid collision among nodes which all detect channel idle, step into c) to do random binary exponent backoff; if the channel is busy, step into b) to do VCS backoff.

b) When the VCS counter decreases to 0, if the time across CSMA slot boundary, step into d); if the time don’t across CSMA slot boundary, the node need to check the channel again, if the channel is idle, step into c) to do random binary exponent backoff, otherwise, return to b) do another VCS backoff.

c) When the random binary exponent backoff counter decreases to 0, if the time across CSMA-CA slot boundary, step into d); if the time don’t across CSMA slot boundary, the node need to check the channel again, if the channel is idle, node can transmit data, otherwise, return to b) do another VCS backoff.

d) During the backoff, if time across CSMA-CA slot boundary, then wait until next beacon period.

The flow of random binary exponent backoff is described as follows:
NB refers to the number of backoff, and is initialized to 0 when the CSMA/CA algorithm is first called. The value of NB adds 1 when the channel access fails each time, and then retries the channel access and sends packet. When the value of NB exceeds the threshold MaxNB predefined by the system, the CSMA/CA algorithm declares a failure and discards the packet. UnitbackoffPeriod refers to the unit backoff time. The BE refers to the binary exponent backoff, and shows the upper limit of random backoff range when the channel competition occurs. The BE is initialized to macMinBE. The random backoff time is shown in the following equation.

\[
\text{Delay} = \text{UnitBackoffPeriod} \times \text{rand}[0, (2^{BE} - 1)] + \text{PE} \tag{1}
\]

a) NB is initialized to 0, BE is initialized to MinBE, PE is initialized according to the priority of traffic.

b) Set backoff timer according to (1), step into c)

c) When the backoff timer is decreased to 0, the node will check the channel state, if the channel is idle, step into d), otherwise, step into e).

d) the MAC sublayer starts to transmit MPDU, if the transmission is successful, the transmission process ends, otherwise, step into e).

e) both NB and BE are increased by 1 (ensure that BE does not exceed MaxBE). If NB is less than or equal to MaxNB, the CSMA/CA algorithm will return to b). If NB is greater than MaxNB, the CSMA/CA algorithm will terminate and return the state of channel access failure.

Figure 3 The flow of random binary exponent backoff.
4. Data Processing

4.1. Transmission and forwarding of data
In HPLC standard, unicast and broadcast are employed to limit the range of packet forwarding. Unicast packet means the destination address is designated when the packet is transmitted, the node will not process the packet if it’s address is not the destination address. Broadcast packet means all the nodes received the packet must process the packet.

Broadcast packet are classified into local broadcasting which don’t need to be forwarded after the node receiving the packet, proxy broadcasting and whole network broadcasting which need to be forwarded after receiving the packet, for packet need to be forwarded, the node need to decide the direction of packet forwarding, for uplink forwarding packet, the destination nodes are those nodes located in uplink direction of source node, for downlink forwarding packet, the destination nodes are all the nodes in the network.

4.2. Packet filtering
During the process of forwarding, the node need to judge whether the packet has been transmitted before, packet can’t be forwarded repeatedly. Just as show in Figure 4, for Node2, it will receive MAC0 twice, one is from Node0 and one is from Node1, for the second time it receives MAC0, it doesn’t need forward the packet again.

4.3. Retransmission
The packets will indicate the destination node whether the packets need an acknowledgment, after receiving the packet, the destination node will send back a ACK packet immediately, if the ACK packet don’t be received during a scheduled time or the received ACK packet is not for the source node, the packed will be retransmitted.
5. **Ns3 Modelling**
We use network simulator Ns3 to evaluate the performance of wireless communication system.

5.1. **Traffic model**
After the formation of electric network, the CSMA slot is used for bearing the control signaling during the network maintenance and power traffic, now, the major traffic in electric network are:
- electricity information collection, including the collection of electricity consumption and magnitude of voltage and current, the performance requirement of real time of this kind of traffic is not high, every node report the information once a day. We simulate this kind of traffic by generating 2 packets by every node randomly and reporting to CCO (central Coordinator) during 50 beacon period after network formation.
- control signalling of network maintenance: node need to transmit some control signalling in order to maintain the network, such as neighbour lists and router information. We simulate this kind of traffic by generating 2 packets by every node randomly and reporting to CCO during 2 minutes after network formation.
- active report of blackout event: this kind of traffic usually are burst traffic and a large scale of nodes simultaneously report to CCO in a short time, we simulate this by generating 1 packet by every node at the same time and reporting to CCO after network formation.

5.2. **Network Topology**
Electric network is multi hop cluster tree topology generally, in real scenario, the proxy node in first level is far away to the CCO but still in the communication range and other nodes are near to the proxy nodes in the first level, in the simulation, we put the CCO node in the center of a circle and set the internal radius and external radius. The internal radius is the communication range between two nodes, and the external radius is two or three times of the communication range between two nodes. other nodes are placed in the ring uniformly.

5.3. **PHY Layer**
The physical layer of wireless communication system intends to employ chirp (linear frequency modulation) and Turbo coding, the SNR-BLER curve can be acquired by link layer simulation. The curve is obtained over AWGN channel and the configurations are as follows:
- spread factor equal to 6, real channel estimation.
- The MPDU is transmitted on the channel by physical layer, the physical layer need to judge whether the MPDU across the CSMA slot boundary according to the MPDU frame duration including the preamble and frame control, it will wait until next beacon period if the frame duration beyond the CSMA slot boundary.
- The PHY only initiates packet reception for transmission with a SNR value above the SNR cut-off value, incoming transmissions which fall below the cut-off value are dropped immediately by the PHY.

5.4. **MAC Layer**
In our simulation, the beacon period is composed of beacon slots and CAMA slot, the length of beacon slot is reserved according to the total number of nodes in the network, the length of CSMA slot can be configured to different values.
- MAC layer generate the packet depend on the traffic model, the packet is put into a transmitting queue and contend for the transmission opportunity based on CSMA-CA algorithm, for packets don’t need an acknowledgement can be deleted from the queue after transmitting successfully, for packets need an acknowledgement can be deleted from the queue after receiving an ACK packet, if the ACK packet don’t be received during a scheduled time or the received ACK packet is not for the source
node, the packet will be retransmitted, if the retransmit number is greater than the MaxRetransmitNumber, then drop the packet and delete it from the transmitting queue.

MAC layer will send a ACK packet to source node immediately after receiving a packet which need an acknowledgement, then it will judge whether the received packet need to be forwarded and the forward direction. If the packet hasn’t been forwarded before, the packet will be forwarded to uplink or downlink according to it’s terminal destination.

![Figure 5 MPDU format](image)

A frame format of MPDU is described as above figure, it is made up of frame control and data load, in our simulation system bandwidth is 3.6M, the spreading factor of frame control and data load is 9 and 6 respectively. The length of beacon in our simulation is 520bytes and the beacon frame duration is 200 milliseconds.

6. Simulation Results

In our simulation, there are 50 nodes in network, one is CCO, the other are station nodes or proxy node, we simulate three kinds of traffic model, the performance merit including drop data rate and average end to end time delay, the configuration parameters are shown as follows:

| Table 1. Configuration Parameters |
|-----------------------------------|
| NodeNum | 50 | Total node number, including CCO |
| LBeacon(s) | NodeNum*0.2 | The length of beacon period |
| LCSMA(s) | 15 | The length of CSMA slot |
| PacketSize(bytes) | 72/136/264/520 | Packet size |
| MinBe | 2/3/4/5 | CSMA-CA algorithm parameter |
| MaxBe | 8 | CSMA-CA algorithm parameter |
| TransmitPower(dbm) | 20 | Transmit power |

Note: for one specific configuration, the simulation results with different random seeds are averaged

6.1. Simulation results of traffic model1

![Figure 6 Drop data rate](image)
Figure 7 Average time delay

For electricity information collection traffic, the drop data rate and average time delay are low because of the low traffic load. The drop data rate and average time delay are increased with the increment of packet size, that is because the longer the packet is, the higher the collision rate is and the longer the backoff time is.

6.2. Simulation results of traffic model2

Figure 8 Drop data rate

The length of some control signalling is long and others may be short, so we simulate all four kinds of packet size. For one specific packet size, the drop data rate is decreased with the increment of MinBe, average time delay is increased with the increment of random backoff time caused by the increment of
MinBe. For one specific MinBe, drop data rate and average time delay are both increased with the increment of packet size, the reason is that for longer packet the probability of collision is higher.

6.3. Simulation results of traffic model 3

Figure 10 Drop data rate

Figure 11 Average time delay

The traffic data is short for active report of blackout event, so in this simulation, the packet size is 72 bytes. The drop data rate and average time delay has not changed obviously with the increment of simulation time, because all the nodes in network generate packets simultaneously, the collision rate is very high and many packets are dropped because of exceeding the max retransmission number even with higher MinBe, and the average end to end time delay also increase with the increment of MinBe.

7. Conclusion

In our paper, we analyze the performance of three kinds of electricity traffic of wireless broadband communication system under cluster tree topology with Ns3 with the reference of HPLC standard, the simulation results offer important lessons for the formulate of wireless broadband communication standard for electric system.

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