The networking performance analysis of wireless broadband communication in electricity system

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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(long range radio), NB-IOT(narrow band internet of thing) are for narrowband which can not 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 the performance of networking 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 [1] 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.

At present, LORA, NB-IOT, SIGFOX and Sub1G are primary micro power wireless communication system, they are just appropriate for low rate service which can not be used to form a hybrid network with HPLC because of the low data rate (less than 100kHz) and narrow bandwidth (less than 500kHz).

It needs to make a wireless wideband communication protocol to provide supplementary router for HPLC to improve the success rate of intelligent meter reading and expand the communication range. Eventually, as the technology matures, the wireless broadband communication can be used to make a hybrid network with HPLC to further optimize the route and decrease the load of network and improve the efficiency of network building.

The frequency band between 470MHz and 510MHz can be used for wireless broadband communication system, the bandwidth can be 4MKHz,2MKHz,1MKHz,500KHz, and the highest data rate can be 200kbps.

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 procedure of nodes joining network can employ the HPLC standard. The frequency and bandwidth need to be changed according to the wireless system.

In our paper, first, we introduce the contents of MAC layer of HPLC which mainly includes the frame format of beacon and the mechanism of beacon transmission and the frame format of association...
command and the procedure of nodes joining network. Then, we give the modelling method for 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 slot and CSMA-CA slot, the beacon slot number is reserved according to the node number of the network. The frame duration of beacon and association commands employ the longest one in HPLC standard: 520bytes, the physical layer intend to employ chirp (linear frequency modulation) which is popular in WSN (wireless sensor network) and Turbo coding. We evaluate the performance of nodes joining network, such as collision rate of association commands and total time of access and the ration of proxy node

2. Related works
The beacon frame format and the processing of nodes joining network of HPLC standard is based on IEEE 802.15.4[2], IEEE 802.15.4 is the most popular and widely used core technique for WSN. The performance analysis of IEEE 802.15.4 MAC protocol has been studied by many researchers. In [3], they propose an improved association processing in 802.15.4 which can significantly reduce the duration of association procedure and evaluate the total time of nodes joining in star topology. OPNET, Ns2, Ns3 and OMNET are popular network simulation software, [4] introduce the modelling method for 802.15.4 with OPNET and give some simulation results and [5] introduce the modelling method for LORA with Ns3 and give some simulation results, but they employ the star topology, in [6], Ns2 is used to simulate the 802.15.4, but the nodes in network is placed regularly beforehand.

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 network building, the network topology may be different with the variation of parameters.

3. HPLC Overview

3.1. Beacon
The channel access mechanism of HPLC based on beacon frame (as shown in Fig. 1) which contain the slot planning information scheduled by CCO (central coordinator), such as the partition of beacon slots, TDMA slot, CSMA-CA slot and binding CSMA-CA slot. CCO will transmit beacon periodically, all the nodes in HPLC network must follow the slot planning allocated by CCO.

Beacon slot and TDMA slot are non contend slot which are allocated to a specific STA (station) node, CSMA-CA slot and binding CSMA-CA slot are contend slot which are occupied by STA nodes which have traffic by contention.

There are three types of beacon frame in HPLC: central beacon which is transmitted by CCO, proxy beacon which is transmitted by PCO (proxy coordinator) and discovering beacon which is transmitted by STA. Central beacon and proxy beacon must be transmitted every beacon period, discovering beacon must be transmitted twice every 170 second since STA nodes join the network. All the beacon frame must be transmitted in beacon slot, beacon slot is scheduled by CCO. STA and PCO transmit the beacon frame in a specific beacon slot indicated by CCO.
3.2. Networking

Nodes will join the network level by level in a cluster tree topology. STA evaluate the received beacon frames and select a proxy node according to the channel quality, the selected proxy node could be CCO or other node in network, for first level STA, the proxy node is CCO, the STA node send an association request to the CCO, CCO will allocate a terminal TEI (equipment identifier) to the STA and send back an association respond after receiving the association request, the STA will join the network successfully after receiving the association respond. That is the process of first level nodes join the network. Then first level nodes can transmit discovering beacon frame at the planned beacon slot which can trigger the new nodes around first level STA nodes to send associate request, the second level node can join the network and transmit discovering beacon frame at the planned beacon slot which can trigger the new nodes around second level STA nodes to send association request. Then, nodes will join the network level by level until nodes located in the farthest distance join the network. Every node can store the router information during the processing of joining the network, such as parent node list and children nodes list and the level number, association commands can be forwarded according to the router information. Fig. 2 shows the flow of association commands forwarding.

3.3. Association command

Association request and association respond are both transmitted in CSMA-CA slot, nodes need to get the transmission opportunity by contention, the channel can be used after collision avoidance. The transmission of association command must be finished within the CSMA-CA slot, not across the CSMA-CA slot boundary and need an acknowledgement, if the ACK packet won’t be received during a scheduled time or the received ACK packet is not for the source node, the association command will be retransmitted, if the retransmit number is greater than the MaxRetransmitNumber, then drop the command.

4. Ns3 Modelling

We use network simulator Ns3 to evaluate the performance of wireless communication system.
4.1. Network Topology

As show in Fig. 3, generally, electric network is multi hop cluster tree topology. In real scenario, the PCO in first level is far away to the CCO but still in the communication range and other nodes are near to the PCO in the first level, in the simulation, we put the CCO in the centre 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.

4.2. Propagation loss

The default propagation loss model was used in Ns3, this model named Logdistance Propagation Loss has a 3.0 exponent at a 46.6777dB reference loss at one meter

\[ R_x = 10 \times \log(p_{rx}) - n \times 10 \times \log(\frac{d}{d_0}) \]  

\( d_0 \): reference received distance is 1 meter  
\( p_{rx} \): received reference electric level is 46.6777dB  
\( n \): exponential factor default value is 3  
\( d \): communication distance between nodes(meter)  
\( R_x \): received electric level

4.3. Error model

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 spread factor equals to 6, employing real channel estimation, we can assume that the system bandwidth is 3.6MHz and transmit power is 20dbm.

We can calculate the communication distance which can meet the requirement of BLER equal to 0.01 between nodes according to the propagation loss model and SNR-BLER curve.

4.4. PHY Layer

The association command is transmitted to the channel by physical layer, the physical layer needs to judge whether the command across the CSMA-CA slot boundary according to the frame duration including the preamble and frame control, it will drop the command 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.
if collision happens, the packets also need to be dropped even the packet’s SNR is higher than the threshold.

Apart from the transmission and reception modeling, the PHY layer also implements a state machine to structure it’s execution flow, there are five states as show in Fig. 4, the transition between states are mostly triggered from the MAC layer, in the PHY_RX_ON and PHY_TX_ON states, the PHY is ready to respectively start a packet reception or transmission. In the PHY_RX_BUSY state, the PHY is busy receiving a transmission, in the PHY_TX_BUSY state, the PHY is sending a transmission. The PHY is in the PHY_IDLE state at the initialization and is in the PHY_RX_ON state for the majority of the time.

The PHY shall provide the capability to perform CCA (clear channel assessment), CCA shall report a busy medium upon detecting any energy above the ED threshold.

4.5. MAC Layer

MAC layer functionality includes the generation, transmission, forwarding and parse of association commands and beacon frame.

There are four state in MAC layer, the transition between states are shown as follows:
state will turn into MAC_SENDING if the CSMA-CA module return CHANNEL_IDLE, otherwise the state will turn into MAC_IDLE. Beacon frame is transmitted on the beacon slot, so the state can be turned into MAC_SENDING from MAC_IDLE without contention. For data need an acknowledgement, the state will turn into MAC_PENDING after the data packet is transmitted, then it will wait for the ACK packet, if the ACK packet is received in scheduled time or the retransmission number is greater than the MaxRetransmitNumber, the state turns into MAC_IDLE, otherwise, the state turns into MAC_CSMA, prepare for the contention for retransmission. For data don’t need an acknowledgement or beacon frame, the state will turn into MAC_IDLE after transmission. The MAC state also trigger the PHY state, in MAC_CSMA and MAC_PENDING state, the PHY_RX_ON state is triggered to do clear channel detection and prepare to receive the ACK, in MAC_SENDING state, the PHY_TX_ON state is triggered to send the packet.

In our simulation, the beacon period is composed of beacon slots and CAMA-CA slot, the length of beacon slot is reserved according to the total number of nodes in the network, all the nodes join the network will transmit beacon frame every beacon period, and the beacon slots were occupied in the sequence of nodes joining the network. The length of CSMA-CA slot can be configured to different values.

Association request is initiated by STA node not joining the network, the terminal destination address is CCO, the PCO selected by the STA node will select the next hop according to the stored router information, then the association request will be forwarded until it reaches the CCO. CCO will generate association respond when it receives an association request, the terminal address is the STA which send the association request, CCO will select next hop according to the stored router information, then the association respond will be forwarded until it reaches the STA, if the STA received the command successfully, then it join the network.

MAC layer generate the association command packet, the packet is put into a transmitting queue and contend for the transmission opportunity based on CSMA-CA algorithm, packets 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 judge whether the received packet need to be forward and the forward direction. If the packet wasn’t forwarded before, the packet will be forward to uplink or downlink according to its terminal destination address.

A frame format of MPDU is described as Fig. 6, it is made up of frame control and data load, system bandwidth is 3.6MHz, the spreading factor of frame control and data load is 9 and 6 respectively. The length of beacon and association command is set to 520bytes in our simulation. so the frame duration is 200 milliseconds.

![Figure 6 MPDU format](image)

### 5. Simulation Results

In our simulation, there are 50 nodes in network, one is CCO, the other are STA or PCO, we simulate the performance of networking, the performance merit including collision rate and access time and PCO ration, 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) | 10/15/20/25 | The length of CSMA slot
---|---|---
PacketSize(bytes) | 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.

**Figure 7 Network Topology**

**Fig. 7** is the network topology in our simulation, there are 50 nodes in the network, and all these nodes form a multi hop cluster topology, there are five hops in this network, the first hop with 6 nodes, the second hop with 26 nodes, the third hop with 10 nodes, the fourth hop with 4 nodes and fifth hop with 3 nodes.

**Figure 8 Collision Rate**

**Fig. 8** shows the collision rate of association commands with different MinBe, we can find that with the increment of the length of CSMA-CA slot, the collision rate is decreased because of more transmission opportunity, at a specific CSMA-CA slot length, the collision rate is decreased with the increment of MinBe because of the long back off time.
Fig. 9 shows the access time with different parameters, we can find that if the configured CAMS-CA slot length is short, such as it equals to 10s, then the access time is longer when the MinBe increased to 5. When the MinBe is small, the collision rate between other nodes is high, but the CCO can receive the association request in a short time because of the short back off time and the opportunity for CCO to send association respond is great, but when increase the MinBe, the back off time is longer and the opportunity for CCO to send association respond is fewer in a limited CSMA-CA slot, although the collision rate is lower. If the configured CSMA-CA slot is longer, then the access time will shorter with the increment of MinBe, that is because the collision rate is lower and the opportunity for CCO to send association respond is great relatively.

Fig. 10 shows the PCO ration of different parameters, we can find that the ration of PCO change little, two curves overlap when the CSMA-CA slot is equal to 20s and 25s. That is because the relation between nodes are basically decided by the location of nodes.

Fig. 11 shows that the PCO ration of different nodes changed much, the denser the nodes are, the higher the ration is.
6. Conclusion
In our paper, we analyse the performance of networking of wireless broadband communication system under cluster tree topology with Ns3 with the reference of HPLC standard, the collision rate of association commands and the access time and the PCO ration were analysed, the simulation results offer important lessons for the formulate of wireless broadband communication standard for electric system.

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