Application of 802.11ah wireless technology in Global Energy Interconnection

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Abstract. The Global Energy Interconnection (GEI) will be the foundation of future clean energy, and it has drawn great challenges for communication technology. GEI has significant need for low power-consuming, long-range, medium-rate sensing and measuring method which can't be achieved by current technology. Hence, in this article, applying 802.11ah in GEI sensing and measuring is proposed; key features in 802.11ah are introduced; the DCF mode base-band circuit is built, and the correctness is verified by experiment.

1 Introduction

The Global Energy Interconnection (GEI) is a smart grid characterized by the global interconnection and ultra-high voltage network. It delivers clean energy to the world. To form a new pattern of energy development in the power grid connectivity and global power optimization in various continents; To establish new energy production and consumption patterns featuring clean energy and high electrification[1].

2 The needs and challenges of global energy interconnection in communication technology

The concept of GEI brings new demands and challenges to communication technology.

The current challenges are: transnational grid interconnection and scheduling, remote energy base management, global clean energy trading.

We can see from the information demand of the GEI that the global demand side, dealing with cross-border transmission scheduling and remote energy base management requirements in operation, transaction and monitoring[2].

Regional demand side, focus on the domestic level, and the distribution network to clean energy allotment, energy trading system, giving full play to the advantages of wide coverage of information, interactive and convenient, to realize regional services.

The GEI will form a unified information architecture that integrates distribution and concentration, tight and loose logic to support the global energy interconnection. The overall architecture of GEI information is shown in figure 1.

Figure 1. GEI information architecture

Internet of Things (IOT) uniquely identifies equipments, connect any articles according to certain protocol and through the network, makes them exchange information and communication, realizes intelligent positioning, identifying, interaction. In the GEI, the research on the IOT is still at progress, the standard is not accomplished, some key technologies are still under research.

3 The application of intelligent sensing technology in energy Interconnection

The communication between equipments is pervasive in the GEI. Measurement monitoring is the basis of GEI operation, which reflects the overall performance of it.

The IOT sensors used for power grid have been extensively studied, such as routing protocols that can help packets avoiding congested areas, and security issues. The sensor network is the basis of intelligent measurement and perception and will be widely used in the energy interconnection. The sensor network will evolve towards self-organization, high bandwidth utilization, self-energized and low power consumption.

The main applications of intelligent sensor technology are:

(1) intelligent power Transmission and substation

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The new generation of smart substations will be widely used in the energy Interconnection to improve the level and quality of information interaction between substations. This requires the online monitoring and early warning of power transmission and transformation equipment, and through data analysis and big data process, to realize the interaction between devices, human and data, to obtain accurate perception of equipment's state, to provide support for intelligent maintenance.

(2) Intelligent distribution

The basis of intelligent decision-making and optimization of energy Interconnection is the acquisition and processing of power distribution information. This application is oriented towards improving the success rate and calculation efficiency of the distribution data acquisition. Comprehensive utilization of information acquired from all process of energy interconnection, realize the power grid and the user's real-time interaction, so as to improve the user's satisfaction, promote the lean marketing management level of power grid.

(3) Big data analysis and prediction

The application of big data analysis and prediction technology in power is mainly focused on the analysis of power load main components and the main factors that affect the power load, so as to facilitate the modeling of load prediction.

We can also see that in order to adapt to the development of the GEI, development based on IOT sensor network information acquisition, data mining, safety protection is very necessary to improve the processing speed and accuracy of huge amounts of data, it electric power dispatching and trading globally. And all of this is based on a sensor network[3].

4 wifi and 802.11

A. WiFi introduction

WiFi uses 2.4 GHz and 5 GHz band radio frequency (RF) technology, replaces the wired LAN, provides all functions of the traditional wired LAN does. It is easy to install, expand and with high mobility, strong confidentiality[4].

The 802.11 series are the standard set by IEEE for WiFi. It involves the physical enhancement technology, QoS guarantees, safety control mechanism, networking mode, network management, co-existence with other protocols, all together to build a set of WLAN standard system.

However, the existing IEEE 802.11 series have some problems as follow:

- The existing 802.11 protocol does not cover the low power consuming considerations of each network node.
- 2.4GHz and 5GHz are the two primary bands used in WiFi, but those two bands are not suitable for long-range transmission. To meet the needs of IOT, IEEE has launched the sub-1GHz 802.11ah standard develop.

802.11ah can be the protocol standard for IOT. It uses OFDM technology in the physical layer, it has enhanced

IEEE802.11 MAC layer technology to match its physical layer technology, it provides the corresponding mechanisms to support its coexistence with ZigBee or Bluetooth technology. Using the sub-1GHz band, it can be widely used in energy Interconnection, industrial automation, building automation, public environmental monitoring and other fields. The 802.11ah final standard is released in 2016. In 2018, chips and systems based on 802.11ah will be put into the market[5].

B. 802.11ah key technology

The advantages of 802.11ah are low power, long-range, massive nodes(up to 6000). This is achieved by the key technologies below:

1) Relay

IOT needs wide coverage, so 802.11ah uses relay technology. The relay is a function entity, includes relay-AP and relay-STA. On the bottom, relay connects with STA, plays as AP. On the up side, relay connects with AP, plays as a STA. In the Fig.2, relay can transfer data packets to make a wider coverage.

Figure 2. relay

2) Traffic indication map(TIM)

To reduce the power consuming, nodes will enter sleep mode. AP sends the TIM element in the beacon packet to inform the sleeping nodes whether there are buffered data for them to receive, as is illustrated in Fig.3. traditional TIM in WLAN only supports 2000 nodes, but IOT needs more, so 802.11ah uses hierarchical TIM. It slices TIM into many pages, and then many blocks for a page, and many sub-blocks for a block. AP sends these pages in the interval of beacons to support massive nodes.

Figure 3. TIM

3) Target wake time(TIM)

In order to achieve low power consumption, node needs to shut down the Tx/Rx module as much as possible to enter a sleep mode, and wake up only when there is data to send or to receive. 802.11ah uses target wake time mechanism, allowing AP to manage the wake up time of subordinate nodes, make them wake up in different time, this reduces the competition, increases

the efficiency of the system, eventually reduces the power consumption of the node.

There are two kinds of TWT: active TWT and passive TWT. In the active TWT, AP will tell the next TWT wake-up time to node in packet; And in the passive TWT, nodes need calculate the wakeup time by the TWT information obtained before.

4)Restricted access window(RAW)

To ensure low power consuming and support a large number of nodes, as well as increase the efficiency of the system at the same time, 802.11ah introduces RAW. RAW keeps the nodes into different groups, and make them transmit signal in specified time period. This makes sure each node have equal chance to transmit, and reduces conflicts, improves the system efficiency.

In the Access stage, the STA wakes up in the specified time, and began to listen to beacon frames, which will carry the RAW information, such as start time, time duration, the number of time slots, and which RAW will the node be assigned to. After receiving such information, STA will know the access time allotted by AP, and before this time the STA enters sleep mode. When the access time arrives, STA wakes up for channel access. As shown in Fig.4, the STA enters sleep mode in the first 4 slots, wakes up for data transmission in the fifth slot.

Figure 4. RAW

5 implementation of 802.11ah

A. architecture of the implementation

This article realizes the 802.11 baseband system, as shown in Fig.5. The main device is XILINX ZYNQ7000 FPGA. The parameters of this FPGA is below:

- 36kb dual-port RAM, 72bit wide maximum, can be configured as two 18kb RAM.
- 18x25 multiply operation, 48 bit adder/accumulator. 25 bit pre-adder.
- 16 transceivers maximum, speed up to 12.5Gb/s.
- 350k logic elements, 218600 look up tables, 437200 F-Fs, 19.1Mb RAM, 900 DSP blocks, supports AES and SHA 256.

Figure 5 baseband circuit

The architecture of software and hardware is Fig.6 and Fig.7.

Figure 6. software

Figure 7. hardware

The physical layer is shown in Fig.8, there are OFDM Tx, OFDM Rx, and AGC in the physical layer.

Figure 8. physical layer

The specifications of the PHY are:

- Clock frequency: 160MHz.
- Bandwidth : 10MHz,20MHz.
- OFDM format: 64 sub-carrier,16-sample cyclic prefix.
- Frame Format: As specified in 802.11ah, SIGNAL field as first OFDM symbol
- Data rate: Each data rate is realized for every MCS.

The architecture of the receiver and transmitter of FPGA core is illustrated in Fig.9 and Fig.10. The packet detection module implements two packet detection schemes: simple energy detection based on RSSI and auto-correlation of the I/Q samples searching for the preamble STS. The antenna selection is automatic. A dual-port circular sample buffer records all incoming samples. A complex channel coefficient is calculated for each non-zero subcarrier to estimate channels. The de-interleaved soft values are decoded using a standard Viterbi decoder.

Figure 9. receiver

Figure 10. transmitter

B. Experiment and conclusions

An experiment is carried for DCF mode bi-directional communication, as is shown in Fig.11. A 802.11ah network is formed with 3 nodes, 1 for AP and 2 for STA. The characteristics of this experiment is below:

- Packet Length: 1400 byte payloads (1428 byte MPDUs, with MAC header and FCS).
- PHY Rate: 18 Mbps (QPSK, code rate 3/4).
- Tx Power: -10 dBm.
- Trial Duration: 300 seconds.
- 2.4GHz channel 1.
- Physical Carrier Sensing Threshold: approximately -70 dBm, when enabled.

Figure 11. experiment placement

We use 4 traffic flows in our experiments, as is shown in Fig.12

Figure 12. traffic flow

The experiments framework include a flexible logging system that runs in real-time at every node. This system keeps a record of every Tx and Rx event at the node. For Tx events the log includes both the high-level MPDU Tx (as implemented in CPU High) and the low-level PHY Tx events for each MPDU. Each low-level Tx record includes the timestamp of the actual PHY transmission plus MAC parameters for the transmission (number of backoff slots, current contention window, re-transmission count, etc.). By retrieving the logs from every node following the experiment and analyzing them together, we can gain significant understanding of the behaviors of the nodes and how various parameters impact performance on short and long timescales.

Fig.13 and Fig.14 plots the received power of every packet for each node, grouped by traffic flow. These plots clearly demonstrate the low-mobility, mid-to-high SNR propagation environment for our experiments. And, as expected, the physical carrier sensing threshold has no substantial impact on Rx power.

Figure 13. physical carrier sensing enabled

Figure 14. physical carrier sensing disabled

Fig.15 and Fig.16 show the throughput of each flow as a function of time. Each throughput curve is computed as a 1 second rolling window of bits received by each node for each flow. This 1 second window is rolled over the full 300 second log in steps of 1 msec.

Figure 15. physical carrier sensing enabled

Figure 16. physical carrier sensing disabled

The 802.11 DCF contention window determines the distribution of available slot counts when selecting a random back-off period. The contention window grows with each failed attempt to transmit a packet. The contention window growth is exponential, starting at a width of 16 and doubling with each re-transmission, up to a maximum width of 1024. Ideally a node's contention window would never increase from 15. In reality packet collisions and losses require re-transmissions, leading to inevitable contention window increases. The contention window resets to its minimum following a successful transmission.

Fig.17 and Fig.18 show the actual contention window value of every node at the time of every PHY transmission. Note, the same rolling average technique used in the above throughput graphs is being employed here. The impact of physical carrier sensing on contention windows is dramatic. As explained above, more collisions lead to more transmission failures, leading to higher expected contention window values, resulting in longer back-off periods and lower throughput.

Figure 17. physical carrier sensing enabled

Figure 18. physical carrier sensing disabled

6 summary

As a new kind of WiFi technology, 802.11ah will be widely used in the field of GEI and IOT for data acquisition. This paper realizes the MAC protocol in 802.11ah using FPGA hardware platform, which is a bi-directional communication. The result is exactly the same as specified in the 802.11 ah standard.

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