Analysis and Application of Carrier Aggregation Technology in Wireless Communications

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Abstract—**Carrier aggregation is a key technology in the LTE-A. Carrier aggregation can be achieved within the same frequency bands continuous carrier aggregate, non-continuous carrier aggregation and different frequency bands within the carrier aggregation. It analyses the two implementations of carrier aggregation: MAC layer aggregation and physical layer aggregate. Combined with demand for power applications, the carrier aggregation HARQ hybrid scheduling control policy is applied, then proposes subcarrier allocation method of the 230MHz band. It can realize the 230MHz frequency band wireless communication system by using carrier aggregation and spectrum-sensing technology. And then completed functional testing in laboratory. It validates that the system does not affect the original 230MHz radio at work.**

Keywords-LTE-A; carrier aggregation ; spectrum sensing; 230MHz frequency; smart grid

I. INTRODUCTION

Smart Grid is built on an integrated, high-speed, bi-directional communications network. It supports system applications by using advanced sensing and measurement techniques, advanced equipment, advanced control methods, and advanced assistant decision. With the construction of the smart grid, it applies high capacity, extra-high voltage (EHV) and a variety of new power electronic components. The electric equipment interconnected will be more large-scale, a huge number, wide variety and widely distributed. What is means of communication can be used for data acquisition and control of these power facilities? It is always an important research topic in the field of electric power communication. Especially in the field of transmission and distribution, the optical fiber communication network coverage is lower. The wireless technology is useful for intelligent monitoring and protection of electric equipment, line and tower, real-time dynamic smart metering, intelligent interaction between power grids with the user. However, the smart grid construction requires monitoring the large number of power nodes. The wireless systems can provide sufficient communication bandwidth. A major means to improve the bandwidth of the wireless system is using the wider spectrum resources. Currently, the State Radio Regulatory Commission allocated 10 simplex frequency points and 15 duplex frequency points for the power system in the 223-231Mhz. The interval is 7MHz bandwidth between sending and receiving. But each working frequency bandwidth is small. It is only about tens of kHz. It can’t meet the high bandwidth communications needs of the smart grid.

In the field of mobile communications, mobile broadband users are growing quickly. The higher peak rate is required for multimedia services and video on demand(VOD) services. In order to meet the challenges of broadband access and the demand for new wireless services, LTE-Advanced (Long Term Evolution) is the evolution technology of the 3G system by 3GPP. The 3GPP proposes LTE-A system key technical indicators[1]. In LTE-A system, the minimum bandwidth is 20MHz, the maximum bandwidth is 100MHz. The downlink peak rate supported in LTE-A is 1Gbit/s, the uplink peak rate is 500Mbit/s. The downlink peak spectrum efficiency is up to 30bit/s/Hz and the uplink is up to 15bit/s/Hz in LTE-A. In system capacity, LTE-A requires to support 200 to 300 concurrent users within each 5M bandwidth. LTE-A delay control is more stringent. The latency of control layer from the transition status to the idle in the connection is lower than 50ms, the latency of conversion from dormant status to the connection is lower than 10 ms; The delay of user level in the FDD mode is less than 5ms, the delay in the TDD mode is less than 10ms.

The potential bands of LTE-A comprise the 450~470MHz, 698~862MHz, 790~862MHz, 2.3~2.4GHz, 3.4~4.2GHz, 4.4~4.99GHz, etc. The system maximum bandwidth supports 100MHz. But it is difficult to find such a wide continuous spectrum, so LTA-A proposes the carrier aggregation (CA) technology [2].This technology can combination multiple discrete spectrum and use them together.

II. THE PRINCIPLE OF CARRIER AGGREGATION

The carrier aggregation technology can aggregate multiple discrete or continuous small sub-band to support higher bandwidth transmission. Among them, each band aggregated is called the component carrier. LTE-A supports continuous carrier aggregation, non-continuous carrier aggregation between same bands or different bands. It can support a

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maximum bandwidth of 100MHz.Terminal of the LTE-A system can normally access one of the carrier, also can receive the services of multiple carriers. Non-continuous carrier aggregation is also called spectrum aggregation. There are three main scenarios of carrier aggregation[3] .

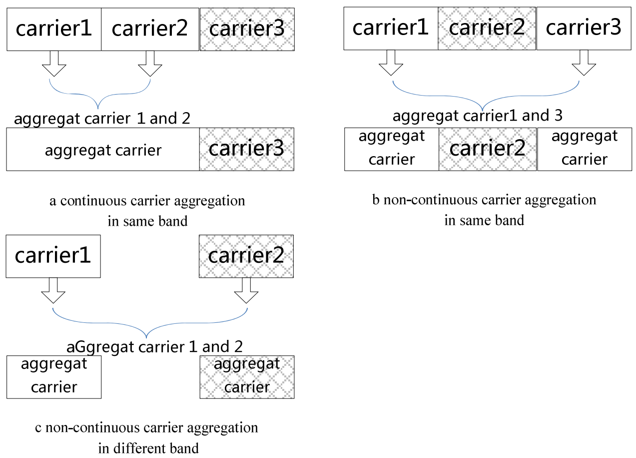


Fig.1 carrier aggregation principle

If the terminal uses carrier aggregation in the current communications, we hope that the terminal is still supporting the carrier aggregation in the switching process and after the switch. It is simple and easy to maintain continuity of the carrier aggregation in the same bands for process of switching and switched. But it may be very complicated in different frequency bands. Therefore, in order to achieve switch easily, the carrier aggregation may only be considered in the same band and the same base station (eNodeB) by 3GPP.

The bandwidth requirements of uplink and downlink are different in LTE-A FDD system. The peak rate requirements of uplink and downlink are different also. The number of aggregation carriers may not be the same in uplink and downlink .The number of carriers is different. It can support asymmetric business of the uplink and downlink[4]. Figure 2 is a reference model of symmetric and asymmetric carrier aggregation in LTE-A system.

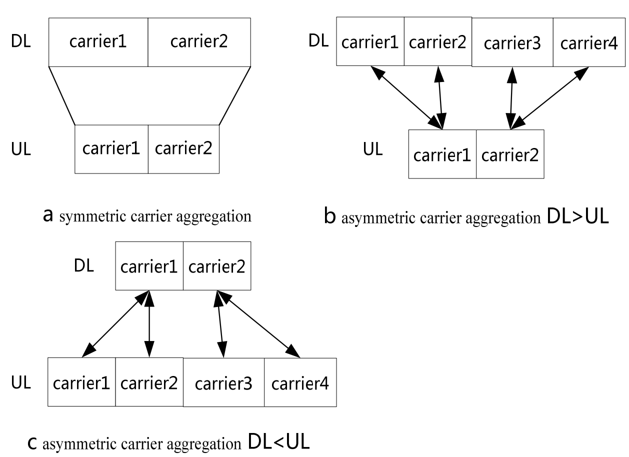


Fig.2 symmetrical carrier or non-symmetrical carrier reference model

Comparing the above two polymerization, the method using asymmetric carrier aggregation can get a higher peak rates, lower peak-to-average ratio. It can reduce the control channel and meet the diversity of users and other advantages. It is also more in line with the actual application requirements. In addition, when using the carrier aggregation, it doesn't consider only the aggregate 20 MHz sub-carrier, it can also be considered the aggregation of other bandwidth carrier. Different bandwidth of the sub-carrier can have a variety of combinations to meet the requirements of the carrier aggregate bandwidth. But in order to reduce complexity of transceiver design, we limit the carrier type number. It can be used to regulate the aggregate carrier combination. For example, in the 2 numbers of carriers case, if you need to 30MHz bandwidth, we only need one 20MHz sub-carrier and one 10MHz sub-carrier combination. The combination of 20MHz and two 5MHz subcarriers will not appear. On the basis of meeting the aggregate bandwidth demand, the way that restrictions the carrier types can limit the number of aggregate carrier, it greatly reduces the complexity of the transceiver design.

III. CARRIER AGGREGATION SCHEME

In LTE-A system, each subcarrier corresponds to an independent data stream. According the layer of aggregate, the aggregate spectrum can be separated into two types: Option A, sub-carrier data stream aggregated at the MAC layer; Option B, the sub-carrier data stream aggregated at the physical layer[5-6]. Shown in Figure 3:

Option A, each sub-carrier occupies an independent transmission block. So each sub-carrier can be based on the actual link state to use a separate link adaptation techniques, use different modulation and coding scheme, has different bit rate, etc. Each sub-carrier has independent HARQ (hybrid automatic repeat request) process and the corresponding ACK (positive acknowledgment) / NACK (negative acknowledgment) feedback. Each RLC (Radio Link Control) entity can use PDU which defined in the LTE system. It can reuse the structure and design of LTE. The changes in the Layer2 are small. It continue to follow the design of the physical layer, such as data block and buffer size, mathematical algorithms, and the operation of the software and hardware can be reused.

In option B, all sub-carriers share a transmission block. They use the same transmission level, the same modulation and coding, the same bit rate for the all sub-carriers. Since all sub-carriers use the same transmission block, it need to redesign the physical layer standard，such as the control channel format, need to redesign the size of the PDU in the RLC layer. All sub-carriers share one HARQ process and the corresponding ACK / NACK feedback. It will conflict with physical layer, MAC layer, RLC layer structure of the original LTE system. It needs to redesign the PDU size of RLC. It will reduce the HARQ efficiency when the transmission block contains too much data.

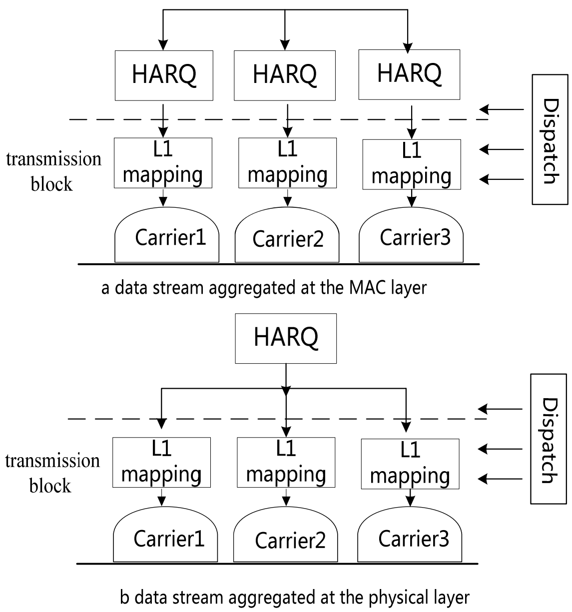


Fig.3 sub-carrier aggregation project

Two options, Option A can reuse the structure and design of the LTE system, each carrier has a separate link adaptation process. In the case of aggregate inter-band sub-carriers, the effects that each carrier used the effect of link adaptation techniques are obvious. Option A physical layer, MAC layer and RLC layer are identical with LTE systems, it has good backward compatibility, and thus can support the LTE system hardware and software equipment. Option B, due to all sub-carriers share a transmission block transfer, the transmission block contains too much data, the efficiency using HARQ becomes low, or even totally unsuitable for the use of HARQ. Option B is not compatible with the LTE system, also need to redesign the physical layer, MAC layer, RLC layer. By comparison, we can see that Option A is easier to achieve a smooth evolution from LTE to the LTE-A. Therefore, Option A is more suitable to carry out follow-up study.

HARQ is a key technology in the aggregate carrier scheduling, it combines effectively two kinds of basic error control method: the FEC (forward error correction) and the ARQ (automatic re-peat request).It provides higher reliability and throughput of the system. Retransmission on the downlink supports asynchronous mode, and retransmission in the uplink supports synchronous mode. The retransmission of HARQ is based on the ACK, NACK, HARQ ACK, HARQ NACK return, It uses on 1-bit signal to do fast and frequently return, rather than the past return ARQ packet (such as the status report). FEC can be used to correct the error pattern often happened, and to reduce the number of retransmissions. In the HARQ way, the code sending by originator not only use to detect errors, but also has a certain degree of error correction ability. Receiving end decoder check errors firstly when it receives a code word. If it is within the error correction capability, it completes the correction automatically. If it is out of the error correction capability, the error can be detected. The receiver send a judgment signal to the sender through the feedback channel. It requires the sender re-sending the error packets. Depending on the retransmission of the contents of hybrid automatic retransmission mechanism, HARQ is separated into three categories: I-type of HARQ, type II HARQ and Type III of HARQ. In I-type HARQ, the transmitter send a new packet while the receiver decoding error occurs, the feedback NACK to the transmitter requires retransmission, the transmitter receives a request and then send the same packet, the receiver merges multiple retransmission of packets. II-Type and III-Type HARQ scheme is incremental redundancy (IR) mechanism, the error packet received will not be discarded. When retransmission, the sender will send a new check bits, the receiver will be stored and decode the subsequent retransmission of the data after the merger.

IV. POLICY APPLIED OF CARRIER AGGREGATE IN POWER

With the deepening of China's smart grid construction work, especially in the power transmission condition monitoring and distribution automation, the use of wireless systems for information collection and data transmission is proposed, and has a good attempt. Reference [7] uses the Mobitex technology to build the distribution wireless communication network. Mobitex is a cellular packet-switched network of dedicated data communication. Its working band is downlink 821-825MHz, uplink 866-870MHz; adjacent channel spacing is 12.5kHz.The rate of downlink and uplink are 8kbit/s, the spectrum utilization is about 0.64bit/Hz. Later, the Mobitex work band can be moved to 230MHz. But because of its low rate and capacity, it is not suitable for the communication requirements of large-capacity power terminal.

The information of power transmission condition monitoring includes the transmission line dancing, arc sag, inclination, line ice, line stress and line temperature, insulator contamination, the tower tilted, meteorological environment of line, line video, etc. The business of distribution automation includes power distribution automation, distribution transformer monitoring, power quality monitoring, the information collection, intelligent demand side management, etc. They achieve information collection and controlled among the switching station, the ring network cabinet, box-type substation, column switching, column transformers, electricity meters and other equipment. It is estimated that the systems of distribution automation and distribution transformer monitoring require 803kbps bandwidth. The system of distribution monitoring and controlling requires about 2480kbps bandwidth, it will up to 4536kbps coupled with the visualization of business needs. According to calculate 3.7 of the average spectral efficiency of LTE-A system, wireless systems need to occupy at least about 1.2MHz spectrum resources.

About the 230MHz band of power, the signal transmission distance is far, the ability of diffraction is better. It can realize a wide range of high-quality wireless coverage combined with efficient terminal-launch technology and high-sensitivity receiver. It is a valuable resource in the power system. However, in the 230MHz frequency range, there have been carried out more narrowband wireless communication services, such as power load management system occupied 15 pairs of pairs frequency and 10 single frequency from 223 MHz to 231 MHz. It is difficult to find a 1.2MHz bandwidth available continuous spectrum in the 230MHz band. Combined with the spectrum sensing technology, polymerization technique described in this paper can be used to build the 230MHz power wireless communication systems. It can avoid automatically the carrier that has been occupied.

The 230MHz power wireless communication system occupies 1.4MHz spectrum bandwidth. The whole band of 223-231Mhz can be divided into seven bands. It facilitates to build the networking of wireless systems. One base station works in a band. The 1.4MHz spectrum is divided into 512 sub-carriers, each sub-carrier bandwidth is 2.8kHz. When the interference of the environment is lower, the spectrum resources can occupy 8MHz spectrum bandwidth. Then the 8MHz of spectrum is divided into 1024 sub-carriers, each subcarrier bandwidth is 8kHz.

Each subcarrier is small, It is different with LTE-A system. In order to improve the carrier carrying data capacity, and improve the frequency efficiency, we must reduce the overhead of each subcarrier signal control. Considering the reusability of existing LTE technology, the carrier aggregation uses hybrid method of data stream aggregated both at the MAC layer and the physical layer. Wireless systems can provide communications services for multiple users, each user can occupy a different numbers of sub-carrier. The sub-carrier aggregation of same user aggregated the data stream at the physical layer. The subcarriers of the same user share a transmission block. The transmission block contains more valid data and less overhead, it will help improve the spectral efficiency. The sub-carrier aggregation of different users aggregated the data stream at the MAC layer. Each user use independent transmission block, it is helpful to modulate individually for each user, and also to control HARQ dispatch between users.

Each user can occupy different numbers of sub-band, and you can use different modulation methods. The method of each user's data transmission mapping to the sub-carriers has two kinds: distributed occupation of multiple sub-band transmission and centralized occupation of multiple sub-band transmission. Shown in Fig.4.

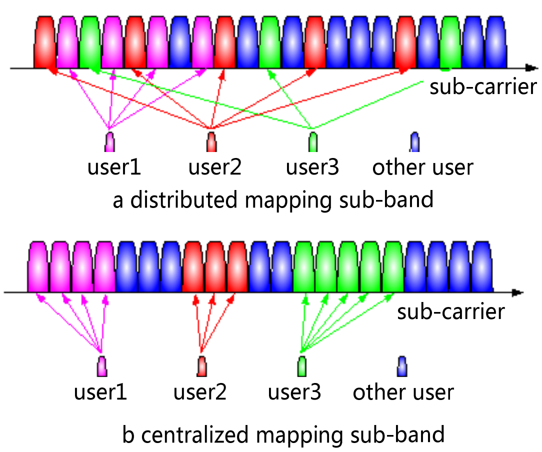


Fig.4 sub-band mapping method

In the distributed mapping sub-band mode, the user's data symbols occupy more than one sub-band dispersedly, the sub-band is distributed by equivalent interval in all sub-band. The numbers of sub-band occupied by different user and different interval between sub-bands are different. The sub-band distribution is shown in Figure 4-a. The user can obtain higher frequency diversity gain by reusing the distributed sub-band.

In the centralized mapping sub-band mode, the user's data symbols concentrated occupied more than one sub-band, the sub-band continuously distribute in all sub-band. The numbers of sub-band occupied by different user can be different. The sub-band distribution is shown in Figure 4-b. The user gets better performance of anti-multi-user interference by reusing the centralized sub-band.

V. APPLICATION EFFECTS

We implement the wireless system by using above techniques, and test the function in the laboratory. The test method is shown in Fig.5.

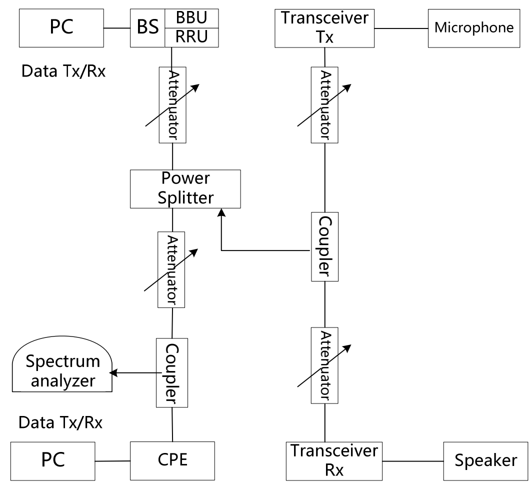
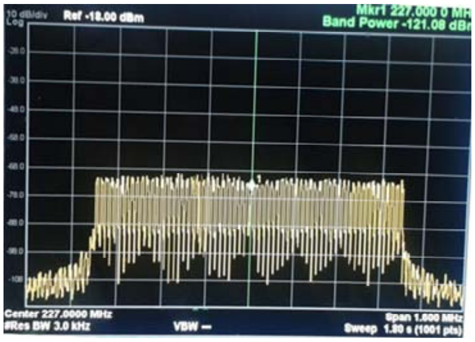
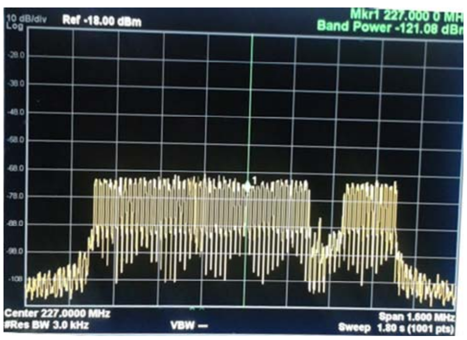


Fig.5 the test system structure

The wireless system consists of base station unit (BS) and user terminal equipment (CPE), where BS is divided into two parts of the indoor part (the BBU) and the outdoor part (the RRU). BBU is responsible for baseband processing in wireless communications, control signaling, spectrum sensing. The RRU includes radio frequency unit(RF), antenna system, it is responsible for the wireless signal transceiver which is analog front-end part of the system. The CPE is equipped with a standard ethernet port, USB port and RS232 port. It connects with the user equipment, carries wireless data transmission. The connection between BBU and RRU is fiber, the connection between RRU and CPE is radio. But because the test is in the laboratory, we use cable to connect the RRU and CPE. In the cable, we add the attenuator to control the signal strength. At the both end of BS and CPE, we use the PC to simulate the user equipment. So the experiment is to send and receive data between the test two PCs. In order to view the work of the spectrum, spectrum analyzer is also added in the cable, which can record the real-time spectrum of working. Meanwhile, we also verify the functions that the system can automatically detect the interference spectrum, startup the conflict avoidance mechanism, automatically shut down the conflict sub-carriers. In the experimental system, we use the voice transceiver, it can simulate the interference occurrence. The test uses the 1.4MHz bandwidth. The results are shown in Fig.6.



a. the spectrum when transceiver is off



b. the spectrum when transceiver is on

Fig.6 test results

The system occupies 1.4MHz bandwidth while working, the center of spectrum is 227MHz. When the transceiver is turned off, the system occupies the entire continuous spectrum, all sub-carriers can be used. As the test result, the maximum bi-directional throughput of the single-carrier wireless system can be up to 2.46Mbps in the 1.4MHz bandwidth mode. The maximum bi-directional throughput can be up to 20.16Mbps in the 8MHz bandwidth mode. The center frequency of the transceiver is near 227.4MHz, the bandwidth is 200kHz. When the transceiver is turned on, the system automatically detects the presence of interference spectrum. It automatically start the avoidance mechanism, the 72 sub-carriers centered of 227.4MHz are disable. The system automatically avoids 200kHz spectrum near the center 227.4MHz. It is shown in Fig.6.(b). The two PCs can communicate normally with each after the system adjusted. At the same time, the voice communication is also normal through the transceiver between microphone and speaker. It verifies that the system does not have any impact on the original 230MHz radio at work.

VI. Conclusions

In the 230MHz band of power, the signal transmission distance is far, the ability of diffraction is better. Although this band exist other traditional 230MHz wireless system, we can still provide a high-bandwidth wireless communication system for power by using spectrum sensing and carrier aggregation technology. With the gradual deepening of the construction process of the smart grid, the numbers of monitoring points needed communication are more and more, they are scattered more widely. The wireless communication systems based on carrier aggregation will be the rapid development and application.

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