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Integration and Connection Test for OpenAirInterface 5G Standalone System

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***Abstract*—In order to measure the transmission performance of real 5G SA communication system, this paper completed the integration and connection test of 5G SA system based on OAI platform and universal software radio peripheral USRP. OAI wireless technology platform is an open source communication platform for open LTE and NR systems. It is committed to the realization of open source 5G NR. This paper introduces how to build 5G NR SA system based on OAI platform in detail, including the structure and principle of 5G NR SA system and the code architecture of OAI platform. Describes the installation and configuration of the 5GC core network, base station gNB, and the user terminal UE. In addition, a variety of user access scenarios including computer terminals and commercial terminals are further tested and implemented. At the same time, the laboratory test results show that the established 5G NR SA communication system can achieve connectivity between UEs and gNB, and maintain a relatively stable connection.**

Keywords—5G mobile communication, Standalone, OpenAirInterface, USRP

I. OAI PLATFORM INTRODUCTION

The freeze of 5G communication system protocol Release 16 marks the formal completion of the first 5G evolution version standard, and China also leads the world to enter the 5G commercial stage. However, relevant researches on 5G are still continuing in various countries and will continue for a long time. Compared with 4G, 5G in time delay, the processing ability, etc, are put forward higher requirements. The traditional software simulation method has been increasingly cannot meet the 5G communication system for the real demonstration, and the performance of wireless channel environment demand of data real-time analysis. So combined with software radio platform and generic server set up standard protocol stack has become one of the main methods of the communication system of research, and has been more and more attention from research institutions at home and abroad. OpenAirInterface (OAI) is one of the most widely used platforms [1].

OAI wireless technology platform is an open source communication platform for open LTE and NR systems, led by EURECOM and conforming to the 3GPP protocol standard. The platform is based on a universal server and a software radio front end, and its communication function is realized through a transceiver connection. OAI provides a complete 4G mobile cellular system based on open source software. It supports access to computer terminals and commercial terminals, and the source code can be modified and compiled according to different needs. At present, the platform is committed to the implementation of open source 5G NR, but there are still shortcomings in data transmission of PUCCH, PRACH and other channels, initial access to SA and other aspects, which need to be further improved.

Based on the OAI platform, it is possible to conduct research, test as well as teaching activities. In [2], a fiber fronthaul with SoftPHY OAI is proposed to achieve long distance, stability and high speed transmission. The work in [3] focuses on the end-to-end network slicing in terms of non-standalone 5G standard, and introduces mobile edge computing to reduce end-to-end delay in the URLLC slice. In [4], an open source SIMULAMET EPC Virtual Network Function is introduced as an easy way to set up a 4G/5G testbed based on OPEN SOURCE MANO and OAI. The authors of [5] discuss how to use OAI as experiments in their new course named "Next Generation Mobile Communication Techniques".

Although OAI can be applied in many cases, it is not easy to establish the platform environment and to optimize its performance. For example, the authors of [6] study on the functional acceleration improvement and structural parallelism to improve the timing of OAI platform.

In this paper, in order to facilitate future research on 5G communication system architecture and key technologies, as well as to enhance the reliability of research results by considering the impact of realistic environmental factors, the OAI-based 5G communication system is established and tested.

This paper is organized as follows. Section 2 introduces the system architecture of 5G network as well as the architecture of OAI platform. Section 3 describes the OAI-based 5G system in detail including both hardware configuration and software design. Section 4 presents and analyzes the testing results of the OAI-based system. Section 5 concludes the whole paper.

II. SYSTEM STRUCTURE AND PRINCIPLE

This section includes three parts: the structure of 5G NR SA system, the code architecture of OAI-based 5G NR SA system, and the network topology of the laboratory physical environment.

A. Structure of 5G NR SA system

5G NR SA system is different from LTE system and 5G

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NSA system. It adopts 5G base station gNB and 5G core network 5GC. The reference model of the system network architecture of 5G SA is shown in Fig. 1.

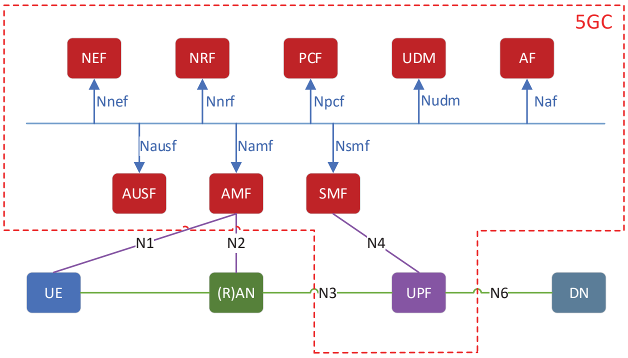

Fig. 1. Reference model of 5G SA network architecture.

The 5GC realizes the control and user plane separation, and the control plane adopts service-based architecture. In [7], there are some network functions in control plane, such as Access and Mobility Management function (AMF), Session Management function (SMF), Authentication Server function (AUSF), Unified Data Management (UDM), Policy Control function (PCF), Network Repository function (NRF), Network Exposure Function (NEF). And User Plane Function (UPF) is involved in user plane.

As for 5G RAN, gNB uses direct way to connect with 5GC in [8]. The base station architecture is bounded by PDCP/RLC layer, which divides gNB into two functional entities: centralized unit (CU) and distributed unit (DU). CU is responsible for RRC/PDCP layer functions, and DU is responsible for RLC/MAC/PHY functions. A CU can carry multiple DUs.

B. Code architecture of OAI-based 5G NR SA system

System source code is mainly divided into two parts: 5GC and RAN. Among them, cn5g code project is the software implementation of 5GC; openairinterface5G code project is the software implementation of RAN. Its overall architecture can be summarized as Fig. 2 shown.

The cn5g project mainly implements four NFs, such as AMF, SMF, UDM, and UPF, which are also divided into four code repositories. The details of each part are described below.

- AMF. The project includes the common definition for 3GPP specifications, RAN CP interface (N2), NAS (N1) terminal and curl HTTP client, the construction of SCTP and the security authentication. AMF implements registration management, connection management, flow management, and access authentication.

- SMF. The project includes the relevant definitions in 3GPP protocol, NAS/NGAP protocol, generic PFCP stack, UDP service. It achieves session establishment, modification, release and other functions. At the same time, SMF manages the session context with the UPF.

- UDM. Its projects include basic definitions in standard protocols as well as 5G-AKA authentication procedures for user identification processing and related subscription services.

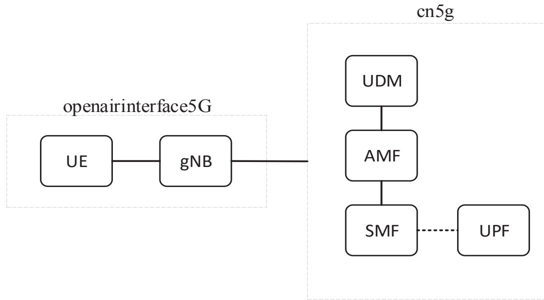

Fig. 2. Software architecture of OAI platform

- UPF. In terms of architecture, it includes two major parts, VPP and Iptables, and four network ports. The N4 interface between UPF and SMF is configured to check data packets, detect applications based on service data flow templates, and receive an optional PFD from SMF. In addition, the end-tags are also sent and forwarded to the source NG-RAN node.

The openairinterface5G project can implement UE or gNB functions by selecting different compilation parameters according to the needs. The project mainly includes three sections: OpenAir1, OpenAir2 and Openair3. On the basis of OAI LTE access network, a direct connection mode between gNB and core network is added. Thus, supporting the implementation of inter cell radio resource management, dynamic resource allocation and connection mobility control in 5G NR SA system.

C. Laboratory physical environment

In the laboratory, the way of combining the universal computer and USRP is adopted. The universal computer completes the baseband processing function, USRP completes the RF transmission and receiving of baseband signals. OAI platform is used as the software to realize the data processing and system control. Above all, the hardware design of 5G communication system mainly includes two devices: USRP and universal computer. There are many kinds of products available on the market. The hardware configuration used in our paper and the network topology of our laboratory setup environment are introduced here.

- Software radio front end. This system selects USRP N310 with good compatibility as the software radio front end. It implements real-time and low-latency processing and connects to a universal computer through high-speed interfaces. Besides, N310 is compatible with a variety of accessories, and can communicate with other devices through copper axis or antenna .

- Universal computer. The system contains three universal computers: 5GC, gNB and computer terminal. Because the functions of each module are different, the requirements for hardware configuration are also different. 5GC and computer terminal need to process less data, so the hardware configuration requirements are lower than gNB. In addition, in order to reduce processing latency and improve processing speed, we install low-latency cores for computer terminals and gNB. In terms of operating system, ubuntu is used for 5GC, gNB and computer terminals. Ubuntu 18.04 is the most commonly used version and is the one used in our article.

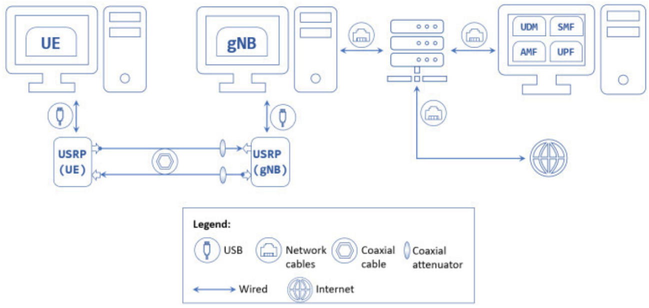

Fig. 3. System architecture of the integrated 5G SA system

- System network topology. In our tests, a set of single user communication system is used, which only contains the most basic network nodes, namely, a core network, a base station and a computer terminal. Its topology is shown in Fig. 3. The USRP device at the base station is connected to the universal computer through USB data cable, and then to the switch through network cable, so as to realize the connection with the core network. Similar to the base station, the universal computer also equipped with a USRP device. The USRP of the computer terminal can be connected with the base station USRP through the coaxial cable, and can also be connected wirelessly by antenna. In the SA networking architecture, the core network does not involve the transmission and receiving of wireless signals. Therefore, the core network just consists of a universal computer. The computer deploys four virtual machines (VMs) for building AMF, SMF, UDM and UPF. It connects to switch through network cables to communicate with internet.

III. System Setup Process

The OAI-based 5G NR SA system includes three parts: core network, base station and user terminal, which will be introduced in detail in this section.

A. Core network construction

The core network consists of four parts: UDM, SMF, AMF, and UPF. The four parts are deployed on four VMs of the same universal computer, forming a complete core network.

- UDM deployment. In the networked state, first download the source code through git. After that, modify parameters in the OAI configuration file as required, where the network port name is an important parameter to be changed. In our system, the UDM is configured with only one Network Interface Controller (NIC). After the preparation is complete, the UDM file can be compiled and started.
- SMF deployment. First, run the SMF script to install SMF components. We can run the -h command to view the functions of each parameter. Then, in the configuration file, change INTERFACE_NAME to the SMF NIC name and IPV4_ADDRESS to the AMF and UDM IP addresses. Lastly, compile and start the command.
- AMF deployment. Start by executing an AMF script to download and install a set of environment dependencies required by AMF. Then, run the vim command to change the AMF NIC name and SMF IP address in the configuration file. After that, go to the scripts directory, compile and start AMF.
- Setup of UPF. The UPF must be installed and compiled with the root permission. The UPF is configured with four NICs. First, execute the UPF script to compile and install the basic environment, VPP, and N4 interfaces required by the UPF. Second, fixed VPP host NETWORK adapter IP address. Third, modify the configuration file. When modifying the configuration file, pay attention to the name, PCI value, IP address, and UE address segment of the NETWORK adapter. Change the IP address of the UPF network adapter connected to the gNB and the SMF IP address as required. Finally, the UPF is compiled and started.

B. The construction of the gNB

Base station gNB, as a part of the access network, consists of two parts: universal computer and software radio front-end USRP. The environment configuration of universal computer, installation driver of USRP and related configuration parameters are described as follows.

- Environment configuration. The universal computer needs to complete baseband processing and to control USRP. The program operation requires high real-time performance. Therefore, in order to improve its performance on existing hardware, it is recommended to use a low-latency kernel and turn off CPU power-saving features. For the installation of low-delay kernel, it is recommended to use the apt-get update command to update the package list. Then download and install the low-delay kernel. There is no hard and fast rule here for the version of low-delay kernel, and it can take effect only after the installation is completed after a restart. On the system selection page, select a low-latency kernel using the advanced boot option. After entering the system, run the uname command to check whether the current kernel is low-latency. Disabling certain CPU features varies depending on hardware, including the C-States, P-States, hyper-threading, and Frequency scaling features of the CPU. You can modify these features by accessing the COMPUTER BIOS or editing system files. Use the i7Z software to check whether the C0 status ratio of the CPU reaches 100%, as shown in Fig. 4. These operations can achieve high hardware capabilities of the computer and thus reduce the requirements on hardware configuration to some extent.
- USRP driver installation. First, download and install the USRP driver by executing the build_oai file compilation command. After the driver is installed, connect the USRP to the computer and run the uhd_find_devices command to check the connection status of the USRP.
- Parameter configuration. Run the source oaienv command to load environment variables. When running this command, ensure that the current working directory of the terminal is OpenAirInterface5G. Run the build_oai file to compile the gNB files and install necessary gNB components. When editing the gNB configuration file, you can access the directory of the configuration file through the Resource Manager and modify the configuration parameters of the configuration file as required. The configuration of the Mobile Country Code (MCC), Mobile Network Code

(MNC), and Network interface address should be consistent with that of the core Network.

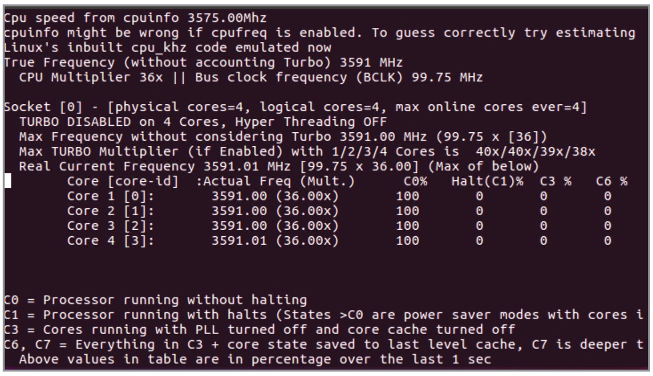

Fig. 4. I7Z interface

C. Building a computer terminal

The function of the universal computer in computer terminals is similar to the universal computer in gNB. In order to better perform baseband processing, it is recommended to use a low-latency kernel and turn off CPU power-saving features. In order to control USRP, USRP driver should be installed.

For the prepared source code, first load environment variables in the OAI root directory to ensure the correct operation of the program. Then compile, install the related files and components of the computer terminal through build_oai.

To adjust running commands and simplify the execution process, the system encapsulates terminal startup commands into startup scripts. In this way, we only need to pay attention to scripts and execution files involved in scripts when editing terminal configuration files. Modify the script information of the computer terminal according to the configuration file selected by gNB above, such as the operating bandwidth, carrier frequency, communication mode, USRP clock and etc. Finally, modify the path and permission of each execution file in the script according to the actual configuration environment.

D. Test platform integration process

After each part is prepared, the whole system can be integrated.

- Start the 5GC. Open four VM Windows to run the AMF, SMF, UDM, and UPF.
- Start the gNB. Connect the USRP to the gNB computer and check whether the connection is successful by using the driver search command. Load environment variables in the OAI root directory and run the gNB execution file.
- Start the computer terminal. Connect the USRP device to the computer of the computer terminal and check whether the connection is successful. Load environment variables in the OAI root directory and run the execution file of the computer terminal. After normal operation, the connection can be established between the USRP and gNB through data receiving and receiving, and the real-time logs printed by both can be used to observe the connection.

IV. Experimental results and analysis

In the whole 5G communication system, most of the startup commands are encapsulated in the execution script. When the system is started, it only needs to run each part of the execution script in sequence, which simplifies the process of system startup. In addition, some running parameters are also encapsulated in the corresponding execution script, which greatly reduces the complexity of running file switching and modification. The system test results in this work are analyzed below.

A. System configurations

System configurations used in the OAI-based 5G NR system platform introduced in this paper are listed in Table I as follows. A Frequency duplex system is integrated with bandwidth of 40MHz on each link (80MHz in total). Due to the limitation of USRP, the antenna configuration is 1 Tx and 1 Rx. The sample rate in USRP processing is 30.72M samples per second.

TABLE I. System configurations

Parameter	Value
Duplex mode	FDD
System bandwidth	40MHz for DL or UL
Sub-carrier spacing	30kHz
Cyclic prefix type	Normal
Antenna configuration	Tx: Rx 1:1
USRP Sample rate	30.72M

B. Test on the data transmission of DL and UL

5G NR SA system based on OAI platform can complete the test of uplink and downlink services. The UL-SCH channel is an uplink shared channel, and the DL-SCH channel is a downlink shared channel. These two channels use HARQ transmission, and the resource configuration can be adjusted according to the modulation mode and transmission power. In addition, according to the test results in Fig. 5, the uplink packet receiving rate is around 99.98%.

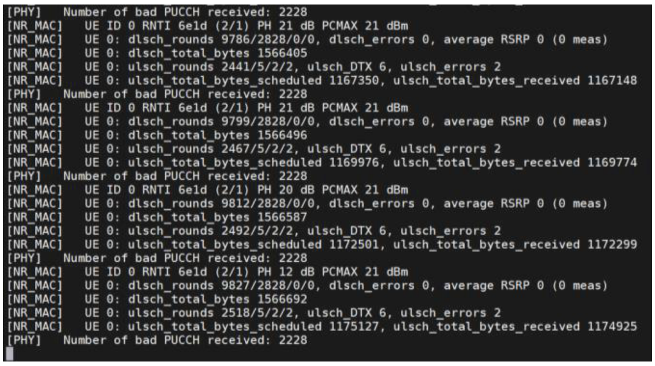

Fig. 5. Testing results of the integrated 5G SA system

C. Test on the signal modulation mode

Fig. 6 shows the constellation diagram of the received signal at gNB side. It can be found that the modulation mode used for signal transmission during our test is QPSK modulation.

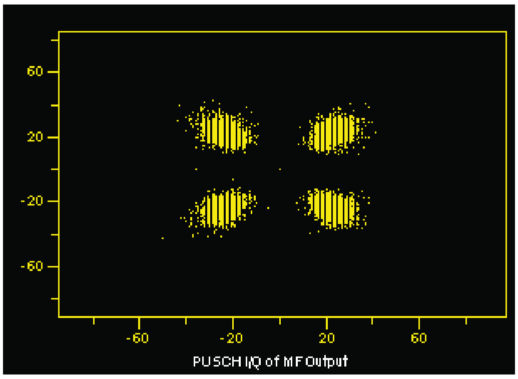

Fig. 6. Constellation of received signals

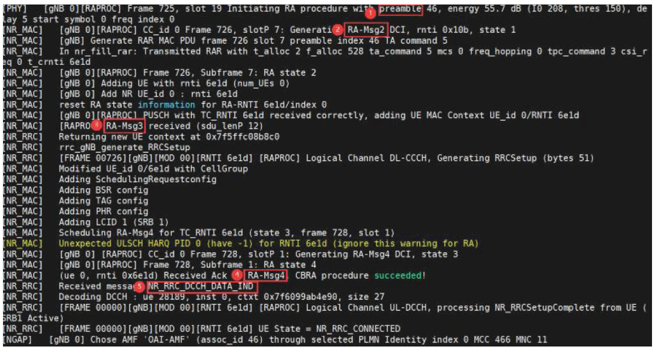

Fig. 7. Random access process

D. 5G NR random access

Fig. 7 shows the random-access process of 5G NR, where Msg1 to Msg5 represents the access procedures [9]. Among them, Msg1 and Msg3 are uplink signals, and Msg2 and Msg4 are downlink signals.

- Preamble is Msg1, which is sent in the PRACH channel [10]. According to the display results, the Preamble index is 46, and the resources used for sending Preamble is frame 725 and timeslot 19. In addition, the target receiving power is 55.7dB.
- Msg2 is demodulated by RA_RNTI to receive the RAR sent by gNB, and TC_RNTI is obtained.
- During the initial access, the unique UE identifier TC_RNTI is sent in the uplink channel to establish the communication link between the base station and the core network, so as to respond to Msg3.
- The Msg3 sends the CCCH SDU, including Contention Resolution Identity MAC CE. UE uses TC-RNTI to demodulate it in Msg4, and the identity in MAC CE is consistent with that sent by UE in Msg3. After this condition is met, UE determines that the random access process is successful, and TC_RNTI is officially converted into C_RNTI.
- Msg5 indicates the RRC access is successful by receiving the NR_RRC_DCCH_DATA_IND message.

Fig. 8. Screen capture of commercial terminal access

E. Commercial terminal access

In addition to the 5G NR SA platform built by computer terminals, commercial terminals can also be used for access. Fig. 8 shows the screen capture of commercial terminals. It is connected to 5G NR SA system built by OAI, and can be seen from the figure that commercial terminal is connected to a customized operator named BUPT, and use 5G network for communication. Meanwhile, the downlink real-time rate is 219K/s.

V. Conclusion

In this paper, the universal computer and software radio platform USRP are used as the hardware foundation and OAI platform as the software architecture to complete the integration and connection test of 5G NR SA system. Through the test results, the uplink and downlink data, modulation mode and random access process of 5G NR are analyzed. The system can transmit and receive data through the USRP connected to the universal computer, process data through the computer, and access users through the computer terminal. In addition, commercial mobile phones can also be supported to be connected to the integrated 5G system. The 5G communication system realized with the help of OAI platform provides certain convenience for further channel research and real-time data measurement under real environment, and lays an important foundation for subsequent research.

References

[1] https://openairinterface.org/

[2] W. Huang and T. Hsu, "Design and Integration of Fiber Fronthaul with Soft PHY for OAI-BASED RAN," 2018 IEEE 23rd International Conference on Digital Signal Processing (DSP), 2018, pp. 1-5.

[3] T. Li, L. Zhao, F. Song and C. Pan, "OAI-based End-to-End Network Slicing," 2018 IEEE 23rd International Conference on Digital Signal Processing (DSP), 2018, pp. 1-4.

[4] T. Dreibholz, "A 4G/5G Packet Core as VNF with Open Source MANO and OpenAirInterface," 2020 International Conference on Software, Telecommunications and Computer Networks (SoftCOM), 2020, pp. 1-3.

[5] P. Lin, S. Huang and X. Li, "Teaching and learning next generation mobile communication networks through open source openAirInterface testbeds," 2017 Asia-Pacific Signal and Information Processing Association Annual Summit and Conference (APSIPA ASC), 2017, pp. 1475-1478.

[6] W. T. Han and R. Knopp, "OpenAirInterface: A Pipeline Structure for 5G," 2018 IEEE 23rd International Conference on Digital Signal Processing (DSP), 2018, pp. 1-4.

[7] 3GPP TS 23.501. System architecture for the 5G System. [2018-06].

[8] 3GPP TS 38.300. NR and NG-RAN Overall description, Stage-2. [2018-10].

[9] 3GPP TS 38.213. Physical layer procedures for control. [2018-10].

[10] 3GPP TS 38.211. Physical channels and modulation. [2020-01].