**Lab 6: Cell Search and MIB Recovery**

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| **Author** | Name： 吉辰卿 Student ID: 11911303 |
| **Introduction:**  In this experiment, we further understand the work flow of transmitter and receiver of LTE system and carry out specific experiments with the help of USRP, a software radio equipment. In the USRP experiment, we firstly installed the USRP driver function in MATLAB. Then, we use an Ethernet connection to let the computer know that the IP address of the USRP. In this way, we can use MTALAB program to control USRP transmitting and receiving data. In this experiment, we use USRP to realize QPSK text transmission and text transmission in LTE system by self-made data set. The following contents are the important points and results of this experiment:  **Theoretical analysis:**   1. **The introduction of USRP hardware**   USRP (Universal Software Radio Peripheral software Radio peripheral) is a hardware platform to realize software radio. It is a very flexible USB device, which is used to connect the computer to the radio frequency world and act as digital baseband and intermediate frequency part in the wireless communication system.  The USRP consists of the USRP mother board, together with the child board and the corresponding antenna. A typical USRP product family consists of two parts: an FPGA mother board with high-speed signal processing, and one or more interchangeable child boards covering different frequency ranges. Together, they carry bitstream data from the antenna to the host computer (receive) or from the host computer to the antenna (send). In each seed board, the USRP series covers the entire range from DC to 5.9GHz, which includes all frequencies from AM broadcasting to beyond Wi-Fi. A typical USRP hardware architecture is as follows:    Figure 1.A typical USRP hardware architecture  In the hardware structure of USRP, the main function of the mother board is IF sampling and conversion between IF signal and baseband signal, and the function of the sub-board lies in RF signal receiving and sending and conversion to IF. There are many types of sub-boards, covering different radio frequency spectrum respectively, and with different transceiver capabilities and gain. The computer is the part that really deals with waveform, modulation and demodulation. A motherboard is connected to a maximum of four child boards.The following diagram briefly describes the basic structure relationship between the USRP mother and child boards :(in this figure, one mother board is connected to four child boards)    Figure 2.The relationship between the mother board and child board of USRP  We briefly discuss the USRP mother board and child board below:   1. **The mother board** The logical structure and functions of the USRP motherboard are as follows:     Figure 3.The logical structure and functions of the USRP mother board  The core of the mother board is FPGA, because all ADC and DAC are connected to FPGA, the equivalent number of 650,000 gates FPGA plays the leading role, it needs to carry out high-bandwidth mathematical processing and reduce the data rate so that the data can be transmitted to PC for processing through USB. In the receiving path, FPGA carries out digital down conversion (DDC) to the digital signal collected by ADC, and carries out variable rate extraction of data through cascade comb filter (CIC). On the sending path, the principle is the same, but in reverse. Because the digital up-conversion is carried out in the AD9862, FPGA carries on the comb interpolation to the data. Because FPGA can process data in parallel, USRP can realize full duplex data processing. In this mode, the receiving and sending channels are completely independent of each other. The only thing that needs to be noted is that the sending and receiving composite rate cannot exceed 32MByte/s.  The FPGA has two main functions: digital down-conversion to baseband of intermediate frequency signals collected by ADC, and variable rate extraction of sample values through cascade comb filter to meet users' requirements for signal bandwidth. The function of interpolation filtering for DAC is also realized in FPGA. Another function is to coordinate the data exchange between ADC, DAC and USB2.0 interfaces as a router.   1. **The child board**   There exists multiple slots on the master, which can be used by a maximum of two receiving and sending boards, or for two transceiver boards. Sub-boards provide RF receiving interfaces or tuners and transmitters. This allows each child board to use two independent RF and antennas when using real sampling. If multiple sampling is used, each child board can use one RF and antenna.  The RF front end in the sub-board is used to convert the received RF signal into intermediate frequency (IF) signal. The RF front end can be represented by the following logical function diagram:  20220513232355  Figure 4.The main function of RF front end  The received RF signal is selected by a low noise amplifier and a low pass filter to amplify the signal with a certain bandwidth, and the center frequency is denoted as fr. The local oscillator of the mixer produces a sine wave with a certain frequency, and the frequency is denoted as fr-fi. Then the mixer outputs signals with the frequencies of fi and 2\*fr-fi and then passes through the low pass filter. Output intermediate frequency signal whose center frequency is fi. In this way, the if signal can satisfy the sampling rate of ADC and thus satisfy the sampling theorem.  Typically, each child board has two connection ports for input or output. The child board has an EEPROM to store the child board identification information and some calibration information, such as DC bias value and IQ signal error, so that the child board can be correctly identified by the system when inserted into the mother board.   1. **The driver function of USRP in MATLAB**   MATLAB has many built-in driver functions about USRP(software radio). These functions can check whether MATLAB is aware of USRP, check the USRP driver version, get the detailed information of the current working USRP, and so on. These built-in driver functions greatly facilitate the debugging of MATLAB programs when we conduct USRP experiments and these functions can be found in the MATLAB help documentation, as follows:  20220513235031  Figure 5.The driver function of USRP can be found in the MATLAB help documentation  Next, I'll introduce a few typical USRP driver functions:   1. **findsdru:**   This function returns a structure array, A, which contains the IP addresses of all the USRP devices connected to the host computer. This function also returns the status of each radio.   1. **getSDRuDriverVersion:**   This function returns the version number of the software installed on the host computer.   1. **probesdru:**   This function returns detailed information about the USRP radio connected to the host computer. If there is more than one USRP radio connected to the host computer, this function returns radio information for the first discovered radio.   1. **sdruload:**   This function loads the default FPGA and UHD firmware images for input device parameter, DEV.   1. **setsdruip:**   This function can sets the IP address of the USRP device. The current IP address is replaced with new IP address, NEWIP. Both CURRIP and NEWIP are dotted quad strings.  Of course, in the later experiments of image transmission and text transmission by USRP, the USRP transmission and receiving system object built in MATLAB also plays a crucial role, as shown below:   1. **comm.SDRuTransmitter:**   The SDRuTransmitter system object sends data to a USRP hardware device, allowing simulation and development for various software-defined radio applications and it enables communication with a USRP board on the same Ethernet subnetwork. So, we can write a MATLAB application that uses the System object or we can also generate code for the System object without being connected to a USRP radio.  This object accepts a column vector or matrix input signal from MATLAB and transmits signal and control data to a USRP board using the Universal Hardware Driver (UHD). The SDRuTransmitter System object is a sink that sends the data it receives to a USRP board. The first call to this object could contain transient values, which would result in packets containing undefined data.   1. **comm.SDRuReceiver:**   The SDRuReceiver System object receives data from a USRP hardware device, allowing simulation and development for various software-defined radio applications and it enables communication with a USRP® board on the same Ethernet subnetwork. Therefore, we can write a MATLAB application that uses this System object, or we can generate code for the System object without connecting to a USRP radio.  This object receives signal and control data from a USRP board using the Universal Hardware Driver (UHD). The SDRuReceiver System object receives data from a USRP board and outputs a column vector or matrix signal of fixed length. The first call to this object could contain transient values, which would result in packets containing undefined data.  **Lab results & Analysis：**  **Task1: The implementation of QPSK text transmission by USRP**  For the text transmission of QPSK by USRP, the program and idea we follow are basically consistent with the transmitter and receiver used in lab3. The only difference is that this time we will be using USRP for data transmission and reception, so the comments on initialization of the USRP structure that were commented out in the previous lab report will be removed here. As follows:  **20220515140654**  Figure 6. The core program of QPSK text transmission transmitter  (including the configuration of the USRP structure)  20220515141111  20220515141625  Figure 7.The part about the program QPSK text transmission receiver that configures the parameters of the USRP structure  What we need to modify is the process of receiving packets in the loop of the receiver program, as shown below:  **20220515141720**  **20220515141753**  Figure 8.The core program of QPSK text transmission receiver  **Special attention should be paid to: in the last class experiment practice, there was a problem in the receiver program, which was finally solved with the help of the teacher.That is: In the receiver, we should do some other modification of the sdruQPSKRX structure, as shown below:**  **20220515161544**  Figure 9.What we need to focus on about the modification at the receiver  **In this structure, we should add more element to the stepImpl function, as shown below:**  20220515162336  Figure 10.What we need to modify at the structure of sdruQPSKRX  Here, we need to see that since we are using USRP transmitter and receiver to get the restored text at the receiver, we start by commenting out the code block that loads the pre-recorded data. Then, we read the IQ signal in a cycle and draw the spectrum diagram of the received text signal and the constellation diagram of the matched filtered signal, as shown below (The following figure also outputs the restored text):  **SEZ1H%6SP7H26JZN)HZJNFQ**  Figure 11.The output of the receiver (including restored text)  **Task2: The implementation of LTE image transmission by USRP**  For LTE image transmission based on USRP, the program framework of transmitter and receiver has been established, and the core program is shown as follows:  20220515143822  Figure 12.The core program of the receiver of LTE image transmission  20220515144516  Figure 13.The part about the program of the receiver of LTE image transmission that configures the parameters of the USRP structure  In the program of receiver, like the program in the last lab report, the image data are received, processed and recovered by the following steps in LTE system:  (Note: **In the last lab report**, I have introduced and explained how the receiver performs image data processing and recovery in LTE system in detail, so I will not explain it here repeatedly).  20220515150420  Figure 14.The process of image data processing and recovery by receiver in LTE image transmission  In this experiment, we used USRP to send image data and saved the transmitted image waveform data, which became our image data set, as shown below:  20220515152327  Figure 15.The data set of image waveform we sent through USRP  (called rxWaveform5.mat)  The size of this data set is 4.5M, and I will submit it together with the report. Next, let's look at the image recovered by the USRP receiver, as follows:  20220515153613  Figure 16.The received image by using our image data set called rxWaveform5.mat  By comparing the restored image data with the transmitted image data, we find that the receiver can basically recover the image. However, due to the interference and noise in the wireless channel, there exists some red interference bars on the left side of the received image, which is a normal phenomenon. | |
| **Experience**  Through the practice of this experimental class, we had an opportunity to practice USRP, who had not actually operated USRP for nearly half a semester. This experiment is quite a compensation for the previous several experimental classes. We firstly use the content learned in Lab3 to realize QPSK text transmission using the annotated program at that time. Although there were some twists and turns in the implementation process, eventually we were able to receive the information in the text more correctly. Finally, we also used different images and tested the transmission of different images in LTE communication system learned in last class by USRP. In the process of testing, we can slightly modify the image waveform data transmitted by USRP to make our own data set. Thus, in the USRP experiment, we can see some noise and interference in the middle of the image when receiving. This is because we have made some changes to the transmitted waveform data, resulting in some interference and errors in the new data set compared with the original image data. In the experiment, we can see these errors very well, which is the biggest surprise to me.  Finally, I paste the screenshot of the class exercise in the lab class:  SEZ1H%6SP7H26JZN)HZJNFQ  Figure 17. Class exercise | |
| **Score** | 自评分数：99 |