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

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| **Introduction:**  In this experiment, we will move into another kind of mobile communication system-- LTE. The biggest difference between LTE system and WiFi system is that the frame structure of LTE system is more complex, especially in frequency domain resource grid. Therefore, in this experiment, we focused on the analysis of LTE system frame structure in the time-frequency domain, and could roughly understand the meaning of different colored areas in the frequency-domain resource network. After that, we focused on understanding the role of LTE channels, and we focused on the basic process of cell search, MIB and business data decoding through MATLAB programming. Through this experiment, we have a macro understanding of LTE system, and we can use the LTE system to simply realize the image transmission.  **Theoretical analysis:**   1. **The main structure of LTE system**   When learning the structure level of LTE communication system, the physical layer channel is the key to learning LTE. The hierarchical structure of UE and eNodeB is shown in the figure below.  20220501153958  Figure 1. Layered structure of LTE communication system  In this experiment, through MATLAB simulation, we will focus on the following four points of physical layer research: (1) frame structure; (2) LTE channel; (3) LTE downlink channel; (4) LTE uplink channel;  So, how do we understand LTE communication system from the physical layer channel of LTE system?  First of all, we must understand the physical layer structure of LTE system, as follows:    Figure 2. The physical layer structure of LTE system  From the figure above, we can see that the physical layer of LTE can be divided into the following time lengths:   1. **LTE system frame:**   An LTE system frame lasts for 10ms and consists of 10 consecutive sub-frames. We usually distinguish the system frames by system frame numbers.   1. **LTE sub-frames:**   Each sub-frame lasts for 1ms and it is divided into two slots, each of which lasts for 0.5ms.   1. **LTE time slot:**   A slot consists of seven normal cycle prefixes and six extended cycle prefixes.  For our further understanding, we should also know that there are two different duplex modes in LTE physical layer: **FDD mode and TDD mode**. The details of the two modes are as follows:    Figure 3. Two working modes of LTE physical layer  From the time domain of the two modes in the figure above, FDD and TDD have roughly the same structure. The duration of their system frames is 10ms, and they are both composed of 10 sub-frames. However, there are some differences in the allocation of sub-frame time-frequency resources between the two modes. These differences need to refer to specific protocols.   1. **The downlink channel of LTE system**   In this experiment, we mainly studied the downlink channel of LTE system. LTE downlink channels are generally divided into two types, one is to transmit information instructions, the other is to transmit data services; The transmission signaling is transmitted through BCH--**>**PBCH channel, and the transmission service is transmitted through DL-SCH--**>**PDSCH channel, the two transmission channels are shown in the red box and arrow below.  20220501161607  Figure 4. The Channel composition of LTE system  The transport layer functions that can be called in the LTE system toolkit are BCH, DL-SCH; The physical layer channel functions that can be called are PBCH, PDSCH, DCI, PHICH and PCFICH, where DCI is used for format control and PHICH is used for feedback retransmission. The simulation in the first part of this experiment is mainly by DL-SCH--**>**PDSCH to transmit an image.   1. **Resource grid for LTE system**   When learning LTE communication system for the first time, it is very important to learn to read resource grid. The following figure shows resource allocation for an LTE system frame:    Figure 5. System frame resource allocation grid in LTE system  We can see from the color-coded area information in the figure above easily: (1) Time-frequency resource distribution of each channel in a system frame; (2) the position of the main synchronization (PSS) and auxiliary synchronization (SSS) signals; (3) location of cell reference signal; (4) the location of the broadcast channel; (5) Location of CFI information; (6) The position of HI; (7) location of PDCCH; (8) the position of PDSCH; In the next section, I will explain what the main functions of these areas are with specific MATLAB programs.   1. **The cell search process of LTE system**   The cell search process of LTE is mainly shown in the figure below:  20220501163500  Figure 6. The main steps of cell search in LTE system  The brief steps of cell search in LTE system are as follows:   1. Search for primary synchronization sequence and secondary synchronization sequence. 2. Do Channel estimation and time synchronization through reference signal (CRS). 3. Retrieve MIB information and obtain system frame number by PBCH channel. 4. SIB information retrieval: As data is transmitted on PDSCH, its location is informed by PDCCH, and the mode of PDCCH is determined by PCFICH. Therefore, SIB information retrieval includes decoding PCFICH, PDCCH and PDSCH information respectively.   Of course, I will describe this complete process in combination with specific procedures later in the experimental results section.  **Lab results & Analysis：**  **Task1: Explain the functions of the following subcomponents respectively**  **Result:**   1. **lteRMCDL.m**   This function mainly used to configure Downlink reference measurement channel. This function returns configuration structure rmccfgout for reference channel rc. This structure uses a channel-specific default configuration. The structure contains the configuration parameters required to generate a given reference channel waveform using the reference measurement channel (RMC) generator tool, lteRMCDLTool.  20220501192821  Figure 7. Information about RMC objects created by this function   1. **lteRMCDLTool.m**   The function mainly used to generate the downlink RMC waveform. lteRMCDLTool.m starts a user interface for the parameterization and generation of the reference measurement channel (RMC) waveform, the resource element grid, and an RMC configuration structure. The main function outputs are specified in the GUI but can also be assigned to variables.   1. **lteFrequencyOffset.m**   This function estimates the average frequency offset of the LTE time domain waveform captured by the receiver by calculating the correlation of the cyclic prefix. Waveform parameters are given by the downlink configuration object ‘enb’. ‘enb’ must contain the NDLRB field to specify that downlink signals are expected in the waveform.  20220501205125  Figure 8. Information about frequencyOffset returned by this function   1. **lteFrequencyCorrect.m**   This function corrects the specified frequency offset in the time domain waveform by performing simple frequency modulation (FM). The parameters of the waveform are specified in the setting structure enb, which must contain either NDLRB or NULRB fields to control the desired downlink or uplink signals. The offset of the input is the frequency offset in Hertz and the output of this function is the waveform after frequency offset correction.  20220501210449  Figure 9. The waveform after frequency offset correction returned by this function   1. **lteCellSearch.m**   This function returns the Cell ID carried by the PSS and SSS sequences in the input waveform, the timing offset to the start of the first frame of the waveform, and the peak correlation magnitude.  **20220501211001**  Figure 10. The Cell ID returned by this function   1. **lteOFDMDemodulate.m**   This function performs OFDM demodulation of the time domain waveform of the given cell setting structure enb. During demodulation, an FFT operation is performed on each received OFDM symbol to recover the received subcarrier value. These values are then used to construct each column of the output resource array grid. FFT is positioned in the middle by cyclic prefixes to allow some degree of channel delay extension while avoiding overlap between adjacent OFDM symbols.  20220501211816  Figure 11. The resource array grid returned by this function   1. **lteDLChannelEstimate.m**   This function returns the estimated channel response between each transmitting and receiving antenna (in the first return parameter), as well as the estimate of the noise power spectral density on the reference signal subcarrier of the enb and resource grid for a given cell range setting(in the second return parameter). Of course, this function can also specifies the channel estimation method and parameters in the channel estimator configuration structure cec.  20220501212428  Figure 12. The estimated noise power spectral density returned by this function   1. **lteResourceGridSize.m**    This function returns a three-element row vector of dimension lengths for the resource array generated from the settings structure, enb.  20220501212841  Figure 13. The three-element row vector of dimension lengths for the resource array returned by this function   1. **ltePBCHDecode.m**   This function mainly decodes MIB information and returns the decode results of PBCH: a vector of soft bits, a vector of received constellation complex symbols, frame number, decoded BCH information bits called MIB, and number of cell-specific reference signal antenna ports.  20220501213829  Figure 14. The MIB information bits returned by this function   1. **ltePCFICHDecode.m**   This function decodes the complex PCFICH symbol pcfichRx and allows us to retrieve CFI information bits from it. Next, we can choose to decode this bit information to obtain CFI information, so as to know the working mode of PDCCH in order to decode PDCCH in the future.  20220501221530  Figure 15. The CFI information bits returned by this function   1. **ltePDCCHDecode.m**   This function performs the inverse of physical downlink control channel (PDCCH) processing on the matrix of the complex modulated PDCCH symbol, symbol and cell range setting structure enb. Channel inverse processing includes resource tuple deinterleaving and cyclic shifting, uncoding, symbol demodulation and unscrambling. This function returns DCI information and PDCCH symbol information. The DCI information will be used in the next configuration before the PDSCH decoding.  20220501222014  Figure 16. The DCI bits information returned by this function   1. **ltePDSCHDecode.m**   This function performs physical downlink shared channel (PDSCH) inverse processing of complex modulated PDSCH symbols using the cell-wide setup structure ENB and the channel-specific configuration structure PDSCH. Channel inverse processing includes channel precoding inverse, layer reflection and code word separation, soft demodulation and demodulation. This function will returns a cell array, dlschBits, of soft bit vectors, or codewords, and a cell array, pdschSymbols, of received constellation symbol vectors resulting from performing the inverse of Physical Downlink Shared Channel (PDSCH) processing.  **Task2: The Implementation of Cell search and MIB/SIB decoding**  **Result&****Analysis:**   1. **Image transmission**   Although the process of using LTE to realize image transmission is complicated, if our program is analyzed by modules, in fact, the architecture and thinking of the program are relatively clear.  Firstly, we need to import and compress the image and generate the binary stream of the image, as shown below:  20220501224311  Figure 17. The preprocessing of imported images  Next, we configure the parameters of LTE downlink and use these parameters to generate LTE multiple baseband waveform, as shown in the following program:  20220501232718  Figure 18. The generation of LTE waveform  The reference measurement channel object is created as follows:  20220504171100  Figure 19. Reference measurement channel  The PDSCH information configured in RMC is as follows:  20220504171422  Figure 20. The PDSCH information configured in RMC  The generated LTE waveform is shown as follows:  20220504170428  Figure 21. The generated LTE waveform  LTE waveform signals are stored in eNodeBOutput variables, as shown below:  20220501232956  Figure 22. The eNodeBOutput variables  Next, we need to design the receiver: Firstly we define the structure parameters of the receiver object, then we initialize the receive object ENodeB, and finally we need to configure the structure of the channel estimation. The program and the ENodeB information is as follows:  20220501233756  Figure 23. The initialization of the receiver object ENodeB  20220504164247  Figure 24. The initialized information of the receiver object ENodeB  Then, we can receive and capture the signal processing. After the signal is captured, we first correct the frequency offset of the received signal, and then conduct cell search. The result of Cell search is that we can use the primary synchronization sequence (PSS) and secondary synchronization sequence (SSS) to obtain the Cell ID, as shown below:  20220501234346  Figure 25. The ID of the cell obtained through the cell search is 88  Since the location of PSS and SSS can be obtained through cell search, then OFDM demodulation and related channel estimation can be performed from subframe 0. The program is as follows:  20220501234831  Figure 26. Channel estimation is performed after cell search  Then, we perform MIB decoding to obtain the frame number of the system: we first extract sub-frame 0 and the result of channel estimation and perform PBCH decoding on it. As a comparison, let's firstly look at the ENodeB's structure information before PBCH decoding:  20220504164815  Figure 27. ENodeB’s structure information before PBCH decoding  After decoding, we can get the frame number of the system, as shown below:  20220501235610  Figure 28. The frame number of this system is 700 after MIB search  After obtaining the frame number of the system, we first store this frame number and then process all sub-frames under this frame. After processing, we need to conduct CFI decoding to obtain CFI information so as to know the working mode of PDCCH. The CFI information obtained is as follows:  20220502000138  Figure 29. CFI information was obtained by demodulation of PCFICH  Then, we can decode PDSCH through the relevant information of CFI and PDCCH. Since THE position occupied by PDSCH in the spectral resource grid is a shared channel, it carries the transmitted image data. Therefore, after decoding PDSCH, we can reconstruct symbol stream and restore and reconstruct image data. The restored image and the original image we transmitted are as follows:  20220502001257  Figure 30. The reconstructed image and the original sent image  At the same time, it can be seen from the command line output that our image transmission uses three system frames in total. If our image is larger, we may need more system frames to transfer the image.  20220502001452  Figure 31. The reconstructed image and the original sent image   1. **The process of receiving signal processing based on IQ data**   In this part, we use the imported IQ data to simulate the whole process of signal processing by the receiver.  Firstly, we import IQ data and initialize the eNodeB object. After that, we will enter the most important link -- cell search.  In cell search, we do not know what duplex mode and cyclic prefix mode are in LTE system at this time. Therefore, we need to obtain PCI information of the cell through PSS and SSS blind inspection. In other words, we assign different duplex mode and cyclic prefix mode to conduct cell search at each detection. After the search, we can get the corresponding PCI information and the corresponding cross-correlation peak size. In the continuous cyclic blind inspection, we determined the corresponding working mode and PCI information (Cell ID) in our LTE system by looking for the maximum cross-correlation peak value. After blind inspection, the Cell ID information obtained is as follows:  20220502003703  Figure 32. LTE duplex mode, circular prefix mode and Cell ID information obtained after blind inspection  Meanwhile, since this program was written by myself in class, I will show the code of the blind check program as follows:  20220504163526  Figure 33. The ID information of the cell was obtained by blind test through the peak of cross-correlation  After that, in order to verify the accuracy of blind detection, the current Cell ID was cross-correlated with the two adjacent Cell IDs, and the results were compared. If the result of the current Cell ID cross-correlation is larger than that of the two adjacent Cell IDs cross-correlation (we can set a threshold for judgment), then the Cell ID obtained by the blind search of the Cell is considered correct. The detailed program is as follows:  20220502094926  Figure 34. Verify the surrounding Cell IDs to check the accuracy of the blind detection results  After obtaining the Cell ID information accurately, we can use the CRS information to perform symbolic synchronization, channel estimation and other operations, as shown below:  20220502095817  Figure 35. Doing symbol synchronization and other related operations by through CRS  Next, we can decode the PBCH channel and search the MIB information to obtain the system frame number and downlink bandwidth. As shown below:  20220502100803  Figure 36. After PBCH decoding, the information of the system frame number is 406  and the bandwidth information is also updated to 50  After that, we can search and decode SIB information. Before decoding, we need to resampling the information, correcting the frequency deviation and finding the starting position of the frame. Then, once we have enough data, we decode the SIB information. Here, we need to note that the decoding of SIB information is mainly divided into three steps, which are the decoding of CFI information, PDCCH and PDSCH respectively.Among them, the main function of CFI information decoding is to obtain the mode information of PDCCH so that we can decode the PDCCH information. The function of PDCCH information decoding is mainly to obtain the position of PDSCH information so that we can decode PDSCH information. PDSCH belongs to the shared channel information, which contains the data we sent. Therefore, in the last step, we will decode PDSCH to get the information we sent.  Therefore, we can see from the above explanation: SIB search and decoding process is an interlocking and logical process. Next, we will run MATLAB program to see some output changes after each step of the decoding process:   1. **Decoding of CFI information**   20220502102720  Figure 37.Output CFI information after decoding CFI information  20220502102833  Figure 38.Updated the CFI information of the enb object   1. **Decoding of PDCCH information**   20220502103156  Figure 39.PDCCH symbol obtained after decoding PDCCH information  20220502103427  Figure 40.Decode the DCI information in the PDCCH information to get the relevant configuration of PDSCH from the DCI   1. **Decoding of PDSCH information**   20220502103750  Figure 41. Obtain the PDSCH symbol size after decoding the PDSCH message  Finally, when we have the PDSCH information, we can get the data to send from it. | |
| **Experience**  Through the two weeks of experimental classes, I have further understood the working principle of the physical layer of LTE system and the search process of cell information、the decoding process of MIB and SIB information. In a conclusion, TLE system is more complicated than WiFi system, which reminds me to consult the help document in time to learn more information not mentioned in class when studying and researching. Through the program learning of these two experimental classes, I gradually understood the complete process of image transmission and data recovery using LTE and was able to try to explain the key steps, which was also reflected in the above experiment result.  Finally, I paste the screenshot of the class exercise in the last lab class:  test1  Figure 42. Class exercise 1  test2  Figure 43. Class exercise 2  lab6-exercise  Figure 44. Class exercise 3 | |
| **Score** | 自评分数：99 |