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

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| **Introduction**  In this lab, we have learned how to use MATLAB to simulate the process of cell search and MIB recovery. In addition, we have also learned how to use LTE system to implement the image recovery based on the USRP pre-recorded data, and also use it to implement the image transmission based on USRP.  From the lecture, we have known that the biggest difference between the LTE system and 802.11a system is that the frame structure of LTE system is more complex, especially in frequency domain resource block. So at this time, 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.  **Theoretical analysis**   1. **Introduction to functions** 2. **lteRMCDL.m**   Configure Downlink reference measurement channel. It returns configuration structure rmccfgout for reference channel rc. This structure uses a channel-specific default configuration, and it contains the configuration parameters required to generate a given reference channel waveform using the reference measurement channel (RMC) generator tool, lteRMCDLTool.   1. **lteRMCDLTool.m**   Generate the downlink RMC waveform. It 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**   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.   1. **lteFrequencyCorrect.m**   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 Hz and the output of this function is the waveform after frequency offset correction.   1. **lteCellSearch.m**   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.   1. **lteOFDMDemodulate.m**   Performs OFDM demodulation of the time domain waveform of the given cell setting structure enb. During demodulation, 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.   1. **lteDLChannelEstimate.m**   Returns the estimated channel response between each transmitting and receiving antenna, 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. This function can also specifie the channel estimation method and parameters in the channel estimator configuration structure cec.   1. **lteResourceGridSize.m**   Returns a three-element row vector of dimension lengths for the resource array generated from the settings structure, enb.   1. **ltePBCHDecode.m**   Decodes MIB information and returns the decoding 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.   1. **ltePCFICHDecode.m**   Decodes the complex PCFICH symbol pcfichRx and allows us to retrieve CFI information bits from it. Then 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.   1. **ltePDCCHDecode.m**   Performs physical downlink control channel (PDCCH) inverse 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.   1. **ltePDSCHDecode.m**   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 return a cell array, dlschBits, of soft bit vectors, or codewords, and a cell array, pdschSymbols, of received constellation symbol vectors resulting from performing Physical Downlink Shared Channel (PDSCH) inverse processing.   1. **Foundation of physical layer** 2. **Frame structure**     From the figure above, it can be easily seen that the physical layer of LTE can be divided into the following time lengths:   1. **LTE system frame**   An LTE system frame lats for 10ms and consists of 10 consecutive subframes.   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**   Each sub-frame lasts for 1ms and it is divided into two slots, each of which lasts for 0.5ms.   1. **OFDM symbol**   Every time slot consists of 7 OFDM symbols with normal cyclic prefix. The 1st CP length is 5.20 and the remaining CP length is 4.68 .   1. **Resource block**     The above figure shows resource allocation for an LTE system frame. It is easily seen from the color-coded area information that time-frequency resource distribution of each channel in a system frame. Also, the position of the main synchronization (PSS) and auxiliary synchronization (SSS) signals. Besides, location of cell reference signal, the location of the broadcast channel and the location of the broadcast channel can be known from the figure. What’s more, location of CFI information, the position of HI and location of PDCCH、PDSCH can be also known from the figure.   1. **Process of cell search and MIB/SIB decoding** 2. **Process of cell search**      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. 5. **Process of MIB/SIB decoding** 6. Extract sub-frame 0 and channel estimation results 7. Perform PBCH demodulation and extract resource elements (REs). If PBCH decoding successful CellRefP ~=0 then update info. Then the MIB decoding can be performed with correct ENB value. 8. Get the frame number and limit the downstream bandwidth. 9. Store received frame number and process subframes within frame 10. Extract subframe and perform channel estimation with the correct number of CellRefP. 11. Perform PCFICH demodulation and extract REs corresponding to the PCFICH 12. Then do CFI decoding and get PDSCH indices. 13. Perform deprecoding, layer demapping, demodulation and descrambling on the received data using the estimate of the channel. 14. Append decoded symbol to stream and transport block sizes. 15. Decode DownLink Shared Channel (DL-SCH) and recode transmitted PDSCH symbols for EVM calculation. 16. Reassemble decoded bits and store data from receive frame.   **Lab results & Analysis**   1. **Flowchart of TestLTE.m**     The figure shown above is the flowchart of TestLTE.m.   1. **Image recovery based on USRP pre-recorded data** 2. **rxWaveform1.mat**     The figure shown above is the recovered image of the USRP pre-recorded data rxWaveform1.mat.   1. **rxWaveform2.mat**     The figure shown above is the recovered image of the USRP pre-recorded data rxWaveform2.mat.   1. **rxWaveform3.mat**     The figure shown above is the recovered image of the USRP pre-recorded data rxWaveform3.mat.   1. **Flowchart of subframeProc.m**     The figure shown above is the flowchart of subframeProc.m.   1. **4G-LTE image transmission based on USRP**     The figure shown above is the image we transmitted at the USRP transmitter with 4G-LTE.    The figure shown above is the part of the code of LTETx.m.    The figure shown above is the part of the code of LTERx.m.   1. **Application of 4G-LTE and 5G communication system** 2. **4G-LTE communication system**   The 4G-LTE communication system is widely used in the field of mobile communication. It provides high-speed data transmission, lower latency, and more stable connections, offering better user experiences for various applications. Some of the applications of the 4G-LTE communication system are shown below:   * **Mobile telephony and data communication**   4G-LTE provides high-speed voice calls and data transfer capabilities for smartphones and other mobile devices, enabling users to make voice calls, send messages, and browse the internet anytime, anywhere.   * **Mobile broadband internet access**   The high-speed data transmission capability of 4G-LTE allows users to enjoy seamless web browsing, social media usage, video and audio streaming, and other online activities through mobile devices, providing an experience close to fixed broadband networks.   * **Mobile applications**   The fast data transmission and low latency of 4G-LTE make various mobile applications more powerful and practical. Examples include real-time video calls, online gaming, music and video downloads, cloud storage, and more, all running smoothly on mobile devices.   * **Internet of Things**   4G-LTE provides reliable connectivity and efficient data transmission for IoT devices, supporting various applications such as smart homes, smart cities, industrial automation, and intelligent transportation. Through the 4G-LTE network, IoT devices can be monitored and controlled in real-time, improving efficiency and convenience.   * **Public safety communications**   4G-LTE is widely used in public safety domains, such as police communication, emergency response, and disaster management. It offers reliable communication channels and high-speed data transmission, facilitating real-time information exchange and coordinated actions for emergency personnel.   1. **5G communication system**   The applications of 5G communication systems are wide-ranging, driving new innovations and developments across various industries and domains. Some of the applications of the 5G communication system are shown below:   * **Mobile communication**   5G provides faster data transmission speeds and lower latency, enabling mobile users to enjoy faster and more stable data connections, supporting high-definition video streaming, virtual reality (VR), augmented reality (AR), and other applications.   * **Internet of Things**   5G offers stronger connectivity and higher capacity for large-scale IoT applications, connecting a multitude of smart devices and sensors, facilitating the development of smart cities, smart homes, intelligent transportation, and more.   * **Autonomous driving and intelligent transportation**   5G technology enables high-speed, low-latency communication between vehicles (V2V) and between vehicles and infrastructure (V2I), promoting the advancement of autonomous driving technology and enhancing road safety and traffic efficiency.   * **Industrial applications**   The high speed, low latency, and reliability of 5G facilitate remote monitoring, robot control, intelligent manufacturing, and other applications in the industrial sector, driving industrial automation and intelligence.   * **Healthcare**   5G technology provides more reliable remote healthcare, remote surgery, real-time monitoring, and other services, strengthening the distribution of medical resources and expanding the coverage of medical services.   * **Virtual reality and augmented reality**   The high speed and low latency of 5G make virtual reality and augmented reality applications smoother and more immersive, providing enhanced experiences in gaming, entertainment, education, and other fields. | |
| **Experience**  **Experience**  孙逸涵:   1. In this lab, I have learned how to use MATLB to simulate the process of cell search and MIB recovery. And also learned how to use LTE system to implement the image recovery based on the USRP pre-recorded data and implement the image transmission based on USRP. 2. When doing the LTE image transmission and reception on the USRP platform, I met some problems at first. So the first part I consider where there might be a problem is the image size mismatching between the transmitter and the receiver, and the second part I consider where there might be a problem is the center frequency and the gain of the USRP. Both of above are the problems of the code, but finally I proved that there is no wrong in the code. Instead, I tried to use ‘findsdru’ instruction to check the connectivity between the USRP and the computer, but there is still no wrong of that, the results always have been ‘success’. However, I find there was a warning on the receiver computer, which said that the center frequency and the gain of the USRP are both out of range, so I tried to use ‘probesdru’ instruction to see the appropriate range of the center frequency and the gain of the USRP, but the results are 0. Therefore, I find the problem is occurred at the receiver USRP, then I changed another one to try my codes, and it ultimately run successfully. But the quality of the received image is not good, so I tried to adjust the center frequency and the gain of the USRP, and finally we set the center frequency of the USRP to 3GHz, and the gain of the receiving USRP to 15dB, and thus we successfully received the image with higher quality than before. I think the reason for that is that when we did our experiment, there were many people in the laboratory, so the noise power was larger than before, and that’s why we cannot received a high-quality image at first.   张旭东:   1. 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. 2. 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.   **In-class lab screenshot**  孙逸涵:   * **Part1**      * **Part2**      * **Part3 & 4**         张旭东:   * **Part1**      * **Part2**      * **Part3 & 4** | |
| **Score** | 100 |