**Lab 5: 802.11a Image Transmission and Reception**

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| **Author** | Name： 吉辰卿 Student ID: 11911303 |
| **Introduction**  This experiment content is very rich: We spent two weeks, discussing how to use 802.11a to carry on the image data transmission and recovery problem. Firstly, we looked at the data structure transmitted using 802.11a, that is, how the data structure is changed from MSDU to PPDU. In order to better understand this process, we use MATLAB communication programming to achieve the process from MSDU to PPDU. Finally, through AWGN channel, the encapsulated image packet is sent to the receiver through wireless channel. At the receiver, we can recover the image data passed in at the transmitter by capturing data packets, processing data packets and image reconstruction. Finally, we discuss the effects of different modulation schemes and SNR on image recovery and received constellation image quality. Finally, we change AWGN channel into hiperlan /2 channel model, which is commonly used in WiFi. We use five submodels of this model --A, B, C, D and E to discuss the relationship between SNR and packet error rate under different models and the relationship between SNR and packet error rate under different modulation schemes respectively. Here is my detailed experiment process:  **Theoretical analysis:**   1. **802.11a Technology**   802.11a is a multi-carrier modulation technology. Also, 802.11a is the successor of the 802.11b wireless networking standard, which has been widely used in offices, homes, hotels and airports. It operates in the 5GHzU-NiI frequency band, with physical layer rates up to 54Mb/s and transport layer rates up to 25Mbps. It can provide 25Mbps wireless ATM interface, 10Mbps Ethernet wireless frame structure interface, and TDD/TDMA air interface; Support voice, data, and image services; A sector can be connected to multiple users, and each user can have multiple user terminals.  802.11a is a standard in the 802.11 standard family applied to wireless LAN. It is mainly used in access hubs and provides a standard for wireless ATM systems. Networks using the 802.11a standard operate at radio frequencies between 5.725GHz and 5.850GHz. This standard uses orthogonal frequency division multiplexing (OFDM) technology, which is especially suited for office LAN. In 802.11a, the data rate can reach 54Mb/s. In terms of interference, 802.11a is superior to 802.11b because it provides more channels available and the frequency of 802.11b is shared with a wide variety of household appliances and medical devices.The second branch of 802.11 is designated 802.11a. Unlike 802.11b, a single carrier system, 802.11a uses the multi-carrier modulation technology of orthogonal frequency division multiplexing (OFDM) to improve frequency channel utilization. Because 802.11a uses the 5.2GHz radio frequency spectrum, it cannot interoperate with either 802.11b or the original 802.11WLAN standard.   1. **Frame Aggregation Technology in 802.11**   Frame aggregation technology is a key technologies of MAC layer, which includes aggregation for MSDU (A-MSDU) and aggregation for MPDU (A-MPDU):   1. **A**-**MSDU**   The A-MSDU technology refers to aggregating multiple MSDUs into a larger load in a certain way. The MSDU here can be considered as an Ethernet message. Usually, when the AP or wireless client receives a message (MSDU) from the protocol stack, it will be marked with the Ethernet message header, which we call A-MSDU Subframe; and before sending it out through the radio port, it needs to be sent out one by one. Converted to 802.11 message format. The A-MDSU technology aims to aggregate several A-MSDU Subframes together and encapsulate them into one 802.11 message for transmission. This reduces the overhead of PLCP Preamble, PLCP Header and 802.11 MAC header required to send each 802.11 message, reduces the number of response frames, and improves the efficiency of message transmission. We can see the model of MSDU in the figure below:  http://images.cnitblog.com/blog/153991/201307/17133653-19648a89b7614e5da39dc2af31439ba1.jpg  An A-MSDU packet consists of several A-MSDU subframes. Each Subframe consists of A Subframe header (Ethernet Header), an MSDU, and 0-3 bytes of padding.  20220331010848   1. **A**-**MPDU**   Different from A-MSDU, A-MPDU aggregates MPDU encapsulated by 802.11 packets. In this case, MPDU refers to data frames encapsulated by 802.11. By sending several MPDU at a time, the PLCP Preamble and PLCP headers required for sending each 802.11 packet are reduced, thus improving the system throughput. The structure of A-MPDU is shown below:  IMG_256  The MPDU format is the same as that defined by 802.11, and MPDU Delimiter is A new format defined to use A-MPDU. The A-MPDU technology also applies only to the scenario where the destination end of all MPDU is the same HT STA.   1. **The main function of the MAC layer**   Add a MAC Header to the MSDU, encapsulate it with FCS as an MPDU, and pass the MPDU to the PLCP sublayer of the physical layer to become a PSDU. The PLCP sublayer is further encapsulated to generate PPDU (Presentation Protocol Data Unit, PPDU). The steps of this process is shown below:  20220331011910  **3. Preamble Field structure in 802.11**  Firstly, let's take a look at the position of Preamble Field in three 802.11 PPDU structures, as shown in the figure below. We can find that in these three PPDU structures, Preamble Field is in the packet head position. Next, let me briefly explain the composition of Preamble Field and the functions of each part.  20220331093138  Figure. The position of Preamble Field in three 802.11 PPDU structures  **1. L-STF**  L-STF, means L-STF (Short Training Field), which is similar to the same fields in 802.11a/b/g and 802.11n. The waveform generation mode of this structure in time domain is shown as follows:  https://pic1.zhimg.com/80/v2-0bbbe9176b180966b47888e423ed91fc_720w.png  The L-STF, along with L-LTF (Long Training Field), contain information that allows the device to detect the signal, perform frequency offset estimation, timing synchronization, etc. The 'L-' stands for 'legacy' and the details of the sequences used in these fields for the 20 MHz signals are the same as the legacy 11a and 11n preamble fields which allows for all 802.11 devices to synchronize to the signal.  In this experiment, we combine the above formula, combine the symbol sequence with the inverse Fourier transform, and continuously copy the generated sequence for 10 times to generate the L-STF sequence in the protocol, MATLAB code and waveform results are as follows:  **20220331094012**  20220331100258  20220331094947  **2. L-LTF**  The legacy long training field (L-LTF) is the second part in the 802.11 OFDM PLCP legacy preamble. The L-LTF is a component of VHT, HT, and non-HT PPDUs. Channel estimation, fine frequency offset estimation, and fine symbol timing offset estimation rely on the L-LTF. The L-LTF is composed of a cyclic prefix (CP) followed by two identical long training symbols (C1 and C2). The CP consists of the second half of the long training symbol.The formula for generating L-LTF is as follows:  https://pic4.zhimg.com/80/v2-7e08ba1658b9b56755324daa2731f1a3_720w.png  In this experiment, we combine the above formula, combine the symbol sequence with the inverse Fourier transform. After that, we took out the waveform at 33-64 moments of the time domain waveform and took it to the front of the sequence to act as a cyclic prefix. After that, we completely copied the generated time domain waveform twice and added it to the back of the time domain waveform to form a complete L-LTF sequence in our protocol. The MATLAB code and results for generating L-LTF sequences are as follows:  20220331095751  **20220331100315**  **20220331095823**  **3.L-SIG**  The legacy signal (L-SIG) field is the third field of the 802.11™ OFDM PLCP legacy preamble. It consists of 24 bits that contain rate, length, and parity information. The L-SIG is a component of HE, VHT, HT, and non-HT PPDUs. It is transmitted using BPSK modulation with rate 1/2 binary convolutional coding (BCC). The formula for generating L-SIG sequence is as follows:  https://pic2.zhimg.com/80/v2-d3f8206122a8a9e728fda6decf06b939_720w.png  By referring to the 801.11 protocol standard and combining with the parameter configuration of our experiment program, we can draw the time domain diagram of the training sequence, as shown below:  **20220331151935**  SIG  LTF  STF  From the above figure, combined with the protocol standard and our parameter configuration, we can easily get the positions and lengths of L-STF, L-LTF and L-SIG, as indicated in the figure above.   1. **Modulation and Coding Scheme in 802.11 (MCS)**   Rate configuration in LTE is achieved through MCS(Modulation and Coding Scheme) index values. MCS takes the factors that affect the communication rate as the columns of the table and the MCS index as the rows of the table to form a rate table. Therefore, each MCS indicator actually corresponds to the physical transmission rate under a set of parameters. Since the introduction of IEEE 802.11n, modulation and coding schemes (MCS) have been used to determine data rates for high-throughput orthogonal Frequency Division Multiplexing (HT-OFDM) wireless connections. Pre-802.11n systems using OFDM define data rates between 6 and 54 Mbps, depending on the modulation and encoding type used. At the same time, we also use other parameters in HT-OFDM, such as channel size, number of spatial streams, coding method, modulation technique and protection interval. Here we can see that each MCS is based on a combination of these parameters. For the 20 and 40 MHz channels, there are 77 different types of MCS, of which 8 are required for the 20 MHz channel and correspond to the necessary basic data rates. Partial MCS rate tables with bandwidths of 20MHz and 40MHz are listed below：    Figure. MCS rate tables **(Left:20MHz Right:40MHz )**   1. **Representation of an image (3D Matrix)**   In this experiment, because our goal is image transmission, so we also need to understand the process of MATLAB reading picture data and showing picture data.The representation of an image can take many forms. Most of the time, it refers to the way that the conveyed information, such as color, is coded digitally and how the image is stored, i.e., how is structured an image file. Several open or patented standards were proposed to create, manipulate store and exchange digital images. They describe the format of image files, the algorithms of image encoding such as compression as well as the format of additional information often called metadata.  In our experiment, the image data we read is stored in a three-dimensional matrix, and the three dimensions of this matrix respectively store the RGB information of each pixel of the image we read. After scaling the matrix and converting it to binary code stream, the binary code stream can be encapsulated into waveform in 802.11a format. The MATLAB code is shown as follows:  20220331161717  **Lab results & Analysis：**  **Task1: Explain the functions of the following six subcomponents respectively**  **Result:**   1. **ResizeImage.m**   To read the image compression, in order to better picture data encapsulation and transmission.   1. **createPSDU.m**   This function mainly implements the encapsulation of binary image data stream into PSDU**(MPDU is called PSDU in physical layer )** packets. In the process of encapsulation, we first determine some MSDU parameters and assemble a complete MSDU packet by way of insufficient length to complement 0. Then we set some parameters of the frame dawn check sequence. By dividing the data into blocks and setting the number of bits required for the MPDU header, we package the MSDU packet into the MPDU packet. Note that: MPDU length =MAC header length +MSDU bit + frame parity bit. Then, we construct the image according to the MPDU format in a circular form and get the complete PSDU packet of the image.   1. **createTxWaveform.m**   This function creates a WLAN packet (also known as PPDU) for our transmission based on the PSDU packet we pass in. In the process of creating the packet, we determine the modulation mode, the number of transmitting antennas, bandwidth and other parameters, then we can generate a baseband Non-HT packet. Of course, in the previous theoretical introduction, we also need to add Preamble Field(L-STF, L-LTF, L-SIG) to the packet header of Non-HT packet. These training sequences can obtain their waveform in time domain through inverse Fourier transform. Finally, by resampling the waveform and normalizing the signal, we can get the final WLAN packet (PPDU) that needs to be transmitted.   1. **createAWGNChannel.m**   This function is used to configure the AWGN channel environment. We can see from reading this function: When configuring the channel environment, we focus on determining the signal power, signal to noise ratio and other parameters. From the target SNR we pass in, this function can help us calculate the SNR of the current channel, so that the input signal waveform through the channel into the subsequent processing.   1. **ReceiverProc.m**   This function is used to further process the received data packets for subsequent image reconstruction. In the process of processing, we first need to obtain the position information of PSDU packet head part training sequence and at the same time to carry out downsampling of received signals. At the same time, we need to generate the corresponding FCS for MPDU unpacking. After that, we unpack the received packets. In the process of unpacking, we first need to detect the packet and adjust the offset in the packet. Then, we extract the non-HT Field part of the data packet and carry out corresponding coarse frequency deviation correction and symbol synchronization operation. After coarse frequency offset correction, we can carry out fine frequency offset correction. At the same time, we can also use the L-LTF part of PDSU packet header for channel estimation. Finally, we recovered the L-SIG part and the parameters in the packet, and corrected the entire packet with the CFO. At the same time, we use the results of the previous channel estimation to recover the bits in the PSDU packet and display the current constellation. Of course, we also need to remove the FCS from the MAC header at the end to process the MAC information.   1. **reBuildImage.m**   This function is used to reconstruct the image data after unpacking and recover the image information from the transmitter, and calculate the corresponding bit error rate in this process.  **Task2: Implement ‘16/64-QAM 802.11a Transmission and Reception’ according to the example.**  **Result:**   1. **16-QAM (MCS = 4)**   From the introduction of MCS in the previous theory section, we can know that in this lab for 16-QAM, we should set MCS to 4. The modify position is shown below:  20220331175904  Then, we only need to modify the size of the SNR to explore the corresponding changes of the received picture quality under different SNR under 16-QAM, as shown in the following figure.   1. **SNR= 23**   **20220331180148**  **Figure. Received image and constellation diagram when SNR = 23 (16-QAM)**   1. **SNR= 29**   **20220331180343**  **Figure. Received image and constellation diagram when SNR = 29 (16-QAM)**   1. **SNR= Inf**   **20220331180511**  **Figure. Received image and constellation diagram when SNR = Inf (16-QAM)**   1. **64-QAM(MCS=6)**   **(1) SNR= 29**  **20220331180823**  **Figure. Received image and constellation diagram when SNR = 29 (64-QAM)**  **(2) SNR= 30**  **20220331181037**  **Figure. Received image and constellation diagram when SNR = 30 (64-QAM)**  **(3) SNR= Inf**  **20220331181327**  **Figure. Received image and constellation diagram when SNR = Inf (64-QAM)**  **Analysis:**  As can be seen from the above recovery results, no matter whether the modulation mode is 16-QAM or 64-QAM, the image quality recovered by the receiver gradually gets better with the increase of the channel SNR, which is completely consistent with our theoretical analysis. At the same time, we can also find that when the SNR of 16-QAM is 23 and 29, the constellation of the data received by the receiver is more clearly identifiable than that of the data received by 64-QAM when the SNR is 23 and 29. This phenomenon can be explained by the conclusion in our previous experimental report: 64-QAM improves the transmission speed compared with 16QAM, enabling the transmitter to send more bit information at the same time. However, because the constellation diagram is more compact, 64-QAM is more difficult for the receiver demodulation to recover the constellation diagram. Macroscopically, 64QAM increases the bit error rate while improving the transmission rate. As a result, when the SNR of the channel is the same, the quality of the constellation map recovered at the receiver using 64QAM is lower than that of 16QAM.  **Task3：Compare the BER under different SNR (HiperLan/2 Channel Models).**  **Result&Analysis:**  **Part 1: Model A: fd = 0 but have different MCS**  For this part, In this part, we mainly explore the influence of different modulation methods on the error packet rate under different SNR when we use Model A of Hiperlan /2 channel. I use the MATLAB document example **“802.11p and 802.11a Packet Error Rate Simulations”.** When using the channel model A，and MCS is 0、2、4、6, fd and Doppler is all equal to 0, I can get the result as fellows: **(I'm sorry that's MCS in the legend)**  20220331211033  Figure. PER vs SNR under different MSC in hiperlan/2 model A  As can be seen from the figure above, for different MCS, within different SNR ranges, the packet error rate is different to some extent. However, I found that this difference could not be quantified in a better way, so I considered to analyze and compare our results from vertical and horizontal perspectives. From the overall picture trend, we can see that the PER decreases as the Signal-to-Noise ratio (SNR) increases, regardless of which modulation we choose. This is because as the signal-to-noise ratio increases, the packet error rate decreases as the noise becomes less disruptive to the decoding. From the horizontal comparison of the figure, because the images with different modulation sequences are relatively scattered, we draw similar packet error rate intervals to compare the SNR. It can be seen that when we compare the fixed packet error rate range, the modulation SNR reaching the same packet error rate interval also increases with the increase of modulation order. The analysis of this problem is actually consistent with our analysis in the previous task, because the higher order modulation scheme increases the transmission rate while causing the packet error rate (is the same as the BER) to be higher than the lower order modulation mode under the same SNR. Therefore, for higher order modulation processes, better transmission channels and less noise interference are needed to achieve the same packet error rate range.  **Part 2: From Model A to E: MCS = 4 and fd = 0**  In this part, we also use the hiperlan/2 channel model but we set MCS to 4 and fd, Doppler is all equal to 0. In this time, we obtained the following results by changing the different channel model. So,I can get the result as fellows:  20220331212218  Figure. PER vs SNR under different channel model in hiperlan/2, MCS is 4  From the image of the results above, we can clearly see that different channel models have a greater impact on the transmission effect, and different channel models have different results.  When we select the local features of the image to study, we can find that: In general, the error packet rate of each channel model tends to decrease with the increase of the SNR, and when the SNR is in the range of 19.5~20.5, all channel models present this trend. At the same time, we can also clearly see that for the three A,B,D channel models, when the SNR ranges from 19.5 to 20.5, the packet error rate has a great decreasing trend, and the decreasing trend is much larger than the increasing trend in the previous interval. For E channel model, the decreasing trend of packet error rate does not improve significantly in this SNR interval. For the C channel model, although the packet error rate has a decreasing trend, the trend is not very prominent. Moreover, it is worth noting that the packet error rate of the C channel model in the range of 18.5-19.5 actually increases with the increase of the SNR, which is contrary to the previous theoretical analysis. However, for these trends, we cannot make a very accurate qualitative analysis because we do not have a detailed understanding of the specific situation of the channel.  In a conclusion: According to our analysis of the experimental results, we can find that channel model D is the channel with the best transmission effect when the SNR is high, channel model C is the channel with the best transmission effect when the SNR is low, and channel model E is the channel with the worst transmission effect in all the SNR range. | |
| **Experience**  Through this lab, I have a more intuitive understanding of the how use MATLAB to achieve IEEE 802.11a and use IEEE 802.11a to transmission image. And in this lab, we also analyze the many theoretical knowledge in IEEE 802.11 and the function of different fields. At the same, I analyze the influence of MCS, SNR and channel model on PER, and get these results.  First of all, I know, this experiment is very informative and we can harvest a lot things in this lab. But I think, the biggest harvest or in this experiment to harvest MATLAB modular object-oriented programming ideas. In this experiment, our 801.11a simulation file is the entry function of our entire program. We can find many function calls in this entry function. When we try to open these functions, we find that they are in other.m files. This also reflects the MATLAB object-oriented programming ideas of the benefits: the realization of some specific functions of the program section into a specific function or module, in the whole program operation only need to call these functions or modules in turn in the main function. Through this programming idea, we can clearly see the position and function of each module in the 802.11a simulation function, and it is easy to read, learn or check and debug these module functions one by one.  Then, at the end of the experiment, we also explore a channel model often used in WiFi System-- Hiperlan/2 channel model. We explore the relationship between packet error rate and SNR under different MCS or different channel models from two different perspectives. Through the exploration of different channel models, we can draw the conclusions: channel model D is the channel with the best transmission effect when the SNR is high, channel model C is the channel with the best transmission effect when the SNR is low, and channel model E is the channel with the worst transmission effect in all the SNR range. However, it is a pity that due to the limited data, we have not been able to establish these five channel models and their specific application scenarios. In this part of the exploration, I think the most important thing is still the conclusion we explored before: Although the high-order QAM modulation model improve the transmission rate and efficiency compared with low-order QAM modulation model, it will inevitably increase the bit error rate. This is because the constellation diagram is more dense, increasing the difficulty of the receiver demodulation and symbol decision.  **More research：**  We also discussed the influence of fd (Doppler frequency deviation) on PER under the same other conditions(MCS= 4 SNR= 20 and we use the hiperlan/2 model A). Finally I get the result figure shown below:  20220331231122  Figure. PER vs Different Doppler frequency deviation  So, from the figure above, we can find that the PER is increased with the fd inceased. Therefore, when fd is high, the PER will be very high and the value is 1, which is a bad receive result.  Finally, I paste the screenshot of the class exercise in the last lab class:  课堂练习1  Figure. Class exercise 1  课堂练习2  Figure. Class exercise 2  通过这个实验，我对如何使用MATLAB实现IEEE 802.11a和如何使用IEEE 802.11a传输图像有了更直观的了解。在这个实验室中，我们还分析了IEEE 802.11的许多理论知识和不同领域的功能。同时分析了MCS、信噪比和信道模型对PER的影响，得到了这些结果。  首先，我知道，这个实验是非常有益的，我们可以在这个实验收获很多东西。但我认为，最大的收获还是在这个实验中收获了MATLAB模块化面向对象编程的思想。在本次实验中，我们的801.11a仿真文件是整个程序的入口功能。我们可以在这个入口函数中找到许多函数调用。当我们试图打开这些函数时，我们发现它们在其他函数中.m文件。这也体现了MATLAB面向对象编程思想的好处:将一些特定函数的程序部分实现为特定函数或模块，在整个程序操作中只需调用这些函数或模块依次在主函数中运行。通过这种编程思想，我们可以清楚地看到各个模块在802.11a仿真功能中的位置和功能，并且这些模块功能易于阅读、学习或逐一检查和调试。  在实验的最后，我们还研究了WiFi系统中常用的信道模型——Hiperlan/2信道模型。我们从两个不同的角度探讨了不同MCS或不同信道模型下的误码率与信噪比的关系。通过探索不同的信道模型,我们可以得出结论:通道模型D是最好的渠道传播效果高信噪比时,通道模型C是最好的渠道传播效应,当信噪比很低,和信道模型E是最差的信道传输的效果在所有信噪比范围。但遗憾的是，由于数据有限，我们未能建立这五种通道模型及其具体应用场景。在这一部分的探索中，我认为最重要的还是我们之前探讨的结论:虽然高阶QAM调制模型比低阶QAM调制模型提高了传输速率和效率，但不可避免的会增加误码率。这是因为星座图比较密集，增加了接收机解调和符号判定的难度。  **更多研究：**  我们还讨论了在其他相同条件下(MCS= 4 SNR= 20，我们使用hiperlan/2模型A) fd(多普勒频率偏差)对PER的影响，最后得到如下结果图:(见上面的结果所示)  因此，从上图可以看出，PER随着fd的增加而增加。因此，当fd值很高时，PER值会很高，其值为1，这是一个不好的接收结果。  最后，我粘贴了上一节实验课的课堂练习的截图: (见上面的截图) | |
| **Score** | 自评分数：98 |