Research and Simulation of Physical Layer Abstraction Model for Next Generation WiFi Integrated Simulation

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Abstract. In this paper, we study the physical layer (PHY) interference abstraction. First, we analyse the physical layer abstraction methods for the next generation wireless local area network (WLAN), including high frequency WLAN such as institute of electrical and electronics engineers (IEEE) 802.11ay and low frequency WLAN such as IEEE 802.11ax, and describe their implementation details. Then the received bit mutual information rate (RBIR) and the mean mutual information (MMIB) of PHY abstraction methods are studied separately. We design process of two PHY abstraction methods and implement them in the simulation platform. Some corresponding simulation results are gived. The simulation results show that the RBIR method accurately predicts link level simulation performance in a simple mapping method.

Keywords: PHY abstraction · RBIR · MMIB · WLAN

1 Introduction

With the large-scale application of smart terminal devices such as PCs and PDAs, the demand for wireless network technologies is increasing rapidly. As a product of computer network and communication technology, Wireless Local Area Networks (WLAN) has become a choice of personal communication and has developed rapidly. A number of research institutes, represented by the Institute of Electrical and Electronics Engineers (IEEE), have developed a series of protocol standards for different scenarios, which have promoted the practical use of WLAN.

With the rapid development of computer technology, the simulation technology has also undergone a leap-forward development. In modern scientific research, with the increasing difficulty of research and the increasing cost, the importance of simulation has become higher and higher. In modern scientific research, it is impossible for every experiment to be realized. Instead, advanced computer technology is used to simulate various physical realizations, which can save a lot of manpower and material resources and financial capacity. Therefore,

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all scientific research institutions and equipment manufacturers conduct software simulation research when conducting scientific research, and then further improve the simulation program through actual hardware physics experiments, so that software simulation can provide simulation results to design hardware. And because of the variety of scenes, the actual products will have various complicated existing network problems at work, and the analysis of the problems requires a lot of manpower, and it is more difficult to reproduce in the laboratory environment. Therefore, a link-level and system-level integrated Wi-Fi simulation platform is required. It supports the configuration of the live network scenario model and the introduction of live network data for virtual reproduction of the network in the real environment for network performance presentation, problem root cause analysis, and algorithm design. For example, the next generation WLAN–802.11ax explicitly requires integrated simulation.

One of the biggest technical challenges of integrated simulation is the physical layer abstraction problem. The purpose of physical layer abstraction is to simulate the receiving process of data packages, to model the interference of Signal to Noise Ratio (SNR) of data packages under different subcarriers accurately, to make it more realistic, and to provide reference for system simulation. Therefore, in the simulation design, the correctness of the calculation of Packet Error Rate (PER) will greatly affect the performance of the simulation design. The computational problem of PER can be summarized as interference abstraction. There are many ways to abstract the physical layer, such as Exponential mapping (EESM), MMIB, RBIR, Constrained Capacity (CC) and so on. Among them, MMIB and RBIR are applied to next generation WLANs 802.11ay and 802.11ax respectively. Therefore, the method of interference abstraction in different forms is an important research direction.

In [1–4], using the mathematical theory of information theory, MIMO channel matrix is equivalent to multiple SISO channel matrices, and the mutual information of bits is calculated. Then the OFDM system scenario of ML receiver is modeled and the general formula of SNR mutual information on each subcarrier is calculated. According to different modulation modes, the calculation formula of mutual trust is deduced. In [5–8], OFDM system does not transmit data in the form of bits, but uses symbols as transmission tools. First, mutual information of each symbol (subcarriers) is calculated, and then the average bit mutual information is obtained. The expression derived from RBIR is too complex and usually uses mapping method. However, the existing studies only focus on specific criteria, without in-depth study of the correlation and difference between different physical layer abstraction methods.

This paper systematically analyses and studies the physical layer abstraction methods for the next generation WLAN, including high frequency WLAN and low frequency WLAN, and analyses their respective advantages and suitable methods for each protocol standard. Then the corresponding simulation results are given. The physical layer abstraction methods of 802.11ax, RBIR and 802.11ay, MMIB, are analyzed separately. Then the similarities and differences are given. The simulation implements the two abstract methods of interference and gives the corresponding simulation results.

The structure of the paper is described briefly as follows. Section 2 describes the details of PHY abstraction methods, such as RBIR and MMIB and so on. Section 3 describes how to implement PHY abstraction methods in the simulation platform and provides the simulation parameter configuration and the simulation results are given and some different methods of PHY abstraction are discussed.

2 PHY Interference Abstraction

2.1 General Introduction

The purpose of PHY abstraction is to accurately predict PER of a data packet, not simulating the actual receiving process of the physical layer which is very difficult to implement. It pays close attention to large-scale fading and small-scale fading of the every channel. The phy abstraction should base on a rule that it is computationally infeasible to simulate actual receiving process of some STAs' physical layer form APs' packet in a WLAN network simulator. The requirement for the PHY abstraction are accurate, computationally simple and easy to implement in simulation. And the PHY abstraction is independent with channel models, not closely associated with the channel. Interference models and MIMO model can be easily derived by simple by abstraction.

System-level simulation generally proves the average system performance, which helps to plan the network topology. For such simulation, the average performance of the system is reflected in the average SNR distribution of the whole cell, which is influenced mainly by the network topology and channel fading. According to modulation and coding scheme (MCS), each subscriber's average SNR was then mapped to the appropriate PER, which based on link-level SNR tables. The calculation of SNR to PER is so complicate that look-up tables is needed to use. The PHY abstraction use mapping function to get the PER of a packet.

In system-level simulation, data packets can not be sent always over AWGN channels. Wireless channel is the most complex, and its fading characteristics depend on the radio wave propagation environment. Different environments have different characteristics of transmission. Wireless channel may be very simple linear transmission, or may be interfered by many different factors. So if the modulation mode is OFDM, different frequency has different the channel gain or loss. In OFDM, the coded symbols of a data packet are sent on lots of subcarriers, so the SNR values which the receiver get are not similar. In addition, because of multipath effect, the channel gain of subcarriers can be very different.

PHY abstraction functions are designed to predict the instantaneous link performance effectively. There are different abstraction methods for kinds of systems such as OFDM, SC and so on. The final purpose of the PHY abstraction is to obtain the packet error rate of a specific fading channel which is much the same with actual receiving PER. System-level simulation will get H matrix and SNR on each subcarrier. Then the physical layer abstraction function is used to get an equivalent SNR (average or other function). The PER of the data package is obtained by SNR-PER mapping table in the Gauss channel. This is the general simulation process. as shown in Fig. 1.

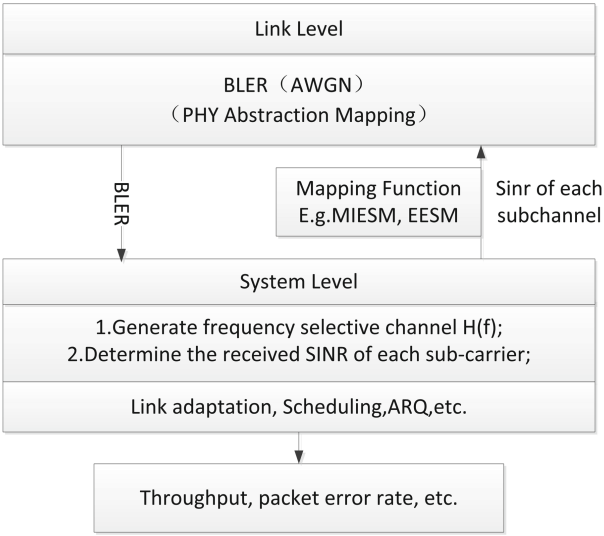

Fig. 1. Relationship of the link-level and system-level.

For all the ESM methods, the channel model and the phy layer for generalized transmission relationship:

$$Y_{output} = H_{channel} X_{input} + U_{AWGN} \tag{1}$$

Y_{output} is the received packet signal vector X_{input} is the transmitted packet signal vector or the transmitted symbol stream, $H_{channel}$ is mimo (or siso) channel matrix, U_{AWGN} is the noise vector, also called add-Gaussian noise.

In general, The base rule is to get an equivalent average SNR ($SNR_{effective}$) in a calculated bits block. The average SNR is not different from the initial SNR. It can represent average SNR of all subcarriers symbol. So, we can not need multipath channel SNR to PER table which is more and difficult to measure, and all we need only AWGN channel SNR to PER table which can get equivalent PER using the effective SNR. The function is different according to the coding type, modulation mode and MCS value. The general expression of PHY abstraction is written as follows:

$$SNR_{effective} = Func^{-1}\left\{\frac{1}{N}\sum_{n=1}^{N} Func(SNR_n)\right\} \tag{2}$$

Where $SNR_{effective}$ is the equivalent or average SNR, SNR_n is the SNR of the n^{th} sub-carrier which are equal in the AWGN channel and different in the multipath channel, N is total number of all subcarriers of a packet determined by channel bandwidth and modulation mode and $Func\left(\bullet\right)$ is an input function which is reversible.

For example, a simple SISO case:

$$y = hx + u \tag{3}$$

where y is a received data, x is a transmitted data, h is channel impulse response at each subcarrier, u is a noise.

Then, $SINR_n$ can be calculated as:

$$SINR_n{=}\frac{\left|h\right|^2 \varepsilon_x}{\sigma_n^2} \tag{4}$$

where ε_x is a signal strength, σ_n^2 is noise variance.

2.2 RBIR

It is also called Mutual Information ESM (MIESM). It is a nonlinear mapping from post SNR to symbol-level mutual information [2]. For PHY actual simulation, receiver receives data packets in the form of bits. So we need to calculate the received bit mutual information rate called RBIR, as shown in Fig. 2. For M-QAM, the above function can be described as follow:

$$Func\left(SNR; M\right) = \log_2 M - \frac{1}{M}\sum_{m=1}^{M} E_U \left\{\log_2\left(\sum_{k=1}^{M}\exp\left[\left(\left|U\right|^2 - \left|\sqrt{SNR}\left(s_k - s_m\right) + U\right|^2\right)\right]\right)\right\} \tag{5}$$

where U is the Gaussian random variable which has best zero-mean and low variance similar to the white noise. The M of function can be 4, 6, and 8 and so on.

$$\gamma_{eff} = \alpha_1 \varphi^{-1}\left(\frac{1}{J}\sum_{j=0}^{J-1}\varphi\left(\frac{\gamma_j}{\alpha_2}\right)\right) \tag{6}$$

We should measure all SNR to PER table in the AWGN channel for different MCS and different coding type. Then these curves can be used for reference by the physical layer abstraction methods.

The PHY abstraction based on RBIR has been described in the following diagram.

2.3 MMIB

MMIB called Mutual Information based approach. Each bit experiences a different equivalent bit-channel because of the different characteristic of different modulation mode [1], as shown in Fig. 3.

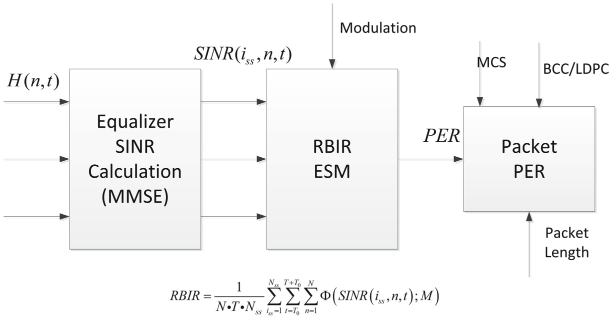

Fig. 2. RBIR based PHY abstraction procedure.

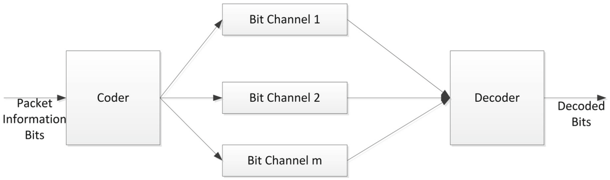

Fig. 3. MMIB based PHY abstraction procedure.

Mutual information of the equivalent channel is:

$$Infor\left(b,L\right) = \frac{1}{n}\sum_{i=1}^{n} Infor(b_i, L(b_i)) \tag{7}$$

where n is the number of bits per constellation, and $Infor(b_i, L(b_i))$ is the mutual information computational function for the input i-th bit.

Mean mutual information through N sub-carriers over the codeword:

$$MInfor = \frac{1}{mN}\sum_{n=1}^{N}\sum_{i=1}^{m} Infor(b_i^n, L(b_i^n)) \tag{8}$$

Since mutual information $I(b_i, LLR(b_i))$ is a function of constellation and SNR, mean mutual information is

$$MInfor = \frac{1}{mN}\sum_{n=1}^{N}\sum_{i=1}^{m} I\left(b_i^{(n)}, L\left(b_i^{(n)}\right)\right) = \frac{1}{N}\sum_{n=1}^{N} Infor_m\left(SNR_n\right) = \frac{1}{N}\sum_{n=1}^{N} Func\left(SNR_n\right) \tag{9}$$

Effective SNR mapping (ESM) function is derived for each modulation as follows:

$$\varPhi\left(x\right) = I_m\left(x\right) = \sum_{k=1}^{K} a_k J\left(c_k\sqrt{x}\right) \tag{10}$$

Detailed values of each parameter are shown in the Table 1.

Table 1. ESM function parameter numerical value.

Modulation	Numerical approximation
BPSK	K = 1, a = [1], c = [$2\sqrt{2}$]
QPSK	K = 1, a = [1], c = [2]
16-QAM	K = 3, a = [0.5 0.25 0.25], c = [0.8 2.17 0.965]
64QAM	K = 3, a = [1/3 1/3 1/3], c = [1.47 0.529 0.366]

Here the above function $J(x)$ can be calculated by using the value in the Table 2:

Table 2. ESM MMIB function parameter numerical value.

Functional expression	Condition
$i_1x^3 + j_1x^2 - k_1x$	$1.6363 \geq x$
$1 - \exp\left(i_2x^3 + j_2x^2 + k_2x\right)$	$\infty \geq x \geq 1.63$

where $i_1 = -0.0421, j_1 = 0.2090$ and $k_1 = -0.0064$ for the first expression, and where $i_2 = 0.00181, j_2 = -0.143$ and $k_2 = 0.0550$ for the second expression.

2.4 Comparison Between RBIR and MMIB

Firstly, the advantages and disadvantages of the two PHY abstraction methods are summarized.

RBIR: The RBIR get match with AWGN results using the above parameters, but do not see results for D-NLOS or UMi channel. The mapping only needs to use AWGN curves and agreeing on AWGN curves is an easier job. Inverting the ESM function above is not that straight forward. Results for different channel models might indicate the need for channel model dependent parameters too. If the scenario is SISO models or MIMO models with linear receivers, a recommended SNR to RBIR mapping is used which is defined by a lookup table unique to each modulation. If channel dependency uses RBIR methods, RBIR functions are obtained by performing link simulations and optimizing parameters for each MCS. A different value of RBIR is obtained for each code rate, even though the modulation is fixed. Does not conform to the definition of information metric. For ML receiver, RBIR modeling needs four parameters for each MCS that are calculated by link simulations. Multiple simple examples also suggest that the RBIR approach as defined can not pass even simple sanity check or basic properties as expected from a mutual information metric.

MMIB: The MMIB can get match (with in 1 dB) with the AWGN curve for UMi channel model (both LOS and NLOS) using the above parameters, but do not see results for D-NLOS. The mapping only needs to use AWGN curves and agreeing on AWGN curves is an easier job. Inverting the ESM function above is not that straight forward. Results for D-NLOS channel might indicate the need for channel model dependent parameters too. If the scenario is SISO models or MIMO models with linear receivers, a recommended SNR to MMIB mapping is used which is defined by a function unique to each modulation. These SNR to MMIB/RBIR mapping are found to be close and hence no difference is expected in these simulations. The dealing methods are similar between MMIB with RBIR. If channel dependency uses MMIB methods, MMIB functions are generated by Numerically obtaining (by Monte-Carlo simulation and numerical integration of LLR PDFs obtained from a Gaussian matrix channel and a constellation mapping model), the theoretical true bit-level MI of a matrix channel and approximating this function with numerical approximations. No AWGN or link simulations are used at any point, as these functions are independent of the underlying system. Because the MMIB is based on mathematical theory. It is derived from information theory. So MMIB functions for ML are capacity measures defined for the underlying bit channel induced by a modulation constellation and the matrix channel. It satisfy all the properties of a bit-level mutual information metric like the SISO MI metrics and not surprisingly show good prediction for ML.

3 Simulation and Performance Evaluation

3.1 Simulation Platform NS-3

NS-3 is a open source, free and new software. It is a network simulator not only for the wireless communications but also for the cable communications. It bases on discrete event simulation which is more authentic than discrete time simulation.

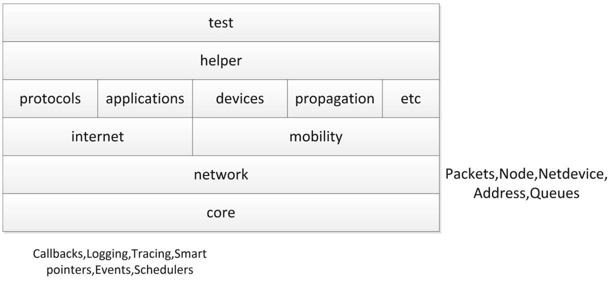

Fig. 4. NS-3 software structure.

We do not study the whole content of NS-3 which is too much and too difficult. Figure 4 shows base structure of NS-3. It is very comprehensive and can simulate many communication modes, even building a WLAN.

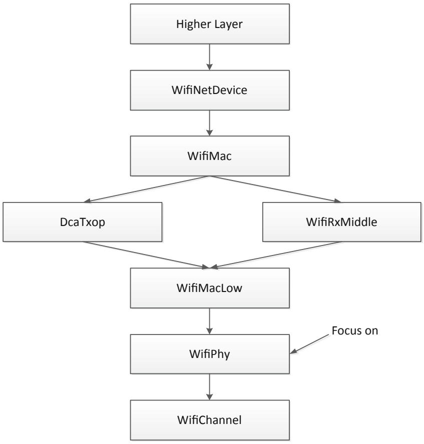

Fig. 5. NS-3 wifi model base structure.

Figure 5 shows base structure of NS-3 wifi model. At the same time, it is also a data packet transmission process. And the simulation mainly pays attention to WifiPhy model and WifiChannel model.

3.2 Implementation of RBIR and MMIB

RBIR: If receiver is receiving a packet, some other packet may be sended to receiver for interference.

(1) Channels generates not only for the both sides of communication but also for the both sides of interference communication. First generates channel impulse response in frequency domain.
(2) According to the number of spatial stream and sub-carriers and initial SNR that is got by the receiver antenna, calculate the decode output SNR. According to frequency-domain channel impulse response calculate equivalent channel matrix. Based on the deduced expression, calculate SNR each sub-carrier and every spatial stream.
(3) According to mapping table or mapping function, calculate RBIR vector through SNR vector. Then calculate RBIR vector to average RBIR.
(4) According to reverse mapping table or reverse mapping function, calculate effective SNR by average RBIR.
(5) According to AWGN channel SNR to PER table, calculate PER for the bits block.

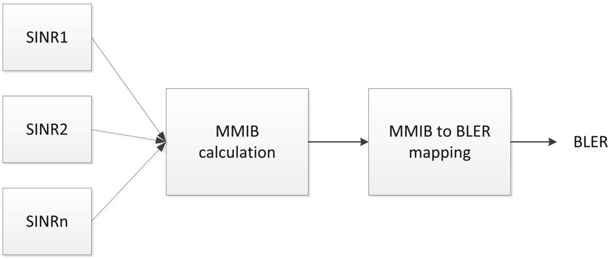

Fig. 6. MMIB produce in NS-3.

(6) Calculate the final PER of a packet and determine if this subframe is successfully received.

$$Uniform\,(0,1)\begin{matrix} > PER \rightarrow \text{transmission success} \\ \leq PER \rightarrow \text{transmission fail} \end{matrix} \tag{11}$$

MMIB: If receiver is receiving a packet, some other packet may be sended to receiver for interference, as shown in Fig. 6.

(1) Channels generates not only for the both sides of communication but also for the both sides of interference communication. First generates time-domain channel impulse response, then calculate channel impulse response in frequency domain.
(2) According to the number of spatial stream and sub-carriers and initial SNR that is got by the receiver antenna, calculate the decode output SNR vector.
(3) According to mapping function one, calculate MMIB vector through SNR vector.
(4) According to mapping function two, calculate BLER by MMIB for the bits block.
(5) For MMIB to BLER mapping the AWGN reference fitting curves for each MCS obtained from Phy layer simulations can be stored. The function is general with some parameters to be determined.

3.3 Design of Simulation Scenarios and Configuration of Simulation Parameters

This simulation was completed on the NS-3 802.11ax platform built by our lab. The simulation scenario is set to 1 cell, 1 AP and 1 STA. The channel model is ITU Winner channel, and the scene are indoor rooms.

Table 3 is about simulation parameters.

Table 3. Simulation parameters

Parameters	Number
AP	1
STA	1
Packet length	1500byte
Data MCS	1–9
TYPE	SU-MIMO
AP Antenna	2
STA Antenna	2

3.4 Performance Evaluation

In this subsection, we analyze the simulation results. As can be seen, the thick lines represents AWGN channel, and the thin lines represents ITU channel and RBIR methods. They are not different. So it is recommended to use RBIR methods to predict the instantaneous link performance (Fig. 7).

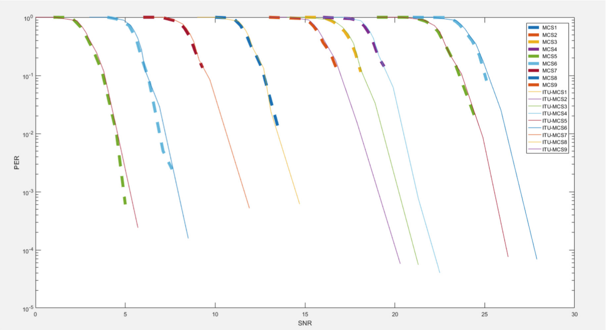

Fig. 7. SNR-PER of RBIR.

4 Conclusion

Firstly, this paper gives a general analysis of physical layer interference abstraction, and points out the main problems and solutions in wireless communication interference abstraction from link performance awareness.

For further analysis, two different interference abstraction methods used in next generation wireless communication systems are analyzed and studied in this paper. The application scope and performance of these two algorithms are compared and analyzed, and the corresponding simulation design is given.

Finally, theoretical analysis and simulation results show that RBIR is more suitable for the next generation WLAN-802.11ax and MMIB is more suitable for the next generation WLAN-802.11ay. RBIR and MMIB, Both methods are based on the average mutual information criterion and are accurate evaluation of transmission error probability.

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