Simulate 802.11b Channel within NS2

Wu Xiuchao, SOC, NUS

wuxiucha@comp.nus.edu.sg

This document describes how to simulate one 802.11b channel in NS2. It focuses on how to simulate wireless transmission error due to bad channel quality. That means BER need to be considered to determine whether one frame is transmitted correctly. To get BER, SNR need to be calculated. The following sections describe current simulation of transmission error in NS2, the methods to calculate SNR and BER, and how to incorporate these methods into NS to achieve our aim --- to simulate 802.11b channels as exactly as possible.

1. 802.11b Channel in NS2

NS2 uses Phy/WirelessPhy to simulate 802.11b wireless channel.

NS2 implements several propagation models, Free Space, Two Ray Ground, and Shadowing models to predict the signal power received by the receiver. The signal strength is used to determine whether the frame is transmitted successfully. Free Space model is used to simulate path loss of wireless communication when line-of-sight path exists between transmitter and receiver. Two Ray Ground model is used when line-of-sight path exists and reflection of ground is considered. Shadowing model simulates shadow effect of obstructions between the transmitter and receiver. It mainly is used to simulate wireless channel in in-door environment. One extension implements Ricean model [B1] to simulate the effect of the mobile terminal movement.

NS2 mainly uses thresholds to determine whether one frame is received correctly by the receiver [B2]. NS2 sets one signal strength threshold (CSThresh_) to determine whether one frame is detected by the receiver. If the signal strength of the frame is less than CSThresh_, this frame is discarded in PHY module and will not be visible to MAC layer. NS2 has another threshold (RxThresh_) for the signal strength of one frame received by the receiver. If one frame is received and received signal strength is stronger than RxThresh_, the frame is received correctly. Otherwise, the frame is tagged as corrupted and the Mac layer will discard it.

When multi-frames are received simultaneously by one mobile node, it calculates the ratio of the strongest frame’s signal strength to the signal strength sum of other frames. NS2 has one threshold (CPThresh_) for this ratio. If it is larger than CPThresh_, the frame will be received correctly and other frames are ignored. Otherwise, all frames are collided and discarded.

In a word, NS2 use thresholds to determine whether one frame is received correctly by the receiver. BER has not been considered.

The following parameters are commonly used to simulate one 802.11b channel with CCK11 in NS2. These values are based on the specification of Orinoco 11b Card [B3].

The Antenna height of transmitter and receiver is 1.5m.
The propagation model is TwoRayGround model.

```
Antenna/OmniAntenna set Gt_      1                    //Transmit antenna gain
Antenna/OmniAntenna set Gr_      1                    //Receive antenna gain
Phy/WirelessPhy set L_ 1.0                            //System Loss Factor
Phy/WirelessPhy set freq_ 2.472e9                     //channel-13. 2.472GHz

Phy/WirelessPhy set bandwidth_ 11Mb                   //Data Rate

Phy/WirelessPhy set Pt_ 0.031622777                   //Transmit Power
Phy/WirelessPhy set CPThresh_ 10.0                    //Collision Threshold
Phy/WirelessPhy set CSThresh_ 5.011872e-12            //Carrier Sense Power
Phy/WirelessPhy set RXThresh_ 5.82587e-09             //Receive Power Threshold; calculated under TwoRayGround model by tools from NS2.

*Mac/802_11 set dataRate_ 11Mb                        //Rate for Data Frames
*Mac/802_11 set basicRate_ 1Mb                        //Rate for Control Frames
```

But there are some errors in this simulation script. Firstly, 25 meter is the receiving range in closed environment. When the environment is closed environment, the propagation model is very complex. Shadow and Multi-Path Fading should be considered. So the shadowing model should be used and RXThresh_ should be calculated by shadowing model if we want to simulate one closed environment. Secondly, this script uses receiver sensitivity as CSThresh_ (Carrier Sense threshold). Receiver sensitivity is the received signal power with which BER is approximately 1.0E-5. Carrier Sense threshold means that, if received signal power is less than this value, the receiver can not detect this frame. So this usage is wrong.

If CSThresh_ and RxThresh_ are only used to determine sense range and receive range and the effect of BER and SNR to frame loss is not considered, these errors will not cause big problems. Otherwise, we should be more careful. The following paragraphs are some of my opinions.

If we want to simulate one Orinoco 802.11b 11Mbps PC card in closed environment, the range should be 25m according to Appendix B. The propagation model should be shadowing model and shadowing factor should be selected according to the specific environment simulated by you.

If we want to simulate one Orinoco 802.11b 11Mbps PC card in open environment, the range should be 160m according to Appendix B. The propagation model is TwoRayGround model.

If you want to simulate one opened environment with movement of the transmitter and receiver, the small scale fading caused by movement should be considered and Ricean model should be used. (Ricean model uses TwoRayGround model to calculate mean receiving power and adds fading effect to it.)

<Table 1> Environments, Propagation models, Range, and RxThresh_ for Orinoco 802.11b

Parameters	**Open**	**Open + Movement**	**Closed**
Propagation Model	TwoRayGround	Ricean	Shadowing
Range	160	160	25
RXThresh_	1.15126e-10 (TwoRayGround)	1.15126e-10 (TwoRayGround)	Calculated by Shadowing model with different parameters corresponding to different environments.

2. Add SNR & BER into NS2

NS2 use threshold to determine whether one frame is received correctly by the receiver. In order to add SNR & BER into NS2, there are two problems to be solved firstly.

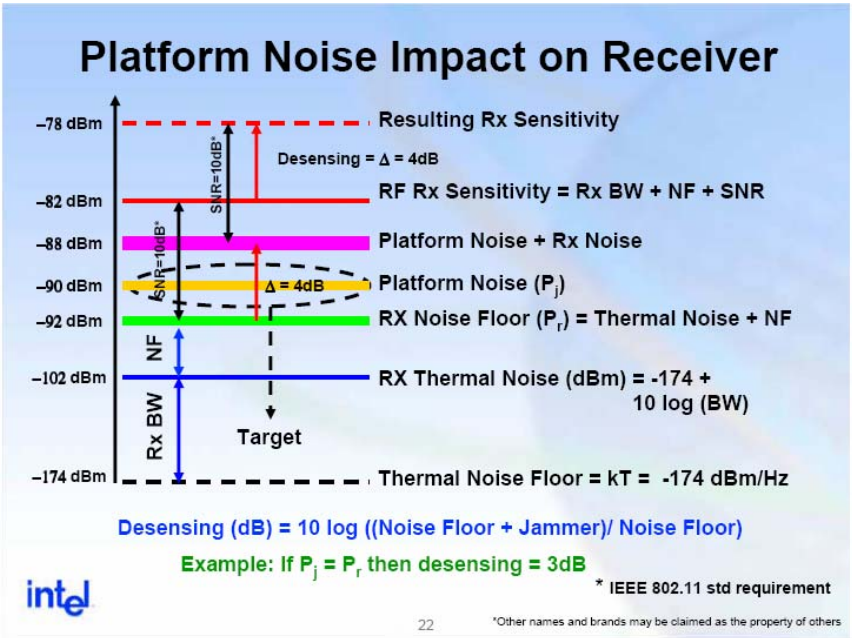
1. How to calculate SNR in NS2?
2. How to calculate BER from SNR?

2.1 Calculate SNR

SNR means Signal to Noise and interference Ratio. In NS2, the signal strength of one frame can be calculated by corresponding propagation model and distance between the transmitter and receiver. The problem is how to get the value of noise and interference.

Noise includes noise generated by the receiver and noise from environment. Interference means other frames received by the receiver simultaneously. Because different environments have different noise distribution, we won't simulate environment noise in our project.

Noise generated by the receiver includes thermal noise and platform noise. The following figure describes the factors which affect receiver sensitivity (Different products may have different receiver sensitivity since their platform noise may be different. And there are different receiver sensitivity for different data rate due to different thermal noise). This figure can also give help to calculate the receiver noise.



<Figure 1> 802.11b Card Receiver Sensitivity

Receiver sensitivity is the received signal power with which BER is less than 10 ^ (-5). To achieve this BER, SNR should be approximately 10. So we can calculate receiver's noise from receiver sensitivity of one card (decrease receiver sensitivity by 10dB).

CSThresh_ is used in PHY module to define carrier sense range. It should be identical to the receiver's noise floor. **Because 802.11b channel use BPSK to transmit preamble of one frame, CSThresh_ of PHY module should calculated from the receiver sensitivity of BPSK.** RxThresh_ should be a little less than receiver sensitivity and larger than CSThresh_. It should be calculated according to range and propagation model.

In NS2, it's MAC but PHY module which knows the interference caused by other frames. So SNR should be calculated in MAC module.

If only one frame is receiving by the receiver, the SNR is calculated by the following formula.

$$SNR = 10\log\left(\frac{Rx\_Power}{Noise\_}\right)$$

* Rx_Power is the frame signal strength at the receiver. It is calculated by propagation model.
* Noise_ should be calculated from the receiver sensitivity of the data rate used by the frame.

If other frames arrive to the receiver when it is receiving one frame, the SNR of this receiving frame is,

$$SNR = 10\log\left(\frac{Rx\_Power}{Noise\_ + \sum_{i=1}^{i-1} Rx\_Power_i}\right)$$

* Rx_Power_i is the signal strength of other frames at the receiver.

2.2 Calculate FER from SNR

When SNR and modulation method are known, BER can be derived theoretically. It also can be gotten by empirical curves measured for particular product. Appendix A gives the relationship between BER and SNR & Modulation of Intersil HFA3681B chipset under AWGN channel model. It also gives the relationship derived theoretically. We will use Intersil HFA3861B empirical curves to simulate wireless transmission error of one 802.11b channel. The first table of Appendix A will be used calculate BER from SNR.

Because Preamble, PLCP header, data of one 802.11b frame may be transmitted with different modulation scheme and different modulation schemes have different receiver noise floor, we should calculated their SNR, BER separately. After that, we can calculate FER of that frame and determine whether the frame is received correctly. One module ErrorModel80211 is added into NS2 to calculate SNR and FER.

2.3 Resulting Mechanisms for Receiving Frames

After SNR & BER calculation is added into NS2. NS2 will use threshold and BER to determine whether one frame is received correctly. CSThresh_, RxThresh_, and CPThresh_ are still here. RxThresh_ may be calculated with large range in order to let frames suffer high BER. CPThresh_ is still 10.

The receive procedure is described in the following paragraphs.

PHY module:
If signal strength is less than CSThresh_, the frame is discarded immediately.
Else if signal strength is less than RxThresh_, the frame is tagged as corrupted and sent to MAC
Else the frame is sent to MAC.

MAC module:
If other frames arrive when the frame is receiving, the signal of other frames is added to noise.
Calculate SNR and BER.
Calculate FER according to frame length.
Use random number to judge whether the frame should be corrupted. If it should be corrupted, the frame is tagged as corrupted.

If the frame is tagged as corrupted, the frame will be discarded later.
Otherwise, the frame is received correctly.

3. 802.11b Channel Used By Us

In our project, we need to estimate link characteristics of one 802.11b channel. The purpose is to improve TCP performance when the last link of one internet path is WLAN. Thus infrastructure mode is used. Used as internet access link, WLAN is designed to be used in door. Thus we'll simulate one in-door 802.11b channel. So shadowing propagation model is used.

When path loss exponent (one parameter of shadowing model) is 4, shadowing model can simulate Orinoco11b card (Appendix B) in closed environment very well. For example, in one closed environment, the range for CCK11 is 25m. If transmitting power is 0.0316W, the frame signal power at 25m is 7.55033e-12≈-81.2dBm. It is very close to Orinoco11b card's receiver sensitivity for CCK11 (-82dBm). The frame signal power at 50m (the range for BPSK) is 4.71896e-13≈-93.3dBm. It is very close to Orinoco11b card's receiver sensitivity for BPSK (-94dBm).

But shadowing model can not simulate Cisco Aironet350 (Appendix C) very well. When path loss exponent is 3.6, shadowing model can simulate Cisco Aironet350 (Appendix C) for BPSK well. The frame signal power at 107m (range for BPSK) is 4.61258e-13≈-93.4dBm which is close to -94dBm (receiver sensitivity for BPSK). But the frame signal power at 46m (range for CCK11) is 9.6338e-12≈-80dBm. It's not close to -85dBm (receiver sensitivity for CCK11).

So we will use shadowing model simulate one 802.11b channel of Orinoco 802.11b card with short preamble. According to the analysis of 2.1, CSThresh_ is equals to -104dBm (receiver sensitivity for BPSK minus 10). Receiver noise floors for BPSK,QPSK,CCK5.5, and CCK11 are -104dBm, -101dBm, -97dBm, -92dBm. Because control frames are transmitted by BPSK in NS2, RxThresh_ should be a little less than receiver sensitivity for BPSK. We will select -95dBm as the RxThresh_. CPThresh_ is set to 10. So the TCL script for our channel is,

```
#The Antenna height of transmitter and receiver is 1.5m.
Antenna/OmniAntenna set Gt_  1          //Transmit antenna gain
Antenna/OmniAntenna set Gr_  1          //Receive antenna gain
Phy/WirelessPhy set L_ 1.0              //System Loss Factor
Phy/WirelessPhy set freq_ 2.472e9       //channel-13. 2.472GHz

ErrorModel80211 noise1_ -104
ErrorModel80211 noise2_ -101
ErrorModel80211 noise55_ -97
ErrorModel80211 noise11_ -92
```

ErrorModel80211 shortpreamble_ 1

#The propagation model is Shadowing model.
Propagation/Shadowing set pathlossExp_ 4
Propagation/Shadowing set std_db_ 0

Phy/WirelessPhy set bandwidth_ 11Mb //Data Rate

Phy/WirelessPhy set Pt_ 0.031622777 //Transmit Power (15dBm)
Phy/WirelessPhy set CPThresh_ 10.0 //Collision Threshold
Phy/WirelessPhy set CSThresh_ 3.1622777e-14 //Carrier Sense Power (-94dBm);
Phy/WirelessPhy set RXThresh_ 3.1622777e-13 //Receive Power Threshold;

***Mac/802_11 set dataRate_ 11Mb //Rate for Data Frames**
***Mac/802_11 set basicRate_ 2Mb //Rate for Control Frames**

4. Others

There are some bugs in NS2.

1. Friss and TwoRayGround propagation have not considered about the situation that the distance equals zero. Although it won't happen in reality, it will cause wield results if simulation script has not considered avoiding this scenario.
2. When MAC calculates transmission time of one frame, it has not considered about that preamble and PLCP header may be transmitted by different modulation scheme with MAC header and Data.

These bugs have been fixed.

Appendix A: BER (SNR, Modulation)

Intersil HFA3861B: The Relationship between BER and SNR & Modulation

SNR(dB)	BPSK(1Mbps)	QPSK(2Mbps)	CCK5.5(5.5Mbps)	CCK11(11Mbps)
5	5e-2	6e-2	4e-2	1.2e-2
6	5e-2	6e-2	1.3e-2	6e-3
7	1.2e-2	1.7e-2	4.1e-3	2e-3
8	4.1e-3	6e-3	1.3e-3	7e-4

9	1.1e-3	1.7e-3	3.3e-4	2.5e-4
10	2.2e-4	4e-4	8e-5	8e-5
11	4e-5	6.3e-5	1.5e-5	2.7e-5
12	2.9e-6	8.9e-6	2.7e-6	8e-6
13	3.6e-7	1.3e-6	5e-7	1.9e-6
14	4e-8	2.7e-7	5e-8	3.9e-7
15	3e-9	4e-8	1e-8	1.02e-7
16	1.8e-10	4e-9	1.1e-9	3e-8
17	1.8e-10	4e-9	1.1e-9	4e-9

Theoretical Relationship between BER and SNR & Modulation from Intersil

SNR(dB)	BPSK&QPSK	CCK5.5(5.5Mbps)	CCK11(11Mbps)
4	9e-2	1.7e-2	4e-2
5	9e-2	3.5e-3	8e-3
6	3e-2	6.2e-4	1.2e-3
7	4.1e-3	7e-5	1.2e-4
8	1.01e-3	5e-6	1.01e-5
9	2e-4	2e-7	3.9e-7
10	2.02e-5	4e-9	7e-9
11	1.8e-6	7e-11	2e-10
12	5.9e-8	7e-11	2e-10
13	1.4e-9	7e-11	2e-10

* The above tables are gotten from curves of Intersil HFA3861B specification [B4]. These curves are expanded to get some pairs of value.

Theoretical Relationship between BER and SNR & Modulation from [B5]

SNR(dB)	BPSK(1Mbps)	QPSK(2Mbps)	CCK5.5(5.5Mbps)	CCK11(11Mbps)
1	1.2e-5	5e-3	8e-2	1e-1
2	1e-6	1.2e-3	4e-2	1e-1
3	6e-8	2.1e-4	1.8e-2	1e-1
4	7e-9	3e-5	7e-3	5e-2
5	2.3e-10	2.1e-6	1.2e-3	1.3e-2
6	2.3e-10	1.5e-7	3e-4	5.2e-3
7	2.3e-10	1e-8	6e-5	2e-3
8	2.3e-10	1.2e-9	1.3e-5	7e-4
9	2.3e-10	1.2e-9	2.7e-6	2.1e-4
10	2.3e-10	1.2e-9	5e-7	6e-5
11	2.3e-10	1.2e-9	7e-8	2.1e-5
12	2.3e-10	1.2e-9	1.2e-8	7e-6
13	2.3e-10	1.2e-9	1.7e-9	1.7e-6
14	2.3e-10	1.2e-9	1.7e-9	5e-7

15	2.3e-10	1.2e-9	1.7e-9	2e-7
16	2.3e-10	1.2e-9	1.7e-9	5.1e-8
17	2.3e-10	1.2e-9	1.7e-9	1.6e-8
18	2.3e-10	1.2e-9	1.7e-9	6e-9
19	2.3e-10	1.2e-9	1.7e-9	2e-9

Appendix B: ORiNOCO11b Card Spec.

	BPSK	**QPSK**	**CCK5.5**	**CCK11**
Receiver Sensitivity	-94dBm	-91dBm	-87dBm	-82dBm
Range-Open(m)	550	400	270	160
Range-SemiOpen(m)	115	90	70	50
Range-Closed(m)	50	40	35	25
Transmit Power	15dBm=0.031622777Watt			
Frequency	2.472GHz			

Appendix C: Cisco Aironet350 Card Spec.

	BPSK	**QPSK**	**CCK5.5**	**CCK11**
Receiver Sensitivity	-94dBm	-91dBm	-89dBm	-85dBm
Range-outdoor(m)	610	457	305	244
Range-indoor(m)	107	76	61	46
Transmit Power	100mW			
Frequency	2.472GHz			

Bibliography

[B1] Ratish J.Punnoose, Pavel V.Nikitin, and Daniel D.Stancil. Efficient Simulation of Ricean Fading within a Packet Simulator. Vehicular Technology Conference . 2000.
Ref Type: Generic

[B2] Mineo Takai, Jay Martin, and Rajive Bagrodia. Effects of Wireless Physical Layer Modeling in Mobile Ad Hoc Networks. 2004.
Ref Type: Generic

[B3] Proxim. ORiNOCO 11b Client PC Card Specification. 2004.
Ref Type: Generic

[B4] Intersil. HFA3861B: Direct Sequence Spread Spectrum Baseband Processor. 2000.
Ref Type: Generic

[B5] Javier del Prado Pavon and Sunghyun Choi. Link Adaptation Strategy for IEEE 802.11 WLAN via Received Signal Strength Measurement. ICC . 2003.
Ref Type: Generic

Receive sensitivity is measured in dBm @BER 10E-5 or (or 8% FER).

Note: IEEE 802.11 15.4.8.1 says that "F" in 8% FER for DSSS devices stands for an MPDU having 1024 octets. 8/100 (errors/frames) / (1024 (octets) * 8 (bits) = approx. 1/100,000 errors/bits = 10-5 BER. i.e. 8% FER should be comparable to 10-5 BER.