Wireless Channel Modeling for Simulator for Adaptive Multimedia Delivery over Wireless Networks

by

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1. Introduction

In the real world, it is a common sense that if we want to deploy a real environment to do some research or get important data for commercial development, a large part of time will be spent on building this environment. In terms of budget and time, in many situations, commercial users or researchers, cannot afford to set up the real environment. On the other hand, with increasing research achievements and computer resources, simulations become a important and widely used methodology to achieve these kinds of goals such as budget planning, or getting important data and features in specified environment. With increasing usage of mobile terminals, people usually play with multimedia applications on mobile devices. Multimedia on wireless network is a huge research filed. The scenario which our simulator is going to simulate is given by Fig. 1.1. A server sends multimedia content to a mobile client, and the client receives the content and try to display it. The part from the access point (AP) to the mobile devices is what we focus on.

One of the most important parts in a simulating process for delivering multimedia contents on wireless networks is to model the wireless channels. With lots of factors, such as radio path loss, shadowing, reflection, scattering, Doppler shift, interference, wireless channel modeling is one of the most complex problems regarding to wireless communication field. In the last fifty years, an amount of channel propagation models are built by researchers [1], such as the basic and ideal free space model [2], widely used empirical Hata model for outdoor propagation path loss in different environments with different correction factors [3], empirical log-normal model for local environment with path exponent and a random component [2]. For small scale fading, there are Rayleigh fading model for radio propagation with no line-of-sight signal component [4], Ricean fading for existing line-of-sight signal component [5], and the more general Nakagami fading model [6]. In addition to these comparatively simpler but widely used model, there are lots of other techniques and models based on complex mathematical methodology, such as Ray-Tracing techniques for site-specific path loss. Besides, some classic and practical modeling theories are proposed, such as finite-state Markov modeling [7].

We combine free space, log-normal shadowing, and Rayleigh fading model in this research

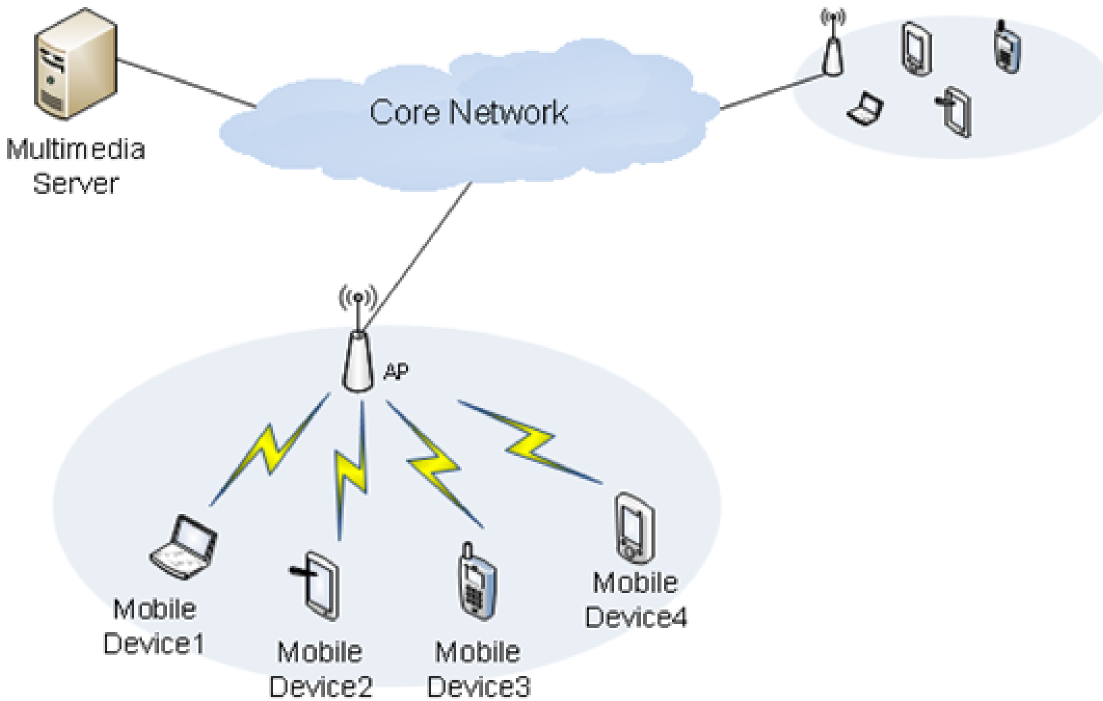

Fig. 1.1. Simulation scenario.

to model a wireless channel. This channel modeling simulator is going to simulate the bit error effect (BEP) of the channel. So the objective of channel modeling in this work is to find out the bit error probability. As shows in Fig. 1.2, a sequence of bits going through a channel. Some bits in this sequence will be changed based on the BEP calculated by channel models. Then the modified bit sequence comes out of this channel with some wrong bits. For example, as shown in Fig. 1.2, if the BEP is 0.1, and the length of bit sequence (that is the number of bits) equals 20, then 2 bits on average in this sequence will be changed (as the red numbers in the figure).

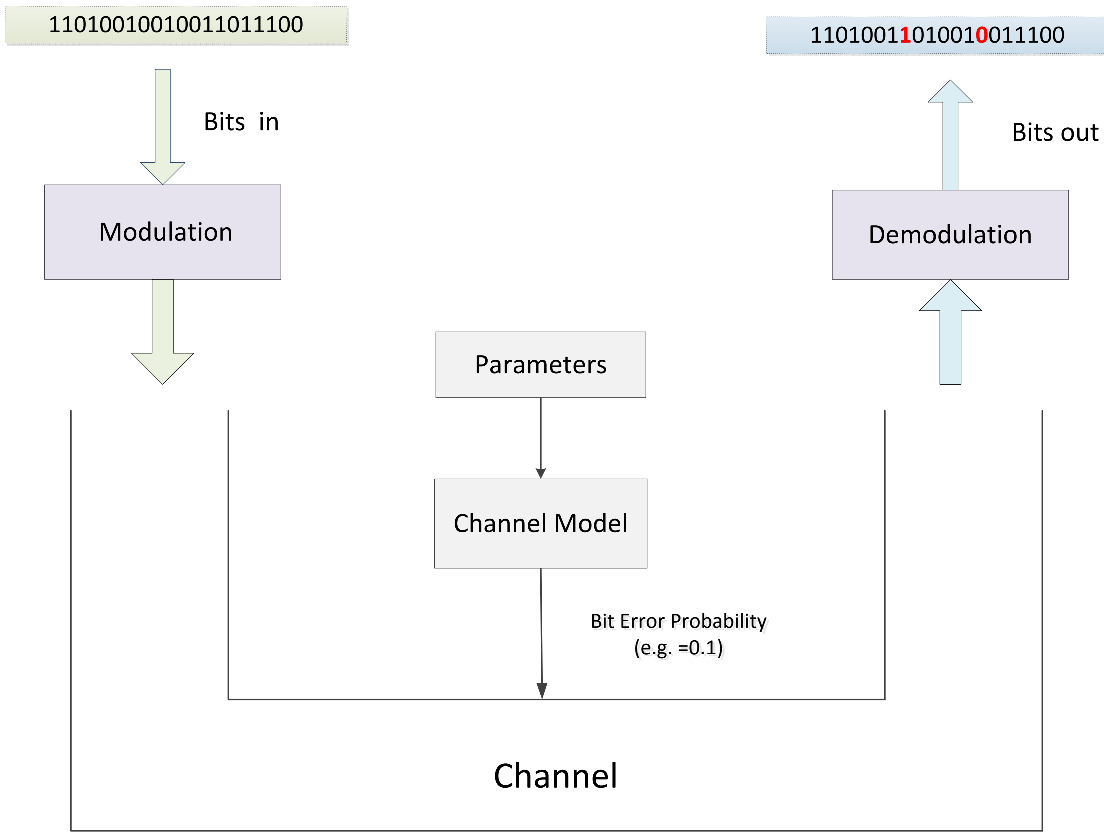

Fig. 1.2. Channel modeling architecture.

2. Three Channel Models

Free space model, log-normal shadowing, and Rayleigh fading are three widely used models in channel modeling. They concern with different factors in a real propagation environment. Free space focus on path loss because of distance. Log-normal shadowing models the effect caused by macro impact. Rayleigh fading shows the signal's random attribute due to small-scale fading. The relationship between the three models is showed in Fig. 2.1.

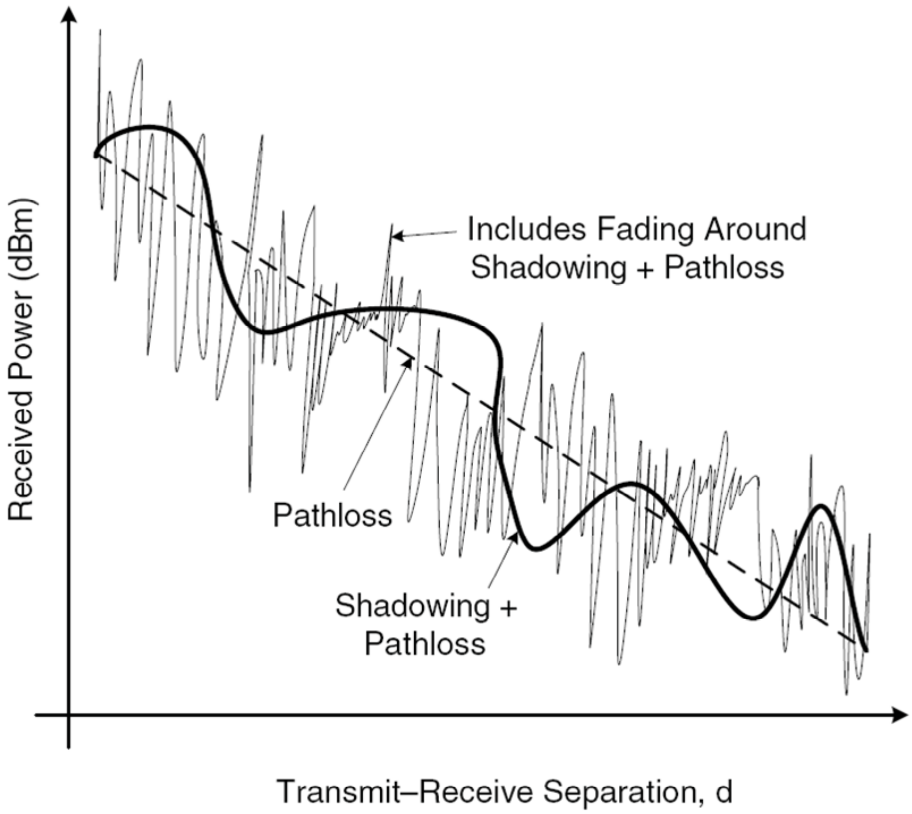

Fig. 2.1. Small scale and large scale fading [8].

2.1. Free Space Model

Free space propagation model is the simplest and most basic model. Free space model does not consider the effect of environment on radio signal, but only the path loss because of transmitter-receiver distance, the gain of antennas, and the radio wavelength. The path loss (in dB) in the free space is given by following equation [2].

$$PL = -10 \log \left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2} \right] \tag{1}$$

where PL is the signal path loss (in dB) from transmitter to receiver, G_t, G_r are the transmitter and receiver antenna gain, respectively, λ is the radio wavelength and d is the distance between

Table 2.1. Path Loss Exponent for Different Environments [2]

Environment	Path Loss Exponent, n
Free Space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

transmitter and receiver. The context in which the free space model can be used is very restrictive, but it is the foundation of many other complex models.

2.2. Log-normal Shadowing

Log-normal shadowing gives a path loss exponent factor to describe the effect of micro environment, and a random factor to describe the shadowing effect. The path loss (in dB) at a local distance d is given by following equation [2].

$$PL(d) = \overline{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma \tag{2}$$

where

$$X_\sigma \sim N(0, \sigma^2) \tag{3}$$

$\overline{PL}(d_0)$ is a reference path loss, which should be measured at a reference distance d_0 close to the transmitter, d is the distance separation from transmitter to receiver, n is an exponent factor depending on the radio propagation environment, and X_σ is a Gaussian random variable with mean value 0 and standard deviation σ. Log-normal shadowing model is widely used because it can model a variety of channel environments using different factor n and X_σ. Some typical values for n are given by researchers in Table 2.1.

As indicated in [2], $\overline{PL}(d_0)$ is usually obtained by the measured data or free space calculation. It is important to choose d_0 as a reference distance which would vary for different environments.

1 km and 1 m are typical values for large and small systems. For this channel modeling study, we use free space propagation model to calculate the reference path loss at the reference location d_0, which will be set to a typical value. The pass loss exponent n will be chosen according to environment.

2.3. Rayleigh Fading

Rayleigh fading is a model that describes the statistical time varying characteristics of radio channels due to multipath propagation. It means that the received signal amplitude follows a Rayleigh distribution. The probability density function (PDF) of a Rayleigh fading signal is given by following equation [2]

$$f(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, & (0 \le r \le \infty) \\ 0, & (r < 0) \end{cases} \tag{4}$$

where r is the instantaneous received signal amplitude in voltage, and σ is the root mean square value of the received signal.

If the radio signal's amplitude follows a Rayleigh distribution, then the signal's power follows an exponential distribution [9] [10].

Let P_r denote the received power in watts. Since $X_r \sim Rayleigh(\sigma)$ and $P_r = \frac{1}{2} X_r^2$, we have $P_r \sim Exponential(\lambda)$ and $\lambda = \frac{1}{\sigma^2}$. That is, the PDF of the exponential distribution is

$$p(P_r) = \lambda e^{-\lambda P_r}, \lambda > 0 \tag{5}$$

where λ is the rate parameter. It should be noted that the expectation of the exponential distribution has special relationship with the rate parameter. That is

$$E[P_r] = \frac{1}{\lambda} = \sigma^2. \tag{6}$$

3. Channel Modeling Implementation

3.1. Combine Three Models

In this study, free space, log-normal shadowing, and Rayleigh fading models are utilized. They focus on different effects to a radio signal. But for a real radio channel, all these effects always come together. That means an instantaneous received signal is a result of hardware, path loss, shadowing, and fading working together. The key part for this work is how to combine these three models together. As presented in [10], the instantaneous received power after multipath reception is represented by Rayleigh distribution, which has a mean value of the local average received signal power resulting from the log-normal shadowing. We use the following steps to achieve this goal.

1) Choose a reference location d_0 close to transmitter, and use free space model in Eq.(1) to calculate the reference path loss PL_0.
2) Use log-normal shadowing model in Eqs. (2) and Eq. (3) to calculate the local path loss from PL_0, d_0, and environment parameters n and σ. Then get the local average received signal power P_l.
3) Generate a received signal amplitude r, which follows a Rayleigh distribution $Rayleigh(\sqrt{P_l})$ by Eq. (4). So as given in Eqs. (5) and (6), the instantaneous received signal power $P_r \sim Exponential(\frac{1}{P_l})$. Here $E[P_r] = P_l$.

At the end of Step 3, we can see that the mean value of instantaneous received signal power is the same as the value calculated according to the log-normal shadowing model.

3.2. BEP and SNR

In this channel modeling study, we simulate the bit error effect of the channel. So the goal is to find out the BEP based on the instantaneous received power. BEP is related to but not the same as the bit error rate (BER). BEP is the probability that one bit happens to have transmitting error. It is only a statistic estimation. BER is the actual percentage of the wrong transmitted bits. In other words, long-term average of BER should equal to BEP. Here we use a mathematical approach to calculate BEP, and then simulate the bit error. Based on simulations, we get BER according to real transmitted bits.

For a special channel and modulation scheme, BEP has a direct relationship with signal to noise ratio (SNR). For this research, only binary phase shift keying (BPSK) and differential phase shift keying (DPSK) are considered and implemented.

For BPSK and DPSK modulation in Rayleigh slow flat-fading channel, we have the BEP given by following equations [2]

$$P_{e,BPSK} = \frac{1}{2}\left(1 - \sqrt{\frac{\gamma}{1+\gamma}}\right) \tag{7}$$

$$P_{e,DPSK} = \frac{1}{2(1+\gamma)} \tag{8}$$

where γ is the average signal energy per bit to noise power spectral density ratio (E_b/N_0) for the fading channel. E_b/N_0 has a relationship with SNR as

$$\gamma = \frac{1}{\rho}\,\mathrm{SNR} \tag{9}$$

we can get following formulas by rearranging Eqs. (7), (8), and (9)

$$P_{e,BPSK} = \frac{1}{2}\left(1 - \sqrt{\frac{\mathrm{SNR}}{\mathrm{SNR}+\rho}}\right) \tag{10}$$

$$P_{e,DPSK} = \frac{\rho}{2(\rho + \mathrm{SNR})} \tag{11}$$

where ρ is the link spectral efficiency in (bit/s)/Hz, which depends on the channel bit rate and bandwidth. For example, if the data rate is 1 Mbit/s, and the channel bandwidth is 22 MHz, then ρ=1/22 (bit/s)/Hz.

3.3. Channel Modeling Process

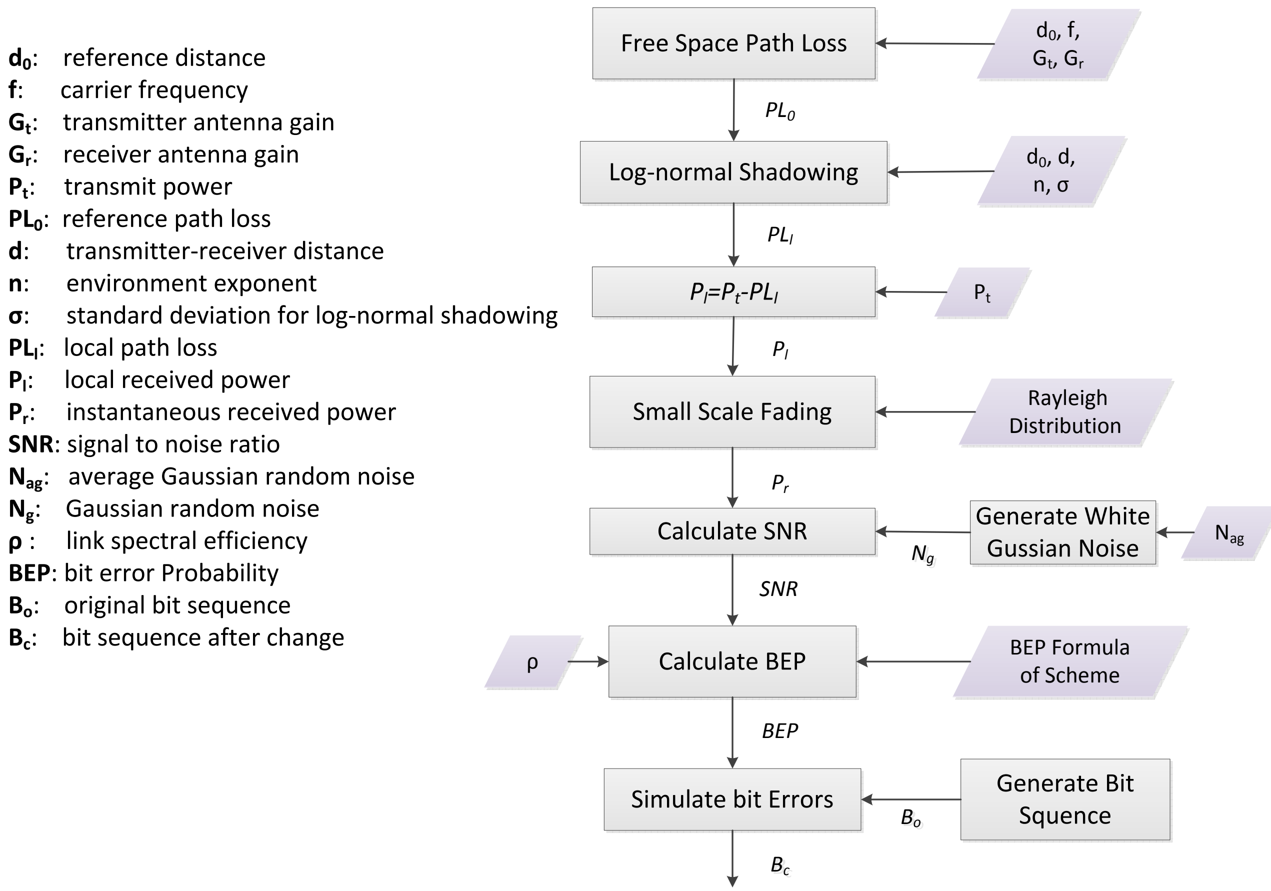

Fig. 3.1. Channel Modeling Process.

Fig. 3.1 gives the flow of the channel modeling. The rectangle stands for processing behavior, and the diamond represents data or formulas, which are provided by users or fixed in program.

1) Use free space path loss model with frequency f, transmitter antenna gain G_t, and receiver antenna gain G_r to calculate the reference path loss PL_0 at location d_0, which is close to transmitter.

2) Use transmitter-receiver distance d, environment parameters (path loss exponent n and Gaussian distribution deviation σ), reference path loss PL_0, and reference location d_0 to get the local average path loss PL_1.

3) When the local path loss have been calculated, giving the transmit power P_t, it is easy to get the local received power P_l by $P_l = P_t - PL_1$.
4) Given local average received power P_l, which results from step 3, and Rayleigh fading prerequisite, generate a random for instantaneous received signal power P_r with mean value of P_l.
5) Generate a Gaussian white noise N_g with user defined average power N_{ag}. Then SNR is obtained.
6) After getting the important value SNR, calculate BEP based on specified formula. The formula varies for different modulation schemes and channel models.
7) Program randomly generates a sequence of bits with user defined length. Change part of the bits (theoretically, it should change 0 to 1, or 1 to 0. In this program, just change the bit (0 or 1) to symbol * to show it as a bad bit after transmitting) based on the bit error probability. This simulates the bit errors in channel transmitting.
8) After the simulation, the modified sequence of bits will be displayed to show which bits have been changed (in symbol *), and BER is also calculated and displayed. Because the bit error simulation is based on BEP, so if the bit sequence is long enough, BER would be equal to BEP.

3.4. Programming Implementation

This channel modeling project is implemented with Java programming language and Eclipse IDE. In this section, the important classes and functions during programming implementation will be listed and briefly explained. Fig. 3.2 shows the important attributes and functions in these classes, as well as the relationship between different classes. In this diagram, they are all described in unified modeling language (UML).

- Class `Filter` has the `main()` method. `Filter` deals with the graphical user interface (GUI), generates bit sequences, and calls methods in other class to implement the simulation process.

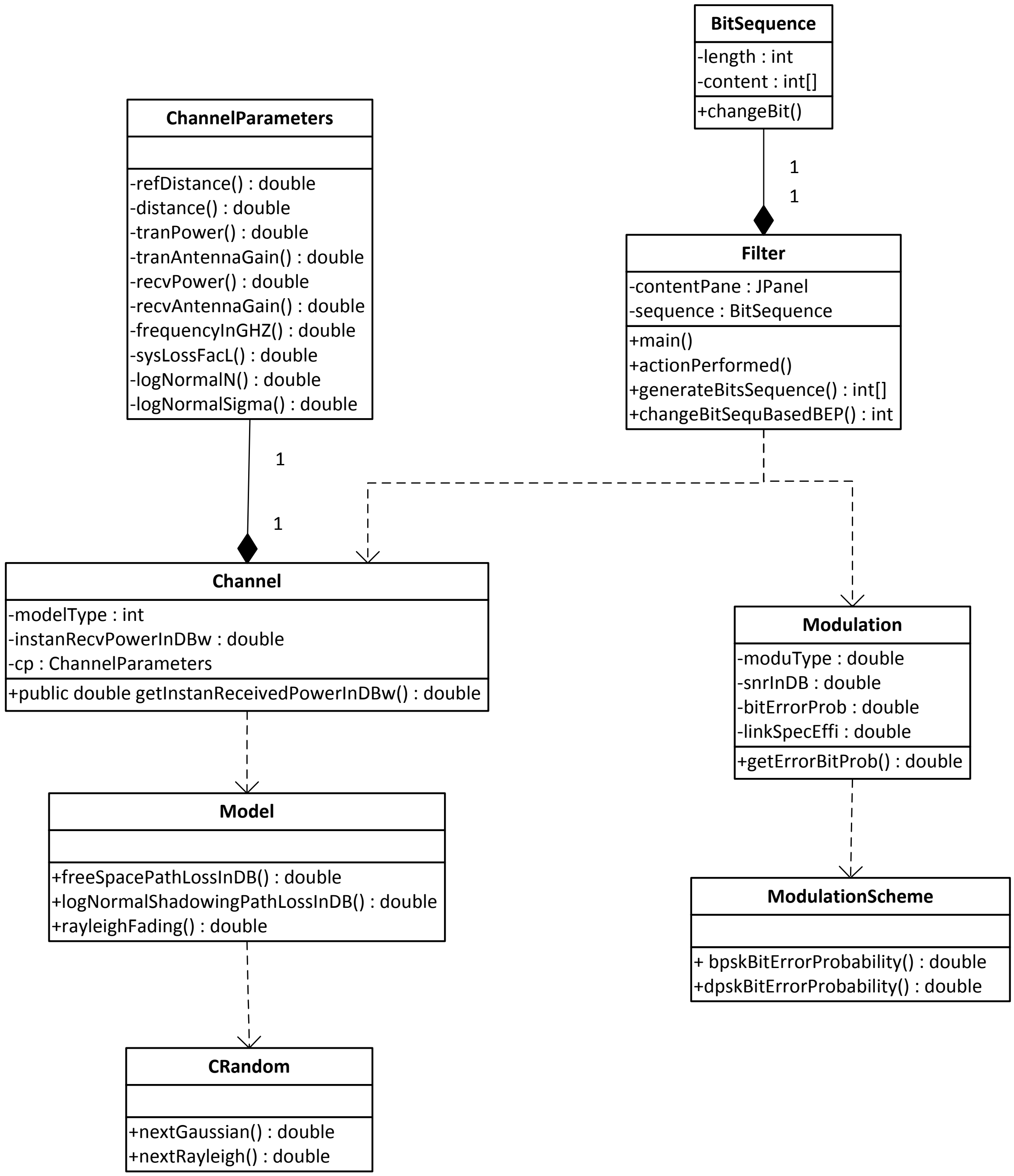

Fig. 3.2. Programming class relationship using UML.

- Class `BitSequence` stores a sequence of bits and provides a basic operation to change one bit in this sequence based on the index of this bit.

- Class `ChannelParameters` is a utility class, which contains all the user defined parameters for channel modeling. When the parameters are passed around the functions, it is more convenient to use one parameters class. Besides, if a new model is added, it is easy to define new parameters in this class.
- Class `Channel` calculates the instantaneous received power based on specified model type and corresponding method in class `Model`. Now only type 1 (combining free space, log-normal shadowing and Rayleigh fading) is available.
- Class `Model` implements three models by three functions. Every function takes corresponding parameters and returns the path loss calculated for this model. It is easily to be extended to other models because of this class. If a new model needs to be added, we just need to put the a new implementation function in this class.
- Class `CRandom` is a utility class, which provides methods to generate Gaussian and Rayleigh random number.
- Class `Modulation` calculates the BEP based on specific modulation type and corresponding method in class `ModulationScheme`. Now only two modulation types are available: type 1 for BPSK and type 2 for DPSK.
- Class `ModulationScheme` implements BEP for two modulations schemes by two functions. Like the class `Model`, it is also easy to be extended to other modulation schemes. If a new scheme is required to be added, we only need to put a new implementation function in this class, and give it a type number.

4. Demo and Analysis

The previous sections give the architecture and the modeling process in detail. In this section, I will give the GUI demo of the simulation and give a comparison between simulation results and the real data.

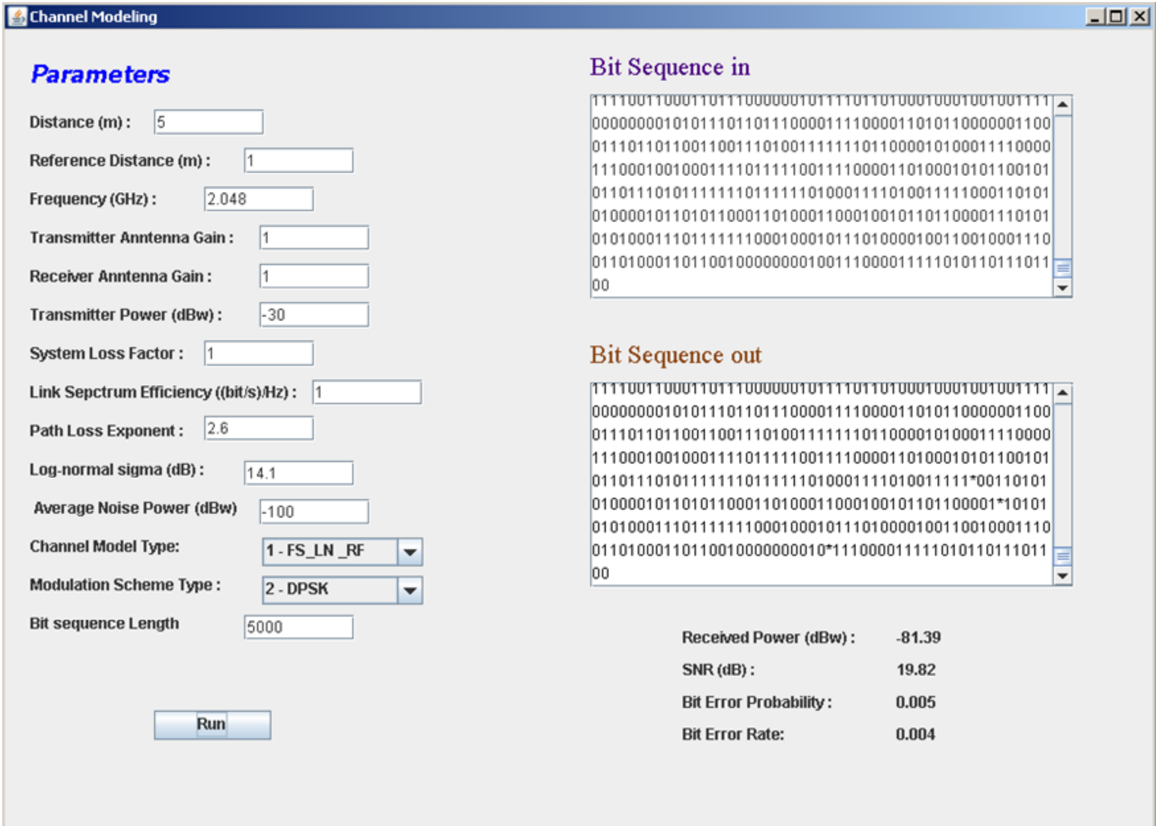

Fig. 4.1. Simulation GUI.

4.1. Channel Modeling Demo

Fig. 4.1 is a modeling demo with some sample user defined parameters (on the left of the panel) and modeling results (on the right of the panel) .

In the left part, there are 14 parameters whose value can be defined by users. For the parameter *Channel Model Type* and *Modulation Scheme Type*, a limited number of types are provided for user's choice. In terms of channel model type, only one type is available now, which combines free space model (FS), log-normal shadowing model (LN) and Rayleigh fading model (RF), and is represented by type 1. In terms of modulation scheme type, BPSK and DPSK are available, and represented by type 1 and type 2, respectively.

In the top right area of the panel, it is the original bit sequence before going through the channel (i.e. before the error simulation by channel modeling). This bit sequence is randomly generated by program automatically with user defined length. And in the middle right of the panel, it shows the modified bit sequence after going through channel (i.e. after the error simulation by channel modeling). Usually, there are a small percentage of bits will be changed. The modified bits, which means the bad bit, are displayed here as *.

If the bit sequence is long enough, we can imagine that some bits in this sequence will undergo different fading effect, which we do not consider in this project. What is the reasonable length of the bit sequence depends on the environment and wireless techniques. Considering IEEE 802.11b (data rate 11 Mbps) and the general scenario with Doppler shift 100 Hz, a bit sequence with length smaller than 10000 is reasonable to undergo the same fading.

In the right bottom of the panel, four important features (received power, SNR, bit error probability and bit error rate) are displayed. All these four parameters result from the modeling process, based on current user defined parameters.

4.2. Result Analysis

Fig. 4.2 shows a comparison between the real received signal strength (single chip transceiver cc2420 and Telos B mote, referring report [11] for technique and experiment environment details). and the simulation data. Both real and simulation result are based on frequency 2.048 GHz, transmitter antenna gain 1, and receiver antenna gain 1. Because of the random attributes of the received signal, every data in both data sets represents the average received signal. For the simulation data, different value stands for the received signal strength at different distances (2m-10m, 1m for gap) and every data is an average of 10 instantaneously received data at this distance.

We can see that our implementation of the channel modeling works fine as shown in this result comparison. The simulation result shows the trends of the signal strength attenuation with increasing transmitter-receiver distance, and the instantaneous received signal's random feature. Based on different parameter tests, the reference location can be a key parameter for the accuracy

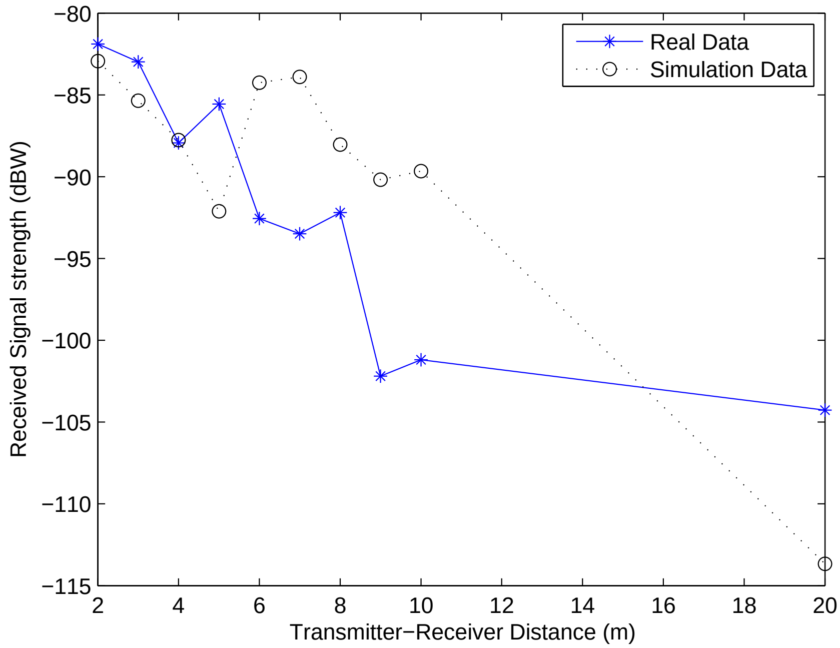

Fig. 4.2. Real Data vs. Simulation Data.

of simulation. Besides, the radio frequency is also an important factor. A high frequency radio can seriously attenuate due to shadowing effect, which will be taken into consideration in future work.

5. Conclusion and Future Work

This channel modeling project provides a easy way to simulate the bit effect. User can choose their own parameters suited for different environments and get the results desired. However this project is only a simple start of the complex modeling process. All the bits in a bit sequence in this modeling process are assumed to receive the same fading. But in a very long sequence, it more reasonable for put different fading effect onto different bits whose time separation is larger than coherence time. The channel models used in this work does not consider other kinds of complicated effects which probably exists in wireless channel (such as interference [12]). Besides, it need to be extended to other useful channel models (such as Ricean fading model for existing line-of-sight propagation path instead of Rayleigh fading) and other popular used and efficient modulation schemes (such as Quadrature Phase Shift Keying (QPSK) and Gaussian Minimum Shift Keying (GMSK)). The application goal of this channel modeling is for adaptive multimedia delivery over wireless network. However, now we don not consider multimedia characteristics related to channel attributes, such as video streaming over fading channel [13]. This is one of the fields that the future work may focus on.

6. Acknowledgements

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