Simulation Research of 802.11n Channel Model D in NS2

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Abstract—In order to imitate the channel characteristics of 802.11n WLAN, this paper analyzes channel model mechanism of Markov stochastic process and implements the extensional module of 802.11n channel in NS2. In the end, through comparing simulation results with standard TGn model, we verify the accuracy of this module which provides efficient physical layer channel simulation foundation for the research of 802.11n protocol.

Keywords—WLAN; 802.11n channel model; Birth-Death Markov process; Channel Capacity; Packet Error Rate;

I. INTRODUCTION

The rapid development of Wireless Local Area Network (WLAN) has not yet broken the bottleneck that the low transmission speed hinders the further development of WLAN. To realize a wide range of services at high rate with high bandwidth and Quality of Services (QoS) assurance, the IEEE 802.11n is presented which adopts MIMO-OFDM (Multiple Input Multiple Output Orthogonal Frequency Division Multiplexing) technology. The research shows that MIMO-OFDM system can transmit information with higher data rate and better QoS. Therefore, the IEEE 802.11n will be able to reach data rates of 600 Mbps, and it guarantees a minimum of 100 Mbps of throughput. Meanwhile, it depresses the Inter-Symbol Interference caused by multi-path fading, enhances immensely transmission performance of wireless communication system. In order to simulate new characteristics of 802.11n physical layer, 802.11n Task Group (TGn) [1] considers and proposes six kinds of channel model applied to adapt to different environments.

At present, there are three kinds of main analytical methods of network performance, including testing by setting up real-world network conditions, mathematics modeling and analysis, and using software such as NS2 or OPNET etc to simulate. The former costs too much apparently. Mathematical modeling seems too complicated, while utilizing NS2 software tools [2] are widely accepted by researchers for its advantages of low cost and flexibility. The 802.11n channel model isn't included in NS2 software environment therefore we need to extend it so that we can realize 802.11n physical layer simulation which is extremely important for study of 802.11n protocol. Based on NS2 and 802.11n channel model provided by TGn, this paper introduces in detail theory and design method of 802.11n channel model and install it into NS2 software. In the end, we validate the accuracy of this module by comparing simulation results with standard TGn reference model [3].

The remainder of this paper is organized as follows. Section II reviews the TGn channel model in IEEE 802.11n proposal. Section III discusses the design principle and strategy for implementation algorithm in detail. Section IV presents the results of simulations designed to validate the accuracy of the 802.11n channel model we designed. Finally, Section V provides a summary of the whole text.

II. TGn CHANNEL MODEL

In July 2003, the 802.11n task group was formed to create a new wireless LAN standard. The main goal of this new standard is to give a throughput of at least 100 Mbps at the MAC data services node. A number of proposals were made that all share three common elements: the use of MIMO-OFDM, 20 and 40 MHz channels, and packet aggregation techniques. Based on this common agreement, a joint group was formed to create the first draft of 802.11n standard.

The key technology to obtain significant higher data rates and increase range performance at the same time is MIMO-OFDM which is the basis of the new 802.11n standard. MIMO-OFDM increases the link capacity by transmitting simultaneously multiple data streams using multiple transmit and receive antennas. It makes it possible to reach data rates that are several times larger than the current highest 802.11a/g rate of 54 Mbps. Meanwhile, it combats effectively multi-path fading, depresses undesired signals. MIMO-OFDM is also the critical techniques of the next generation wireless communications.

There are a number of adverse factors in wireless communication environments, such as multiple paths fading, Doppler frequency shift, and fast time varying of channel etc. Especially in the complicated electromagnetic conditions of room, the existing multi-path effects, frequency selective fading and interference signal etc. make it more difficult to transmit data packets at a high rate than wired networks. For different environment, radio signals reflecting from buildings, walls, furniture, and other conductive surfaces travel in clusters—multiple reflections of the same signal arriving at the receiver at different times with different amplitude from the same direction. At the same time, the MIMO channel model includes Doppler shifts, which are amplitude functions of signals caused by moving objects such as people and cars. Hence, in order to adapt various occasions, TGn provides 6 kinds of channel models—A through F based on
MIMO-OFDM, which is applied in different places, including household, office and Exhibit Hall etc [1]. The relations of between channel model and corresponding propagation environment parameters are shown as TABLE I.

**TABLE I. SUMMARY OF MODEL PARAMETERS**

<table>
<thead>
<tr>
<th>Channel Model</th>
<th>Path</th>
<th>Ricean factor K</th>
<th>rms delay spread(ns)</th>
<th>Tap</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>LOS/NLOS</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>LOS/NLOS</td>
<td>15</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>LOS/NLOS</td>
<td>30</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>LOS/NLOS</td>
<td>50</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>LOS/NLOS</td>
<td>100</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>LOS/NLOS</td>
<td>150</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

Model A is a test mode. Model B represents a typical small office environment. Model D, same as Model C, is a large open space (indoor and outdoor), Not Light Of Sight (NLOS) conditions. Model F represents a large metropolitan environment. K-factor values for LOS conditions, open environments have higher K-factor than small environments. K-factor for LOS conditions applies only to the first tap, for all other taps, K=-∞dB.

The path loss model consists of the free space loss $L_{FS}$ (slope of 2) up to breakpoint distance and slope of 3.5 after the breakpoint distance. For each of the models different breakpoint distance $d_{BP}$ was chosen.

\[
L(d) = L_{FS}(d) \quad d \leq d_{BP} \\
L(d) = L_{FS}(d_{BP}) + 3.5 \log_{10}(d/d_{BP}) \quad d > d_{BP} \tag{1}
\]

Where $d$ is a transmitting-receiving separation distance in m. The path loss parameters are summarized in TABLE II, the standard deviations log-normal (Gaussian in dB) shadow fading are also included.

**TABLE II. PATH LOSS MODEL PARAMETERS**

<table>
<thead>
<tr>
<th>Model</th>
<th>$d_{BP}$ (m)</th>
<th>Slope before $d_{BP}$</th>
<th>Slope after $d_{BP}$</th>
<th>Shadow fading std.dev(dB) before $d_{BP}$</th>
<th>Shadow fading std.dev(dB) after $d_{BP}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>3.5</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td>3.5</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td>3.5</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>3.5</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>20</td>
<td>3.5</td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>30</td>
<td>3.5</td>
<td>3</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

In the actual application, it is necessary to select suitable channel model to simulate wireless channel transmission characteristics according to the current environment so that we can set up network devices reasonably.

**III. 802.11N CHANNEL MODEL D DESIGN BASED ON MARKOV CHAIN**

A. Design Principle

Reliable MAC simulations should rely upon a realistic emulation of the Physical Layer of each Station. Specifically, PHY behavior it’s not fully described by the average Packet Error Rate (PER) at a given SNR. In fact, jitter, delay, and throughput depend on the instantaneous behavior of the channel. The more evident aspect that should be included in MAC simulation is the time correlation of the packet error events. In order to emulate this aspect, simple Markov chains, representing the status of the channel (e.g. Good or Bad) have been proposed so far. Channel Capacity (CC) is a suitable metric to predict PHY performance Error! Reference source not found. Moreover, the “instantaneous” value of the CC can be used to predict the “instantaneous” packet error probability. Hence, if PER versus CC curve is available from link-level simulations (e.g. as a Look-Up-Table [LUT]), it is sufficient to generate the stochastic process that represents the CC versus time in the MAC simulator [5]. Then the CC’s instantaneous value can be used to read the PER vs CC LUTs.

In order to reproduce the CC stochastic process in a MAC simulator without embedding the whole channel model, it’s necessary to characterize the process itself and then to define a proper low complexity method to reproduce it [6]. The Markov chain has been identified as the most suitable method thanks to its low complexity costs in terms of implementation and computational load. In particular, a Birth-Death Markov process has been chosen [7].

![Birth-Death Markov chain for generating the channel capacity](image)

Each state of the Markov chain corresponds to a given value of CC (see Error! Reference source not found.). Capacity values of contiguous states are spaced $\Delta C$ b/s/Hz. In this way, the CC process is approximated with a step-wise process. The Birth-Death Markov process is characterized by the following matrix of transition probabilities:

\[
\Pi = \begin{bmatrix}
\pi_{1,1} & \pi_{1,2} & 0 & 0 \\
\pi_{2,3} & \pi_{2,2} & \pi_{2,3} & 0 \\
0 & \ldots & \ldots & \ldots \\
0 & 0 & \pi_{S-1,N} & \pi_{S,N}
\end{bmatrix}
\tag{2}
\]

$\pi_{ij}$ represents the probability that the subsequent state is the i-th, given that the current state is the i-th; $\pi_{i,j-1}$ represent the probability that the subsequent state is the (i+1)-th (i-1)-th, given that the current state is the i-th. We can generate a transition probability matrix by extracting with a simple statistical analysis, the transition probabilities.
of the equivalent Birth-Death Markov process, whose states correspond to the CC values.

B. Strategy for Implementation Algorithm

The emulation consists basically of two parts: one side is the generation of the CC process through a Markov chain for each radio link [8]; the other sides are that reading the PER versus CC LUT for the specified PHY and SNR and drawing for the erroneous packet event according to the instantaneous value of PER given by the LUT (see Figure 2).

Figure 2. scheme of the emulation of a real PHY into a MAC simulator

Figure 2 presents the process of emulation. First, compute SNR according to transmission distance, shadowing propagation model etc, and then get the CC value at one moment by reading corresponding LUT of SNR. Finally, the MAC layer decides whether the current packet is damaged or not by comparing CC with spectrum efficiency [9].

IV. SIMULATION AND VERIFICATION

According to aforementioned algorithm, we add 802.11n channel model D module in NS2 [10] [11] to simulate the data packets error in wireless environment.

Generate the network topology utilizing NS2 software (see Figure 3). Node 0 and AP (node 1) are connected using wired network. Wired node 0 sends its data packets to node 2 through AP. In order to reflect the channel characteristics, we discard the MAC layer’s retransmission scheme of NS2. 802.11n channel model D is adopted between node 1 and node 2. Parameters are listed as follow: model D, 4x4 antennas, antenna spacing 0.5λ, no LOS, carrier frequency 5.25 GHz; Time clock (Δt) 1 ms, capacity step 1 b/s/Hz. High quantity level of packets (10³) are transmitted. These statistical characterizations are shown below.

A. Probability density function (PDF) of CC

Here, for different SNR values, by counting the number of different CC values, we get the probability of CC as shown in Figure 4.

Figure 4. PDF of the Channel Capacity of MIMO 4x4 Model D

Where Capacity is the CC, f(C) represents the probability of CC for different SNRs.

B. Cumulative density functions (CDF) of CC

Compute the cdf of CC according to pdf of it. Result is shown in Figure 5.

Figure 5. CDF of the Channel Capacity of MIMO 4x4 Model D

C. Step-wise process of CC

The CC values vary from time to time. In the process of simulation, we record the states of CC at different time as shown in Figure 6.
D. PER statistics

Here, for different spectrum efficiency, record the number of erroneous packets, where Es/No represents SNR. The statistical result is shown in Figure 7.

![Figure 7. PER for different spectral efficiency](image)

During simulation, we record PDF, CDF, PER etc. All of these results are same as literature [7]. Ultimately, we implement the standard TGn channel model in ns2 simulation environment.

V. CONCLUSIONS

This paper analyzes and implements the standard TGn channel model D based on Birth-Death Markov process. CC is a good predictor of PER and condenses in a single number to denote the instantaneous quality of the Wireless Channel. This model is easy to be implemented in a MAC simulator and should not slow down the simulations thanks to the simplicity of the Markov Chain. A drawback is the relative high number of matrix to be provided. In a dedicated section, the number of required matrixes will be evaluated. The Markov Chain reproduces with relatively high accuracy the CC process; the main limitation is the step-wise character of the resulting process.

REFERENCES