The Effect of Propagation Models on IEEE 802.11n Over 2.4 GHz and 5 GHz in Noisy Channels: A Simulation Study

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Abstract. IEEE 802.11 wireless local area networks (also called Wi-Fi) are widely used as Internet access technologies due to its availability, high-speed, low-cost, and standardization world-wide. While the performance of Wi-Fi has been studied and reported extensively in the network literature, the effect of radio propagation models on system performance in noisy channels has not been fully explored yet. This paper, therefore, investigates the effect of propagation models (two ray ground, path loss shadowing, and overall shadowing) over 2.4 GHz and 5 GHz on the performance of a typical 802.11n network in noisy channels. A campus-wide 802.11n network simulation model is developed for the said study using the Riverbed (OPNET) Modeler 18.7. We consider both real-time (e.g. voice and video) and non-real time (e.g. FTP) applications to generate traffic on the network. Simulation results show that FTP download time and FTP upload response times have significant effect on radio propagation models as well 2.4- and 5 GHz channels. However, the effect of propagation models on VoIP packet delays, jitter as well as video delays is found to be insignificant. The findings reported in this paper provide some insights into Wi-Fi performance under noisy channels that can help network researchers/engineers to contribute further towards developing next generation Wi-Fi networks capable of operating in noisy channels.

Keywords: IEEE 802.11n · Radio propagation models · Noisy channel

1 Introduction

Wireless Local Area Networks (WLANs) are one of the profound components of today's communications network of any organization. Regardless of the various backbone network technologies, the network access layer should support wireless technologies to keep pace with the current and upcoming wireless devices. Various WLAN standards have been standardized by IEEE including 802.11n operating either on 2.4 GHz or 5 GHz channels.

In this paper we investigate the impact of radio propagation models on 802.11n over 2.4 GHz and 5 GHz noisy channels. Riverbed Modeler 18.7 [1] is used as simulation tool to develop network models for performance study.

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The rest of the paper is organized as follows. Section 2 provides an introduction to 802.11n standard and focuses on both 2.4 GHz and 5 GHz channel implementations. Section 3 describes the simulation environment and network model for two scenarios based on operating frequencies of 2.4 GHz and 5 GHz. Section 4 discusses the simulation results and model validation. Section 5 concludes the paper.

2 Background and Related Work

With increase in the demand of high throughput applications; the accessibility of these applications over wireless network has also escalated. This started the discussions and technological research to come up with solutions to increase the data rate over wireless channels. IEEE 802.11n standard [2] came into the horizon from the aspect of high throughput and data rate in mind. The said standard is designed using the Multiple Input Multiple Output (MIMO), incorporating with improved security and frame aggregation. The details on the process and design of 802.11n standard can be found in [3]. From this paper's point of view we are interested in mainly 802.11n implementations over 2.4 GHz and 5 GHz channels. The channel characteristics of 802.11n is highlighted in Table 1.

Table 1. IEEE 802.11n channel characteristics (2.4 GHz and 5 GHz channel)

Parameters	802.11n 2.4 GHz	802.11n 5 GHz
Frequency	2.4 GHz	5 GHz
Modulation	MIMO-OFDM	MIMO-OFDM
Bandwidth	20 MHz	40 MHz
Data rate	Up to 288.8 Mbps	Up to 600 Mbps

We have simulated 802.11n campus network over 2.4 GHz and 5 GHz to investigate the effect of radio propagation models on system performance in noisy channels. The details of simulation environment and network model is discussed next.

2.1 Noisy Channels

In real life environment, the communication channel possesses some characteristics that will either lost some frames completely or introduce errors in data being communicated over the channel. These errors may be identified and in some cased corrected or rectified at the receiving end; such channels are called noisy channels. However, we can simulate an environment with the channel which is not introducing any errors or any packet losses; such channels are known as perfect channels.

In this paper, we simulated both perfect and noisy channels to observe the effect of radio propagation models. Perfect channel is being simulated using the default settings of the Riverbed Modeler. However, the noisy channel is simulated by increasing the noise figure of Riverbed Modeler default values from 1 to 5.

2.2 Radio Propagation Models Used in the Simulation

We considered three well-known indoor propagation models (two-ray ground, shadowing path loss, and the overall shadowing) in the Riverbed Modeler-based simulation study to find out the effect of these propagation models on system performance. A brief description of each of the propagation model is given below.

Two-Ray Ground Reflection Model: The two-ray ground model is a single line-of-sight path between two mobile nodes is seldom the only means of propagation. The model considers both the direct path and a ground reflection path. This model provides more accurate prediction at a long distance than the free space model [9].

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \tag{1}$$

where:

- P_r = received signal power
- d = separation between transmitter and receiver
- P_t = transmitted signal power (in Watts)
- G_t = transmitter antenna gain (Set to '1' in the simulation)
- G_r = receiver antenna gain (Set to '1' in the simulation))
- L = System 'Loss' factor (loss of signal waves that weren't captured by the receiver. L = 1 means no loss was noted by the hardware)
- h_t = Height of the transmitting antenna (meters)
- h_r = Height of the receiving antenna (meters)

Shadowing Path Loss Model: One of the two shadowing models is known as the path loss model. The path loss model predicts the mean received power at distance d, denoted by Pr(d). It uses a close-in distance d_0 as a reference. While two-ray model predicts the received power as a deterministic function of distance but the received power at a certain distance is a random variable due to multipath propagation effects, which is also known as fading effects [9].

$$\left[\frac{P_r(d)}{P_r(d_0)}\right]_{dB} = -10\beta \log\left(\frac{d}{d_0}\right) \tag{2}$$

where:

- β = path loss exponent, and is usually empirically determined by field measurement.

The path loss exponent (β) for two ray ground (line-of-sight) varies from 1.6 to 1.8, Shadowed urban area varies from 2.7 to 5, and the Overall shadowing (Obstructed office) varies from 4 to 6. Larger values correspond to more obstruction and hence faster decrease in average received power as distance increases [9].

Overall Shadowing Model: The shadowing model reflects the variation of the received power at certain distance. It is a log-normal random variable, that is, it is of Gaussian distribution if measured in dB (ns 2010). The overall shadowing model is represented by:

$$\left[\frac{P_r(d)}{P_r(d_0)_{dB}}\right] = -10\beta\log\left(\frac{d}{d_0}\right) + X_{dB} \quad (3)$$

where:

- X_{dB} = a Gaussian random-variable with zero mean and standard deviation σ_{dB}. σ_{dB} is called the shadowing deviation and is also obtained by measurement.

The typical values of shadowing deviation (σdB) for an office (hard partition) is 7, for office (soft partition) is 9.6, and for factory (line-of-sight) varies from 3 to 6 [4].

3 Simulation Study

The simulation study explores the effect of radio propagation models on 802.11n performance over 2.4 GHz and 5 GHz in noisy channels. For the purpose of investigation, we consider Auckland University of Technology (AUT) south campus network environment having various subnets for each building ensuring that traffic flows and inter-subnet communication taking place. The 802.11n infrastructure network is modeled using Riverbed Modeler 18.7 [1]. This section describes in detail the simulation models and parameter settings.

3.1 Modelling the Network

The network model is based on the logical topology of AUT South Campus Network as shown in Fig. 1. We have simulated 25 wireless nodes of mixed traffic across 6 subnets linked to a Gigabit Ethernet backbone.

The characteristics of simulated voice and video traffic at the packet level is investigated. For modeling voice and video traffic, a Voice over Internet Protocol (VoIP) and Video-conferencing applications were chosen, respectively. The simulation environment is designed to investigate the impact of radio propagation channels on 802.11n 2.4 GHz and 5 GHz over noisy channels. We develop an AUT South Campus Network simulation model containing various subnets for each building. The subnets are wirelessly linked to access points (APs) which are connected to a wired Gigabit Ethernet backbone network. Riverbed Modeler (Previously OPNET Modeler) is used as simulation tool for network performance study. We work on two simulation scenarios; one for 2.4 GHz channel and the other one for 5 GHz channel. The parameters used in the simulation are listed in Table 2.

The Server (FTP) is located in the center of the network infrastructure building (MB), and five buildings/subnets (MA, MD, ME, MH and MC) are connected through a backbone Gigabit Ethernet switch.

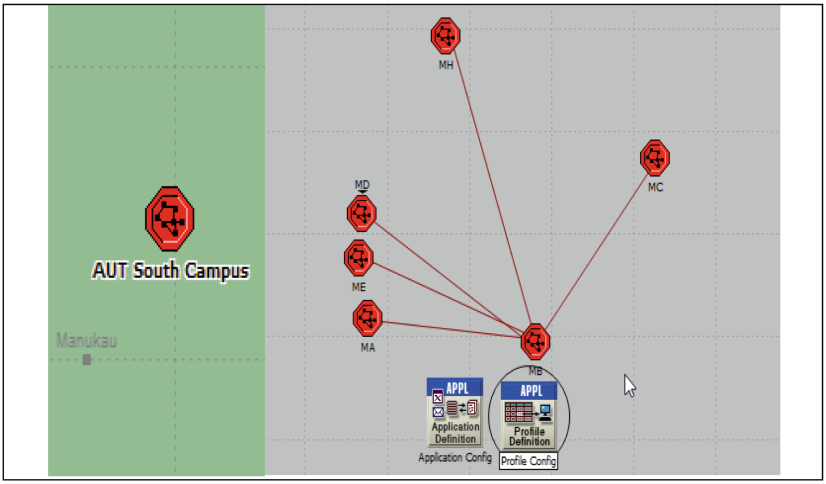

Fig. 1. High-level view of the simulated AUT South Campus Network

Table 2. Parameters used in the simulation

Parameter	Value
AP transmit power	32 mW
No. of wireless nodes	25
Application/Traffic	FTP, VoIP, Video-conferencing
FTP	High load
VoIP encoder	PCM quality
Video-conferencing	Low resolution
Propagation models	Two ray ground, Shadowing pathloss, Overall shadowing
Wireless node mobility	0
Length of simulation	60 min

Figure 2 shows the simulation topology of the MB subnet. The parameters we have investigated are FTP Download and Upload response times, VoIP delay and jitter, Video delay and throughput, and WLAN Throughput.

Figure 3 shows the screen shoot of a wireless node configuration where FTP traffic was set to high loads. We ran our simulation models in noisy channels. We also ran simulation under perfect channel condition for comparison purposes.

3.2 Validating Simulation Model

To validate the results, we have used two validation techniques discussed in [5]. Firstly, we have used the concept of face validation, which is when the model's behavior is expected and reasonable. Second, we compare our results with the work already published in the literature [6–8]. We have also checked the simulation log file ensuring

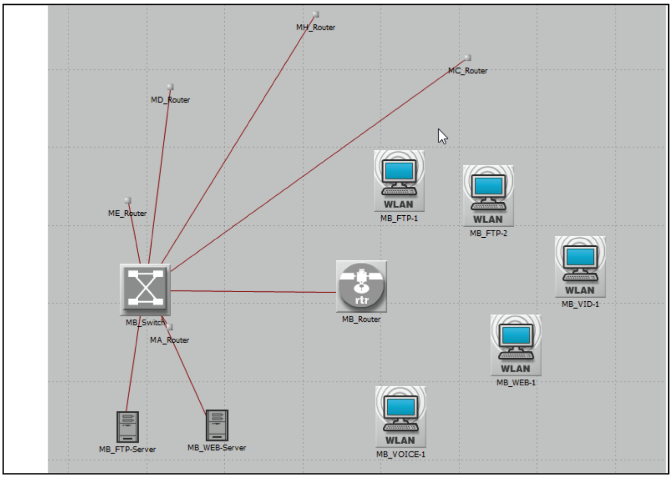

Fig. 2. AUT South Campus subnet in the MB building

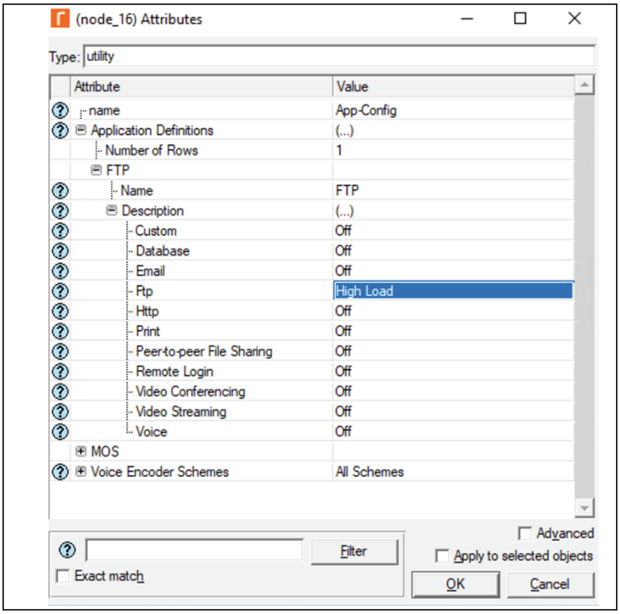

Fig. 3. Node configuration in which FTP traffic set to high loads

that models run smoothly without unexpected errors. Moreover, we have also simulated our network on multiple machines and for varied period of times to rectify any anomalies in the simulation.

4 Results and Discussion

We observe the effect of three radio propagation models (two ray ground, Shadowing Path Loss, and overall shadowing) on 802.11n 2.4 GHz and 5 GHz in noisy channels. The results for perfect channel are also presented for comparison purposes. Using Riverbed Modeler simulator, we measure FTP download and upload response times, VoIP packet delays and Jitter, Video packet delays and Throughput, and WLAN Throughput. The summary of research findings is presented in Table 3.

Table 3. Summary of simulation results for noisy channel (2.4 GHz and 5 GHz)

Performance metric	802.11n performance in noisy channel					
	Two ray ground		Shadowing path loss		Overall shadowing	
	2.4 GHz	5 GHz	2.4 GHz	5 GHz	2.4 GHz	5 GHz
FTP download (s)	0.31 (0.31)	7.3 (5.9)	0.14 (0.33)	24 (11.9)	0.41 (0.36)	27 (4.8)
FTP upload (s)	0.33 (0.33)	10.9 (23)	0.58 (0.44)	32 (24)	0.45 (0.33)	28 (21)
VoIP delay (s)	0.1 (0.1)	0.11 (0.1)	0.1 (0.1)	0.11 (0.1)	0.1 (0.01)	0.11 (0.11)
VoIP jitter (s)	0.0000007 (0.023)	0.0000024 (0.0000034)	0.001 (0.012)	0.0000026 (0.0000035)	0.011 (0.014)	0.0000026 (0.0000027)
Video delay (s)	0.028 (0.28)	0.89 (0.09)	0.28 (0.22)	0.088 (0.09)	0.28 (0.034)	0.089 (0.09)
Video throughput (Mbps)	0.14 (1.85)	1.4 (1.4)	10.78 (1.78)	1.4 (1.4)	10.78 (1.78)	1.4 (1.4)
WLAN throughput (Mbps)	16 (16)	18 (17)	24 (25)	18 (17)	25 (26)	18 (19)

Note: *Values in the bracket () represent the perfect channel.*

4.1 Effect of Radio Propagation Model

The two ray ground model is used in the simulation as default setting for Riverbed Modeler where a connection represents off a surface and "Bounces" to a different connection. In our findings we observe that there are small differences in Jitter and Video Throughput while there is not much differences in any of the other parameter. These differences are observed at 1.0 noise level which is "Perfect" and at a 100-noise level which is "Noisy". We also observe that there is a difference of 16 s in Jitters and a difference of 450,000 s in Video Throughput.

Shadowing Path Loss model is simulated by considering an object between the transmitter and destination addresses which interfere with the transmissions. Results obtained show that there are significant differences between Path Loss and Two Ray Ground models.

The overall Shadowing is a model in which the topology is outside of the specified terrain causes interference in the transmissions causing larger delays than Shadowing Path Loss. We also observe FTP (upload and download response), Video (delay and throughput) and WLAN throughput performance deteriorates for overall shadowing model over 5 GHz channel. This is due to its distance from the specified terrain.

4.2 Effect of 2.4 GHz and 5 GHz

Another interesting observation of our simulation study is the effect of 2.4 GHz and 5 GHz channel on system performance. For FTP traffic, 2.4 GHz channel performs much better than 5 GHz channel for all three propagation models. Moreover, the system performance changes to overall shadowing. Our simulation results (Table 3) show network throughput increase over 5 GHz channel (using two ray ground model) as compared to that of 2.4 GHz channel.

The summary of our research findings is presented in Table 4. We observe the effect of three propagation models on system performance in noisy channels for mixed traffics including FTP, VoIP, and Video. Our findings show that the shadowing path loss model performs best for FTP downloads whereas two ray ground model performs well for FTP uploads, Video throughput, and WLAN throughput over 2.4 GHz. The effect of propagation models on VoIP and Video delay performance is found to be insignificant. The overall shadowing over 5 GHz channel performs worst in all traffics investigated including FTP, VoIP, Video, and WLAN throughput.

Table 4. Summary of findings

Metrics	Good performance with	Worse performance with
FTP download (s)	Shadowing path loss (2.4 GHz)	Overall shadowing (5 GHz)
FTP upload (s)	Two ray ground (2.4 GHz)	Overall shadowing (5 GHz)
VoIP delay (s)	Impact on propagation model is not significant	
VoIP jitter (s)	Impact on propagation model is not significant	
Video delay (s)	Impact on propagation model is not significant	
Video throughput (Mbps)	Two ray ground (2.4 GHz)	Overall shadowing (5 GHz)
WLAN throughput (Mbps)	Two ray ground (2.4 GHz)	Overall shadowing (5 GHz)

5 Conclusion

In this paper we investigated the effect of radio propagation models on the performance of an 802.11n campus network over 2.4 GHz and 5 GHz in noisy channels. In the investigation, we considered three well-known radio propagation models such as two ray ground, shadowing path loss and overall shadowing. Simulation results obtained have shown that the shadowing path loss model over 2.4 GHz performed excellent for FTP download. However, the two-ray ground model performed the best for FTP (upload), VoIP and Video traffics over 2.4 GHz. The overall shadowing model over 5 GHz performed worst for all traffics investigated. An investigation of the impact of radio propagation models on a wide-area network is suggested as future work.

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