Performance Evaluation of Wireless Networks

Hetal Jasani
Michigan Technological University
Houghton, MI 49931
E-mail: hjasani@mtu.edu

Yu Cai
Michigan Technological University
Houghton, MI 49931
E-mail: cai@mtu.edu

Abstract

In this paper, we identify the various effects on radio signal strength due to the change in antenna height, elevation change, and the distance between the transmitter and the receiver. We use OPNET TMM (Terrain Modeling Module) to characterize the channel of the wireless communications using Free Space propagation model and Longley-Rice propagation model. The first contribution of the paper is to simulate radio signals being distributed over the varying terrain to see the changes in the signal strength. These signal strengths are observed as the receiver is moved over a simulated path that goes through many elevation changes. The second contribution of this paper is to simulate the RTS/CTS mechanism to evaluate the performance of IEEE 802.11 MAC protocol. We have concluded our findings by analyzing the different network statistics such as data traffic sent/received, WLAN Delay, network throughput.

1. Introduction

OPNET [1] has ability to model either military or commercial wireless networks with sufficient fidelity to be helpful in analysis in a time critical research scenario. The TMM enables you to enhance the accuracy of your OPNET simulations by taking into account signal loss due to terrain effects. The TMM can use both physical features (such as mountains and the curvature of the earth) and environmental factors (such as ground conductivity and surface refractivity) as inputs to calculate signal loss.

In this paper, we have used the TMM to explore the effect of different terrain on wireless communication. It includes two propagation models: Free Space and Longley-Rice. The TIREM propagation model is available from OPNET as an optional module. In addition, you can create custom propagation models as needed. The TMM adds several capabilities when installed with OPNET and the Wireless module: 1) consideration of terrain effects in path loss calculations, 2) display of elevation lines on a background map or image and 3) visualization of terrain and signal strength along a defined path. These added capabilities bring the following advantages to the accuracy of wireless network simulations: 1) it helps to determine whether transceivers can communicate due to the terrain, 2) it helps to determine the effects of environmental conditions on communications, and 3) it increases accuracy of propagation loss, signal strength, and noise.

In addition, the effect of RTS/CTS mechanism on collision in WLAN (Wireless Local Area Network) has been explored in this paper. Collision detection in WLAN is difficult since all wireless stations may not be able to listen to each other at all the times. A station may not be in the range of all other stations. In Figure 1, Nodes A, B, and C are within range of access points, but are not within a range of each other. Node A may detect a transmission from Node B, but not from Node C. If Node A listens and hears no traffic, it might assume the medium is free of transmission, while Node C is actually transmitting. This problem is known as hidden terminal problem (or hidden node problem) [3, 4, 5, 7]. In this situation, if Node A starts transmitting, collision will happen. As a result, both Node A and Node C would need to retransmit their respective packets, which results in higher overhead and lower throughput.

An optional feature of the RTS/CTS (Request to Send/Clear to Send) function had been included in the IEEE 802.11 standard [6] to control station access to the medium when collisions occur due to the hidden node. This option is also known as virtual carrier sensing. With the proper use of
RTS/CTS, we can fine-tune the operation of WLAN since it solves the hidden node problem and provides additional protection against collisions [5].

![Figure 1: Hidden Node Problem](image)

Figure 1: Hidden Node Problem

Figure 2 demonstrates RTS/CTS scheme. Please note that it makes use of SIFS (Short Interframe Space) only and NAV (Network Allocation Vector) to reserve the medium.

The net result of introducing overhead (i.e., RTS/CTS frames) and reducing overhead (i.e., fewer retransmissions) would increase the performance of WLAN using RTS/CTS. If network doesn't have any hidden nodes, the use of RTS/CTS will only increase the amount of overhead, which may reduce throughput. In this case, the additional RTS/CTS frames cost more in terms of overhead than what you gain by reducing retransmissions. Moreover, when data frame is much longer than RTS frame, usage of RTS/CTS is more helpful, in particular [2, 3, 8, 9].

We evaluate, in this paper, the effectiveness of RTS/CTS mechanism on the performance of IEEE 802.11 network. We use OPNET Modeler [1] to simulate two different scenarios and to compare the results. In the following sections, we discuss the simulation environments for TMM and RTS/CTS situations and analyzed the results of our simulation experiments. At the end, we have discussed the conclusions of our findings.

2. Terrain Module Simulation Environment

2.1. TMM Simulation Situation

Here we have a moving researcher with a wireless device that has a constant connection to the transmitter located to the East. Each portion of the movement trajectory is set for a 10 minute step, and the simulation is run for five hour time period. During this simulation time, the elevation of the wireless device varies between 500 and 2500 feet.

We identify the various effects on radio signal strength due to the change in antenna height, elevation, and the distance between the transmitter and the receiver. By simulating radio signals being...
distributed over the Rocky Mountains (varying terrain), we are able to see the changes in the signal strength as the receiver is moved over a simulated path that goes through many elevation changes. Figure 3 shows a situation including the transmitter, receiver, and the trajectory.

![Figure 3: Simulation Setup for TMM](image)

### 2.2. Propagation Models

#### 2.2.1. Propagation Models.

In order to take a closer look at the signal strength, we decided to use two well-known propagation models to calculate the effects it would have.

#### 2.2.2. Free-Space Model.

The free-space model is a more simplistic model that mostly accounts for distance between the transmitter and the receiver [10]. It assumes that there are perfect propagation conditions and that there is a clear line of sight between the transmitter and the receiver. It predicts that received power decays as a function of the T-R separation distance raised to some power [12].

#### 2.2.3. Longley-Rice Model.

The Longley-Rice model is a far more complex model that attempts to account for many different variables that may come into play when simulating signal strength. Some of these environment variables include: vertical or horizontal polarization, refractivity, earth’s curvature, permittivity, conductivity, and seven different pre-made climate codes [11]. This model is particularly useful for providing realistic changes in signal strength over various climates and terrain.

### 2.3. Simulation Results and Discussions for TMM

In Figure 4 (Attenuation Vs. Distance), the yellow line (lower line) represents the Longley-Rice propagation model and the red line (upper line) represents the Free Space model. The transmitter and the receiver are set to be vertically polarized at the height of 20m. As you can see, the further away the receiver moves from the transmitter, the higher the attenuation on the signal. Since the Longley-Rice model is much more detailed, the attenuation is much higher and probably more realistic. The Free Space model has a much more linear type relationship between the distance and the attenuation, which is not very realistic given the elevation changes during the simulation.

![Figure 4: Attenuation Result at Different Distances](image)

To show the further effects of elevation change on signal strength, the height of the transmitter antenna has been raised to 100m. The height of the antenna makes a big effect on signal strength. As shown in Figure 5, attenuations in the Longley-Rice model

![Figure 5: Attenuation Result for Raised Antenna](image)
parallels that of the Free Space model for an extended period. It shows that line of sight has been given higher importance compared to the other variables considered into the Longley-Rice computational model. At 60m distance, they started to separate as shown by yellow (lower) line and red (upper) line in Figure 5.

![Figure 6: Fresnel Zone for Raised Antenna](image)

In Figure 6, you can see the estimated Fresnel zone for an antenna that has a 100 meter high transmitter and a receiver that is 20 meters high. The Fresnel zone is an elliptical region surrounding the line-of-sight path between transmitting and receiving antennas. Fresnel zones are used to help calculate obstruction of the signal path.

![Figure 7: Traffic Received](image)

This Figure 7 shows the traffic received at sink (transmitter or base station) during the simulation. You can see that each graph differs greatly depending on the propagation model used. The free space model, which assumes perfect propagation conditions, shows no real change in traffic received. The other two more realistic models (Longley-Rice and TIREM) actually incorporate elevation into the equation. It shows that the lower height cause packets to be dropped due to an unstable connection with the transmitting antenna.

3. RTS/CTS Simulation Environment

3.1. RTS/CTS Simulation Situation

Now, the second contribution of this paper is discussed. We have simulated the effectiveness of RTS/CTS mechanism using OPNET [1] Modeler. It incorporates a detailed and accurate model of the physical channel and of the IEEE 802.11 MAC layer. The Two-way ground path loss model is used as radio propagation model. Most of the physical and MAC layer parameters of OPNET are following the IEEE 802.11 standard [6].

![Figure 8: Network Topology for RTS/CTS](image)

As shown in Figure 8, we have placed two nodes and one receiver representing a campus-wide WLAN. Receiver, here, may represent an access point for WLAN. We have drawn a trajectory for Node A, on which it moves according to the predefined amount of time and distance during the simulation. We have set up our simulation such that Node A will move 430 meters (Node A is going out...
of range of Node $B$) along the path represented in the Figure 8 over the course of about five minutes.

We have run two scenarios in our simulation to evaluate the effect of RTS/CTS mechanism. During the second scenario, nodes are not using RTS/CTS mechanism in the first scenario while running a simulation. In contrast, Nodes use the RTS/CTS mechanism. Various results are recorded over the course of the 1000 second simulation time.

### 3.2. Simulation Results and Discussions for RTS/CTS

Figures 9 to 10 show the comparison results related to both simulation scenarios (i.e., RTS/CTS disabled and enabled). In order to reduce the amount of collisions caused by hidden terminal problem, the IEEE 802.11 protocol can use the RTS/CTS mechanism optionally [4, 8]. We have conducted the same experiment, but with the RTS/CTS mechanism enabled on all nodes in the network. This should allow us to eliminate some, but not all of the collisions caused by the hidden terminal problem.

**Figure 9: WLAN retransmission attempts**

Figure 9 shows the WLAN retransmission attempts by Node $A$. The retransmission attempts are increased when Node $A$ begins to move. However, the amount of retransmission attempts is about 8 times fewer than RTS/CTS disabled scenario. This means that there was a significant drop in retransmissions due to the collisions.

Figure 10 shows the WLAN Delay. Due to less number of retransmissions, the WLAN delay drops drastically for the period when the nodes are hidden to each other. It is important to note that the delay is now little higher when Node $A$ and $B$ can hear each other (not hidden). It is due to the overhead caused by the RTS/CTS handshake mechanism.

**Figure 10: WLAN Delay**

From these results, it appears that the RTS/CTS handshake mechanism helps to improve the WLAN performance when nodes are hidden from each other. According to the results of our simulations, mobility doesn’t have a big impact as we originally suspected. Due to the overhead of RTS/CTS packets, there will be some increases in WLAN delay, but end users may not notice them. This simulation also shows that proper configuration of all network devices is extremely important. With RTS/CTS disabled, network performance dropped significantly and in fact it may have rendered many services unusable. With RTS/CTS enabled, WLAN delay stayed around 30ms, outgoing traffic remained stable, and numbers of collisions were kept to a minimum.

At 350 seconds, Node $A$ becomes a hidden node to Node $B$ (and vice versa) for approximately 300 seconds. During this period, use of RTS/CTS frame exchange reduces the number of collisions (and therefore retransmissions) significantly. CTS message sent by the receiver node informs the surrounding nodes about the upcoming data
transmission attempt of the other node and its reservation of the channel.

4. Conclusions

Based on our first set of simulations of TMM, with the radio signal being propagated over the Rocky Mountains, there are a number of observations you can make on channel conditions. With the Free-Space model, distance is the primary factor to consider since it assumes the clear line-of-sight path between the transmitter and receiver. When using a more realistic model, such as Longley-Rice, path loss is predicted using the path geometry of the terrain profile and the refractivity of the troposphere. With higher antenna, you are able to keep the attenuation to the minimum. The higher antenna will have less obstruction and better signal strength due to more clear line-of-sight area in the Fresnel zone.

In the second set of simulations, we evaluate the effectiveness of optional RTS/CTS handshake mechanism on the performance of the IEEE 802.11 [6] based WLAN. When analyzing the performance of WLAN, throughput, packet loss rate, number of retransmissions, and number of collisions should be observed. We have simulated two scenarios in the OPNET Modeler with and without RTS/CTS mechanism enabled on network nodes. We have analyzed our findings by comparing the total WLAN retransmissions, data traffic sent/received, WLAN Delay of mentioned scenarios. In hidden node problem situation, it is useful to enable the RTS/CTS mechanism for mobile nodes. However, it is vital to remember that it also increases the overhead of RTS and CTS packets. For scenarios where hidden terminal problem may not exist, it is better to avoid using an optional RTS/CTS handshake mechanism for IEEE 802.11 based WLAN.

5. References