Investigating the Influence of Propagation Loss Models on RSS and Throughput in Wi-Fi ns-3 Simulations

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***Abstract*—This paper investigates the influence of different propagation loss models on the performance of a simple ad-hoc IEEE 802.11n network. Using the network simulator ns-3, I analyze the effects of various propagation models on throughput and received signal strength (RSS) for two nodes engaged in UDP traffic. To assess the models' behavior in different propagation environments, simulations are conducted across a range of internode distances. My results demonstrate that the choice of propagation loss model has a significant impact on network performance, particularly at longer distances. I further identify key differences between the models in terms of their ability to accurately predict network performance under various propagation conditions.**

I. Introduction

The well-known network simulator ns-3 [1] provides a variety of propagation loss models [2] to account for signal attenuation in various network scenarios. However, selecting the most suitable model is crucial for reliable performance evaluations. This paper investigates the distinct effects of five propagation loss models on Wi-Fi throughput and RSS across varying internode distances. The models under consideration, implemented as identically named classes in ns-3, are:

- *FriisPropagationLossModel* [3]
- *FixedRssLossModel* [4]
- *ThreeLogDistancePropagationLossModel* [5]
- *TwoRayGroundPropagationLossModel* [6]
- *NakagamiPropagationLossModel* [7]

In this paper, I provide insights into the relative performance of these models and highlight their suitability for different network configurations.

A. Propagation Loss Models under Consideration

FriisPropagationLossModel:
This model is based on the Friis free-space propagation model [8], which models the line-of-sight path loss incurred in a free-space environment, devoid of any objects that create absorption, diffraction, reflections, or other effects.

FixedRssLossModel:
This model sets the received power to a fixed value, regardless of the distance between the nodes.

ThreeLogDistancePropagationLossModel:
This model is a variation of the log distance model by [9], which assumes an exponential path loss over the distance. It considers three distance fields (near, middle and far) with different propagation exponents.

TwoRayGroundPropagationLossModel:
Originally developed by [10], this model assumes multipath propagation through reflections on the ground.

NakagamiPropagationLossModel:
This model implements the stochastic Nakagami-m fast fading model defined by [11], which accounts for multipath fading. It does not consider path loss due to the distance traveled by the signal.

II. Methodology

A wireless network scenario was implemented using the ns-3 network simulator 3.40. Two nodes were positioned in a flat environment, each equipped with an IEEE 802.11n Wi-Fi card operating in the 5 GHz band. Both nodes used the simple ad-hoc Wi-Fi Medium Access Control (MAC) protocol. The output power of each Wi-Fi card was set to 10 dBm, assuming an omnidirectional antenna with gain of 1 dBi. For the upper layers, IP and UDP were used to generate traffic with a data rate of 75 Mbps and an application layer packet size of 1450 Bytes.

To evaluate the impact of propagation on throughput and RSS, simulations were conducted for each of the five propagation models. For each, simulations were performed with increasing internode distances, starting from 1 meter and incrementing by 1 meter until the measured throughput reached 0 Mbps. To eliminate cross-effects between simulations, a new simulation environment was established for each new distance set.

The simulations were executed using ns-3 3.40 on a Windows Subsystem for Linux 2 environment on a Microsoft Windows 11 Home system with 16 GB of DDR4 RAM and using a 6-core AMD Ryzen 5 5600H CPU.

A. Simulation Parameters

Important simulation parameters affecting the throughput were set as follows: The interval between packets sent by the client was set to 0.0001547 seconds following a desired data rate of 75 Mbps. To achieve such throughput in a 5 GHz IEEE802.11n band, the physical channel was explicitly configured to use a channel width of 40 MHz as specified in [12]. The attribute determining the maximum amount of packets to be sent by the client was set to the maximum unsigned integer of the data type `uint32_t` of the corresponding attribute ”MaxPackets” with the help of ns-3 class `UdpClientHelper` [13]. Furthermore, to ensure a constant position of the nodes during each simulation run, their position was set with the help of the class `ConstantPositionMobilityModel` [14].

B. Model-Specific Configuration

Model-specific configurations were explicitly set as follows: The Fixed RSS model, which assumes a constant signal strength threshold for the receiver above which no loss occurs, was configured to model an RSS of -80 dBm.

Regarding the Two Ray Ground model, additional positioning parameters for the z-axis (height) were set for both nodes to 2 meters. The height of both antennas was set to 1 meter above the nodes’ z coordinate. For the remaining models, default parameters were implicitly established.

C. Determining the Simulation Time

A preliminary experiment was conducted to identify a common simulation time for reliable results across all propagation models. Therefore, the simulation was run with a fixed internode distance of 5 meters using the Friis model. Fig. 1 displays the measured throughput in Mbps for varying simulation time, identifying an asymptotic steady state around approximately 50 seconds after which the throughput changes insignificantly.

III. Results

Given the steady state identified in Fig. 1, the simulation time for the simulations measuring throughput and received signal strength is set to 50 seconds for all propagation models.

The simulation results observing the throughput over varying distances are displayed in Fig. 2. Accordingly, the progression of RSS across varying distances is visualized in Fig. 3 for all propagation models. Concerning throughput Friis, Three Log Distance and Two Ray Ground show a staircase-like descent, with distinct and stepped decreases at regular intervals with increasing distance. The steady decline in throughput is sensible since these models assume that the signal power decreases at a rate proportional to the inverse square of the distance between the transmitter and receiver. This is reflected in the logarithmic-like descent in the received signal level visualized in Fig. 3. The staircase-like progression can be attributed to the changing modulation schemes. As the nodes move farther apart, the signal strength diminishes steadily and the physical layer components of the receiving node adjust the modulation to adapt to the lower signal quality. It shall be noted that in Fig. 2 as well as Fig. 3, the line graphs of the Friis and Two Ray Ground models visually overlap.

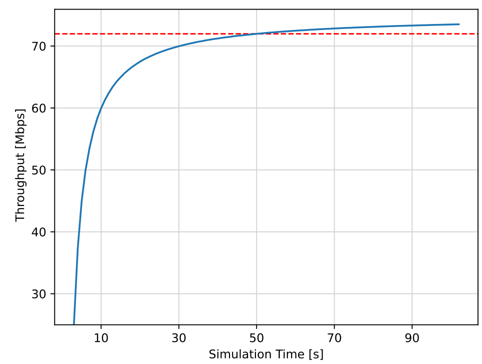

Fig. 1. Progression of throughput over simulation time.

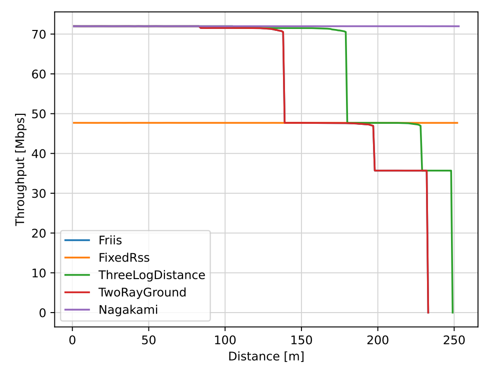

Fig. 2. Progression of throughput over varying distance.

The Fixed RSS and Nakagami models return a stable throughput throughout 249 meters, which marks the maximum zero-crossing reached among all other models. Given that Fixed RSS consistently provides a constant received power level unaffected by transmission power and the distance between the receiver and transmitter, the outcome aligns with the steady received signal strength depicted in Fig. 3 for this model. An interesting finding is the progression of throughput and received signal strength for the Nakagami model. The variance in the received signal level apparent in Fig. 3 around the mean of approximately 9.03265 dBm is balanced out and results in a stable throughput of roughly 72.8841 Mbps.

IV. Summary

The five investigated propagation loss models show distinct effects on throughput and received signal level over varying distances. It is important to examine one’s use case before deciding on one model.

The models that account for realistic factors such as free space path loss, ground effects, and atmospheric conditions include Friis, Three Log Distance, and Two Ray Ground.

The Nakagami model predominantly models the effects of fading and shadowing and applies an underlying stochastic distribution to the power level. It is therefore suitable for modeling wireless channels in the presence of strong shadowing due to e.g. walls and multipath fading as in urban areas,

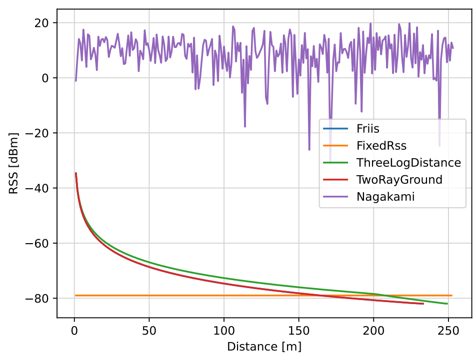

Fig. 3. Progression of RSS over varying distance.

which can lead to rapid and unpredictable fluctuations in signal strength. The high variance in the received signal level of the simulations using the Nakagami model in Fig. 3 emphasizes this characteristic.

In contrast, the Fixed RSS model assumes a received signal strength regardless of the transmit power and is therefore not suitable for most realistic Wi-Fi network scenarios. A sensible use case for this model would be found in scenarios where nodes are very close together and the signal quality is not affected by the distance between them.

To create a more comprehensive and realistic representation of signal propagation in various environments it is a sensible approach to chain multiple propagation models. While the Nakagami model performs well in accurately representing shadowing and fading, the Friis model offers a more precise depiction of path loss in free space. As a direction for future work, it may be valuable to examine the effects of different combinations of propagation loss models.

Promoting reproducibility and future investigations, the ns-3 code used for running the simulations is openly accessible under [15].

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