Evaluating Propagation Models in Wi-Fi Simulations Using ns-3

Communication in Distributed Systems (CiDS)

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***Abstract*—This paper evaluates five propagation models implemented in ns-3 (Friis, Fixed RSS, Three-Log Distance, Two-Ray Ground, and Nakagami) by simulating a Wi-Fi communication scenario using IEEE 802.11n in the 5 GHz band. The study investigates how these models influence signal strength and throughput across varying distances. Additionally, the impact of simulation runtime on throughput stability is analyzed. The results highlight the strengths and limitations of each model, offerring insights to help researchers select the most suitable model for their scenarios like IoT networks.**

***Index Terms*—ns-3, Propagation Models, Wi-Fi, IEEE 802.11n, Wireless Networks, Signal Strength, Throughput, Nakagami Model, Two-Ray Ground Model, Fixed RSS Model, Friis Model, Three-Log Distance Model, 5 GHz Band, IoT**

I. Introduction and Motivation

Understanding the influence of propagation models is critical for accurately simulating wireless networks. These models influence key metrics such as signal strength and throughput, which are essential for designing efficient communication systems. This paper aims to provide a comparative analysis of propagation models implemented in ns-3 version 3.42 [1] and demonstrate how simulation runtime affects observed throughput. By doing so, it provides guidance for researchers seeking reliable and realistic simulation configurations. The simulated scenario focuses on two Wi-Fi nodes operating in the IEEE 802.11n standard in the 5 GHz band. It varies the distance between the nodes and records the signal strength and throughput for each model. Additionally, a preliminary experiment investigates the effect of simulation runtime on throughput stability. The study by Stoffers and Riley [2], which offers a comprehensive comparison of the models implemented in ns-3, served as a key reference for understanding the behavior of propagation models in ns-3.

II. Methodology

A. Simulation Setup

I simulated a point-to-point Wi-Fi connection between two nodes in ns-3, with one node acting as the source and the other as the receiver, using the following configuration parameters:

- MAC Layer: AdhocWifiMac
- Transmit Power: 10 dBm
- Antenna Gain: 1 dBi (omnidirectional)
- Traffic Pattern: UDP traffic with 1450-byte packets at 75 Mbps
- Mobility Model: ConstantPositionMobilityModel
- Propagation Models:
  - FriisPropagationLossModel
  - FixedRssLossModel
  - ThreeLogDistancePropagationLossModel
  - TwoRayGroundPropagationLossModel
  - NakagamiPropagationLossModel

Except for Fixed RSS (signal strength fixed at -80 dBm) and Two-Ray Ground (frequency set to 5 GHz and antenna height set to 1 meter), the propagation models were left at their default configurations. This decision ensures a standardized comparison across models without introducing additional biases or manual adjustments. The adjustments were necessary to align the model parameters with the simulation setup, ensuring a functional Wi-Fi connection. The distance between the nodes along the x-axis was increased incrementally by 5 meters (to allow multiple test iterations), starting at 1 meter, until no connection was possible. The maximum distance was set to 251 meters, as this was the point where no connection was possible for most models, except for the Fixed RSS model, where signal strength remains constant, and the Nakagami model, where signal fading can cause strength fluctuations. Signal strength is measured at the receiver's physical layer, while throughput is calculated using ns-3's FlowMonitor. In the preliminary experiment, the simulation runtime is varied from 0 to 120 seconds to observe its effect on throughput stability at a fixed distance of 1 meter, using the FriisPropagationLossModel. Instead of using higher-level application helpers like OnOffHelper or UdpClientHelper/UdpServerHelper, I implemented traffic generation manually, based on the wifi-simple-adhoc example, using raw UDP sockets. This approach involved directly scheduling packet transmissions, providing fine-grained control over packet size, interval, and count. Although the packet size was set to 1450 bytes, the observed throughput first slightly exceeded 75 Mbps. The FlowMonitor reported a packet size of 1478 bytes, indicating that the discrepancy was due to the additional overhead from the headers, which increased the physical packet size beyond the application layer payload. To accurately match the expected throughput, the inter-packet interval must be based on the total packet size, which includes the application layer payload (1450 bytes) and the UDP and IP headers (8 + 20 bytes = 28 bytes).

$$\text{Inter-packet Interval} = \frac{1478 \times 8}{75 \times 10^6} = 0,000157653\, s$$

B. Expected Differences

- Friis, Three-Log Distance and Two-Ray Ground describe free-space path loss, with the Two-Ray Ground accounting for ground reflections. All of them should decrease signal strength logarithmically with distance.
- Fixed RSS should provide constant signal strength regardless of distance.
- Nakagami simulates fading effects, which should result in fluctuating signal strengths.

III. Results

A. Preliminary Experiment: Runtime vs. Throughput

Fig. 1 shows throughput increasing with runtime for the Friis model at a fixed distance of 1 meter. Throughput stabilizes near 75 Mbps after approximately 60 seconds, indicating that transient effects impact early results. Thus, a runtime of at least 60 seconds is recommended for reliable results.

B. Distance vs. Signal Strength

Fig. 2 compares signal strength across distances for all models.

- Friis, Three-Log Distance, and Two-Ray Ground show the expected logarithmic declines, starting at approximately -34 dBm down to approximately -82 dBm.
- Fixed RSS remains constant at -79 dBm.
- Nakagami shows fluctuations due to fading, with occasional constructive interference causing positive signal strength values ranging from approximately 17 dBm to approximately -7 dBm. These measured values are highly time-dependent, as fading varies over time. Consequently, both the packet size and the inter-packet interval influence the sampling process.

C. Distance vs. Throughput

Fig. 3 illustrates throughput trends with distance.

- Friis, Three-Log Distance, and Two-Ray Ground maintain near-max throughput (approximately 74 Mbps) at shorter distances, dropping down to 0 Mbps sharply after several thresholds.
- Fixed RSS throughput remains consistently at approximately 50 Mbps due to its static signal strength.
- Nakagami throughput does not mirror its signal strength fluctuations and remains relatively constant near the max throughput (approximately 74 Mbps) due to the sufficient average signal strength.

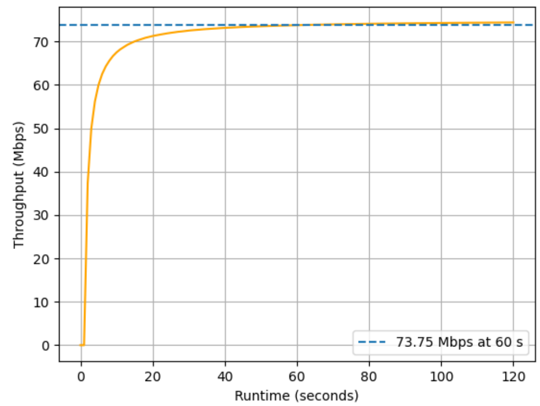

Fig. 1. Runtime vs. UDP Throughput with ns3::FriisPropagationLossModel over 1 m

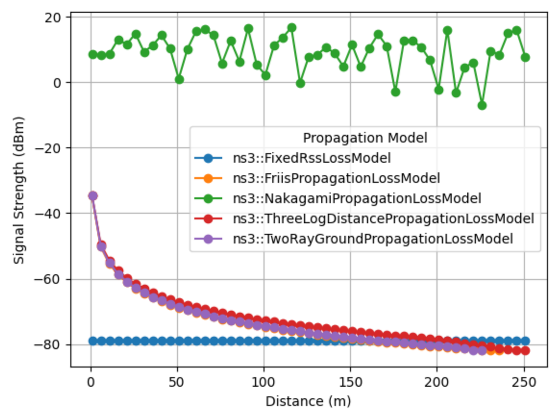

Fig. 2. Distance vs. Signal Strength for the five different propagation models

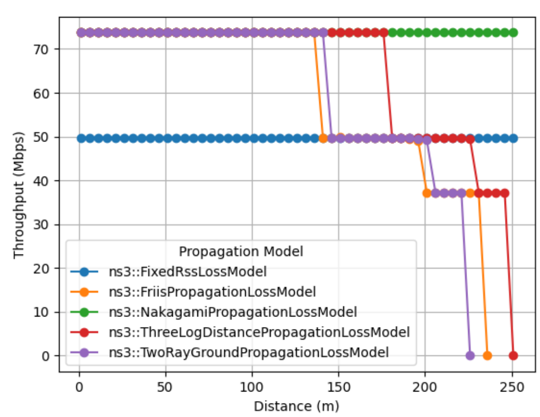

Fig. 3. Distance vs. UDP Throughput for the five different propagation models

IV. Summary

A. Key Findings

- Propagation models significantly affect signal strength and throughput.
  - Friis, Three-Log Distance and Two-Ray Ground offer accurate modeling for free space, suburban and ground reflection scenarios.
  - Fixed RSS simplifies simulations but may lead to unrealistic results.
  - Nakagami effectively models fading but introduces variability.
- Simulation runtime impacts throughput stability; runtimes under 60 seconds may yield unreliable results.

The source code and resulting data are available in the associated GitHub repository [3], enabling reproducibility and further exploration.

B. Future Work

Future studies could explore how mobility and interference affect propagation models, including scenarios with multiple nodes like vehicular networks. Testing the models with TCP traffic could also provide valuable insights, especially for applications that require reliable data transmission.

References

[1] ns-3 Network Simulator, Website. [Online]. Available: https://www.nsnam.org/. [Accessed: Jan. 14, 2025].

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[3] F. Jülich, "CiDS," GitHub Repository, 2025. [Online]. Available: https://github.com/fabianjuelich/cids. [Accessed: Jan. 14, 2025].