Comparison of Wireless Propagation Loss Models

Niklas Frondorf

Institute for Cyber Security & Privacy
University of Applied Sciences Bonn-Rhein-Sieg
Sankt Augustin, Germany
niklas.frondorf@smail.inf.h-brs.de

Abstract—**In this paper five different wireless propagation loss models are being compared against each other. To evaluate the models a simulation is used. The experiment in which the models are used involves two Wi-Fi nodes. As the distance between the nodes increases, the signal strength and the throughput at the receiving node is observed. Of those models that take the distance between the nodes into account, all show the same behaviour. They all decrease the throughput in discrete steps when a certain threshold of signal strength is crossed.**

I. Introduction and Motivation

This paper is about the evaluation of selected propagation loss models in a given scenario. The models are being evaluated in a scenario with two Wi-Fi nodes with varying distance. The goal of this evaluation is to quantitatively compare the models and to see if they are fit to be used in the given scenario. Other researchers might profit from this paper when choosing propagation loss models for a similar experiment.

II. Methodology

A. Scenario

The scenario for every propagation loss model is the same. There are two Wi-Fi nodes communicating in one direction using the IEEE 802.11n standard[1] operating in the 5GHz Band. Both nodes use the Adhoc Wi-Fi MAC. The output power of the Wi-Fi cards is fixed to 10 dBm. Both nodes have an omnidirectional antenna with a 1 dBi gain. The upper layers of the communication are IP and UDP with a data-rate of 75 Mbps and a packet size of 1450 bytes.

The scenario is simulated by the ns-3 network simulator in the version 3.43[2]. The following propagation loss models of ns-3 where used to conduct the comparison:
- FriisPropagationLossModel[3, 28.1.1]
- FixedRssLossModel[3, 28.1.8]
- ThreeLogDistancePropagationLossModel[3, 28.1.4]
- TwoRayGroundPropagationLossModel[3, 28.1.2]
- NakagamiPropagationLossModel[3, 28.1.7]

The exact configuration of each model can be seen in the source code[1].

B. Expected Behaviour

Since all models have either a well known equation or a pre-defined behaviour, a certain outcome is expected from each one of them.

a) *FriisPropagationLossModel:* The equation for this model in ns-3 is:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi d)^2 L} \qquad (1)$$

Based on this equation, it can be assumed that the observed signal strength at the receiving node is quadratically decreasing when the distance increases.

b) *FixedRssLossModel:* The ns-3 documentation for this model says: "This model sets a constant received power level independent of the transmit power."[3, 28.1.8]. Based on that, the received signal strength should essentially be a constant value.

c) *ThreeLogDistancePropagationLossModel:* This model is essentially the same as the LogDistancePropagationLossModel of ns-3. The only difference is that this model has three distance fields. For each distance field the path loss is calculated by this equation in ns-3:

$$L = 10 \cdot n_0 \cdot \log_{10}\left(\frac{d}{d_0}\right) \qquad (2)$$

To get the loss over the total length, all of the distance field losses are summed up. Based on that equation it can be assumed that the received signal strength gets logarithmically smaller as the distance increases.

d) *TwoRayGroundPropagationLossModel:* The equation for this model in ns-3 is:

$$P_r = \frac{P_t G_t G_r H_t^2 H_r^2}{d^4 L} \qquad (3)$$

Based on this equation is can be assumed that the received signal strength gets quartically smaller as the distance increases.

e) *NakagamiPropagationLossModel:* This ns-3 model implements the Nakagami-m fast fading model[4]. "The model does not account for the path loss due to the distance traveled by the signal [...]"[3, 28.1.7]. Based on this the model should behave very similar to the FixedRssLossModel.

---

[1]https://github.com/0x6e66/wifi-propagation-experiment

The only difference being the constant value of the received signal strength.

C. Determining the simulation time

To determine a sufficient runtime for the simulation, a preliminary simulation experiment was conducted. In this experiment the TwoRayGroundPropagationLossModel was used and the distance between the two nodes was set to 20 meters. The results of this experiment can be seen in Fig. 1, where the throughput is plotted against the simulation time. From Fig. 1 it is clear that the simulation settles on a certain value at around five seconds. Based on that, all other simulations are run with a simulation time of five seconds.
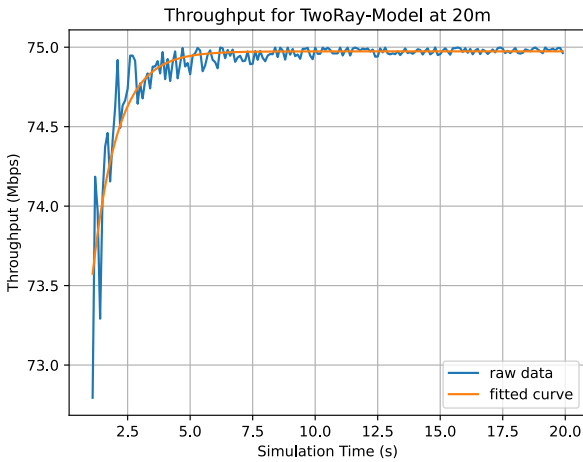

Fig. 1: UDP Throughput for TwoRayGroundPropagationLossModel at fixed distance of 20m

III. Results

For each propagation loss model the simulation was run with the distance increasing by 1 meter every iteration. The simulation was run until the throughput was lower than 10^{-3} Mbps or the maximum distance of 300 meters was reached. The throughput was calculated with the help of the FlowMonitor class from ns-3. In turn the received signal strength was calculated by taking the average of all reported values during the simulation using a callback function to collect data when packets where received.

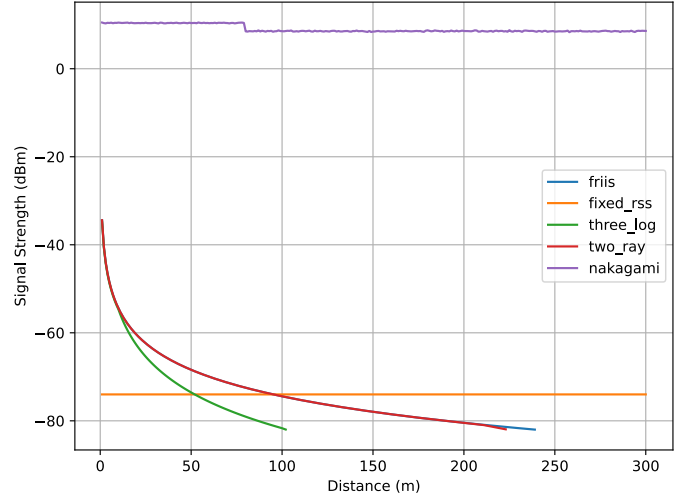The results of the experiment are shown in Fig. 2 and Fig. 3.

Fig. 2: Received Signal Strength for variable distances between the Wi-Fi nodes

Fig. 2 shows that the predictions from Section II.B hold very well. The distance has next to no impact on the FixedRss-LossModel and NakagamiPropagationLossModel. The only difference here being the little drop in signal strength in the NakagamiPropagationLossModel at around 80 meters. This drop cloud be explained by the implementation of the model. The documentation of ns-3 says: "The implementation of the model allows to specify different values of the m parameter [...] for three different distance ranges"[3, 28.1.7]. It could be that the default parameter for the first distance in the model is around 80 meters.

The other models behave pretty much as expected. The difference in loss of signal strength between the TwoRayGroundPropagationLossModel, FriisPropagation-LossModel and ThreeLogDistancePropagationLossModel can be attributed to the configuration of the models in the simulation.

Whats interesting here is that the plots of the FriisPropagationLossModel and TwoRayGroundPropagationLossModel look nearly identical with the only difference being that the FriisPropagationLossModel takes a little longer to loose connection.
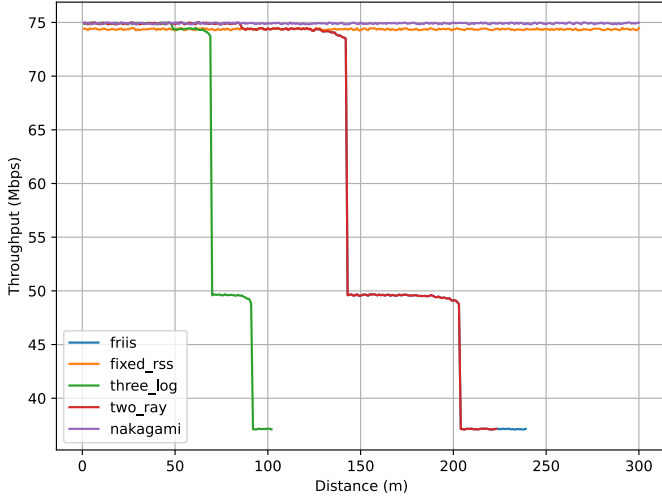
Fig. 3: UDP Throughput for variable distances between the Wi-Fi nodes

Fig. 3 shows the impact the received signal strength has on the throughput on the receiving Wi-Fi node. Since the signal strength of the FixedRssLossModel and NakagamiPropagationLossModel essentially stays constant, so does the throughput.

The more interesting cases are the remaining models. The throughput seems to degrade in a discrete manner. It is notable that the discrete steps in which the throughput decreases are the same for all three models. Since the ThreeLogDistancePropagationLossModel has a larger loss of signal strength (as the distance increases) than the FriisPropagationLossModel and TwoRayGroundPropagationLossModel, the throughput decreases sooner than the other models.
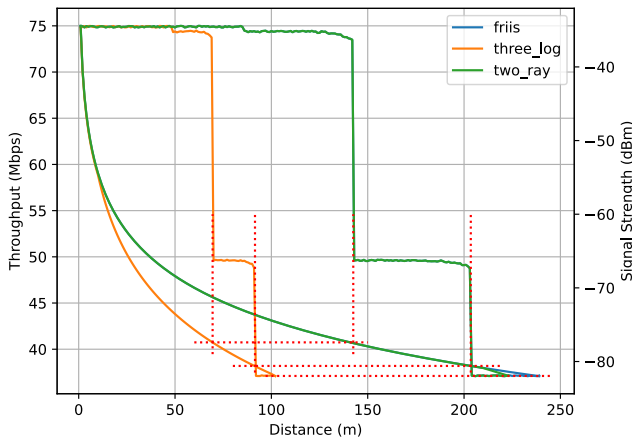

Fig. 4: UDP Throughput for variable distances between the Wi-Fi nodes

Further analysis revealed an interesting correlation between the three models. The discrete steps of loss of throughput actually occur at the same distance the signal strength crosses a certain threshold. These thresholds are the same for all of the three models that show this behaviour. The thresholds are approximately −77.4, −80.6 and −81.9 dBm. The assumption can be made that the discrete steps of throughput loss can

be attributed to the IEEE 802.11n standard[1]. This is further illustrated in Fig. 4 where the throughput and signal strength are put in one graph. This shows the correlation between the throughput of all the three models. The dotted red lines show that all sudden drops in throughput actually occur at the same level of signal strength in all three models.

IV. Summary

The results of this experiment show that the FixedRss-LossModel and NakagamiPropagationLossModel are a poor choice for an experiment that only analyses the variation of distance between two Wi-Fi nodes. Based on their definition and implementation distance doesn't impact these models and thus these models have no relevant results.

The FriisPropagationLossModel, ThreeLogDistancePropagationLossModel and TwoRayGroundPropagationLossModel work well with the described scenario and reveal an interesting correlation, which could be the consequence of the chosen Wi-Fi standard (IEEE 802.11n standard[1]).

Other researchers who are attempting to conduct a similar experiment should avoid the FixedRssLossModel and NakagamiPropagationLossModel as they serve no purpose in this scenario.

Future work might focus on finding an explanation for the correlation between throughput and signal strength. The current assumption is that this is due to the IEEE 802.11n standard[1]). This future work would try to validate or falsify this assumption.

References

[1] "IEEE Standard for Information technology– Local and metropolitan area networks– Specific requirements– Part 11: Wireless LAN Medium Access Control (MAC)and Physical Layer (PHY) Specifications Amendment 5: Enhancements for Higher Throughput," *IEEE Std 802.11n-2009 (Amendment to IEEE Std 802.11-2007 as amended by IEEE Std 802.11k-2008, IEEE Std 802.11r-2008, IEEE Std 802.11y-2008, and IEEE Std 802.11w-2009)*, vol. 0, no. , pp. 1–565, 2009, doi: 10.1109/IEEESTD.2009.5307322.
[2] nsnam, "ns-3." [Online]. Available: https://www.nsnam.org/releases/ns-3-43/
[3] nsam, "ns-3 Documentation. Chapter 28: Propagation." [Online]. Available: https://www.nsnam.org/docs/models/html/propagation.html
[4] M. Nakagami, "The m-Distribution—A General Formula of Intensity Distribution of Rapid Fading," *Statistical Methods in Radio Wave Propagation*. Pergamon, pp. 3–36, 1960. doi: 10.1016/B978-0-08-009306-2.50005-4.