Comparison of Wireless Propagation Loss Models

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***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 qualitatively compare the models and to see if they are fit to be used in the given scenario. Other researchers might profit from this research 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 datarate 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 predefined behaviour, a certain outcome is expected from each one of them.

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

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

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:

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

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:

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

Based on this equation, it 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.

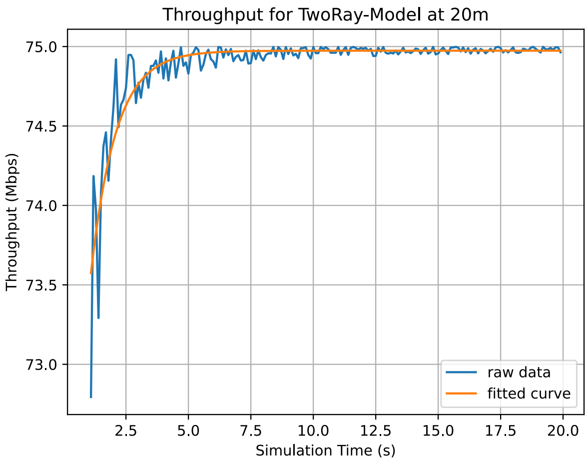

Fig. 1: UDP Throughput for TwoRayGroundPropagationLossModel at fixed distance of 20m

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.

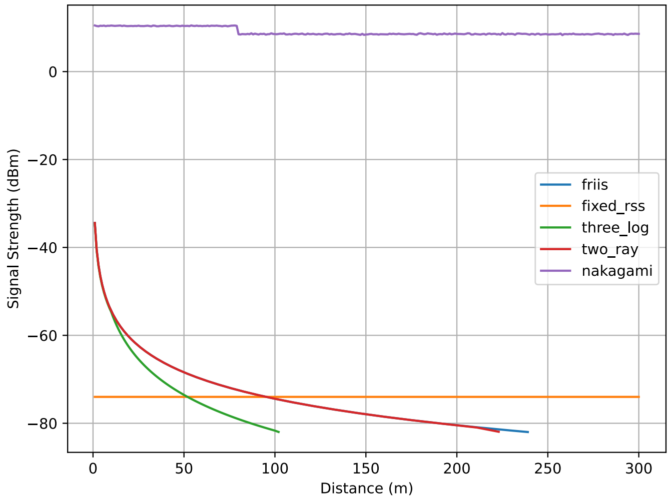

Fig. 2: Received Signal Strength for variable distances between the Wi-Fi nodes

Fig. 2 shows that the predictions from Section II.B hold very well. The distance has next to no impact on the FixedRssLossModel 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, FriisPropagationLossModel 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.

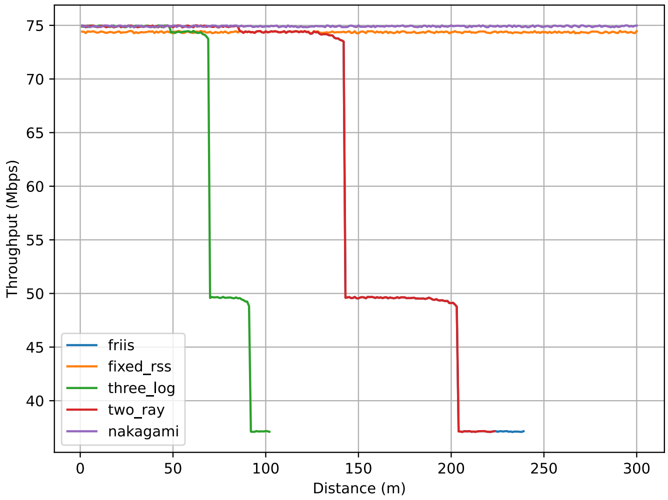

Fig. 3: UDP Throughput for variable distances between the Wi-Fi nodes

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.

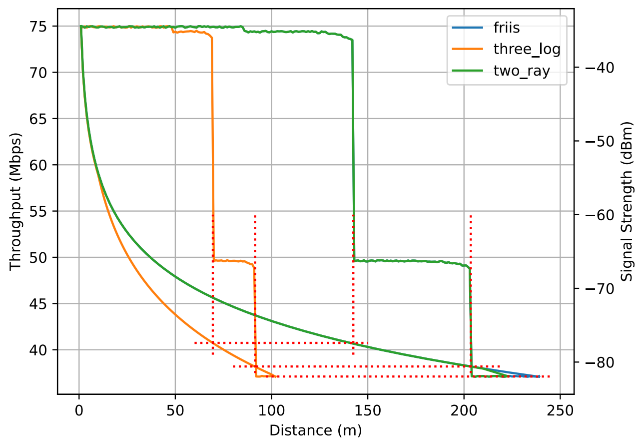

Fig. 4: Correlation between the throughput and signal strength

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. 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.

The discrete steps in which the throughput decreases are a direct consequence of how the IEEE 802.11n standard[1] handles loss of signal strength.

802.11n/HT and 802.11ac/VHT MCS, SNR and RSSI

HT MCS	VHT MCS	Modulation	Coding	20MHz Data Rate 800ns	20MHz Data Rate 400ns	20MHz Min. SNR	20MHz RSSI	40MHz Data Rate 800ns	40MHz Data Rate 400ns	40MHz Min. SNR	40MHz RSSI	80MHz Data Rate 800ns	80MHz Data Rate 400ns	80MHz Min. SNR	80MHz RSSI	160MHz Data Rate 800ns	160MHz Data Rate 400ns	160MHz Min. SNR	160MHz RSSI
1 Spatial Stream																			
0	0	BPSK	1/2	6.5	7.2	2	-82	13.5	15	5	-79	29.3	32.5	8	-76	58.5	65	11	-73
1	1	QPSK	1/2	13	14.4	5	-79	27	30	8	-76	58.5	65	11	-73	117	130	14	-70
2	2	QPSK	3/4	19.5	21.7	9	-77	40.5	45	12	-74	87.8	97.5	15	-71	175.5	195	18	-68
3	3	16-QAM	1/2	26	28.9	11	-74	54	60	14	-71	117	130	17	-68	234	260	20	-65
4	4	16-QAM	3/4	39	43.3	15	-70	81	90	18	-67	175.5	195	21	-64	351	390	24	-61
5	5	64-QAM	2/3	52	57.8	18	-66	108	120	21	-63	234	260	24	-60	468	520	27	-57
6	6	64-QAM	3/4	58.5	65	20	-65	121.5	135	23	-62	263.3	292.5	26	-59	526.5	585	29	-56
7	7	64-QAM	5/6	65	72.2	25	-64	135	150	28	-61	292.5	325	31	-58	585	650	34	-55
	8	256-QAM	3/4	78	86.7	29	-59	162	180	32	-56	351	390	35	-53	702	780	38	-50
	9	256-QAM	5/6			31	-57	180	200	34	-54	390	433.3	37	-51	780	866.7	40	-48
2 Spatial Streams																			
8	0	BPSK	1/2	13	14.4	2	-82	27	30	5	-79	58.5	65	8	-76	117	130	11	-73
9	1	QPSK	1/2	26	28.9	5	-79	54	60	8	-76	117	130	11	-73	234	260	14	-70
10	2	QPSK	3/4	39	43.3	9	-77	81	90	12	-74	175.5	195	15	-71	351	390	18	-68
11	3	16-QAM	1/2	52	57.8	11	-74	108	120	14	-71	234	260	17	-68	468	520	20	-65
12	4	16-QAM	3/4	78	86.7	15	-70	162	180	18	-67	351	390	21	-64	702	780	24	-61
13	5	64-QAM	2/3	104	115.6	18	-66	216	240	21	-63	468	520	24	-60	936	1040	27	-57
14	6	64-QAM	3/4	117	130.3	20	-65	243	270	23	-62	526.5	585	26	-59	1053	1170	29	-56
15	7	64-QAM	5/6	130	144.4	25	-64	270	300	28	-61	585	650	31	-58	1170	1300	34	-55
	8	256-QAM	3/4	156	173.3	29	-59	324	360	32	-56	702	780	35	-53	1404	1560	38	-50
	9	256-QAM	5/6			31	-57	360	400	34	-54	780	866.7	37	-51	1560	1733.3	40	-48
3 Spatial Streams																			
16	0	BPSK	1/2	19.5	21.7	2	-82	40.5	45	5	-79	87.8	97.5	8	-76	175.5	195	11	-73
17	1	QPSK	1/2	39	43.3	5	-79	81	90	8	-76	175.5	195	11	-73	351	390	14	-70
18	2	QPSK	3/4	58.5	65	9	-77	121.5	135	12	-74	263.3	292.5	15	-71	526.5	585	18	-68
19	3	16-QAM	1/2	78	86.7	11	-74	162	180	14	-71	351	390	17	-68	702	780	20	-65
20	4	16-QAM	3/4	117	130	15	-70	243	270	18	-67	526.5	585	21	-64	1053	1170	24	-61
21	5	64-QAM	2/3	156	173.3	18	-66	324	360	21	-63	702	780	24	-60	1404	1560	27	-57
22	6	64-QAM	3/4	175.5	195	20	-65	364.5	405	23	-62			26	-59	1579.5	1755	29	-56
23	7	64-QAM	5/6	195	216.7	25	-64	405	450	28	-61	877.5	975	31	-58	1755	1950	34	-55
	8	256-QAM	3/4	234	260	29	-59	486	540	32	-56	1053	1170	35	-53	2106	2340	38	-50
	9	256-QAM	5/6	260	288.9	31	-57	540	600	34	-54	1170	1300	37	-51			40	-48

Fig. 5: MCS table for IEEE 802.11n

Fig. 5 shows the thresholds of signal strength when the IEEE 802.11n standard changes the modulation for the signal. These modulation schemes determine the maximum throughput possible. This explains the observations mentioned before.

IV. Summary

The results of this experiment show that the FixedRssLossModel 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.

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

References

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