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An Investigation on the Use of ITU-R P.1411-7 in IEEE 802.11N Path Loss Modelling

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Abstract—Free space path loss modelling is a model used to model path loss propagation for Wireless Local Area Networks. In some cases, the estimation of path loss by the FSL model can be inaccurate as it does not take into account the effects of multipath propagation. The International Telecommunication Union Recommendation, ITU-R P.1411-7 provides prediction methods for the planning of short-range outdoor radio communication systems and radio local area networks in the frequency range of 300 MHz to 100 GHz. This recommendation further proposes a location variability correction, ρ, which models the standard deviation of field strength due to small scale fading. This paper investigates the feasibility of using the ITU-R P.1141-7 Recommendation to estimate the path loss for 802.11n signals experienced by pedestrians in a suburban environment. Received signal strengths were collected from field experiments, and the measured path loss was compared with estimated path loss values. The results show that for areas with high levels of small scale fading, the ITU-R P.1141-7 was able to estimate the path loss for IEEE 802.11n signals with a higher accuracy of 10 dB than the FSL model.

1. INTRODUCTION

The 802.11n standard was officially released by the Institute of Electrical and Electronics Engineers (IEEE) in 2009 [1]. 802.11n was introduced to overcome the limitations of 802.11 a/b/g technology such as limited capacity, channel inefficiency and susceptibility to the radio frequency (RF) level loss.

802.11n has theoretical data rates up to 600 Mbps and a throughput between 20 Mbps to 200 Mbps in practice [2]. 802.11n has an increased range of reception due to reduced signal fading [2]. The reduced fading is achieved partially through the use of improvement in coverage and capacity. This is achieved through the use of Multiple Input and Multiple Output (MIMO) technology and Orthogonal Frequency Division Multiplexing (OFDM) [2]. OFDM converts a frequency-selective channel into a parallel collection of frequency flat sub-channels, and the receiver recovers the original signal by comparing all the sub-channels. The advantages of OFDM are high spectral efficiency, reduced sensitivity to the time synchronization errors and robustness to intersymbol interference (ISI) and co-channel interference [3]. MIMO, on the other hand, takes multipath as an advantage and uses advanced signal processing techniques such as Spatial Multiplexing (SM), Space-Time Block Coding (STBC) and Transmit Beamforming (TxBF) to combine and recover the original information at the receiver [3]. In 802.11n, the use of up to $4 * 4$ MIMO is possible in uplink and downlink [1].

IEEE 802.11n suffers from signal degradation due to propagation loss. Propagation loss is introduced as signals propagate through free space and attenuated by air and other obstacles that obstruct the Line of Sight of signal propagation. Due to this propagation loss, efficient packet retransmission is also a requirement to ensure the client receiver continuing to receive signals at a determined Quality of Service.

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At the physical layer, accurate estimation of path loss is critical in planning of hotspot Access Point (AP) deployment as this will ensure a lower interference environment, lower operational cost and reduced coverage gaps. To estimate path loss, Free Space Path (FSL) loss modeling [4] is a model used to model path loss propagation for Wireless Local Area Networks (WLAN). However, the estimation of path loss by the FSL model can, in some cases, be inaccurate as it does not consider the effects of multipath. In reality, no matter wether Line of Sight exists between the transmitter and receiver or not, some amount of signal strength is lost due to small scale fading. Small scale fading is a fading phenomenon experience due to the Doppler effect and is often experienced by pedestrians or mobile user equipment [5]. Past field experimental works in [6–8] have shown that the ITU-R P.1411-7 recommendation [9] can be used for the accurate prediction and planning of short-range outdoor radio communication systems and radio local area networks in the frequency range 300 MHz to 100 GHz. One past work [10] uses this recommendation in their simulation works to estimate the path loss of IEEE802.11n APs in a heterogeneous network.

The ITU-R P1411-7 recommendation takes into consideration the effect of small scale fading [15] often experienced by mobile users or pedestrian. Location variability correction, ρ, is a standard deviation of field strength due to small scale fading used in ITU-R P.1411-7 path loss model to estimate path loss more accurately.

The relevant sections in the ITU-R P1411-7 that will be investigated in this research are Sections 4.1 and 4.3. Section 4.1 is used to model path loss propagation in street canyons, or otherwise urban environments. Section 4.3 models path loss between terminals located from below roof-top height to near street level. The typical receiver-transmitter distance is less than 3 km and the height of the terminals are up to 3.0 m. Section 4.3 can be used to model path loss in urban and suburban environments.

2. CALCULATION OF PATH LOSS AND MODEL PARAMETERS

In this investigation, the ITU-R P.1411 model is compared with the performance of the Free Space Path Loss (FSPL) model. The log normal path loss model is also predominantly used to estimate path loss in NLOS environments. However, the log normal path loss model is not considered as a comparison in this investigation because the distance considered for this investigation is less than the valid distance for log normal modelling [11].

2.1. Free Space Received Power Model

The received signal power can be calculated using

$$P_R\,(\mathrm{dB}) = P_T + G_T + G_R + 20\log_{10}(\lambda/4\pi d) \tag{1}$$

where P_R is the received signal strength in dBm, P_T the transmitting power in dB, G_T the transmitting antenna gain in dB, G_R the receiving antenna gain in dB, λ the wavelength in m, and d the distance between the transmitter and receiver in m [4].

2.2. Free Space Path Loss (FSPL) Model

Free space path loss (FSPL) can be calculated using the Friis transmission equation. This equation was proposed by Harald T. Friis in 1945 [5]. The path loss is estimated by this model using

$$EIRP\,(\mathrm{dBm}) = P_T + G_T \tag{2}$$

$$FSPL\,(\mathrm{dB}) = EIRP + G_R - P_R \tag{3}$$

where *EIRP* is the Effective Isotropic Radiated Power and *PL* is the Path Loss (PL) between the transmitter and the receiver.

2.3. Recommendation ITU-R P.1411-7 Model

Recommendation ITU-R P.1411-7 explains the propagation data and prediction methods for the planning of short-range outdoor radio communication systems and radio local area networks in the frequency range of 300 MHz to 100 GHz [9].

The path loss estimation given in Section 4.3 of ITU-R P1411-7 [9] for a line-of-sight (LoS) scenario can be calculated using

$$L_{LoS}(d,p) = L_{LoS}^{median}(d) + \Delta L_{LoS}(p) \tag{4}$$

$L_{LoS}^{median}(d)$ and $\Delta L_{LoS}(p)$ can be calculated using Eq. (5) and Eq. (6) respectively.

$$L_{LoS}^{median}(d) = 32.45 + 20\log_{10} f + 20\log_{10}(d/1000)20 \tag{5}$$

$$\Delta L_{LoS}(p) = 1.5624\sigma \left(\sqrt{-2\ln(1-\rho/100))} - 1.1774\right) \tag{6}$$

f is the frequency in MHz and d the distance between terminals in m. Standard deviation σ is given as 7 dB. Location variability correction, ρ, is the standard deviation of field strength due to small scale fading.

The path loss estimation given in Section 4.3 of ITU-R P1411-7 [9] for a non-line-of-sight (NLoS) scenario can be calculated using

$$L_{NLoS}(d,p) = L_{NLoS}^{median}(d) + \Delta L_{NLoS}(p) \tag{7}$$

$L_{NLoS}^{median}(d)$ for suburban environment and the correction factor, $\Delta L_{NLoS}(p)$, can be calculated using Eq. (8) and Eq. (9) respectively [9].

$$L_{NLoS}^{median}(d) = 9.5 + 45\log_{10} f + 40\log_{10}(d/1000)20 \tag{8}$$

$$\Delta L_{LoS}(p) = \sigma N^{-1}(p/100) \tag{9}$$

f is the frequency in MHz and d the distance between terminals in m. Standard deviation σ is given as 7 dB. An approximation of the value for N^{-1} is given in ITU-R P.1546 [12].

In this study, the location variability with a ρ of 50%, 90% and 99% is considered. These values are considered after the LoS distance, and d_{LoS} was observed during the experiments. Each value of ρ corresponds to a d_{LoS} for how far the LoS existed between the transmitter and the receiver before becoming obstructed by clutter such as foliage. As suggested by ITU-R P.1411-7, after the d_{LoS} distance, the path loss estimation uses Eq. (7) for the path loss modelling. Table 1 shows the ρ values and the d_{LoS} considered.

2.4. Measured Path Loss (PL)

The measured path loss from the collected RSS is calculated using [5]

$$PL\,(\text{dB}) = P_{Tx} + G_{T_x} + G_{RX} - Losses \tag{10}$$

Table 2 summarizes the technical parameters used to calculate the measured path loss and also the values used to estimate the path loss using the FSPL and ITU-R P.1411-7.

Table 1. Table of LoS and NLoS location variability corrections [9, 12].

p (%)	ΔL_{LoS} (dB)	ΔL_{NLoS} (dB)	d_{LoS} (m)
50	0.0	0.0	44.4
90	10.6	9.0	16.2
99	20.3	10.3	9.9

Table 2. Technical parameters for estimation of path loss [13].

BS Transmit Power, P_{TX}	30 dBm
Transmit antenna Gain, G_{TX}	10 dBi for 802.11n & 5 dBi for 802.11g
Receiver Gain, G_{RX}	10 dBi for 802.11n & 5 dBi for 802.11g
Total Cable Loss, *Losses*	7 dB

3. FIELD EXPERIMENT DESCRIPTION

3.1. Test Environments

The locations selected for the field experiments had suburban environments. The Access Points were placed at the height of 2.3 m at all locations. The selected were suburban residential areas with car park, netball courts, tennis courts, playgrounds, small trees, medium dense foliage, double-storey link houses and apartments with maximum 5-storey building heights. The locations also had wide roads surrounded by tall trees.

3.2. Field Experiment Setup

Two 5 dBi omnidirectional antennas at 2.4 GHz were used to capture the receive signals at varying distances from the AP. For 802.11g data collection, only an antenna was used for transmission and reception as 802.11g does not support MIMO. An environmental thermometer was used to measure location temperature before and after the experiment.

Figure 1 shows the setup of field experiment. At each test location, signal strength was gathered at every 10 m spacing from the Access Point until a distance at which the signal of the 802.11g and 802.11n signals could not be detected anymore. A 20 MHz signal bandwidth was used as channel bandwidth.

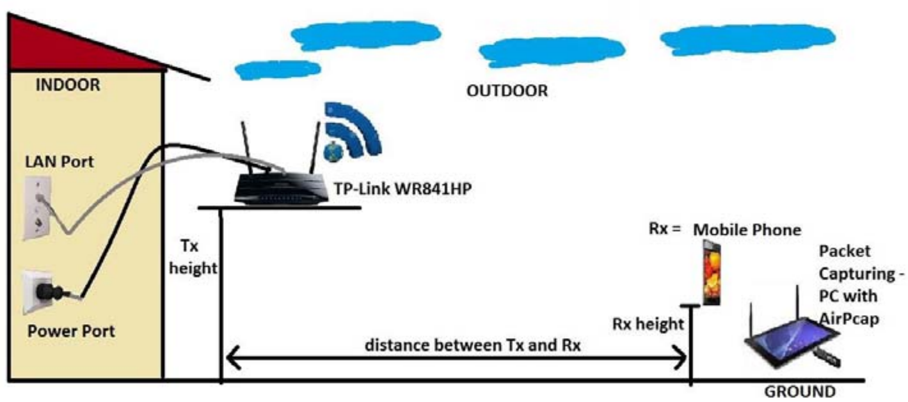

Figure 1. Field experiment setup.

4. RESULTS AND DISCUSSIONS

4.1. Received Signal Strength (RSS)

Figure 2 shows that the average collected received signal strength [14] for all the test locations at all distances was significantly lower than that estimated using Free Space Receive Power Model. The margin between the estimated free space loss and actual 802.11n signal strength is approximately 30 dB. The margin between free space estimation and actual 802.11g signal strength is approximately 40 dB. This is because the collected received power experiences attenuation and loss through scattering, reflection and absorption due to clutter and foliage.

It was observed that the 802.11n signals generally have higher received power than 802.11g signals. This is an expected observation, and the contributing factor to this is likely the use of MIMO in 802.11n.

4.2. Comparison of Measured Path Loss with FSPL Estimated Path Loss

Figure 3 shows that in general, the measured path loss was observed to increase dramatically with distance for the 802.11g and 802.11n signals compared to the path loss estimated by the FSPL model.

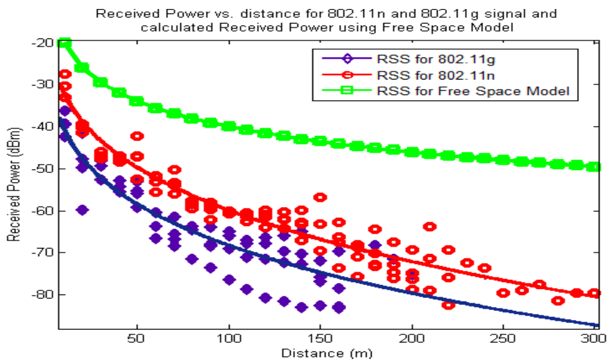

Figure 2. Average received power vs. distance for 802.11n and 802.11g signal and calculated received power using free space model.

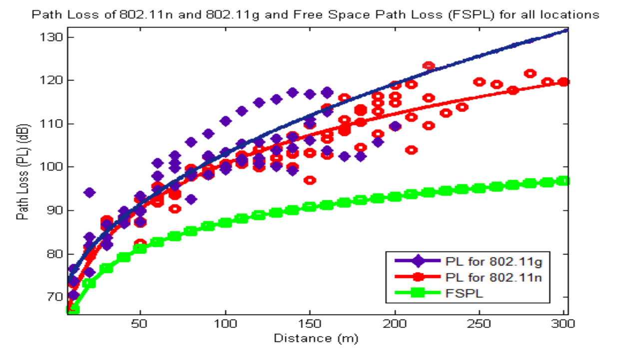

Figure 3. Average path loss of measured and FSPL for locations.

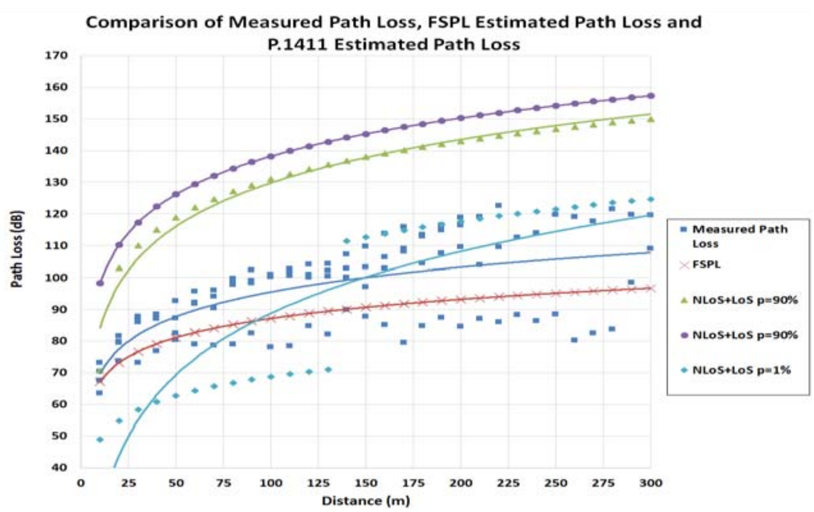

Figure 4. Averaged measured path loss, FSPL estimated and P.1411 estimated path loss (LoS + NLoS components).

The margin difference between the path loss estimated by the FSPL model and the measured path loss for the 802.11n signals is approximately 23 dB. This difference margin is even greater for 802.11g; the margin of estimation between FSPL and measured path loss for the 802.11g is approximately 32 dB.

4.3. Comparison of Measured Path Loss with ITU-R P.1411-7 Estimated Path Loss

Figure 4 shows the path loss estimation of the P.1411 model and the FSL model assumed to be experienced by the 802.11n signals. The estimation of the FSL model was more accurate than the path loss estimated by the P.1411 model when the combination of $L_{LoS}^{median}(d)$ and $L_{NLoS}^{median}(d)$ was considered. The FSL was able to estimate the actual path loss with a worst case margin difference of 10 dB, making the FSL model estimation more accurate.

Figure 5 shows that when only the NLoS component of the P.1411 model is considered, its estimation of the actual path loss suffered by the 802.11n signals is worse than that was estimated by the FSL model. The FSL estimates with an error margin of 10 dB while the P.1411 estimates with an average error margin of 13 dB. At distances less than 75 m, the P.1411 estimation is comparable to that of the FSL model.

Figure 6 shows that when the LoS estimation in the P.1411 model is used, the path loss estimation

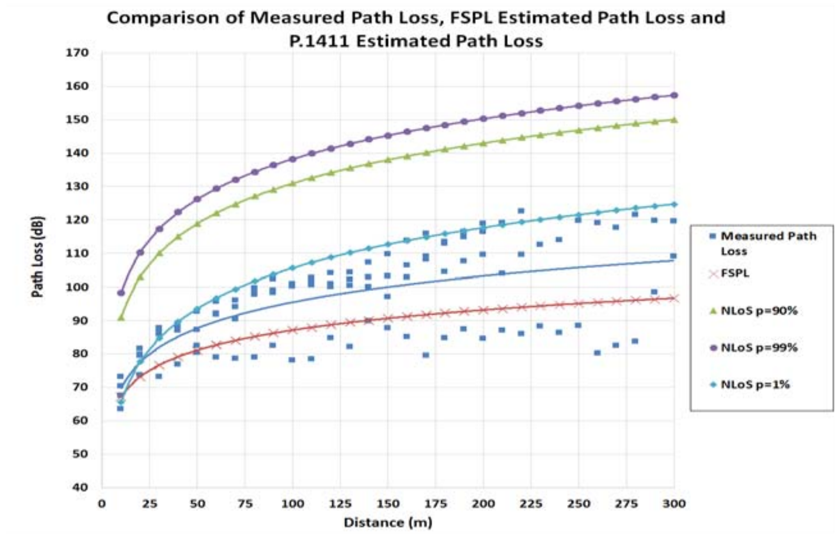

Figure 5. Averaged measured path loss, FSPL estimated and P.1411 estimated path loss (NLoS components).

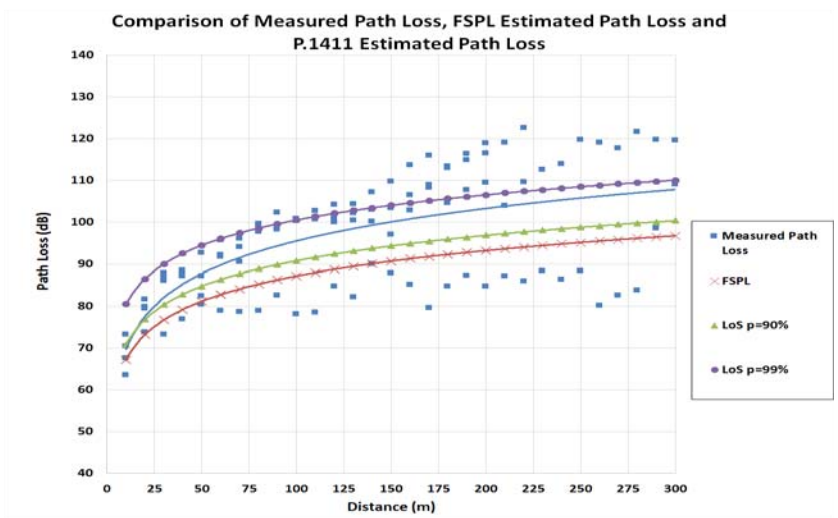

Figure 6. Averaged measured path loss, FSPL estimated and P.1411 estimated path loss (LoS component only).

is more accurate than the estimation of the FSL model for 802.11n. The estimation accuracy of the P.1411 model increases as distance increases between transmitter and receiver.

The P.1411 model with a location variability of 99% is able to estimate with a margin of approximately 3–5 dB while the FSL model estimates with a 10 dB margin. With a location variability of 90%, the P.1411 estimates the path loss with a margin of between 5–7 dB from the measured path loss. A location variability of 90–99% translates to a line of sight of approximately 15 m, which was the case for most of the field measurement locations. This line of sight distance is also the general clearance in a suburban environment before the signals reach foliage or low rise buildings.

The combination of the NLoS and LoS components as shown in Figure 4 could not estimate the path loss as accurately as when only the LoS component was considered. This is because suburban environment generally has good transmitter-receiver clearance due to the clutter in suburban environments generally having low height. Thus, considering the NLoS path loss component overestimated the path loss substantially.

5. CONCLUSIONS

Field experiments were conducted to gather signal strengths of 802.11g and 802.11n signals in suburban areas in Malaysia. The gathered data were then translated to path loss and compared to path loss estimated by the FSPL model and the ITU-R P.1411 model. ITU-R P.1411 takes into account the effect of small scale fading. ITU-R P.1411 uses the location variability parameter to allow corrections for the path loss estimation. A location variability of 90–99% translates to a line of sight of approximately 15 m, which is the general clearance in a suburban environment before the signals reach foliage or low rise buildings. The results showed that the difference between the path loss estimated by the FSPL model and the measured path loss in the field experiment for the 802.11n signals was approximately 23 dB. This difference margin is even greater for 802.11g with the margin approximately 32 dB. The study concludes that the use of the P.1411 path loss model considering only the LoS path loss estimation can improve the accuracy of path loss estimation experienced by a user in a suburban environment. The estimation using P.1411 can be used with the ρ set between 90–99% as this range of location variability yields accurate path loss estimation in suburban environments in Malaysia. The accuracy of path loss estimation is improved between 5–7 dB when using P.1411 instead of the FSL model, and this amount of signal strength can have a significant impact on the planning of green WiFi zones. By using the P.1411 model to estimate the path loss, hotspot planning can be done in a more cost-effective manner. It can also improve the interference scenario in places with high density of WiFi hotspots.

6. FUTURE WORK

For future research, the experiment can be repeated in an urban environment to study the feasibility of using P.1411 to estimate path loss of 802.11n signals. Future research can also study in detail the estimation accuracy of P.1411 when MIMO is used in 802.11n.

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