Progress In Electromagnetics Research Letters, Vol. 54, 55–59, 2015

Applying ITU-R P.1411 Estimation for Urban 802.11N Network Planning

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Abstract—Underestimation of path loss when planning the deployment of 802.11n APs can lead to coverage gaps and user dissatisfaction. The use of Free Space Path Loss modelling can sometimes lead to underestimation of path loss in urban environments when the effect of small scale fading is not considered. A field experiment was conducted with the aim to investigate the applicability of the ITU-R P.1141-7 Recommendation in path loss estimation of 802.11n signals in an urban environment in Malaysia. The results showed that Section 4.3 of ITU-R P.1411-7 can estimate the path loss of 802.11n signals with very low error margins of between 0 dB and 5 dB for transmitter receiver distances of 50 m and more. At these distances, the average difference of path loss estimation between FSPL and measured path loss is approximately 18 dB. The study concludes that 802.11n APs may need to be placed at closer proximities than previously assumed if FSPL is used to model the path loss. This is to ensure that targeted traffic is actually offloaded; coverage gaps are reduced; user satisfaction is improved.

1. INTRODUCTION

The use of Carrier Grade WiFi by mobile operators [1] to reduce coverage gaps and increase capacity in the outdoor has been seen as a way forward in the planning of heterogeneous networks. The correct estimation of path loss when planning deployment of 802.11n Access Point (AP) is critical to ensuring that the objective of reducing coverage gaps is really met. Furthermore, even while deploying these APs in a planned manner, it is crucial to ensure that the AP deployments do not cause unwanted co-channel interference problems in the mobile network. High co-channel interference between APs can lead to reduced throughput performance [2], deterring the second objective of deploying these APs, which is to resolve high hotspot capacity problems.

Due to the omni-transmission of the 802.11n APs, the setting of the power on the AP can be manipulated to manage the coverage radius of each AP. 802.11n has a theoretical transmission distance of 100 m with acceptable quality of service [3, 13]. Network planning therefore may assume that placing an AP node every 100 m is sufficient to improve the capacity and ultimately the performance of these heterogeneous networks. However, underestimation of path loss can cause significant coverage gaps and reduced levels of user satisfaction.

The signal power received by the user terminal depends on the distance of the user to the AP, in other terms, the transmitter-receiver distance. The signal strength will also be affected by the amount of clutter between transmitter and receiver. The losses due to the distance and the clutter along the signal propagation path are known as path loss. In an urban setting, Rayleigh fading [4] will cause small-scale fading effects which must also be taken into consideration when estimating path loss.

The Free Space Path Loss (FSPL) model [5, 14] is pre-dominantly used to model propagation loss for Wireless Local Area Networks (WLAN) such as 802.11n APs. This is because the APs are generally

Received 28 May 2015, Accepted 8 July 2015, Scheduled 14 July 2015
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targeted to cover a distance between 100 m and 150 m [3], for which a general Line of Sight (LoS), or free-space, is expected to exist. The estimation of path loss by the FSPL model also does not consider the effects of multipath.

A certain amount of signal strength propagating from transmitter to receiver in an urban environment is almost definitely lost due to small-scale fading [4]. Past works in [6–8] have used the ITU-R P.1411-7 recommendation [9] to predict path loss of local area networks. Recently, field experiments done in [10] have shown that ITU-R P.1411-7 can predict path loss in a suburban environment with higher accuracy than the FSPL.

The ITU-R P.1411-7 recommendation takes into consideration the effect of small-scale fading [11] experienced by mobile users or pedestrian. The recommendation uses suitable correction factors to consider the small-scale fading effect in the estimation of more accurate path loss. Section 4.1 of ITU-R P.1411 [9] is proposed to be used to model path loss 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 in urban environments.

2. TEST LOCATIONS AND TERRAIN DESCRIPTION

The field experiment was conducted in 20 locations around the Klang Valley and Selangor in Malaysia as shown in Figure 1. The locations were selected based on their urban environment, consisting of high rise buildings along narrow roads. The rows of tall buildings provide the possibility of long path delays. The large numbers of moving vehicles in the area also act as reflectors adding Doppler shift to the reflected waves.

The AP in the test, a M5350 802.11n mobile router, was used as the transmitter, transmitting at 20 dBm and at 2.4 GHz. The AP was set at a height of 2.0 m, while the user terminal set at a height of 1.0 m was used to surf a YouTube video. The transmitter and receiver have 0 dBi and 10 dBi gains, respectively. The mobile router and receiver laptop are both wireless, thus no cable losses are considered in the subsequent analysis for this study. At each location, the AP location was set at the markers shown in Figure 1. Data were collected at every 10 m interval from the AP, with high-rise buildings and vehicles on both sides of the transmission path. Lamp posts, signboards, low foliage and stone obstructions provided other clutter. The maximum coverage of the APs varied from 80 m–110 m depending on the test locations and the surrounding environment.

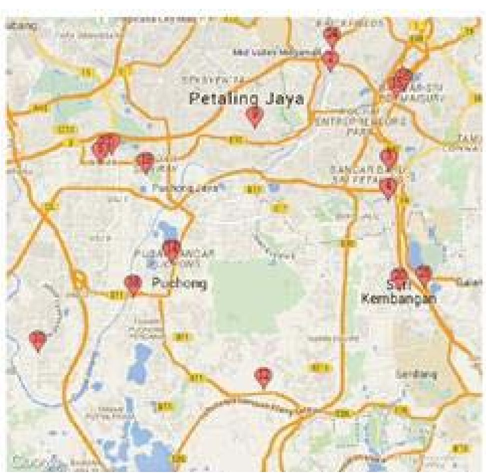

Figure 1. Test locations.

3. CALCULATIONS

3.1. Measured Path Loss Calculation

The received signal strength (RSS) is translated to path loss using

$$Measured\_path\_loss = P_T + G_R - P_R - G_R \tag{1}$$

where P_R is the measured received signal strength in dBm, P_T the transmitting power in dB, and G_R the receiving antenna gain in dB. In this experiment, G_R is set to 0 dB.

3.2. Free Space Path Loss (FSPL) Estimation

Power received, P_R, when assuming Free Space Path Loss (FSPL) is calculated using

$$P_r\,(\text{dB}) = P_T + G_T + G_R - 20\log_{10}(\lambda/4\pi d) \tag{2}$$

where P_T is transmit power in dB. G_T and G_R are transmit and received gains in dB. λ is the wavelength in m and d the distance between the transmitter and receiver in m [5].

3.3. ITU-R P.1411-7 Model Estimation

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

The path loss estimation given in Section 4.1 of ITU-R P.1411-7 calculates the upper bound for path loss experienced in a line-of-sight (LoS) scenario using

$$L_{LoSu} = \left|20\log_{10}\left(\lambda^2/8\pi h_b h_m\right)\right| + C\log_{10}(d\lambda/4h_b h_m) + fade\_mar \tag{3}$$

The first term in Eq. (3) estimates the breakpoint distance, in this investigation case, 64 m. C is taken to be 25 for cases where the distance from AP is less than the breakpoint distance, and 40 if the distance from AP is greater than the breakpoint distance. A 20 dB fading margin, *fade_mar*, is assumed in the modeling. h_b and h_m are the heights of the 802.11n AP and user terminals, respectively, and d is the transmitter-receiver distance [9].

The path loss estimation given in Section 4.3 of ITU-R P1411-7 [9] is

$$L_{LoS}(d,p) = [32.45 + 20\log_{10} f + 20\log_{10}(d/1000)] + \left[1.5624\sigma\left(\sqrt{-2\ln(1-p/100))} - 1.1774\right)\right] \tag{4}$$

$$L_{NLoS}(d,p) = [9.5 + 45\log_{10} f + 40\ \log_{10}(d/1\ 000) + L_{urban}] + \sigma N^{-1}(p/100) \tag{5}$$

where f is the frequency in MHz and d the distance between terminals in meters. Standard deviation σ is given as 7 dB. Location variability correction, p, is the standard deviation of field strength due to small scale fading. Given the urban setting, the analysis is focused on ρ of 90% and 99%. Each value of ρ corresponds to a d_{LoS}, which indicates how far the LoS existed between the transmitter and the receiver before becoming obstructed by clutter. After the d_{LoS} distance, the Non-Line-of-Sight (NLoS), $L_{NLoS}(d,p)$, is used to estimate the path loss. Table 1 shows the relationship of ρ values and d_{LoS}. Table 1 also shows values used to estimate the NLoS path loss from Eq. (5) [12].

Table 1. Relationship of d_{LoS}, p, and $\sigma N^{-1}(p/100)$ (dB) [9, 12].

p (%)	$\sigma N^{-1}(p/100)$	d_{LoS} (m)
90	9.0	16
99	16.3	10

4. COMPARISON OF MEASURED PATH LOSS WITH ITU-R P.1411-7 ESTIMATED PATH LOSS

Figure 2 shows that after 20 m, the FSPL model predicts the path loss with an error margin between 8 dB and 12 dB. On the other hand, the upper bound estimation of the ITU-R P.1411 model predicts the path loss with an error margin of 3 dB and 12 dB at distances after 20 m. The estimation by ITU-R P.1411 is more accurate than the FSPL estimation until approximately 80 m. At 80 m, both models estimate the path loss with equal amounts of error margin.

Figure 3 shows that the estimation by Section 4.3 of ITU-R P.1411-7 with a location variability of $p = 99\%$ was able to estimate the actual path loss [curve shown by long dash line] with an error margin

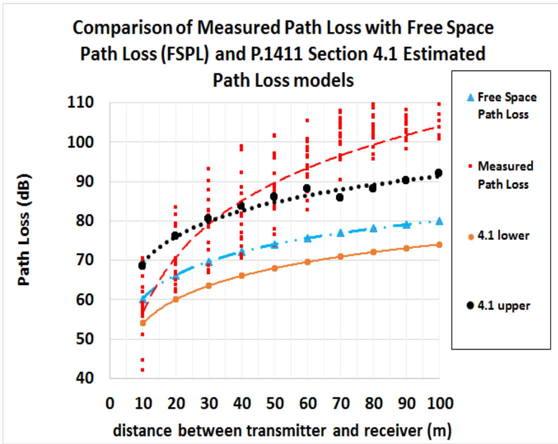

Figure 2. Comparison measured path loss, free space path loss (FSPL) estimated and P.1411 Section 4.1 estimated path loss.

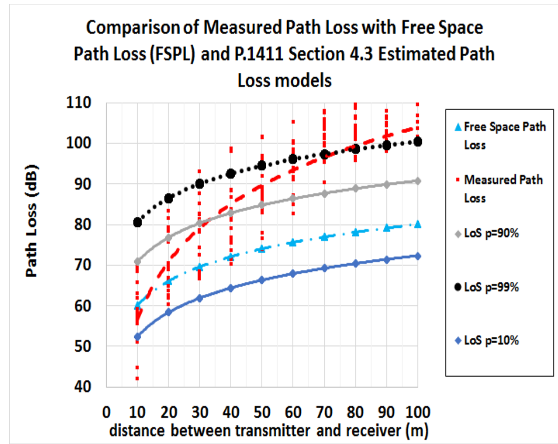

Figure 3. Comparison of measured path loss (measured PL) with path losses estimated by P.1411 Section 4.3 at different ρ values.

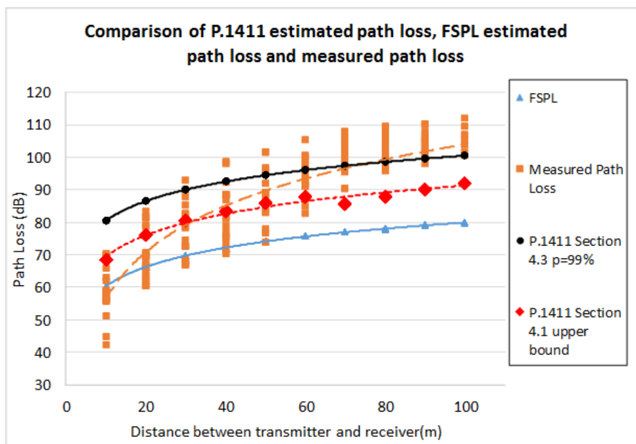

Figure 4. Comparison of measured path loss (actual) with path losses estimated by FSPL, P.1411 Section 4.1 and P.1411 Section 4.3.

of between 0 dB and 10 dB for transmitter-receiver distance of more than 30 m. At these distances, the margin of estimation between actual measurement and the FSPL estimation is between 10 dB and 24 dB. The high estimation accuracy at $p = 99\%$ corresponds to the general observation of clutter in urban environments, where signals encounter obstacles within 10 m from point of transmission.

Figure 4 shows the comprehensive comparison of measured path loss, with the estimated path loss by the FSPL model and relevant P.1411 models. Both Sections 4.1 and 4.3 of the ITU-R P.1411 are able to estimate the path loss with higher accuracy than the FSPL in urban environments at transmitter-receiver distance of more than 30 m. The estimation by Section 4.3 becomes more accurate as transmitter-receiver distance increases. At distances of 50 m and more, Section 4.3 estimates the path loss with an error between 0 dB and 5 dB. The high estimation accuracy is due to the type of urban environment where the experiments were carried out. These environments, by observation, were noted to be similar to the type of environments described in Section 4.3 of the ITU-R P.1411.

5. CONCLUSIONS

To study the applicability of using the ITU-R P.1411-7 in path loss modelling of 802.11n signals, field experiments were conducted in urban areas in Malaysia. The actual path loss values from these experiments were compared with those estimated by the FSPL model and ITU-R P.1411 model, which takes into consideration small scale fading effects encountered in urban environments. The results show that Section 4.3 of ITU-R P.1411-7, when applying the location variability parameter, p, of 99%, can estimate the path loss of 802.11n signals with very low error margins of between 0 dB and 5 dB for transmitter receiver distances of 50 m and more. At these distances, the FSPL estimates the path loss with a margin error of between 16 dB and 24 dB. The average difference of path loss estimation between FSPL and ITU-R P.1411 is approximately 18 dB. The study concludes that the use of Section 4.3 of ITU-R P.1411 for path loss estimation can improve the planning of urban deployment of 802.11n APs. The previous scenario of deploying potentially one AP per 100 m in a planned manner by mobile operators who wish to offload their data traffic to Carrier Grade WiFi nodes may be overestimated. These APs may need to be placed at closer proximities to ensure the target amount of traffic is actually offloaded to enhance the network capacity performance. The underestimation of path loss will cause unwanted gaps in the coverage and reduced user satisfaction, especially at cell edges.

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