Investigation of Foliage Effects via Remote Data Logging at 5.8 GHz

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Abstract: - This paper presents an unconventional methodology in examining the extent of vegetation blockage effects imposed on near line-of-sight (NLOS) fixed wireless links based on Institute of Electrical and Electronics Engineers (IEEE) 802.11a Wireless Local Area Network (WLAN) standard operating at frequency 5.8 GHz of Unlicensed National Information Infrastructure (UNII) band. By employing the concept of remote data logging, power received measurements were acquired constantly via a remote server for 24 hours and seven days a week from three dissimilar NLOS links within the campus of Universiti Teknologi Malaysia (UTM) in which it can best be described as suburban environment. These point-to-point links deployed in conjunction with wireless campus are impeded directly or indirectly by vegetation. The behaviour of these site-specific links performance is studied. The average excess path loss inclusive of foliage loss which is relevant to the climate of a tropical country is derived. Comparison of tabulated results between these divergent fixed wireless links besides exploratory data analysis is presented.

Key-Words: - Foliage, Path loss, Propagation, Fixed, Wireless, Near Line-of-sight

1 Introduction

The propensity of trees appearing within the vicinity of both transmitting and receiving antennas is inevitable especially in suburban and rural regions where topographic features are much more dominant than buildings. This will result in an adverse effect on the receiving signal besides other attenuating factors such as terrain, buildings and so forth. The establishment of a reliable link between antennas of fixed wireless systems is often desired while having to deal with path loss due to obstructions existing in the vicinity. Foliage is a significant feature in the degradation of signal. Propagation mechanisms associated to vegetation consists of propagation through trees and propagation over trees [1].

Apart from that, the changes of trees such as growth over time of operation will affect the condition of the link even if the link is performing well at the moment. Removing all obstructing trees is an impractical solution. This scenario refers to the dilemma encountered in the deployment of wireless campus in Universiti Teknologi Malaysia (UTM). Hence, the effect of foliage should be taken into consideration in the planning of fixed wireless links in addition to the distortion of signal by other physical obstructions mentioned earlier.

There has been numerous measurement campaigns in the past to study on the effects of foliage be it microwave or millimetre wave signals. Propagation measurements through vegetation over a range of frequencies have been previously accounted in rain forests of India [2] between 50-800 MHz, through a single tree [3] between 1 and 4 GHz, at fixed access links [4] between 3 and 30 GHz, and in a forested urban park [5] between 0.9 and 1.8 GHz, in various foliage and weather conditions [6] between 2 and 60 GHz. Study on short-range back scattering and propagation measurements of equatorial foliage in Singapore which is similar to our local vegetation were reported by Lu et al. [7] for a wide frequency band from 100 MHz to 1 GHz.

For data acquisition, previous research works were mainly executed on-site dealing with measurement configurations such as a single tree indoor or outdoor, a line or multiple lines of trees outdoor along the streets or buildings, a small forest or orchard, and a large forest covering a region [2]-[12]. In addition to foliage effects of deciduous and coniferous trees, building penetration loss measurements in residential areas and homes were carried out simultaneously in the 5.85 GHz U-NII band [13]. Building penetration attenuation was reported at an average value of 14 dB while signal degradation due to tree shadowing was between 11 and 16 dB as well as 15 and 21 dB for close-in house shadowing corresponding to the height of receiving antenna. Besides that, Karlsson et al. [14] presented radio channel characterisation by taking into account of tree influences as well at 3.1 and 5.8 GHz for Fixed Wireless Access (FWA) systems. In comparison to the theoretical LOS path loss, the excess path loss obtained was between 1 and 16 dB for both frequencies with a few decibels higher for 5.8 GHz than the former. The effect of trunk and branches of trees was found to be much more significant than the leaves on the path loss. Not much difference was observed when evaluating the delay intervals and delay spreads for both frequencies due to multipath components of buildings reflections.

This work is also motivated by the fact that most of the studies were done in countries with temperate climate where seasonal variations such as summer, autumn, winter and spring occur throughout the year. Foliages studied were mainly classified as deciduous trees and coniferous trees. Deciduous trees are trees that shed their leaves seasonally. Coniferous trees can be easily identified as they have needle shaped or scale like leaves. The previous studies mainly addressed effects of foliage by performing measurements under two scenarios which are full foliated or non-foliated.

As such, investigation of foliage impact on signal fading which is relevant to local environment is still scarce since trees in Malaysia are classified as evergreen trees that retain most of their leaves throughout the year. This paper intends to introduce an alternative measurement technique to determine the average value of excess path loss which is inclusive of foliage attenuation by measuring and characterizing the signal distortion attributed to vegetation that exists in the vicinity of point-to-point links based on Institute of Electrical and Electronics Engineers (IEEE) 802.11a Wireless Local Area Network (WLAN) standard at 5.8 GHz Unlicensed National Information Infrastructure (UNII) band.

This paper is organized as follows. The equipment setup, approach used for data collection and description of the measurement environment are detailed in section 2. In section 3, measurement results in tabular and graphical forms are presented and discussed. For validation purpose, the results acquired will be compared with the previous investigations. The final section shall summarize this paper.

2 Measurement Details

2.1 Equipment setup

Antennas deployed for NLOS links are linearly polarized Radial Linear Slot Array (RLSA) antennas and directional antenna with a gain of 7 dBi and 17 dBi respectively. The latter antenna is only installed as a transmitter at block K11 in students' residential college, Tun Razak College. These antennas are installed below the rooftop onto the walls or pillar. Unshielded twisted pair (UTP) cables category 5e (CAT5e) are then used to connect the antennas to the switches as illustrated in Figure 1. From the switches, the connection will be either directed to a server which is linked to fibre optic source or an access point in which internet access can be provided to end users who are mainly students.

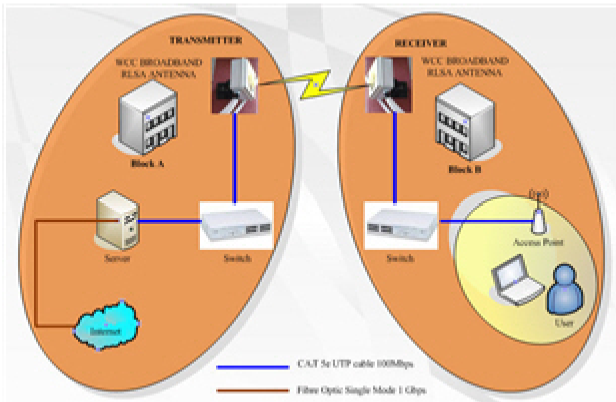

Fig. 1: Equipment setup for a point-to-point link

The equipment setup is slightly different in Wireless Communication Centre (WCC) as it becomes the monitoring hub which facilitates remote logging. With reference to Figure 2, from the source of Internet, router is connected to the switch using CAT 5e UTP cable. As of the switch, it is connected to server which is employed specifically for data acquisition. Remote logging display as well as configurations can be performed via a monitor and keyboard. Apart from that, an Uninterruptible Power Supply (UPS) is employed in order to provide emergency power whenever there is any occurrence of power disruption which will eventually results in data loss.

For real-time configuration and monitoring, Virtual LAN (VLAN) which is an implementation of IEEE 802.1Q is setup. Without having to deal with the constraint of physical location, VLAN enables end users communication while maintaining efficient LANs segregation. Hence, administration costs related to any abrupt changes or relocations can be greatly reduced since VLAN allows the sharing of a physical network [15]. Since data logged from each wireless links are to be directed to the remote server located in WCC, other settings required is by adding a specific route that will lead them to the accurate destination. The destination corresponds to the specific Internet Protocol (IP) address of remote server.

The router board employed has built-in scripting language which enables some router maintenance tasks automatically by means of executing user-defined scripts bounded to some event occurrence through a scripting host. Let's identify the point-to-point link to be monitored as site A and B where router board is connected to site A. Hence, the script is defined from the remote server to log variable of signal strength or power received at site A for one minute interval daily. These logs are then sent to the remote server running on a syslog daemon. The archive log files are also sent via e-mail each day besides retrieving logged data manually from the local program files directory of the remote server.

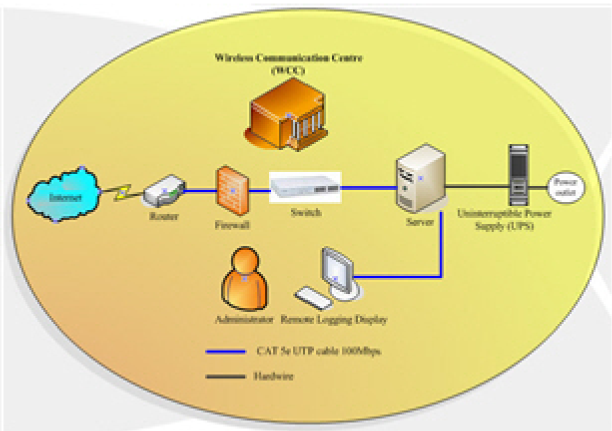

Fig. 2: Equipment setup for remote data acquisition

2.2 Measurement Scenarios

The NLOS links investigated encompass divergent scenarios as portrayed in the subsequent figures. There is a large tree obstructing the path between block K11 in Tun Razak College and Visiting Professor's Residence while the subsequent link from Astaka to Jalan Ladang Security Post is hindered by a row of trees. The estimated heights of receiving antennas at Visiting Professor's residence and Jalan Ladang Security Post are 4.6678 metres and 2.07 metres from ground level respectively. The tree species identified at the specific locations are depicted in Table 1 [16]. With the aid from total station, the average obstructing tree height is about 15.2138 metres and 15.894 metres high correspondingly.

On the other hand, NLOS link from students' residential block MA1 to block L20 involves a transmitting and a receiving antenna being positioned at higher terrain and near to the ground correspondingly with trees and street light masts existing nearby. The transmitting antenna is mounted on the wall at the fifth level of block MA1 which is about 18 metres high while the receiving antenna is mounted on the wall at the first level of block L20 which is about 3.3528 metres high. Despite the fact that it is not being directly blocked by trees, there are some planted in the vicinity of the link.

Fig. 3: Obstruction by a single tree

Fig. 4: Obstruction by a row of trees

Table 1: Tree species for NLOS links

Location of NLOS Link	Tree Species
Block K11 and Visiting Professor's Residence	Scientific name: *Samanea saman* Family: *Leguminosae* Synonym: *Enterolobium saman, Mimoosa saman, Pithecellobium saman* Common name: *Cow Tamarind, Pukul Lima, Rain Tree* Origin: *Tropical America*
Astaka and Jalan Ladang Security Post	Scientific name: *Cinnamomum iners* Family: *Lauraceae* *Synonym:* *Cinnamomum eucalyptoides T. Nees, Cinnamomum nitidum Blume, Cinnamomum paraneuron Miq* Common name: *Wild cinnamon, Kayu manis hutan* Origin: *India, Indochina & Malesia*

3 Data Analysis and Discussion

Data logged prior to being slice and dice is usually identified as raw data. Modest investment of time is mandatory for data preparation or data screening before running any form of analysis.

3.1 Pre –processing Data

The tasks performed after data acquisition involves data filtering followed by insertion of formula functions into Excel worksheets.

Data filtering is a foremost step of pre-processing data. With reference to Figure 5 and Figure 6, there will be other unwanted information such as '*wireless, info'* and '*system, info'* appearing in the raw data. The former often exists when there are occurrences of wireless link either being disconnected or connected while the latter exists when the administrator logins remotely and makes any configuration changes. A text editing tool known as TextPad is utilised to find and delete all irrelevant information coexisting in the same text file for each day. Comparing both figures, it is observed that raw data logged for NLOS link from block K11 to Visiting Professor's Residence contains more irrelevant information than the one logged for NLOS link from Astaka to Jalan Ladang Security Post. Thus, it can be deduced that NLOS link obstructed by a single tree encounters more wireless disconnections as compared to NLOS link obstructed by a row of trees in this case of study.

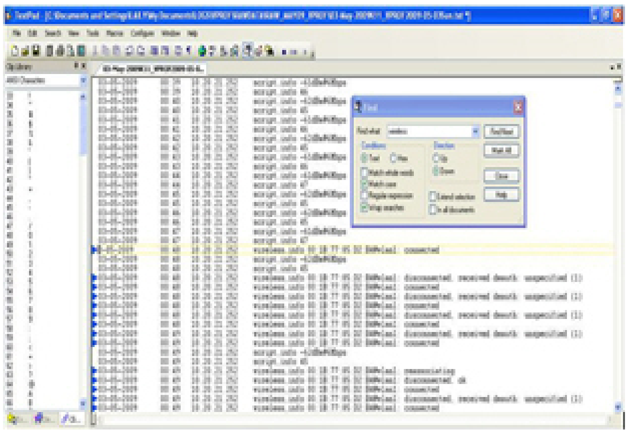

Fig. 5: Raw data filtering (data logged for NLOS link from block K11 to Visiting Professor's Residence)

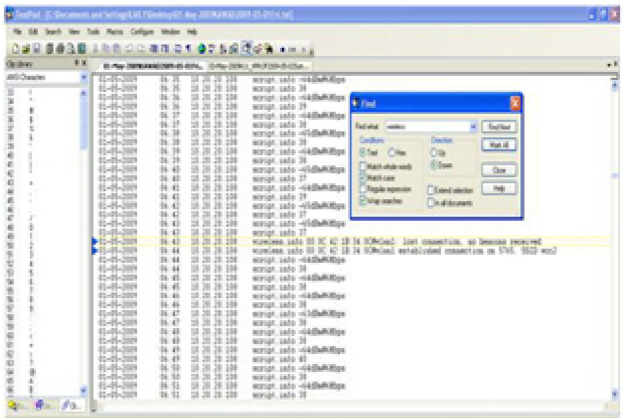

Fig. 6: Raw data filtering (data logged for NLOS link from Astaka to Jalan Ladang Security Post)

Filtered data obtained is then inserted with formula functions using Excel worksheets. Before doing so, it is imperative to check for missing values. Missing values are common for statistical analysis which will lead to gaps in the data and biased approximation. Missing data occurred is classified as missing completely at random (MCAR) in which the distribution of missing data is unpredictable. Randomly missing data of five percentages or below from a large data set poses less serious effects. Still, there are no definite guidelines for the amount of acceptable missing data from a sample size [17].

Since the time interval fixed at each minute, there should be 1440 data which corresponds to 1440 minutes per day. Too much missing values in a sample will eventually results in invalid conclusions. Hence, filtered data with less than five percentage of missing values will only be processed further whereas those not meeting this criterion will be omitted. In other words, filtered data need to be screened to have at least 1368 of data values for each day. There are days when extensive data loss occurred. The factors identified are accidental physical switching adapter disconnection or being switched off, malfunction of switching adapter besides network and power outages.

There are three formula functions to be inserted into Excel worksheets. The first deals with determining transmitter power based on data rates logged. Transmitter power mode set is default in which data rates corresponds to the default value of wireless card used. The subsequent formula function seeks to compute total path loss.

Total path loss, L calculated is the summation of free space loss and excess loss. It is worth noting that excess loss is inclusive of foliage loss and other losses which will be computed using the final formula Excel function by the subtraction of total path loss from free space loss as shown in the equations below [18]-[20].

$$P_r = P_t + G_t + G_r - L_f - L_e \qquad (1)$$

Where
P_r: power received in dBm
P_t: power transmitted in dBm or dBW
G_t: gain of the transmitter antenna in dBi
G_r: gain of the receiver antenna in dBi
L_f: free space path loss in dB
L_e: path loss in excess of free space loss

$$L = L_f + L_e \qquad (2)$$

Frequency used besides transmission distances and free space loss computation for the links studied are listed below.

Table 2: Transmission distances and free space loss computation

NLOS Link	Frequency (MHz)	Distance (km)	Free Space Loss (dB)
Block K11 to Visiting Professor's Residence	5745	0.0754	85.1750
Astaka to Jalan Ladang Security Post	5765	0.2053	93.9055
Block MA1 to Block L20	5805	0.3580	98.7955

3.2 Exploratory Data Analysis

Graphs are plotted based on power received and excess path loss.

3.2.1 Power Received

The following figures illustrate power received logged for one day at one minute interval for each point-to-point links of interest.

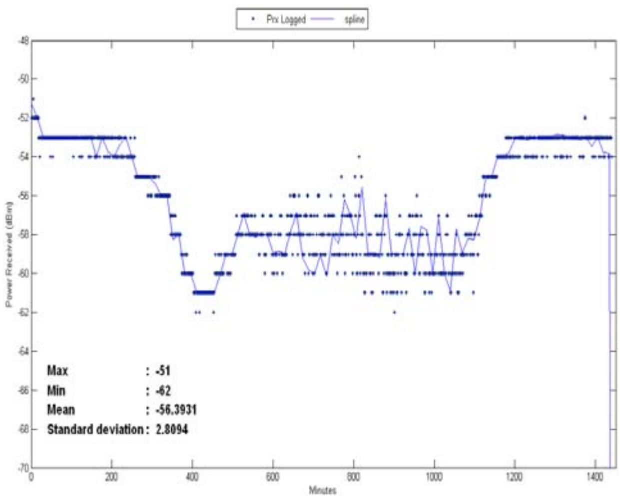

Fig. 7: Plot of power received at block K11 for a day

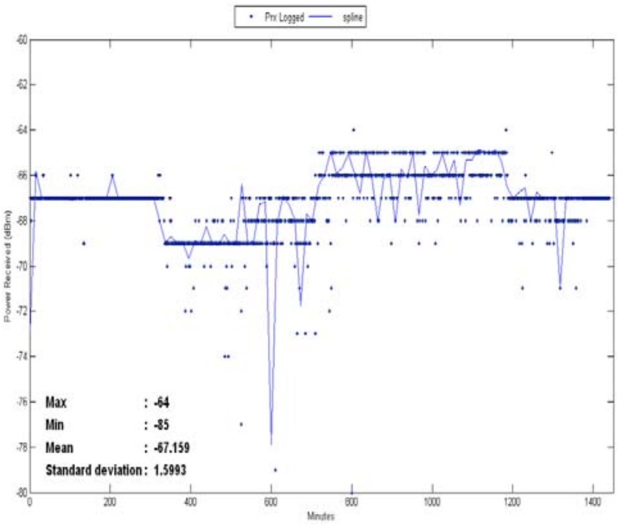

Fig. 8: Plot of power received at Astaka for a day

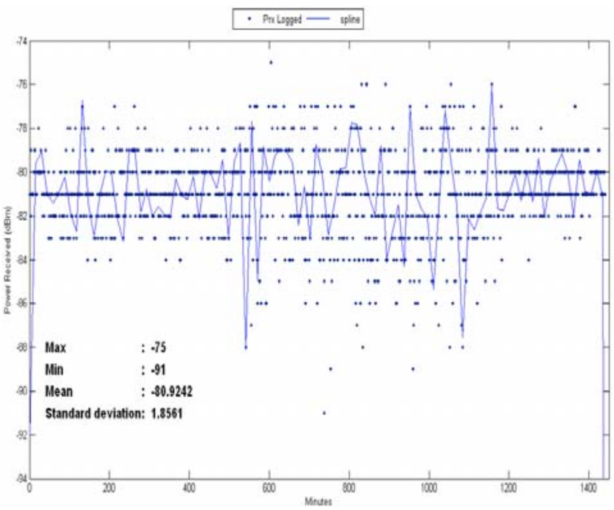

Fig. 9: Plot of power received at block L20 for a day

By further examining plots for NLOS links, it is observed that power received at block L20 in Fig. 9 shows the most consistent signal variation amongst all. This can be attributed to the fact that the main component of traversing signal is not directly impeded by obstructions as compared to the other two with dominant obstruction of tree or trees along the propagation path. At lower receiver height and being positioned in a cluttered environment, power received at block L20 could be enhanced by the summation of direct ray, ground reflected ray, diffracted and scattered rays from adjacent buildings and lamp posts respectively as well as scattered rays from trees nearby.

This link shares some similarity with NLOS link from Astaka to Jalan Ladang Security Post as shown in Fig. 8 whereby there is a road in between the transmitting and receiving antennas. In contrast, the latter link is being obstructed by a row of trees planted on the roadside with both transmitting and receiving antennas deployed at lower heights. Vehicles such as cars and buses driving past may possibly affect the power received at block L20 and Jalan Ladang Security Post during the day from 7:00 am to 6:00 pm or from 421 to 1081 minutes. This perhaps explains the significant signal fades in both plots of power received during that time range when the traffic is busier. Upon inspection, the maximum and minimum power received for both NLOS links have a considerably large difference of 16 dB and 21 dB correspondingly for the particular day.

In comparison, NLOS link from block K11 to Visiting Professor's Residence displays distinct signal fluctuations within a time range too as shown in Fig. 7. It is observed that received signal began to drop significantly from 256 minutes or 4:15 am. The received signal fluctuated steadily after around 1201 minutes or 8:00 pm on that specific day. Contrary to the two NLOS links discussed above, road and traffic remain to be non-existent here. Hence, the signal variation can be attributed to the movement of leaves and branches during windy conditions.

Vegetation movement under the influence of wind have been identified as a significant factor of signal fading as reported in [21] - [24]. Power received will vary greatly during higher wind speed and vice-versa. This factor is applicable and therefore noteworthy to NLOS link from Astaka to Jalan Ladang Security Post as well given that the direct signal is transmitted through vegetation for these two point-to-point links. As such, the swaying of non-static and random orientated leaves and branches will certainly affect the quality of the received signal. In spite of that, mean power received logged at block K11 was relatively high albeit the fact that its link has to succumb to frequent wireless disconnection at times which was evidently revealed in raw data logged. This implies that the link reliability is affected.

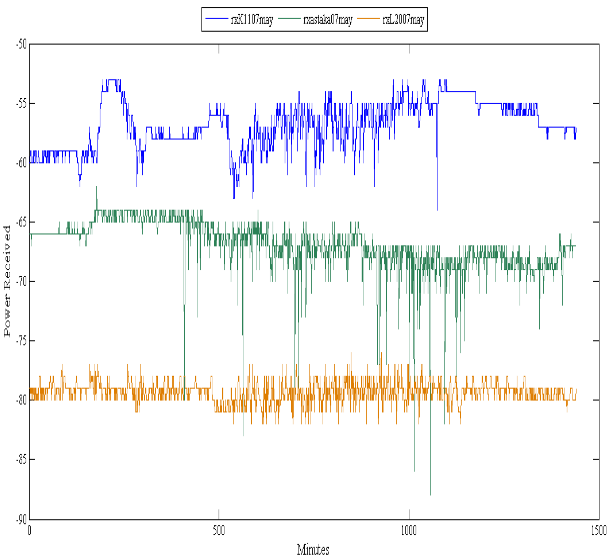

Fig. 10: Plot of power received for all NLOS links

The above figure depicts power received logged with no occurrence of data loss throughout the day for the three NLOS links studied. Power received at block K11, Astaka and block L20 are represented by blue, green and orange lines respectively. From the same plot, it could be seen that NLOS links blocked by vegetation encounter more abrupt signal drops as compare to the other link that is not directly being obstructed by trees. There is a larger amount of variation observed for power received at Astaka than block K11.

Power received at Astaka on that day was found to plunge until the lowest signal strength of -88 dBm from the highest logged signal strength of -62 dBm. Data statistics is listed in Table 3. However, the minimum signal strength logged at block K11 was -64 dBm and the maximum value was -53 dBm. Conversely, the power received at block L20 is observed to vary steadily without any sudden and significant signal drop. By comparison, the result indicates that foliage effects on wireless links are apparent and therefore should be given due consideration. The averages of mean power received each day for all NLOS links are tabulated in Table 4.

Table 3: Data statistics of power received plots for NLOS links on Thursday, 7th of May 2009

Power Received at	Max (dBm)	Min (dBm)	Mean (dBm)	Standard deviation
Block K11	-53	-64	-56.7625	2.0133
Astaka	-62	-88	-66.925	2.1977
Block L20	-76	-82	-79.3181	0.94326

Table 4: Average power received for NLOS links

NLOS Link	Total Days	Mean Power Received (dBm)		
		Max	Min	Average
Block K11 to Visiting Professor's Residence	41	-51.3322	-61.2946	-55.8004
Astaka to Jalan Ladang Security Post	41	-65.0382	-67.7295	-66.5405
Block MA1 to block L20	87	-77.9611	-84.9979	-80.2181

3.2.2 Excess Path Loss

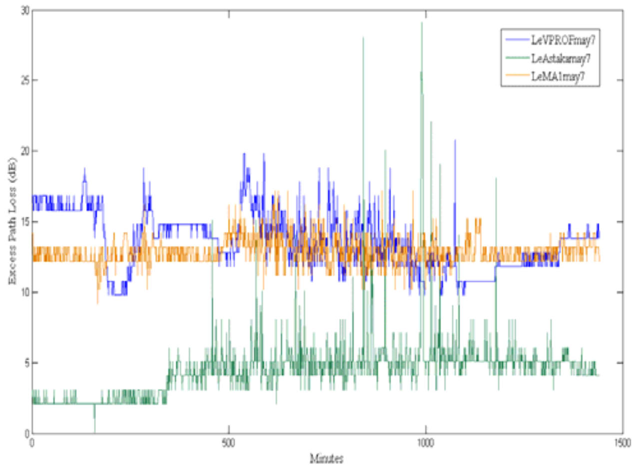

Fig. 11: Plot of excess path loss for NLOS links for a day

Excess path loss or excess attenuation is computed from the Excel worksheets. Fig. 11 illustrates excess path loss acquired throughout the day for all NLOS links of interest. The statistics of each plot is listed in Table 5. Prior to discussion earlier, sudden signal drop at Astaka resulted in the extreme value of excess path loss which was as high as 26.0945 dB on that particular day. Despite that, the received signal strength logged was considerably good at times which eventually produce a much reduced mean value of excess attenuation. On the contrary, even though the power received logged at block K11 is typically higher than the other NLOS links, the average excess path loss is found to be the highest amongst all.

The received signal logged is most probably a combination of multipath components such as direct, diffracted and scattered paths. The rain tree growing in between block K11 and Visiting Professor's Residence has a stout trunk with a broad diameter of umbrella-shaped canopy. With the presence of vegetation, the increased excess path loss can be attributable to diffracted and scattered paths caused by twigs, tree trunk and leaves. The fact that the leaves of rain tree having a comparable size to the wavelength of the frequency, 5.745 GHz which is 5.22 cm might contribute to the higher signal attenuation. Moreover, leaves which contain a great deal of water could absorb the intended signal and degrade it even further.

As compared to NLOS link from Astaka to Jalan Ladang Security Post, the propagating signal has to travel further through the row of trees with smaller trunks since the link distance is longer at about 0.2053 km. There could be diffractions from the side or canopy edges of the trees besides scatter components and reflections from the traffic and lamp posts nearby. All these are thought to compensate for the signal loss thereby contributing significantly to the decreased excess path loss. On the other hand, the excess path loss of NLOS link from block MA1 to block L20 could be explained by the existence of obstructions in the vicinity of the link specifically in the first Fresnel zone since the position of receiving antenna is in close proximity to the ground. The signal could be attenuated by the diffractions from rooftop and walls of buildings nearby, diffractions from the top and edges of adjacent trees as well as reflections from lamp posts and traffic.

Table 5: Data statistics of excess path loss plots for NLOS links for a day

Excess Path Loss of NLOS Link From	Max (dB)	Min (dB)	Mean (dB)	Standard Deviation
Block K11 to Visiting Professor's Residence	20.8250	9.8250	13.5875	2.0132
Astaka to Jalan Ladang Security Post	26.0945	0.0945	5.0195	2.1977
Block MA1 to block L20	17.2045	9.2045	12.9031	0.9832

In order to characterise signal fading, an attempt is made to fit the excess path loss computed for each NLOS links with statistical distributions generally used namely normal or Gaussian, Log-normal, Rician and Rayleigh distributions in both Probability Density Function (PDF) plot. The Gaussian and Rician distributions are found to resemble the data best for NLOS link from block K11 to Visiting Professor's Residence as shown in Fig. 12. Theoretically, it is known that Rician distribution is fitted for LOS scenario. Hence, this fitting result indicates that there is a direct signal through the foliage combined with other multipath signals most possibly caused by scatterings and diffractions arriving at the receiver. It also shows good agreement with path loss measurement done in [10] at 2.485 GHz which followed a Rician distribution as well. The measurement location is similar with terrain and foliage blockages.

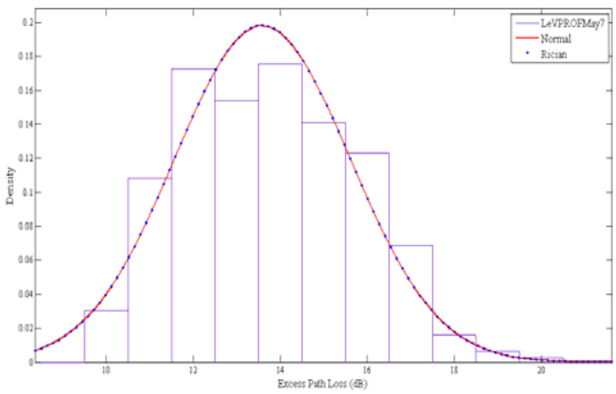

Fig. 12: Typical PDF for NLOS link from block K11 to Visiting Professor's Residence

However, the excess path loss for NLOS links from Astaka to Jalan Ladang Security Post and from block MA1 to block L20 are best represented by log-normal distributions as illustrated in the following figures. As observed from the PDF figures, Log-normal distribution is extremely asymmetrical unlike normal distribution. This result shows good agreement with data collected by Perras and Bouchard [6] who discovered that radio frequency attenuation characteristics through trees in frequency bands from 2 to 60 GHz is best represented by the Extreme Value and Log-normal distributions.

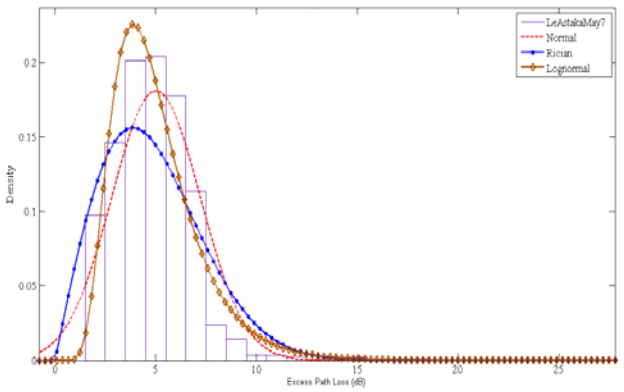

Fig. 13: Typical PDF for NLOS link from Astaka to Jalan Ladang Security Post

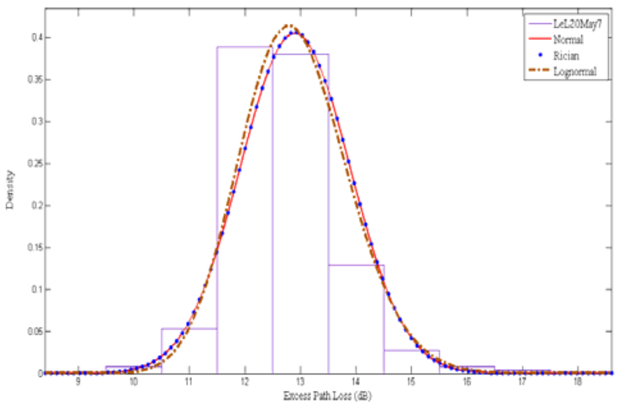

Fig. 14: Typical PDF for NLOS link from block MA1 to block L20

The subsequent tables list the mean excess path loss per day for each NLOS links studied and the average of excess path loss from all the mean values acquired. It is worth noting that days listed are not continuous and might be dissimilar between the links as only data logged that meet the criterion of less than five percentage of missing values shall be taken into consideration.

Table 6: Average excess path loss for all NLOS links

NLOS Link	Total Days	Mean Excess Path Loss (dB)		
		Max	Min	Average
Block K11 to Visiting Professor's Residence	41	18.1196	7.3111	12.2615
Astaka to Jalan Ladang Security Post	41	5.7345	3.1327	4.6306
Block MA1 to block L20	87	20.1316	11.5489	14.3868

Based on the results obtained as shown in Table 6, it is found that NLOS links examined which are obstructed by a single tree and a row of trees recorded an average of 12.2615 dB and 4.6306 dB excess path losses correspondingly within 41 days. It can be deduced that blockage by a single tree has a greater effect on the propagating signal as compared to obstruction by a row of trees. This result shows good agreement with measurement results done by Karlsson et al [14] in which the excess path loss to theoretical LOS path loss is between 1 and 16 dB at 3.1 and 5.8 GHz frequencies. The measurement locations are quite similar with obstructions by either one tree or trees which consist of small and large deciduous trees. Apart from that, the outcome also conforms to the findings in [4]. Dalley et al found that the average attenuations for a dry and a wet foliated tree are 12 and 19 dB at 5.85 GHz frequency. In addition, the increased average excess path loss for NLOS link from block MA1 to block L20 can be due to worst case scenarios evidently observed by the maximum mean excess path loss computed, 20.1316 dB within the 86 days. This infer that the maximum excess path loss should be considered as the worst case scenarios for each NLOS links as the received signal is dependent on the ever-changing propagation environment from time-to-time.

5 Conclusion

In a nutshell, measurement conducted produce good insight on the effects of foliage in distorting signal for point-to-point link at 5.8 GHz. NLOS links examined which are obstructed by a single tree and a row of trees recorded an average of 12.2615 dB and 4.6306 dB excess path losses respectively within 41 days. Excess path loss derived from data logged is inclusive of other additional losses after deduction of free space loss from total path loss computed. This outcome shows good agreement with previously published works. The results acquired provide general applicability to the environment within the campus.

This remote data logging methodology can be employed to further investigate on the problematic NLOS links especially those which are hindered by trees. Signal degradation attributed to trees should not be overlooked especially in the planning of fixed terrestrial communication links besides terrain and man-made blockages. The knowledge of propagation effects due to foliage is imperative in order to establish a reliable near line-of-sights links.

References:

[1] Barclay, L. W., *Propagation of Radiowaves,* 2nd. ed. London, UK: The Institution of Electrical Engineers, 2003.

[2] R.K. Tewari, S. Swarup, and M. N. Roy, Radio Wave Propagation through Rain Forests of India, *IEEE Transactions on Antennas and Propagation*, Vol.38, No.4, 1990, pp. 433-499.

[3] Benzair, K., Measurements and Modelling of Propagation Losses through Vegetation at 1-4 GHz, *IEE Ninth International Conference on Antennas and Propagation,* 1995, pp. 54-57.

[4] J. E. J. Dalley, M. S. Smith, and D. N. Adams, Propagation Losses Due to Foliage at Various Frequencies, *IEE National Conference on Antennas and Propagation,* 1999, pp. 267-270.

[5] J. C. R. Dal Bello, G. L. Siqueira, and H. L. Bertoni, Theoretical Analysis and Measurement Results of Vegetation Effects on Path Loss for Mobile Cellular Communication Systems. *IEEE Transactions on Vehicular Technology*, Vol.49, No.4, 2000, pp. 1285-1293.

[6] S. Perras and L. Bouchard, Fading Characteristics of RF Signals Due to Foliage in Frequency Bands from 2 to 60 GHz, *The 5th International Symposium on Wireless Personal Multimedia Communications*, 2002, pp. 267-271.

[7] Y. Lu, Y. Cheng, W. Liu, H. W. Seah, H. L. Chan, L. C. Tai, M. Lesturgie, P. Borderies, and R. Guern, Low Frequency Radar Phenomenology Study in Equatorial Vegetation-Preliminary Results. *RADAR 2002*, 2002, pp. 70-74.

[8] J. Goldhirsh and W. J. Vogel, Roadside Tree Attenuation Measurements at UHF for Land Mobile Satellite Systems, *IEEE Transactions on Antennas and Propagation*, Vol.35, No.5, 1987, pp. 589-596.

[9] I. H. Cavdar, H. Dincer, and K. Erdogdu, Propagation Measurements at L-Band for Land Mobile Link Design, *Proceedings 7th Mediterranean Electrotechnical Conference,* 1994, pp. 1162-1165.

[10] Michael J. Gans, Noach Amitay, Y. S. Yeh, T. C. Damen, Reinaldo A. Valenzuela, Choelhang Cheon, Jeho Lee, Propagation Measurements for Fixed Wireless Loops (FWL) in a Suburban Region with Foliage and Terrain Blockages, *IEEE Transactions on Wireless Communications,* Vol.1, No.2, 2002, pp. 302-310.

[11] T. Sofos and P. Constantinou, Propagation Model for Vegetation Effects in Terrestrial and Satellite Mobile Systems, *IEEE Transactions on Antennas and Propagation,* Vol.52, No.7, 2004, 1917-1920.

[12] Douglas O. Reudink, M. F. Wazowicz, Some Propagation Experiments Relating Foliage Loss and Diffraction Loss at X-Band and UHF Frequencies, *IEEE Transactions on Communications*, Vol.21, No.11, 1973, pp. 1198-1206.

[13] G. Durgin, T. S. Rappaport, and H. Xu. Measurements and Models for Radio Path Loss and Penetration Loss in and Around Homes and Trees at 5.85 GHz. *IEEE Transactions on Communications,* Vol.46, No.11, 1998, pp. 1484-1496.

[14] A. Karlsson, R.E. Schuh, C. Bergljung, P. Karlsson, and N. Lowendahl, The Influence of Trees on Radio Channel at Frequencies of 3 and 5 GHz, *IEEE VTS 54th Vehicular Technology Conference*, 2001, pp. 2008-2012.

[15] IEEE Standard for Local and Metropolitan Area Networks, *Virtual Bridged Local Area Networks,* New York, USA, IEEE Std 802.1Q™, 2005.

[16] C. M. Boo, K. Omar-Hor, C. L. Ou-Yang, *1001 Garden Plants in Singapore*, Singapore: National Parks Board, 2003.

[17] Tabachnick, B. G., Fidell, L. S., *Using Multivariate Statistics.* 5th. ed. Boston, USA: Pearson/Ally & Bacon, 2007.

[18] Clark, M. P., *Wireless Access Network: Fixed Wireless Access and WLL Networks — Design and Operation,* West Sussex P019 1UD, UK: John Wiley & Sons, 2000.

[19] Morais, D. H., *Fixed Broadband Wireless Communications: Principles and Practical Applications*, Upper Saddle River, N. J.: Prentice Hall, 2004.

[20] Saunders, S. R., and Aragon-Zavala, A., *Antennas and Propagation for Wireless Communication Systems*, UK: John Wiley & Sons, Ltd., 2007.

[21] Pelet, E. R., Salt, J. E. and Wells, G., Effect of Wind on Foliage Obstructed Line-of-sight Channel at 2.5 GHz, *IEEE Transactions on Broadcasting*, Vol.50, No.3, 2004, pp. 224-232.

[22] R. Lewenz, Path Loss Variation Due to Vegetation Movement, *IEE National Conference on Antennas and Propagation*, 1999. pp. 97-100.

[23] M. H. Hashim and S. Stavrou, Wind Influence on Radio Waves Propagating through Vegetation at 1.8 GHz, *IEEE Antennas and Wireless Propagation Letters*, Vol.4, 2005, pp. 143-146.

[24] D. Crosby, V. S. Abhayawardhana, I. J. Wassell, M.G. Brown, and M. P. Sellars, Time Variability of the Foliated Fixed Wireless Access Channel at 3.5 GHz, *IEEE 61st Vehicular Technology Conference*, 2005, pp. 106 – 110.

[25] Lysko A.A, Johnson D.L, A Study of Propagation Effects in a Wireless Test Bed, WSEAS Transactions on Communications, Vol. 7, Issue 8, 2008, pp. 857-871.