Mobile Path Loss Characteristics for Low Base Station Antenna Height in Different Forest Densities

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Abstract— **This paper presents studies of propagation in a suburban forest based on a measurement campaign at a frequency of 1.8 GHz. We investigated how tree density affected path loss-distance and the fast fading characteristic depends on base tree size and base station antenna height in a range of 3, 4, and 5 m above ground while the receiving antenna height was fixed at 1.8 m above ground. The path loss exponent is found that to average 3.8, 3.7 and 2.2 for the measurement areas of high, medium, and low densities respectively. The high density area with low tree heights provides maximum path loss exponents. Path loss in the same density area depends on the number of trees in the direct path between the transmitter and the receiver. The measurement of signal variation shows that a multi-path contribution becomes more significant as the base station antenna is raised.**

Index Terms—**mobile path loss, low base station, different forest densities.**

I. INTRODUCTION

FOREST is a significant feature which affects radio wave propagation in rural and suburban areas at the mobile communication bands. Shadowing, scattering, and absorption by trees and other vegetation cause substantial path loss. There are three different approaches for the prediction of the field strength in a forest. On the first hand there are empirical models, based on the regression of measurement data such as Weissberber's model [1] and COST 235 ITU model [2]. These models lie in their mathematical simplicity and are easy to use. However they have many drawbacks, such as their strict dependence on specific measured data and their failure to relate to the physical processes involved. On the other hand there are semi-empirical models, based on some physical considerations and regression analysis such as [3],[4]. These models provide higher accuracy while they are also easy to use. However there some physical considerations such as the density and size of trees that are not included in these models. These make the models provide poor accuracy in some environments. Additionally there are deterministic models based on Geometrical and Uniform Theory of Diffraction (GTD/UTD) such as The Tamir model [5] and The Shukla model [6] or Radiation Energy Transfer Theory (RET) [7] and Full Wave Solutions [8]. These models are sacrificed with excessive computation time and the requirement of detailed databases. Julio Cesar R. et al. [9] have reported on studies of propagation in an urban forested park area for a transmitting antenna height of 12 to 84 m. Authors in [10] and [11] have modeled the effects of trees. However these studies have not included consideration of different tree categories such as tree size and tree density which affect propagation characteristics especially for low antenna height in micro-cell communication.

To overcome the above limiting factors of the vegetation models, this paper presents studies of propagation in a suburban forest based on a measurement campaign at a frequency of 1.8 GHz. We investigate how tree density effected path loss-distance, and the fast fading characteristic depends on base tree size and base station antenna height in a range of 3, 4, and 5 m above ground while the receiving antenna height was fixed at 1.8 m above ground. The statistical analysis are also obtained at all receiver sites.

The measurements were performed in a forested park known as Phutthamonthon, located in Nakornprathom, Thailand, from May to August 2005. The vegetation of Phutthamonthon consists of more than 100 different kinds of trees. We classified groups of trees into 1) high density trees, 2) medium density trees, and 3) low density trees.

The characteristics of the path loss from tree density effects give information to predict a signal strength in forest areas for low base station antenna height systems. Another advantage is estimating mobile location from received signal strength in the forest.

This paper, first presents measurement methods and locations. Section 3 presents path loss. Section 4 present fast fading characteristics, and finally conclusion.

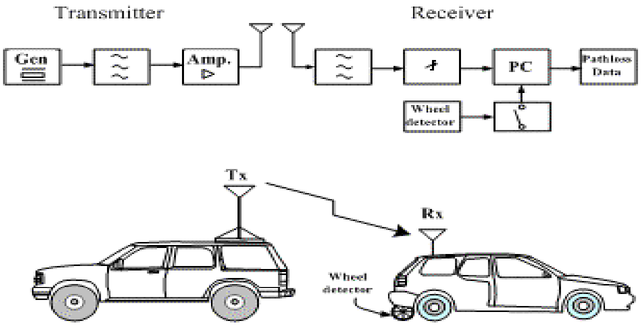


Fig.1 Measurement system

II. MEASUREMENT METHODS AND LOCATIONS

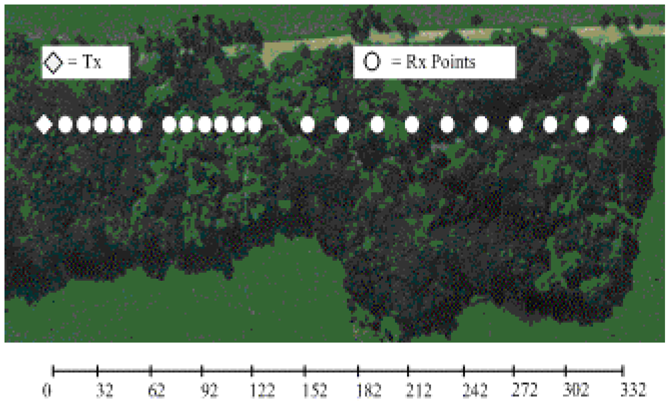
The measurements were performed in Putthamonton garden. using a fixed transmitter and a narrow-band (20KHz) portable spectrum interfaced with a microcomputer at a frequency of 1.8 GHz. The fixed transmitter consisted of a network analyzer (with 18 dBm power output) and $\lambda/4$ omni-directional antenna with 10x10 cm^2 ground plane (2.2 dBi gain). We also used the same type of antenna for signal strength measurement via a recorder as shown in Fig. 1. The transmitting antenna heights were varied for 3, 4, and 5 m while a receiving antenna height was fixed at 1.8 m. Three different tree densities were studied for tree loss in low medium and high tree densities. The received power was recorded for 120 s using a 2.0 Hz sample rate for each measurement point in order to determine path loss and analysis the fast fading provoked by movement of the tree leaves due to wind. The wind speed was recorded between measurements from May to August 2005 in the rainy season. The distance between each measurement point was about 10 to 20 m. The measurement data was recorded from 4 local area path loss measurements as follows

-High density areas

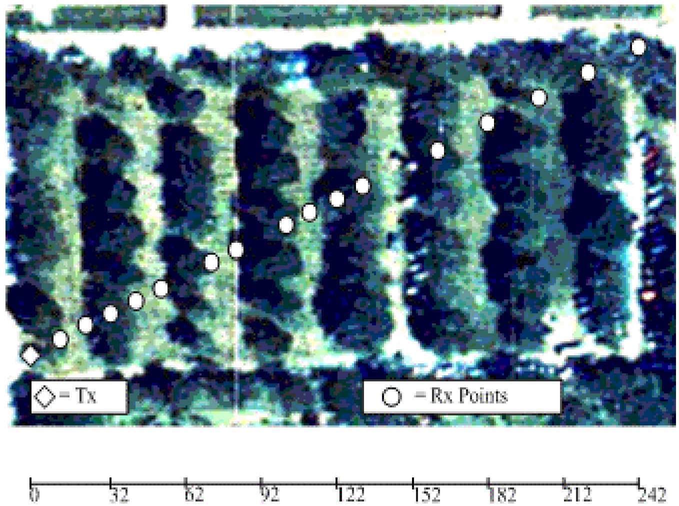
There are two studied location areas 1) Perennial trees with a typical height of 17 m with 0.4 m diameter trunks and 6 m diameter canopies. The trees are generally separated from each other by about 5 m and have an average density of 80 trees/50x50 m^2. The typical leaves have dimensions of about 17 x 5 cm and the mean density is about 952 leaves/m^3. 2) Mango trees with typical height of 4.3 m with 0.17 m diameter trunks and 3 m diameter canopies. The trees are generally separated from each other about by 5 m and have an average density of 72 trees/50x50 m^2. The typical leaves have dimensions about 30 x 6 cm and the mean density is about 222 leaves/m^3.

-Medium density area

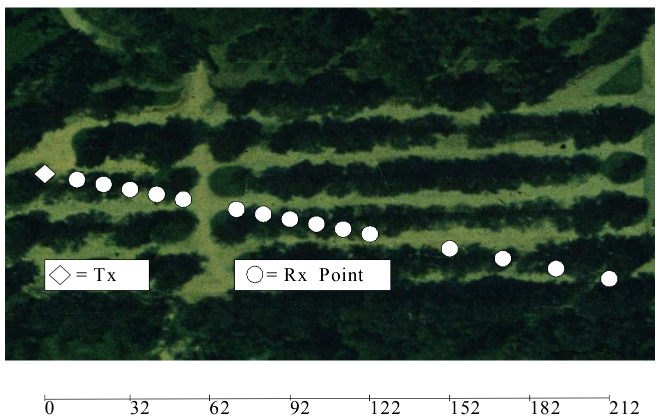
The area consists of perennial trees with typical heights of 8.9 m with 0.36 m diameter trunks and 8 m diameter canopies. The trees are generally separated from each other by about 5 m and 7 m for row and column respectively. The



a) Density of 0.032 trees/m^2



b) Density of 0.009 trees/m^2



c) Density of 0.005 trees/m^2

Fig. 2 Propagation media category and measurement points

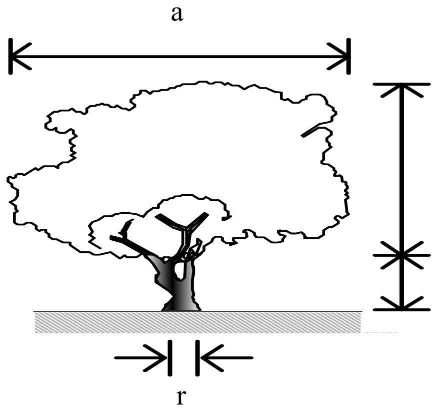


Fig.3 Structure of trees

average density of trees are 52 trees/50x50 m^2. The typical leaves have dimensions of about 14 x 7 cm and the mean density is about 750 leaves/m^3.

-Low density areas

There are two studied locations, 1) Burma Padauk trees with a height of 6.5 m with 0.25 m diameter trunks and 8.6 m diameter canopies as shown in Fig. 2 b). The trees are generally separated from each other by about 5 m and 20 m for row and column respectively. The average density of trees are 23 trees/50x50 m^2. The typical leaves have dimensions of about 8 x 5 cm and the mean density is about 690 leaves/m^3. and 2) Burma Padauk trees with a height of 6.2 m with 0.22 m diameter trunks and 9 m diameter canopies as shown in Fig. 2 c). The trees are generally separated from each other about 5 m and 20 m for row and column respectively. The average density of trees are 12 trees/50x50 m^2. The typical leaves have dimensions of about 7 x 4 cm and the mean density is about 714 leaves/m^3.

-Grass area

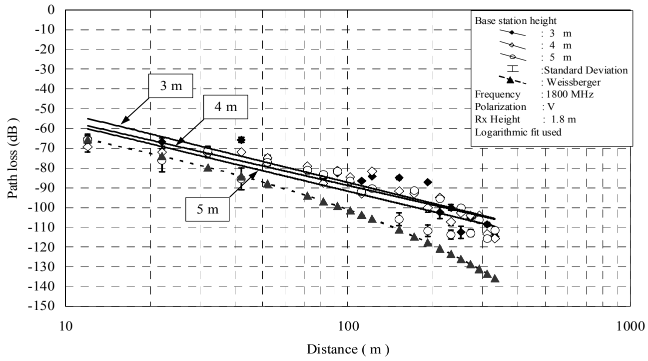
This area consists of flat grass with height of 0.4 m in area of 300x100 m^2 . There are few trees in the area.

III. PATH LOSS

An empirical path loss model can be written in the form

$$PL(d)\ [\text{dB}] = PL_0(\text{dB}) + 10n\log(d) \quad (1)$$

Where PL_0 is path loss at reference distance, n is path loss exponent and d is distance between the transmitter and the receiver. Fig.4 shows the measurement path loss in different density areas compared with The Weissberger model. The standard deviation represents the signal fluctuation due to wind and multi-path. We tried to keep to the wind speed to make sure that the measured path loss depends on only tree environment. The path losses for the low density area in



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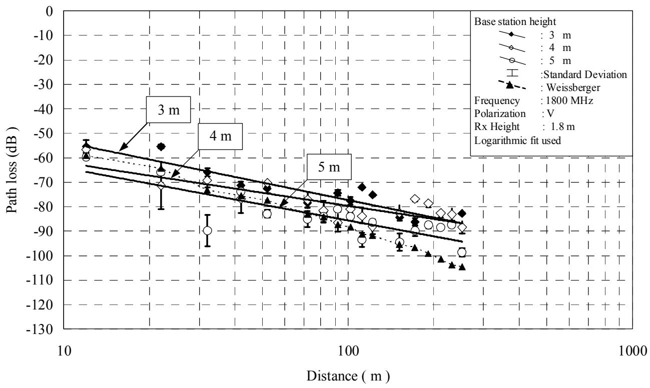
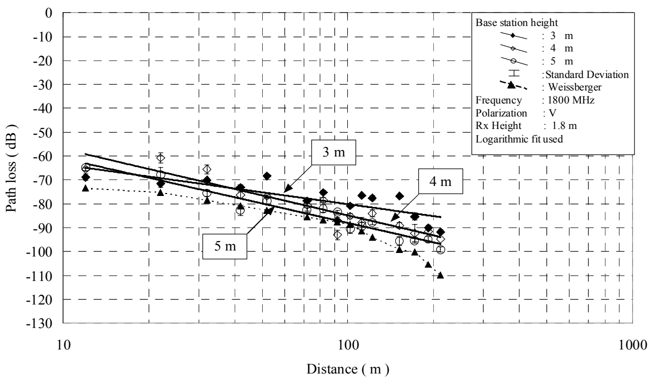
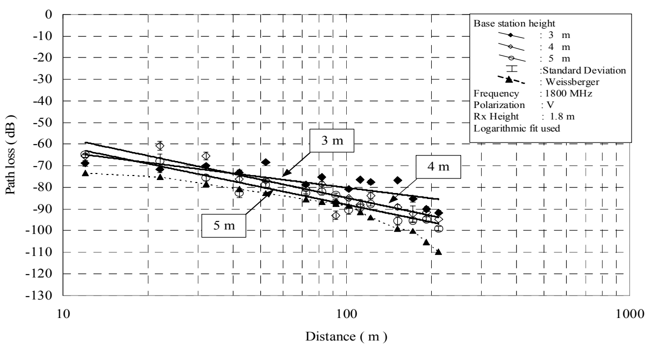


b) Density of 0.009 trees/m^2



c) Density of 0.005 trees/m^2



d) Grass area

Fig.4 Measurement path loss at the different areas

Fig.4 c) are high attenuation for h_b of 4 m and 5 m. This is because the trees in the low density area are small size. This makes the transmitting signal have high attenuation from the leaves of the trees in the low density area, while the height of trees in the medium and low density areas are nearly equal and same type of tree. This makes the path loss in these areas dependant on the number of trees in the direct propagation path between the transmitter and the receiver as shown in Fig 4 b) and c). The number of trees in direct propagation path between the transmitter and the receiver for the high, medium and low density areas are 0.16, 0.03, and 0.06 trees/m respectively. The path losses for the grass area are shown in Fig 4 d). Summary of the path loss exponents as the parameters of tree structure in Fig. 3 are shown in Table I, where subscript 1, 2 and 3 of the path loss exponent n denote the case for $h_b = 3$ m, 4 m, and 5 m respectively.

Table I Summary of the path loss exponents as parameters of tree structure

Areas	Number of tree / m^2	Tree structure				leave dimension (m^2)	leaves $/m^3$	Path loss exponents		
		a	b	c	r			n_1	n_2	n_3
High desity	0.032	6.0	12.0	5.0	0.40	0.17 x 0.05	952	3.5	3.3	3.4
	0.028	3.0	3.0	1.3	0.17	0.30 x 0.06	222	4.4	4.2	4.1
Medium desity	0.021	8.0	7.0	1.9	0.36	0.14 x 0.07	750	3.5	3.9	-
Low desity	0.009	8.6	4.0	2.5	0.25	0.08 x 0.05	690	2.2	1.8	2.2
	0.005	9.0	4.0	2.2	0.22	0.07 x 0.04	714	1.7	2.8	2.7
Grass	-	-	-	-	-	-	-	1.9	1.6	1.8

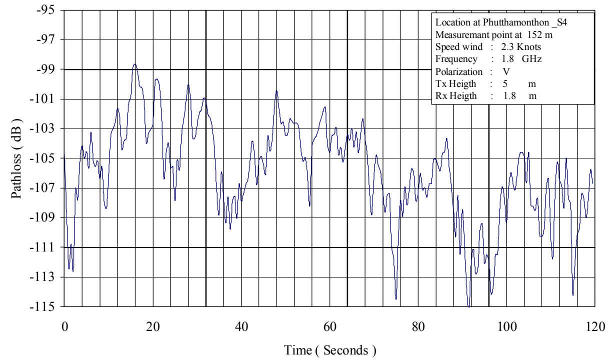
To compare the measured path loss with the empirical models, we selected the Weissberger model in which the distance traveled by signals through the trees is determined from the tree structure in the real environment and presented as additional loss to free space attenuation

$$PL(d_t,f)[\text{dB}] = 1.3 f_0^{\,0.284}\, dt^{\,0.588},\quad 14 \le d_t \le 400 \text{ m} \qquad [2]$$

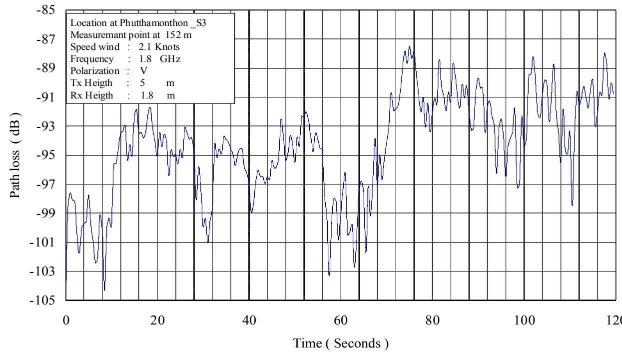
and

$$PL(d_t,f)[\text{dB}] = 0.45 f_0^{\,0.284}\, dt^{\,1.0},\quad 0 \le d_t \le 14 \text{ m} \qquad [3]$$

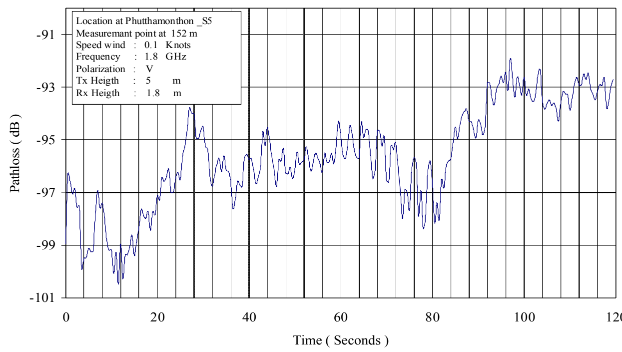
where f_0 is the radiated frequency in GHz, and d_t is the distance between the antennas within the vegetation. The comparison results are shown in Fig 4 a) to c) for high, medium and low density areas respectively. The distances d_t t were determined from the tree environments. We found that the Weissberger model did not agree with measurement data in a high density area. This is because the trees are very tall compared with the antenna height. So the signal propagation within trees are only attenuated by the trunks. However the Weissberger model can agree with measurement data in medium and low density areas where the height of trees are nearly equal to the antenna height. So the signal propagation within trees are attenuated by the trunks and the canopies.



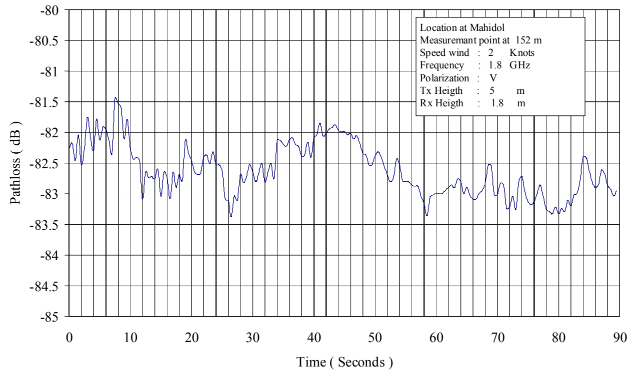
a) Density of 0.032 trees/m^2



b) Density of 0.009 trees/m^2

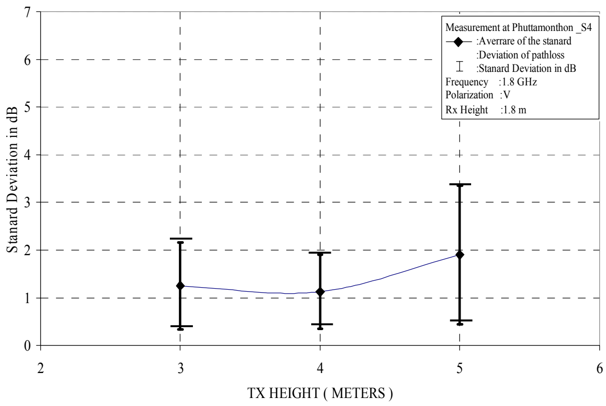


c) Density of 0.005 trees/m^2

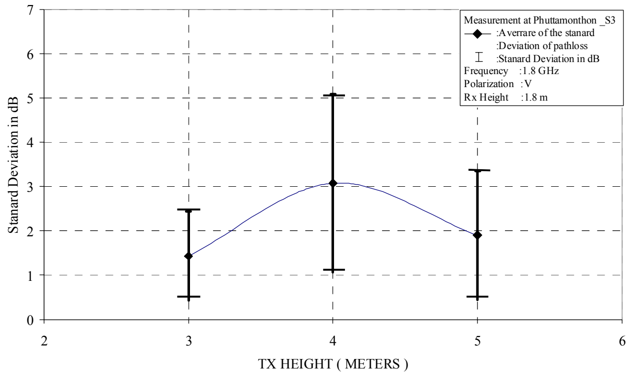


d) Grass area

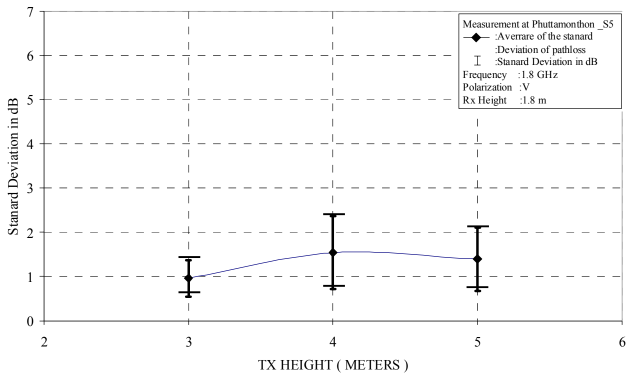
Fig.5 Variation of the received path loss with time in the different areas



a) high density area with 0.32 trees/m^2



b) low density area with 0.009 trees/m^2



c) low density area with 0.005 trees/m^2

Fig.6 Variation of the standard deviation of pathloss with TX Height in different areas.

IV. FAST FADING CHARACTERISTICS

In multi-path environments, a radio signal arrives at the receiver through a great number of paths. This make the distribution of sampled values of the magnitude of the received signal follow a Rayleigh distribution when the receiver is shadowed so that no one path provides the dominant contribution to the received signal, while the distribution of the received signal can be described by a Rician or Nakagami fading when one contribution is significantly stronger than the other.

Statistical analysis of the fast fading can be made using the Rician distribution due the physical interpretation of its K-factor, defined as the ratio between the power of the dominant signal to that in the multi-path components. The K-factor is varied with inversed standard deviation σ of the variation in received path loss. Therefore in this paper we can analyze the fast fading by using the standard deviation. Fig. 5 shows the variation of the measured path loss with time in the different areas. The results confirm that there is large fading in high density areas. Fig. 6 shows the variation of the standard deviation of path loss with the transmitting antenna height. It is seen that σ in general increases with increasing antenna height. This result indicates that there are a lot of the multi-path components due to scattering from leaves for high antennas.

V. CONCLUSION

Propagation characteristics in different forest densities at a frequency of 1.8 GHz have been studied in Phutthamon-thon, Nakornprathom. The path loss exponent is found to average 3.8, 3.7 and 2.2 for the measurement areas of high, medium, and low density respectively. The high density area with low tree heights provides maximum path loss exponents. Path loss in the same density area depend on the number of trees in the direct path between the transmitter and the receiver.

The measurement of signal variation shows that a multi-path contribution becomes more significant as the base station antenna is raised.

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