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An Empirical Based Path Loss model with Tree Density Effects for 1.8 GHz Mobile Communications Using Fuzzy Regression

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Abstract: - Upper-and lower-bound path loss models in the forests are presented in this paper. We performed measurements in different forest densities at a frequency of 1.8 GHz with 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 forest was classified to different density areas namely, high-, medium-, low- density and grass area**.** We proposed upper-and-lower bounds path loss models which depend on max and min values of sample path loss data. It does not depend on sample size. This makes our models limit path loss within the boundary lines while the confidence interval of standard regression is depended on the sample size. Comparison between the fuzzy regression model and conventional regression model shown that the proposed model agrees with measured data while the conventional regression model provides over estimation.

Key-Words: - fuzzy regression, mobile path loss, low base station, different forest densities.

1 Introduction

Forests are significant features which affect 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. Therefore in this paper, we performed measurements in forests at a frequency of 1.8 GHz to model mobile path loss characteristics.

While estimation of path loss in the forest with low base station antenna height is necessary for local wireless system and micro-cell design, we could not find more accurate path loss models from conventional empirical methods in [1]-[4] because of uncertain tree structures in the forest caused by type and density of trees including time-varying effect wind speed.

It would, therefore, be extremely useful if the upper and lower bound of path loss could be estimated. Although upper and lower bound estimations have already been performed for the UHF band [5]-[6], however they were not included tree density effects with their influence on wave propagation that is very high.

To solve this problem, we propose new upper and lower bound formulas for propagation path loss in forest using fuzzy linear regression. The spread of the boundary lines of the fuzzy models depend on maximum and minimum value of a given data. It does not depend on sample size. In standard regression models the width of confidence intervals depends on standard deviation, sample size, and significance level. In case of small standard deviation, the width of confidence intervals often disable the proper estimation process. The application of the fuzzy approach eliminate this problem.

This paper, first presents measurement methods and locations. Section 3 presents standard regression model. Section 4 presents modelling path loss with fuzzy linear regression, Section 5 presents numerical results, Section 6 presents comparison between fuzzy and conventional regression models, and finally conclusion.

2 Measurement Methods and Locations

The measurements have already been done in [4]. They 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

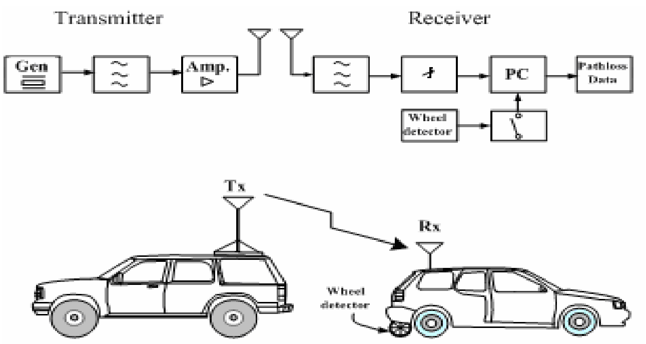
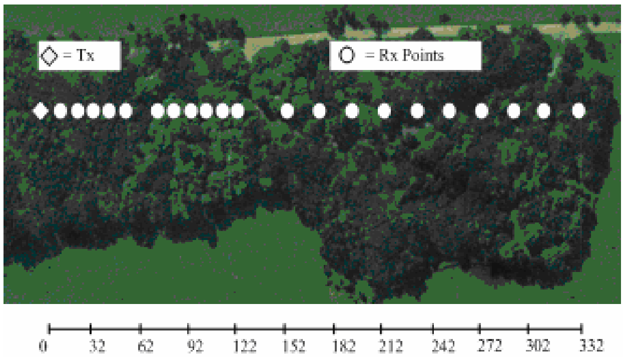


Fig.1 Measurement system

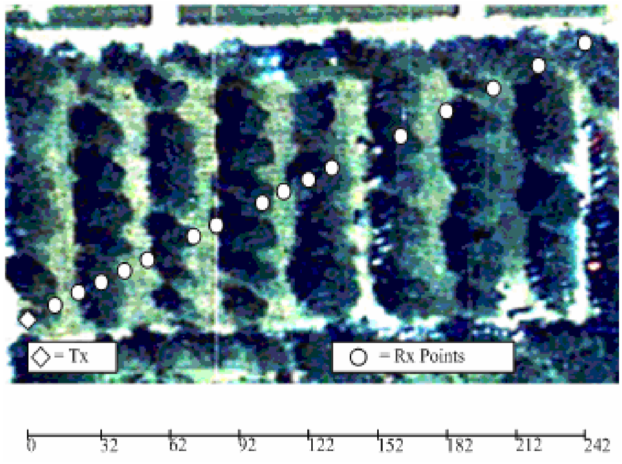
18 dBm power output) and λ/4 omni- directional antenna with 10x10 cm^2 ground plane (2.2 dBi gain). We also used the same type of antenna for signal strength measurement via a recorder as shown in Fig. 1. The transmitting antenna heights were varied for 3, 4, and 5 m while a receiving antenna height was fixed at 1.8 m. All measurements are vertical polarization. Three different tree densities were studied for tree loss in low, medium, and high tree densities. In order to determine path loss and analysis the fast fading provoked by movement of the tree leaves due to wind, there are two modes for measurements 1) The received power was recorded for 120 s using a 2.0 Hz sample rate for each measurement point. 2) The received power was recorded every 0.25 λ tracking with wheel detector along direct propagation path. The wind speed was recorded between measurements from May to August 2005. It was average about 2.1 Knots. The distance between each measurement point was about 10 to 20 m. The measurement data was recorded from 6 local areas for path loss measurements as follows

2.1 High density areas

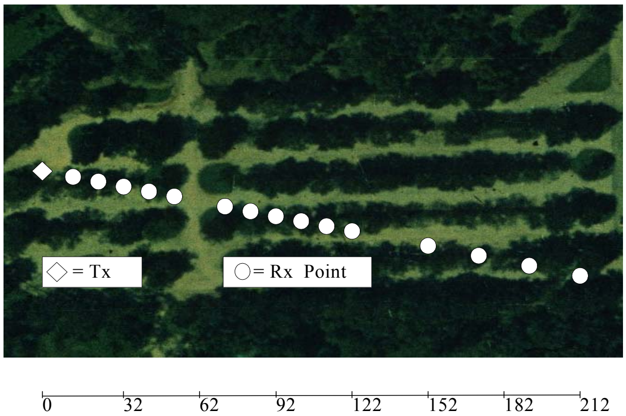
There are two studied location areas 1) Perennial trees with a typical height of 17 m with 0.4 m diameter trunks and 6 m diameter canopies as shown in Fig. 1 a). The trees are generally separated from each other by about 5 m and have an average density of 80 trees/50x50 m^2. The typical leaves have dimensions 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.



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 environment category and measurement locations

2.2 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 measurement points 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.

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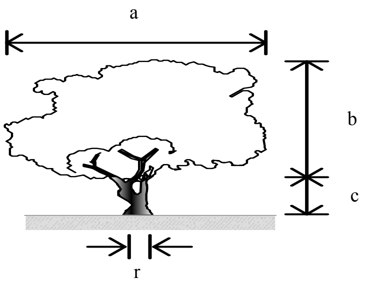


Fig.3 Parameters of tree structure

2.3 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.

2.4 Grass area

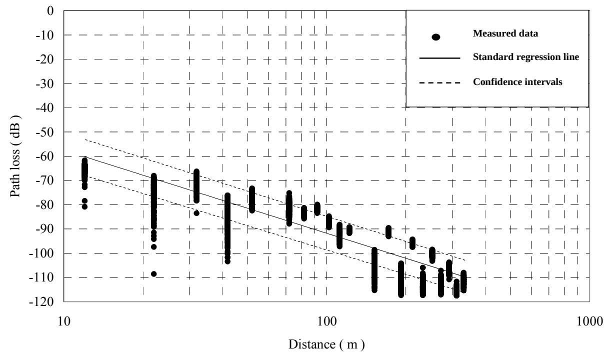
This area consists of flat grass with height of 0.4 m in area of 300x100 m^2 . There are few trees in the area.

3 Standard Regression Model

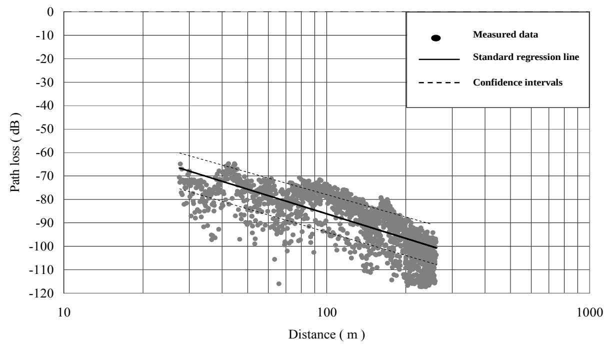
An empirical path loss model can be written in the form

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

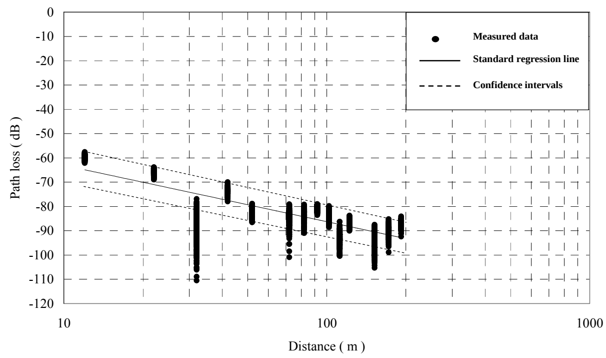
Where PL_0 is path loss at reference distance, n is path loss exponent and d is distance between the transmitter and the receiver. Fig.4 shows standard regression of the measurement path loss in different density areas with different transmitting antenna height. The confidence interval in the figure is a certain range of standard deviation [7]. 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.



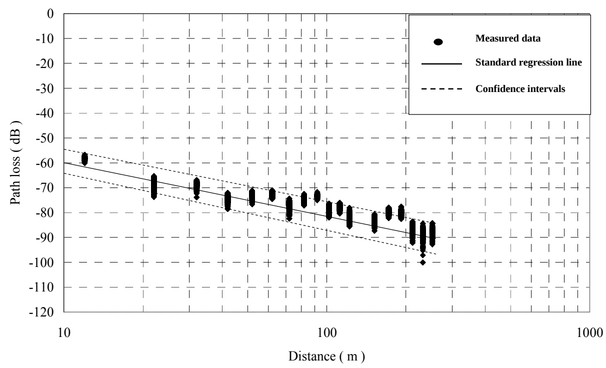
a) Density of 0.032 trees/m^2 with h_t = 5 m



b) Density of 0.021 trees/m^2 with h_t = 3 m



c) Density of 0.009 trees/m^2 with h_t = 5 m



d) Grass area with h_t = 3 m

Fig.4 Standard regression of measurement path loss at the different areas

Table 1 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	0.17x0.05	952	3.5	3.3	3.4
	0.028	3.0	3.0	1.3	0.17	0.30x0.06	222	4.4	4.2	4.1
Medium desity	0.021	8.0	7.0	1.9	0.36	0.14x0.07	750	3.5	3.9	-
Low desity	0.009	8.6	4.0	2.5	0.25	0.08x0.05	690	2.2	1.8	2.2
	0.005	9.0	4.0	2.2	0.22	0.07x0.04	714	1.7	2.8	2.7
Grass	-	-	-	-	-	-	-	1.9	1.6	1.8

4. Modelling Path Loss With Fuzzy Linear Regression

In this section, we introduce fuzzy regression to expand the conventional linear regression model to represent possible regions of path loss data.

4.1 Fuzzy regression model

In fuzzy regression model [8], the parameter in (1) are replaced with fuzzy numbers as shown in (2) to cover a wide range of data.

$$PL(dB) = A_0(dB) + A_1 log(d) \qquad (2)$$

The parameter $A_0, A_1, \ldots$ are determined that the observed data are encompassed by the fuzzy regression model. The variable $PL(dB)$ is also fuzzy number, which has a region of data covered in a varying degree of possibility. Fig. 5 show the triangular fuzzy set representing the fuzzy number A_i with three crisp parameters, namely $a_i, c_i^+, c_i^- \, (c_i^+, c_i^- \geq 0)$. Here, a_i is the most likely value of the regression parameter, whereas c_i^+ and c_i^- are possible maximum spread from a_i to the higher and lower values of the parameter, respectively. We use the expression $A = (a_i, c_i^+, c_i^-)$ to represent such a triangular fuzzy number.

In the modeling process, the mean value a_i of the fuzzy number is simple determined by conventional regression. The spread parameters c_i^+ and c_i^- are determined by optimization.

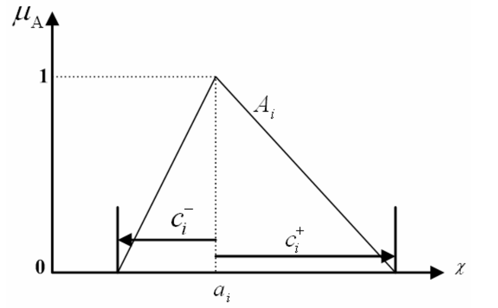


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Fig. 5 The triangular fuzzy set representing the fuzzy number

4.2 Range Optimization

To determine the remaining parameters for the fuzzy numbers (c_i^+ and c_i^-) we apply linear programming to fit the model to the given data. The optimization process is formulated as follows:

Minimize:

$$\sum_{d=1}^{n} \{c_0^+ + c_1^+ \log(d)\} \qquad (3)$$

subject to

$$a_0 + a_1 \log(1) + c_0 + c_1 \log(2) \geq PL(2)$$
$$\vdots$$
$$a_0 + a_1 \log(n) + c_0 + c_1 \log(n) \geq PL(n)$$
$$\vdots$$
$$a_0 + a_1 \log(1) - c_0^- - c_1^- \log(2) \leq PL(2)$$
$$\vdots$$
$$a_0 + a_1 \log(n) - c_0^- - c_1^- \log(n) \leq PL(n) \qquad (4)$$

and

$$c_0^+, c_0^-, c_1^+, c_1^- \geq 0$$

where n is the total number of measured data points.

The parameters a_i are determined by the method of linear regression. The parameters c_i^+ and c_i^- are determined as the optimal solution of the LP problem (3) –(4). The FLR models for propagation path loss are presented in form

$$PL(dB) = [a_0, c_0^+, c_0^-] + [a_1, c_1^+, c_1^-]\log(d) \qquad (5)$$

Where d = distance between transmitter and receiver.

The optimization is aimed at fitting the model within as narrow a range as possible, while covering all the data considered within the region.

4.3 Fuzzy parameters modification

Because of outlier data, the resultant range of fuzzy model may appear large boundary. A method to narrow down the boundary is α cuts of the fuzzy numbers in (2) to modify their range. By using a single parameter α ($0 \le \alpha \le 1$), A_0 and A_1 are modified as

$$A_0 = \left\langle a_0, c_0^+ \times (1-\alpha), c_0^- \times (1-\alpha) \right\rangle$$
$$A_1 = \left\langle a_1, c_1^+ \times (1-\alpha), c_1^- \times (1-\alpha) \right\rangle \quad (6)$$

At α =0, the original fuzzy regression model are obtained while the value of α increase toward 1, the model become the conventional regression.

5. Numerical Results

By solving this LP problem of measured data and using α cuts, the following FLR models are obtained:

5.1 High density area with density of 0.032 tree/m^2.

Path loss models for transmitter height of 3 m, 4 m, and 5 m are written in (7), (8) and (9) respectively.

PL_{ht_3} = [50,20,10]+[33,6,0]log(*d*); d ≥ 10 m (7)

PL_{ht_4} = [55,20, 5]+[33,0,2]log(*d*); d ≥ 10 m (8)

PL_{ht_5} = [56,26,13]+[36,0,1]log(*d*); d ≥ 10 m (9)

5.2 Medium density area with density of 0.021 tree/m^2

Path loss models for transmitter height of 3 m and 4 m are written in (10) and (11) respectively.

PL_{mt_3} = [51,24,13]+[35,0,1]log(*d*); d ≥ 10 m (10)

PL_{mt_4} = [45,25,10]+[44,0,2]log(*d*);d ≥ 10 m (11)

5.3 Low density areas with density of 0.009 tree/m^2

Path loss models for transmitter height of 3 m, 4 m, and 5 m are written in (12), (13) and (14) respectively.

PL_{lt_3} = [55,18,10]+[23,0,0]log(*d*); d ≥ 10 m (12)

PL_{lt_4} = [62,15,10]+[18,0,0]log(*d*); d ≥ 10 m (13)

PL_{lt_5} = [63,17,9]+[23,3,0]log(*d*); d ≥ 10m (14)

5.4 Grass area

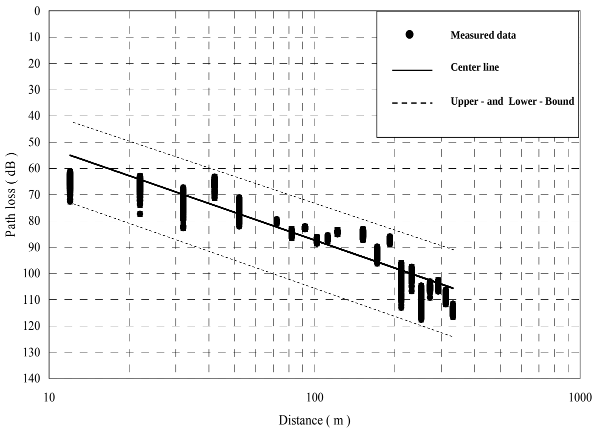
Path loss models for transmitter height of 3 m, 4 m, and 5 m are written in (15), (16) and (17) respectively.

PL_{gt_3} = [58,10,10]+[21,4,0]log(*d*); d ≥ 10 m (15)

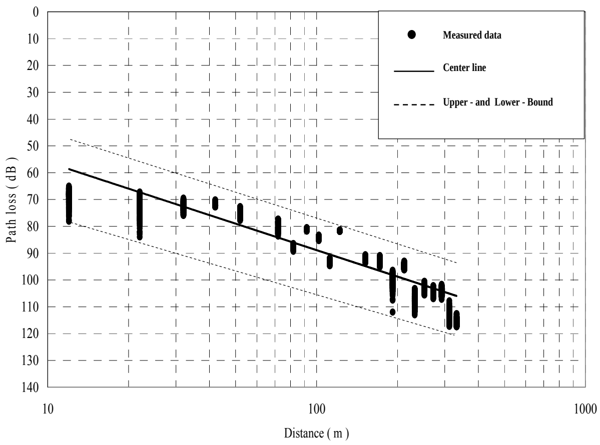
PL_{gt_4} = [59, 9, 6]+[17,0,0]log(*d*); d ≥ 10 m (16)

PL_{gt_5} = [58, 8, 6]+[20,1, 2]log(*d*); d ≥ 10m (17)

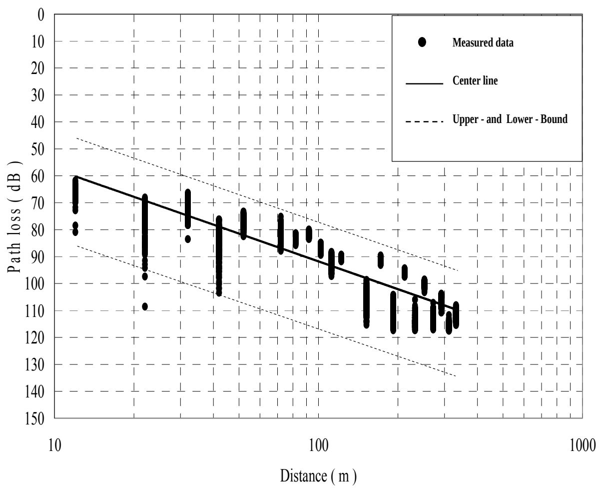
Path loss distance characteristics with fuzzy regression are shown in Fig. 6 -9 for high density area, medium density area, low density area and grass area respectively. Estimated path loss bounds are shown by dot lines in the figures. The center lines or solid lines are the same as conventional regression while spreading of the upper- and lower- lines are depended on max and min values of data. These spreading are generally increased with density of trees. This is because of influence of multi-path components including leave movement from wind. In case of the medium density area of 0.021 trees/m^2, the spreading of the upper- and lower- lines are wider than in case of the high density area of 0.032 trees/m^2. This is because there are low side trees in the medium density area that their leaves make a lot of scattering and attenuation as shown in Fig. 7. and table 1. While in case of high density area, the trees are high side therefore the scattering and attenuation are generally occurred via only trunk and branch of trees. We determined the α cut to eradicate the outliers at lower bound for Fig. 6 c), Fig. 7 a), b), and Fig. 8 a), b). The α cut values are in a range of 0.2 to 0.5.



a) ht = 3 m

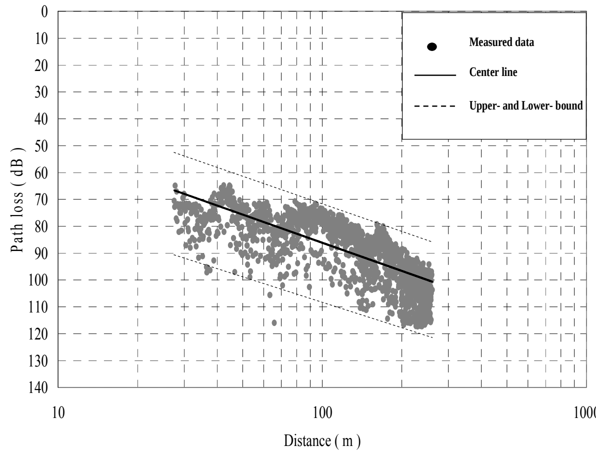


b) ht = 4 m

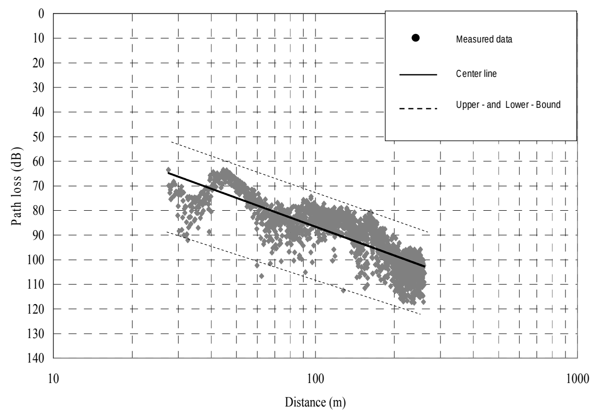


c) ht = 5 m

Fig.6 Fuzzy regression of measurement path loss in the density area of 0.032 trees/m^2. with different transmitter antenna height.



a) ht = 3 m

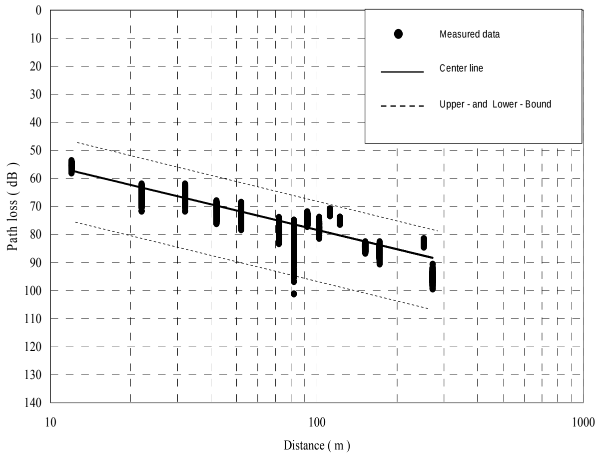


b) ht = 4 m

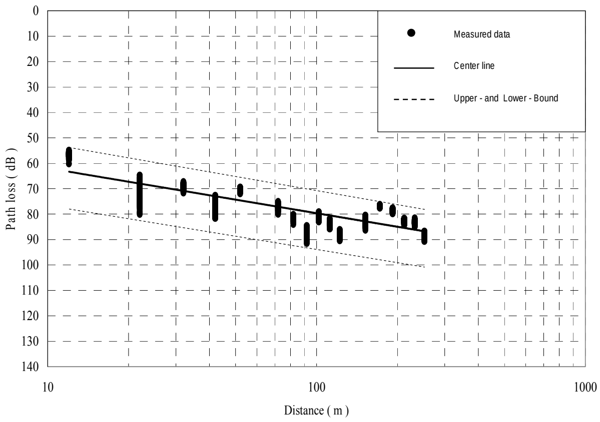
Fig.7 Fuzzy regression of measurement path loss in the density area of 0.021 trees/m^2. with different transmitter antenna height.

6 Comparison Between Fuzzy and Conventional Regression Models

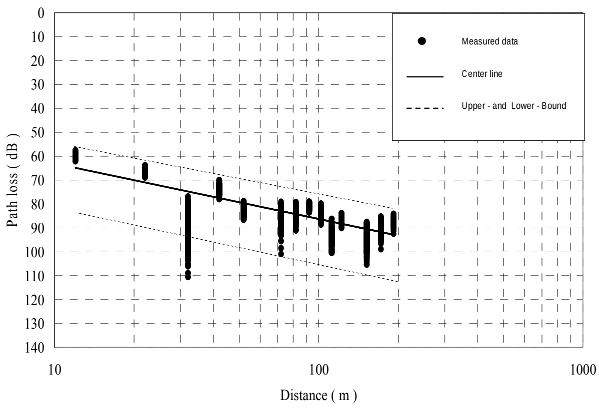
To check our proposed model, we performed path loss measurement in another high and low density area with density of 0.028 trees/m^2 and 0.005 trees/m^2 respectively. The fuzzy models in (7)-(9) and (12)-(14) were applied for high and low density area respectively. Fig. 10 shows a comparison between the fuzzy and conventional regression model for high density area at transmitting antenna height of 3 m. The upper- and lower- bound of the fuzzy models agree with measured path loss while those of the conventional regression models are over estimation at their upper-and lower- bounds. Summary of comparisons are shown in Table 2.



a) ht = 3 m

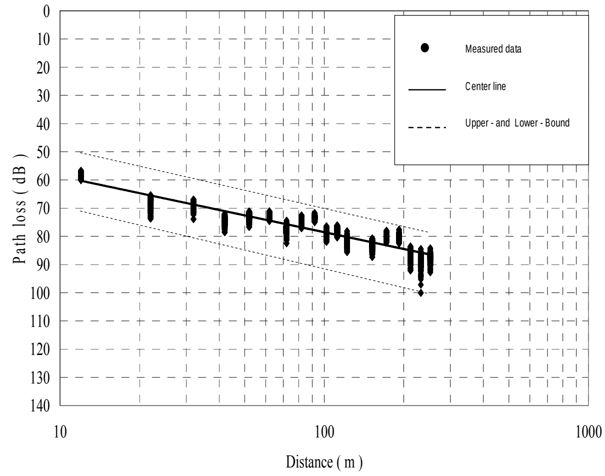


b) ht = 4 m

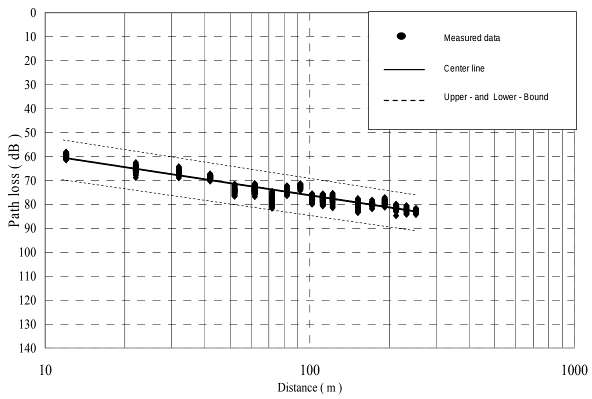


c) ht = 5 m

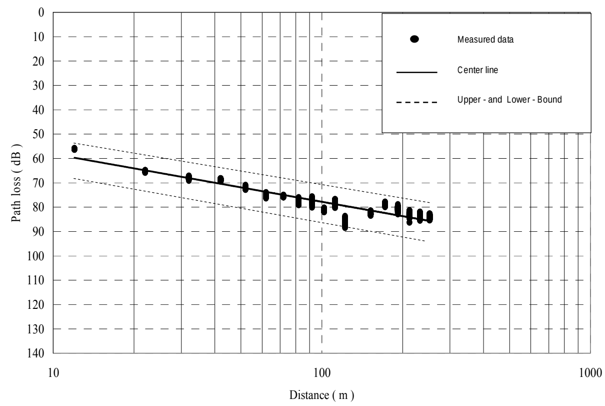
Fig.8 Fuzzy regression of measurement path loss in the density area of 0.009 trees/m^2. with different transmitter antenna height.



a) ht = 3 m

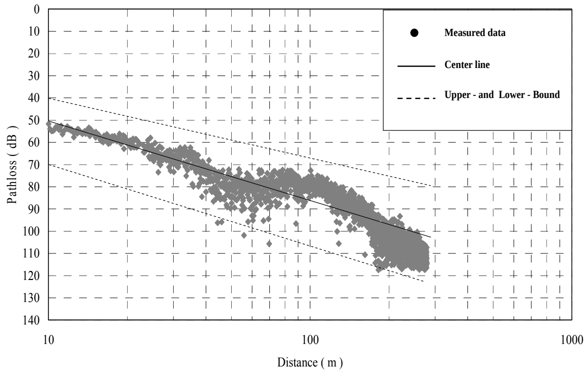


b) ht = 4 m

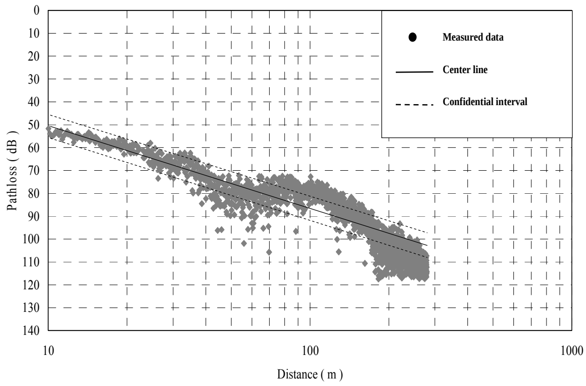


c) ht = 5 m

Fig.9 Fuzzy regression of measurement path loss in the grass area. with different transmitter antenna height.



a) fuzzy regression



b) standard regression

Fig. 10 Comparison between fuzzy and standard regression for high density area with h_t= 3 m.

Table 2 Summary of comparison % path loss error between fuzzy regression and conventional regression

Methods	Density area	Number of trees/m2	Antenna height (m) 3	4	5
conventional	high	0.028	45	40	9.6
	low	0.005	7	53.3	27.6
fuzzy	high	0.028	1	0.9	0
	low	0.005	0.1	5.9	0

7 Conclusion

Propagation path loss in different forest densities at a frequency of 1.8 GHz have been modeled using fuzzy linear regression. The forest was classified to different density areas namely, high-, medium-, low- density and grass area. The spread of the boundary lines of the fuzzy models depend on maximum and minimum value of a given data. It does not depend on sample size. This makes the proposed model limit path loss data within the boundary lines. The proposed models agree with the measured data at the transmitting height in range of 3 to 5 m and the receiving antenna height of 1.8 m.

Acknowledgment

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