Accurate Prediction of Available Path Number and Delay Spread Considering Path Existence Probability in Wideband Mobile Propagation

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Abstract

To designing higher-speed digital mobile communication systems, we must predict the multi-path propagation characteristics more accurately. Available path number and delay spread are effective indicators that make it easy to evaluate multi-path propagation.

In this paper, we propose a novel delay profile model that can predict the available path number and the delay spread accurately due to its inclusion of path existence probability and its consideration of city structure characteristics such as building height. We clarify its validity by field measurement results.

1. Introduction

In designing high-speed digital mobile communication systems, e.g. IMT-2000, and systems beyond IMT-2000, we need reliable signal transmission technologies that can reduce the degradation caused by inter-symbol interference raised by multi-path propagation. Therefore, it is important to clarify the propagation characteristics so as to more accurately predict the multi-path propagation effects which will allow us to assess and optimize the transmission technologies.

In order to evaluate the characteristics of wideband mobile propagation easily, evaluation values such as number of available paths and delay spread, etc. are very useful. Therefore they have been measured in various conditions and locations.

These evaluation values can be basically obtained from the delay profile. The delay profile generally depends on the distance from base station (BS), the antenna height of BS and city structure such as building etc. Moreover, the shape of the delay profile depends on the bandwidth. Therefore, these evaluation values also vary with the above parameters.

The prediction models described in previous studies basically do not take these parameters into account in assessing the available path number and the delay spread.

We proposed an empirical path delay profile model that can take both the bandwidth and the distance from BS, the antenna height of BS and building height around MS into account [1]-[3]. This model assumed that paths forming the delay profile always existed at every path resolution interval. In actual fact, however, some paths may not be present in any given interval. In order to obtain more accurate predictions, we extend our delay profile model by introducing the path existence probability, which presents the probability that a path does exist at a path interval.

In this paper, we propose a model that can predict the available path number and the delay spread based on our proposed empirical delay profile model, which takes account of path existence probability, and clarify its validity by field measurements.

TABLE 1: FIELD MEASUREMENT PARAMETERS

		Urban Area		Suburban Area	
		Hatchobori	Takebashi	Chiba	Mitaka
Carrier Frequency		3.35GHz 5.2GHz 8.45GHz	3.35GHz	3.35GHz 5.2GHz 8.45GHz	3.35GHz
Chip Rate		12.5Mcps, 25Mcps, 50Mcps			
Tx Power		10W			
BS	Tx Antenna	Co-linear Antenna:8.0dBi			
BS	Tx Antenna Height	50m	105m	50m	30m
MS	Rx Antenna	Dipole Antenna:2.5dBi			
MS	Tx Antenna Height	3m			

2. Field Measurements

We carried out field measurements using a sliding correlator with bandwidth, B, of 12.5Mchip per second (cps), 25Mcps and 50Mcps in four areas (Hatchobori, Takebashi, Chiba-Newtown and Mitaka) in Japan. Hatchobori and Takebasi are typical urban areas in Tokyo; the average building height is about 25-30m. Chiba-Newtown and Mitaka are typical suburban areas near and in Tokyo, the average building height is about 8m to 12m, respectively. Table 1 shows the field measurement parameters.

In data processing, to convert continuous delay profiles into discrete delay path profiles, we selected the path with the highest peak and set path selection inhibition areas, within $\Delta\tau$ (=1/B) on both sides of the selected path, in order to avoid the path spreading caused by bandwidth B. Next, we selected the path with the next highest peak in the areas other than the path selection inhibition areas [1]. This approach yields the path delay profile. In addition, when estimating the path

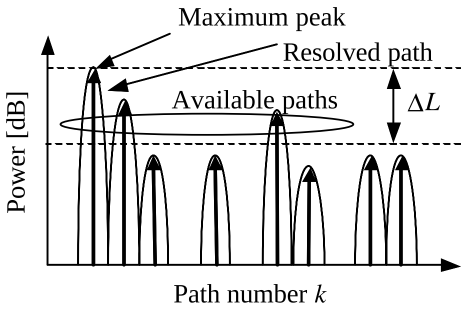


Fig. 1: Path delay profile and definition of ΔL

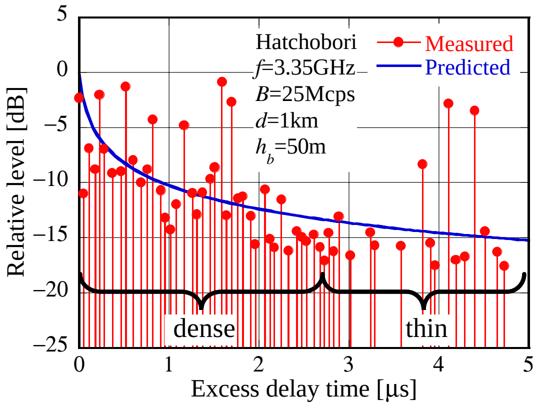


Fig. 2: An example of short-term path delay profile in urban area

delay profiles, we select the available paths within ΔL [dB] from the highest peak as shown in Fig. 1 [1].

Fig. 2 shows an example of path delay profile at the distance from BS, d=1km, and at bandwidth, B = 25Mcps in Hatchobori.

3. PROPOSED MODEL

A. *Empirical path delay profile model*

The short-term delay profile $E_s(k,d)$ in dB can be presented as a combination of the long-term predicted value $E_L(k,d)$[dB] and the short-term variation $G(0,\sigma^2)$[dB] due to shadowing, given by a random variable with a log-normal distribution as follows [1].

$$E_s(k,d) = E_L(k,d) + G(0,\sigma^2) \qquad (1)$$

The delay profile $E_L(k,d)$ normalized by all available paths' power $A(d)$, is as follows [2], [3].

$$E_L(k,d) = \alpha(d)\log(k) - A(d) \qquad (2)$$

where

$$\alpha(d) = -\{19.1 + 9.68\log(h_b/<H>)\}B^{\{-0.36+0.12\log(h_b/<H>)\}} \times d^{\{-0.38+0.21\log(B)\}} \qquad (3)$$

$$A(d) = 10\log\left\{\sum_{k=1}^{N_{path}} 10^{E_L(k,d)/10}\right\} \approx 10^{\{10.3+10.93\log(\log N_{path})-(3.57+5.17\log(\log N_{path}))|\alpha(d)/10|\}/10} \qquad (4)$$

$$N_{path} = 10^{-\Delta L/\alpha(d)} \qquad (5)$$

- k : excess delay time normalized by time resolution $1/B$ corresponding to bandwidth B and k=1, 2, 3,---
- $<H>$: average building height (m, 5-50m: height above the mobile station ground level)
- h_b : BS antenna height (m, 20-115m, h_b > $<H>$: height above the mobile station ground level)
- d : distance from the BS (km, 0.5-3 km)
- B : bandwidth or chip rate (MHz, 0.5-50MHz)
- f : carrier frequency (GHz, 0.7-15GHz)
- σ : standard deviation of the short-term variation (about 5dB in typical urban areas)

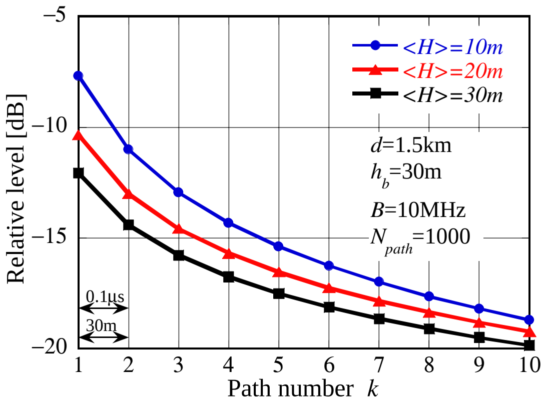


Fig. 3: Predicted long-term path delay profile $E_L(d,k)$: the parameter is the average building height $<H>$

- ΔL : the level difference between the peak path's power and cut-off power (dB) as shown in Fig. 1
- N_{path} : effective path number (the number of available paths taking ΔL into account)

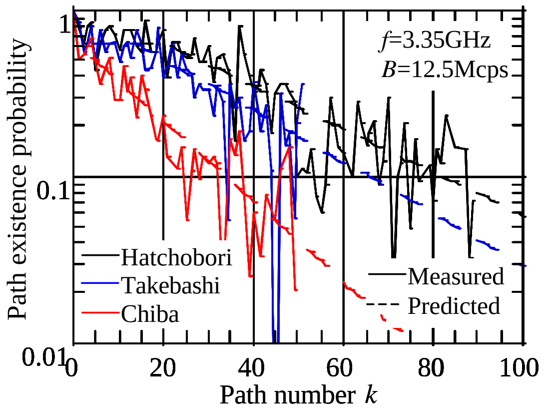
Fig. 3 shows an example of the prediction made by Eq. (2) with parameter $<H>$. It is clear that the proposed model does show the impact of the city structure.

In Fig. 2, we also plot prediction values calculated by Eq. (2) at the measurement condition of Hatchobori. From this figure, we find that the predicted trend is in good agreement with that of the measured values.

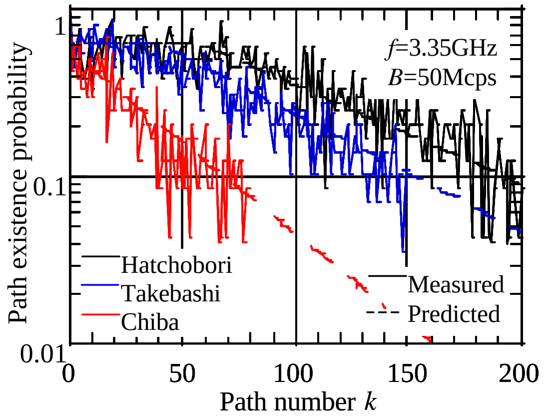
B. *Path existence probability*

In Eq. (2), a path exists in every interval, i.e. k=1, 2, ---,. This, however, is not all ways true in actual conditions [4], [5]. From Fig. 2, we can understand this phenomenon since the paths with long delay time fade away. Therefore, we first clarify the characteristics of path existence in each interval.

Fig. 4 shows the probability of path existence obtained from measurement data in the three areas at B=12.5Mcps and 50Mcps. The horizontal axis presents path number k. From



(a) 12.5Mcps



(b) 50Mcps

Fig. 4: Path existence probability

this figure, the probability can be approximated as a constant for small k and an exponential function for large k. Since the shape of the probability depends on bandwidth B and average building height $<H>$, we take these parameters to be key parameters. By using the multiple regression analysis method, we modelled the path existing probability, $p(k)$ as follows.

$$p(k) = \min(0.63,\ \left(0.59e^{-0.0172B} + (0.0172 + 0.0004B) < H >\right) \times \exp[-((0.077 - 0.00096B) - (0.0014 - 0.000018B) < H >)k] \quad (6)$$

where $\min(x, y)$ selects the minimum value between x and y. In Fig. 4, we also plot the values calculated by Eq. (6). The estimated values yielded by Eq. (6) are in good agreement with the measured values. This paper assumes that each path exists with probability of $p(k)$ and does not exist with probability of 1-$p(k)$.

C. *Proposed model considering path existence probability*

We propose the short-term path delay profile model that combines the empirical short-term path delay profile model of

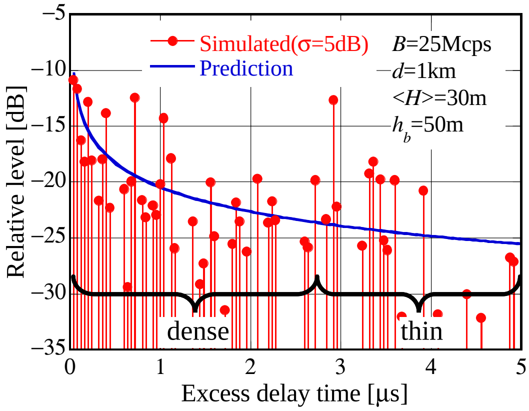


Fig. 5: An example of path delay profile $E_w(d,k)$

Eq. (1) with the path existence probability of Eq. (6). $E_w(k,d)$ in dB, can be expressed as follows.

$$\begin{aligned} E_w(k,d) &= E_S(k,d) + 10\log p(k) \\ &= E_L(k,d) + 10\log p(k) + G(0,\sigma^2) \end{aligned} \quad (7)$$

Fig. 5 shows an example of a predicted short-term delay profile considering path existence. The path density of the predicted path delay profile shown in Fig. 5 is very similar to that of the measured path delay profile shown in Fig. 2.

4. Prediction of Available Path Number and Delay Spread

We obtained the delay profile with shadowing by running Monte Carlo simulations on a computer. In these simulations, we set the standard deviation of the short-term variation as σ=5dB. We simulated the delay profile and evaluated the available path number and delay spread. We performed 1000 runs at each location and obtained a cumulative probability of available path and delay spread. With respect to the delay spread, we estimated the 50% median of simulation results as the value of the delay spread. The delay spread, $S(d)$, is defined as follows[6].

$$S(d) = \sqrt{\frac{\sum_{k=1}^{N_{path}} ((k-1)/B - T_D)^2 10^{E_w(k,d)/10}}{\sum_{k=1}^{N_{path}} 10^{E_w(k,d)/10}}} \quad (8)$$

where T_D is the average delay given as follows.

$$T_D = \frac{\sum_{k=0}^{N_{path}} ((k-1)/B) 10^{E_w(k,d)/10}}{\sum_{i=k}^{N_{path}} 10^{E_w(k,d)/10}} \quad (9)$$

Here we set ΔL as15dB as an example.

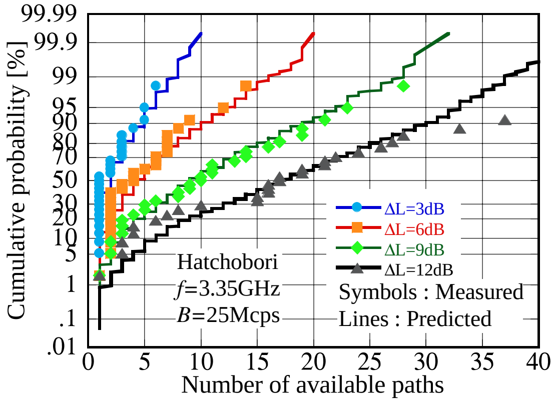


Fig. 6: An example of cumulative probability of the available path

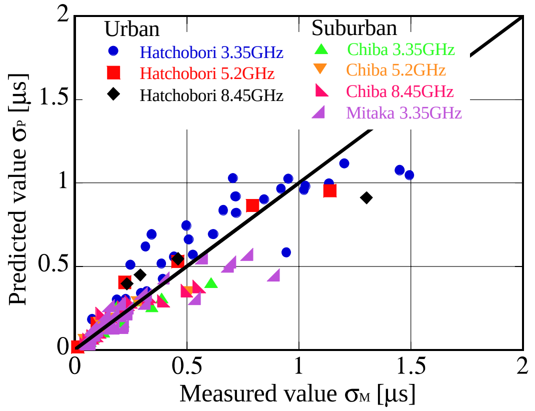


Fig. 7: Measured delay spread vs. predicted delay spread

5. Results

A. Available path number

Fig. 6 shows the cumulative probability of the available path number in Hatchobori as a function of ΔL. The number of available paths at 50% (median) is 1 path at ΔL=3dB, 4 paths at ΔL =6dB and 10 paths at ΔL =9dB. The available path number can also be evaluated by using the prediction model with shadowing. In Fig. 6, we also plot the values calculated at the measurement condition of this figure. Fig. 6 shows that the predicted values are in good agreement with the measured values, so the proposed model is valid.

B. Delay spread

Fig. 7 shows the measured and estimated delay spread at various locations in the areas given in Table 1. We see from Fig. 7 that the estimated values are in good agreement with the measured values, so the proposed formula is valid. Fig. 8 shows the estimation error of delay spread normalized by the measured value. The estimation error follows a Log-Normal distribution with median value of 0dB and standard deviation of σ=0.3.

6. Conclusion

We proposed a novel delay profile model that can predict the available path number and the delay spread accurately due to its inclusion of the path existence probability and its consideration of not only the bandwidth but also the distance from BS, antenna height of base station, and city structure (building height).

We showed that estimated values are good agreement with measured data, so the proposed models are valid.

The proposed models are convenient and useful for evaluating the wideband radio transmission characteristics at various bandwidths and in various areas.

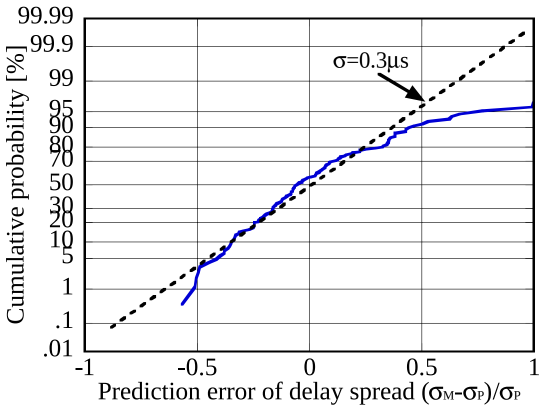


Fig. 8: Prediction error of delay spread

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