Mobile radio delay spread prediction based on frequency correlations

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1. Introduction

It is important to clearly understand multipath propagation to develop high speed digital mobile communication system[1~5]. The r.m.s. delay spread can be directly obtained by measuring the delay profile. The problem has been that delay profile measurements that are accurate must be taken for a wide frequency band. For example, with wideband measurement equipment using pseudo-noise signals, a frequency band of 10MHz is necessary for accuracy of 200ns.

Jakes proposed delay spread prediction method using narrow frequency bands[5]. This narrow band method is based on coherent bandwidth, which is derived by correlating the received levels of different frequencies. The delay spreads in both N.Y. and Tokyo have been measured by this method [5,1]. This method is simple but it requires that we predict the type of delay profile, which is generally assumed to be exponential. If the actual delay profile is not exponential, the method results in prediction errors.

This paper proposes a new prediction method that is based on the delay profile with the maximum likelihood of appearing. We call this the SPSP method which stands for spread prediction by selecting profile type. The prediction errors of Jakes and SPSP methods are compared through computer simulation and measurements.

2. Prediction method

2.1 Jakes method

The delay profile observed in an urban area is assumed to be exponential ($\exp[-t/S]$)[5]. In this type of profile, the relation between coherence bandwidth B and delay spread S can be expressed as[5]

$$S = \frac{1}{2\pi B} . \qquad (1)$$

Where B is the bandwidth that gives the correlation coefficient of 0.5.

The Jakes method predicts delay spread using eq.(1), but if the delay profile is not exponential, the Jakes method results in prediction errors. We calculated the prediction errors of the Jakes method, when the delay profiles are the function types shown in Fig.1. The result in Table 1 shows that, for example, when delay profile is the $\exp(-t^2)$ type, the prediction error is 17%. Prediction error increases in proportion to the difference between the exponential type and the real profile.

2.2 SPSP method

The SPSP method, which predicts delay spread on the basis of which delay profile is most likely to appear is shown in Fig.2. With this method, frequency correlation function types corresponding to different delay profile types are memorized. The correlation data are calculated using the measured levels of different frequencies received at any given instant. The correlation functions are fitted to the correlation data by adjusting delay spread value of the function. The predicted value of the delay spread is obtained, when one of correlation functions best fits the correlation data.

As examples of memorized correlation function types, we use four types: the exponential($\exp(-t)$), exponential 2nd power($\exp(-t^2)$), triangle and square type. The four types are shown Fig. 3.

For four types, the relation between coherence bandwidth B and delay spread S can be expressed as

$$S = \frac{1}{2\pi B} \cdot A \quad . \qquad (2)$$

The coefficient A of the four types are shown in Table 2.

3. Evaluation through computer simulation

3.1 Simulation

We performed computer simulation using a delay profile model to compare the prediction error of the Jakes and SPSP methods. The delay profile model consists of clusters of separated delayed waves. The envelope of each cluster is assumed to be the exponential function. The delay profile model is shown in Fig. 4. The real value of delay spread S_r is directly calculated for the delay profile model. The prediction error of the Jakes and SPSP methods are evaluated by the real value S_r and prediction values S_P.

3.2 Prediction error

The real value S_r and prediction values S_P are calculated using two variables which are the difference in delay time (T_2-T_1) and the power ratio (P_2/P_1). The contour lines of S_r and S_P of the Jakes and SPSP methods are respectively shown Figs. 5 and 6. With the SPSP method, prediction error is improved 10~30% compared with the prediction error of the Jakes method.

4. Evaluation through measurements

4.1 Measurements

The measurements of delay spread and received levels were performed in suburbs of Yokosuka. The distance between the transmitter and receiver was less than 2 km, and the delay spreads were measured with wideband measurement equipment. At the same time, the received levels of four frequencies were measured by narrow band measuring receivers. The delay spreads obtained by the wideband measurement were assumed to be the real value S_r. The prediction values S_P of the Jakes and SPSP methods based on the received levels were measured over distances of 50 m.

4.2 Prediction error

In the Jakes method, coherent bandwidth B was calculated by the least squares method using correlation data of between 0.2 and 0.8. For one-third of the data, it was impossible to obtain a coherent bandwidth B, because the correlation data were one-sided lower or higher than the value of 0.5. The average prediction error was 36% for two-thirds of the data. Secondly, coherent bandwidth B was found by fitting the exponential function to the correlation data. In this method, the average prediction error was 46% for all data.

The prediction values of the SPSP method are shown Fig. 7. The average prediction error of the SPSP method was 37%, which corresponds to about a 10% improvement over the Jakes method. Most measured delay spreads were less than 3 μs, and a long delay profile was not observed.

5. The characteristics of SPSP method

The SPSP method is characteristic in improving prediction accuracy by using information on delay profile type that are implied in measured correlation data. The Jakes method takes no account of such information.

It is possible to further improve prediction accuracy of the SPSP method by carefully selecting the memorized delay profile types. However, there is a limit to accuracy improvement, because when the number of measured correlation data is small, memorized functions are not effectively used. The number of correlation data is limited by frequency bandwidth so the prediction accuracy of SPSP method is also limited by frequency bandwidth.

6. Conclusion

The proposed SPSP method for the prediction of delay spread based on received levels correlations of different frequencies improves prediction accuracy. The prediction errors of the new method were clarified through computer simulation and measurements.

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Table 1 Prediction errors by Jakes method

profile type	prediction error
exp(-t)	0%
$\exp(-t^2)$	17%
triangle	22%
square	24%

Table 2 Coefficient, A, by delay profile type

profile type	coefficient A
exp(-t)	1
$\exp(-t^2)$	0.86
triangle	0.82
square	0.81

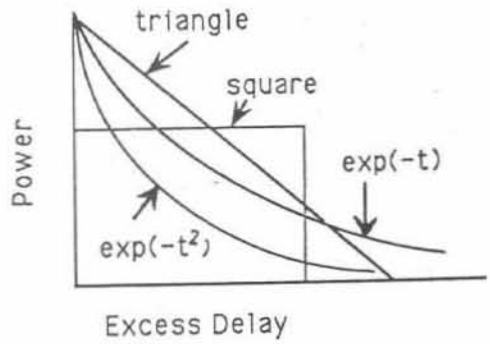

Fig.1 Type of delay profile

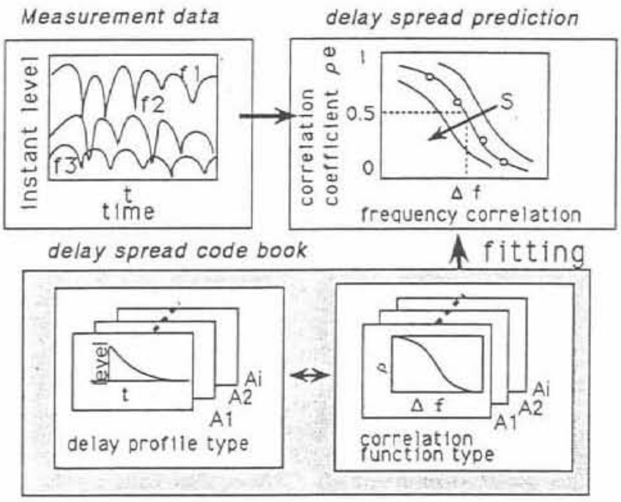

Fig.2 SPSP method

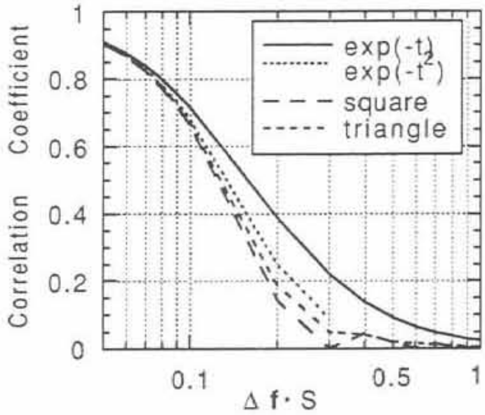

Fig.3 Envelope correlation v.s. normalized frequency separation

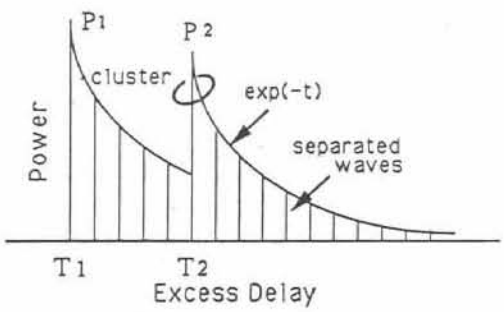

Fig.4 Delay profile model

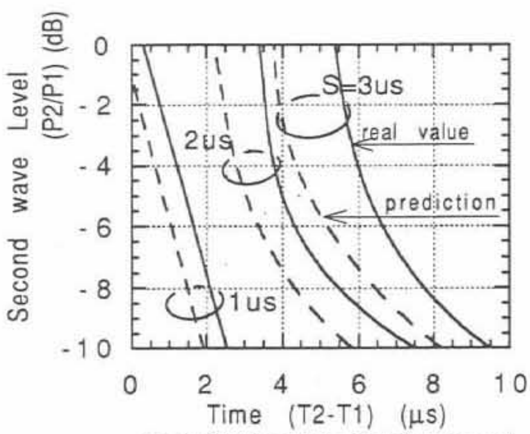

Fig.5 Contour-line of delay spread for delay profile model using Jakes method

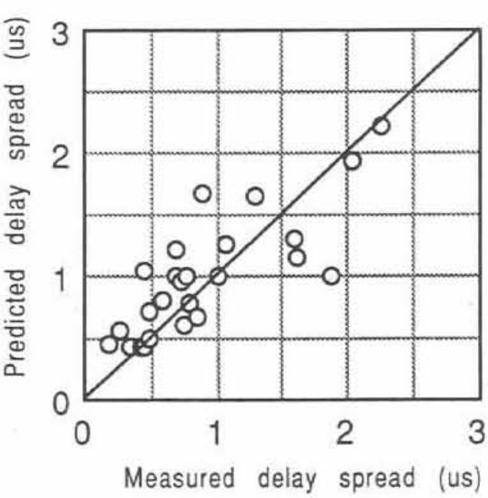

Fig.7 Measured v.s. predicted delay spread using SPSP method

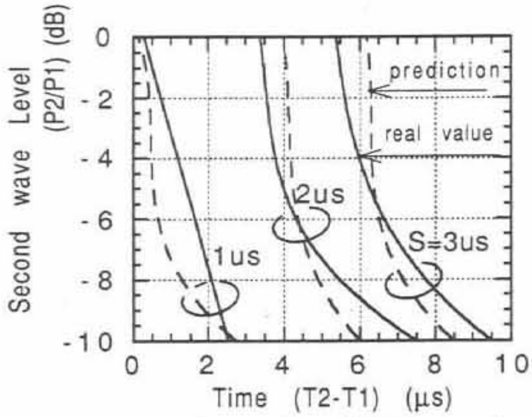

Fig. 6 Contour-line of delay spread for delay profile model using SPSP method