Utilizing Markov Transition Model to Accurately Predict
Wideband Propagation Channel Parameters

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Abstract

The data rates required to support multimedia services over wireless communication systems is rapidly increasing. Mobile radio propagation channel characteristics play a very important role in assessing the performance of a wireless wideband communication system. The mean excess delay and RMS delay spread are the two main parameters that dominate wideband propagation characteristics. The wideband data were measured on the campus of National Taiwan University and a wideband propagation channel model, based on the Markov transition model, was proposed to understand the characteristics of wideband propagation. The approach is to characterize multipath channel using different states and to describe the multipath intensity profile associated with each state, using a modified near-far echoes model, whose parameters were extracted from the measured data. The statistical characteristics of the simulated wideband channel parameters closely match those of the measured data. The results of this study demonstrate that the proposed method has the potential for conveniently and efficiently predicting the wideband channel parameters of the wireless communication systems.

Keywords – Wideband Markov model, wideband propagation channel modeling
I. Introduction

The data rates required to support multimedia services over wireless communication systems is rapidly increasing. Mobile radio propagation channels play a very important role in assessing the performance of a wireless wideband communication system. Several channel models have been proposed for modeling the radio propagation channel of a wideband wireless communication system. Such methods can be classified into two categories. The first is the category of time-domain (TD) methods. Such methods use a given set of channel parameters \( \{\beta, \theta, \tau\} \) (amplitude, phase and delay) to model the characteristics of a wideband channel [1-7]. The second category is of frequency-domain methods, which describe frequency-selective fading, based on the space-frequency correlation of the channel (delay power spectrum, DPS), or based on Fourier transformation of the space-time correlation function (Doppler spectrum) [8]. Such methods completely specify the channel parameters of a DPS with reference to a simple measurement of wideband power, and fit those parameters into a mathematical model [9]. Moreover, a model of the latter type can be used to elucidate the effect of small-scale fading in the adjacent subcarrier frequencies of an OFDM system. However, a few wideband channel models that are based on wideband measurement data have been reported to predict the variation in channel parameters that is related to the large-scale environmental changes that occur when a mobile user is in motion [10].

In our previous studies [11-14], a Markov chain transition method was used to predict the
statistical characteristics and variation in the channel parameters associated with the large-scale environmental changes of a narrowband propagation channel. Measurements on a wideband channel were analyzed on the campus of the National Taiwan University to clarify wideband propagation characteristics. The wideband channel properties of mean delay and RMS delay spread can be extracted from measured data [7]. The statistical analysis of the measured data can easily predict the error rate performance of a wideband communication system. Moreover, an accurate model is herein developed to predict wideband propagation channel parameters. The proposed model is based on the near-far echoes model [4]. The Markov transition model is used to predict the variation in channel parameters that occurs caused by the motion of a mobile unit. The proposed wideband propagation channel model with appropriate model parameters can be used to predict the quality and performance of the wireless communication systems conveniently and efficiently.

The rest of this paper is organized as follows. Section II details the proposed wideband Markov transition model, which combines a modified model of near-far echoes with a Markov chain transition model to predict the parameters that specify a wideband channel. A measurement system was set up and a series of measurements taken near the campus of National Taiwan University to verify the proposed model. Section III presents the setup of the measurement system. Section IV considers the extraction of model parameters and the state splitting method. The statistical characteristics of mean delay and RMS delay spread values,
calculated by the proposed predictive method are compared with those of measured data, to verify the proposed wideband Markov transition model. Section IV presents the results. Section V draws conclusions.

II. Wideband Markov Transition Model

This paper proposes a new method for predicting the characteristics of wideband propagation channels, which combines a Markov transition model with a modified near-far model. The approach is to characterize multipath channel according to different states and elucidate the multipath intensity profile associated with each state, using the modified near-far echoes model whose parameters will be extracted from the measured data.

A. Modified Near-Far Echoes Model

The near-far echoes model [4] classifies received signals as one of the three components - direct path, near echoes or far echoes. Figure 1 shows the multipath intensity profiles obtained using the near-far echoes model. The total number of echoes is \( M = 1 + M_{NE} + M_{FE} \). The direct path exhibits one of the three propagation states - clear, shadowed or blocked. \( M_{NE} \) is the total number of near echoes, whose arrival times are Poisson distributed. The average power of the near echoes, \( P_{0m} \), exponentially decreases as the delay, \( \tau_m \), increased. The number of far echoes is \( M_{FE} \) and mean value of multipath powers of far echoes is \( \lambda_{FE} \). The delays of the far echoes are uniformly distributed between \( \tau_e \) and \( \tau_{max} \). Figure 2 shows an
example of a realistic multipath intensity profile in a particular measurement scenario and indicates how it fits into the near-far echo model. As indicated in Fig.2, the near-far echoes model depend on additional statistical characteristics to simulate the multipath intensity profile more accurately. A Rayleigh distribution, instead of a fixed power, is applied to each delay tap, to increase the accuracy of this model. The authors’ previous study detailed the proposed modified near-far echoes model and compared the simulated mean delay and RMS delay spread with those of the measured, in several measurement scenarios [15]. The results of that study revealed that the modified near-far echoes model that is applied to Rayleigh statistical distribution can improve the accuracy of the prediction of the wideband channel parameters by more than 20%, in terms of both the mean excess delay and the RMS delay spread values.

**B. Wideband Markov Transition Model**

In this paper, a Markov transition model is used to predict the variation in channel parameters related to the large-scale environmental changes caused by the motion of a mobile user. A new model for predicting the characteristics of wideband propagation, which combines a Markov transition model with modified near-far model, is introduced. According to the Markov chain stochastic process theorem, the switching between different attenuation levels can be assumed to be quasi-stationary over a short period. The propagation
environment can be represented by one of a finite number of possible channel states. Switching between two propagation states can be specified a discrete-time Markov transition matrix. Let \( \{A_1, A_2, \ldots, A_m\} \) be the thresholds of the strengths of the received signals. Let \( S = \{A_{s_1}, A_{s_2}, \ldots, A_{s_J}\} \) be a sequence of random variables, which represents the set of finite states of fading signal levels. If the attenuation of the strength of the received signal is \( A_m \leq A_{s_n} < A_{m+1} \), then the fading channel state is the state \( s_m \). Therefore, the random process \( \{A(n)\} \) is called as a M-state Markov process. If the discrete-time Markov chain is currently in state \( s_i \) at time index \((n-1)\), then it moves to state \( s_j \) at time index \( n \) with a transition probability denoted by \( p_{ij} \). The transition probabilities, \( p_{ij} \), can be expressed as follows.

\[
p_{ij} = \Pr(L(n) = L_{s_j} | L(n-1) = L_{s_i}), \forall j, i \in \{1,2,\ldots,J\}
\]

Furthermore, let \( w_i \) denote the steady state probability, and let this probability be the average probability of the occurrence in \( i^{th} \) state. The vector of state probabilities is defined as,

\[
W = [w_1, w_2, \ldots, w_N]
\]

Therefore, the matrices of state probabilities and transition probabilities must satisfy the following equations.

\[
w_i = N_i / N_f, \text{ and } \sum_i w_i = 1
\]

\[
p_{ij} = N_{ij} / N_i, \text{ and } \sum_{i,j} p_{ij} = 1
\]

where \( N_i \) is the number of frames in state \( i \); \( N_f \) is the total number of frames, and \( N_{ij} \) is
the number of transitions from state i to j.

Based on the modified near-far echoes model, the measured multipath intensity profiles are separated into three groups (G, L, and H) according to the T threshold values; T can be represented as,

$$T_i = \frac{\sigma_i}{m_i}$$  \hspace{1cm} (5)

where $m_i$ and $\sigma_i$ are the mean and standard deviation of the $i^{th}$ frame intensity of the direct path along a certain route, respectively. The T value is a parameter used to elucidate the fluctuation in the strength of a signal due to the large-scale environmental changes that change the direct path component of a particular multipath intensity profile. The probability of experiencing a deep fade increases with T. The multipath intensity profile is expressed as,

$$P(\tau) = \frac{1}{2\pi\tau_{RMS}} e^{-\tau \tau_{RMS}}, \tau > 0$$  \hspace{1cm} (6)

The RMS delay spread value, $\tau_{RMS}$, describes the relationship between relative powers of the taps and their delays. Maintaining a good communication for a long time is difficult when the RMS delay spread is high. The instantaneous RMS delay spread value in near echoes is \cite{7}

$$\tau_{RMS} = \sqrt{\frac{1}{P_T} \sum_{l=1}^{n} P_l \tau_l^2 - \tau_0^2}$$  \hspace{1cm} (7)

where $\tau_l$ and $P_l$ are the arrival time and power associated with each delay path; $n$ is the number of multipath; $\tau_0$ is the mean excess delay, and $P_T = \sum_{l=1}^{n} P_l$ is the total power.

Therefore, the mean RMS delay spread value of the $i^{th}$ interval in the Markov model can
also be defined as,

\[
\tau_{i, \text{RMS}} = \frac{\sum_{m=1}^{M} \sqrt{\frac{1}{P_{m,t}} \sum_{l=1}^{n} P_{m,l} (\tau_{m,l}^2 - \tau_{m,0}^2)}}{M}
\]  

(8)

where M is the number of delay profiles in the \( i^{th} \) interval.

Based on the modified near-far echo model, we separate the measured multipath intensity profile into three different signal attenuation groups according to the average power of direct path, each of which is further divided according to whether their multipath intensity profile has a similar decay rate in the near echoes. As mentioned above, switching among different attenuation signal strengths can be represented as a Markov stochastic process, based on the assumption that the propagation channel is quasi-stationary over small periods. Then, the steady state probability matrix and state transition probability matrix are determined. Figure 3 presents the block diagram of the classification of the propagation states obtained using a wideband Markov transition model. The procedure for classifying the states, finding the parameters and generating the simulated signals is as follows.

1. Measured signals are divided into small frames, each of which includes ten measured fading signal strengths, and each frame is represented by a state. Calculate the mean power, the standard deviation, and the mean RMS delay spread associated with all frames.

2. Use moving average method to remove the components of path loss from the measured data and establish thresholds for three signal attenuation groups, determined by the
equal-probability distribution of T values associated with direct path components.

3. Each of the three groups is further separated into n states, \( G_1..G_n, \ L_1..L_n, \) and \( H_1..H_n, \) according to its decay rate.

4. Average the impulse responses in the same state and extract the parameters of the modified near-far model, including mean power, standard deviation, mean delay time and number of multipaths.

5. Calculate the state matrices and state transition matrices.

6. Produce the simulated received signals based on the transition matrices and random number generating process. Figure 4 shows a block diagram of the simulation procedure.

### III. Measurement Setup

A measurement system was established and a series of measurements were conducted on the campus of the National Taiwan University to validate the proposed wideband Markov model. The receiver device was a RUSK vector channel sounder, which was developed by the University of Erlangen-Nuremberg and MEDEV GmbH in Germany, to measure the time-variant propagation characteristics of mobile radio channels [16]. The measurement system, depicted in Fig. 5, can be separated into two main parts - the mobile transmitter and the antenna array receiver. The mobile transmitter is an arbitrary waveform generator that sends an un-modulated original base-band test signal with a bandwidth of 120MHz, and a
local oscillator that up-converts the carrier frequency to 1.95GHz. The synchronization of the
two ends is maintained by the rubidium frequency references that should be calibrated before
measurement. An eight-element antenna array with a uniform spacing of $\lambda/2$ is positioned
in front of the antenna array receiver. Each element of the antenna array is vertically
polarized with a beamwidth of 120 degrees. The antenna array was used to detect
continuously the channel variation and the direction of arrival (DOA). After the received
signals are filtered and down-converted, channel information is stored on a hard disk and
extracted and analyzed offline using a personal computer. The transmitted test signals are
wideband signals so the receiver is equipped with a high-speed multiplexer. The multipath
characteristics can be detected with a high temporal resolution. Figure 6 depicts the channel
sampling by a vector channel sounder. The duration of the vector impulse sampling can be set
from 0.8$\mu$s to 25.6$\mu$s for making measurements in different environments. The vector channel
sounder system also includes post-processing software, called MATSYS, for offline analysis.
It is constructed on a MATLAB interface, such that received data can easily be imported into
OR the MATLAB workspace and be analyzed by user-defined functions or programs. Figure
7 shows measurement paths (paths 1, 2, and 3) on a partial digital map of National Taiwan
University. The antenna array receiver is located on the fifth floor of the Electrical
Engineering building (RX). However, only the signals received from one selected antenna
element are analyzed. The transmitter is mounted on the top of a vehicle that drives along the
three paths. The carrier frequency is 1.95GHz and the bandwidth is 120MHz.

IV. Model Validation

An important problem associated with the Markov transition model is to choose the number of states and determine the model parameters in each state. No theoretical method of making such a choice exists. Some approaches have been suggested to solve this problem [17,18]. In the proposed wideband Markov model, three propagation groups (G, L and H) are partitioned using the probability density function of $T$, extracted from the the measured data concerning the direct path, as depicted in Fig.8. The proposed model uses a Markov transition matrix to describe the variation in the signal strengths with the user environment.

The modified near-far echoes model specifies the multipath intensity profile in each scenario, and the Markov transition model predicts the variation in the channel parameters caused by large-scale environmental changes when the mobile unit is in motion. The use of the equal-probability method is compared with that of the equal-delay methods in partitioning the states of a multipath intensity profile. These two methods were proposed by Patzold to characterize the discrete Doppler frequencies [19]. The concepts of these two methods are extended and applied to a finite state Markov model. The equal-probability method is defined as having the same probability distribution in each propagation group, determined from its direct path power strengths. This approach can effectively improve the occupation time of a
high probability state in the transition matrix associated with a finite state Markov model. The approach also avoids the effects of catastrophic states that can cause the catastrophic propagation of errors. Figure 9(a) plots the state probability profile. Besides, the equal-delay method is defined as having the same observation delay time in all states, according to its RMS delay spread value. This method directly partitions the equal delay time, using appropriate interval of the RMS delay spread values. Figure 9(b) shows the state probability profile obtained using an equal delay method. Table 1 compares the rms error obtained using the equal-probability method with that obtained using the equal-delay method, for a multipath intensity profile. The rms errors of the statistical characteristics, PDF and CDF, of the RMS delay spread are 0.00838 and 0.0202, and those of the mean excess delay are 0.0202 and 0.0221, respectively. The results indicate good agreement between the measured and the simulated wideband channel parameters obtained by using the equal-probability method. However, the number of states that satisfies the memory requirement while avoiding wasting simulation time must be determined. As indicated in Fig.10, when the number of states, n, is increased to 12, the rms errors of the measured and simulated RMS delay spread value become steady. This study addresses three propagation groups partitioned by the direct path power intensity, each of which is further divided into 12 states, according to whether the groups’ multipath intensity profiles exhibit a similar decay rate in the near echoes region. For the purposes of the simulation, 36 states were classified. Data measured along the first,
second, and third paths are used to determined the model parameters and demonstrate the capacity of the proposed model for modeling the characteristics of a wideband propagation channel. According to these model parameters, the proposed method can be easily applied to accurately predict the propagation characteristics in similar environments. Simulated and measured wideband channel parameters obtaining from different paths are investigated. In this paper, the probability distribution functions (PDF) of mean delay and RMS delay spread obtained from the simulation results are compared with those of the raw data. Figure 11 compares the root-mean-square errors of the measured mean excess delay and the RMS delay spread values, with the simulated mean excess delay and the RMS delay spread values obtained on all selected LOS measurement paths. The close agreement between the simulated and measured data shows the feasibility of applying the proposed model to predict wideband channel parameters. As shown in Fig. 12, data measured as the vehicle followed along the first path were used to determine the parameters of the wideband model, including $T$ and the RMS delay spread; these model parameters were then used in the proposed wideband Markov transition model to predict wideband propagation characteristics obtained from the second path. Simulation results show good agreement between the measured and simulated data. The proposed method can easily be applied to predict propagation characteristics in similar environments.
V. Conclusions

This study has proposed a novel and effective method to predict the parameters of a wideband propagation channel using a modified near-far echoes model and the Markov transition model. The wideband measurement data were used to derive the parameters of the modified near-far model and generate the Markov transition matrix. The simulated and measured data were highly consistent with respect to mean excess delay and the RMS delay spread values. Simulation results show the potential of the proposed method in conveniently and efficiently predicting the parameters that govern a wideband channel in a wireless communication system.

Acknowledgments

The authors would like to thank the National Science Council of the Republic of China, Taiwan (Contract No. NSC 90-2213-E-027-002) and Taiwan Cellular Corporation (Contract No. R90001) for financially supporting this research.
References


## Table I

Rms errors of RMS delay spread and mean excess delay in P.D.F and C.D.F., the between the values obtained using the equal probability method and those obtained using the equal delay method in wideband Markov models

<table>
<thead>
<tr>
<th>Methods</th>
<th>RMS delay spread</th>
<th>Mean excess delay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PDF</td>
<td>CDF</td>
</tr>
<tr>
<td>Equal probability</td>
<td>0.84e-2</td>
<td>2.02e-2</td>
</tr>
<tr>
<td>Equal delay</td>
<td>3.29e-2</td>
<td>3.59e-2</td>
</tr>
</tbody>
</table>
Fig. 1 Near-far echoes channel model
Fig. 2 Example of a multipath intensity profile
Fig. 3 Block diagram of the classification of the propagation states in a wideband Markov transition model
Fig. 4 Block diagram of the procedure for generating simulated receiving signals.
Fig. 5 System setup of RUSK channel sounder

[(a): mobile transmitter, (b): antenna array receiver]
Fig. 6 Channel sampling of a vector channel sounder
Fig. 7 Paths on the campus of National Taipei University along which wideband data was measured
Fig. 8 Probability density function of T of direct path power signals obtained using an equal probability method
Fig. 9 Comparison of the differences between the state occurrence probability obtained using the equal delay method (a) and that obtained using the equal probability method.
Fig. 10 Relationship between number of states and rms error between measured and simulated RMS delay spread
Fig. 11 Probability density function of the RMS delay spread and the mean excess delay of the measured and simulated fading signals obtained on paths 1, 2 and 8.

[Solid line: measured; dotted line: proposed model]
Fig. 12 Comparison of the probability distribution function of the simulated data with that of the measured data, using parameters extracted from the fading signals measured along the first path and fitted to the data that correspond to the second path.

[Solid line: measured; dotted line: proposed model]