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SEMI-DETERMINIST MARKOV MODEL FOR MODELING 1.8GHz WIRELESS PROPAGATION CHANNEL IN URBAN TAIPEI CITY

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Abstract: In this paper, a semi-determinist Markov model for propagation channel modeling is introduced. Walfisch-Ikegami model with digital map is used for simulating the path loss due to the distance increased between transmitter and receiver, and Markov model and Rice's sum of sinusoid method is used for simulating the multipath fading due to environmental phenomenon and user mobility. The proposed model is applied to evaluate the error probabilities of different modulation schemes (QPSK and DPSK) in a typical urban Taipei city. Numerical results reveal that the statistical properties of the simulated data are quite close to that of the measured data. Our proposed model not only can be used to predict the fading statistics, but also to evaluate the system performances of a mobile user terminal.

1. Introduction

For modern mobile communication systems, the radio channel simulator plays an indispensable role during the research stage. When a signal is transmitted into the mobile channel, the electromagnetic waves propagate through a physical medium with physical objects and structures, such as trees, buildings, etc. In addition to the user is in motion, the terrestrial objects continue to affect the strength of the received signal and the Doppler effect occurs. In order to analyze the performance of mobile communication systems, it is necessary to develop statistical models that reasonably approximate the propagation environment. With an accurate channel model, it becomes feasible to optimize and compare various designs by analysis and simulations. The multiplicative processes in the propagation channel can be classified into three types of fading - path loss, shadowing and fast fading [1]. In previous works, papers [2, 3] only used digital filter, Rice's sum of sinusoid method or Rayleigh distribution to simulate fast fading. Though this method could somehow determine Doppler effect, but it couldn't describe the changing morphology of the environment. A Markov chain transition method is used to predict the statistical properties and the variation of channel parameters due to the large-scale environmental changes of a narrowband propagation channel [4, 5]. Though this model could somehow accurately predict the shadowing properties, but it couldn't describe the Doppler effect. In this paper, a semi-determinist propagation channel model is introduced. Walfisch-Ikegami model with digital map is used for simulating the path loss due to the distance increased between transmitter and receiver, and Markov model and Rice's sum of sinusoid method is used for simulating the multipath fading due to environmental phenomenon and user mobility. The simulation procedure is applied to compare with real propagation measurement data.

2. Mobile radio propagation channel modeling

Based on physical electromagnetic wave propagation mechanism and ignore the AWGN, we can model the equivalent received signal $y(t)$ as the superposition of all multipath components of the transmitted signal $x(t)$ [6],

$$y(t) = \sum_{i=1}^{M} x(t-\tau_i) a_i \exp[-j2\pi f_c \tau_i + j2\pi f_m t \cos\theta_i] \tag{1}$$

where M is the number of multipath. For the ith multipath component, a_i is the complex amplitude, τ_i is the delay time, f_m is the maximum Doppler shift and θ_i is the direction of the ith multipath component with respect to the mobile velocity vector. If the bandwidth of transmitted signal is much less than the inverse of multipath delay, then we can rewrite (1) as,

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$$\begin{aligned} y(t) &\approx x(t-\tau_0)\left[\sum_i a_i \exp\left[-j2\pi f_c \tau_i + j2\pi f_m t\cos\theta_i\right]\right] \\ &= A\cdot x(\mathrm{t}-\tau_0)\cdot\alpha\cdot\gamma\cdot\beta(\mathrm{t}) \end{aligned} \tag{2}$$

where A is the path loss, τ_0 is the approximated delay time, α is a real-valued number characterizing the slow-varying fading signals, γ is the compensation factors, and $\beta(t)$ is the normalized small-scale fading factor varying with time. Thus, the propagation channel model can be characterized as including path loss component (A), shadowing component (α), and fast fading component ($\beta(t)$).

2.1. Path loss prediction

The path loss component of the measured data can be estimated using the Walfisch-Ikegami model with information obtained from the digital map, including the average height of buildings, the density of buildings, the average width of roads, and the type of environment. In [7], the model parameters of Walfisch-Ikegami model are extracted and verified as an accuracy model for predicting the path loss in urban Taipei city. Thus, the measured data, with the path loss component subtracted out, can be further used to develop the proposed semi-determinist Markov model.

2.2. Semi-determinist Markov model

In wireless communication, propagation channel can be characterized as including path loss, shadowing and fast fading components. Various channel models have been proposed in the literature, but no measurement based on the combinations of shadowing and fast fading effect has been introduced yet. In past, Markov chain model was used to model the large-scale environmental effects on the slow-varying received signals very well. However, when the user is in motion, the terrestrial objects continue to affect the strength of the received signal and the Doppler effect occurs. Therefore, the small-scale channel impairments causing by the Doppler shift were distinct effects for the wireless communication system performance. According to above motivations, a semi-determinist Markov model is presented. The propagation properties of shadowing components with slow-varying signal can be modeled as a finite state Markov model (FSMM), while the fast fading properties can be treated as following Rice's sum of sinusoids method. The procedures for classifying states, finding parameters and generating simulated signals are described as follow.

a) Using Walfisch-Ikegami model with digital map to simulate the path loss.
b) Subtract path loss from raw data and then separate the shadowing and fast fading signals by passing the measured data through a low pass filter. Each signal is divided into small frames.
c) Establish thresholds for both shadowing (L states) and fast fading (S states) signals.
d) Calculate the mean value and standard deviation (std) of both shadowing and fast fading signals for all frames. The mean values and stds of both shadowing and fast fading signals are averaged in each state as the input model parameters to the lognormal distribution function.
e) Set $E\left[\beta(t)^2\right]=1$ for fast fading signals and then return the compensation factors γ in (2) relative to shadowing states.
f) Calculate the steady-state matrices and state transition matrices for shadowing components and set the maximal Doppler frequency for fast fading components.
g) Generate the simulated received signals using the transition matrices and the random number-generating process.

3. Model validation

A measurement was set up nearby the campus of the NTUT in urban Taipei. The detail description of the measurement system is presented in [7]. First of all, validating our model has the capability of predicting the path loss. A typical case of comparison between prediction and measurement results of path loss is shown in Fig. 1. In this case, the base station antenna was mounted on the third, fourth, and fifth floors, respectively. The digital maps with databases of building information, such as average building height, average road width, and environment type, are used to extract model parameters for Walfisch-Ikegami model. The prediction model simulated the propagation behavior much similar to the measured data for the whole route. Table I shows the root mean square (RMS) errors between simulated and measured data in the different floors.

Table I
RMS errors between prediction and measurement of path loss

Antenna Location	RMS Error (dB)
3F	8.2
4F	9.1
5F	8.4

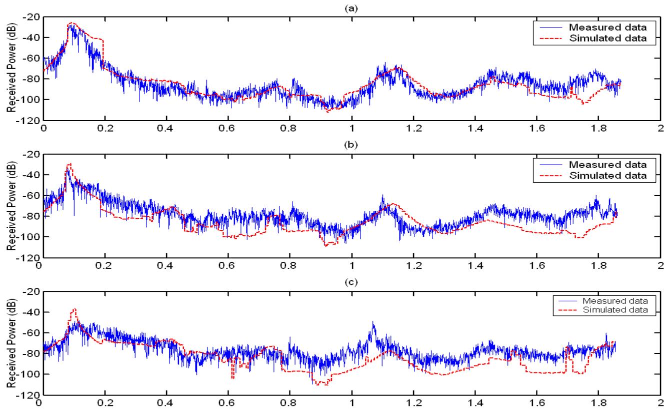

Fig. 1 Received power level and estimated path-loss power level measured at the third floor (a), fourth floor (b), and fifth floor (c).

In addition to predict the statistical properties of shadowing and fast fading, the steady-state vector and transition matrix of Markov model was extracted by data measured in the different floors. In figure 2, we compared the probability density function (PDF), level crossing rate (LCR) and cumulative density function (CDF) of shadowing simulation results with the raw data at third floor. By observing simulated and measured statistical properties, our model can predict the first-order and second-order statistical properties very well and had closed match with measured data.

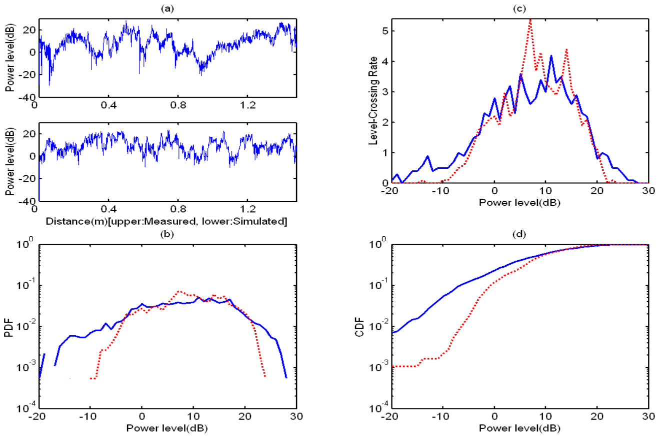

Fig. 2 Comparisons of simulated and measured time series (a), PDF (b), LCR (c), and CDF (d) in the third floor case.

For the other cases, comparisons of the RMS errors difference between the measured and simulated data are shown in Table II. Besides, the statistical properties of fast fading can be predicted by Rice's sum of sinusoids method. With maximum Doppler frequency 100Hz, the Fig. 3 shows the simulated and theoretical results of autocorrelation, PDF, CDF, and LCR of Rayleigh process by using the Rice's sum of sinusoids.

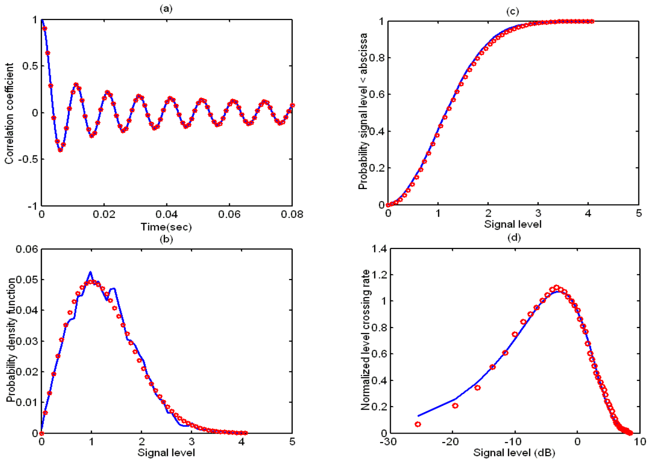

Fig. 3 Comparisons of simulated and theoretical (a) correlation coefficient, (b) PDF, (c) CDF, and (d) LCR

Table II
The RMS errors of PDF, LCR, and CDF between simulated and measured signals for various floors

Antenna Location	RMS Error		
	PDF	LCR	CDF
3F	0.013697	1.1008	0.058434
4F	0.013751	1.1515	0.058691
5F	0.014697	1.2275	0.063622

Besides, the propagation channel model can be used to evaluate the performance of digital transmission schemes. The error probability performance depends on the modulation format. This section analyzes the BER performance of the QPSK and DPSK modulation schemes using the proposed channel model with various Doppler effects. The detailed simulation parameters are shown in Table III.

Table III
Simulation parameters

Modulation scheme	QPSK&DPSK
Symbol duration	3.7μs (GSM standard)
Channel estimation	57 transmitted bits contain the 1st pilot bit
Carrier frequency	1.8GHz
Semi-Markov chain Propagation channel	10 states Markov chain Doppler frequencies: 30Hz (18km/hr), 70Hz (42km/hr), 120Hz (72km/hr), and 180Hz (108km/hr)

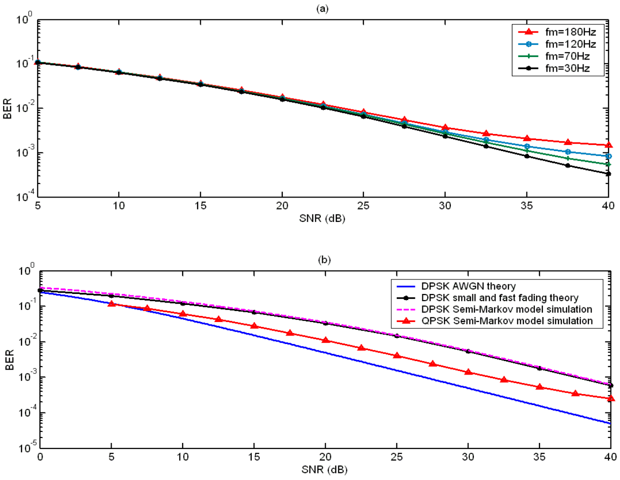

Fig. 4 (a) QPSK error performance in semi-Markov model with different Doppler effects (b) DPSK and QPSK error performances in Semi-Markov model with f_m=30Hz

Fig. 4(a) indicate that the error performance of QPSK modulation scheme using our proposed semi-deterministic Markov model. The additional consideration of large timescale fading effects in the QPSK modulation scheme is to cause the evident error performance decay. To mitigate those impairments, the adaptive coding and modulation schemes are effective to improve the error performance and reach a distinct requirement by utilizing the realistic channel information quality. Besides, we also assess the error performance of non-coherent DPSK modulation scheme using our semi-deterministic Markov model. In this simulation, the Doppler frequency is set as 30Hz in small-scale fading generator and combine shadowing simulator by using Markov chain method; moreover, the theoretical error performance of a DPSK system operating over a time-varying Raleigh fading channel is evaluated by [8]. The simulation result is shown in Fig.4 (b). The simulation result is also compared the difference between QPSK and non-coherent DPSK modulation schemes in our proposed channel model.

4. Conclusions

A channel simulator is introduced to model propagation channel impairments. The simulation results are compared with measured data for the fading statistics and bit error rates of QPSK and non-coherent DPSK modulation schemes. The results show good agreement between the simulation and measurement results. Our proposed model not only can be used to predict the fading statistics, but also to evaluate the system performances of a mobile user terminal.

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