A Wireless Channel Simulation Method Using Doppler Spectrum Models

이종길*

Jong Gil Lee*

본 연구는 한국과학재단 지정 인천대학교 멀티미디어 연구센터의 지원으로 수행되었음

ABSTRACT

It is very important to simulate various mobile communication channels for the reliable system design and performance tests. Therefore, a new method is proposed in this paper to improve the conventional one for the purpose of the efficient channel simulation having various characteristics. A newly proposed method can simulate any narrow band channel very efficiently from the given Doppler power spectrum model. Also, it has many simulation advantages considering the variety of wireless channel conditions since parameters related with channel characteristics, such as a signal power, signal to noise ratio, direct signal power ratio, etc., can be easily changed according to various propagation environments to be tested.

요 약

다양한 이동통신 채널의 모의구현은 시스템 구현 및 검증에 매우 중요한 요소이다. 따라서 본 논문에서는 이동통신 채널을 효율적으로 모의할수 있는 방법을 제안하였다. 새롭게 제안된 방법은 주어진 도플러 스펙트럼 모델로부터 협대역 이동통신 채널의 발생을 가능하게 함으로서 신호대 잡음비, 직접 및 간접 전파경로, 신호전력등의 다양한 전파환경을 고려한 채널의 구현이 가능하다.

키워드
mobile communication, Doppler model, wireless channel

I. Introduction

The best way to check the mobile communication system design and performance is the field test and measurements. However, it is very difficult to perform the complete field test under the various environments. Therefore, the efficient channel simulator is essential for the laboratory tests to verify the reliability and characteristics of implemented systems. Gaussian noise filtering and Jakes model are conventional methods for narrowband channel simulation[1][2]. Jakes model to represent the channel as the sum of complex sinusoids is very popular. However, this method requires the large number of complex sinusoids to be summed for an accurate simulation and the weights for sinusoids should be appropriately adjusted to get the desired Doppler

*인천대학교 정보통신공학과

접수일자 : 2003. 3. 17

spectrum model. A very careful consideration is needed in using the Jakes model. Therefore, it is not easy to obtain the simulation channels having various characteristics as they are desired.

In this paper, a new method is suggested to solve these problems. It simulates Rayleigh and Rician mobile channels from the desired Doppler spectrum models. The proposed method is very convenient and efficient for the channel simulation under the various propagation environments.

II. Channel Simulation from Doppler Models

Rayleigh and Rician channels are very widely used and considered to be appropriate in most cases. Therefore, a new method is proposed considering these two mobile channels.

1. Simulation of Ralyleigh fading channels

The envelope $R(t)$ of a received signal is described by a well-known Rayleigh distribution which is given by[3]

$$P_r(R) = \frac{R}{\sigma^2}\exp(-\frac{R}{2\sigma^2}) \tag{1}$$

where σ^2 is the average power. The probability distribution of a power P represented by R^2 can be shown to have an exponential distribution,

$$P(p) = \frac{1}{\sigma^2}\exp(-\frac{p}{\sigma^2}). \tag{2}$$

Therefore, representing the Doppler power spectrum and white Gausian noise components as S_k and N_k respectively, the probability distribution of a received signal, P_k is given by

$$P(P_k) = \frac{1}{S_k+N_k}\exp(-\frac{P_k}{S_k+N_k}). \tag{3}$$

The received Doppler power spectrum can be obtained using the power spectrum sample, S_k and the noise, N_k. Considering a basic probability theory, the probability distribution of P_k, $P(P_k)$ has the following relationship with a uniformly distributed random variable X_k, of which value is located between 0 and 1,

$$P(P_k)dP_k = P_x(X_k)dX_k \tag{4}$$

Integrating both sides, P_k can be written as

$$P_k = -(S_k + N_k)\ln(X_k) \tag{5}$$

Using this method, any Rayleigh channel can be simulated for the desired Doppler spectrum and the background noise. Hence, The simulated channel in time domain is given by

$$I(i) + jQ(i) = \frac{1}{L}\sum_{k=1}^{L}\sqrt{P_k}\exp(j\theta_k)\exp(j\frac{2\pi}{N}ki) \tag{6}$$

where θ_k is a uniformly distributed random variable between 0 and 2π. Here, L is the number of Doppler power spectrum data. Therefore, As mentioned before, Rayleigh channels of various characteristics can be easily simulated from equations (5) and (6).

2. Simulation of Rician fading channels

It is generally supposed that LOS(line of sight) propagation path does not exist in mobile communication channels. However, LOS paths can exist as cells are divided into smaller areas. The envelope of these signals are described by a well-known Rician probability distribution which is

$$P_r(R) = \frac{R}{\sigma^2}\exp\left[-\frac{R^2+R_s^2}{2\sigma^2}\right] I_0\left(\frac{RR_s}{\sigma^2}\right) \tag{7}$$

where R_s is the envelope of a dominant component with a LOS Path and I_0 is a zero-order first kind modified Bessel function. Therefore, for the Rician channel simulation, the components of an arbitrary Doppler spectrum model can be divided into a direct component with LOS path, $y_1(t)$ and an indirect component $y_2(t)$ as described in Rayleigh channels. The total Doppler power spectrum model, $S_T(f)$ is represented by

$$\begin{aligned} S_T(f) &= (Y_1(f)+Y_2(f))^*(Y_1(f)+Y_2(f)) \\ &= |Y_1(f)|^2 + |Y_2(f)|^2 + 2A\,\mathrm{Re}(Y_2(f_0)) = S_1(f) + S_2'(f) \end{aligned} \tag{8}$$

Here, * means the complex conjugate and $Re(Y_2(f_0))$ is the real part of $Y_2(f_0)$. The Doppler power spectrum of $y_2(t)$, i.e., $S_2(f)$ is given by

$$S_2(f) = S_2'(f) - 2A\sqrt{S_2(f_0)}\cos(\theta(f_0)) \tag{9}$$

where $\theta(f_0)$ is the uniformly distributed phase at Doppler frequency f_0 . It should be noted that the spectrum shape of $S'_2(f)$ is same with that of $S_2(f)$ except the added constant value. Hence, $S'_2(f)$ can be easily obtained by simple manipulation. Also, using (6), $y_1(t)$ from LOS path is given by

$$I(t) + jQ(t) = \frac{1}{L} A\exp(j\theta_{k_0})\exp\left(j\frac{2\pi}{N}k_0 i\right) \tag{10}$$

where θ_{k0} is a constant phase and k_0 is an integer between 1 and L. For the Rician case, if the number of sample is L, the sum of LOS signal and indirect signal with a total system background noise N_T can be represented by

$$S_T = A^2 + \sum_{k=1}^{L} S_{2_k}, \quad N_T = \sum_{k=1}^{L} N_k \tag{11}$$

Also, a variable K which determines the shape of Rician distribution, can be expressed as

$$K = \frac{A^2}{\sum_{k=1}^{L} S_2} \tag{12}$$

Here, it can be seen that the distribution shape becomes Rayleigh as K goes to zero while it becomes a Gaussian distribution if the value of K is much greater than one. By varying K and SNR, various Rician channels can be easily simulated using the method given here.

III. Simulation Results

1. Rayleigh channel

Assuming outdoor environments, Rayleigh channels are simulated using the newly suggested method in this paper based on the Clarke and Parson Doppler spectrum models[4][5]. Of course, Channel simulation is very easy for any Doppler spectrum model to be tested. Here, channel simulations are done for the popular outdoor Doppler spectrum models, the Clarke model and the Parson model. Figure 1 shows the envelope signal of the simulated channel from the Clarke model example and Figure 2 is obtained from the Parson model example where the maximum Doppler frequency and SNR are 186 Hz and 10 dB respectively.

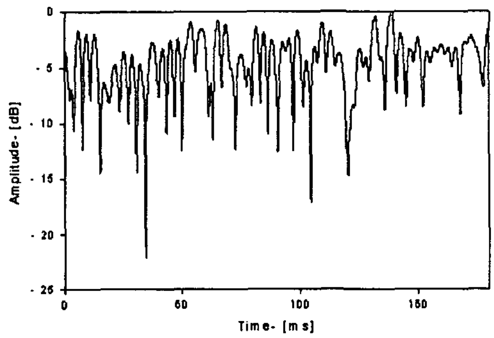

Fig. 1 Rayleigh channel simulation for the Clarke mode

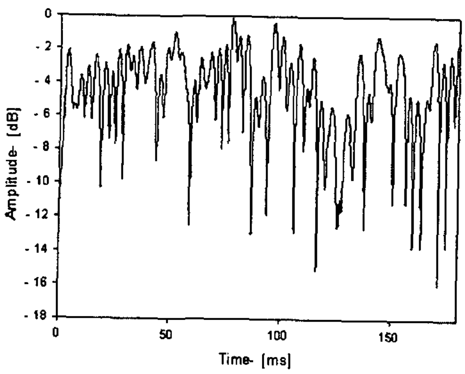

Fig. 2 Rayleigh channel simulation for the Parson model

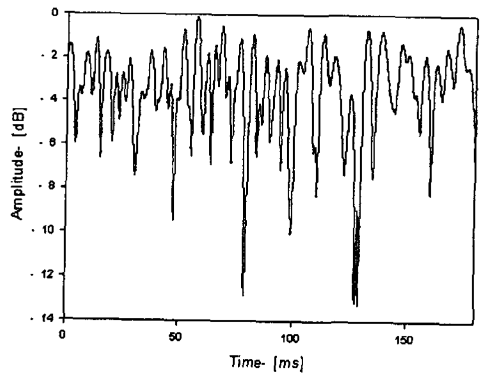

Fig. 3 Rician channel simulation for the Clarke model

2. Rician Channel

If the LOS path does exist, the received power at certain frequency is much greater than that of other frequencies. Therefore, in the Rician case, the popular Doppler spectrum models are almost same except that they contain an impulse power at a certain frequency f_0. Of course, channel characteristics are changed as K in Equation (12) varies, where K represents the power ratio of LOS path to indirect paths. Simulated channels will be Gaussian or Rayleigh distributed if K becomes too large or very small. Figure 3 and Figure 4 show the simulated channels of the Clarke and Parson model examples for K=1 which is a typical value to get a Rician distribution. Here, a certain frequency f_0 is chosen as 20.49 Hz and the maximum Doppler frequency and SNR are same as used in the Rayleigh cases, Figure 1 and Figure 2. Figure 5 shows the channel simulation results for the Clarke model example as K varies. As seen in Figure 5, the simulated channel characteristics are improved as K gets larger.

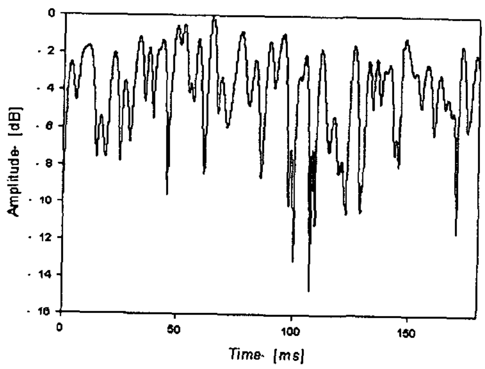

Fig. 4 Rician channel simulation for the Parson model

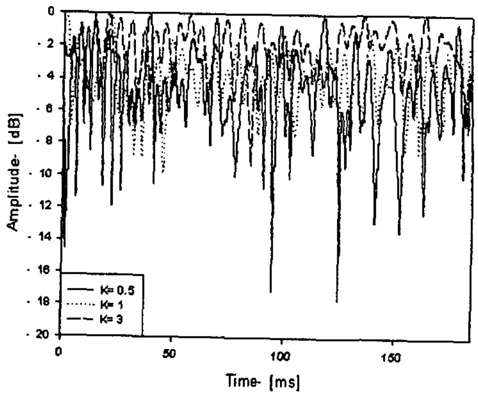

Fig. 5 Channel simulation results as k varies in the Clarke model

IV. Conclusions

In this paper, an efficient channel simulation method is newly suggested. It is very simple and convenient since users can simulate various mobile channels directly from any arbitrarily chosen Doppler spectrum model. As seen in simulation results, various Rayleigh and Rician channels can be simulated according to chosen parameters and Doppler models. Therefore, using this new method, the reliability and performance tests of mobile communication systems can be done more completely in the laboratory level. It is very simple and much easier than conventional methods to simulate various specific mobile channels which are desired to be investigated.

References

[1] J. R. Ball, "A real-time fading simulator for mobile radio", Radio and Electronic Engineer, 52, No. 10, pp. 475-478, 1982

[2] W. C. Jakes, Jr., Microwave mobile communications, John Wiley & Sons, New York, 1974

[3] K. Pahlavan and A. Levesque, Wireless Information Networks, John Wiley & Sons, New York 1995

[4] R. H. Clarke, "A statistical theory of mobile radio reception", Bell Systs. Tech. J., 47, pp. 957-1000, 1968

[5] J. D. Parson and M. F. Ibrahim, "Signal strength prediction in built-up areas. part2: signal variability", IEE Proc. 130, pt. F, No. 5, pp 385-391, 1983

[6] T. Aulin, "A modified model for the fading signal at a mobile radio channel", IEEE Trans., VT-28, No. 3, pp. 182-203, 1979

저자소개

이종길(Jong Gil Lee)

1982년 2월 연세대학교 전자 공학과 (공학사)

1985년 1월 미국 Case Western Reserve University, Electrical Eng. (M.S.)

1990년 5월 미국 Clemson University, Electrical Eng. (Ph.D.)

1991년 1월~1993년 2월 삼성전자 특수연구소

1993년 3월~현재 인천대학교 정보통신공학과 교수

※관심분야: 무선통신, 레이다신호처리, 통신시스템, 스펙트럼분석