World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:5, No:3, 2011

Coverage Availability for the IEEE 802.16 System over the SUI Channels with Rayleigh Fading

Shiann-Shiun Jeng, #Chen-Wan Tsung, Hong-You Liou, Chun-Chieh Chang, and Jia-Ming Chen

Abstract**—**The coverage probability and range of IEEE 802.16 systems depend on different wireless scenarios. Evaluating the performance of IEEE 802.16 systems over Stanford University Interim (SUI) channels is suggested by IEEE 802.16 specifications. In order to derive an effective method for forecasting the coverage probability and range, this study uses the SUI channel model to analyze the coverage probability with Rayleigh fading for an IEEE 802.16 system. The BER of the IEEE 802.16 system is shown in the simulation results. Then, the maximum allowed path loss can be calculated and substituted into the coverage analysis. Therefore, simulation results show the coverage range with and without Rayleigh fading.

Keywords**—**OFDM, coverage, SUI channel, IEEE 802.16

Open Science Index, Electronics and Communication Engineering Vol:5, No:3, 2011 publications.waset.org/6816/pdf

I. Introduction

ORTHOGONAL frequency division multiplexing (OFDM) is the most popular wireless communication technique in recent years and adapted in IEEE specifications, e.g. 802.11 and 802.16 serial standards. The coverage range of the 802.11 system is restricted within approximately 100 m. Therefore, the IEEE 802.16 serial standards have been proposed to solve this problem. The IEEE 802.16 system has not only a higher data rate but also a wider transmission range; the maximum data rate may achieve 75 Mbps and the maximum coverage range may achieve 50 km [1]. However, in reality, the coverage range and probability vary with different wireless environments for an IEEE 802.16 system. Thus, evaluating IEEE 802.16 system coverage probability and transmission range before constructing a base station is extremely important. In [2], the coverage of the IEEE 802.16 system was predicted for several channel models using different modulation schemes. In [3], the IEEE 802.16 system performance, including transmission range, was analyzed. In [4], the coverage analysis for WiMAX systems was presented by using the free space propagation model.

Department of Electrical Engineering, National Dong Hwa University.No. 1, Sec. 2, Da Hsueh Rd., Shoufeng, Hualien, 97401, Taiwan.

#Department of Computer and Communication, Shu Te University

#No. 59, Hun Shan Rd., Yen Chau, Kaohsiung, Taiwan
ssjeng@mail.ndhu.edu.tw, #cwtsung@mail.stu.edu.tw, m9623053@ems.ndhu.edu.tw, m9823022@ems.ndhu.edu.tw and d9323005@ems.ndhu.edu.tw

In [5], the coverage analysis of the IEEE 802.16d system over the Stanford University Interim (SUI) channel was studied and applied by the smart antenna system. IEEE 802.16 specifications propose that the SUI channel model [6] is suitable for evaluating the performance of IEEE 802.16 systems. In this paper, the performance of the IEEE 802.16e system is evaluated by utilizing the SUI channel model. This work also applies Rayleigh fading to the path loss model of the SUI channel and analyzes the coverage availability. Simulation results show the coverage probability with Rayleigh fading over the SUI channels.

The remainder of this paper is organized as follows. Section II introduces the SUI channel model and presents the basic analysis of the coverage probability. Section III proposes the coverage probability with Rayleigh fading. Section IV presents the simulation results for the performance evaluation and the coverage availability. Finally, the conclusion of this work is drawn in Section V.

II. Preliminary

A. The Description of SUI Channels

For the SUI channel model [6], a set of six typical channels is selected for three terrain types and described as follows. For Terrain type A, SUI-5 and SUI-6 channels are hilly terrain with moderate-to-heavy tree densities. For Terrain type B, SUI-3 and SUI-4 channels are hilly terrain with light tree densities or flat terrain with moderate-to-heavy tree densities. For Terrain type C, SUI-1 and SUI-2 channels are flat terrain with light tree densities. The basic path loss equation of the SUI channel model is

$$\overline{PL}(r) = A + 10\gamma \log_{10}\left(\frac{r}{r_0}\right) + X_f + X_h + s \quad (1)$$

where r is the distance (m) between a transmitter and receiver, and r_0 is the reference distance (m). In this work, r_0 is 100 m, and r has to be larger than r_0. A can be represented as

$$A = 20\log_{10}\left(\frac{4\pi r_0}{\lambda}\right) \quad (2)$$

where λ is the wavelength of the propagation wave. γ is a random variable that can be represented as

Open Science Index, Electronics and Communication Engineering Vol:5, No:3, 2011 publications.waset.org/6816/pdf

$$\gamma = a + bh_b + \frac{c}{h_b} + x\sigma_\gamma \tag{3}$$

where h_b is base-station antenna height and between 10 m and 80 m. The values of *a, b, c* and σ_γ depend on the scenarios and are shown in Table 1, and *x* is a Gaussian random variable with a zero mean and unit variance.

In (1), the terms X_f and X_h are modified factors for the receiver antenna frequency and height, respectively. Notably, X_f and X_h are defined as

$$X_f = 6\log\left(\frac{f}{2000}\right) \tag{4}$$

and

$$\begin{aligned} X_h &= -10.8\log\left(\frac{h_r}{2.0}\right) \quad \text{for Terrain Types A and B} \\ X_h &= -20.0\log\left(\frac{h_r}{2.0}\right) \quad \text{for Terrain Type C} \end{aligned} \tag{5}$$

where *f* is receiver antenna frequency (MHz) and h_r is receiver antenna height and between 2 m and 10 m.

In (1), *s* is a lognormal-distributed path loss factor that accounts for shadow fading caused by trees and terrain structures. In [6], the standard deviation of *s*, which depends on terrain type, is typically 8.2–10.6 dB. Additionally, *s* can be represented as a zero mean Gaussian random variable.

$$s = y\sigma \tag{6}$$

where *y* is a Gaussian random variable with a zero mean and unit variance. In [7], variability σ depends on different environments, e.g., suburban or urban environments. Thus, σ can be represented as

$$\sigma = \mu_\sigma + z\sigma_\sigma \tag{7}$$

where μ_σ is the mean of σ, σ_σ is the standard deviation of σ, and *z* is a Gaussian random variable with a zero mean and unit variance. Table 1 shows the values of μ_σ and σ_σ. Therefore, *s* can be represented as a Gaussian random variable with a zero mean and variance μ_σ^2.

B. Coverage Probability Analysis

After describing the path loss model of SUI channel model, this study analyzes the coverage probability of an IEEE 802.16 system over SUI channels. Fig. 1 shows a cell coverage area. Assume that Δr approaches 0. For any variable *r*, the average coverage probability of the IEEE 802.16 system [7], P_{cell}, can be represented as

TABLE I PARAMETERS OF THE SUI CHANNEL MODEL

Model Parameters	Terrain A	Terrain B	Terrain C
a	4.6	4	3.6
b	0.0075	0.0065	0.005
c	12.6	17.1	20
σ_γ	0.57	0.75	0.59
μ_σ	10.6	9.6	8.2
σ_σ	2.3	3.0	1.6

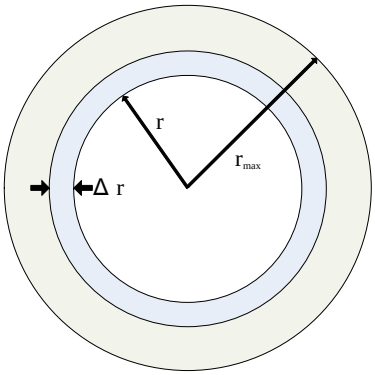


Fig.1 Cell coverage area for probability analysis

$$P_{cell} = \frac{1}{\pi r_{\max}^2}\int_{r=0}^{r_{\max}} P_e(r)\times 2\pi r dr \tag{9}$$

where $r_{\max}$ is the maximum transmission range of the IEEE 802.16 system and $P_e(r)$ is the probability of the path loss below the threshold value at distance *r* and described clearly in Sec. III.

III. THE ANALYSIS OF COVERAGE PROBABILITY WITH RAYLEIGH FADING

For the SUI channel model, the path loss model without Rayleigh fading is described in Sec. II-A. In this section, Rayleigh fading is added on the path loss model of the SUI channel model, and then the analysis of the coverage probability is presented. Therefore, the new path loss model with Rayleigh fading can be represented as

$$PL(r) = A + 10\gamma\log_{10}\left(\frac{r}{r_0}\right) + X_f + X_h + s + R \tag{10}$$

where *R* is Rayleigh fading factor and has a log-Rayleigh distribution. If path loss ($PL(\cdot)$) is less than the path loss threshold (L_{th}) at distance *r*, the probability of coverage fraction, $P_e(r)$, can be expressed as

$$P_e(r) = P(PL(r) < L_{th}) \tag{11}$$

where L_{th} can be represented as

$$L_{th} = (P_t + G_t) - S_r \tag{12}$$

Open Science Index, Electronics and Communication Engineering Vol:5, No:3, 2011 publications.waset.org/6816/pdf

where P_t is transmission power and G_t is antenna gain at the transmitter. S_r is the minimum input level sensitivity of the receiver [8] and can be represented as

$$S_r = -102 + SNR_r + 10 \cdot \log\left(f_s \cdot \frac{N_{used}}{N_{FFT}} \cdot \frac{N_{sch}}{16} \right) \quad (13)$$

where SNR_r is the SNR (dB) at the receiver when the BER reaches the threshold value; N_{sch} is the number of allocated subchannels (the default number of subchannels with no sub-channelization is 16); N_{used} is the number of subcarriers; and N_{FFT} is the FFT size. f_S is the sampling frequency (MHz). Then, (10) is substituted to (11), and the probability of coverage fraction can be rewritten as

$$\begin{aligned} P_e(r) &= P\left(PL(r) < L_{th}\right) \\ &= P\left(A + 10\gamma \log_{10}\left(\frac{r}{r_0}\right) + X_f + X_h + s + R < L_{th} \right) \end{aligned} \quad (14)$$

Assuming B=10log$_{10}$(r/r_0), (14) can be rewritten as

$$P_e(r) = P\left(B\gamma + s + R < L_{th} - \left(A + X_f + X_h \right) \right) \quad (15)$$

Let D be L_{th} - (A + X_f + X_h). Then, the probability is represented as

$$\begin{aligned} P_e(r) &= P\left(B\gamma + s + R < D\right) \\ &= \iiint_{B\gamma+s+R<D} f(s)dsf(B\gamma)d\gamma f(R)dR \\ &= \int_{-\infty}^{\infty} f(v) \int_{-\infty}^{D-v} f(s) \int_{-\infty}^{D-v-s} f(R)dR \cdot ds \cdot dv \end{aligned} \quad (16)$$

where the distribution of R can be represented as

$$f(\mathrm{R}) = \frac{10^{R/20}}{\sigma_R^2} e^{-\left(10^{R/20}\right)^2 / 2\sigma_R^2}, \quad (17)$$

where σ_R^2 is the variance of the random variable R. The distribution of s in (16) can be represented as

$$f(s) = \frac{1}{\sqrt{2\pi}\mu_\sigma} \exp\left(-\frac{\mathrm{s}^2}{2\mu_\sigma^2} \right) \quad (18)$$

where μ_σ^2 is the variance of the random variable s. The distribution of $B\gamma$ in (16) can be represented as

$$f\left(B\gamma\right) = \frac{1}{\sqrt{2\pi}B\sigma_\gamma} \exp\left(-\left[B\gamma - B\left(a - bh_b + \frac{c}{h_b} \right) \right]^2 \Big/ 2B{\sigma_\gamma}^2 \right) \quad (19)$$

where $B(a\text{-}bh_b\text{+}c/h_b)$ is the mean of the random variable $B\gamma$ and $B\sigma_\gamma^2$ is the variable of the random variable $B\gamma$. Substituting (16) into (9), the average coverage probability with Rayleigh fading can be represented as

$$\begin{aligned} P_{cell} &= \frac{1}{\pi r_{\max}^2} \int_{r=0}^{r_{\max}} P_e(r) \times 2\pi r dr \\ &= \frac{1}{\pi r_{\max}^2} \int_{r=0}^{r_{\max}} \iiint_{B\gamma+s+R<D} f(s)dsf(B\gamma)d\gamma f(R)dR \times 2\pi r dr \end{aligned} \quad (20)$$

In the simulation of this study, the numerical analysis of the coverage probability with Rayleigh fading is calculated by utilizing (21) in Sec. IV. Comparing the coverage probability with Rayleigh fading, the analysis of the coverage probability without Rayleigh fading is shown in [5] and represented as (21) simply.

$$\hat{P}_{cell} = \frac{1}{\pi r_{\max}^2} \int_{r=0}^{r_{\max}} \iint_{B\gamma+s<D} f(s)dsf(B\gamma)d\gamma \times 2\pi r dr \quad (21)$$

IV. Performance Evaluation

The flowchart of the IEEE 802.16e system for the simulation in this paper is shown in Fig. 2. To overcome the inter-symbol interference (ISI), the cycle prefix (CP) is utilized. According to the IEEE 802.16e specification [1, 8], the setup parameters are demonstrated in Table 2. The QPSK modulation is used in this simulation. The FFT size is 512. The number of data subcarriers is 360, the number of pilot subcarriers is 60, and the number of null subcarriers is 92. The FEC is not used in order to save the consuming time of the simulation. The channel Bandwidth is 5 MHz. The operating frequency is 2.5GHz. The subcarrier frequency spacing is 10.94 kHz. The OFDM symbol duration is 114.2 μs, while the CP duration is 22.8 μs. The SUI-1 and SUI-6 channels are used and their parameters are shown in Table 3 [6].

Fig. 3 shows the BER over the AWGN, SUI-1 and SUI-6 channels. While the BER is 10^{-4}, the required SNRs for the BER over the SUI-1 and SUI-6 channels are more than that over the AWGN channel, i.e. increasing by about 1 dB and 7 dB, respectively. After obtaining the required SNR under BER=10^{-4}, the receiver sensitivity can be calculated by (13), and then the maximum allowed path loss can be calculated by (12). The link-budget is shown in Table 4. The transmission power is 46 dBm, and the transmission antenna gain is 17 dB. The height of the transmitter antenna is 80 m, and the height of the receiver antenna is 10 m. X_f and X_h can be calculated from (4) and (5), respectively. Then, Table 5 shows the receiver sensitivity and the maximum allowed path loss of the SUI-1 and SUI-6 channels. When the threshold BER is 10^{-4}, the

Open Science Index, Electronics and Communication Engineering Vol:5, No:3, 2011 publications.waset.org/6816/pdf

required SNRs of the SUI-1 and SUI-6 channels are 11.8 dB and 17.2 dB, respectively. Therefore, the receiver sensitivities of both channels are -84.2478 dBm and -78.8478 dBm, respectively. Then, the maximum allowed path losses of the SUI-1 and SUI-6 channels are 147.2478 dB and 141.8478 dB, respectively. After the maximum allowed path loss is obtained, the coverage probability with and without Rayleigh Fading can be calculated by (20) and (21) respectively. Fig. 4 and 5 show the coverage probability with and without Rayleigh fading versus cell radius over the SUI-1 and SUI-6 channels, respectively. Table 6 shows the cell radius of the SUI-1 and SUI-6 channels without and with Rayleigh fading under the coverage probability of 99%. For the SUI-1 channel, the cell radius without Rayleigh fading is 4198 m, and the cell radius with Rayleigh fading is 3524 m. The cell radius with Rayleigh fading is less than that without Rayleigh fading, i.e. decreasing by 674 m. For the SUI-6 channel, the cell radius without Rayleigh fading is 1327 m, and the cell radius with Rayleigh fading is 1123 m. The cell radius with Rayleigh fading is less than that without Rayleigh fading, i.e. decreasing by 204 m. Therefore, the simulation result depicts that the cell radius may gets smaller when Rayleigh fading is considered into the propagation model.

V. Conclusion

The relationship between coverage probability and cell radius of the IEEE 802.16 system is determined by different wireless scenarios. The SUI channel model is used as the channel model according to the IEEE 802.16 standard. This paper presents a novel coverage probability analysis scheme with Rayleigh fading for the OFDM system over the SUI channel. While BER is 10^{-4} and coverage probability achieves 99%, the cell radius of the SUI-1 and SUI-6 channels with Rayleigh fading decreases by 674 m and 204 m, respectively. It is foreseen that the cell radius becomes smaller when the SUI channel with Rayleigh fading is considered. Thus, the simulation result show that transmission ranges of the SUI-1 and SUI-6 channels with Rayleigh fading decreases to 16.1 % and 15.4% less than those without Rayleigh fading, respectively.

References

[1] IEEE Standard for Local and metropolitan area networks Part 16: 'Air Interface for Fixed Broadband Wireless Access System', 2004.

[2] Plitsis, G.: 'Coverage prediction of new elements of systems beyond 3G: the IEEE 802.16 system as a case study'. *in Proc. IEEE VTC'03-Fall*, vol. 4, pp.2292 – 2296, Oct., 2003.

[3] Burbank, J.L.; Kash, W.T.: 'IEEE 802.16 broadband wireless technology and its application to the military problem space'. *in Proc. IEEE MILCOM'05*, vol. 3, pp. 1905 – 1911, Oct., 2005.

[4] L. M. A. Jalloul and S. P. Alex, "Coverage Analysis for IEEE 802.16e/WiMAX Systems," *IEEE Trans. on Wireless Comm.*, vol. 7, no. 11, pp. 4627-4634, Nov., 2008.

[5] S. S. Jeng, J. M. Chen, C. W. Tsung and Y. F. Lu, "Coverage Probability Analysis of IEEE 802.16 System with Smart Antenna System over SUI Fading Channels," *IET Comm.*, vol.4, no.1, pp. 91-101, Jan. 2010.

[6] Erceg, V., Hari, K., Smith, S. et al.: 'Channel models for fixed wireless application'. tech. rep., IEEE 802.16.Broadband Wireless Access Working Group, January 2001.

[7] Saunders, S.: 'Antennas and propagation for wireless communication systems', (John Wiley, 2007, 2nd edn.), pp. 186-187.

[8] IEEE Std. 802.16e-2005 and IEEE Std. 802.16™-2004/Cor1-2005: 'IEEE Standard for Local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in Licensed Bands, and Corrigendum 1', 2006.

TABLE II Parameter Setup for the OFDM system

Simulation Parameters	States
FFT Size	512
Number of Data Subcarrier	360
Number of Pilot Subcarrier	60
Number of Null Subcarrier	92
FEC	No use FEC
Modulation Scheme	QPSK
Channel	SUI-1 and SUI-6 channels
Cannel Bandwidth	5MHz
Subcarrier Frequency Spacing	10.94kHz
Operating Frequency	2.5GHz
OFDM Symbol time	114.2 μs
CP duration	22.8 μs

TABLE III The SUI-1 and SUI-6 Channels

Channel Model		Path 1	Path 2	Path 3	Unit
SUI-1	Delay	0	0.4	0.9	μs
	Power	0	-15	-20	dB
SUI-6	Delay	0	14	20	μs
	Power	0	-10	-14	dB

TABLE IV Link-Budget of the 802.16 system

System Parameters	Value
Tx Height (m)	80
Rx Height (m)	10
Tx Power (dBm)	46
Tx Antenna Gain (dB)	17

TABLE V Calculation of the maximum allowable path loss

Require Uncodode BER = 10^{-4}	Receiver SNR (dB)	Sensitivity (dBm)	Maximum Allowed Path Loss(dB)
SUI-1	11.8	-84.2478	147.2478
SUI-6	17.2	-78.8478	141.8478

TABLE VI Coverage ranges under the different conditions

Threshold：99% Coverage Probability for uncoded BER = 10^{-4}		
SUI-1	Cell radius without Rayleigh Fading	4198m
	Cell radius with Rayleigh Fading	3524m
SUI-6	Cell radius without Rayleigh Fading	1327m
	Cell radius with Rayleigh Fading	1123m

Open Science Index, Electronics and Communication Engineering Vol:5, No:3, 2011 publications.waset.org/6816/pdf

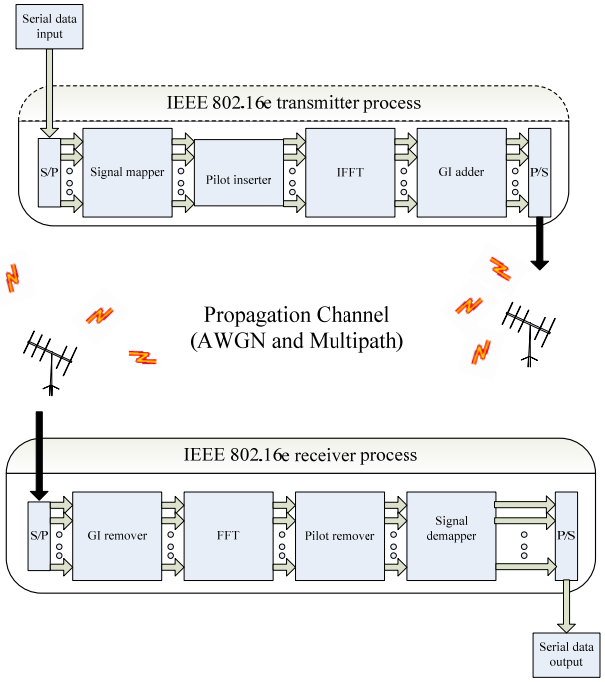


Fig. 2 The flowchart of the OFDM system

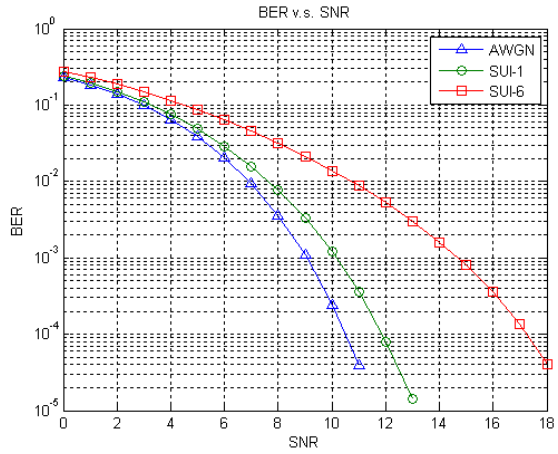


Fig. 3 The BER of the OFDM system over the AWGN, SUI-1 and SUI-6 channels

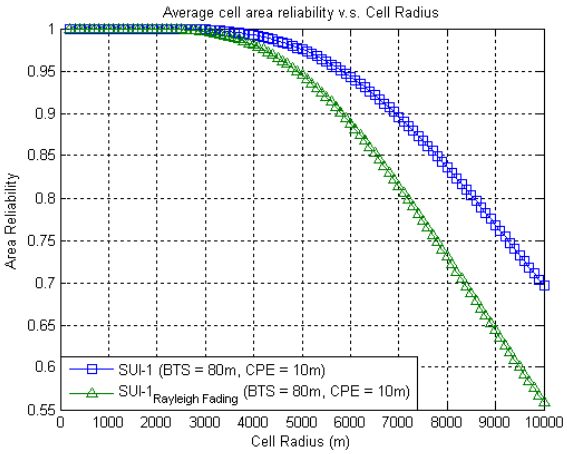


Fig. 4 The coverage with and without Rayleigh fading over the SUI-1 channel

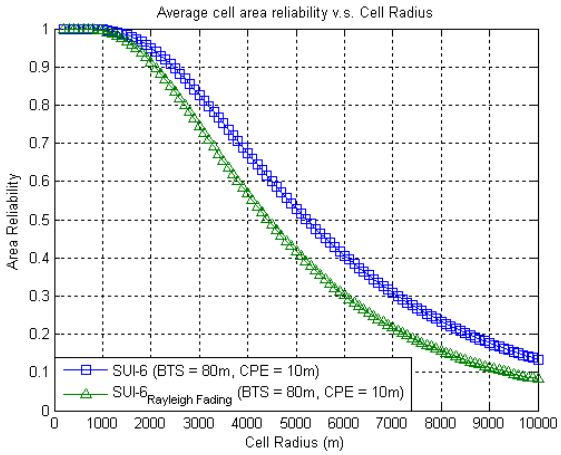


Fig. 5 The coverage with and without Rayleigh fading over the SUI-6 channel