CDMA2000 Downlink Performance Analysis Based on Deterministic Ray-Tracing Channel Model

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Abstract— This paper presents frame error rate (FER) properties of downlink in CDMA2000 system with the movement of the mobile terminal in high-rise urban environment. The site-specific channel model based on ray-tracing technique is chosen for this analysis with the established cells and sectors for the current IS-95 service. The tendency of FER according to the position of the mobile terminal is analyzed. From this analysis, we can infer the possibility of using the established IS-95 cell plannings for the CDMA2000 service.

I. Introduction

With the grown of mobile communication services, it is expected that there will be an enormous increase of data traffic to result in more service capacity. In order to meet more capacity, microcells and picocells are adopted in high density service area and furthermore multi-layered cell structure will be used in the third generation (3G) communications systems, so called IMT-2000 [1],[2].

Data service is usually more sensitive to BER performance than voice. Therefore it is crucial to meet BER requirement for successful mobile data communication service. In the procedure of cell planning it is important to predict exact wideband channel characteristics, which is required to estimate accurate BER performance within a given cell coverage.

The well known empirical channel model such as Okumura-Hata model or COST-231 model provides only narrow band channel characteristics at the mobile station (MS). Moreover these empirical models are not adequate for high-rise urban environment, since they cannot consider shadow fading effect properly.

In order to overcome shortcomings of these empirical models, radio propagation prediction tool based on ray-tracing technique can be used to obtain site-specific channel properties in high-rise environment. Channel models obtained from this kind of site-specific prediction tool provide not only narrowband properties but also wideband properties of the channel.

In this paper, ray-tracing technique is used to predict the received signal power and the impulse response of the channel at an arbitrary position within the cell in high-rise urban environment. Parameters of tapped delay line model representing wideband channel properties were obtained from impulse responses generated by ray-tracing simulation tool.

With simulated channel model mentioned above, the properties of FER variation were obtained while MS moves along different routes within a given cell or into other cells.

In section II, functional constitution of the channel simulator is described briefly. The typical cell sites in high-rise urban environment used in the analysis are explained in section III. The simulation results of downlink performance of CDMA2000 system are shown in section IV. The conclusion is following in section V.

II. Channel Simulator

The block diagram of CDMA2000 transceiver used in this analysis is illustrated in Fig. 1. According to 3GPP2 standard for CDMA2000 system, the data stream is coded with 1/4 rate convolutional encoder and block interleaver. For simplicity, perfect power control is assumed so that power control process is omitted here. Each data symbol modulated by Quadrature Phase Shift Keying (QPSK) is spreaded by one of the 63 Walsh sequence whose length is 64. It is assumed that the forward link signals are synchronized at chip level and frequency is recovered perfectly.

Before Walsh coded signal transmitted, complex multiplication is performed on each chip with two different pseudo noise (PN) sequence whose period is $2^{15}-1$. For the synchronous CDMA system, all BSs share the same PN-sequence with different time offset so that MS can distinguish a specific BS from others using this time offset.

In general, it is hard to have line of sight (LOS) path from transmitter to receiver in high-rise urban environment. Hence the mobile communication channel is assumed a frequency selective fading channel with Rayleigh fading statistics.
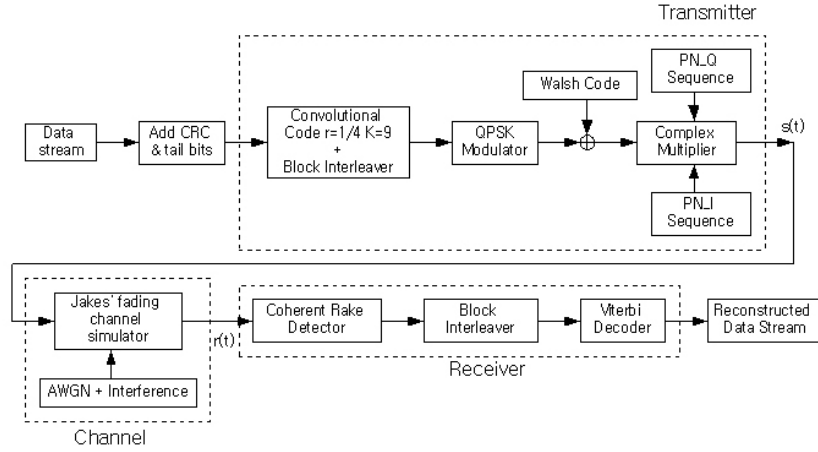
fig 1 Simulated transceiver model

The propagation channel can be implemented as a wide band tapped delay line model as illustrated in Fig.2. The complex valued tap weights are statistically independent stationary random processes whose statistics follow Rayleigh distribution with unit mean power. The Rayleigh PDF is expressed as

$$P(f_k) = \begin{cases} \dfrac{f_k}{\delta^2} \exp\left(-\dfrac{f_k^2}{2\delta^2}\right) & 0 \le f_k \le \infty \\[2em] 0 & f_k < 0 \end{cases} \tag{1}$$

where δ is the root mean square (RMS) value of received signal before envelope detection and δ^2 the time-averaged power of received signal before envelope detection, respectively.
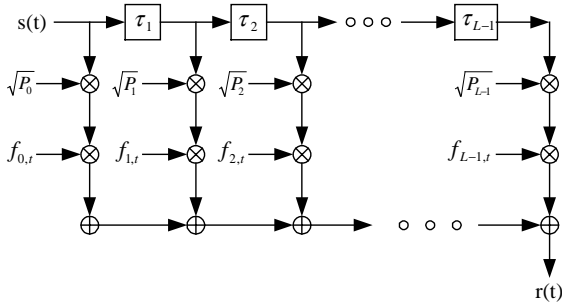

fig 2 Wideband tapped delay line model

Rayleigh fading is generated using modified Jakes' model in order to avoid correlations between tap weights when the original Jakes' model is used. The modified Jakes' model parameters [4] can be represented as follow

$$f_k(t) = f_{i,k}(t) + j f_{q,k}(t), \ for \ k = 1 \ to \ N_0 \tag{2}$$

$$f_{i,k}(t) = 2 \sum_{n=1}^{N_0} \cos(\theta_{nk}) \cos(\omega_n t + \pi k / 2) \tag{3}$$

$$f_{q,k}(t) = 2 \sum_{n=1}^{N_0} \sin(\theta_{nk}) \cos(\omega_n t + \pi k / 2) \tag{4}$$

$$\theta_{nk} = \frac{\pi n k}{N_0}, (k = 1, 2, \dots, N_0 - 1)$$

$$\omega_n = 2\pi f_d \cos\left(\frac{2\pi(n - 0.5)}{N}\right)$$

$$N = 4(N_0 + 1)$$

where f_d ($= 2\pi v/\lambda$) is Doppler frequency, λ the wave length, v the speed of mobile, and N_0 the number of oscillators, respectively. It is confirmed that the correlations between tap weights are less than 0.01 during the entire simulation interval. As a result, tap weights can be assumed to be independent each other.

The received signal at MS is represented in the following equation.

$$r(t) = \sum_{k=0}^{L-1} s(t - \tau_k) \sqrt{P_k} f_k(t) \tag{5}$$

where $s(t)$ is the transmitted signal from BS, P_k the mean power of kth path, τ_k the absolute delay of kth path, and L the number of multipath, respectively. These parameters characterizing wideband channel properties are obtained from the result of ray-tracing simulation with building and terrain information of concerned area in this analysis.

Ray-tracing results show that multipaths sometimes exist within one chip duration (T_c). However, those multipaths are recognized as a single path by the receiver.

The received signal at MS is demodulated by the RAKE receiver with coherent maximal ratio combiner. As BS transmits pilot and data signal together, we can estimate the channel characteristics from the received pilot signal. 3-finger RAKE receiver is usually used to simplify the receiver structure of MS, which is the case of this analysis. The detected symbol from the RAKE receiver are deinterleaved and passed to Viterbi decoder to estimate transmitted data.

fig 3 Building footprint of Yeoui-do

III. Simulation Environment

FER performance evaluation heavily depends on how accurately the wideband channel mode used in the analysis describes the actual channel environment.

It is well known that empirical channel model shows limitations in its application to high-rise urban environment and cannot provide wideband channel properties as well. Therefore, in this paper, ray-tracing technique is used to predict wideband channel properties at an arbitrary position within the cell in high-rise urban environment. Parameters of tapped delay line model, which is used for easy implementation of wideband channel properties in time domain, were obtained from impulse responses simulated by ray-tracing tool.

Accuracy of ray-tracing technique such as VPL or WiSE is proved well in the literature[5],[6].

Ray-tracing technique has the advantages as follows.

First, it is easy to obtain site-specific channel properties. Second, it provides a wideband channel model in the form of superposition of time delayed and amplitude weighted delta function.

The building footprint, locations of BSs and route of moving MS used in the ray-tracing is represented in Fig. 3.

The ray-tracing simulation was carried out at 2 GHz band in the area of Yeoui-do, Seoul, Korea. The height of each building in this area has an average of 34 m, which is equivalent to the height of 10 stories building, and a standard deviation of 19.5 m. In addition, the area in interest has almost flat terrain and the street shape of nearly rectangular grid.

BSs used in this analysis have 2 or 3 sector antennas as illustrated in the Fig. 3. And the heights of BS1, BS2, and BS3 are 55.9 m, 31.5 m, and 56.2 m, respectively. Thick lines in the Fig. 3. show the test routes for MS. MS is assumed to have an omni-directional receiving antenna with height of 1.7 m.

The distance between each consecutive MS position is 1 m ($\approx 6.6\lambda$) along route 1 and 3 m ($\approx 20\lambda$) along route 2 and 3.

IV. Results

In this section, we present the numerical results of FER performance obtained from computer simulations. The simulations were carried out for CDMA2000 forward link mentioned in section 2 for moving MS along three test routes in Yeoui-do. Once there exits LOS path between BS and MS, amplitude of first path follows Rician statistics and all others do Rayleigh statistics.

Radio Configuration 3 of 3GPP2 physical layer standard is adopted, where data rate per channel is 9.6 kbps(192 symbols/20ms) and the block size of interleaver after convolutional encoding used in this simulation is 768 bits.

Transmitted signals by BS consist of three components (pilot signal, data signal for desired user and data signals for other users). Pilot signal occupies 20% of the total transmitted power by BSs and each user shares the rest of total transmitted power. In this analysis, two different number of users in reference cell (8 and 20 users per reference cell) was considered in order to compare the performance difference between two different percent signal power of desired user (10% and 4% of total transmitted power by BSs).

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Hard hand-off was assumed and interference signals were presumed as AWGN whose power is equal to non-coherent sum of multipath components' power from adjacent cells for simplicity of calculation. The FER performance along three routes is illustrated in Fig. 4 – 6.

Examining frame error performance, they show pattern of burst error depend-ing on the MS position.

Relatively high burst frame error is observed at MS position where there exists only a single obstructed path which is composed of multiple sub-paths. Considering interference from adjacent cell, MS positions having relatively low C/I ratio give higher burst FER than having relatively high C/I ratio.

In case of no multipath diversity, there is no way to avoid high FER except that data transmission rate is reduced to overcome fading effect by increasing the redundancy of channel coding. Therefore multi-rate
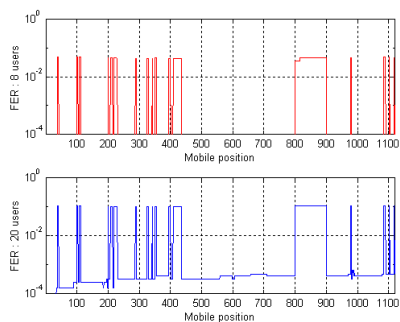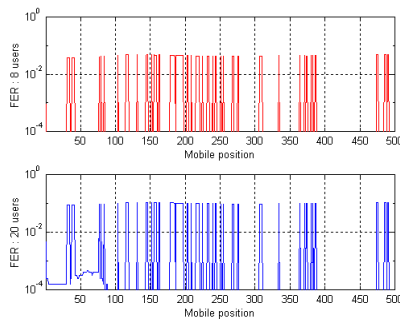

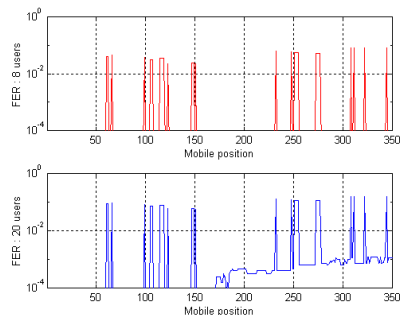fig 4 FER along Route 1

fig 5 FER along Route 2

fig 6 FER along Route 3

modulation schemes and good rate adaptation algorithm is required to enhance the performance of the downlink in CDMA2000 system. The result of this study can help to develop a efficient rate adaptation algorithm and optimized cell planning strategy for CDMA2000 system.

On the other hand, MSs with relatively low C/I ratio caused by strong interference signals from adjacent cells gives another type of burst frame error although their FER is lower than the former case.

This type of error can be avoided by power control of desired user signal in reference BS, but total transmission power of BSs is limited so that increasing transmission power of any particular user can cause sacrifice of other users. Therefore, it needs to be very careful to control transmission power of any particular user adaptively.

Another method to enhance the performance is to assign different total transmission power of BSs depending on environment.

Beam forming for desired user in BS using smart antenna is another attractive solution to overcome low C/I ratio problem.

V. Conclusion

Simulated FER performance at CDMA2000 downlink based on deterministic wideband channel model in high-rise urban environment is presented. It is revealed that performance can be affected by multipath conditions. Careful speculation on simulated FER performance results tells us that multi-rate transmission, effective control of desired user signal, well planned assignment of total transmission power of BSs, and beam forming of user signal by smart antenna, etc. can improve the system perfor-mance.

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