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CDMA 방식의 IMT-2000 시스템에서 음성 및 데이터 트래픽에 대한 역방향링크의 성능 평가

Performance Evaluation of Reverse Link for Speech and Data Traffic in CDMA-Based IMT-2000 System

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요 약

본 논문에서는 음성 및 데이터 트래픽에 대한 비트오율 성능이 CDMA 방식의 IMT-2000 시스템에서 역방향링크의 시뮬레이션 결과에 의해서 평가되었다. 역방향링크에서 시뮬레이션은 ITU-R에서 제시한 옥내, 도보, 그리고 차량 환경에 대하여 수행되었다. 또한 시뮬레이션에서 BER 성능을 향상시키기 위한 기술로 1.6 kHz 전력제어, 5-tap FIR 필터를 이용한 페이딩신호의 진폭과 위상 추정, 그리고 연판정 Viterbi 및 Reed-Solomon 복호 등이 적용되었다. 시뮬레이션 결과로는 최적의 파일롯전력 대비 트래픽전력의 비, 핑거수에 따른 BER 성능, 그리고 10^{-6} BER에서 길쌈부호와 Concatenated 부호와의 성능비교를 제시하고 있다.

Abstract

In this paper, the bit error rate (BER) performance for the speech and data traffic is evaluated by results of the reverse link simulation of CDMA-based IMT-2000. Simulations in the reverse link are achieved for indoor, pedestrian, and vehicular environments, which are provided by ITU-R. Also, in these simulations, the fast power control of 1.6 kHz rate is applied. The amplitude and phase of the fading signal are estimated by using the 5-tap FIR filter, and the soft-decision Viterbi and Reed-Solomon (RS) decoding are applied. Simulation results provide the optimum ratio of pilot power to traffic power, the BER performance according to the number of fingers, and performance comparison between convolutional code and concatenated code at 10^{-6} BER in 5 MHz system.

I. INTRODUCTION

International mobile telecommunications-2000 (IMT-2000) is third generation mobile systems, which are scheduled to start service around the year 2000. They will provide access, by means of one or more radio links, to a wide range of telecommunication services supported by the fixed telecommunication networks (e.g. PSTN/ISDN), and to other services which are specific to mobile users. Key features of IMT-2000 are as follows: high degree of commonality of design worldwide, compatibility of services within IMT-2000 and with the fixed networks, high quality, and use of a small pocket terminal with worldwide roaming capability[1],[2].

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This paper evaluates the BER performance of the reverse link in CDMA-based IMT-2000[3]. The BER performance is evaluated by computer simulations, which are applied over indoor, pedestrian, and vehicular environments as channel environments suggested in ITU-R. In addition, Rayleigh fading model for those channel environments is applied by Jake's model. Thus, the multipath fading channel is modeled to consider the path delay and path power of ITU-R channel model.

Also, this paper provides the ratio of pilot power to traffic power according to speech and data traffic. In order to apply coherent demodulation in the reverse link, the pilot signal per a user should be transmitted. In general, the transmission scheme of pilot signal could be classified by pilot channel aided scheme and pilot symbol aided scheme. Then, in this paper, the pilot channel aided scheme is chosen as a transmission scheme of a pilot signal. In the coherent demodulation of the reverse link, the minimization of the other-user interference due to the pilot signal is a significant problem. The solution of this problem is provided by the selection of the optimum ratio of pilot power to traffic power, which is selected by the interference increment caused by one other-user in the same cell. Simulation results for three channel environments show the optimum ratio of pilot power to traffic power in 9.6 kbps speech traffic case and in 38.4 kbps and 76.8 kbps data traffic case.

We evaluate the demodulation performance for the number of fingers in channel environments of multiband systems. Also, the BER performance for the convolutional code and concatenated code in data traffic is compared. The speech traffic should be maintained as the BER less than 10^{-3} and must limit transmission delay of speech signal. Thus, the depth of interleaving to randomize the burst errors is limited by the requirement for transmission delay. However, the data traffic is not almost limited by transmission delay. Therefore, the channel coding for data traffic is composed of concatenated coding combined by RS coding and inner and outer interleaving.

Ⅱ. RADIO LINK PARAMETERS OF CDMA-BASED IMT-2000

The radio link parameters of CDMA-based IMT-2000 are described in Table 1. The multiple access scheme of CDMA-based IMT-2000 is direct sequence code division multiple access (DS-CDMA). Also, to utilize the limited radio resource flexibly, CDMA-based IMT-2000 has chosen the multiband systems. This paper proposes the multiband systems that are composed of 1.25 MHz, 5 MHz, and 20 MHz bandwidths, and the chip rates corresponding to such multiband systems are 0.9216 Mcps, 3.6864 Mcps, and 14.7456 Mcps, respectively. The pseudonoise (PN) sequence spreading uses short PN sequences and long PN sequence. The cell sites are distinguished by the

Table 1. Radio link parameters

Radio Access	DS-CDMA / FDD
Chip Rates	0.9216 / 3.6864 / 14.7456 Mcps
Carrier Spacing	1.25 / 5 / 20 MHz
Spreading Codes	Shortened PN (20 msec in $2^{20}-1$) & Long PN ($2^{42}-1$)
Orthogonal Code	Walsh code
Inter BS Operation	Synchronous
Modulation / Spreading	Forward link : QPSK / QPSK Reverse link : QPSK / OCQPSK
Channel Coding	Convolutional code for speech Concatenated code for data
Voice Coding	Variable rate CS-ACELP
Frame Length	10 msec
Diversity	Antenna + RAKE
Power Control	Fast Closed loop + Open loop

unique code-phase offset of short I/Q PN sequences and the user channels in the forward link are done by Walsh code sequences. Also, the user channels in the reverse link are distinguished by the unique code-phase offset of a long PN sequence, and then the pilot, traffic, signaling channels within one user channel are done by three Walsh code sequences. Because CDMA-based IMT-2000 is intercell synchronous system similar to IS-95, the short I/Q PN sequences assigned to all cell sites are the same. Then, in order to distinguish the cell sites, the unique code-phase offset of the short I/Q PN sequences is assigned to each cell site.

The modulation and spreading schemes in the forward link are the QPSK scheme for the data signal and chip signal, in the reverse link, QPSK modulation for data signal and orthogonal complex QPSK (OCQPSK) spreading for chip signal are chosen.

The channel coding schemes are designed as (3,1,9) convolutional coding for speech traffic and concatenated coding for data traffic, which is combined by (3,1,9) convolutional coding and (47,41,8) RS coding. Also, since RS code is utilized for error correction as well as error detection, the hybrid automatic repeat request (ARQ) is applied. The speech coding scheme is the variable rate CS-ACELP that the full rate and frame length are 8 kbps and 10 msec, respectively. For the forward link, the fast closed-loop power control is only applied. However, the power control scheme for the reverse link applies the open-loop and fast closed-loop power control. To improve the BER performance, the reverse link utilizes the dual antenna diversity and RAKE diversity, while the forward link does only the RAKE diversity.

Ⅲ. RECEIVER STRUCTURE OF REVERSE LINK

The communication system model of the reverse link as shown in Fig. 1 can be classified by five components:

- RS coder-outer interleaver-convolutional coder-inner interleaver
- PN spreader-pulse shaping filter-power amplifier
- Multipath fading channel
- Automatic gain control-matched filter-PN despreader
- Correlator-fading amplitude/phase estimator-combiner-inner deinterleaver-Viterbi decoder-outer interleaver-RS decoder

In this paper, the channel coding scheme is implemented in two types. In general, the BER less than 10^{-3} in speech traffic is required, while BER less than 10^{-6} in data traffic is required. Thus, the channel coding for speech traffic applies convolutional coding in conjunction with interleaving, and the channel coding for data traffic does concatenated coding in conjunction with outer and inner interleaving. The concatenated coding scheme utilizes outer Reed-Solomon code and inner convolutional code. Also, in this scheme, the hybrid ARQ scheme using RS code is proposed.

PN spreading for the coded symbol is achieved by short and long PN codes. The pulse shaping filter is typically finite impulse response (FIR) digital filter, and its correlation property is given by

$$R(\tau) = \frac{\sin(\pi\tau/T_c)}{(\pi\tau/T_c)}, \tag{1}$$

where τ is timing error and T_c is a PN chip period.

The power amplifier has its output power controlled digitally, then the closed-loop power control used in this paper controls the output power as the period of 0.625 msec. Two components (I and Q) after convolutional coding are represented as complex quantities. Thus, the

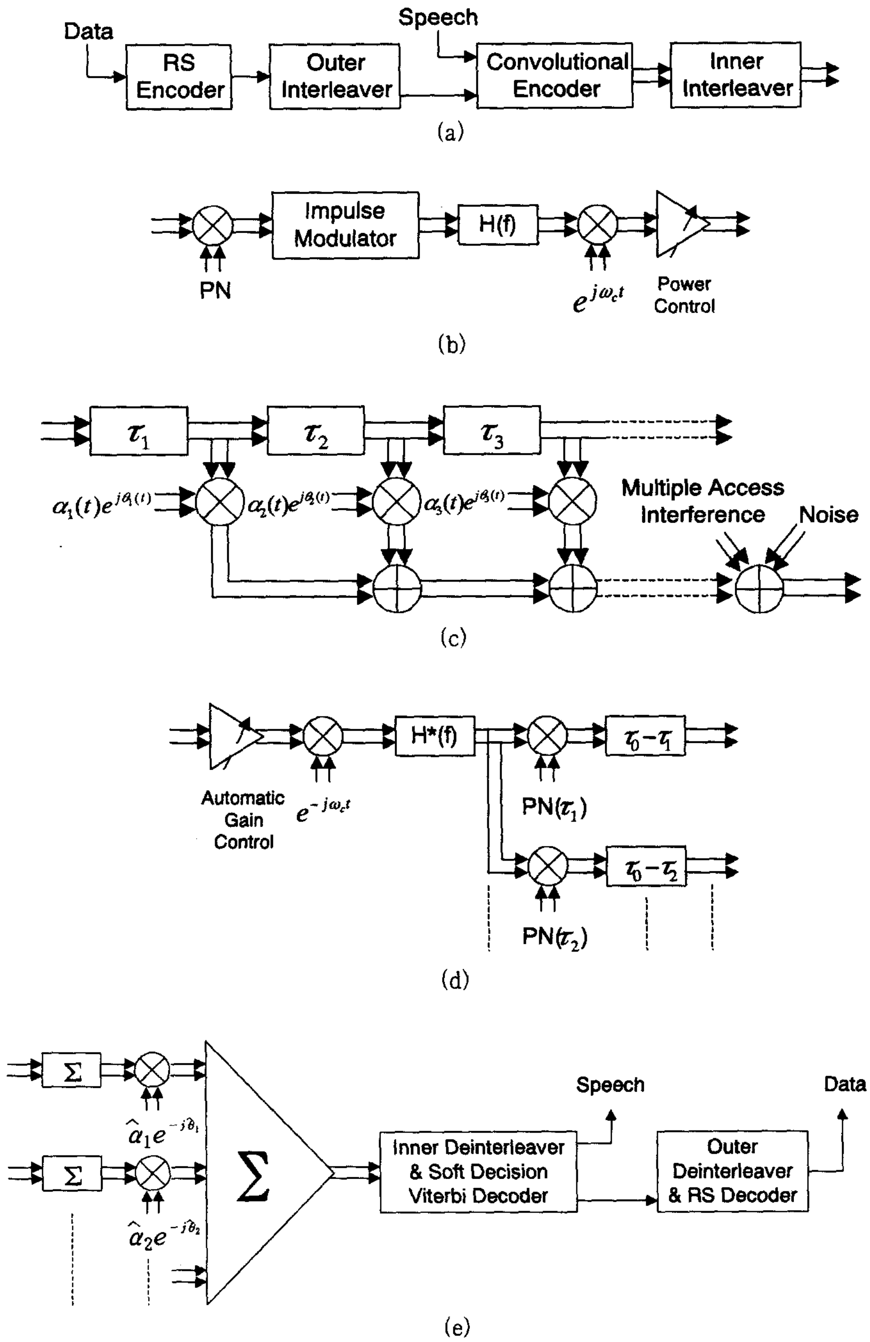

Fig. 1. Communication system of IMT-2000 reverse link.

(a) RS encoder-outer interleaver-convolutional encoder-inner interleaver,

(b) PN spreader-pulse shape filter-upconverter-power amplifier,

(c) Multipath fading channel,

(d) Automatic gain control-downconverter-matched filter-PN spreader,

(e) Correlator-fading amplitude & phase estimator-combiner-inner deinterleaver-Viterbi decoder-outer interleaver-Reed Solomon decoder.

quadrature spreading by multiplication by I/Q PN sequences with orthogonality, the two-branch baseband filters $H(f)$, and upconverting carrier multipliers are successively treated.

The multipath fading channel used in this paper is the tapped delay line model, which each path is distinguished by T_c and a random variable with Rayleigh distributed amplitude and uniformly distributed phase. Thus, the complex transfer function of the L-component multipath channel is given by

$$g(t) = \sum_{l=1}^{L} \alpha_l(t) e^{j\theta_l(t)}. \qquad (2)$$

The channel environments in the reverse link are classified by the indoor, pedestrian, and vehicular environments. Then, the speed of mobile station in the indoor and pedestrian environments is 3 km/h, while the speed of mobile station in the vehicular environment is 120 km/h. Thus, the channel impulse response and Doppler frequency of the multipath channel applied in simulation are determined by the channel impulse responses provided in ITU-R, the carrier frequency, and mobile station speed. In this paper, the chip rates for 1.25 MHz, 5 MHz, and 20 MHz are 0.9216 Mcps, 3.6864 Mcps, and 14.7456 Mcps, respectively. Then, the channel impulse responses according to chip rates can be reformed as follows. If the delay spread of channel is more than a chip period of each system, the l-th path power according to the chip period $E[\alpha^2{}_l]$ is reformed as

$$E[\alpha_l^2] = \sum_{i=l}^{I} E[\alpha_i^2] R^2(\tau_l - \tau_i), \qquad (3)$$

where I is the number of taps in ITU-R channel, and $E[\alpha_i^2]$ and τ_i are the power and time delay of the i-th tap, respectively. Also, $R(\tau)$ of the bandlimited filter is given in (1).

The optimum receiver for such a fading channel is shown in (d) and (e) of Fig. 1. The automatic gain control (AGC) normalizes the noise variance to unity. After downconversion, matched filtering by $H^*(f)$ and A/D conversion, the received signal is despread independently for each multipath component by multiplying by the I/Q PN sequences delayed by the amount equal to the delay of that multipath component. In order to line up the multipath components after despreading, each path is delayed by a complementary amount $\tau_0 - \tau_l$, $l = 1, 2, \cdots, L$ where τ_0 is greater than any of the path delays. The each despread signal to be time aligned is integrated by each correlator. The correlator output of each path is multiplied by the amplitude and phase of each path component and inputted to the combiner. The amplitude and phase of a fading path are estimated by the channel estimation filter that is composed of 5-tap FIR filter.

The output of the combiner is deinterleaved on a sample by sample basis, and subsequently decoded by a soft-decision Viterbi decoder. For data traffic, the outputs of the Viterbi decoder are grouped into 8-bit symbols and deinterleaved on a 8-bit symbol basis, and finally decoded by a RS decoder.

Ⅳ. BER PERFORMANCE EVALUATION

In this section, the BER performance of the reverse link for the proposed IMT-2000 radio interface is evaluated by computer simulations and user capacity for speech and data traffic is calculated. Simulations are achieved for the following conditions:

- Monte carlo method is used for performance simulation.
- The carrier frequency is 2 GHz.
- The indoor, pedestrian, and vehicular environments proposed in ITU-R are considered.
- The 5 MHz system is considered.
- As the method of performance improvement

of reverse link, the dual antenna diversity, 1.6 kHz fast closed-loop power control, path diversity, convolutional coding for speech traffic, and concatenated coding for data traffic are applied. In the fast closed-loop power control, the power control step size and power control loop delay are given by 0.5 dB and 1.25 msec, respectively. Also, the power control bit error rates for speech and data traffic are given by 4 % and 10 % for speech traffic and by 1 % and 10 % for data traffic.

- To improve the estimation performance for the amplitude and phase of a fading signal, the 5-tap FIR filter with 250 Hz pass bandwidth and 500 Hz stop bandwidth is utilized.
- 10 msec inner interleaver and 20 msec outer interleaver are utilized.

4-1 Optimum Ratio of Pilot Power to Traffic Power

In the coherent demodulation scheme using the pilot signal in the reverse link, interference is due to other-user traffic signal as well as other-user pilot signal. Thus, to minimize the interference due to other user interference, it is very important to minimize the increment of interference caused by one other-user. By referencing[4],[5], the interference increment $\triangle I$ due to one other-user is given by

$$\triangle I = (D_t + E_{cp}/E_{ct})E_{ct}\exp\{(\alpha\beta)^2/2\}, \quad (4)$$

where D_t is the activity factor of the traffic signal, and E_{cp}/E_{ct} is the ratio of pilot power to traffic power. E_{ct} is represented by E_b/PG as the PN chip energy of a user traffic. Then, E_b is the required E_b/I_0 for 10^{-3} BER or for 10^{-6} BER when the total noise spectral density I_0 is normalized as 1. α and β are the power control error and ln10/10 respectively.

From Table 2 to Table 5, the interference increment due to one other-user of speech traffic and data traffic is shown by changes of E_{cp}/E_{ct} in channel A of 5 MHz when the traffic data rate before convolutional encoding is given by 9.6 kbps for speech traffic and by 38.4 kbps and 76.8 kbps for data traffic. Namely, the interference increment $\triangle I$ due to one other-user in the same cell is represented as (4), and if the interference factor due to other-cell users is defined as r_f, the interference increment due to one user in the other cell is represented as $r_f \triangle I$.

Tables 2 and 3 show the interference increment due to one other-user at 10^{-3} BER in channel A of the indoor and vehicular environments when the power control bit error rate, P_e, is given by 10% and 4% respectively. From Table 2, when E_{cp}/E_{ct} is given by −5 dB, the smallest $\triangle I$ due to one other-user is shown as values of −25.52 dB for P_e = 10 % and of −26.19 dB for P_e = 4 %. Then, from Table 3 of channel A of the vehicular environment, the smallest $\triangle I$ is shown as values of −24.08 dB for P_e = 10 % and of −24.56 dB for P_e = 4 % when E_{cp}/E_{ct} is given by −4 dB and −5 dB respectively. Thus, in 9.6 kbps speech data rate, the optimum at 10^{-3} BER is given by −5 dB or −4 dB.

Table 2. Interference increment due to one other-user in channel A of indoor environment and 10^{-3} BER.

P_e	E_{cp}/E_{ct}	E_b/I_0	σ	$\triangle I$(D_t = 3/8)
10%	−3 dB	1.20 dB	1.24 dB	−25.04 dB
	−4 dB	1.35 dB	1.32 dB	−25.41 dB
	−5 dB	1.70 dB	1.38 dB	−25.52 dB
	−6 dB	2.25 dB	1.43 dB	−25.39 dB
4%	−3 dB	0.50 dB	1.22 dB	−25.68 dB
	−4 dB	0.80 dB	1.28 dB	−26.02 dB
	−5 dB	1.00 dB	1.35 dB	−26.19 dB
	−6 dB	1.40 dB	1.42 dB	−26.19 dB

Table 3. Interference increment due to one other-user in channel A of vehicular environment and 10^{-3} BER.

P_e	E_{cp}/E_{ct}	E_b/I_0	σ	$\triangle I(D_t = 3/8)$
10 %	-3 dB	1.90 dB	2.40 dB	-23.86 dB
	-4 dB	2.20 dB	2.43 dB	-24.08 dB
	-5 dB	2.70 dB	2.45 dB	-24.06 dB
	-6 dB	3.20 dB	2.49 dB	-23.96 dB
4 %	-3 dB	1.75 dB	2.35 dB	-23.97 dB
	-4 dB	2.02 dB	2.37 dB	-24.31 dB
	-5 dB	2.20 dB	2.40 dB	-24.56 dB
	-6 dB	2.85 dB	2.42 dB	-24.31 dB

Table 4. Interference increment due to one other-user in channel A of indoor environment and 10^{-6} BER.

Rate (P_e)	E_{cp}/E_{ct}	E_b/I_0	σ	$\triangle I$ ($D_t = 1$)
38.4 kpbs (10 %)	-7 dB	3.15 dB	1.01 dB	-15.77 dB
	-8 dB	3.25 dB	1.06 dB	-15.80 dB
	-9 dB	3.65 dB	1.09 dB	-15.53 dB
	-10 dB	4.25 dB	1.11 dB	-15.01 dB
76.8 kbps (1 %)	-11 dB	2.75 dB	0.96 dB	-13.62 dB
	-12 dB	3.05 dB	1.01 dB	-13.39 dB
	-13 dB	3.25 dB	1.05 dB	-13.22 dB

Tables 4 and 5 show the interference increment due to one other-user at 10^{-6} BER in channel A of the indoor and vehicular environments of 5 MHz. In the Table 4 of the indoor environment, the smallest $\triangle I$ is shown as values of -15.80 dB and -13.62 dB when E_{cp}/E_{ct} is given by -8 dB for 38.4 kbps data and -11 dB for 76.8 kbps data, while the smallest $\triangle I$ in the vehicular environment is shown as values of -14.42 dB and -12.39 dB when is given by -9 dB for 38.4 kbps data and -12 dB for 76.8 kbps. Thus, the optimum

Table 5. Interference increment due to one other-user in channel A of vehicular environment and 10^{-6} BER.

Rate (P_e)	E_{cp}/E_{ct}	E_b/I_0	σ	$\triangle I$ ($D_t = 1$)
38.4 kpbs (10 %)	-7 dB	4.15 dB	2.32 dB	-14.25 dB
	-8 dB	4.20 dB	2.35 dB	-14.35 dB
	-9 dB	4.25 dB	2.37 dB	-14.42 dB
	-10 dB	4.65 dB	2.42 dB	-14.08 dB
76.8 kbps (1 %)	-11 dB	3.55 dB	2.20 dB	-12.37 dB
	-12 dB	3.55 dB	2.30 dB	-12.39 dB
	-13 dB	4.55 dB	2.27 dB	-11.46 dB

E_{cp}/E_{ct} for 38.4 kbps data is given by -8 dB or -9 dB, and the optimum E_{cp}/E_{ct} for 76.8 kbps data is given by -11 dB or -12 dB.

4-2 Demodulation Performance Analysis for The Number of Fingers in 5 MHz

In A, the interference increment $\triangle I$ for E_{cp}/E_{ct} is evaluated for the pedestrian and vehicular environments in 5 MHz.

Fig. 2 shows the BER performance for E_{cp}/E_{ct} in the indoor environment. From this figure, the better performance is shown in the case of BER more than 10^{-3} when antenna diversity is only applied. However, if 10^{-4} BER for speech traffic and 10^{-6} BER for data traffic are required, the best performance is shown when antenna diversity and path diversity are applied. Because the fading path powers in the channel A of indoor environment are given by 0.93 and 0.04, respectively, the amplitude and phase of the received signal with 0.93 path power could be estimated at low E_{cp}/I_0, while the estimation of the amplitude and phase of the received signal with 0.04 path power could cause the estimation error at low E_{cp}/I_0.

Fig. 3 shows the BER performance for E_{cp}/E_{ct}

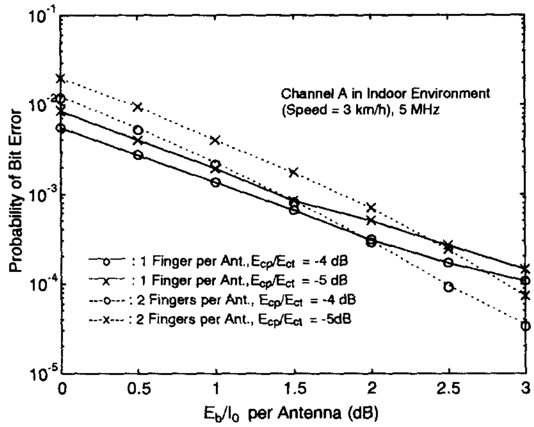

Fig. 2. BER for the number of fingers per antenna in channel A of indoor environment.

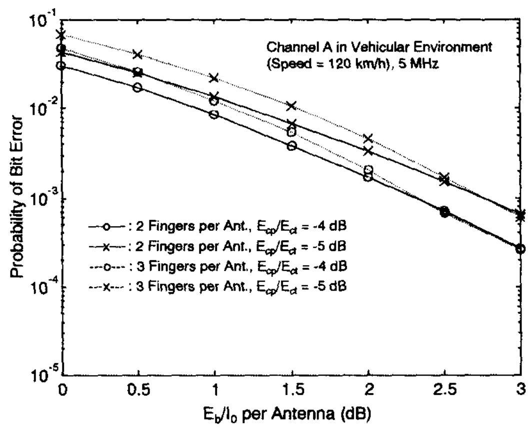

Fig. 3. BER for the number of fingers per antenna in channel A of vehicular environment.

and the number of fingers in the vehicular environment. From this figure, the better performance is shown in the case of BER more than 10^{-3} when the maximal ratio combining of two fingers per antenna is applied. In the channel A of vehicular environment, the fading path powers are given by 0.49, 0.36, and 0.085, respectively. Thus, the amplitude and phase of the received signal with 0.49 and 0.36 path powers could be estimated at low E_{cp}/I_0, while the estimation of the amplitude and phase of the received signal with 0.085 path power could cause the estimation error at low E_{cp}/I_0.

The reason of curve trends exchange as E_b/I_0 is higher is that at lower E_b/I_0, combining multipaths with two or three fingers increases power control error in contrast to one finger but at higher E_b/I_0, the second and the third multipath's signal energy increases and this makes the power control error decrease.

4-3 BER Performance Comparison Between Convolutional and Concatenated Coding in Data Traffic

Fig. 4 shows the BER performance comparison between convolutional only and concatenated coding for data traffic in indoor and vehicular environments of 5 MHz when data information rate is given as 35.2 kbps. The BER performance for convolutional only is evaluated to consider the addition of 16 cyclic redundancy code (CRC) bits to check frame error. per antenna which is required to maintain 10^{-6} BER is represented 5.2 dB for convolutional coding and 3.8 dB for concatenated coding in pedestrian environment, and 4.9 dB for convolutional coding and 4.3 dB for concatenated coding in vehicular environment. Thus, the gain of the required E_b/I_0 due to concatenated coding compared to convolutional

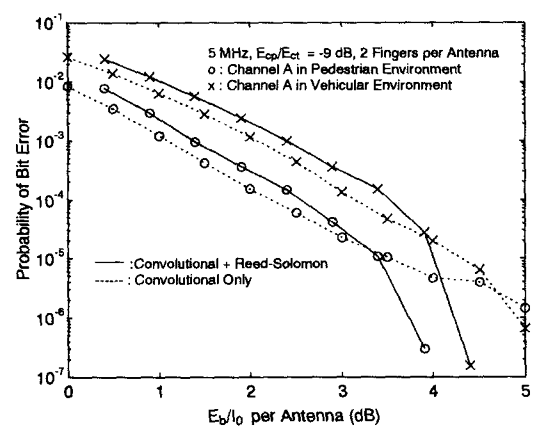

Fig. 4. BER for convolutional and concatenated coding in data traffic.

coding is shown as 1.4 dB in the indoor environment and 0.6 dB in the vehicular environment. It is a simulation error that the dotted line (convolution only) exceeds solid line (convolution + Reed-Solomon) at E_b/I_0 4 dB under pedestrian environment.

V. CONCLUSION

In this paper, the BER performance for CDMA-based IMT-2000 are evaluated by the results of the reverse link simulation in ITU-R channel environments. Simulations in the reverse link are made for 5 MHz system and for the multipath fading model that uses Jake's model. The optimum ratio of pilot power to traffic power for speech traffic is selected about −5dB, while that for data traffic is done about −9 dB for 38.4 kbps data and about −11 dB for 76.8 kbps data. In 5 MHz system, the optimum number of fingers per antenna for the indoor environment is given as 1 for 10^{-3} BER and 2 for 10^{-6} BER, while that for the vehicular environment is given as 2 regardless of the BER performance. The gain of the required E_b/I_o due to concatenated coding compared to convolutional coding for data traffic is resulted in 1.4 dB for the pedestrian environment and 0.6 dB for the vehicular environment.

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