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Performance Analysis of Fixed-Point Simulations on cdma2000-1x Downlink*

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Abstract: Based on the physical layer standard of cdma2000, the performance analysis of fixed-point simulations is presented in this paper on cdma2000-1x downlink. The effects of quantization and finite wordlength, which have typically been assumed negligible in floating-point simulations, become significant for fixed-point simulations. The complete fixed-point simulation platform for cdma2000-1x downlink is developed by EDA tool — COSSAP. The structure and performance of the key component in cdma2000 systems, the RAKE receiver, are discussed in details. Comparisons of results between floating-point and fixed-point simulations lead to some important conclusions, which provide certain references for the implementation of practical systems.

Key words: cdma2000, fixed-point simulation, RAKE receiver

The third generation mobile communication systems are being developed around the world. The choice of CDMA has become the mainstream as the air interface scheme in the wireless mobile networks because of its potential capacity and other technical factors such as soft handoff (or site diversity) and anti-multipath fading capabilities[1]. cdma2000 is among the favoured candidates for the third generation mobile communication systems.

In the previous analysis of transmission performance of the physical layer in cdma2000 systems, floating-point simulations are generally adopted for their numerous advantages, including large dynamic range, high data precision, and very small possibility of data overflow during arithmetic operations. In fixed-point simulations and implementation of practical systems, however, signals must be sampled and quantized before manipulations through special digital signal processing hardware units. Finite wordlength representations of the signals lead to loss in data precision. During signal processing operations, adders, multipliers and memories with finite wordlength lead to further loss in data precision. Moreover, problems of data overflow must be seriously considered due to small dynamic range.

In this paper, great importance has been attached to the influence of fixed-point operations on some key components in the system such as the RAKE receiver and the Viterbi decoder, and their corresponding performances are discussed in details, respectively. Comparisons of results between floating-point and fixed-point simulations lead to some important conclusions, which provide certain references for the implementation of practical systems.

In section 1, the structures of the fixed-point simulation system and the RAKE receiver are presented. Simulation results are discussed in details in section 2 and comparisons of results between floating-point and fixed-point simulations are also presented. Finally, conclusion is drawn in section 3.

1 System Model

1.1 Structure of fixed-point simulation system

Based on the physical layer standard of cdma-2000, we have established the fixed-point simulation system for cdma2000-1x downlink.

Fig.1 shows the baseband transmitting part of the system. After being channel-coded by a specific convolutional code and block interleaved, the data symbols on Forward Fundamental Channel are scrambled by a long PN code and then transformed into QPSK sym-

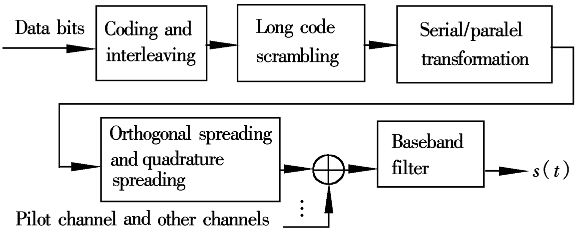

Fig.1 Basedband transmitting part of cdma2000-1x downlink

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bol sequences, that is, I-data and Q-data. I and Q data sequences are orthogonally spread by a Walsh code and then spread in quadrature by a pair of channel PN sequences. After addition with signals from other channels, the spread signal is baseband filtered and transmitted over a multipath Rayleigh fading channel.

Fig.2 shows the baseband receiving part of the system. After matching filtered, the received signal is normalized in its dynamic range before A/D conversionis carried out. After channel estimation and RAKE combining, the data symbols are demodulated just according to the inverse process of modulation mentioned above. Before being deinterleaved and soft-decision Viterbi decoded, the data symbols are normalized in their power frame by frame and quantized for the second time. At the end of the link, the bit error rate is calculated.

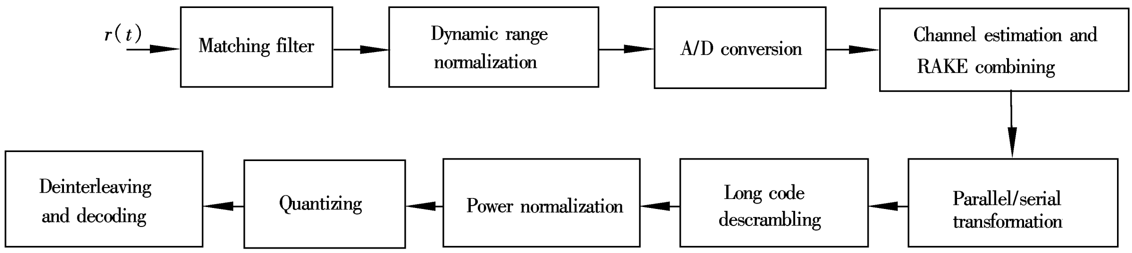

Fig. 2 Baseband receiving part of cdma2000-1x downlink

1.2 Structure of fixed-point RAKE receiver

In cdma2000-1x downlink, the transmitted signal consists of forward pilot channel and K forward traffic channels and control channels. The equivalent baseband transmitted signal is given as follows:

$$u(t) = x_0(t) + \sum_{i=1}^{K} x_i(t) = \left[\sqrt{P_0}\, d_0(t) + \sum_{i=1}^{K}\sqrt{P_i} d_i(t) w_i(t)\right]\cdot p(t) = \left[\sum_{i=0}^{K}\sqrt{P_i} d_i(t) w_i(t)\right]\cdot p(t) \quad (1)$$

where $x_i(t)$ is the signal of the i-th channel; $x_0(t)$ is the signal of forward pilot channel; $d_i(t)$ is the information sequence taking on the values of $+1$ and -1 with equal probability; $w_i(t)$ is the Walsh function assigned to the i-th channel and P_i is the transmit power of the i-th channel; $p(t)$ is the equivalent complex PN sequence given by

$$p(t) = p_{\mathrm{I}}(t) + \mathrm{j} p_{\mathrm{Q}}(t) = \sum_{n=-\infty}^{+\infty} p_{\mathrm{I}}(n) h(t - nT_{\mathrm{c}}) + \mathrm{j}\sum_{n=-\infty}^{+\infty} p_{\mathrm{Q}}(n) h(t - nT_{\mathrm{c}}) \quad (2)$$

where $h(t)$ is the normalized chip waveform; $T_{\mathrm{c}} = 1/W$ is the chip duration and W is the signal bandwidth.

Through a tapped-delay-line channel model with L taps[2, 3], the received signal $r(t)$ can be written as

$$r(t) = \sum_{k=0}^{L-1} c_k(t) u(t - kT_{\mathrm{c}}) + n(t) \quad (3)$$

where the time-variant tap weights $\{c_k(t) 0 \leqslant k \leqslant L-1\}$ are statistically independent complex Gaussian random processes. Suppose $c_k(t) = \alpha_k(t)\mathrm{e}^{-\mathrm{j}\theta_k(t)}$, where $\alpha_k(t)$ represents the amplitude of slowly varying independent stationary Rayleigh random process and $\theta_k(t)$ is the random variable uniformly distributed on $[0, 2\pi)$. $n(t)$ is a zero-mean complex Gaussian random process representing additive white Gaussian noise (AWGN) with two-sided power spectral density N_0.

Fig.3 illustrates the structure of the fixed-point RAKE receiver. The RAKE receiver output after diversity combining, U_m can be expressed as

$$U_m = \sum_{l=0}^{L-1} y_{ml}\hat{c}_l^{*} \qquad 1 \leqslant m \leqslant K \quad (4)$$

where $y_{ml} = \int_{lT_{\mathrm{c}}}^{lT_{\mathrm{c}}+T_{\mathrm{s}}} r(t) p^{*}(t - lT_{\mathrm{c}}) w_m^{*}(t - lT_{\mathrm{c}})\mathrm{d}t$; $\{\hat{c}_l^{*}, 0 \leqslant k \leqslant L-1\}$ are the conjugate values of the estimated channel parameters; and T_{s} is the symbol duration before spreading.

In cdma2000-1x downlink, pilot-assisted channel estimation is performed to obtain the knowledge of the amplitude, phase and delay of each path signal that is selected for combining. After despreading of forward pilot channel, the output of the correlator is

$$y_{\mathrm{p}l} = \int_{lT_{\mathrm{c}}}^{lT_{\mathrm{c}}+N_{\mathrm{p}}T_{\mathrm{c}}} r(t) p^{*}(t - lT_{\mathrm{c}})\mathrm{d}t \quad (5)$$

where N_{p} is channel estimation interval length and is expected to be as large as possible to make channel estimation accurate under the condition that channel parameters $\{c_l, 0 \leqslant l \leqslant L-1\}$ are almost invariable during this interval. Then we have

$$y_{\mathrm{p}l} = 2N_{\mathrm{p}}T_{\mathrm{c}}\sqrt{P_0}\, c_l + n_{\mathrm{p}l} \quad (6)$$

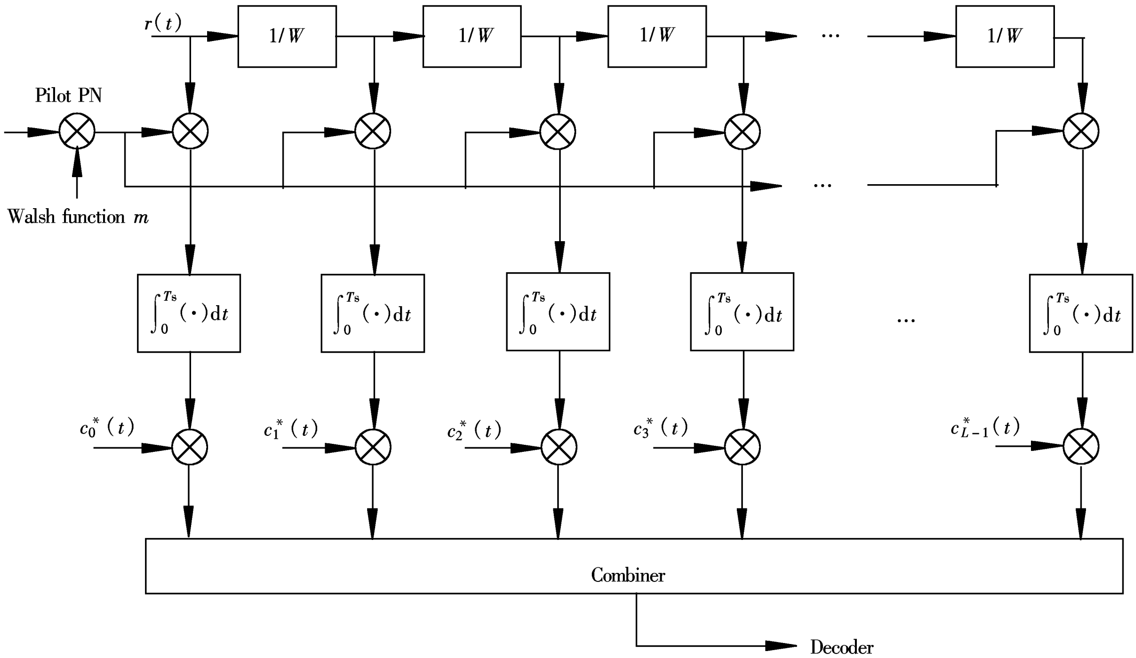

Fig.3 Structure of RAKE receiver for cdma2000-1x downlink

where n_{pl} is the correlation output of Gaussian noise. Thus the estimated value of c_l is

$$\hat{c}_l = \frac{y_{pl}}{2N_p T_c \sqrt{P_0}} \tag{7}$$

The equivalent baseband received signal must be normalized in its dynamic range before channel estimation and RAKE combining, which is implemented by analogic AGC in practical systems. Then A/D conversion is performed to the signals from in-phase channel and quadrature channel respectively. The wordlength of A/D converters is equal to 4 bits, 6 bits or 8 bits. If the wordlength is 8 bits, the signals are converted into integers ranging from − 128 to 127. Thus signal processing is changed from floating-point operations to fixed-point operations.

Whether in floating-point simulations or fixed-point simulations, channel estimation has significant influence on the RAKE receiver that is very important to mitigate the multipath fading effect in the CDMA systems. The choice of the wordlength of the accumulator in the channel estimation unit must meet the requirements of full-precision operations. Suppose the wordlength of the A/D converter before RAKE receiver is 8 bits, if the channel estimation interval length is 256 chips, the wordlength of the accumulator should be 16 bits; if the channel estimation interval length is 512 chips, the wordlength of the accumulator should be 17 bits. An averaging manipulation is performed on successive estimated channel parameters by extracting the highest 8 bits of the result from the accumulator.

Before being soft-decision Viterbi decoded, the data symbols are normalized in their power frame by frame and quantized for the second time with the wordlength of 3 or 4 bits.

2 Simulation Results and Performance Analysis

In the following simulations, we adopt a kind of typical channel configuration, that is, 1 Sync Channel, 1 Paging Channel, 1 Dedicated Control Channel, 1 Forward Fundamental Channel whose data rate is 9.6 kbit/s, 1 Forward Supplemental Channel whose data rate is 76.8 kbit/s and 1 Forward Pilot Channel are included[4]. Here only Forward Fundamental Channel is demodulated and its bit error rate is calculated, so other channels act as multiple-access interference. The spread signal is transmitted over a multipath fading channel model of ITU M.1225 for vehicular environments. The size of the searching window in channel estimation unit is 12 chips, and the step length in searching is 1 chip. The number of fingers for RAKE combining is 3[5].

Fig.4 shows the average BER performance as a function of the average E_b/N_0 with different values of wordlength of the A/D converter. We can see that when the ADC wordlength is equal to 2, the fixed-point simulation system can't work at all. When the ADC wordlength increases to 4, the average BER drops dramatically. If the ADC wordlength is equal to 8, the average BER performance of the fixed-point simulation system is very close to that of the floating-point simulation system.

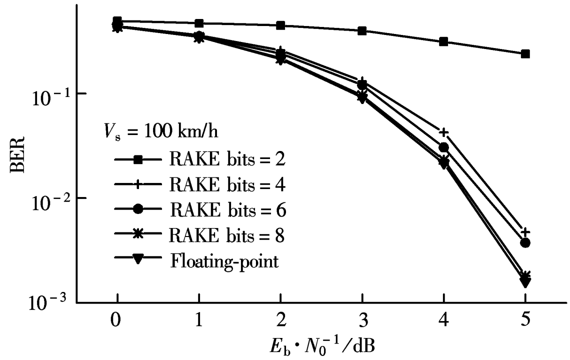

Fig.4 BER performance with different ADC wordlength

Fig.5 shows the average BER performance as a function of the average E_b/N_0 with different values of the quantization wordlength before the Viterbi decoder. The results show that when the quantization wordlength is equal to 4, the average BER performance of the fixed-point simulation system is very close to that of the floating-point simulation system. If the quantization wordlength is equal to 3, the performance loss is less than 0.5 dB compared with the performance of the floating-point simulation system.

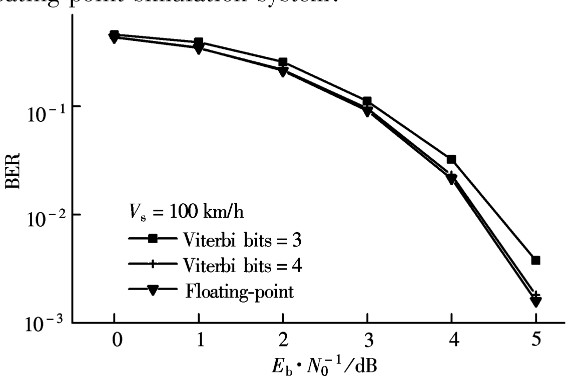

Fig.5 BER performance with different quantization wordlength

Fig.6(a) shows the average BER performance as a function of the average E_b/N_0 for the cases of channel estimation interval length equaling 256 chips, 512 chips and 1 024 chips, respectively, where mobile velocity is 100 km/h. As the channel estimation interval length increases, the average BER performance of the system improves dramatically due to the fact that the channel experiences slow fading.

For the case of mobile velocity equaling 300 km/h in Fig.6(b), as the channel estimation interval length increases from 512 chips to 1 024 chips, the average BER performance improvement is not as obvious as that for 100 km/h. The higher the mobile velocity is, the faster the channel changes due to the Doppler effect. Under this circumstance, with the increase of channel estimation interval length, the estimated values of channel parameters are less accurate.

For the case of mobile velocity equaling 500 km/h in Fig.6(c), as the channel estimation interval length increases from 512 chips to 1 024 chips, the average BER performance worsens dramatically. Under this circumstance, the channel estimator fails to track the fast fading channel so the estimated values of channel parameters are not accurate at all.

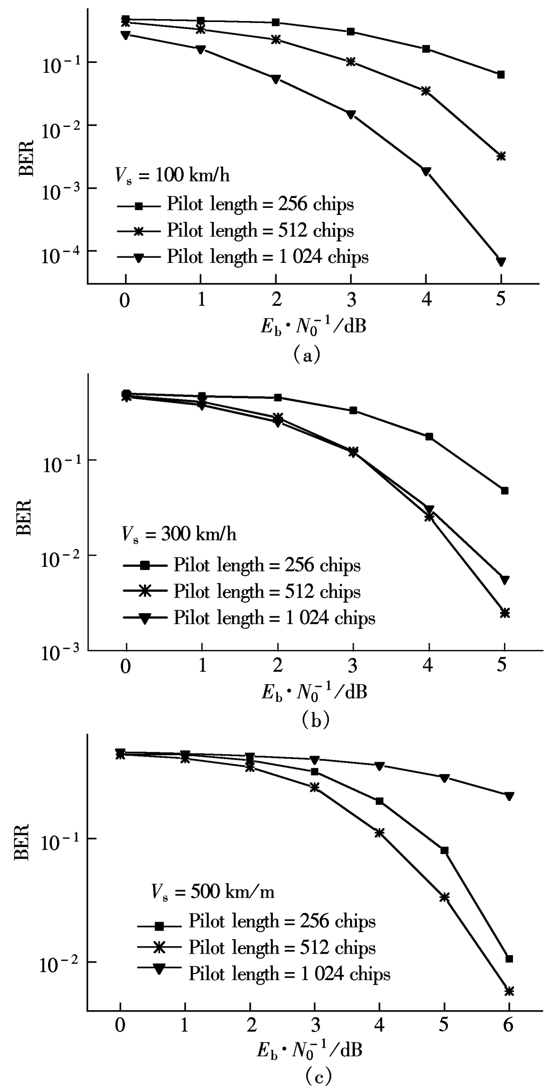

Fig.6 BER performance with different channel estimation interval length

Fig.7 shows the average BER performance as a function of the average E_b/N_0 with different mobile velocities. We can see that BER performance curve corresponding to 100 km/h crosses with that corresponding to 300 km/h (Here channel estimation interval length is 512 chips). For one thing, the channel estimation interval length for 100 km/h is not long enough to effectively suppress the noise influence. For another, although the estimated values of channel parameters become less accurate due to the fast change of the channel for the case of 300 km/h, the Viterbi decoder, together with the block interleaver and deinterleaver, is good at correcting burst errors, which to some extent compensates the performance loss of the RAKE receiver.

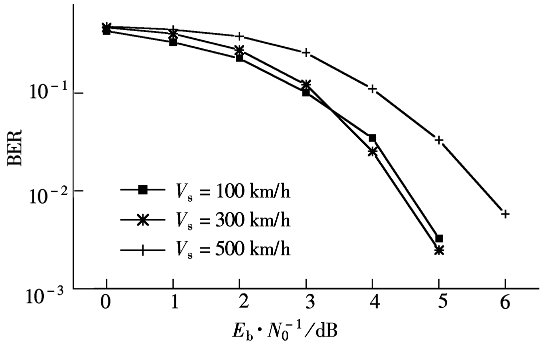

Fig.7 BER performance with different mobile velocities

In practical systems, the transmission power of Forward Pilot Channel is A_0 times that of Forward Fundamental Channel and A_0 is called pilot power gain factor. Fig.8 shows the average BER performance as a function of the average E_b/N_0 with different A_0. The results show that as A_0 increases from 0 to 6 dB, the average BER performance is improved by nearly 2 dB. When A_0 is equal to 9 dB, the average BER performance is similar to that of $A_0 = 6$ dB.

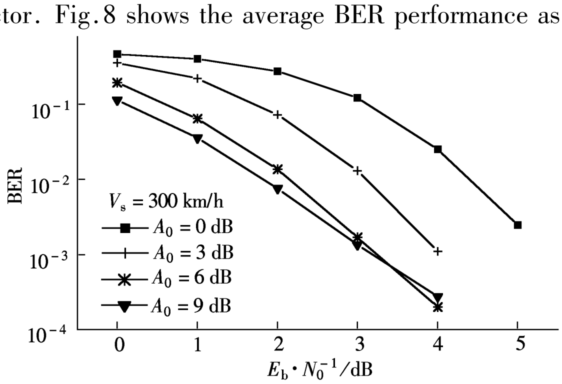

Fig.8 BER performance with different pilot power gain factors

3 Conclusion

If the ADC wordlength before the RAKE receiver is 8 bits and the quantization wordlength before the Viterbi decoder is 4 bits, the average BER performance of the fixed-point simulation system is very close to that of the floating-point simulation system.

The averaging interval for the channel estimation should be adaptively optimized in order to satisfy a wide mobile speed range for the third generation mobile communication systems.

When the pilot power gain factor, A_0, is between 6 and 9 dB, the needs of practical systems can be satisfied.

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cdma2000-1x 下行链路定点仿真研究

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摘 要 本文依据 cdma2000 物理层标准，以浮点仿真为基础，建立了 cdma2000-1x 下行链路的定点仿真平台，重点研究了定点化处理对于 RAKE 接收机和 Viterbi 译码器性能的影响，并且将仿真结果进行了比较和分析，对实际系统的实现具有一定的指导和借鉴价值.

关键词 cdma2000，定点仿真，RAKE 接收机

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