Packet Acquisition

for a CDMA/TDD Packet Radio System

Jin Young Kim

School of Electronics Engineering
Kwangwoon University
447-1, Wolgye-dong, Nowon-gu
Seoul 139-701, Korea

ABSTRACT

In this paper, an adaptive packet acquisition performance of a CDMA/TDD packet radio system is analyzed and simulated in a frequency-selective Rayleigh fading channel. The frequency-selective fading process is assumed to be WSSUS model which is typical for a satellite and a mobile radio communications. The performance is evaluated in terms of packet error probability. In this adaptive packet acquisition scheme, an auxiliary training sequence is placed within data packet to estimate time-varying channel state. From the simulation results, it is confirmed that the proposed acquisition scheme significantly improves packet error performance compared to the conventional fixed acquisition scheme, especially, for the case of low Doppler frequency. The analysis in this paper can be applied to the design of a CDMA/TDD packet radio system.

I . INTRODUCTION

Both FDD (frequency division duplex) and TDD (time division duplex) modes have been employed in FDMA (frequency division multiple access) and TDMA (time division multiple access) in order to separate forward and reverse links on mobile channels. The CDMA (code division multiple access) system has been under operation based on the FDD mode. Recently, the TDD mode attracts a lot of attentions in the development of the IMT-2000 system [1-3]. The TDD base station measures the reverse response of the reverse link, and uses a matched filter to the channel. It then pre-matches the signal it wishes to transmit on the forward link since its impulse response is identical.

The main advantage of the TDD is the reciprocity of forward and reverse links, which facilitates the implementation of a number of power control and diversity techniques without increased complexity, leading to simpler mobile stations.

The CDMA/TDD system has been proposed as a promising solution for multimedia traffic service since it has many kinds of benefits [3,4]; 1) simple channel access for discontinuous data transmission, 2) open loop power control, and 3) capability to use pre-RAKE combining and efficient antenna diversity techniques, etc. For an efficient operation of the CDMA/TDD system, synchronization is a critical issue in a wide variety of levels which include network, packet, bit, and chip synchronization levels. Previous research on the CDMA/TDD systems has primarily focused on resource allocation, power control, diversity technique, and capacity analysis, etc. In this paper, we focus on the aspects on packet synchronization for the CDMA/TDD packet radio system. Adaptive packet acquisition scheme is proposed and simulated under various kinds of environments. In the CDMA/TDD packet radio system, a packet begins with a synchronization preamble. The packet acquisition process involves detection of packets and a suitable procedure to acquire initial packet timing. For detection of the packets, a conventional fixed-threshold control scheme has been employed. However, in a multipath and a multiuser environment, interference power usually fluctuates.

The previous research on the packet acquisition for a CDMA/TDD packet radio system has focused on acquisition time performance only in a packet synchronization level [5]. However, from the overall system perspective in a CDMA/TDD packet radio system, the packet acquisition has an influence on the RAKE reception performance because it determines the tap delay settings used in the RAKE receiver.

In this paper, the adaptive RAKE reception performance of

This research was supported in part by University Academic Basic Research of the Institute of Information Technology Assessment (IITA) of Korea under Grant 2001-037-3.

a DS/SSMA packet radio system is evaluated in a frequency-selective Rayleigh fading channel. The frequency-selective fading process is assumed to be WSSUS model which is typical for a satellite and a mobile radio communications. In the DS/SSMA packet radio system, a packet header in each packet is used to derive initial tap delays for multipath combining in RAKE reception. A typical RAKE receiver employs a fixed tap delay scheme where tap delays are set during packet acquisition and remains fixed for entire packet reception. In order to optimize performance, an adaptive packet acquisition scheme is proposed in this paper by placing auxiliary training sequences periodically within data payload for tracking the strongest multipath component in a time-varying channel environment. This auxiliary sequence is used for estimation of channel state. The duration of auxiliary training sequence is set to be much longer than the channel symbol duration to ensure an accurate channel estimate.

The rest of this paper is organized as follows: In section II, proposed system and channel model are described. In section III, the packet error probability is derived. Simulation results and discussions are presented in section IV. In Section V, some conclusions are drawn.

II. SYSTEM MODEL

In a CDMA/TDD packet radio system, a packet begins with a short synchronization preamble. Processing such a preamble to provide the necessary timing information is common practice in burst-type communication systems. In a packet radio system, packet-type services are designed for on-off sources which do not generate any information during an off period. Because discontinuous transmission is used, a fast acquisition process is required for each transmission burst in order to re-establish a physical link with minimal delay.

The performance is analyzed in terms of packet error probability. BPSK (binary-phase-shift-keying) modulation is employed with noncoherent RAKE combining using maximal ratio combining (MRC) which weighes each branch signal by the signal amplitude at that branch. The packet error probability is evaluated by varying the parameters such as Doppler frequency, FEC (forward error correction) code rate, and the length of auxiliary training sequence.

II.1. Transmitter Model

For a CDMA/TDD system with K users, the *kth* user's transmitted signal is given by

$$s_k(t-\tau_k) = \sqrt{2P_k}\, d_k(t-\tau_k) a_k(t-\tau_k) \cos(\omega_c t + \phi_k), \qquad (1)$$

where P_k is the signal power, $d_k(t)$ is a data sequence with bit duration T, $a_k(t)$ is a spreading sequence with chip duration T_c, τ_k is propagation delay, ω_c is carrier frequency, and ϕ_k is phase parameter of carrier. Assume that the power P_k is independent of the propagation delays and phase parameters. Suppose $d_k(t)$ and $a_k(t)$ are sequences of $\{1, -1\}$ with rectangular pulse shape. The spreading sequence $a_k(t)$ is generated at a rate M chips per data pulse. During demodulation at the receiver, the composite signal is multiplied by a replica of the spreading sequence so that the desired data sequence is obtained at the receiver output.

II.2. Channel model

In a typical UHF or microwave radio channel, Rayleigh fading is encountered for a non-line-of-sight environment. When the multipath delay spread of the channel is greater than the chip duration of PN code, frequency selectivity should be considered [6]. In the CDMA/TDD system, individual paths can be distinguished if they are mutually separated by delays greater than chip duration. The WSSUS (wide-sense-stationary-uncorrelated-scattering) fading model has been employed to model the frequency-selective fading channel. This model is quite general and includes the double selective (i.e. selective in both time and frequency) channels. Only frequency selectivity is considered in this paper.

The channel covariance function for a frequency-selective fading channel is given by

$$g_i(t) = \rho_i(\tau, 0) = \rho_i(\tau, t-s), \quad \text{for all t, s,} \qquad (2)$$

A frequency-selective fading channel exhibits memory and therefore introduces intersymbol interference into the received signal. It is assumed that the selectivity of the channel is such that, in the detection of the data symbol, we need to be concerned only with the ISI due to the two adjacent data symbols. This condition is equivalent to assuming that $g_i(t) = 0$ (for $|\tau| > T$).

III. PERFORMANCE ANALYSIS

In the performance analysis, the perfect carrier and bit synchronization are assumed. In a RAKE receiver, each of correlators is synchronized to the distinct path, and the outputs of correlators are combined to estimate the received data symbol. It is assumed that the multipath delay spread is much less than one data symbol period, so that intersymbol interference can be ignored. For an application in mobile cellular environments, we consider hexagonal cell pattern. Each of cell is assumed to have the same user distribution within a cell. With K users for each cell, the received signal going through a fading channel is given by

$$r(t)=\sum_{i=1}^{K}A_i\alpha_i d_i(t-\tau_i)a_i(t-\tau_i)\cos(\omega_0 t+\theta_i)$$

$$+\sum_{i=K+1}^{jK}A_i\alpha_i\left(\frac{d_{ji}}{d_{1i}}\right)^{\gamma/2}d_i(t-\tau_i)a_i(t-\tau_i)\cos(\omega_0 t+\theta_i)$$

$$+n_w(t), \tag{3}$$

where A_i is unfaded amplitude of the *ith* received signal, α_i is independent Rayleigh random variable representing fading each with parameter σ^2, θ_i is random carrier phase, γ is path loss exponent which describes how the received power falls off with distance, d_{1i} is distance from the *ith* mobile to base station of interest, d_{ji} is distance from the *ith* mobile to the *jth* base station, and $n_w(t)$ is AWGN with two-sided power spectral density $N_0/2$. The propagation delays τ_i is uniformly distributed in [0, T], and the carrier phases θ_i is uniformly distributed in [0, 2π]. All delays and phases are assumed independent of one another and independent of the data.

Let reference user(desired user) be user 1. The decision statistic of the reference user (user 1) is given by

$$Z_1(T)=A_1\alpha_1 T+\sum_{i=2}^{K}A_i\alpha_i I_i(T)\cos\theta_i$$

$$+\sum_{i=K+1}^{jK}A_i\alpha_i\left(\frac{d_{ji}}{d_{1i}}\right)^{\gamma/2}I_i(T)\cos\theta_i+N_g(T)\text{'} \tag{4}$$

where $N_g(T)$ is a zero-mean Gaussian random variable with variance N_0T, θ_1 and τ_1 are set to equal to zero without loss of generality, and $I_i(T)$ is given by [7,8]

$$I_i(T)=\int_0^T d_i(t-\tau_i)a_i(t-\tau_i)a_1(t)dt\,. \tag{5}$$

If we define the random variable ξ_i by

$$\xi_i=\begin{cases}1, & 2\le i\le K\\ \left(\dfrac{d_{ji}}{d_{1i}}\right), & K+1\le i\le jK\end{cases} \tag{6}$$

the decision statistic of reference user is modified by

$$Z_1(T)=A_1\alpha_1 T+\sum_{i=2}^{K}A_i\alpha_i\xi_i I_i(T)\cos\theta_i+N_g(T)\text{,} \tag{7}$$

When power control within each cell is perfect, that is, $A_k=A$ ($1\le k\le K$), then the total interference including AWGN is given by

$$\sigma_t^2=N_0T+\frac{A^2\sigma^2T_c^2M}{3}(K-1+\sum_{i=K+1}^{jK}\xi_i^2)\text{,} \tag{8}$$

Since *p.d.f.* of MAI and self interference is difficult to obtain, the CDMA/TDD system can be evaluated using some approximations. For a large number of users, the *p.d.f.* is usually assumed to approximate Gaussian process with a variance equal to the sum of variances of individual interfering users. Thus, the effect of AWGN, MAI, and fading can be incorporated into performance analysis simply by increasing variance of interference.

Under the assumption of sufficiently long interleaver and FEC technique, the codeword errors become independent. When the codeword errors are *i.i.d.* within each packet, the packet error probability is given by

$$P_e=\sum_{k=t+1}^{L}\binom{L}{k}P_c^k(1-P_c)^{L-k}\,, \tag{9}$$

where L is overall packet size including packet header and payload data packet in bits, t is error correcting capability of the FEC scheme, and P_c is codeword error probability.

IV. SIMULATION RESULTS

For a hexagonal cell pattern, 7 cells consist of one cell of interest and 6 cells of the first tier. Although there are many cells in the geographical area, it is a reasonable to consider only thefirst tier because the adjacent cell interference from cells of the first tier is dominant. For simulation examples, carrier frequency f_c = 1900 MHz, overall length of packet L = 511 (bits), the number of adjacent cells j = 6, processing gain M = 64, and path loss exponent γ = 4 were assumed. The Gold code is selected as a PN code because it has good crosscorrelation property, and a large size of code set for multiple access applications. The chip waveform is a rectangular pulse form.

To enhance reliability of packet transmission, the FEC scheme is typically employed in a CDMA/TDD packet radio system. In this paper, the (n, λ, t) BCH code is used as an FEC scheme [9]. A packet is taken as a codeword which is assumed to be L=n where L is over packet length including packet header and payload bits. Let $L_d = \lambda$ denote the number of payload data bits per packet, we have code rate of $r = L_d / \lambda = L_d / L$. Then, it is known that the relationship between L, r, and the maximum number of correctable errors t is given by r = (L - 9t)/L.

In Fig. 2, packet error probability vs. E_b / N_0 is shown for code rate r = 0.86 and the length of auxiliary training sequence = 150 chips with varying vehicle speed. When the vehicle speed is v = 50 km/h, the maximum Doppler frequency becomes $f_d = f_c \cdot (v / c)$ = 41. 7 Hz (c is speed of light). It is shown that packet error probability is significantly reduced by adaptive packet acquisition scheme. When the vehicle speed is slow, the performance improvement becomes more drastic.

In Fig. 3, packet error probability vs. E_b / N_0 is shown for vehicle speed v = 10km/h and the length of auxiliary training sequence = 150 chips with varying the FEC code rate r. The code rate of 1.0 represents the uncoded case. By lowering the code rate, we achieved lower packet error probability. It is confirmed that the FEC is effective in improving packet error performance.

V. CONCLUSIONS

The adaptive packet acquisition has been proposed for a CDMA/TDD packet radio system. From the simulation results, it is confirmed that the adaptive acquisition scheme significantly improves packet error performance compared to the fixed acquisition scheme, especially, for the low Doppler frequency. And, it can be recommended that the length of auxiliary training sequence should be larger than the channel symbol duration. Therefore, since the CDMA/TDD systems are generally used for low-mobility applications such as indoor, picocell environments, we can find an application of this paper to the design of a CDMA/TDD packet radio system operating in a frequency-selective fading channel.

REFERENCE

[1] T. Ojanpera, J. Skold, J. Castro, L. Girard, and A. Klein, "Comparison of multiple access schemes for UMTS," *in Proc. IEEE VTC'97*, pp. 490-494, Phoenix, AZ, U.S.A, May 1997.

[2] T. Ojanpera and R. Prasad, *Wideband CDMA for Third Generation Mobile Communications*, Artech House, 1998.

[3] R. Esmailzadeh, M. Nakagawa, and E. A. Sourour, "Time-division duplex CDMA commuications," *IEEE Personal Commun.*, vol. 4, no. 2, pp. 51-56, Apr. 1997.

[4] G. J. R. Povey, "Capacity of a cellular time division duplex CDMA system," *IEE Proc.- Commun.*, vol. 141, no. 5, pp. 351-356, Oct. 1994.

[5] J. Y. Kim and J. H. Lee, "Parallel acquisition scheme for direct-sequence spread-spectrum multiple-access packet radio communication," *IEE Electronics Letters*, vol. 31, no. 12, pp. 948-950, June 1995.

[6] R. Price and P. E. Green, "A communication technique for multipath channels," *Proc. IRE*, vol. 46, pp. 555-570, Mar. 1958.

[7] M. B. Pursley, "The role of spread spectrum in packet radio network," *Proc. IEEE*, vol. 75, no. 1, pp. 116-134, Jan. 1987.

[8] E. Sousa, "Interference modeling in a direct sequence packet radio network," *IEEE Trans. Commun.*, vol. 38, no. 10, pp. 1475-1482, Oct. 1990.

[9] G. C. Clark, Jr. and J. B. Cain, *Error Correction Coding for Digital Communications*, Plenum, 1981.

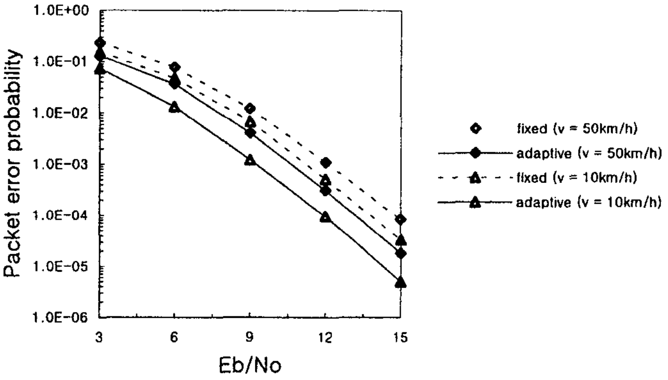

Fig. 1. Packet error probability for varying vehicle speed.

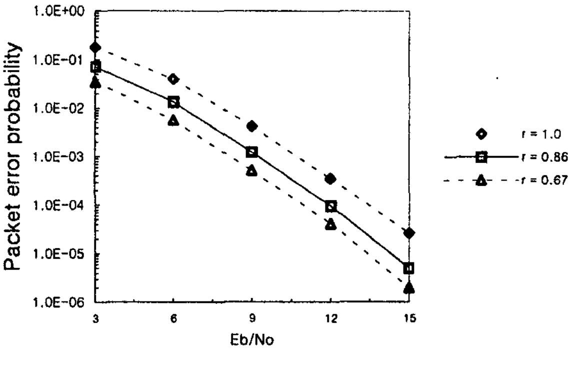

Fig. 2. Packet error probability for varying FEC code rate.