On the Application of PN Acquisition Scheme to a DS/SSMA Packet Radio System

Jin Young KIM¹, Student Member and Jae Hong LEE¹, Nonmember

SUMMARY The performance of a noncoherent parallel matched-filter (MF) acquisition scheme with a reference filter (RF) is evaluated for a direct-sequence/spread-spectrum multiple access (DS/SSMA) packet radio system in a mobile cellular environment. This acquisition scheme employs a RF to estimate the variance of interference at the output of detecting MF. Acquisition-based packet throughput of the parallel MF-RF scheme is derived for an AWGN and a Rayleigh fading channels. Packet throughput of a parallel MF-RF acquisition scheme is compared with those of a serial MF scheme, a serial MF-RF scheme, and a parallel MF. From the numerical results, it is shown that the packet throughput decreases with the number of users in the system, and increases with the preamble length. Imperfect power control causes packet throughput to decrease especially when the power control error is large. The considerations in this paper can be applied to the reverse link (mobile-to-base station) design of a DS/SSMA system for packet-type services.

key words: acquisition, DS/SSMA, packet throughput, packet radio

I. Introduction

Direct-sequence (DS) spread-spectrum (SS) packet radio systems have attracted much interest for multiple access (MA) communications in such commercial applications as digital cellular and personal communications networks[1],[2]. For effective and reliable communications in a DS/SS system, a receiver must synchronize a locally generated pseudonoise (PN) code with the incoming one[3]. The synchronization of a DS/SS system consists of two steps: acquisition (coarse alignment) and tracking (fine alignment). During acquisition process, PN code uncertainty region is searched until the incoming and locally generated PN codes are sufficiently closely (typically, within a chip) aligned[3]. PN tracking process serves to reduce the alignment error which remains after acquisition and to maintain the alignment error using feedback loops such as DLL (delay-locked loop) or TDL (tau-dither loop). Because the acquisition process mainly determines the code synchronization time, it should be achieved as fast as possible for rapid initial link setup and smooth handoffs in a mobile environment. Because communication cannot take place before acquisition has been achieved, the quick and effective acquisition schemes are required. We focus our attention only on the acquisition problem.

In a DS/SSMA packet radio system, a packet begins with a short synchronization preamble. Processing a such a preamble to provide the necessary timing information is common practice in burst-type communication systems[4]. 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 preamble length for the maximum packet throughput depends on various parameters such as the number of information symbols in a data burst and symbol error probability[5]. For the maximum packet throughput, a tradeoff exists between probability of correct synchronization and mean synchronization time. In a DS/SSMA packet radio system, a finite number of short PN codes is used in the preamble for a fast and effective acquisition.

Several methods for acquiring SS waveforms and the technology available to implement SS receiver has been proposed and analyzed[6]–[11]. A highly efficient method of acquisition is to detect the received signal by passing it through a matched filter (MF) and detecting the time at which the output magnitude is maximum[6]. Matched filtering is one of the methods to acquire the phase of received PN code. The MF acquisition scheme is largely classified into two categories, that is, a serial and a parallel schemes. In a serial MF acquisition scheme, only one MF is used[7] while in a MF parallel acquisition scheme, a bank of parallel MF’s are employed[8]. To reduce mean acquisition time, a parallel search strategy has often been employed. The performance of noncoherent parallel MF acquisition scheme has been investigated for a system without a reference filter (RF)[8]. The RF is used to estimate the variance of interference at the output of the detecting MF[9]. In the previous researches, the acquisition schemes for only single-user case have been analyzed where the evaluation of mean acquisition time is the main task. The application of acquisition scheme for a packet radio system has been proposed[10],[11]. For DS/SSMA applications, multiple access interference (MAI), due
to multiple users, should be considered in the performance analysis. Since MAI component is inherent in a DS/SSMA system, it must be incorporated with signal, AWGN, and fading components in the analysis of acquisition performance.

In this paper, a noncoherent parallel MF-RF acquisition scheme is proposed and analyzed for a DS/SSMA packet radio system. A parallel MF-RF acquisition scheme has been known to achieve faster acquisition than serial MF schemes, a parallel MF without RF scheme [11]. Owing to the difficulty of synchronizing the phase of a low spectral-density DS/SSMA signal, the noncoherent acquisition schemes is adopted. The acquisition performance is evaluated in terms of packet throughput. The performance analysis is based on a fixed receiver blocking probability criterion. The expressions of packet throughput are derived for an AWGN and a Rayleigh fading channels. Although the main characteristic of a PN acquisition scheme is mean acquisition time, we choose packet throughput as a performance measure for an application of a PN acquisition scheme to a mobile cellular packet radio system. The PN acquisition performance may pose a limit to the DS/CDMA capacity which are more stringent than those coming from bit error rate (BER) or outage probability specifications [12]. In such an environment, packet throughput can be a more reasonable performance criterion than mean acquisition time because packet throughput is a major performance measure in a packet radio system. The mean acquisition performance for a parallel MF-RF acquisition scheme has already been analyzed [13], [14].

This paper is organized as follows: In Sect. 2, a system model of noncoherent parallel MF-RF and packet structure are described. In Sect. 3, DS/SSMA is modeled, and the packet throughput is derived for an AWGN and a Rayleigh fading channels. Numerical examples are presented in Sect. 4, and conclusions are drawn in Sect. 5.

2. System Model

The model of a DS/SSMA packet radio system is shown in Fig. 1. For a DS/SSMA system with $K$ users, the $k$th user’s transmitted signal is given by

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

(1)

where $P_k$ is the signal power, $d_k(t)$ is a data sequence, $a_k(t)$ is a spreading sequence, $\tau_k$ is propagation delay, $\omega_c$ is carrier frequency, and $\phi_k$ 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 $1, -1$ 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.

Since the carrier phase is not easy to obtain in a mobile environment, noncoherent modulation and demodulation is considered. In the modulation process, to enhance the packet transmission reliability during transmission, channel coding is usually employed. The channel coded data is spread by a PN spreading code, then it is transmitted through the mobile radio channel. The packet in the urban mobile channel goes through fading and shadowing.

In the demodulation process, the PN acquisition and frame synchronization is first performed in the receiver. When the delay spread is larger than chip duration, the RAKE receiver can be implemented by a digital matched filter, memory array, and processing unit. The output of RAKE receiver passes through channel decoder. The decoded output becomes an estimate of transmitted data. As a practical example, in a IS-95
standard (Qualcomm CDMA), the RAKE receiver is employed to obtain path diversity gain. In this standard, the chip rate is 1.2288 Mcps and delay spread is about a few microseconds when operating in a urban environment.

A noncoherent parallel MF acquisition scheme with RF is shown in Fig. 2. It consists of a bank of \( N \) noncoherent parallel I-Q MF’s and a I-Q MF corresponding to RF. The parallel MF-RF scheme was adopted to provide fast acquisition. The received signal is first down-converted to inphase and quadrature components. The reference filter is employed to estimate the variance of interference at the output of the upper branch of Fig. 2 in order to control the false alarm probability. The reference I-Q MF provides a reference level for the synchronization decision. At each sampling instant within the PN sequence, the number of repetitions for which the output of the upper branch exceeds that of the lower branch is monitored. When the output of parallel detecting MF’s exceeds the reference MF output multiplied by a gain factor, a start signal is sent to the receiver code generator. Then, the system goes into a verification mode. The gain factor is chosen to keep the false alarm probability below a certain limit. The parallel detecting I-Q MF’s are loaded with transmitted PN codes and reference I-Q MF is loaded with a PN code orthogonal to the transmitted PN codes. If the length of MF is much shorter than the transmitted PN code length, the reference I-Q MF is loaded with a section of PN code. This makes the noise distribution at the reference I-Q MF output unbiased. Each of transmitted PN codes consists of \( M = T/T_c \) chips where \( T \) and \( T_c \) are data bit and chip durations, respectively. The number of taps in a detecting (or reference) I-Q MF is \( M/\Delta \) where \( \Delta \) is a phase adjustment parameter (or phase updating step size). A running average of the output of a reference I-Q MF is multiplied by a gain factor. The result is used as a decision threshold. A I-Q MF of \( N \) parallel detecting MF’s is shown in Fig. 3.

The acquisition scheme in the analysis has two modes of operations: a search mode and a coincidence detection (CD) mode (or a verification mode). In the search mode, a tentative decision is made on the delay of the received signal. In the CD mode, a more accurate decision is achieved to avoid false alarms. The output of \( N \) detecting MF’s is compared to the threshold at the \( M T_c \) intervals, which ensures independent observations. Assume that the code uncertainty region is a full code length of \( MN \) chips. Each sample at the decision device corresponds to one of the \( MN/\Delta \) phases in the code uncertainty region.

The packet data structure used in the scheme is shown in Fig. 4. Suppose a preamble consists of \( N \) identical \( M \)-chip PN codes. The first PN code \( PN_1 \) is for the search mode. The second code \( PN_2 \) is not processed and used to provide the receiver extra time to adjust the phase of its locally generated PN code. The remaining \( N - 2 \) PN codes are used to determine an optimum sampling instant for the CD mode. At the end of a CD mode, if \( N' \) out of \( N - 2 \) CD tests are larger than the threshold of CD mode, acquisition is accepted and data demodulation begins. Otherwise, the local PN code returns to \( PN_1 \) and search for acquisition is repeated.

3. Performance Analysis

In a DS/SSMA system, MAI can be modeled as an AWGN process with variance equal to the MAI variance[15],[16]. With a jointly Gaussian approximation of MAI components, we gain unconditional independence within a single desired data bit. The actual inter-
ferences from other users are uncorrelated. Therefore, if we model the MAI components from interfering transmitters as jointly Gaussian random variables, then the MAI components are unconditionally independent [17]. In the reverse link of a DS/SSMA system, other users transmit with orthogonal PN codes and their signals can be assumed to go through fading independently.

Assume that the receiver has no knowledge about signal strength prior to the reception of a preamble. A packet is assumed to be correctly processed when the following conditions are satisfied [18]: 1) receiver should not be blocked by a preceding false coincidence detection. 2) first preamble bit must be detected. 3) acquisition decision must be confirmed at the end of the preamble.

A. DS/SSMA Modeling

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 [19]. With K users for each cell, the received signal going through a fading channel is given by [20]

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

(2)

where \( A_i \) is the faded amplitude of the ith received signal, \( \{ \alpha_i \} \) is independent Rayleigh random variable representing fading each with parameter \( \sigma^2 \); \( \theta_i \) is random carrier phase; \( \gamma \) is path loss exponent which describes how the received power falls off with distance, \( d_{ii} \) is distance from the ith mobile to base station of interest, \( d_{ji} \) is distance from the ith mobile to the jth mobile, and \( n_w(t) \) is AWGN with two-sided power spectral density \( N_0/2 \). The propagation delays \( \{ \tau_i \} \) are uniformly distributed in \([0, T]\), and the carrier phases \( \{ \theta_i \} \) are uniformly distributed in \([0, 2\pi]\). 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 [21]

\[ Z_1(T) = A_1 \alpha_1 T + \sum_{i=2}^{K} A_i \alpha_i I_i(T) \cos \theta_i \\
+ \sum_{i=K+1}^{K+1} A_i \alpha_i \left( \frac{d_{ji}}{d_{ii}} \right)^{\gamma/2} I_i(T) \cos \theta_i + N_g(T) \]

(3)

where \( N_g(T) \) is zero-mean Gaussian random variable with variance \( N_0 T \). \( \theta_1 \) and \( \tau_1 \) are set to equal to zero without loss of generality, and \( I_i(T) \) is given by

\[ I_i(T) = \int_0^T d_i(t - \tau_i) a_i(t - \tau_i) a_1(t) dt. \]

If we define the random variable \( \xi_i \) by

\[ \xi_i = \begin{cases} 
1, & 2 \leq i \leq K, \\
\left( \frac{d_{ji}}{d_{ii}} \right)^{\gamma/2}, & K+1 \leq i \leq jK, 
\end{cases} 
\]

(5)

the decision statistic of reference user is modified by

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

(6)

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

\[ \sigma^2 = N_0 T + \frac{A^2 \sigma^2 T_c^2 M}{3} \left( K - 1 + \sum_{i=K+1}^{K+1} \xi_i^2 \right) \]

(7)

With a bandpass filter (BPF) of a bandwidth \( B = 2/T_c \), at the receiver frontend, it was shown that \( MN/\Delta \) samples from a noncoherent parallel MF-RF are mutually independent and average noise power in BPF output is \( \sigma^2 = N_0/T_c \). [3].

The detection threshold of envelope detector is determined according to CFAR (constant false alarm rate) detection criterion. When the output of MF exceeds search mode threshold \( t_1 \), the constant false alarm probability is given by

\[ P_{fa} = \exp \left( -\frac{1}{2} \frac{\beta'}{\beta} \right) \]

(8)

where \( t_1 \) is the threshold of a search mode normalized by \( \sigma^2 \).

In a search mode with \( MN/\Delta \) independent samples at the decision device, false alarm probability is approximated as

\[ P_F = 1 - (1 - P_{fa})^{MN/\Delta} \approx P_{fa} \frac{MN}{\Delta} \]

for \( P_{fa} \ll 1 \).

(9)

The detection probability of a search mode is given by

\[ P_D = \sum_{n=0}^{2MN-1} \frac{(-1)^n}{(n+1)} \binom{2MN-1}{n} \exp \left( -nM \frac{\gamma}{n+1} \right) \\
\cdot Q \left( \sqrt{2M - \frac{\gamma}{n+1}}, \sqrt{(n+1)\beta'} \right) \]

(10)
where $\gamma_i$ is an input signal-to-noise ratio (SNR), and $Q(\cdot, \cdot)$ is the Marcum’s Q-function. In a coincidence detection, the probability of a successful CD at each test is given by

$$P_C = Q\left(\sqrt{2\gamma_0}, \sqrt{t_2'}\right),$$  

(11)

where $\gamma_0 = M \gamma_i$ is the output SNR of an detecting MF and $t_2'$ is the threshold of a verification mode normalized by $\sigma_T^2$. The probability of a successful CD is given by

$$P_{CD} = \sum_{k=N}^{N-2} \binom{N-2}{k} P_C^k (1 - P_C)^{N-2-k}. \quad (12)$$

When a false acquisition decision occurs, the probability of a false CD at each test is given by

$$P_{FC} = \exp\left(-\frac{t_2}{2}\right). \quad (13)$$

Then the probability of a false CD is given by

$$P_{FCD} = \sum_{k=N}^{N-2} \binom{N-2}{k} P_{FC}^k (1 - P_{FC})^{N-2-k}. \quad (14)$$

The average blocked time due to a false acquisition decision is given by

$$T_B = (N - 1 + L_d P_{FCD})T,$$  

(15)

where $L_d$ is the number of data bits in a packet and $T$ is the duration of a packet data bit. The average number of acquisition decisions between receptions of two consecutive packets is given by

$$\eta = \frac{T_S}{T + P_{F} T_B}, \quad (16)$$

where $T_S$ is average time between the arrivals of two consecutive packets. The average block time of the receiver during $T_S$ is $BP_F T_B$. Thus, from (9), (15), and (16), the probability of receiver blocking becomes

$$P_B = \frac{\eta P_F T_B}{T_S} = \frac{\eta P_F T_B}{1 + (N - 1 + L_d P_{FCD})P_{fa}MN/\Delta}.$$  

(17)

From (8), (10), and (15), acquisition-based packet throughput is given by

$$\rho = (1 - P_B)P_D P_{CD} \quad (18)$$

Note that acquisition-based packet throughput does not mean packet throughput of an overall packet receiving system. The packet throughput of an overall system usually means the probability that a packet is successfully processed in the overall packet receiving system. Since this paper concentrates only on the acquisition subsystem at the receiver frontend, to find the overall packet throughput, the rest part of the packet receiving system should be considered. If the acquisition-based packet throughput is $\rho_1$ and the packet throughput for the rest part of the packet receiving system is $\rho_2$, the packet throughput of overall system is given by

$$\rho = \rho_1 \rho_2.$$  

B. Rayleigh Fading Channel

In a typical UHF or microwave land mobile radio channel, Rayleigh fading is encountered for a non-line-of-sight environment. Assume that a fading process is constant during $k$ successive chips with $k \ll M$, and the successive groups of $k$ chips have correlation. For a Rayleigh fading channel, the constant false alarm probability is modified by

$$P'_{fa} = \exp\left(-\frac{\beta t_1'}{2(1 + \gamma_i)}\right). \quad (19)$$

In a search mode, detection probability is given by

$$P'_D = (1 + \gamma_i) \exp\left[-\frac{\beta t_1'}{2(1 + W \gamma_i/M)}\right] \sum_{n=0}^{2MN-1} (-1)^n \left(\frac{2MN - 1}{n}\right) \frac{\exp\left(-\beta t_1'/2(1 + \gamma_i)\right)}{1 + n(1 + W \gamma_i/M) + \gamma_i}, \quad (20)$$

where $W$ is the conditional variance of a correct cell normalized by in-phase (or quadrature) signal variance. With some derivation, the false alarm probability is approximated as

$$P'_F = \exp\left[-\frac{\beta t_1'}{2(1 + W \gamma_i/M)}\right] \quad (21)$$

In a coincidence detection, the probability of a successful CD at each test becomes

$$P'_C = \exp\left[-\frac{t_2'}{2(1 + W \gamma_i/M)}\right] \quad (22)$$

The probability of a false CD at each test is given by

$$P'_{FC} = \exp\left[-\frac{t_2'}{2(1 + \gamma_i)}\right] \quad (23)$$

The probability of a false CD is given by

$$P'_{FCD} = \sum_{k=N}^{N-2} \binom{N-2}{k} P_{FC}^k (1 - P_{FC})^{N-2-k}. \quad (24)$$
Then the probability of receiver blocking is obtained by

\[ P'_B = \frac{(N - 1 + L_d P_{aCD}) P_{aMN}}{1 + (N - 1 + L_d P_{aCD}) P_{aMN}} / \Delta. \]  

(25)

Through the similar procedures as the case of an AWGN channel, *acquisition-based packet throughput* is also obtained by

\[ \rho' = (1 - P'_B) P'_D P'_CD. \]  

(26)

C. Effect of Imperfect Power Control

The reverse link of DS/SSMA system is typically designed to be asynchronous, and an asynchronous DS/SSMA system is vulnerable to the “near-far problem” in which very strong undesired signal at a receiver swamp out the effect of weaker, desired signal. A solution to the near-far problem is the use of power control, which attempts to ensure that all signals from the mobiles within a given cell arrive at the base station of that cell with equal power. In the above analysis, perfect power control is assumed within each cell. To obtain the sensitivity of this scheme to imperfect power control, the received unfaded amplitude of the ith user \( A_i \) is no longer a constant. It is well known that power control has a major impact on the performance of a DS/SSMA system. The primary objective of power control is to maximize system capacity, and an additional benefit is to minimize power consumption of a mobile unit \([22]\).

Power control systems can be open loop or closed loop. In the open loop case, the mobile adjusts its own transmit power based on the level of its received power. In the close loop case, the base station commands the mobile to either increase or decrease its power. The command from the base station is base upon the level of the signal it receives from the mobile. The performance of power control depends on power control algorithm, speed of adaptive power control, transmitter dynamic range, spatial distribution of users, fading, and shadowing, etc. \([23]\). To consider the effect of imperfect power control, a more specific description of the \( \{A_i\} \) is required. Since the imperfect power control affects PN acquisition performance, its effect is considered by modeling the power control error as a uniform distribution or a lognormal distribution.

For a uniform distribution of power control error, it is assumed that \( A_1 = A \) and \( A_i = \lambda_i A(i > 1) \), where the \( \{ \lambda_i \} \) are independent identically distributed \((i.i.d.)\) random variables. The \{A_i\} are assumed to be distributed around the desired value A. For a power variation parameter V, the probability density function \( (p.d.f.) \) of the \( \lambda_i \) is given by

\[ f_{\lambda_i}(\lambda) = \begin{cases} \frac{1}{2V}, & A - V \leq \lambda_i \leq A + V, \\ 0, & \text{otherwise}, \end{cases} \]  

(27)

Note that \( V = 0 \) corresponds to the case of perfect power control, and \( V = 0.707 \) and \( V = 1 \) correspond to the cases of average power for any user varying by \( \pm 50\% \) and \( \pm 100\% \) about its nominal value, respectively. The “V” is a power variation parameter in a uniform distribution of power control error. For example, in the case of \( V = 0.707(=1/\sqrt{2}) \), the average power of any user is varied by \( \pm 50\% (=1/2 = (1/\sqrt{2})^2) \).

For a lognormal distribution of power control error, the effect of imperfect power control can be taken into account by modeling power of each user to be lognormally distributed about nominal received power \([24],[25]\). For perfect power control, the logarithmic standard deviation of power control error, \( \sigma_p \), is 0 dB. The typical value of \( \sigma_p \) is 1 dB to 3 dB in the real operating environment for a DS/SSMA system \([26]\).

4. Numerical 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 the first tier because the adjacent cell interference from cells of the first tier is dominant. For numerical examples, carrier frequency \( f_c = 900 \) MHz, vehicle speed \( v = 50 \) km/h (maximum Doppler frequency \( f_d = f_v/c = 41.7 \) Hz), the length of data packet \( L_d = 1200 \) (bits), phase adjustment parameter \( \Delta = 1/2 \), receiver blocking probability \( P_B = 10^{-5} \) (typical value in a packet radio system), the number of adjacent cells \( j = 6 \), and path loss exponent \( \gamma = 4 \) were assumed. The number of successful CD tests is chosen to be \( N' = [(N - 2)/2] \) for majority vote in verification mode where \( [x] \) is an integer part of \( x \). The value of a gain factor \( \beta \) is chosen numerically to ensure constant false alarm probability \( P_{fa} \leq 10^{-6} \). 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.

In Fig 5, acquisition-based packet throughput is compared for serial and parallel MF-RF’s in an AWGN and a Rayleigh fading channels as the number of users is varied. The numerical examples are shown for the processing gain \( M = 127 \), the preamble length \( N = 10 \), the output SNR = 15 dB, and perfect power control. It is shown that the packet throughput decreases with increasing number of users. Also it is shown the parallel MF-RF scheme achieves higher throughput than the serial MF-RF scheme. The throughput performance is degraded in a Rayleigh fading channel compared to an AWGN channel due to the fading effects.

In Fig 6, acquisition-based packet throughput vs. the preamble length is compared for serial and parallel MF-RF’s in an AWGN and a Rayleigh fading channels. The numerical examples are shown for \( K = 10, M = 127, \) output SNR = 15 dB, and perfect power con-
control. It is shown that the packet throughput increases as the preamble length increases. The parallel MF-RF scheme yields higher throughput than the serial MF-RF scheme, and the throughput degradation is more severe in a Rayleigh fading channel than an AWGN channel.

In Fig. 7, acquisition-based packet throughput of a parallel MF-RF vs. output SNR is shown for a Rayleigh fading channel with preamble length as a parameter. The numerical examples are shown for $M = 127, K = 5$, and perfect power control. It is shown that the throughput increases with increasing preamble length, long preamble causes the mean acquisition time to increase. There is a tradeoff between preamble length and mean acquisition time. As expected, the packet throughput of packets increases with increasing SNR.

In Fig. 8, acquisition-based packet throughput of a parallel MF-RF vs. output SNR is shown for a Rayleigh fading channel with the number of users as a parameter. The numerical examples are shown for $M = 127, N = 10$, and perfect power control. It is shown that the throughput of packets decreases as the number of users in the system increases. It is also shown that the packet throughput increases with increasing output SNR. Although it is generally accepted that the packet throughput can be significantly increased with increasing output SNR, Figs. 7 and 8 illustrate that the increase of throughput is actually smaller due to the Rayleigh fading effects.

In Fig. 9, acquisition-based packet throughput of a parallel MF-RF vs. preamble length is shown for a Rayleigh fading channel with processing gain as a parameter. The numerical examples are shown for $K = 10$, the output SNR = 15 dB, and perfect power control. It is shown that the packet throughput increases with increasing preamble length, but long preamble degrades the mean acquisition time performance. There exists trade-off relationship between packet throughput performance and mean acquisition time performance.

In Fig. 10, acquisition-based packet throughput of a parallel MF and a parallel MF-RF vs. the number of
Fig. 9 Packet throughput vs. preamble length for a Rayleigh fading channel with the process gain as a parameter. \((K = 10, \text{ output SNR} = 15 \text{d}B, \text{perfect power control})\).

Fig. 10 Packet throughput vs. the number of users of for a Rayleigh fading channel with and without reference filter. \((M = 127, N = 10, \text{output SNR} = 10 \text{d}B, \text{perfect power control})\).

users is compared for a Rayleigh fading channel. The parallel MF without RF was analyzed in [8]. The numerical examples are shown for \(M = 127, N = 10\), the output SNR = 10 dB, and perfect power control. It is shown that the packet throughput decreases with the increasing number of users. The degradation of packet throughput is more severe in a Rayleigh fading channel than in an AWGN channel as the number of users increases. The MF-RF schemes achieve higher throughput than the MF schemes without RF. The parallel MF-RF scheme is demonstrated to perform better than the parallel MF in MA environments. Therefore, the RF gives an advantage in MA applications because it is used to estimate the variance of MAI at the output of the detecting MF's.

In Fig. 11, the effect of imperfect power control is evaluated in terms of acquisition-based packet throughput when the power control error is modeled as a uniform distribution and a lognormal distribution. The numerical examples are shown for \(M = 127, N = 10\), and the output SNR = 10 dB. It has been found that the power control error causes mean acquisition time to increase in a DS/SSMA PN acquisition subsystem for both the uniform distribution and the lognormal distribution of power control error. The imperfect power control causes packet throughput to decrease, and the performance degradation is significant for larger power control error. Therefore, for higher packet throughput, it is necessary to achieve power control as accurate as possible.

The Eqs. (18) and (26) for packet throughput is not a convex or concave function, so the optimum value for \(M\) and \(N\) cannot be easily found. Also, it is not easy to prove the optimality in a mathematical approach. But when the trade-off of receiver complexity and performance is made, from the empirical results varying the other system parameters for each situation, the optimum values for \(M\) and \(N\) in the given environment (which is characterized by the system parameters) are supposed to be \(M = 127\) and \(N = 10\) to 12.

5. Conclusions

The acquisition-based packet throughput has been proposed and evaluated for the noncoherent parallel MF-RF acquisition scheme for a DS/SSMA packet radio system. The analysis shows that the parallel MF-RF scheme yields better performance and deemed more appropriate for a DS/SSMA packet radio system than previously proposed schemes without reference filter. It is shown that the packet throughput decreases with increasing number of users in the system, and increases with the increasing preamble length. For a long preamble, there exist a burden on hardware complexity in its implementation and increase of mean acquisition time, therefore, the trade-off between packet throughput and mean acquisition time should be made. Also it is shown that the noncoherent parallel MF-RF ac-
acquisition scheme achieves higher throughput than the serial MF schemes and the parallel MF scheme without RF for both an AWGN and a Rayleigh fading channels. Imperfect power control causes packet throughput to decrease especially when the power control error is large.

In a DS/SSMA packet radio system, the performance measures are typically packet throughput or packet error rate. The main point in this paper is to give the insight to the reader about the effect of PN acquisition performance on the DS/SSMA system. Since the PN acquisition performance may pose a limit to a DS/SSMA packet radio system [27], we concentrate on the performance based mainly on PN acquisition performance. And, the main task of PN code synchronization consists of PN acquisition and PN tracking. Overall PN synchronization time is mainly determined by PN acquisition time, so the PN tracking performance has less effect than PN acquisition performance on the overall performance of a DS/SSMA packet radio system.

For better performance in a DS/SSMA packet radio system operating in a Rayleigh fading environment, the variable packet length scheme (or also called "adaptive packet length scheme") may be considered by varying the packet length according to the fading severity. We have not included the variable length packet scheme because we are mainly interested in the new definition and evaluation of packet throughput based on acquisition performance, and the system is more complicated when the variable length packet scheme is employed (eg. fading severity estimator). Of course, the variable packet length scheme is expected to reach better performance than fixed packet length scheme at the cost of receiver complexity. The considerations in this paper can be applied to the reverse link (mobile-to-base station) design of a DS/SSMA system for packet-type services.

References


Jin Young Kim was born in Seoul, Korea, on February 8, 1968. He received the B.S. and M.S. degrees in electronics engineering from Seoul National University, Seoul, Korea, in 1991 and 1993, respectively. He is currently working toward the Ph.D. degree at School of Electrical Engineering of Seoul National University, Seoul, Korea. His research interests include spread-spectrum communications for applications to mobile and satellite communication systems, adaptive antenna array, packet radio communication, multiple access, multimedia transmission technique, wireless ATM, detection theory, and information theory. He is a member of IEEE, KITE, KICS, and an associate member of IEE.

Jae Hong Lee received the B.S. and M.S. degrees in Electronics Engineering from Seoul National University, Seoul, Korea, in 1976 and 1978, respectively. He received the Ph.D. degree in Electrical Engineering from the University of Michigan, Ann Arbor, Michigan, in 1986. From 1978 to 1981 he was with the Republic of Korea Naval Academy, Jinhue, Korea, as an Instructor and Lieutenant. In 1987 he joined the Department of Electronics Engineering at Seoul National University (SNU), Seoul, Korea where he is currently a Professor of the School of Electrical Engineering. He was a Member of Technical Staff at the AT&T Bell Laboratories, Whippany, New Jersey, during a sabbatical year of 1991-92. From 1992 to 1994 he served as the Chairman of the Department of Electronics Engineering at SNU. He served as the Head of Operation and Planning Division of the Institute of New Media and Communications at SNU from its foundation in 1992 to 1994 for which he has also served as the Head of Wireless and Satellite Communications Research Division since 1992. He served as the Chairman of the Mobile Communication Society of the Korean Institute of Communication Sciences (KICS) from 1992 to 1996 and has served as the Chairman of the Korea Chapter of the IEEE Vehicular Technology Society since its foundation in 1994. His current research interests include communication and coding theory, spread-spectrum system, and their applications to wireless communications, and intelligent transport systems. He is a member of the IEEE, KITE, KICS, and Tau Beta Pi.