논문 00-25-9A-11

한국통신학회논문지 '00-9 Vol.25 No.9A

CDMA Uplink 채널 구조와 Staggered Burst 파일럿을 이용한 DBCE 검출 기법

정회원 나 종 래*, 이 창 수**, 강 양 기***

A New CDMA Uplink Channel Structure and DBCE Detection Scheme Using Staggered Burst Pilot

Jongray Na*, Changsu Lee**, Yanggi Kang*** *Regular Members*

요 약

본 논문에서는 새로운 staggered burst 파일럿(SBP)의 개념을 도입하여 CDMA uplink 채널 구조를 제안하였다. 즉, 데이터 채널과 병렬로 파일럿 채널을 두고 셀상의 이동체 들이 파일럿을 staggered 형태로 공유하는 구조이다. 이를 위한 recursive DBCE 알고리듬에 의한 coherent 검출 기법을 제안하고 분석하였다. 본 방법은 uplink 채널 상에서 파일럿 burst가 주기적으로 가해지므로 이전의 오 동작에 대해 스스로 정상적으로 복귀되는 특징을 가지며 이로 인해 가우시언 잡음이나 도플러 전이효과에 매우 안정적으로 동작함을 입증하였다. 실험 결과에 의하면 burst 파일럿 개념을 도입함으로써 E_b/N_0가 0.068dB로 무시할만한 손실을 가짐을 보였다. 또한 도플러효과에 대한 실험에 있어서 이동체가 160Km/H로 주행 시 이상적인 coherent 검출 기법과 비교했을 때 required E_b/N_0는 2.0dB 이하로 저하되었다. 제안된 SBP 방법은 DBCE를 위한 별도의 correlator가 필요함에도 불구하고 매우 간단히 구현할 수 있는 장점을 지니고 있으며 기존의 내부, 또는 외부적인 파일럿을 가진 다른 coherent 검출기에 비하여 좋은 성능을 가짐을 보였다.

ABSTRACT

A new coherent detection scheme with data based channel estimation(DBCE) for CDMA/BP (staggered burst pilot in parallel) channel structure is proposed. Because the pilot burst initiates DBCE operation periodically, it is shown to be remarkably stable to Gaussian noise and Doppler shift with proper parameter settings. In our own system parameter settings, there is a negligible loss (0.068 dB) in E_b/N_0 by the introduction of the burst pilot. When compared with an ideal coherent detection, the required E_b/N_0 on Doppler shift corresponding to the speed of 160 Km/H is degraded less than 2.0 dB. The burst pilot can be implemented without complexity even though some extra correlators are needed for DBCE. This improvement is superior to the previously coherent CDMA detectors with external or internal pilot.

I. Introduction

As the standardization of IS-95 [1] in digital cellular system proceeds, there are many practical approaches to improve the uplink performance in direct sequence CDMA technology. For the new digital CDMA-based communication systems as in PCS, wireless multimedia, and IMT-2000, most of

---

* 아이젠반도체통신(주)(jrna@nuri.net),
** 수원대학교 전자공학과(cslee@mail.suwon.ac.kr),
*** (주)오프너스(ygkang@openers.co.kr)

논문번호 : 00236-0626, 접수일자 : 2000년 6월 26일

the schemes are based on coherent detection which is evident to show 2-3 dB improvement to the existing noncoherent uplink even though up-banded operation of IS-95 is possible [2].

To enable coherent detection, accurate channel estimation is necessary via fading channel environment. There are two types of channel estimation. Type A is to use external unmodulated pilot channel in parallel with data modulated channel [3]-[5]. Type B is to insert pilot symbol between data streams before spreading, that is, in serial so that the receiver splits data and pilot symbol into two streams again [6]-[8].

In [3] of type A, continuous pilot channel is suppressed with -6 dB power intensity relative to traffic(data modulated) channel. But still the total interference from pilots in 4 mobiles consumes 1 traffic channel interference. It is a lot of loss in channel capacity unless the interference canceller is used in the receiver.

In [4]-[5] of type A, separate differentially coded channel is used as a pilot channel in parallel with traffic channel since it can be re-coded to remove the modulation data for the coherent demodulation. The differentially coded channel also carries data with noncoherent uplink. This is not complete in the sense of coherent demodulation.

Recently, type B of pilot symbol aided(PSA) arrangement for uplink DS-CDMA communication is widely accepted in the practical implementation. It does not require extra correlator to despread the pilot channel because it uses internal pilot embedded periodically in the data channel. The selection of a pair of data and pilot symbol relates to applied coherent channel estimation and performance [9].

In type B, compensation after channel estimation is required to reduce errors in the detection from imperfect channel estimation because it is based on periodically inserted pilot symbol. Two compensation schemes as linear interpolation and recursive least square (RLS) are applied in [6] and [8], respectively.

The second order linear interpolation is relatively simple, but shows a degradation at the maximum practical speed. RLS estimation shows little degradation until practical speed, but requires complicated computation. That is, computational complexity and degradation is in opposite direction.

In this paper, a data based channel estimation is applied to the CDMA uplink with staggered burst pilot to combine the simple implementation and less degradation at the practical maximum speed in our own system parameter settings. The staggered burst pilot is of type B. The detailed features which was presented in [11]-[14] will be discussed after the performance evaluation.

Ⅱ. Channel Structure of CDMA Uplink with Staggered Burst Pilot

Before we discuss channel structure of the CDMA uplink with staggered burst pilot, we describe proposed downlink channel structure which is similar to conventional IS-95. Table 1 shows signal flow diagram of CDMA/BP modulation part. The bandwidth of proposed CDMA/BP is 5 MHz, and we have variable data rates of 38.4, 19.2, 9.6, and 4.8 Kbps, which is spreaded with PN code of 4.096 Mcps chip rate. The unique feature in CDMA/BP is to put burst pilot in uplink channel in order to reduce power of terminal and interference when continuous pilot is used.

The CDMA downlink has 64 channels which consist of pilot, sync, paging, and traffic channel. It's bandwidth is 4.096MHz. The convolutional encoder is applied to information data, whose rate is $\frac{1}{2}$ and constraint length is 9. After maintaining 38.4Kbps block interleaving, spreading PN code modulation with Walsh function, I, Q spreading with two short pilot PN code, and quadrature carrier modulation are performed sequentially. Spreading with long code enables users to ensure security.

Figure 1 shows the structure of the downlink traffic channel. Downlink traffic channel transmits

Table 1. Signal flow diagram of CDMA/BP modulation part.

Digital Processing for Modulation	Downink	Uplink
Convolutional Encoder	$r=\frac{1}{2}$, K=9(38.4/76.8, 19.2,9.6,4.8 Ksps	$r=\frac{1}{2}$, K=9(38.4/76.8, 19.2,9.6,4.8 Ksps
Symbol Repetition	76.8/153.6, 38.4, 19.2, 9.6 Ksps	76.8/153.6, 38.4, 19.2, 9.6 Ksps
Block Interleaver	76.8/153.6 Ksps	76.8/153.6 Ksps
Puncture (1 of every 6 inputs)	64/128 Ksps	64/128 Ksps
Long Code	Cyphering (64/128 Ksps)	Spreading (64/128 Ksps → 4.096 Ksps)
Power Control	Punctured MUX (64/128K + 800 sps → 64/128 Ksps)	None (20 ms frame)
Walsh	Spreading (64/128 Ksps → 4.096 Mcps)	Orthogonal (4.096 Mcps)
QPSK	QPSK (4.096 Mcps)	(O)QPSK + Pilot Burst (4.096 Mcps)

voice frame with 32Kbps ADPCM per 5ms. For 38.4Kbps traffic channel, the output rate of convolutional encoder with code rate $\frac{1}{2}$, and constraint length 9 is 76.8Ksps which can be 64Ksps by $\frac{1}{6}$ puncturing. Therefore the real convolutional code rate is $\frac{1}{2}\cdot\frac{6}{5}=\frac{3}{5}$. The 4.096Mcps long code is decimated by $\frac{1}{64}$ and the resulting 64Ksps code is modular 2 added.

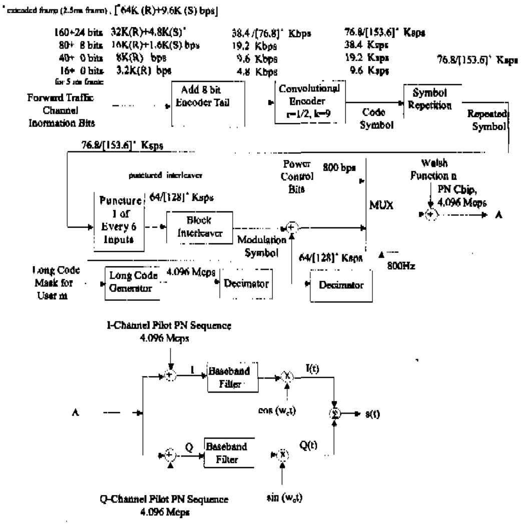


Fig 1. Downlink CDMA channel structure for traffic channel.

Figure 2 shows the staggered burst pilot structure proposed in this paper. The proposed burst pilot is different from the previous approaches. First, the proposed burst pilot is in parallel with traffic channel, that is, not in multiplexing of traffic and pilot channel. Secondly, during the burst transmission it has about 6 dB higher power than normal traffic power and repeats for every super frame interval (80 ms). Each burst of all mobiles has different offset relative to the start point of received super frame as reference and does not last no more than the next burst in the other mobile so that they do not overlap each other.

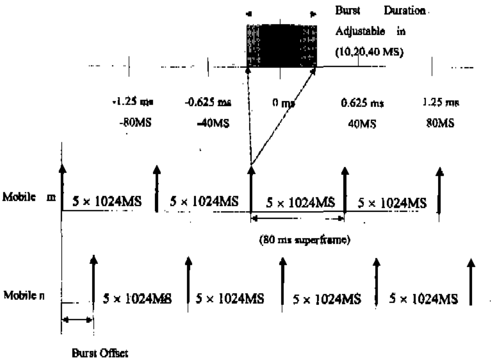


Fig 2. Reversed link pilot channel structure with stagged burst.

Functional block diagram of the proposed system based on Figure 2 can be described as follows. The downlink consists of pilot, sync, paging, and access channels. The down pilot channel is strong enough to provide clean phase tracking and used for superframe reference in the uplink transmission. The sync channel provides additional message for synchronization as superframe boundary. Each channel data are spreaded to 4.096 Mcps(chip per second) by Walsh sequences. The frame length is 5 ms, and the super frame is 80 ms since these values are suitable for the application of the proposed scheme.

As the pilot channel is discontinuous, we newly introduce MS(modulation symbol) to describe the repetitive width of the symbol of the pilot channel. The maximum burst duration allowed is (80ms)/N_s where N_s is the total number of offset slots. For N_s=64, maximum burst duration can be 80 MS where 1 MS is 64 chips. Usually 40 MS is used.

Figure 3 shows detailed uplink CDMA channel structure for traffic channel. In uplink traffic channel, a basic voice frame transmits per 5ms for 32Kbps ADPCM. We can increase data rate with 2.5ms for 64Kbps still images and G4 fax. Thus 160bits per 5ms for 32Kbps voice and 160bits per 2.5ms for images and G4 fax can be transmitted. The voice bit can be varied by 160, 80, 40, 16 bits. The frame quality indicator bits of 24, 8 are added to 160, 80 bits as in IS-95. The 38.4Kbps traffic channel can be described. Regarding the traffic channel of 38.4Kbps, the convolutional encoder output of code rate $\frac{1}{2}$, and constraint length 9 is 76.8Ksps. Burst pilot channel with all zeros are modular 2 added to Walsh function 0. Then it is transmitted with 6dB higher power after QPSK modulating. Burst pilot is transmitted with 10, 20 or 40MS pulse width at every 80ms. The uplink access channel is composed of 8Kbps data rate and uses continuous pilot during access state. Also a detailed uplink access channel structure is described in Figure 4.

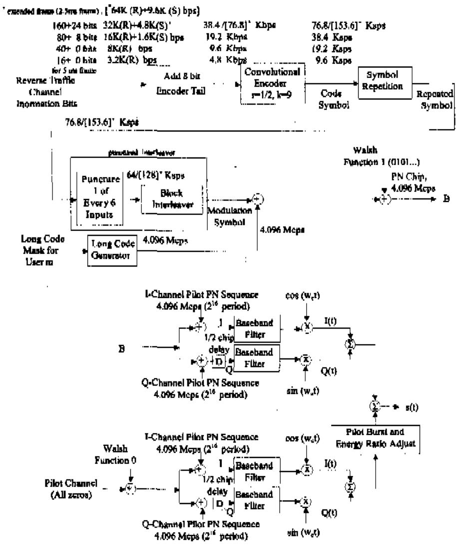


Fig 3. Uplink CDMA channel structure for traffic channel.

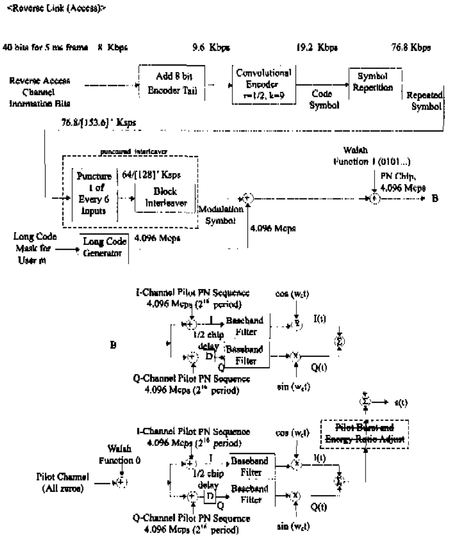


Fig 4. Uplink CDMA channel structure for access channel.

The width and period of burst pilot is specified as in Figure 5. I, Q PN code for spreading the bandwidth with 4.096MHz can be described as following polynomials.

$$p_I = x^{16} + x^{12} + x^3 + 1 \tag{1}$$

$$p_Q = x^{16} + x^{13} + x^{12} + x^{11} + x^7 + x^6 + x^3 + 1 \tag{2}$$

The correlation between p_I, and p_Q is sufficiently small and the period is 2^{16}-1. Thus we can make the period 2^{16} by augmenting 0 when 15 subsequent 0 is occurred as in IS-95.

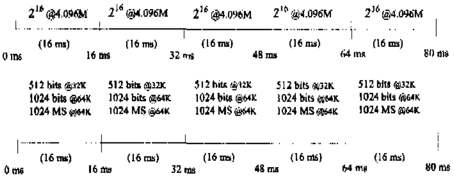


Fig 5. A comparison between I/Q PN sequence and data rate.

Ⅲ. Data Based Channel Estimation (DBCE) Scheme

Each multipath component demodulator ("finger") has its own pilot sequence tracking loop. It is started by the time delay estimation of a given path as determined by pilot's pseudo random sequence "searcher''. The received signal, $y_k^{(I)}(n)$, $y_k^{(Q)}(n)$ before the despreading can be represented as follows [10].

$$\begin{aligned} y_k^{(I)}(n) &= \sqrt{E_c}[A_k(n)+x_k(n)W_1(n)] \\ &\quad a_k^{(I)}(n)\alpha(n)\cos\phi(n)+\nu^{(I)}(n), \end{aligned} \tag{3}$$

$$\begin{aligned} y_k^{(Q)}(n) &= \sqrt{E_c}[A_k(n)+x_k(n)W_1(n)] \\ &\quad a_k^{(Q)}(n)\alpha(n)\sin\phi(n)+\nu^{(Q)}(n), \end{aligned} \tag{4}$$

where E_c is the energy per chip, $x_k(n)$ is the data value (±1) during a chip duration, and $W_1(n)$ is one of Walsh sequences. The index k is used to indicate that the modulator and signal generator pertain to the k-th user(mobile) of the multiple access system. And $a_k^{(I)}, a_k^{(Q)}$ are user specific sequence and $\nu^{(I)}(n)$, $\nu^{(Q)}(n)$ are the contributions of all other (uncorrelated) multi-path components as well as those of all other users. $A_k(n)$ is defined as follows.

$$A_{k,}(n)=\begin{cases} A_{k,}(N), & \text{if } \textit{n is within the burst "}\bigcap\textit{val"} \\ 0, & \textit{otherwise} \end{cases} \tag{5}$$

When the burst is presented and $A_k(n)=A_k\neq 0$, the estimate of $\alpha(n)\cos\phi(n)$ and $\alpha(n)\sin\phi(n)$, $\hat{\alpha}\cos\hat{\phi}$ and $\hat{\alpha}\sin\hat{\phi}$ can be obtained by simply averaging over a number of modulation symbol(MS), N_p, as described below.

$$(\hat{\alpha}\cos\hat{\phi})(\tau) = \frac{1}{\sqrt{E_c A_k N_p}}\sum^{N_p} y_k^{(I)}(n+\tau)a_k^{(I)}(n), \tag{6}$$

$$(\hat{\alpha}\sin\hat{\phi})(\tau) = \frac{1}{\sqrt{E_c A_k N_p}}\sum^{N_p} y_k^{(Q)}(n+\tau)a_k^{(Q)}(n), \tag{7}$$

where, τ is the timing error(correlation distance). $A_k N_p$ should be as large as possible without exceeding the period over which $\alpha(n), \phi(n)$ remain relatively constant. A_k is given 6 dB higher than the traffic channel signal and N_p is assumed 20 times more than the symbol width N_d. This will ensure fast and correct $\hat{\alpha}\cos\hat{\phi}$, $\hat{\alpha}\sin\hat{\phi}$ channel estimation for the searcher operation.

The optimum demodulator forms the weighted, phase-adjusted, and delay-adjusted sum of L multipath components. But we consider only single path component for simple analysis in this paper. The result for the n-th chip after multiplication by the quadrature-user-specific pseudo random sequences is

$$\begin{aligned} y_k(n) = &\sqrt{E_c}x_k(n)\alpha(n)\hat{\alpha}\cos(\phi-\hat{\phi}) \\ &+\hat{\alpha}(\nu^{(I)}(n)\cos\hat{\phi}+\nu^{(Q)}(n)\sin\hat{\phi}) \end{aligned} \tag{8}$$

summing over the specific N chips over which $x_k(n)$ is constant (±1), we have

$$\begin{aligned} Y_k(n) = &\pm\sqrt{E_c}N\alpha(n)\hat{\alpha}\cos(\phi-\hat{\phi}) \\ &+\sum^{N}\hat{\alpha}(\nu^{(I)}(n)\cos\hat{\phi}+\nu^{(Q)}(n)\sin\hat{\phi}) \end{aligned} \tag{9}$$

On the other hand, $\alpha(n)$ and $\phi(n)$ may vary during the off-burst region which is the time interval where the pilot burst doesn't exists. We still need to continue channel estimation even though the pilot burst will not be available in the off-burst region. But (6) and (7) can not be applied because $A_k=0$ in the off-burst region. So we need to devise other method for the channel estimation.

To cope with this problem, this paper introduces data based channel estimation(DBCE) scheme. Once channel estimation is performed as in (6) and (7), the demodulator component is available from (9). We introduce the variables, N and N_a which are defined below.

N : the symbol demodulation width measured by chip unit in the demodulation block.

N_a : the accumulation width measured by demodulation symbol unit in the channel estimation block.

To estimate the demodulate component, the next channel estimate is recursively performed as follows.

$$\begin{aligned} \hat{\alpha}\cos\hat{\phi} = &\frac{1}{\sqrt{E_c N_a N}}\sum^{N_a}[\textit{sign}\, Y_k(n)\{\sum^{N} y_k^{(I)}(n+\tau) \\ &W_1(n)a^{(I)}(n)\}], \end{aligned} \tag{10}$$

$$\hat{\alpha}\sin\hat{\phi} = \frac{1}{\sqrt{E_c N_a N}} \sum^{N_a} \Big[sign\, Y_k(n) \Big\{ \sum^{N} y_k^{(Q)}(n+\tau) W_1(n) a^{(Q)}(n) \Big\} \Big]. \tag{11}$$

where *sign(x)* = 1 for $x \geq 0$ and -1 for $x < 0$.

In (10) and (11), $A_k(n)$ corresponds to 1. Thus N_a needs to be A_k times larger than the N_p in (6) and (7) to keep similar stable channel estimation. This scheme is robust to noise and phase error, $\phi - \hat{\phi}$, under the proper design parameters. The proper number of N_a will be analyzed in the next section.

Depending on the arrival of pilot burst, we use two different channel estimate equation pairs of (6), (7) and (10), (11). The operation of the finger can be summarized as the following steps.

Step 1: Wait until the pilot burst arrives. Then estimate the channel with (3) and (4).
Step 2: Demodulate the signal component with (6).
Step 3: Estimate the channel as follows:

$$(\hat{\alpha}\cos\hat{\phi},\ \hat{\alpha}\sin\hat{\phi}) = \begin{cases} eq.(6)\text{ and }(7), & \text{if } A_k(n) = A_k \neq 0 \\ eq.(10)\text{ and }(11), & otherwise. \end{cases}$$

Then repeat to step 2.

Figure 6 shows the block diagram to implement these operations. The tracking loop can easily detect the presence of pilot burst. By squared summing the components in (6) and (7), $\hat{\alpha}$ can be obtained independent of carrier phase difference ϕ. Thus if the $\hat{\alpha}$ is greater than certain threshold, it is considered the presence of burst. So this decision is easily used in the step 3 implementation. In this scheme, pilot burst with long period is still important for the following reasons.

First, it initiates the channel estimation to start finger operation. The burst pilot based channel estimation in the tracking loop will overwrite the estimation based on data. This will help to continue self recovery from the possible rare loss of channel estimation within the off-burst region.

Secondly, the searcher uses the burst pilot to find multipath components. As it finds stronger multipath signal, it will assign the portion to the current finger to participate in the rake receiver combining.

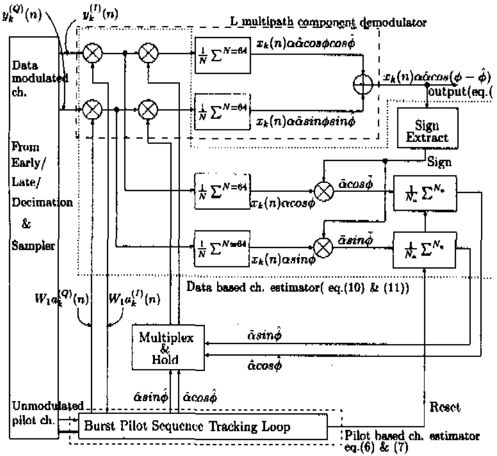


Fig 6. Block diagram to implement data based fast channel estimation. N_a can be 10, 20, 30 and 40.

Ⅳ. The Stability of Data Based Channel Estimation

The proposed data based channel estimation is shown to be very stable to Gaussian noise as shown in Figure 7. It is not affected by the Gaussian noise in the range of N_a=10, 20, 40 and 80. When the mobile moves from the cell sites with incident angle θ, Doppler shift is given by $f_D = v/\lambda \cdot \cos\theta$. The maximum estimation error is given by

$$\phi_e = \phi - \hat{\phi} = 2\pi f_D t_{N_p}, \tag{12}$$

where t_{N_p} is the period of channel estimation.

The phase error ϕ_e needs to be kept less than $\pi/2$ for the correct data demodulation and channel estimation. And the received energy of the demodulated output $Y_k(n)$ in (6) will be reduced by $\cos^2\phi_e$. For β dB reduced received power, the maximum Doppler frequency, f_D, relates as follows.

$$f_D = \frac{32000}{\pi} \cdot \cos^{-1}(10^{-0.05\theta}) \cdot frac\frac{1}{N_a}, \tag{13}$$

$$v = c \cdot \frac{f_D}{f_c}, \tag{14}$$

In the simulation, carrier frequency f_c, coded data rate, spreading chip rate are given as 1850 MHz, 64 Kbps, and 4096 Mcps, respectively. In this case, mobile velocity and maximum Doppler frequency is related as v (Km/H) = 0.58378 f_D. Again, Figure 7 shows that DBCE is very stable to Gaussian noise for the various N_a. Here Q(·) is the theoretical values of BER to E_bN_0. Figure 8 shows bit error rate(BER) degradation for N_a = 20 to E_b/N_0. As the mobile speed increases up to practical maximum speed 160 Km/H, the required E_b/N_0 increased by 2dB compared to the theoretical values of 0 Km/H marked as $Q(\cdot)$. Figure 9 is redrawn from Figure 8 to show the required E_b/N_0 without error correction to vehicle speed.

In our system parameter settings, there is negligible loss (0.068 dB) in E_b/N_0 by the introduction of the burst pilot. When compared with an ideal coherent detection, the simulation result shows that the required E_b/N_0 on Doppler shift corresponding to the practical speed of 160 Km/H is degraded less than 2.0 dB. If N_a is given smaller, this degradation at high speed becomes smaller. This is easily achievable provided that E_b/N_0 is maintained so that the probability of channel estimation error is very small. The two extra correlators in the cell site can be simply implemented with 1 adder and 1 integer multiplier (small digits, e.g. 4 bit by 4 bit) per correlator without burden. This implementation is simple even though it requires extra correlators. The pilot burst is usually stronger than traffic in the on-burst region which is the time interval where the pilot burst exists. It is remarkable that the extra dynamic range required in the mobile transmitter can be compensated by the less required E_b/N_0 for the same BER.

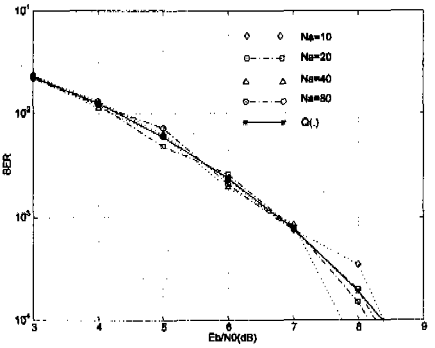


Fig 7. BER vs. E_b/N_0 for Gaussian noise.

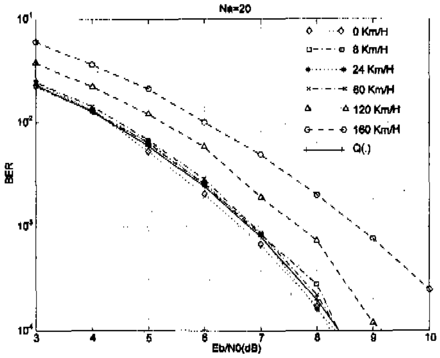


Fig 8. BER degradation in $N_a = 20$ for mobile speed.

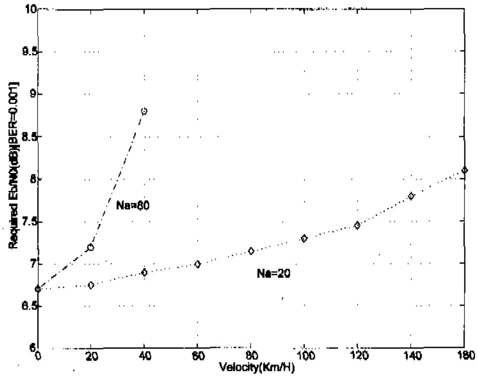


Fig 9. Required E_b/N_0 vs. speed for $N_a = 20$ and 80.

V. Conclusion

This paper proposes a coherent detection scheme with data based fast channel estimation. Once the channel estimation is started by staggered up-link burst pilot, the proposed data based channel estimation is shown to be remarkably stable even to Gaussian noise and Doppler shifts with proper parameter setup. Even for a rare loss of data based channel estimation, the proposed coherent detection scheme has a self recovery property with the repetitive burst pilot. This adds more robustness to the proposed CDMA/BP uplink channel structure. As the channel estimate is performed based on the continuous data, it shows faster stable estimation than that based on pilot symbol inserted between data streams.

참고문헌

[1] TIA/EIA IS-95 Interim standard, TIA, Jul. 1993.

[2] JTC (PN3384), Radio System Characterization for the Proposed IS-95 Based CDMA PCS Standard, Nov. 3 1994.

[3] JTC (TAG-7), Proposed Wideband CDMA PCS Standard, Jan. 1995.

[4] G. Brismark, et al, "Coherent Detection Scheme for the Uplink Channel in a CDMA System", *Proc. IEEE Veh. Technol. Conf.*, pp. 729-732, 1994.

[5] A. Baier, et al, "Design study for a CDMA-based third generation mobile radio system", *IEEE J. Select. Areas in Commun.*, vol. 12, no. 4, May 1994.

[6] F. Ling, "Coherent Detection with Reference Symbol Based Channel Estimation for Direct Sequence CDMA uplink Communications", *Proc. IEEE Veh. Technol. Conf.*, Secaucus, NJ, pp. 400-403, May 1993.

[7] T. A. Sexton and F. Ling, "Implementation of a Coherent Reverse Channel 900MHz CDMA Receiver with Reference Symbols", *Proc. IEEE Internat. Conf. on Communications*, Seattle, Washington, vol. 2, pp. 1024-1028, Jun. 1995.

[8] A. Higashi, T. Taguchi and K. Ohno, "Performance of Coherent Detection and Rake for DS-CDMA uplink Channels", PIMRC95, Toronto, pp. 436-440, Sep. 1995.

[9] S. Sampei and T. Sunaga, "Rayleigh Fading Compensation for QAM in Land Mobile Radio Communications", *IEEE Trans. Veh. Technol.*, vol. 42, no. 2, pp. 137-147, May 1993.

[10] A. J. Viterbi, CDMA (Principles of Spread Spectrum Communication), Addison- Wesley Wireless Communications Series, 1995.

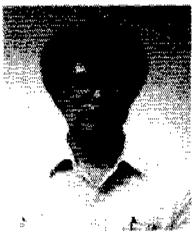
[11] Jongray Na and Yanggi Kang, "The Effects of Staggered Burst Pilot in CDMA Reverse Link" *The 2nd Internat. Workshop on Multi-Dimensional Mobile Commun.*, Seoul, pp. 792-795, Jul. 1996.

[12] J. Na, Y. Kang, and H. B. Lee, "A Finger Implementation of CDMA Receiver with Staggered Burst Pilot in Reverse Link" *Proc. 4th Internat. Symposium on Spread Spectrum Techniques & Applications*, Mainz, Germany, pp. 32-36, Sep. 22-25 1996.

[13] Jongray Na and Yanggi Kang, "A Coherent Detection Scheme with Data Based Fast Channel Estimation for CDMA Uplink with Staggered Burst Pilot" *Proc. 2nd Internat. Conf. on Personal, Mobile and Spread Spectrum Commun.*, Hong-Kong, pp. 101-104, Dec. 1996.

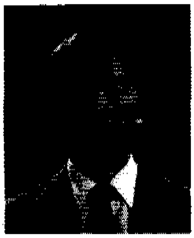
[14] J. Na, "Error Performance Analysis of Data Based Fast Channel Estimation for CDMA Uplink with Staggered Burst Pilot" *Proc. IEEE Veh. Technol. Conf.*, Arizona, USA, pp. 2177-2181, May 4-7 1997.

나 종 래(Jongray Na) 정회원



1981년 2월 : 서울대학교 전자공학과 졸업
1983년 2월 : 서울대학교 제어계측공학과 공학석사
1990년 2월 : KAIST 전기 및 전자공학과 공학박사
1990년 3월~1996년: ETRI 선임연구원
1997년~현재 : 아이젠반도체통신(주) 대표
<주관심 분야> CDMA 모뎀, VHDL 기반 로직설계, 영상처리, 마이크로콘트롤러 응용

이 창 수(Changsu Lee) 정회원



1985년 2월 : 서울대학교 제어계측공학과 졸업
1987년 2월 : 서울대학교 제어계측공학과 공학석사
1997년 2월 : 서울대학교 제어계측공학과 공학박사
1997년 9월~현재 : 수원대학교 전자공학과 조교수
<주관심 분야> Wavelet 응용, 이동통신, 신경회로망, 영상처리

강 양 기(Yanggi Kang)

1993년 2월 : 동국대학교 전자공학과 졸업
1995년 2월 : 동국대학교 전자공학과 석사
1995년 3월~2000년4월 : ETRI 연구원
2000년 5월~현재 : (주)오프너스
<주관심 분야> 이동통신, CDMA 시스템 분석