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셀룰라 시스템에서의 공통 파일럿 채널에 기반한 다운링크 빔포밍 방안

(A Downlink Beamforming Method with Phase Reference to Common Pilot Channel in Cellular Systems)

이 준 성*, 이 충 용*

(Joonsung Lee and Chungyong Lee)

요 약

본 논문에서는 셀룰라 이동통신 시스템에서 BPSK 신호전송시 공통 파일럿 신호가 존재하는 상황에서의 코히어런트 검출을 위한 다운링크 빔포밍 방안을 제안한다. 통화채널과 공통채널의 위상차이를 줄이며 다른유저의 간섭을 줄이기 위해 신호대 간섭비를 기반으로 하는 비용함수와 이를 구하는 방안을 제안한다. 모의실험결과를 통해 제안된 방안이 두 채널간의 위상차이를 줄이고 시변채널에서의 개선된 비트오율 성능을 확인 할 수 있다.

Abstract

A new downlink beamforming method is proposed for coherent detection of Cellular systems with BPSK modulation where there exists only common pilot channel. To solve phase mismatch between traffic and pilot signals at desired mobile and to reduce interference to other mobiles, the proposed downlink beamforming method considers a cost function of signal to interference ratio criteria and gives a solution for the cost function. The computer simulation showed that the proposed method can solve the phase mismatch problem and give improved BER performance in time-varying channels.

Keywords: Coherent detection, downlink beamforming, pilot signal, traffic signal, phase mismatch, SIR criteria

Ⅰ. Introduction

Beamforming which is a spatial processing of signals using array antenna is a promising technique to improve capacity and coverage in mobile communication systems[1-7]. Though study on beamforming systems has been mainly focused on uplink beamforming so far, the need for study on downlink beamforming is increasing recently, since wireless communication moves to high data rate service such as internet download[7]. Previous works for downlink beamforming using common pilot channel[5-7] have assumed that the phase of traffic beam is matched to that of pilot beam over the main lobe region of traffic beam or there exists mobile-supported feedback channel that requires complete redesign of uplink and downlink protocols and is only applicable to slow-varying channel environment. However, since beam patterns of traffic signals (narrow beams) and beam pattern of common pilot signal (broad beam) are different in general as shown in Fig.1, scatterers in wireless channel make the phases of received traffic signals different from the phase of received pilot signal. We call it "the phase mismatch problem" in this paper. It is obvious that coherent detection based on common pilot causes performance degradation

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* 정회원, 연세대학교 전기전자 공학과
(Dept. of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea)

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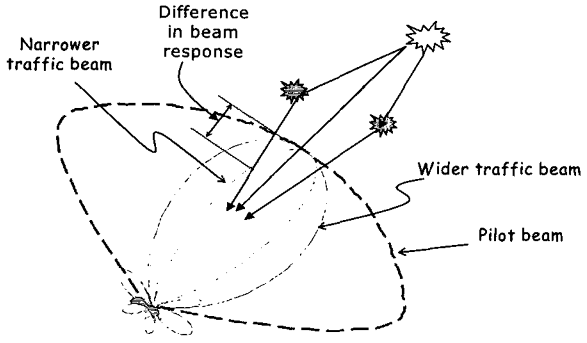

그림 1. 다운링크 빔포밍을 위한 공통채널과 통화채널의 빔패턴

Fig. 1. Beam patterns of traffic signal and common pilot signal for downlink beamforming[1].

due to the problem.

In general, the phase mismatch problem can be mitigated if we form traffic beam as wide as possible to cover whole scattering area. However, this approach results in the tradeoff between interfering other mobiles and phase match at mobile. On the other hand, if we use auxiliary pilot for each traffic channel, coherent demodulation can be achieved successfully. However, disadvantageously, the use of auxiliary pilots does not exploit inherent efficiency in using common pilot for all downlink channels and requires change of specification. Although downlink auxiliary pilot is defined in the standard for CDMA-2000 systems[8], common pilot may be used as a phase reference for all traffic users due to resource efficiency. Therefore, the use of common pilot channel is desirable. In this paper, we propose a downlink beamforming method to minimize both phase mismatch at a desired mobile and interference to other mobiles simultaneously when common pilot channel is used for coherent detection in DS/CDMA systems with BPSK modulation.

Ⅱ. System Description for Downlink Beamforming

Suppose N mobile users share the same sector in which an M-element uniform linear array is equipped. A wide sense stationary uncorrelated scattering model[1] [2] is employed to represent channel. Let $\mathbf{w}_i$ and $\mathbf{w}_{cp}$ denote downlink beamforming weight vectors of traffic channel for i-th user and common pilot channel for all users, respectively. Then, the transmitted signal vector $\mathbf{x}(t)$ from base station antenna array can be expressed as

$$\mathbf{x}(t) = \sum_{i=1}^{N} \mathbf{w}_i s_i(t) + \mathbf{w}_{cp} s_p(t) \tag{1}$$

where $s_k(t)$and $s_p(t)$ are signal transmitted to the mobile terminal of user k and downlink common pilot signal, respectively. Common pilot, which serves as a phase reference for all traffic channels in cell, enables coherent detection at mobile, while auxiliary pilot serves as phase reference only for corresponding traffic channel. We assume all mobile users have the same number of uplink and downlink delay paths. Then, the received signal at mobile user k is given by

$$\begin{aligned} r_k(t) = & \sum_{i=1}^{N} \sum_{l=1}^{L_k} \mathbf{w}_i^H \mathbf{h}_k^l(t) s_i(t)(t-\tau_k^l) + \\ & \sum_{l=1}^{L_k} \mathbf{w}_{cp}^H \mathbf{h}_k^l(t) s_p(t)(t-\tau_k^l) + n_k(t) \end{aligned} \tag{2}$$

where $\mathbf{h}_k^l(t)$, $\tau_k^l(t)$, $\mathbf{n}_k^l(t)$ and L_k are downlink channel vector, time delay corresponding to the l path of user k, noise of user k and number of multipath signals, respectively. Also, $s_k(t)$ and $\mathbf{h}_k^l$ are assumed to be zero-mean and uncorrelated each other. Open loop downlink beamforming system obtains the information of downlink channel from uplink channel. Though, in frequency division duplex environment, the correlation between bidirectional wireless channels is low, the correlation of the 2nd order statistics of bidirectional wireless channels is high [3]. Also, the bidirectional commonality is hold in direction of arrival (DOA) and average signal strength, even if the frequency of uplink is different from the frequency of downlink. Downlink wireless fading channel for the l-th path of user k can be modeled as [3]

$$\mathbf{h}_k^l = \alpha_k^l \mathbf{a}_k(\theta_k^l) \tag{3}$$

where α_k^l is the complex path strength including shadowing, path loss and fast fading effect for user k and $a_k(\theta) = [1, e^{j2\pi sin\theta/\lambda}, \cdots, e^{j2\pi(M-1)sin\theta/\lambda}]$ is the downlink steering vector. Here, d, θ and λ denote the distance between adjacent antenna elements, incident angle of a path signal and wavelength of downlink signal, repectively. As the steering vector is a function of frequency, the downlink steering vector is different from the uplink steering vector. However, in the matched array approach, it can be assumed they are same [3].

III. Proposed Downlink Beamforming Method

In this section, we propose a downlink beamforming method that can solve the phase mismatch problem for coherent detection of DS/CDMA system with BPSK modulation.

1. Relation of phase msimatch between common pilot and traffic channel

The received signal at the mobile for user k can be expressed as

$$r_k(t) = \underbrace{\sum_{l=1}^{L_k} w_k^H h_k^l(t) s_k(t-\tau_k^l)}_{r_d(t)} + \underbrace{\sum_{l=1}^{L_k} w_{cp}^H h_k^l(t) s_p(t-\tau_k^l)}_{r_p(t)} + \underbrace{\sum_{\substack{i=1 \\ i \neq k}}^{N} \sum_{l=1}^{L_k} w_i^H h_i^l(t) s_i(t-\tau_k^l)}_{r_{int}(t)} + n_k(t) \tag{4}$$

where $r_d(t)$, $r_p(t)$and $r_{int}(t)$ indicate desired traffic signal, common pilot signal and interference caused by the signals intended for other mobiles, respectively. Then, we can see from (6) that the power of $r_d(t)$ for user k is given by

$$\begin{aligned} P_d &= E\, r_d(t)^2 \\ &= w_k^H \mathbb{R}_k w_k \end{aligned} \qquad 5)$$

where $\mathbb{R}_k = \sum_{i=1}^{L_K} E[h_k^l(t) h_k^{lH}(t)]$.

Here, $E\{\cdot\}$ denotes expectation operator.

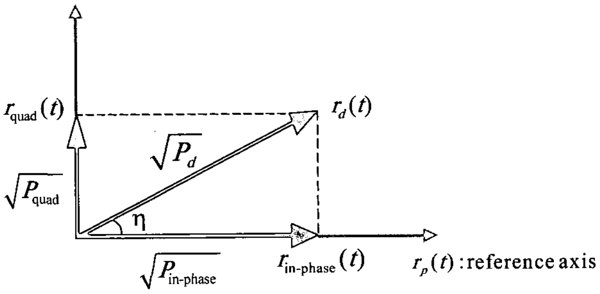

그림 2. 특정유저에서의 통화채널과 공통채널의 위상부 정합 모델

Fig. 2. Phase mismatching model for traffic and pilot signals at target mobile.

Generally, whole P_d does not contribute to signal power component when carrying out coherent detec-tion, because there exists phase mismatch between $r_d(t)$ and $r_p(t)$ due to their different weight vectors for down link beamforming as mentioned before.

Noting that the generalized angle η between any two random variables a and b is defined as its cosine-squared angle: $cos^2\eta = E[ab^*]/(E[a]^2) \cdot (E[b]^2)$, where $(\cdot)^*$ indicates complex conjugate operator. Then, the cosine-squared angle between $r_d(t)$ and $r_p(t)$ is calculated as (see Fig. 2)

$$cos^2\eta = \frac{|\, w_k^H \mathbb{R}_k w_{dcp} |^2}{(w_k^H \mathbb{R}_k w_k)(w_{cp}^H \mathbb{R}_k w_{dcp})} \tag{6}$$

In Fig.2, using the cosine-squared·angle, in-phase component and quadrature component of P_d are calculated as $P_{in-phase} = w_k^H \mathbb{R}_k w_k cos^2\eta$ and $P_{quad} = w_k^H \mathbb{R}_k w_k (1 - cos^2\eta)$, respectively. By insert (6) into $P_{in-phase}$ and P_{quad}, we obtain

$$P_{in-phase} = |\, w_k^H \mathbb{R}_k w'_{dcp} |^2 \tag{7}$$

$$P_{quad} = w_k^H \mathbb{R}_k w_k - |\, w_k^H \mathbb{R}_k w'_{dcp} |^2 \tag{8}$$

where $w'_{cp} = w_{cp}/\sqrt{w_{cp}^H \mathbb{R}_k w_{cp}}$ we can see that phase mismatch between $r_d(t)$, $r_p(t)$ causes P_{quad}, which degrades the system performance.

2. Proposed SIR cost function

The proposed downlink beamforming method is based on maximizing power of desired signal and minimizing the power of interference at the same time. Originally, the power of $r_{int}(t)$ is given by

$$P_{int} = \sum_{\substack{i=1 \\ i \neq k}}^{N} \boldsymbol{w}_i^H \boldsymbol{R}_k \boldsymbol{w}_i \tag{9}$$

On the other hand, we can consider a modified interference $\hat{r}_{int}(t)$ to other mobiles in same cell caused by the signal intended for user k. Then, the power of $\hat{r}_{int}(t)$ is defined as

$$\hat{P}_{int} = \sum_{\substack{i=1 \\ i \neq k}}^{N} \boldsymbol{w}_k^H \boldsymbol{R}_i \boldsymbol{w}_k \tag{10}$$

Now, let us define a signal to interference ratio (SIR) cost function $Z(\boldsymbol{w}_k)$ for the k-th mobile as

$$\begin{aligned} Z(\boldsymbol{w}_k) &= \frac{P_{in-phase}}{P_{quad} + \hat{P}_{\mathrm{int}}} \\ &= \frac{|\,\boldsymbol{w}_k^H \boldsymbol{R}_k \boldsymbol{w}'_{dcp}|^2}{\boldsymbol{w}_k^H \boldsymbol{R}_k \boldsymbol{w}_k - |\,\boldsymbol{w}_k^H \boldsymbol{R}_k \boldsymbol{w}'_{dcp}|^2} \end{aligned} \tag{11}$$

In principle, the SIR values of all users are coupled, which makes SIR based downlink beamforming a complicated task. Instead, the proposed cost function using $\hat{r}_{int}(t)$ is not real SIR which can be measured at mobile, but a virtual one. Although this cost function is virtual, maximizing this cost function can keep balance between phase match and interference suppression. Therefore, we can expect that SIR at each mobile increases globally. Also, since this cost function is dependent on $\boldsymbol{w}_k$ regardless of the weight vectors of other users, this cost function may decouple each mobile.

Ⅳ. Simulation Results

To investigate the performance of the proposed downlink beamforming method, we set up the following cellular environment. The base station was three-sectorized and each sector covered azimuth angle range of 120 degrees. The base station was equipped with a uniform linear array with eight antenna elements and antenna spacing was half of wavelength. The weight vector of common pilot channel was obtained as $\boldsymbol{w}_{cp}$=[0.85, 0.65, -0.04, 0.04, -0.01, 0.09, -0.111, -0.0011]^T by using [11]. Each user had three delay paths and processing gain was 32. The frequency division duplex mode was evaluated with $f_d = 2GHz$ and $f_u = 1.8GHz$. The detailed simulation parameters are given in Table 1.

표 1. 모의실험 파라메터
Table 1. Simulation Parameters.

System model	CDMA20001X Up/Downlink
Fading model	Rayleigh fading channel
Carrier frequency	Downlink: 2GHz Uplink: 1.8GHz
Number of multipath	3
Angular spread	10°
Number of users	20
Number of antenna elements	8
Antenna type	Uniform Linear Array
Mobile speed	120Km
Downlink spreading gain	32

In CDMA2000 downlink system[8], two orthogonal codes are allocated for traffic and pilot channels. Common pilot to traffic channel power ratio was assumed 0.25 and traffic signals were allocated with equal powers. In single cell, twenty mobiles were located with uniform distribution. Angular spreads, Δ_i, was 10 degrees equally for all mobiles, where angular spread was various. Corresponding covariance matrices were calculated by

$$\boldsymbol{R}_i = \frac{1}{\Delta_i} \int_{\theta_i - \Delta/2}^{\theta_i + \Delta/2} \boldsymbol{a}(\phi)\boldsymbol{a}(\phi)^H d\phi \tag{12}$$

where $\boldsymbol{a}(\phi)$ is normalized steering vector at angle ϕ.

Fig. 3 shows that SIR performance of auxiliary

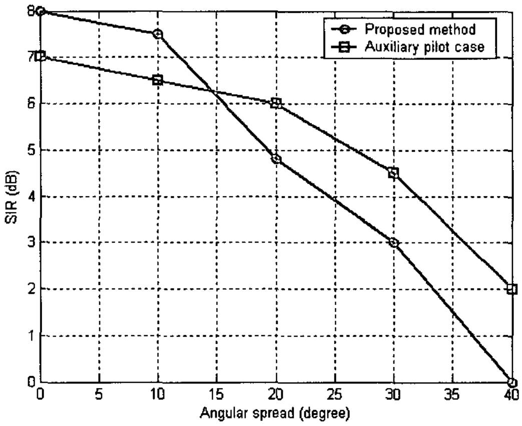

그림 3. angular spread의 변화에 따른 신호대 간섭비의 성능

Fig. 3. SIR performance according to angular spread variations.

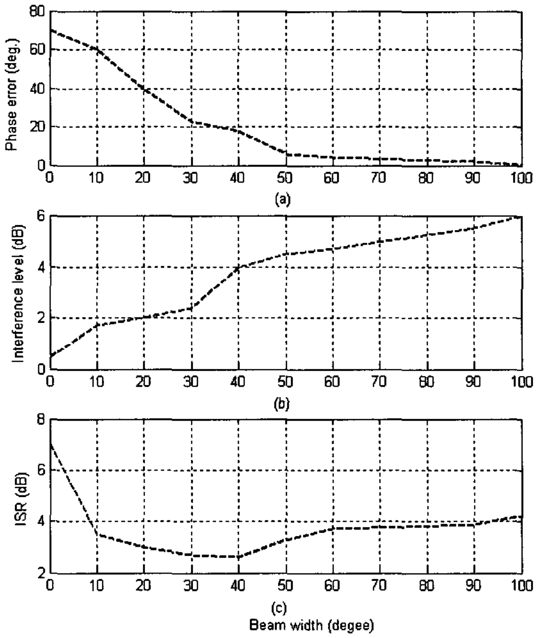

그림 4. 빔폭의 변화에 따른 위상차이 에러, 간섭의 변화와 간섭대 신호비의 변화

Fig. 4. Phase mismatch error, interference variation and $(P_{quad}+\hat{P}_{\text{int}})/P_{in-phase}$ (interference to signal ratio: ISR) according to beam width.

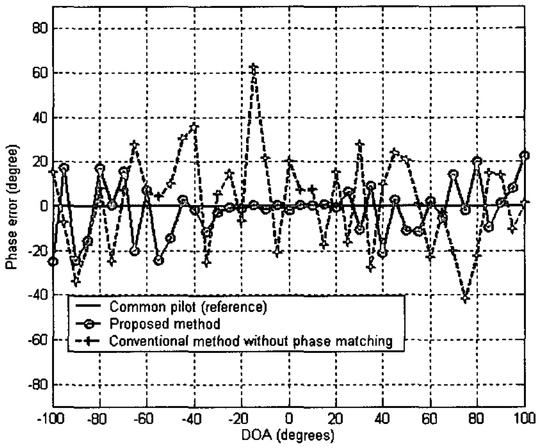

그림 5. 빠른 페이딩 채널에서의 공통채널과 통화채널의 위상 불일치

Fig. 5. Phase mismatch between pilot beam and traffic beam in fast fading channel.

pilot case is limited as decreasing angular spreads due to interference from its own auxiliary pilot. Therefore, common pilot channel case becomes more desirable for macro cell environment which usually has small angular spread, since it can save downlink channel resources while maintaining performance similar to that of auxiliary pilot case. In Fig. 4, as traffic beamwidth increases, phase mismatch is decreased while total interference level is increased. However, in order to solve phase mismatch problem, the proposed method leads to broaden traffic beam-width up to 30 degrees. In Fig. 4, we can see that phase mismatch becomes small while interference goes to be large as beam width increases, and they are compromised at the beam width at which $P_{quad}+\hat{P}_{int}/P_{in-phase}$ is minimized (here, 30 degrees). Therefore, the compromised weight vector can be obtained through the proposed method. Fig. 5 plots phase mismatch property of the proposed method in time-varying channels. It can be seen that phase matching is fitting well between -15 degree to 15 degree (major concern range). Fig.6 illustrates BER performance at mobile station with and without considering phase matching in time-varying channel environment. This result indicates that the proposed method achieves good phase matching property so that it gives improved BER performance in time-varying channel. Fig.7 depicts the compared BER performance between common pilot case and auxiliary pilot case for small(< 10 degree) and large (> 60 degree) angular spreads. We can see that the proposed method is promising when the angular spread is small, where the proposed method gives performance similar to the case using auxiliary pilot.

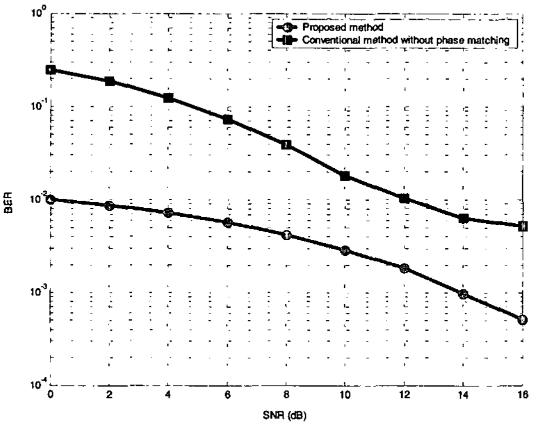

그림 6. 일반방안과 제안된 방안의 비트오율 성능
Fig. 6. BER performance of the proposed method and the conventional method.

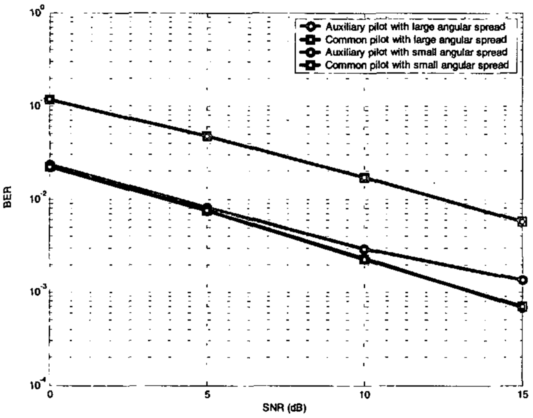

그림 7. 크고작은 angular spread의 변화에 따른 보조파일럿과 공통파일럿의 비트오율 성능
Fig. 7. BER performance of the common pilot case and auxiliary case for small and large angular spread.

Therefore, the proposed method is effective, especially in macro cell environment with small angular spread.

V. Conclusion

A downlink beamforming method, which minimizes auxiliary pilot case for small and large angular spreads both phase mismatch at mobile and interference to other mobiles simultaneously, is developed to achieve coherent detection for DS/CDMA systems with BPSK modulation when only common pilot channel is available. We have derived a solution for the SIR cost function which reflects the phase mismatch effect between common pilot and traffic channels. The simulation results showed that the proposed method gives good phase matching property and improves BER performance in time-varying channel environments, especially for macro cell environment with small angular spread.

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저 자 소 개

이 준 성(정회원)
2004년 현재 연세대학교 전자공학과 박사과정.
1995년~2004년 현재 삼성전자 IT Center Wireless 개발팀 근무 중.

<주관심분야: 통신신호처리, 어레이 신호처리, MIMO 시스템>

이 충 용(정회원)
1995년 Georgia Institute of Technology 박사 졸업.
1996년~1997년 7월 삼성전자
1997년 9월~현재 연세대학교 전자공학과 부교수

<주관심분야: 통신신호처리, 어레이 신호처리, MIMO 시스템>