A SUGGESTION FOR HANDLING THE AUXILIARY PILOT CHANNEL FOR THE SMART ANTENNA BTS OPERATING IN CDMA2000 1X SIGNAL ENVIRONMENT

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ABSTRACT

Amongst many difficulties in downlink beamforming, it has been known that the problem of channel estimation could be resolved by using the auxiliary pilot channel when the dedicated pilot channel is not defined to each of the subscribers as in CDMA2000 1X signal environment. In this paper, we present a systematic procedure of utilizing the auxiliary pilot channel together with the common pilot and traffic channel. The multipath signal environment is first scrutinized in such a way that the necessary conditions for adopting the auxiliary pilot be analyzed. The performance of the downlink beamforming of a given smart antenna base transceiver station (SA BTS) is shown through the various computer simulations and experimental data which have been obtained from our SA BTS, which has been implemented for the CDMA2000 1X standard. The SA BTS shown in this paper supports all the commercial channels defined in the CDMA2000 1X standard.

1. INTRODUCTION

Since adaptive antenna arrays provide a way of spatially filtering out co-channel interfering users from the cell which the desired user is in and from the neighboring cells, the use of the SABS is an attractive way to increase the capacity of CDMA systems. The use of adaptive antenna arrays at the base station can increase the capacity of a mobile radio network due to the capability of mitigating the interference [1]. The purpose of uplink beamforming is to receive as much power as possible from the desired user and as little power as possible from any undesired user. Also, the purpose of downlink beamforming is to transmit as much power as possible to the desired user and as low power as possible to any undesired user [2].

This paper addresses the problem of channel estimation arising in the SA BTS during the downlink beamforming. If the downlink pilot channel is transmitted with a sector-wide beam while the traffic channel is transmitted through a narrowly shaped beam in a given SA BTS, then the two channels at the receiving (RX) mobile terminal can be considered as being different in a multipath signal environment, which causes the channel estimation to be wrong. To overcome this problem of erroneous channel estimation in the downlink beamforming, the auxiliary pilot has been defined with some different values of extended Walsh words in the communication standard of CDMA2000 1X [3]. In this paper, we first analyze the multipath signal environments in order to scrutinize exactly in what signal environments the auxiliary pilot signal is indispensable and what happens if it is not available in those signal environments. Then, we present a systematic procedure of applying the auxiliary pilot signal including an efficient call processing method based on the concept of software-download between a given SA BTS and mobile terminals. The performance of the downlink beamforming utilizing the auxiliary pilot in accordance with the proposed call processing procedure is analyzed through the various computer simulations and experimental data obtained from the SA BTS [4], which has been implemented for CDMA2000 1X standard.

2. CHANNEL MODEL

Let us consider a half wavelength spaced, uniform linear array consisting of N antenna elements. The transmitted base-band signal from the SA BTS for downlink beamforming can be written as

$$\mathbf{s}(t) = \sum_{j=1}^{J} \sqrt{P_j}\, \mathbf{w}_j^{\,H} d_j(t) W_j(t) \tag{1}$$

where P_j, $d_j(t)$ and $\mathbf{w}_j$ denote the transmitting (TX) power, the TX signal, and downlink beamforming weight vector for the jth mobile terminal, respectively. $W_j(t)$ is the Walsh code and H means the complex conjugate transpose. The received signal at the jth mobile terminal can be written as

$$r_j(t) = \tfrac{1}{\sqrt{Q}} \sum_{k=1}^{K} \sum_{q=1}^{Q} \alpha_{k,q}(t)\, \mathbf{s}(t-\tau_k) \cdot \mathbf{a}(\theta_k) + n_j(t) \tag{2}$$

where K, Q, $\alpha_{k.q}(t)$ and $\mathbf{a}(\theta_k)$ are the number of multipath, the number of scattered components at each propagation path, the fading factor, and the steering vector, all of which are associated with the j th mobile terminal, respectively, and $n_j(t)$ is the AWGN with τ_k being the propagation delay. In (2), it is assumed that the propagation delay of every scattered component within a given propagation path is identical.

3. AUXILIARY PILOT CHANNEL

In this section, we first analyze the multipath signal environments in order to scrutinize exactly in what signal environments the auxiliary pilot channel is indispensable and what happens if it is not available in those signal environments. Then, we present a performance analysis of downlink beamforming utilizing the auxiliary pilot in a CDMA2000 1X system through the various computer simulations.

As the multipath on downlink distorts the phase relationship between the sector-wide pilot channel and the traffic channel transmitted through a narrow shaped beam, the phase of each path can be compensated for correctly only when a separate pilot is assigned to each of subscribers. That is, if a common pilot is used for every user, while the traffic signal is transmitted through the narrowly shaped beam assigned to each of the subscribers, then the phase of the two signals must be different from each other when there exists multipath. This causes a serious problem in channel estimation especially when the difference of path delays is less than one chip duration (T_c). One way to resolve this problem is to assign an auxiliary pilot to each subscriber.

When a common pilot is used in a signal environment in which two paths delay with τ_1 and τ_2 is less than T_c, the received signal at mobile terminal can be written from (1) and (2) as

$$r(t) = \sum_{k=1}^{2} \alpha_k \{\mathbf{w}^H d_{tch}(t-\tau_k) W_{tch}(t-\tau_k) \cdot \mathbf{a}(\theta_k) + d_{pich}(t-\tau_k) W_{pich}(t-\tau_k)\} \quad (3)$$

where the subscript *tch* and *pich* denote the traffic and pilot channel, respectively. In (3), we assumed that there exists single scatter per path and the fading factor is constant during a symbol period. We also omitted the noise and interference from other users in (3). To obtain the channel information at mobile terminal, the received signal of (3) is multiplied by Walsh code of the common pilot channel and integrated over a given symbol interval. Then, assuming the processing gain is high enough to suppress the co-channel interferences, we obtain $y_{pich} = \alpha_1 + \alpha_2$. Similarly, for the traffic channel, we obtain $y_{tch} = (\alpha_1\beta_1 + \alpha_2\beta_2) \cdot d_{tch}$ where $\beta_1 = \mathbf{w}^H \cdot \mathbf{a}(\theta_1)$ and $\beta_2 = \mathbf{w}^H \cdot \mathbf{a}(\theta_2)$. Note that both β_1 and β_2 cannot be all real-valued at the same time because they are obtained by correlating a weight vector to the two distinct steering vectors, $\mathbf{a}(\theta_1)$ and $\mathbf{a}(\theta_2)$. Consequently, the final phase compensated traffic signal would be

$$\hat{y}_{tch} = (\alpha_1 + \alpha_2)^* (\alpha_1\beta_1 + \alpha_2\beta_2) \cdot d_{tch} \quad (4)$$

which is not equal to traffic information d_{tch}. In short, the phase characteristic of the traffic and common pilot channel are different from each other such that the traffic information cannot be retrieved correctly. Note that the erroneous channel compensation has occurred because the multipath could not be separated as a result of despreading. Note that if the propagation delays of the multipath are different by further than the chip duration, i.e., $|\tau_1 - \tau_2| > T_c$, the searcher at the RX mobile terminal would be able to separate the multipaths through the despreading procedure. Then, the final phase-compensated traffic signal with a proper Rake combining would be

$$\hat{y}_{tch} = \{|\alpha_1|^2 \beta_1 + |\alpha_2|^2 \beta_2\} d_{tch} \quad (5)$$

Note that when the SA BTS operates normally, the weight vector for the first and second propagation path, respectively, should correspondingly compensate the steering vectors $\mathbf{a}(\theta_1)$ and $\mathbf{a}(\theta_2)$. Consequently, in the signal environment of $|\tau_1 - \tau_2| > T_c$, the traffic information can be retrieved correctly even with the common pilot, if the weight vector can compensate the corresponding channel steering vector. From the above discussions, in order to provide a stable channel estimation in both cases of $|\tau_1 - \tau_2| < T_c$ and $|\tau_1 - \tau_2| > T_c$, it is necessary that the auxiliary pilot should be assigned to each of the subscribers when a dedicated pilot for each user is not available.

With the auxiliary pilot being assigned to each subscriber, when the multipaths are not separable due to $|\tau_1 - \tau_2| < T_c$, the received signal at mobile terminal can be written as

$$r(t) = \sum_{k=1}^{2} \alpha_k \{\mathbf{w}^H [d_{tch}(t-\tau_k) W_{tch}(t-\tau_k) + d_{apich}(t-\tau_k) W_{apich}(t-\tau_k)] \cdot \mathbf{a}(\theta_k) + d_{pich}(t-\tau_k) W_{pich}(t-\tau_k)\} \quad (6)$$

where the subscript *apich* denotes the auxiliary pilot. After the despreading procedure described above, the final phase compensated traffic signal can be written as

$$\hat{y}_{tch} = |\alpha_1\beta_1 + \alpha_2\beta_2|^2 \cdot d_{tch} \quad (7)$$

from which the traffic information d_{tch} is retrieved correctly. It can straightforwardly be observed that the auxiliary pilot gives correct phase information for the case of $|\tau_1 - \tau_2| > T_c$ as well.

To assign the auxiliary pilot to each subscriber, distinction of each subscriber by using a different Walsh code length is necessary. If the Walsh code of the same code length as that of the traffic channel is used to assign the auxiliary pilot, then it causes the Walsh code resources for the traffic channels to be used up as auxiliary pilots. Therefore, the Walsh code length of the auxiliary pilot should be longer than that of the traffic channel, i.e., 64 in

CDMA2000 1X. In this paper, the Walsh code length of 128, 256, and 512, have been assigned for the auxiliary pilot for the performance analysis.

4. CALL PROCESSING

When the auxiliary pilot is assigned in the SA BTS for downlink beamforming, the conventional call processing procedures should be modified. Three states in the conventional call processing procedures, such as initialization state, idle state, and system access state, are the same in the call processing with the auxiliary pilot. But, the traffic state in the conventional call processing should properly be modified. In this paper, we claim that it is possible to provide a modified call processing procedure solely based on software download between the SA BTS and mobile terminals, once a given mobile terminal is capable of decoding the auxiliary pilot as well as the common pilot. Conversely speaking, it is necessary for the modem chip of mobile terminal to be able to decode the auxiliary pilot for all possible extensions of Walsh codes. The modified call processing procedures for the auxiliary pilot can be summarized as follows. When the SA BTS receives the ORM (Origination Message) [5] from the mobile terminal through the access channel, which itself is a call request, the SA BTS sets up traffic channel and transmits the auxiliary pilot channel together with a null traffic channel. When the auxiliary pilot and null traffic are transmitted to the mobile terminal, the base station also transmits ECAM (Extended Channel Assignment Message) through the paging channel, which includes information about the Walsh value and length of the auxiliary pilot. After receiving the ECAM from the SA BTS, the hardware configuration of the mobile terminal should be adjusted to receive and decode the auxiliary pilot and null traffic channel. The mobile terminal also transmits the traffic channel preamble for which the SA BTS responds with BS_ACK_ORDER. Finally, the mobile terminal transmits the null traffic channel which is the response to BS_ACK_ORDER. Then, the SA BTS sends Service Option Response Order and the mobile terminal transmits primary traffic in accordance with service option.

5. NUMERICAL RESULTS

In this section, we present numerical results obtained from computer simulations and experimental measurements. For computing the weight vector during the uplink, the adaptive beamforming algorithm shown in [6] has been used. Figure 1 shows the uncoded average bit error rate (BER) at a mobile terminal when a Walsh length of 128 is used for the auxiliary pilot in multipath signal environment of two propagation paths with path delay of τ_1 and τ_2. A three sector environment is assumed so that the users are

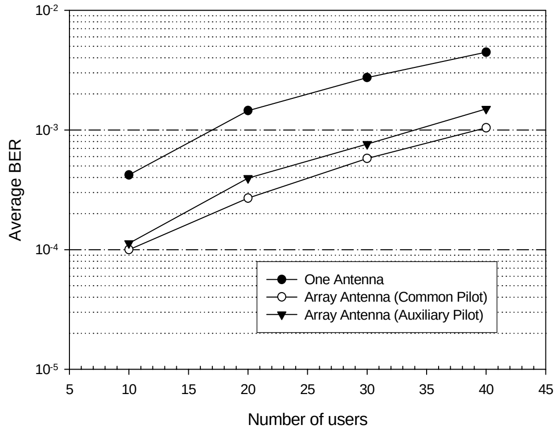

Fig. 1. BER of the downlink beamforming ($|\tau_1 - \tau_2| > T_c$)

uniformly distributed at each sector and the carrier frequency of uplink and downlink is 1.77625GHz and 1.86625GHz, respectively. In Fig. 1, we can see that the assignment of the auxiliary pilot itself causes an increase of interferences, which in turn causes a slight degradation compared to the case of a common pilot. Meanwhile, when the propagation path delay of τ_1 and τ_2 is less than one chip duration, i.e., $|\tau_1 - \tau_2| < T_c$, it is confirmed that the SA BTS with auxiliary pilot performs normally while that with common pilot only becomes completely useless. Note that the phase value of the common pilot signal should inherently be different from that of the traffic signal in this case as discussed earlier.

Fig. 2 shows a photograph of the indoor experimental environment. A smart antenna BTS with 6 antenna elements for uplink beamforming and 4 antenna elements for downlink beamforming was used as the base station and the commercial PCS (Personal Communication Service) terminals are used as the mobile terminals. The FER (Frame Error Rate) of mobile terminal is measured from the DM (Diagnostic Monitor). From computer simulations and experimental measurements, it is clear that the SA BTS should operate together with the auxiliary pilot in order to provide reliable channel estimation in the multipath signal environment. It is noteworthy that the auxiliary pilot itself is another source of interference when the mobile terminal decodes the common pilot at the initial stage of communications, although the auxiliary pilot seems to be indispensable to resolve the problem of channel estimation in the multipath signal environment.

6. CONCLUDING REMARKS

In this paper, we first analyze the signal environments of multipath downlink beamforming SA BTS in order to find under what signal environments the auxiliary pilot is inevitable and what happens if the auxiliary pilot is not

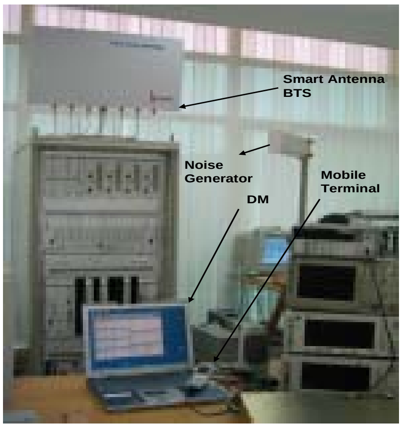

Fig. 2. Experimental environment of indoor test

available. Then, we present how to apply the auxiliary pilot to the SA BTS for downlink beamforming. We also proposed a modified call processing procedure for handling the auxiliary pilot channel through a software download between SA BTS and target subscribers. The receiving performance of the target mobile terminal has been analyzed through computer simulations and experimental measurements obtained from our SA BTS that has been implemented for the CDMA2000 1X standard.

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REFERENCES

[1] J. Blogh and L. Hanzo, *Third generation systems and intelligent wireless networking*, John Wiley and Sons, 2002.

[2] S. Choi and D. Yun, "Design of adaptive antenna array for tracking the source of maximum power and its application to CDMA mobile communications," *IEEE Trans. Antenna Propagat.*, vol. 45, no. 9, pp. 1393-1404, Sept. 1997.

[3] 3GPP2, "Physical layer standards for cdma2000 spread spectrum systems," C.S0002-D v1.0, 2003.

[4] H. Im, et al., "Implementation of smart antenna base station for IS-2000 1X," in *Proc. VTC*, 2003, pp. 582-586.

[5] 3GPP2, "Upper Layer (Layer 3) Signaling Standard for cdma2000 Spread Spectrum Systems," C.S005-D v1.0, 2004.

[6] S. Choi and D. Shim, "A novel adaptation beamforming algorithm for a smart antenna system in a CDMA mobile communication environment," *IEEE Trans. Veh. Technol.*, vol. 49, pp.1795-1799, May 2000.