A SWICHED BEAM ANTENNA SYSTEM COMBINED WITH MULTIUSER DETECTORS

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Abstract

The multiuser detector (MUD) has been used in order to reduce the multiple access interference in the CDMA system. However, it requires very high computational complexity. In this paper, we propose a switched beam antenna system combined with multiuser detectors (MUD) to alleviate the problem. In the proposed system, the parallel searcher estimates the beam directions of each user's multipath signals. Then, the parallel interference cancellation is performed within a pre-performed beam signal (partial decorrelation). Therefore, the required hardware complexity and the processing delay are significantly reduced. We have simulated the proposed system and our simulation results show that the proposed interference canceller achieves high SINR in a heavy interference channel, where a conventional spatial filtering system or a conventional MUD system cannot achieve.

I. INTRODUCTION

Recently, the multiuser detectors (MUD) [1-2] have been studied in order to reduce the multiple access interference (MAI) and to alleviate the near-far problem. The multiuser detector regenerates the other users' signals and subtracts these signals from a received baseband signal in order to reduce the MAI. However, there are several factors that limit the performance of the MUD system. One factor is intercell interference which coming from the adjacent cells. The other factor is the fraction of energy captured by a RAKE receiver. That is, a RAKE receiver with L fingers only capture the energy in the L strongest multipaths but there are additional received energy in additional paths. Therefore, the performance of the MUD is severely degrades when the number of users in a cell increases. Moreover, the MUD requires high computational complexity.

The combination of an adaptive array antenna in the spatial domain and the MUD in the temporal domain [3] has been proposed to solve these problems. In the structure, the spatial filtering system suppresses the interference coming from other than the desired user's direction, while the MUD removes the remaining MAI. However, since the interference canceller, in the structure, does not have the direction-of-arrival information for the users' signals, the decorrelation detector not only removes the interferences which coming from the directions close to the desired user's signal but also removes the interferences having arrival angles different from that of the desired user. So, it requires lots of computational time and the hardware complexity. Yu and Litva [4] uses a multibeam antenna system in order to reduce the computational complexity of the MUD system. In the structure, the partial decorrelation is performed within a pre-preformed beam. In the structure, the high power users' signals, after the despreading, are assumed to be the desired beam signal. So, the demodulators for all the users are still required in each beam to compute the output power of the demodulated signal. So, even if the processing time for the decorrelation is reduced, it still requires hardware complexity.

In this paper, we propose a switched beam antenna system combined with multiuser detectors. In the proposed system, after the fixed beamforming, a parallel searcher estimates the beam directions of each user's multipath signals. Therefore, only the users' signals within the same beam are used for the MUD (partial decorrelation). Since the MUD works only in one performed beam signal, the required hardware complexity and the processing delay are significantly reduced. Moreover, the probability of the imperfect cancellation is reduced since the average MAI in a beam signal is less than the total MAI

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in a cell. Therefore, the proposed system can achieve low BER with less computational complexity, in a heavy interference channel, where the conventional spatial filtering system or the MUD only system cannot achieve.

II. The Interference Cancellation Systems

Assume that there are K users sharing the same bandwidth. The received baseband signal is the sum of all users' signals and noise :

$$r(t) = \sum_{k=1}^{K} \rho_k \sqrt{P_k}\, b_k(t-\tau_k)c_k(t-\tau_k) + n(t) \tag{1}$$

where, $b_k(t)$, which has a time period T_b, is a kth user's binary sequence and $c_k(t)$, which is a sequence of chips which have a time period of T_c, is a kth user's spreading code. ρ_k, τ_k, and P_k are the Rayleigh distributed channel attenuation, time delay, and the power of the kth user's signal, respectively. K is a number of active users in a cell and $n(t)$ is an additive White Gaussian Noise.

In this paper, we considered the parallel interference canceller (PIC) structure. Therefore, all the other users' signals are regenerated and subtracted from the received baseband signal. The pth user's output signal at the end of the PIC stages becomes

$$z_{PIC}^{p}(t) = r(t) - \sum_{\substack{k=1 \\ k\neq p}}^{K} \hat{\rho}_k \sqrt{P_k}\, \hat{b}_k(t-\hat{\tau}_k)c_k(t-\hat{\tau}_k) = \rho_p \sqrt{P_p}\, b_p(t-\tau_p)c_p(t-\tau_p) + I_C^p + I_I^p + n(t) \tag{2}$$

where, $\hat{\rho}_k$, $\hat{\tau}_k$ are the estimated channel attenuation and time delay of the kth user's signal, respectively. I_C^p is a cancellation interference, which is caused due to the limited fingers, and I_I^p is an imperfect cancellation interference. Imperfect cancellation is caused due to non-accurate signal regeneration and cancellation, which is caused by inaccurate data or channel parameter estimation.

The performance of the parallel interference canceller system is depends on the cancellation interference and the imperfect cancellation interference. However, the cancellation interference increase as the number of active users in a cell increases since a RAKE receiver has limited fingers. And this makes the probability of the imperfect regeneration increase. Therefore, the performance of the PIC system severely degrades as the number of users in a cell increases. Moreover, the PIC system requires high computational complexity in order to remove all the other users' signals simultaneously. So, we employ a switched beam antenna system to the PIC in order to alleviate these problems.

III. The Proposed Interference Canceller

In this section, two cases are considered : single path channel and multipath channel.

A. Single path channel

Considering a uniform linear arrays (ULAs) consisting of M identical and omnidirectional sensors. The baseband sensor output vector, at some time *t*, can be expressed as

$$\mathbf{r}(t) = \sum_{k=1}^{K} \rho_k \sqrt{P_k}\, b_k(t-\tau_k)c_k(t-\tau_k)\mathbf{a}(\theta_k) + \mathbf{n}(t) \tag{3}$$

where, θ_k is the direction-of-arrival (DOA) of the kth user's signal, $M\times 1$ vector $\mathbf{a}(\theta_k)$ represents the response of the array to a unit impulse from bearing θ_k, and M is the number of array elements. Also, the $M\times 1$ vector $\mathbf{n}(t)$ is the additive white Gaussian noise (AWGN) vector.

Fig. 1 shows the proposed interference canceller. In the proposed system, the switched beamformer operates by forming a set of performed beams using N pre-determined weighting vectors. The output of the switched beamformer can be represented as

$$\mathbf{y}(t) = \mathbf{W}^{\mathbf{H}}\mathbf{r}(t) \tag{4}$$

where, $\mathbf{y}(t) = [y_1(t)\ \ y_2(t)\cdots y_N(t)]^T$ is the output at the switched beamformer, where $y_n(t)$ is the output at the nth beam. $\mathbf{W} = [\mathbf{w}_1\ \ \mathbf{w}_2\cdots \mathbf{w}_N]$ is an pre-determined weighting matrix, where $\mathbf{w}_n$ is a complex weighting vector for nth direction. The output at the nth beam can be expressed as

$$y_n(t) = \sum_{k=1}^{K} \rho_k \sqrt{P_k}\, b_k(t-\tau_k)c_k(t-\tau_k)\mathbf{w}_n^H \mathbf{a}(\theta_k) + n_n(t) \tag{5}$$

The pre-performed beam signals ($y_n(t)$) are stored in the corresponding buffers for MUD. The parallel searcher, which is consists of a bank of matched filters, receives N performed beam signals and selects the best beam signal for each user's signal and sends the results to the controller. The controller controls the switching matrix1 in order to input the best performed beam signal to the demodulator of a user. There are two different user groups in eq. (5), one is the signals coming from the *n*th beam direction and the other is the signals coming from other than the *n*th beam direction. So, we divide all the users' signals in eq. (5) into two groups. Without loss of generality, we assumed that the 1st user's signal, which coming from the *n*th beam direction, is the desired signal. Then, eq. (5) can be rewritten as

$$y_n(t) = \sqrt{P_1}b_1(t-\tau_1)c_1(t-\tau_1)\mathbf{w}_n^H\mathbf{a}(\theta_1) + \sum_{\substack{k=2 \\ k\in beam\ n}}^{K} \rho_k \sqrt{P_k}b_k(t-\tau_k)c_k(t-\tau_k)\mathbf{w}_n^H\mathbf{a}(\theta_k) + I_n^{other} + n_n(t) \quad (6)$$

In eq. (6), the second term is due to the interference coming from the *n*th beam direction, and the third term is due to the interference coming from other than the *n*th beam direction.

$$I_n^{other} = \sum_{\substack{k=2 \\ k\notin beam\ n}}^{K} \sqrt{P_k}b_k(t-\tau_k)c_k(t-\tau_k)\mathbf{w}_n^H\mathbf{a}(\theta_k) \quad (7)$$

In eq. (7), since these interferences are coming from other than the *n*th beam direction, $\left|\mathbf{w}_n^H\mathbf{a}(\theta_k)\right|^2$ is very low. Therefore, the second term in eq. (6) dominates the interference so that we removes the second term only in the proposed system. After passing the switching matrix1, the signals are respreaded and regenerated using the beam signal selected in the parallel searcher. Then, the regenerated signals, which coming from the same beam direction, are inputted to the same MUD block using the switching matrix2. The switching matrix2 is also controlled by the controller. Then the PIC is performed within the same beam signal. The 1st user's output signal at the end of the corresponding PIC block becomes

$$\begin{aligned} z_{PIC}^p(t) &= y_n(t) - \sum_{\substack{k=2 \\ k\in beam\ n}}^{K} \hat{\rho}_k \sqrt{P_k}\hat{b}_k(t-\hat{\tau}_k)c_k(t-\hat{\tau}_k)\mathbf{w}_n^H\mathbf{a}(\theta_k) \\ &= \rho_p \sqrt{P_p}b_p(t-\tau_p)c_p(t-\tau_p)\mathbf{w}_n^H\mathbf{a}(\theta_p) + I_{C,n}^p + I_{I,n}^p + I_n^{other} + n_n(t) \end{aligned} \quad (8)$$

With the assumption that all the users' signals are power controlled, $\rho_k^2 P_k\left|\mathbf{w}_n^H\mathbf{a}(\theta_k)\right|^2$ in the same beam direction has similar power. That is, $\rho_k^2 P_k\left|\mathbf{w}_n^H\mathbf{a}(\theta_k)\right|^2 \approx P$. In eq. (8), $I_{C,n}^p$ is a cancellation interference caused due to the limited fingers and $I_{I,n}^p$ is an interference due to imperfect signal cancellation. However, the power of the $I_{C,n}^p$ is relatively low compare to the power of the I_C^p in eq. (2). This is because the number of users in a beam is relatively smaller than that of a sector. This makes the probability of the imperfect cancellation low, so that the performance of the system increased. Moreover, the required hardware complexity and processing delay reduced significantly because the PIC is performed within a beam signal. The interference, I_n^{other}, is affected to the SIR of the system. However, I_n^{other} is already reduced by the switched beamformer (because of the spatial filtering for *n*th beam direction), so the expected performance degradation due to I_n^{other} is not serious.

B. Multipath Channel

In the practical wireless channel, the users' signals are received with multipath signals and each path signal may be received from the different beam direction. In the situation, the same structure, proposed in Fig. 1, can be used. In the case, the parallel searcher searches the beam directions of all the resolvable multipath signals. This information also sends to the controller. The controller controls the switching matrix1, 2 in order to input the regenerated path signals, which coming from the same beam direction, to the same PIC block. And the interference-cancelled path signals are inputted to the corresponding demodulator via a switching matrix3 which is controlled by the controller.

IV. SIMULATION RESULTS

In order to assess the performance of the proposed interference canceller, a number of simulations have been performed. In the simulations, we used a linear array with six elements and uniform spacing of half wavelength between successive sensors. We considered the six fixed beams for the switched beam antenna system. The processing gain was 63 and 2 multipath signals for each user were considered in the simulation. We assumed that the time delay and phase of the desired user's signal were perfectly estimated. The angles of arrivals for the other users' signals were assumed to uniformly distribute over $[-p/3, p/3]$. We compare the SINR of the proposed system to the conventional parallel interference cancellation system and the switching beam antenna system when the number of active users in a cell increased form 1 to 50. Average SINR from twenty simulation runs is plotted in Fig. 2. As shown in Fig2., when there are small number of the active users in a cell, the conventional PIC system has a good performance, however, when the number of the active users increased, the performance of the multiuser detector is severely degraded. This is because the imperfect cancellation noise is increased as the number of active users in a cell increased. The SINR for the proposed interference canceller is good enough even though the number of active users in a cell increased.

V. CONCLUSION

In this paper, we proposed the switched beam antenna system combined with multiuser detectors in order to reduce the computational complexity of the MUD system. In the proposed system, the required computational complexity for the PIC is reduced significantly since the MUD is performed within a beam signal. Moreover, the probability of the imperfect cancellation is reduced since the MAI in a beam signal is less than the total MAI in a cell. Therefore, the proposed interference canceller has a good performance in a heavy interference channel.

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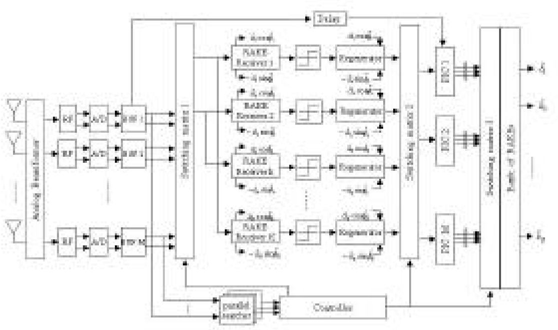

Fig. 1 Proposed interference Canceller.

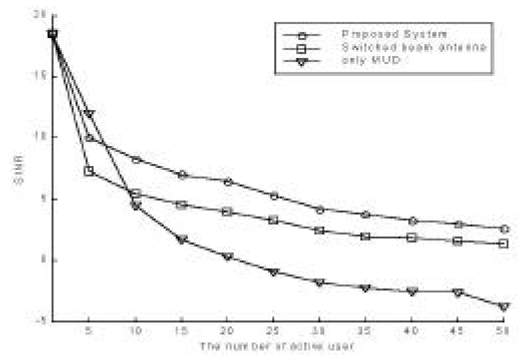

Fig. 2 Simulation results.