A BEAM CONTROL METHOD FOR SDMA IN WIDEBAND FIXED WIRELESS ACCESS SYSTEMS

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1 Introduction

Ka-band fixed wireless access (FWA) systems, such as LMDS, are now being introduced for high-speed point-to-multipoint radio links, because of speedy and low-cost deployment[1]. In the FWA systems, one of the candidate techniques to enhance their subscriber capacity is the space-division multiple access (SDMA) technique by adaptive arrays[2]. The base station with the adaptive array for SDMA can communicate the subscribers simultaneously in the same frequency channel by multiple orthogonal beams, when the subscribers are sufficiently separated in azimuth angle.

Recently, the digital beam forming technique has been mainly investigated for mobile communications. But FWAs usually have a much higher bit rate, thus, the phased array, which is not restricted by heavy digital signal processing load, is preferable to DBF. We have derived an adaptive null forming algorithm for phased arrays which uses only the array output power[3]. The algorithm, based on constrained power minimization (CPM), can place nulls in the directions of interference while maintaining a specified response to the desired subscriber.

In this paper, we apply the CPM algorithm to form the multiple orthogonal beams for SDMA in the fixed wireless access. The CPM algorithm as well as the DOA estimation on the entry of a newly installed subscriber terminal for the simple phased array, which observes only the array output power and do not require the input vectors, allows us to reduce the interference from other co-channel subscribers in the same sector cell. Also, we investigate the effect of the DOA estimation error on the CIR performance by the SDMA of the simple CPM algorithm.

2 The phase control algorithm based on CPM using only the array output power

The principal idea of the phase control algorithm proposed in [3] is that the gradient for the update recursion of CPM is derived only from the deviation of the array output power by phase weight perturbation. Thus, the complex baseband signals demodulated from individual array elements are not required.

Assume a phased array of K elements as shown in Figure 1. The CPM algorithm for phased array chooses its phase weights to minimize the output power while maintaining the gain to the desired subscriber. The update recursion of the CPM algorithm for the k-th element ϕ_k of the phase weights $\boldsymbol{\Phi}$ is given by [4], i.e.

$$\phi_k(m+1) = \phi_k(m) + \mu \left\{ \nabla_{\phi_k} P(\boldsymbol{\Phi}) + \beta \sin\left(\phi_k(m) - \phi_k(0)\right) \right\} \tag{1}$$

where m is the iteration number, μ is the step size, β is the constraint coefficient, $\phi_k(0)$ is the initial phase weight which is chosen so that the beam pattern has the maximal gain to the desired terminal, and $\nabla_{\phi_k} P(\boldsymbol{\Phi})$ is the gradient of array output power $P(\boldsymbol{\Phi})$ with respect to the phase shift for the k-th element signal. In the original method[4], individual input signals are required to calculate the gradient. The authors have proposed a new optimization algorithm utilizing the fact that the gradient can be alternatively expressed as follows without input signals[3].

$$\nabla_{\phi_k} P(\boldsymbol{\Phi}) = \frac{P(\boldsymbol{\Phi} + \Delta\boldsymbol{\Phi}_k) - P(\boldsymbol{\Phi} - \Delta\boldsymbol{\Phi}_k)}{2\sin(\Delta\phi)} \tag{2}$$

where $\Delta\boldsymbol{\Phi}_k = [0, \cdots, 0, \Delta\phi, 0, \cdots, 0]^T$; then $\boldsymbol{\Phi} + \Delta\boldsymbol{\Phi}_k$ is the phase weights when only the phase shift for the k-th element signal is shifted by $\Delta\phi$ radian. Eq.(2) shows that the observation of $P(\boldsymbol{\Phi} + \Delta\boldsymbol{\Phi}_k)$ and $P(\boldsymbol{\Phi} - \Delta\boldsymbol{\Phi}_k)$ leads to the obtaining of $\nabla_{\phi_k} P(\boldsymbol{\Phi})$ indirectly and thus phase weights can be updated only from the array output power with two additional phase-shift operations.

3 Beam control for SDMA using the simple CPM in Ka-band FWA systems

Here we present the SDMA method using the CPM algorithm for the Ka-band FWA. In the proposed SDMA approach, first, the direction of each subscriber is found, and then at the following communication signal burst, the direction knowledge-base is utilized for SDMA with multiple orthogonal beams. In the Ka-band FWA, a line-of-sight is basically maintained between a fixed terminal and a base station, and the terminal uses a high-gain directional antenna with a narrow beamwidth of a couple of degrees to accomplish a sufficient link budget. Thus reflections and diffractions are much weaker than the line-of-sight path. Therefore, by a slight modification of a typical communication protocol shown below, the direction of each fixed subscriber can be detected by the base station.

A typical TDM/TDMA frame format comprising both control timeslots and communication timeslots is assumed. When a new subscriber terminal transmits a request for entry to a base station in an uplink control slot, the base station allocates some uplink communication slots to the terminal for detecting the direction. the terminal transmits a proper signal with fixed transmission power during the allocated slots, and the base station scans a sharp beam or null to detect the direction of the subscriber. A direction knowledge-base can be made by the continuing direction detection scheme for all new subscribers. In FWA systems, the direction of a subscriber is fixed, and therefore the direction knowledge-base made here can be utilized for the following communication with the subscriber.

To simplify the following presentation, we assume that there are two co-channel subscribers for SDMA. The actual direction of subscriber 1 and subscriber 2 are θ_1 and θ_2, respectively, and the estimated direction by the above mentioned process are $\hat{\theta}_1$ and $\hat{\theta}_2$, respectively. The subscriber terminals individually transmit their requests for communication with the base station in uplink control slots. If the difference of estimated directions $\Delta\hat{\theta} = |\hat{\theta}_1 - \hat{\theta}_2|$ is larger than a certain threshold $(\Delta\theta)$th, the base station allocates an uplink TDMA time slot to both the terminals. During the allocated slot, these terminals transmit uncorrelated signals. and then the phase weights $\boldsymbol{\Phi}_1$ and $\boldsymbol{\Phi}_2$ to form the multiple beams that can be intended towards individual subscribers are designed simultaneously based on the CPM algorithm. Here, the initial weights for $\boldsymbol{\Phi}_1$ and $\boldsymbol{\Phi}_2$ are chosen so that the outputs from the individual array elements are co-phased when the signals income from $\hat{\theta}_1$ and $\hat{\theta}_2$, respectively. Then, $\boldsymbol{\Phi}_1$ is revised based on the CPM presented in the previous section such that the beam pattern of the antenna array has null at θ_2 while trying to maintain the gain toward $\hat{\theta}_1$. $\boldsymbol{\Phi}_2$ is similarly revised such that the pattern has its null at θ_1 while trying to maintain the gain toward $\hat{\theta}_2$. Thus, multiple subscribers can share the same radio channel with the orthogonal beams.

To define the above algorithm completely, the threshold of the direction difference between the two subscribers $(\Delta\theta)$th have to be decided. Thus, the relationship between the direction difference $\Delta\theta = |\theta_1 - \theta_2|$ and the CIR performance by the proposed algorithm, taking the effect of the DOA estimation error (e.g., $\hat{\theta}_1 - \theta_1$) into the consideration, is investigated in the following section.

4 Simulation results

The CIR performance with respect to the direction difference $\Delta\theta$, considering the error of the estimated direction of the subscribers are obtained by numerical simulations. Especially, the error of the estimated direction of the desired terminal is crucial for CPM algorithm.

When the proposed scheme is implemented to the actual the DOA estimation error of the proposed scheme is caused by various reasons, which comprise the quantization of the array output power and the directive gain deviation during the beam scan. We assumed that the DOA estimation error is Gauss-distributed, as shown in Figure 2. Three different values of standard deviation (SD) , 0.5, 1.0 and 1.5 degrees, are considered.

An eight-element uniform linear antenna array with separation of one half wavelength shown in Figure 3 was assumed. The boresight of the array was directed to the center of a 90-degree sector cell. The element radiation pattern is assumed to be ($\cos^{0.8}\theta$).

The CPM algorithm is used to form two orthogonal beams to offer SDMA to two subscribers. One of the two subscribers is uniformly-distributed in the 90-degree sector cell under the restrictions that the direction difference of the two $\Delta\theta$ is a certain constant value and both subscribers are in the sector cell. The number of trials for each value of $\Delta\theta$ is 10000. Both subscribers transmit different DQPSK signals with the same power (CNR=20dB) simultaneously. Tables 1 shows the simulation conditions. The step size and the constraint coefficient is referred by [4]. K, P_s, P_0, denote the number of array elements, the received power from a desired subscriber at the individual elements, the total received power at the individual elements, respectively.

For the simplicity, co-channel interference from the adjacent cells can be neglected by proper channel allocation to the cells.

Figure 4 shows that the relation of the direction separation of the two subscribers and the CIR with 99% reliability obtained by the converged beam pattern, with the different values of SD of the DOA estimation error. The required CIR for a typical FWA link is around 20 dB, and thus the requirement is satisfied if the SD of the DOA estimation error is less than 1.5 degrees and the direction separation is more than 25 degrees. Figure 5 shows the converged radiation patterns under the following conditions: the SD of the estimation error is 1 degree, the direction separation is 25 degrees, $\theta_1 = 15°$, $\theta_2 = 41°$, $\hat{\theta}_1 = 16.7°$, and $\hat{\theta}_2 = 41.7°$. There is a slight difference between the subscriber direction and the peak of the mainlobe because of the DOA estimation error and the small direction separation between the two subscribers, but the null is accurately directed to the undesired subscriber.

5 Conclusions

We applied the simple CPM algorithm to form the multiple orthogonal beams for SDMA in the fixed wireless access. The CPM algorithm as well as the DOA estimation for the initial phase weights observes only the array output power and do not require the input vectors.

The relationship between the direction difference and the CIR performance by the proposed algorithm, taking the effect of the DOA estimation error into the consideration, was investigated in order to decide the threshold of the direction difference between the two subscribers. Our simulations showed that the SDMA with the CIR of 20 dB or more is accomplished if the direction difference between two subscribers is more than 25° and the SD of DOA error is less than 1.5 degrees. A subject of our future work will be investigation of the accurate DOA estimation algorithm in the case of various degradation reasons, including the effect of the quantization of the array output power.

References

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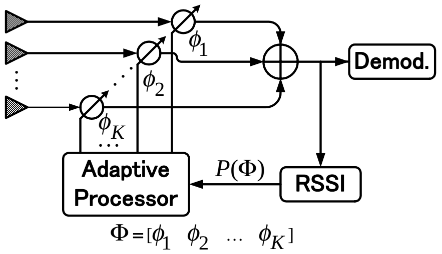

Figure 1: Adaptive phased array with array output RSSI

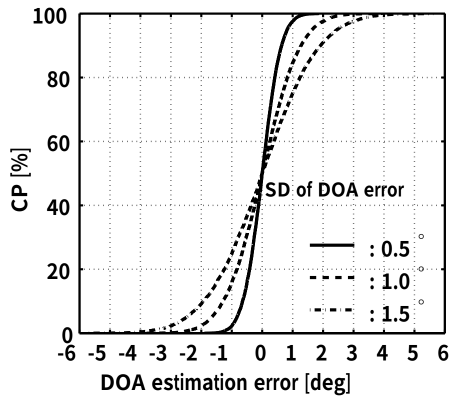

Figure 2: Assumed DOA Estimation Error Model

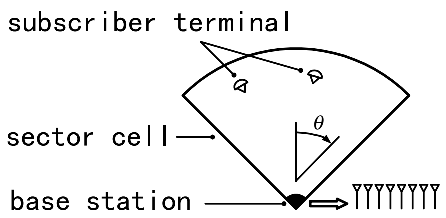

Figure 3: An eight-element directional linear array

Table 1: The parameters in Eqs.(1) and(2) used in the simulation

Rotation angle	$\Delta\phi = 90°$
Constraint coefficient	$\beta = 2KP_s$
Step size	$\mu = -0.01/P_0$
Iteration count	200

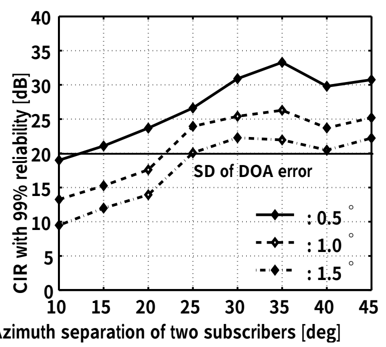

Figure 4: The effect of the direction difference of two subscribers on CIR

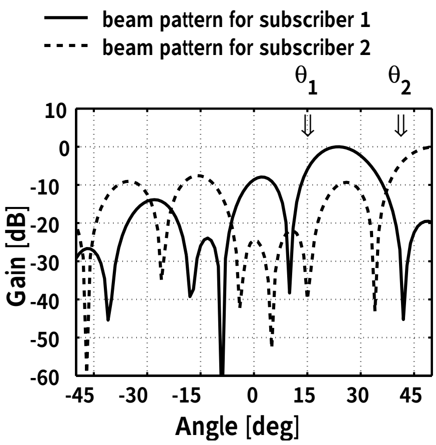

Figure 5: Multiple beam patterns by final weights