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Joint Beam-Power Coordinative Scheduling of Neighboring Sectors in Cellular Systems

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Abstract

Beam cooperative scheduling of downlink transmission is an important technique to improve the spectrum efficiency in next generation mobile networks. This paper focuses on switched beams (the emission angles of the beams are fixed) and proposes a joint beam-power coordinative scheduling algorithm among neighbor sectors in the downlink of mobile systems. Each sector coordinates the applied order and transmitted power of the beams with adjacent interfering sector, so as to reduce inter-sector interference and maximize throughputs. This scheduling problem is modeled as a constrained optimization problem and solved by our proposed iterative approach. Computer simulation shows that the proposed approach significantly outperform the existing round robin beam servicing approach and the approach that applies only beam cooperative scheduling.

Index Terms: Cellular System; Cooperative Beam Scheduling; Constrained Optimization

1. Introduction

The next generation of wireless networks will use MIMO (Multi-Input Multi-output) antenna arrays to achieve high spectral efficiency [1]. The system will also adopt full frequency reuse to realize high transmission speed. However, full frequency reuse introduces more interference among adjacent sectors [2]. How to reduce inter-sector interference becomes a serious problem.

As a low complexity interference suppression technology, beamforming in the downlink has two patterns to increase cell coverage as well as improve cell edge spectral efficiency. In the pattern of adaptive beamforming, antenna array's weights change according to user's direction-of-arrival. This pattern works well but requires complex signal-processing and additional radio frequency (RF) chain to track signals. In the pattern of switch beamforming, the emission angle of each beam is fixed and multiple narrow beams together cover a sector-wide

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area. It is not a theoretically optimum way of using multiple antenna elements, but it presents an excellent tradeoff between performance and complexity. It requires only a single dynamic switch to control antenna handoff [3]. We focus on the switch beamforming in this paper.

The WIMAX system applies switch beamforming in the downlink transmission, where the downlink subframe is partitioned into several time slots [4]. Each sector in a slot randomly chooses one from a predetermined set of beams to serving users that lie within that beam. A simple round robin or random beam serving approach was applied. Beams overlap in a slot is possible to occur, which will lead to significant interference. Hence, this approach may not always be desirable.

Most existing beam coordinative scheduling algorithms require a cluster center to perform beam scheduling for all sector in this cluster. Such cluster usually includes a large number of sectors. The centralized algorithm is computationally expensive and also requires significant backhaul resource for exchanging information [5-6]. Ref.[1] proposed a distributed algorithm, in which each sector can get the optimal beam applied order independently by coordinate transmissions between sectors. In [1] transmission power of each beam is uniform. However uniform coverage of all beams may not be desirable, we propose a distributed joint beam-power coordinative scheduling algorithm among neighbor sectors in the downlink of mobile systems. The transmitted power of each beam is based on the current MS distribution to improve power efficiency and maximize system throughput.

2. Beam Cooperation Scheduling

The distributed algorithm proposed in [1] only considers two facing sectors. The scheduling beams in the coordination area is illustrate in Fig.1.

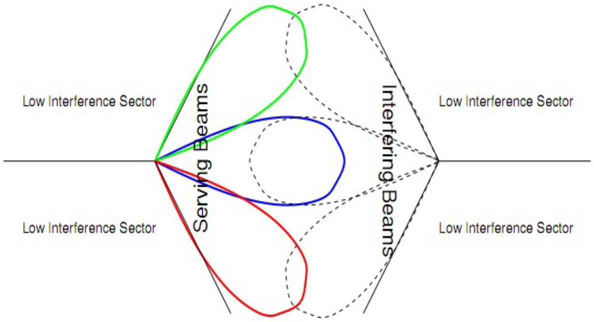

Fig 1. Two facing sectors in the cooperation area

Consider any sector (called sector A) and assume that it can use one of M beams while the sector facing it (called sector B) can use one of N beams. We assume that a scheduling period (a subframe) is partitioned into several time slots and in each slot a single beam is used in each sector. In order to keep the fairness of beams, the scheduling period should have $T = \min(M,N)$ slots at least and each beam could be chosen only once in each period.

At the beginning of a scheduling period, each sector in the coordination area calculates the utility of itself based on the exchanged channel information with adjacent sectors through the X2 interface. Finally sectors can determine the beam applied order to achieving the goal of maximize the sum utility over all sectors in the coordination area. For a given beam pair, the total utility of the coordination area in a subframe is calculated as follow.

Assume there are S users in beam m of sector A and users can work only when sector A use beam m. For example, if sector A use beam m and sector B use beam n, user i in beam m can measure and report the $SINR$, denoted as $\gamma_{m,n}(i)$, of this beam pair to serving sector.

Let $\hat{r}_{m,n}(i)$ denotes the average rate of user i at the former scheduling period, $r_{m,n}(i)$ represents the average rate at the current scheduling period, $x^*_{m,n}(i)$ denotes the number of resources allocated to user i. $r_{m,n}(i)$ is calculated by[1].

$$r_{m,n}(i) = a\hat{r}_{m,n}(i) + (1-a)x^*_{m,n}(i)\ln(1+\gamma_{m,n}(i)) \tag{1}$$

Where a is the filter coefficient to update the rate of user. Assume there are Q resources in each sector. Ref.[1] applied proportionally fair allocation algorithm in [7] for user fairness. Let $x^*_{m,n}(i)$ denote the optimal number of resource allocated to user i and $s_{m,n}(i)$ denote the resource allocation coefficient of user i. $x^*_{m,n}(i)$ is given by

$$x^*_{m,n}(i) = \frac{1}{S}(Q + \sum_{i=1}^{S} s_{m,n}(i)) - s_{m,n}(i) \tag{2}$$

$$s_{m,n}(i) = \frac{a\hat{r}_{m,n}(i)}{(1-a)\ln(1+\gamma_{m,n}(i))} \tag{3}$$

The utility of user i is given by

$$U_{m,n}(i) = \ln(r_{m,n}(i)) \tag{4}$$

Similarly calculate the utility of rest users in beam m sector A. Finally we can determine the sum utility of sector A when using beam pair (m, n) as

$$F_{m,n}(A) = \sum_{i=1}^{S} U_{m,n}(i) \tag{5}$$

Similarly calculate the sum utility of sector B and define $F_{m,n}(B)$ as the utility of sector B.

Consider sector A can use one of M beams while sector B can use one of N beams. There are $M*N$ beam pairs in the coordination area. The objective of beam cooperation is to find the optimal beam pair as

$$\{m^*, n^*\} = \arg\max_{(m,n)}(F_{m,n}(A) + F_{m,n}(B)) \tag{6}$$

The transmitted power of each beam is identical in the distributed algorithm proposed in [1]. The algorithm is suitable for the case of user uniform distribution. However user distribution is not that in practice. If there is none or rare users in a beam, the power of this beam is same as other beam may cause the waste of power resources. If a hot spot in a sector, the transmitted power of this beam should be increased and try to get more resources than other beams.

3. Joint Beam-Power Cooperation Scheduling

In this section we propose a joint beam-power coordinative scheduling algorithm among neighbor sectors in the downlink of mobile systems. Each sector coordinates the applied order and transmitted power of the beams with adjacent interfering sector, so as to reduce inter-sector interference and maximize throughputs.

This algorithm considers the common scenario of three facing sectors in the cellular network, shown in Fig. 2. Assume that a scheduling period is partitioned into several slots and in each slot just a single beam is used in each sector. Each beam may have different transmitted power at the different slot, but the average transmitted power of each beam in a scheduling period is fixed. There are direct exchange interfaces among sectors in the cooperation area. Each sector can pass information of users to neighbors by interfaces, such as channel gain and user's locations.

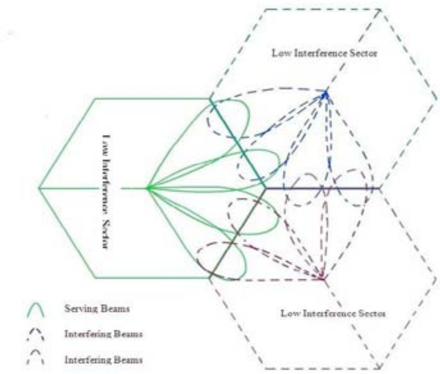

Fig 2. Three facing sectors in the cooperation area

At the beginning of a scheduling period, each sector in the coordination area executes the scheduling algorithm, so as to independently calculate the applied order and transmitted power of the beams. When total beams have been transmitted, a new scheduling period starts.

This scheduling problem is modeled as a constrained optimization problem. For an cooperation area let A, B, C denote three facing sectors and each sector can use one of N beams in each slot. Let $N \times 1$ vectors $\mathbf{t}_A$, $\mathbf{t}_B$, $\mathbf{t}_C$ denote the applied order of beams according with above sectors and $\mathbf{p}_A$, $\mathbf{p}_B$, $\mathbf{p}_C$ denote the transmitted power of beams respectively in a scheduling period.

Because users' locations are known, angles between users and each beam can be calculated. Let $\theta_{k,m}^A$ denote the angle between user k and beam m in sector A, so the channel gain of user k in sector A can be shown as follow when beam m is working [8].

$$G_{k.m}^A = \frac{S_0^A * G_0^A * A(\theta_{k,m}^A)}{L(d_k^A)} \tag{7}$$

Where S_0^A denotes the shadow fading and G_0^A captures the combined gain of the noise, the cable loss and the penetration loss. $A(\theta_{k,m}^A)$ is the antenna gain of user k when sector A uses beam m and $L(d_k^A)$ accounts for the path loss of user k [9]. Similarly calculate $G_{k,n}^B$ and $G_{k,l}^C$, which denote the channel gain of user k in other sectors.

For a given applied order and transmitted power of beam, the sum throughput of cooperation area in a slot can be obtained as follow.

First, calculate $SINR$ of the users based on the channel gain reported by each user. In slot n, when sector A using beam $t_A(n)$, sector B using beam $t_B(n)$ and sector C using beam $t_C(n)$, only S users locating beam $t_A(n)$ can be served if just consider sector A. The $SINR$ of user k is such that

$$SINR_k(n) = \frac{p_A(n) \cdot G_{k,n}^A}{No \cdot w + p_B(n) \cdot G_{k,n}^B + p_C(n) \cdot G_{k,n}^B} \tag{8}$$

where No is the power spectral density of noise and w is the bandwidth of the single resource.

Assume that S users locating in beam $t_A(n)$ use the max C/I allocation algorithm [10] to share total Q resources in sector A and each user have enough data to occupy the allocated resources. The number of resources allocated to k is [10]

$$x_k^*(n) = \frac{\log_e(1 + SINR_{\text{k}}(n))}{\sum_{\text{k}=1}^{S} \log_e(1 + SINR_{\text{k}}(n))} * Q \tag{9}$$

Based on the $SINR$ of all users and allocated resource number, the throughput of sector A in slot n is

$$F_A(n) = \sum_{k=1}^{S} w \cdot \log_e(1 + SINR_k(n)) * x_k^*(n) \tag{10}$$

Similarly calculate the throughput of sector B, C respectively in slot n and finally the total throughput of cooperation area in a scheduling period is the function of the applied order $\mathbf{t}_A$, $\mathbf{t}_B$, $\mathbf{t}_C$ and the transmitted power $\mathbf{p}_A$, $\mathbf{p}_B$, $\mathbf{p}_C$.

$$F(\mathbf{t}_A, \mathbf{t}_B, \mathbf{t}_C, \mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C) = \sum_{n=1}^{N} \left[F_A(n) + F_B(n) + F_C(n)\right] \tag{11}$$

The optimal applied order and transmitted power of the beams can be got by maximize the above function.

$$\left\{\mathbf{t}_A^*, \mathbf{t}_B^*, \mathbf{t}_C^*, \mathbf{p}_A^*, \mathbf{p}_B^*, \mathbf{p}_C^*\right\} = \arg\max F(\mathbf{t}_A, \mathbf{t}_B, \mathbf{t}_C, \mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C) \tag{12}$$

s.t.

$$\frac{1}{N}\sum_{\text{i}=1}^{N} p_A(i) \le P_A; \frac{1}{N}\sum_{\text{i}=1}^{N} p_B(i) \le P_B; \frac{1}{N}\sum_{\text{i}=1}^{N} p_C(i) \le P_C; \tag{13}$$

$$p_A(i) \geq 0; p_B(i) \geq 0; p_C(i) \geq 0;\ i = 1, 2, \ldots\ N \tag{14}$$

$$\mathbf{t}_A,\ \mathbf{t}_B,\ \mathbf{t}_C \in \{1,2,\ldots N\} \tag{15}$$

Equations (13)-(15) describe the practical constraints in reality communication system. Eq. (13) denotes that the average transmitted power of each beam is limited and (14) denotes the transmitted power of each beam is large than zero. Eq. (15) implies that the applied order of beams is expressed by integer within 1～N.

This constrained optimization model is a mixed prog-ramming problem, because $\mathbf{t}_A$ $\mathbf{t}_B$ $\mathbf{t}_C$ is integer describing the applied order of beams and $\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C$ is real numbers describing the transmitted power of beams. This problem is difficult to solve directly, so we propose an iterative approach that split it into an integer programming problem for applied order and a nonlinear programming problem for transmitted power. The detail is shown as follow.

Step 1: Randomly select a group of constraint values as $\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C$'s initial values and set the total throughput of cooperation area's initial value as 0.

Step 2: Based on the values of $\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C$, calculate the optimal solution of $\mathbf{t}_A$ $\mathbf{t}_B$ $\mathbf{t}_C$. This is an integer programming problem. Because the values of $\mathbf{t}_A$ $\mathbf{t}_B$ $\mathbf{t}_C$ are limited, we can use exhaustive searching.

Step 3: Based on the current values of $\mathbf{t}_A$ $\mathbf{t}_B$ $\mathbf{t}_C$, get the optimal solution of $\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C$. This is an optimization problem of continuous differentiable function and we can use the classic gradient descent method to solve it.

Step 4: Calculate the total throughput of cooperation area based on optimal solutions of $\mathbf{t}_A$ $\mathbf{t}_B$ $\mathbf{t}_C$, $\mathbf{p}_A, \mathbf{p}_B, \mathbf{p}_C$ got by step 2-3. If the difference of throughput between two adjacent iterations is less than a threshold then stop this iteration and output the final result, else go to step 2. The flow of the proposed algorithm is illustrated in Fig.3.

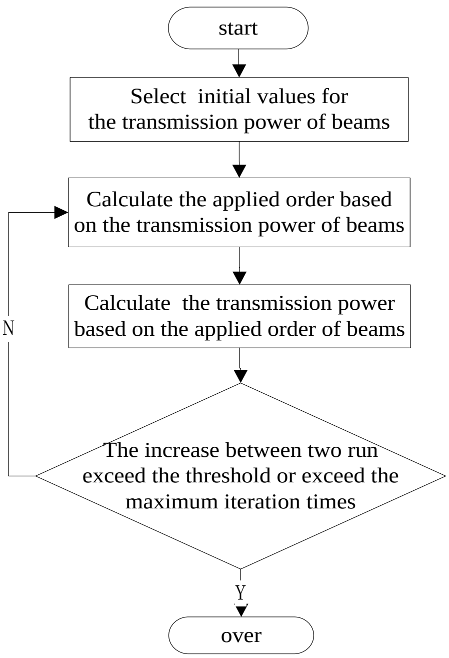

Fig 3. The flos of the proposed algorithm

4. Computer Simulations

We assume there are 4 beams in each sector and the angle of the beam is exactly 30° (see Fig. 2). This simulation is based on 2MHz bandwidth and the frequency reuse factor is 1. The total transmitted power of each sector in a scheduling period is 43dBm and the power spectral density of noise is -174 dBm/Hz.

We will use a simplified model for the transmissions channel, not considering the frequency selective feature, just focus on channel gain shown in (7). Shadow fading is modeled as a log-Normal random variable with standard deviation of 8 dB and inter-sector correlation coefficient of 0.5. Loss factor G_0 is 0 dB [8]. Assume Shadow fading and Loss factor are identical in each sector. The antenna gain of user k, i.e., $A(\theta_{k,m}^{A})$ is calculated as

$$A(\theta_{k,m}^{A}) = -\min(12 * (\frac{\theta_{k,m}^{A}}{\theta_{3dB}})^2, A_m) \tag{16}$$

Because the angle of the beam is exactly 30°, the angle of antenna gain reduction to 3dB denoting θ_{3dB} is 17.5° and the maximization of antenna gain A_m is 20 dB.

The path loss of user k is calculated by

$$L(d_k^A) = 128.1 + 37.6\log_{10}(d_k^A) \tag{17}$$

where d_k^A is the distance between user k and sector A. Because the user distribution is not uniform in a sector in actual network, the simulation base on the case of hotspot user distribution. Each sector has a hotspot and all users around this hotspot obey the Gaussian distribution. Fig.4 illustrates the case of hotspot user distribution, where there are 50 users in a sector.

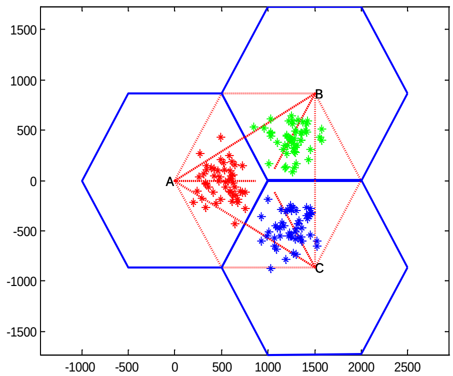

Fig 4. User distribution of sectors

We compare our proposed algorithm with the existing round robin beam servicing approach [4] and the approach that applies only beam cooperative scheduling [1].

In Fig.5 we plot the sum throughput of cooperation area where the number of users varies from 5 to 50 and the total number of resource 25 in each sector. As the number of users increases, the sum throughput of cooperation area increases at first and finally reaches a plateau in all three kinds of scheduling algorithm. Computer simulation shows that the joint beam-power coordinative scheduling algorithm perform best, because it not only avoid the adjacent beam collision but also improve the utilization of power resource by dynamically changing the transmitted power according to the users distribution.

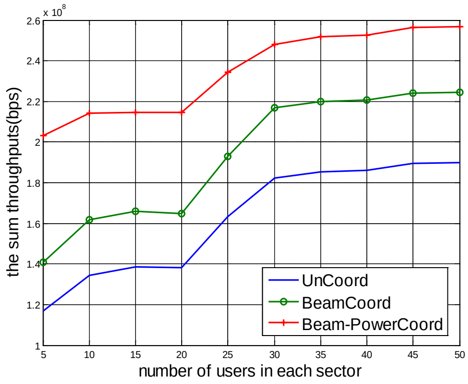

Fig 5. The sum throughput of cooperation area

The cumulative distribution function (CDF) of normalized throughput of sector A is shown in Fig. 6. Assume there are enough resource in system and each user at least get one resource. The normalized throughput is calculated by: (throughput of user – minimum value of throughput) divided by the gap of throughput between the maximum and the minimum. The joint beam-power coordinative scheduling proposal significantly outperforms other algorithms in improving the performance of edge user.

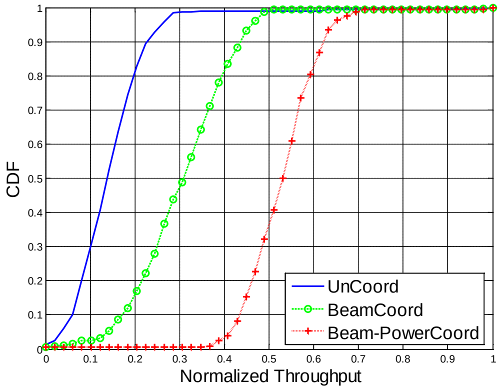

Fig 6. The CDF of normalized throughput of sector

5. Conclusion

In this paper we propose that the power of each beam should be adjusted based on its serving users, so as to improve the utilization of power resource and maximize the system throughput. The simulations have shown the performance improvement when considering joint beam and power allocation.

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