Beamforming and Band Allocation for Hybrid FDMA/CDMA

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Abstract: Hybrid FDMA/CDMA (Multiband) is a promising approach to increase the capacity of CDMA systems, while maintaining compatibility with existing systems. It is currently being considered for third generation mobile and personal communication systems. In Multiband systems, each band provides similar air link capacity, hence, the performance can be enhanced by optimizing channel assignment methods. In this paper, a power control load based band allocation algorithm is proposed. This algorithm will solve the problem of degradation in performance at high traffic loads.

1 Introduction

Due to the demand for increased capacity of code division multiple access (CDMA) systems Multiband CDMA is introduced. The system is a combination of two well known modulation and Multiple Access (MA) techniques, Frequency Division Multiple Access and CDMA. In FDMA the available spectrum is divided into distinct bands, and each connection is allocated to a band. The CDMA provides a frequency reuse factor, $R_u = D/R = 1$, where D is the reuse distance and R is the cell radius. It also provides guard bands much smaller than pure FDMA.

The available wideband spectrum is divided into smaller number of spectra with smaller bandwidths. Each of these smaller subchannels becomes a narrowband CDMA system having a processing gain lower than the original CDMA system. This hybrid scheme has an advantage of allocating different users to different subspectrum bandwiths depending upon their requirements.

Multiband CDMA provides the opportunity to address the near-far effect problem more directly by separating strong ("near") and weak ("far") users into separate bands. The weak users are not competing with strong users, and a lower received power is acceptable. Therefore, this translates to a lower transmitted power from the mobile. The other important advantage to Multiband CDMA is its backward compatibility for the IS-95A standard [1].

Multiband CDMA offers many advantages including compatibility and hardware simplicity. The PC-based and least load based band allocation proposed in [2, 3], respectively, encountered degredation in the performance at high loads, this is shown in Fig. 1. In this paper, sharing the radio spectrum effectively in high capacity systems is important. Therefore, a new approach to band allocation was introduced to improve the system using a combination of Resource Allocation Algorithms (RAA), power control and beamforming. The usefulness of the power control is due to the fact, that the interference level is proportional to the transmission power, therefore balancing the powers is a necessity. Beamforming, on the other hand, adjusts the beam pattern such that the effective signal to interference is optimally increased.

In Section II, antenna arrays is described in details. Section III and IV discusses power control based load sharing, band allocation for Multiband CDMA. The proposed algorithm proved to have the best performance in relative to simple power control techniques as will be shown later on. In section VI a new algorithm is proposed and the anticipated results are described.

2 Antenna Array and Beamforming

An antenna array consists of a set of antennas, which is designed to receive signals radiating from some specific directions and attenuate signals radiating from other directions of no interest. The output of array elements are weighted and added by a beamformer to produce a directed main beam with adjustable nulls. In order to reject the interferences, the beamformer has to place its null in the directions of sources of interference, and steer to the direction of the target signal by maintaining constant gain. A sample antenna array pattern, which is depicted in Figure 2 shows this effect [4].

Let us assume that an antenna array each consist of K elements, and consider a cochannel set which

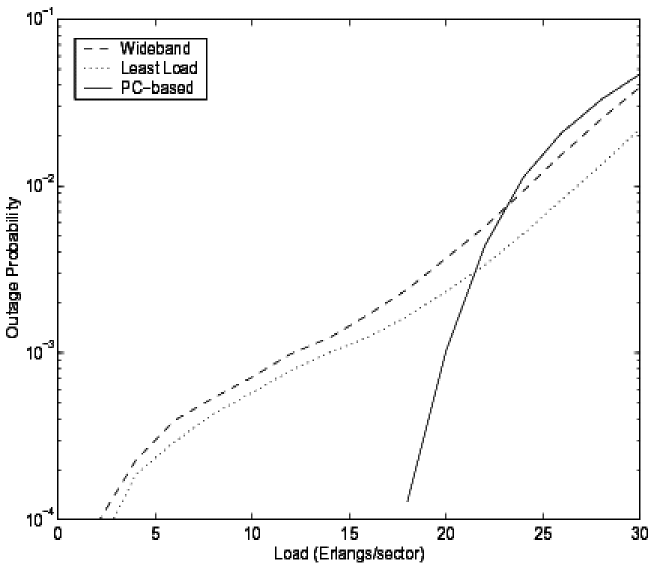

Figure 1: Outage probability versus load for wideband CDMA, multiband CDMA with least load band allocation, and multiband CDMA with the power-control-based band allocation [2].

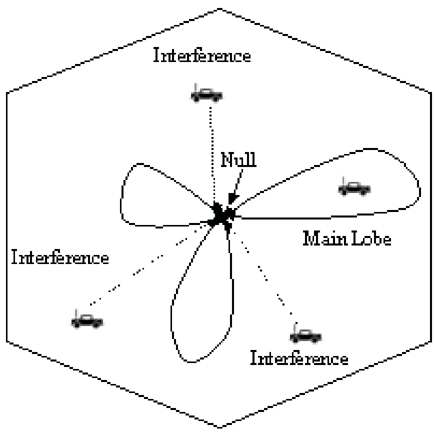

Figure 2: Sample Antenna Area Pattern

consist of M transmitter and receiver pairs that denote the signal from the j^{th} source by $s_j(t)$ and its power by P_j. The received signal at the i^{th} receiver can be written as follows [4]

$$x_i(t) = \sum_{j=1}^{M} \sqrt{P_j} s_j(t) \mathrm{a}_{ji} + \mathrm{n}_i(t) \tag{1}$$

where a_{ji} is a $K \times 1$ vector called the spatial signature or response of the i_{th} array to the j^{th} source and $\mathbf{n}_i(\mathrm{t})$ is the thermal noise vector at the input of this array.

3 Joint power control and beamforming

In this approach, the bands are assumed to be sufficiently spaced so that no interference exists between bands. Beamforming is introduced to further reduce interference between users. The cochannel interference ratio for the i^{th} user after despreading and finding the optimal weight vector, w_i and power allocation, is expressed as,

$$\Gamma_i = \frac{G_p p_i g_{ii}}{\sum\limits_{j=1, j\neq i}^{M} g_{ij} g_{ai}(w_i, a_{ij}) pj + n_i w_i^H w_i} \tag{2}$$

where G_p is the processing gain, n is the thermal noise at the receiver, and M is the number of users operating in the band. The gain from terminal j to base i is denoted by g_{ij} and the antenna power gain given by g_{ai}. In order to perform power control, Eqn. (1) is rewritten taking in account the minimum acceptable link quality, γ_t , in matrix form and solved by performing the iterations,

$$P^{n+1} = G_p(\gamma_t F^W \mathbf{P} + \mathrm{u})$$

where $F^W = g_{ij} g_{ai}(w_i, a_{ij})/g_{ii}$ when $j \neq i$ and $F = 0$ otherwise, and $\mathbf{u}$= $n_i w_i^H w_i / g_{ii}$. At each iteration, transmitters update their powers based on the interference measured at the receivers and the link gain between each mobile and base station.

In this paper, the following constrained power control is used,

$$P_i^{n+1} = \begin{cases} p(n), & \text{if } p(n) \leq p_m ax \\ 0, & \text{if } p(n) \geq p_m ax \end{cases} \tag{3}$$

where $p(n)$ is given as the limit of the following iteration,

$$P_i^{n+1} = \gamma_t \sum_{j\neq i}^{M} \frac{g_{ji} g_{ai}(w_i, a_{ij})}{g_{ii}} P_k^n + \gamma_t \frac{n_i w_i^H w_i}{g_{ii}}$$

By minimizing the power under poor conditions the weak users remain in the channel until its conditions improve without causing significant interference to users in the system. This approach will minimize the outage caused by 'tail events" when the interference of a cell is significantly high.

4 Band Allocation

The Multiband system implement frequency reuse by alternating band assignments between base stations, and cochannel interference is reduced.

Shrader [2] proposes an algorithm which uses DCPC to balance the received carrier to interference ratio (CIR) for all users. Each base station orders the bands from the preferred band down to the most protected band, where all users connected to the same BS initially utilize the same band.

The results obtained in Figure 1 indicate that this algorithm performed better than both a wideband system and least load algorithm at low loads [3]. The degradation of the performance at high loads is due to the fact that more users than necessary are being switched to the protected band or dropped from the system. In the algorithm proposed, users are switched according to the least load algorithm which is defined as follows:

> Calls are assigned to cells with the minimum load (link counts) [3]. If multiple locations achieve the minimum load the assignment is random among them each having equal probability.

5 Proposed Algorithms

Our proposed algorithm modifies the PC-based band allocation algorithm [2] in such a way that it includes both beamforming and a load balancing algorithm. The steps of the algorithm are described below:

1. **Initialization:** Users are assigned to a base station and begin transmitting on the initial band for that base station at transmission power, P_o
2. **Power Control**:Beamforming is performed for the base station at each iteration and power control algorithm is run until it converges. After choosing the BS with the least required power, the mobile i updates the power according to the current beamforming and base station assignment as follows,

$$
\begin{aligned}
P_i^{n+1} &= \min_{wij, j\in B_i}\{\gamma_i \sum_{k\neq i} \frac{G_{kj}G_{ai}(\mathrm{w}_{ij}^{n+1}, a_{kj})}{G_{ij}} P_n^k \\
&+ \frac{\gamma_i N_j {\mathrm{w}_{ij}^{n+1}}^H \mathrm{w}_{ij}^{n+1}}{G_{ij}}\}, i = 1, 2, ..., M
\end{aligned}
$$

subject to ${\mathrm{w}_{ij}^{n+1}}^H a_{kj} = 1$.

3. **Band Switching**: Users with poor conditions transmitting at minimum power are candidate for permanent removal with a given probability. Otherwise users are switched to the band with the least load and assigned nominal power.

4. **Algorithm Completion**: The process starts again at step 2 until no users are transmitting at power P_{min}.

This algorithm make use of the power control based RAA stated in [4] by solving the problems encountered in [3].

6 Conclusions

This paper presented RAA based on power control. The proposed algorithm suggested a compromise between them in order to minimize the problems faced by the PC-based band allocation algorithm at high loads. The integration of power control and beamforming offers a high performance and can covert some highly loaded infeasible systems into feasible ones. The least load algorithm, on the other hand, will switch users between bands more conservatively, hence reducing the outage in a highly loaded traffic situation. Future work involves investigating other cell interference (OCI) in which dropped or temporary removed users can be added back to bands whose OCI has dropped significantly, thus making the CIR acceptable.

References

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