Channel Allocation in SDMA Cellular Systems

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Abstract: Spatial Division Multiple Access (SDMA) is recognized as a promising technique for improving capacity in future cellular systems by exploiting the spatial filtering capability of adaptive antennas. In SDMA systems, in-cell users can share the same channel, making the channel allocation strategy an important role in the system performance. In this paper, we analyze by simulation different strategies for channel allocation in cellular systems employing adaptive antennas and SDMA technique. Results show that high performance in SDMA systems is achieved by balancing channel reuse among cells and channel reuse within cells. Attempts to maximize channel reuse within cells may increase excessive co-channel interference, limiting capacity. Results also show that, while carried traffic is not severely affected by high level of user mobility, other performance parameters, such as the number of channel reassignment requests, are strongly affected by user mobility.

I. INTRODUCTION

The rapid growth in demand for cellular mobile communications has created the need to increase system capacity through more efficient utilization of the frequency spectrum. The deployment of base station adaptive antennas, together with advanced signal processing techniques, has been recognized as one of the most promising techniques for controlling co-channel interference in cellular systems, leading to the required system capacity improvement [1]. The spatial filtering capability of adaptive antennas can be used to implement the Spatial Division Multiple Access (SDMA) technique, where in-cell users are allowed to share the same traffic channel. Narrow beams are steered toward desired users in order to filter out interference caused by co-channel users located in the same cell and in other cells. When the SDMA technique is employed in cellular systems, traffic channels must be appropriately allocated, in order to efficiently reuse channels within cells and among cells, while dealing with intrinsic issues of SDMA, such as the minimum angular distance between in-cell co-channel users and the near-far problem [2-4].

In this paper, we analyze the performance of four representative dynamic channel allocation (DCA) algorithms for SDMA cellular systems [5]. We show by simulation that high performance in SDMA systems (in terms of carried traffic, outage probability, and channel reassignment request rate) is achieved by balancing channel reuse among cells with channel reuse within cells, as discussed later. Attempts to maximize channel reuse within cells may increase excessively co-channel interference in the system, limiting system capacity and degrading the overall performance.

II. ADAPTIVE ANTENNAS AND SDMA SYSTEMS

Adaptive antennas at the base stations have been studied as a technique for increasing coverage range and improving system capacity [1]. Capacity improvement can be achieved through two different approaches. In the first approach, adaptive antennas are used to reduce the co-channel interference by steering a high gain in the direction of the desired mobile stations and/or very low gains in the direction of the undesired co-channel mobile stations. The resulting co-channel interference reduction allows cluster size reduction, improving the system capacity. In the second approach, usually referred to as Spatial Division Multiple Access (SDMA), adaptive antennas are used to allow channel reuse within the cell, by filtering out co-channel interference from in-cell users in the spatial domain, as depicted in Fig. 1.

In the SDMA approach, the capacity improvement depends on the ability of the system to allocate the same channel to several in-cell users. Three major factors determine this ability [6]:

1. adaptive antenna parameters - beamwidth and side lobe level determine the spatial filtering capability;
2. propagation channel - multipath propagation channel with a large angular dispersion reduces the potential number of in-cell co-channel users;
3. spatial distribution of users - clustered in-cell users create difficulty for spatial filtering.

In order to efficiently exploit the spatial filtering capability of adaptive antennas in SDMA, appropriate dynamic channel allocation strategy must be employed [2-4], as discussed next.

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Dy11amic Cllallllel Allocatio11
Algorithm
Partitioning Algorithm
In this paper, we analyze four representative dynamic allocation algorithms suitable for do not make any explicit attempt to reuse channels within that channels can be reused within cells, in order to maximize system performance. In this paper, we analyze four representative dynamic allocation algorithms suitable for SDMA systems: Concentrated Channel Load Algorithm (CCL), Equal Channel Load Algorithm (ECL), Autonomous Reuse Partitioning Algorithm (ARP), and Least Interference Algorithm (LIA). CCL and ECL explicitly exploit the fact that channels can be reused within cells, while ARP and LIA do not make any explicit attempt to reuse channels within cells. These four algorithms are briefly described below.

1) Concentrated Channel Load Algorithm (CCL): CCL attempts to maximize channel reuse within the cell, while maintaining the quality of service above a given minimum acceptable level, in terms of signal-to-interference ratio (SIR) [3]. When a mobile requests for a channel, the algorithm allocates the most used channel at the serving cell at that moment, among all channels satisfying the condition $\text{SIR} > \text{SIR}_{\text{ADM}}$ on both uplink and downlink, where SIR$_{\text{ADM}}$ is the minimum acceptable SIR for call admission. Therefore, CCL tries to reuse channels within the cell as much as possible.

2) Equal Channel Load Algorithm (ECL): With ECL, the serving base station allocates the least used channel at the serving cell, among all channels satisfying the condition $\text{SIR} > \text{SIR}_{\text{ADM}}$ on both links [3]. This allocation strategy attempts to uniformly distribute the traffic in the cell among all channels.

3) Autonomous Partitioning Reuse Algorithm: (ARP) The allocation procedure with ARP starts by measuring the interference on all channels in the system (busy and idle channels) following a common sequence to all cells. The algorithm allocates the first channel that satisfies the condition $\text{SIR} > \text{SIR}_{\text{ADM}}$ on both links [8]. APR algorithm tries to create a structured channel reuse pattern, by creating concentric rings within the cells. Different rings employ different channel reuse patterns, leading to an efficient overall channel reuse [9].

4) Least Interference Algorithm (LIA): LIA selects the channel with the least interference among all channels (busy and idle channels) that meets the condition $\text{SIR} > \text{SIR}_{\text{ADM}}$ on both links [10]. LIA tends to select idle channels before selecting a channel already in use in the cell, reducing the overall co-channel interference.

The adopted allocation strategy is used for new calls, handoff calls or channel reassignment, using different values of SIR$_{\text{ADM}}$. We will analyze the performance of each algorithm in terms of carried traffic per cell, number of channel reassignment requests per call and the probability that the signal-to-interference ratio is below a given threshold (also called outage probability).

III. Simulated System

In order to evaluate the performance of the allocation algorithms in SDMA, a cellular system with 81 equal size hexagonal cells was simulated, with base stations located at the center of the cells. Each base station is equipped with an ideal adaptive antenna with flat-top radiation pattern, beamwidth of 45° and constant side lobe level of ~30 dB with respect to the maximum gain. It is supposed that base station adaptive antennas can perfectly track all their mobile stations.

In order to avoid boundary effects of finite cellular system, the toroidal universe technique is employed [9]. A pool of 63 channels is available to the entire cellular system, and any base station can use any channel, as long as the interference level on the selected channel is below a given threshold. The propagation channel model consists of distance-dependent path loss, with path loss exponent $n=3.5$, and log-normal shadowing, with standard deviation equals 8 dB. Additionally, propagation through multipath is modeled by using the Macrocell Geometrically Based Single Bounced Circular Model [1], with radius of scatterers $R_c = 100$ m. Two multipath components plus the line-of-sight component are simulated. It is assumed that multipath components arrives at the receiver antenna with no time delay with respect to the line-of-sight component. Since we are not interested in the small scale fading effects, but only in the effects of the dispersion of angle of arrival of the multipath components on the system performance. The uplink and downlink propagation channel models are assumed to be identical. Calls arrive at the system following a Poisson distribution. The call duration follows an exponential distribution, with mean call duration equal to 100 seconds. The call arrival rate is adjusted to obtain the desired offered traffic per cell. When a call arrives at the system, a channel is allocated to the call according to the allocation technique under test. Channel reassignments may be necessary during the call in order to keep the link quality above the minimum acceptable level.

A particular channel is allocated to a call if the signal-to-interference ratio on the channel is above the threshold SIR$_{\text{ADM}} = 21$ dB for new calls, and SIR$_{\text{ADM}} = 19$ dB for on-going calls requesting a channel reassignment. An on-going call will request a new channel if SIR drops below the threshold SIR$_{\text{TH}} = 14$ dB. Finally, a call is dropped if the SIR on its channel drops below the threshold $SIR_D = 12$ dB for 5 seconds.

User mobility model

Mobiles move along segments of straight lines, and change direction every 10 seconds. The mobile speed $v$ is kept constant over the entire duration of the call and is assigned to the mobile at the beginning of the call. Two classes of users are simulated regarding mobility:

- **Pedestrian**: the speed $v$ is a random variable that follows a half-cosine-shaped probability density function, over the interval from 0 to $v_{\text{max}} = 5$ km/h;
- **Vehicular:** the speed $v$ is a random variable that follows a half-cosine-shaped probability density function over the interval from 0 to $v_{\text{max}} = 60$ km/h.

The half-cosine-shaped probability density function $f_r(v)$ is defined as:

$$f_r(v) = \begin{cases} K \sin(v \pi / v_{\text{max}}) & \text{for } 0 \leq v \leq v_{\text{max}} \\ 0 & \text{otherwise} \end{cases}$$

where $v_{\text{max}}$ is the maximum speed and $K$ is adjusted in order to obtain $\int f_r(v) \, dv = 1$.

These two classes of users are combined to create two user mobility profiles:

- **Hybrid I:** 80% pedestrian + 20% vehicular;
- **Hybrid II:** 20% pedestrian + 80% vehicular.

Therefore, profile Hybrid I is predominantly pedestrian, while profile Hybrid II is predominantly vehicular.

**Power Control Technique**

Power control is employed on both uplink and downlink, using the Autonomous Signal-to-Interference Ratio Balancing technique [7]. The transmitter power $P_i$ is adjusted at the $i$-th iteration according to:

$$P_i = P_{i-1} \frac{SIR_T}{SIR_{R,i}}$$

where $SIR_T$ is the target signal-to-interference ratio, $SIR_{R,i}$ is the measured signal-to-interference ratio, and $P_{i-1}$ is the transmitter power adjusted at the $(i-1)$-th iteration. The Autonomous Signal-to-Interference Ratio Balancing technique attempts to adjust the signal-to-interference ratio such that all links sharing the same channel will have the same signal-to-interference ratio $SIR_T$. In all simulation results presented in this paper, we set $SIR_T = 21$ dB.

### IV. RESULTS

In this section we discuss the simulation results. Firstly, in Section IV-A, we compare the capacity improvement achieved by using algorithms ARP and LIA with adaptive antennas in non-SDMA mode and in SDMA mode. In non-SDMA mode, base stations are equipped with adaptive antennas, but channels cannot be shared among in-cell users. Therefore, in non-SDMA mode, adaptive antennas are used to reduce interference from co-channel cells and increase channel reuse among cells. Comparison in Section IV-A will be restricted to algorithms ARP and LIA, since they can be used in both non-SDMA and SDMA mode. Algorithms CCL and ECL cannot be used in non-SDMA mode. Later, in Section IV-B, we compare the performances of all four algorithms described in Section II-A in SDMA mode. Finally, we analyze in Section IV-C the effects of user mobility on the performance of the allocation algorithms.

#### A. Capacity improvement due to spatial filtering capability

We begin the analysis of the results by comparing the performance of algorithms LIA and ARP in different situations regarding how spatial filtering is used to increase system capacity. Fig. 2 shows the blocking probabilities for LIA and ARP under user mobility profile Hybrid I for (i) omnidirectional base station antennas, (ii) adaptive base station antennas, in non-SDMA mode and (iii) adaptive base station antennas, in SDMA mode. The figure clearly shows the capacity improvement achieved by using adaptive antennas. Algorithm ARP presents a better performance than algorithm LIA, due to the structured reuse pattern created with ARP. The concentric rings in the cell area autonomously created by ARP allows for a more efficient channel reuse among cells.

It is interesting to note from Fig. 2 that, the combined use of adaptive antennas in the non-SDMA mode with either LIA or ARP algorithm optimizes the usage of channels to such an extent that, the additional ability to reuse channels within cells (SDMA mode) leads to only moderate additional capacity improvement.

#### B. Performance of DCA algorithms in SDMA mode

In this section, we compare the performance of all four algorithms in SDMA mode and user mobility profile Hybrid I. Fig. 3 shows the blocking probabilities for LIA, ARP, ECL and CCL algorithms. We can see that, although algorithms CCL and ECL are designed for SDMA application, their performances in terms of carried traffic are poorer than that achieved by algorithms ARP and LIA. In fact, CCL provides the lowest carried traffic per cell among all four algorithms.
The performance of channel allocation algorithms is not only described by the carried traffic, but also by other metrics, such as the number of reassignment requests per call and outage probability. A large number of channel reassignment requests per call leads to a high signaling load, which, of course, is not desirable. Similarly, high outage probability corresponds to poor link quality. Table I shows the carried traffic, channel reassignment request rate and outage probability (for threshold SIRo = 17 dB) at a blocking probability of 2%, for all algorithms and mobility profile Hybrid I. We also include in this table the results for non-SDMA cases for comparison purposes. The results from Table I show that the high carried traffic provided by algorithm ARP is at the expense of high outage probability and large number of reassignment requests per call. High carried traffic is achieved by packing co-channel calls closer together, leading to small reuse distances. Therefore, calls will experience moments of excessive co-channel interference triggered by user mobility and propagation channel effects, requiring channel reassignment during the call. On the other hand, LIA attempts to allocate channels experiencing low co-channel interference, resulting in low outage probability and small number of channel reassignment requests. Therefore, LIA algorithm achieves slightly lower carried traffic than ARP, but presents better performance in terms of outage probability and number of channel reassignment requests.

Table I also shows that algorithms ECL and CCL, that apparently would directly benefit from the spatial filtering capability of base station adaptive antennas, lead to poor performance regarding both carried traffic and the effects of co-channel interference as well. It is interesting to note that the use of adaptive antennas in both non-SDMA and SDMA modes greatly reduces outage probability and channel reassignment request rates.

C. Effects of user mobility on performance
TABLE III

Performance Under Different User Mobility Profiles:

<table>
<thead>
<tr>
<th>User mobility profile</th>
<th>Traffic - Erlang per cell</th>
<th>pb (%)</th>
<th>Rre</th>
<th>pb (%)</th>
<th>Rre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hybrid I</td>
<td>Hybrid II</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIA</td>
<td>52.2</td>
<td>2.0</td>
<td>0.9</td>
<td>2.7</td>
<td>3.0</td>
</tr>
<tr>
<td>ARP</td>
<td>56.9</td>
<td>2.0</td>
<td>1.5</td>
<td>2.5</td>
<td>4.8</td>
</tr>
<tr>
<td>ECL</td>
<td>49.4</td>
<td>2.0</td>
<td>1.4</td>
<td>3.0</td>
<td>4.1</td>
</tr>
<tr>
<td>CCL</td>
<td>41.5</td>
<td>2.0</td>
<td>1.2</td>
<td>2.3</td>
<td>3.4</td>
</tr>
</tbody>
</table>

Table II presents simulation results in terms of carried traffic at 2% of blocking probability for all four allocation algorithms and user mobility profiles Hybrid I and II. We can see that for all algorithms higher level of user mobility causes little degradation on the carried traffic. However, this "immunity" of carried traffic to user mobility is at the expense of negative effects on other performance metrics. A fair analysis of the effects of mobility on the performance must be carried out by measuring the performance metrics at the same traffic load for both user mobility profiles. Table III shows the resulting blocking probability \( P_b \) and number of channel reassignment requests per call \( R_{RE} \) for all four algorithms under different user mobility profiles, but at the same carried traffic. The carried traffic used for each algorithm is that one that results in 2% of blocking probability for user mobility profile Hybrid I.

A channel reassignment is requested whenever SIR on uplink or downlink drops below a given minimum acceptable level. The number of channel reassignment requests is closely related to how close co-channel users are distributed in the system (in-cell users and users located in different cells). Therefore, allocation algorithms that achieve high carried traffic, such as ARP, may lead to a high number of reassignment requests, as observed in Table III. In SDMA systems, a request for a channel reassignment may be triggered by beam collision, that occurs when two in-cell co-channel users get too close to each other (small angular separation), such that spatial filtering is no longer possible [7]. Another mechanism that can trigger a request for channel reassignment is known as "the near-far problem": a mobile gets too close to or too far from its serving base station such that the side lobe attenuation of the narrowbeam adaptive antenna is no longer enough to attenuate in-cell co-channel interference and guarantee the desired SIR [7].

**CONCLUSION**

We have analyzed in this paper the performance of several algorithms in SDMA systems. Two of the algorithms, namely ECL and CCL, explicitly attempt to benefit from the fact that, in SDMA systems, channels can be reused within cells. While CCL tries to reuse channels within cells as much as possible, ECL tries to uniformly distribute the load of traffic over all channels available in the cell. The other two algorithms, LIA and ARP, are not particularly designed for SDMA systems. LIA attempts to minimize the interference level on all channels, while ARP attempts to create a structured channel reuse pattern throughout the entire coverage area.

Simulation results showed that attempts to maximize channel reuse within the cell do not lead to high capacity. With CCL algorithm, as channels are reused several times within cells, the overall interference level increases, limiting the system capacity. Simulation results also showed that strategies based on balancing channel reuse among cells with channel reuse within cell, as achieved by ARP and LIA, lead to high carried traffic. However, for the case of ARP this high capacity is at the expense of high channel reassignment requests rate due to high interference. On the other hand, LIA algorithm achieves slightly lower carried traffic than ARP, but presents better performance in terms of outage probability and number of channel reassignment requests.

We also analyzed the performance degradation due to user mobility. Results showed that, while carried traffic is not severely affected by high level of user mobility, other performance parameters, such as the number of channel reassignment requests and outage probability, are strongly affected by user mobility.

**REFERENCES**


