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Cellular network configuration with co-channel and adjacent-channel interference constraints

Mohan R. Akella[a], Rajan Batta[a, b, *], Moises Sudit[a], Peter Rogerson[b, c], Alan Blatt[b]

[a] Department of Industrial Engineering, University at Buffalo (SUNY), Buffalo, NY 14260, USA
[b] Center for Transportation Injury Research, CUBRC, University at Buffalo (SUNY), Buffalo, NY 14260, USA
[c] Department of Geography, University at Buffalo (SUNY), Buffalo, NY 14260, USA

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Abstract

Design of cellular networks has drawn much recent interest from the OR scientific community. A challenging issue is the handling of channel interference constraints. Co-channel interference occurs when the same channel is reused within a threshold distance. Adjacent-channel interference occurs when two channels with adjacent or nearby frequencies are used in the same cell tower. We present a mathematical programming formulation for this channel allocation problem with both types of interference constraints—it also includes decisions on location of cell towers. Our focus is on the special case where a cell tower and/or channel can interfere with at most two other towers/channels. By establishing theoretical properties for channel allocation amongst towers under this circumstance, we develop an efficient solution procedure. An iteration of the procedure uses a heuristic to locate the cell towers, then allocates the channels to the towers using a polynomial-time algorithm, and finally improves this allocation using a simulated annealing procedure. The iterative steps are embedded within an external simulated annealing method. This nested simulated annealing procedure provides encouraging computational results compared to a standard commercial solver like ILOG CPLEX 8.1. The major contribution of the work is the simultaneous consideration of co-channel and adjacent-channel interference constraints.

Keywords: Base station location; Frequency channel assignment; Simulated annealing

1. Introduction

Increases in demand and the poor quality of existing service led mobile service providers to research ways to improve the quality of service and to support more users in their systems. Because the amount of frequency spectrum available for mobile cellular use was limited, efficient use of the required frequencies was needed for mobile cellular coverage. Cellular radio systems rely on an intelligent allocation and reuse of channels throughout a coverage region. Each cellular base station (BS) is allocated a group of radio channels to be used within a small geographic area called a *cell*. BSs in adjacent cells are assigned channel groups, which contain completely different channels than neighboring cells. The BS antennas are designed to achieve the desired coverage within the particular cell. By limiting the coverage area to within the boundaries of a cell, the same group of channels may be used to cover different cells that are separated from one another by distances large enough to keep interference levels within tolerable limits. The design process of

* Corresponding author. Department of Industrial Engineering, University at Buffalo (SUNY), Buffalo, NY 14260, USA. Tel.: +1 716 645 2357; fax: +1 716 645 3302.
E-mail address: batta@eng.buffalo.edu (R. Batta).

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selecting and allocating channel groups for all of the cellular BSs within a system is called *frequency reuse* or *frequency planning*.

1.1. Channel assignment strategies

For efficient utilization of the radio spectrum, a frequency reuse scheme that is consistent with the objectives of increasing capacity and minimizing interference is required. A variety of channel assignment strategies have been developed to achieve these objectives. Channel assignment strategies can be classified as either *fixed* or *dynamic*. In a fixed channel assignment (FCA) strategy, each cell is allocated a predetermined set of voice channels. If all the channels in that cell are occupied, the call is *blocked* and the subscriber does not receive service.

In a dynamic channel assignment (DCA) strategy, voice channels are not allocated to different cells permanently. Instead, each time a call request is made, the serving BS requests a channel from the mobile switching center (MSC). The switch then allocates a channel to the requesting cell following an algorithm that takes into account the likelihood of future blocking within the cell, the frequency of use of the candidate channel, the reuse distance of the channel, and other cost functions. DCA reduces the likelihood of blocking, which increases the trunking capacity of the system, since all available channels in a market are accessible to all of the cells. DCA strategies require the MSC to collect real-time data on channel occupancy, traffic distribution, and relative signal strength indicator (RSSI) of all channels on a continuous basis. This increases the storage and computational load on the system but provides the advantage of increased channel utilization and decreased probability of a blocked call.

1.2. Interference

Interference is the major limiting factor in the performance of cellular radio systems. Sources of interferences include another mobile in the same cell, a call in progress in a neighboring cell, other BSs operating in the same frequency band, or any non-cellular system that inadvertently leaks energy into the cellular frequency band. Interference on voice channels causes cross-talk, where the subscriber hears noise in the background due to an undesired transmission. Interference is more severe in urban areas, due to the large number of BSs and mobiles. Interference has been recognized as a major bottleneck in increasing capacity and is often responsible for dropped calls. The two major types of system-generated cellular interference are *co-channel interference* and *adjacent-channel interference*.

Frequency reuse implies that in a given coverage area, there are several cells that use the same set of frequencies. These cells are called *co-channel cells*, and the interference between signals from these cells is called *co-channel interference*. To reduce co-channel interference, co-channel cells must be physically separated by a minimum distance to provide sufficient isolation due to propagation.

Interference resulting from signals that are adjacent in frequency to the desired signal is called *adjacent-channel interference*. The problem can be particularly serious if an adjacent-channel user is transmitting in very close range to a subscriber's receiver, while the receiver attempts to receive a BS on the desired channel. Adjacent-channel interference can be minimized through careful filtering and channel assignments. By keeping the frequency separation between each channel in a given cell as large as possible, the adjacent-channel interference may be reduced considerably. The above content describing the origin and the concept of wireless communications is based on Rappaport [1].

For simplicity, in this paper we focus on channel assignments in FDMA systems. In this context, a channel is referred to as a frequency channel. However, the idea may as well be applied to TDMA systems, provided that we refer to a channel as a time slot. We also focus our attention on the FCA strategy as opposed to a DCA scheme. This is motivated by the fact that under uniform and heavy load, FCA outperforms DCA (see [2]) and that the computational burden in case of DCA is very intensive when compared to FCA.

2. Literature review

This work introduces an integrated cellular planning model. There are few papers in the literature that deal with the cell tower location problem integrated with the frequency assignment problem (FAP). Tutschku et al. [3] present ICEPT—integrated cellular network planning tool—a new mobile radio network planning tool that identifies four basic design aspects of mobile communication systems: *radio transmission*, *mobile subscriber*, *resource allocation*, and *system architecture*. Rodrigues et al. [4] applied the concepts of two outdoor environment classic problems, the