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Online call control in cellular networks revisited

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ABSTRACT

Wireless communication networks based on frequency division multiplexing (FDM in short) play an important role in the field of communications, in which each request can be satisfied by assigning a frequency. To avoid interference, each assigned frequency must be different from the neighboring assigned frequencies. Since frequencies are scarce resources, the main problem in wireless networks is how to fully utilize the given bandwidth of frequencies. In this paper, we consider the online call control problem. Given a fixed bandwidth of frequencies and a sequence of communication requests arriving over time, each request must be either satisfied immediately after its arrival by assigning an available frequency, or rejected. The objective of the call control problem is to maximize the number of accepted requests. We study the asymptotic performance of this problem, i.e., the number of requests in the sequence and the bandwidth of frequencies are very large. In this paper, we give a 7/3-competitive algorithm, say CACO, for the call control problem in cellular networks, improving the previous 2.5-competitive result, and show that CACO is best possible among a class of HYBRID algorithms.

1. Introduction

Frequency Division Multiplexing (FDM in short) is commonly used in wireless communications. To implement FDM, the wireless network is partitioned into small regions (cells) and each cell is equipped with a base station. When a call request arrives at a cell, the base station in this cell will assign a frequency to this request, and the call is established via this frequency. Since frequencies are scare resources, to satisfy the requests from many users, a straightforward idea is reusing the same frequency for different call requests. But if two calls which are close to each other are using the same frequency, interference will happen and that will violate the quality of communications. Thus, to avoid interference, the same frequency cannot be assigned to two different calls with close distance to each other. In general, the same frequency cannot be assigned to two calls in the same cell or neighboring cells.

There are two research directions on the fully utilization of the frequencies. One is the *frequency assignment problem* [2,4,5,7,8,11], and the other is *call control problem* [3,9,10]. In the frequency assignment problem, each call request must be accepted, and the objective is to minimize the number of frequencies to satisfy all requests. In call control problem, the bandwidth of frequencies is fixed, thus, when the number of call requests in a cell or in some

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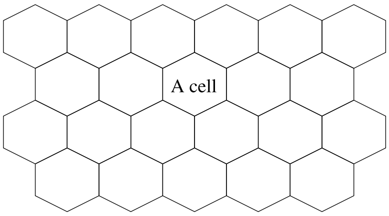

Fig. 1. An example of a cellular network.

neighboring cells is larger than the total bandwidth, the request sequence cannot be totally accepted, i.e., some requests would be rejected. The objective of the call control problem is to accept as many requests as possible.

1.1. Problem statement

In this paper, we consider the online version of the call control problem. There are ω frequencies available in the wireless network. A sequence σ of call requests arrives over time, where $\sigma = \{r_1, r_2, \ldots, r_t, \ldots\}$, r_t denotes the t-th call request and also represents the cell where the t-th request arrives. When a request arrives at a cell, the system must either choose a frequency to satisfy this request without interference with other assigned frequencies in this cell and its neighboring cells, or reject this request. When handling a request, the system does not know any information about future call requests. We assume that when a frequency is assigned to a call, this call will never terminate and the frequency cannot be changed. This assumption does not reflect the world exactly, however, it is a basic case for the call control problem. The objective of this problem is to maximize the number of accepted requests.

We focus on the call control problem in cellular networks, in which each cell is a hexagonal region and has six neighbors, as shown in Fig. 1.1. The cellular network is widely used in wireless communication networks.

1.2. Performance measure

To measure the performance of online algorithms, we use the competitive ratio [1] to compare the performance between the online algorithm and the optimal offline algorithm which knows the whole request sequence in advance. In the call control problem, the output is the set of accepted requests. For a request sequence σ, let $A(\sigma)$ and $O(\sigma)$ denote the number of accepted request of an online algorithm A and the optimal offline algorithm O, respectively. We focus on the asymptotic performance for the call control problem, i.e., the number of requests and the number of frequencies are very large positive integers. The asymptotic competitive ratio for an online algorithm A is

$$R_A^\infty = \limsup_{n\to\infty} \max_\sigma \left\{ \frac{O(\sigma)}{A(\sigma)} \;\middle|\; O(\sigma) = n \right\}.$$

1.3. Related work

How to fully utilize the frequencies to satisfy the communication requests is a very fundamental problem in theoretical computer science and wireless communications. Both the frequency assignment problem and the call control problem are well studied during these years.

The offline version of the frequency assignment problem in cellular networks was proved to be NP-hard by McDiarmid and Reed [7], and two 4/3-approximation algorithms were given in [7,8]. In the online frequency assignment problem, when a call request arrives, the network must immediately assign a frequency to this call without any interference. There are mainly three strategies: Fixed Allocation [6], Greedy Assignment [2], and Hybrid Assignment [4]. If the duration of each call is infinity and the assigned frequency cannot be changed, the hybrid algorithm gave the best result for the online frequency assignment, i.e., a 2-competitive algorithm for the absolute performance and a 1.9126-competitive algorithm for the asymptotic performance.

For the call control problem, the offline version is NP-hard too [7]. To handle such problem, greedy strategy is always the first try, when a call request arrives, the network chooses the minimal available frequency to serve this request, if any frequency is interfere with some neighboring assigned frequency, the request will be rejected. Pantziou et al. [9] analyzed the performance of the greedy strategy, proved that the asymptotic competitive ratio of the greedy strategy is equal to the maximal degree of the network. Caragiannis et al. [2] gave a randomized algorithm for the call control problem in cellular networks, the asymptotic competitive ratio of their algorithm is 2.651. Later, the performance of the randomized algorithms was improved to 16/7 by the same authors [3], they also proved the lower bound of the asymptotic competitive ratio for the randomized algorithm is at least 2. Recently, a deterministic algorithm with asymptotic competitive ratio 2.5 was given in [10], and the lower bound of the asymptotic competitive ratio for the deterministic algorithm was proved to be 2.

1.4. Our contributions

In this paper, we consider the deterministic algorithms for the online call control problem in cellular networks, and give a 7/3-competitive algorithm, improving the previous 2.5-competitive result. Moreover, we define a class of algorithms, say HYBRID. Both the algorithm in [10] and ours are two special algorithms in HYBRID, and our algorithm is best possible among HYBRID.

2. Call control in cellular networks

The idea of our algorithm for call control problem in cellular networks is similar to the algorithm in [10]. Cellular networks are 3 colorable, each cell can be associated with a color from $\{R, G, B\}$ and any two neighboring cells are with different colors. Partition the frequencies into four sets, F_R, F_G, F_B, and F_S, where F_X ($X \in \{R, G, B\}$) can be only used in cells with color X and F_S can be used in any cell. We define a class of algorithm, say **HYBRID**, for