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Call admission control policies in cellular wireless networks with spectrum renting

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ABSTRACT

Radio spectrum is scarce and precious resource in wireless networks. To efficiently utilize radio spectrum, a wireless network can rent radio channels from another wireless network and returns back the rented channels when the rented channels are required to be withdrawn. The rental and withdrawal of radio channels result in two phenomena: (i) variable number of radio channels in a wireless network and (ii) call dropping due to the channel withdrawal. Call admission control aims to provide good quality-of-services for mobile users while efficiently utilize radio channels. Many call admission control policies in the previous literatures were studied without the two phenomena. In this paper, we study three call admission control policies, namely, fixed-reservation policy, single-threshold policy and multiple-threshold policy in a wireless network which rents channels from another wireless network. We develop numerical analyses to analyze and compare the performances of the three call admission control policies. Numerical results show that the multiple-threshold policy produces higher throughput than the single-threshold and fixed-reservation policies under the same constraint of quality-of-services.

1. Introduction

Radio spectrum can be divided into radio channels by means of multiple access methods such as Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA), etc. Mobile users then use radio channels to access wireless services. Since radio spectrum is scarce and precious, radio spectrum should be efficiently utilized in order to allow more mobile users to access wireless services in a limited radio spectrum. In the past, a large amount of radio spectrum has been statically assigned to various radio systems. However, Federal Communications Commission (FCC) indicated that most of the radio spectrum in the radio systems is underutilized [1]. One possible way to efficiently utilize the radio spectrum is to allow spectrum sharing between various radio systems [2–5]. One radio system can rent radio spectrum from (or out to) another radio system. Then, mobile users in one radio system can dynamically access the radio spectrum in another radio system. That is, when mobile users suffer insufficient channels in one radio system, mobile users can attempt to use idle channels in another radio system.

Cellular wireless networks provide services for mobile users in service areas which consist of cells. When a new mobile user arrives at a cell, a call admission control procedure is initiated to determine whether or not to admit the mobile user according to an admission constraint. If the admission constraint is satisfied, the mobile user is admitted; otherwise, the mobile user is blocked. The probability that a new mobile user seeking admission into a cell is blocked is called new call blocking probability. From the viewpoint of system providers, the new call blocking probability should be as low as possible such that more mobile users are accommodated in wireless systems and channels are utilized efficiently.

Mobile users may roam around in cellular wireless networks. When a mobile user moves from one cell to a neighbor cell, a hand-off procedure is enabled to maintain the mobile user's communication. If the neighbor cell can provide sufficient channels to satisfy the channel requirement of the mobile user, the mobile user continues its communication; otherwise, the mobile user is dropped. The probability that a hand-off call attempt is dropped is called hand-off dropping probability. The hand-off dropping probability is an important metric of quality-of-service (QoS) in wireless networks. From the perspective of mobile users, dropping an ongoing call is annoying; hence, mobile users expect that the hand-off dropping probability can be kept below a certain value at any load.

To fully utilize limited radio channels, a new mobile user should be admitted into a cell as long as there are free channels to satisfy the channel requirement of the new mobile user, which, however, may lead to high hand-off dropping probability at heavy load. In order to provide mobile users with satisfactorily low hand-off dropping probability while efficiently utilize radio channels, two major call admission control policies, reservation policy and threshold policy, have been proposed in [6–12]. Instead of accepting a new call until free channels are insufficient for a new call, the two major call admission control policies use admission

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constraints to determine whether or not to accept a new call. The reservation policy, also called trunk reservation or guard channel policy, is to exclusively reserve a number of channels for hand-off calls [6–8]. In the reservation policy, a new call arrival is admitted into a cell if the number of free channels in the cell is greater than the number of reserved channels. Otherwise, the new call arrival is blocked; that is, a new call could be blocked even though free channels are sufficient for the new call. The threshold policy uses a threshold, called admission threshold, in a call admission procedure [11,12]. The threshold policy admits a new call arrival into a cell if the number of mobile users in the cell is less than an admission threshold and free channels are sufficient to satisfy the channel requirement of the new call. Otherwise, the new call arrival is blocked. In both reservation and threshold policies, a hand-off call is admitted into a cell if there are free channels to satisfy the channel requirement of the hand-off call. The reservation and threshold policies produce low hand-off dropping probability at the expense of an increase in new call blocking probability. To provide satisfactorily low hand-off dropping probability for mobile users at a minimum expense of an increase in new call blocking probability, a minimum number of reserved channels and an optimal admission threshold are carefully selected in the reservation and threshold policies, respectively [9,10,12]. The reservation and threshold policies produce good performance and can be easily implemented. All the papers in [6–12] consider an environment in which mobile users merely use channels that are statically assigned to one system.

In this paper, we consider cellular wireless networks with spectrum renting. In such an environment, a wireless network that rents out its radio channels to another wireless network always has the first priority to use its radio channels; that is, the wireless network can withdraw its radio channels from another wireless network when the wireless network requires the radio channels. A mobile user is forcibly dropped when the radio channel occupied to the mobile user is withdrawn. The probability that a mobile user is dropped when the withdrawal occurs is called withdrawal dropping probability in this paper. To reduce the number of dropped calls due to the withdrawal, a wireless network does not rent out all its channels [13]; that is, partial channels are reserved for the wireless network. When the wireless network requires channels, the wireless network first uses the reserved channels instead of withdrawing channels.

According to the description in the previous paragraph, we observe that the channel rental and channel withdrawal result in two phenomena: one is the variable number of radio channels in a wireless network; the other is the call dropping due to channel withdrawal. The aforementioned papers [6–12] discuss call admission control schemes in an environment without the two phenomena. However, it is more complicated to find the optimal number of reserved channels or find the optimal value of an admission threshold in a cellular wireless network with the variable number of channels than that in a cellular wireless network with the fixed number of channels. In addition, the number of reserved channels or the value of an admission threshold affects the probability that all radio channels in a cell are occupied, and as mentioned before, a channel withdrawal causes one or more dropped calls when all radio channels are occupied. The selection of reserved channels and an admission threshold also impacts the withdrawal dropping probability. To the best of our knowledge, there is no research to study call admission control policies in a cellular wireless network which leases radio channels from another wireless network. Due to the above reasons, we study threshold and reservation based call admission control policies in a cellular wireless network which rents idle radio channels from another wireless network.

Three call admission control policies, namely, fixed-reservation policy, single-threshold policy and multiple-threshold policy, are studied in this paper. The fixed-reservation policy reserves a fixed number of radio channels for hand-off calls. The single-threshold policy employs a single threshold to determine whether or not to accept new calls. To adapt the characteristic of the variable available number of radio channels, the multiple-threshold policy uses multiple thresholds to determine whether or not to admit new mobile users. The multiple-threshold policy can use different thresholds in different cases in each of which the total number of channels available for mobile users in a cell is different. Numerical analyses are developed to analyze the performances of the three call admission control policies. Using the numerical analyses, we can select the optimal number of reserved channels in the fixed-reservation policy and the optimal values of the admission thresholds in the single-threshold and multiple-threshold policies such that the QoS requirements (in terms of hand-off dropping and the withdrawal dropping probabilities) of mobile users are satisfied while throughput is maximized. Numerical results show that the multiple-threshold policy produces higher throughput than the single-threshold and fixed-reservation policies under the same QoS constraint of hand-off dropping and withdrawal dropping probabilities.

The rest of this paper is organized as follows. Section 2 describes an environment of spectrum renting. The fixed-reservation, single-threshold and multiple-threshold call admission control policies then are described in Section 3. Section 4 describes our numerical analyses of the three call admission control policies. Subsequently, numerical results are described in Section 5. Finally, some concluding remarks are presented in Section 6.

2. The environment of spectrum renting

In this section, we describe a cellular environment of spectrum renting, in which a cellular wireless network can rent radio channels from or out to another cellular wireless network.

A cellular wireless network may be licensed for holding a radio spectrum over a long period of time. The licensed radio spectrum can be further divided into radio channels. The licensed radio channels in a cellular wireless network are called "licensed channels" herein. After mobile users register in a cellular wireless network, the mobile users can use the licensed channels in the cellular wireless network. In addition, when the mobile users are using the licensed channels in the cellular wireless network, the cellular network does not forcibly withdraw the licensed channels from the mobile users. Although a mobile user may request one or more channels, we assume, for simplicity, that a mobile user merely requires one channel in this paper.

A cellular wireless network can rent its licensed channels out to another wireless network. In this paper, a wireless network that rents out its licensed channels is referred to as "channel owner". A cellular network can also rent radio channels from a channel owner. A cellular network that rents radio channels from a channel owner is referred to as "channel renter". For a channel renter, the radio channels that are rented from a channel owner are called "rented channels". Once a channel renter rents channels from a channel owner, the rented channels can be allocated to those mobile users that register in the channel renter if mobile users in the channel owner do not use the rented channels. It is possible that a mobile user in a channel owner requests a licensed channel which is being occupied by a mobile user in a channel renter. Since a mobile user in a channel owner has higher priority to use a licensed channel than that in a channel renter, a channel owner will forcibly withdraw the licensed channel occupied by the user in the channel renter. Note that a channel owner withdraws its channels when mobile users in the channel owner request the channels; that is, the channel withdrawal in a channel owner is dependent on the