A Fair and Efficient Spectrum Assignment for WiFi/WiMAX Integrated Networks

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***Abstract*—In recent years, integrated wireless networks and spectrum sharing in such networks have been researched actively. We have also proposed a spectrum assignment method for improving the average throughput of the whole network. In this method, however, WiFi users would obtain higher throughput at the expense of WiMAX users. This would be unfair in WiFi/WiMAX integrated networks. To overcome this problem, this paper proposes a fair and efficient spectrum assignment method for such networks. Finally, simulation experiments show the excellent performance of the proposed method.**

Keywords-*spectrum assignment; spectrum sharing; dynamic spectrum access; WiFi; WiMAX.*

I. INTRODUCTION

With advances in communication technologies, network services available via the Internet have become widely diversified. People can use such services not only via wired networks but also via wireless networks. With the demand for multimedia services via wireless networks growing, just as for wired networks, the bandwidth of cellular networks is growing and the number of wireless LAN access points (APs) is increasing greatly.

There are already several wireless systems being used in practice, including Cellular [1], WiFi [2], and WiMAX [3], [4]. Each system uses its own spectrum as prescribed by law to avoid interference.

However, these wireless communication systems operate independently, because the mechanisms of these systems are fundamentally different. Therefore, switching between systems must be performed manually by users. To avoid this inconvenience, an integrated network [5], [6], within which these systems can interwork, has been designed as a next-generation wireless communication system. In such an integrated network, mobile users can have seamless, continuous communication via the best available wireless communication system, according to the application or the local conditions of the wireless systems. Therefore, it will be possible to provide better communications for mobile users.

However, the available spectrum resources are finite, and so other approaches that use radio resources more effectively are being considered. As mentioned above, although the amount of available radio spectrum for a particular form of wireless communication is decreasing because of the increasing diversity of wireless networks, the traffic demand for wireless networks is increasing with the increasing variety of broadband applications. To address this dilemma, “cognitive radio” [7], [8] is receiving much attention.

Cognitive radio technologies can be classified as either multimode systems or dynamic spectrum access (DSA) systems [9], [10]. Multimode systems select between a number of independent wireless systems according to the communication environment of the user and the condition of each wireless system. Conversely, a DSA-based wireless system can make secondary use of the radio frequency spectrum that other wireless systems are using. The frequency spectrum is used more efficiently in DSA systems than in multimode systems.

We have proposed a spectrum assignment method for improving the average throughput of the whole network [11]. However, because this method focuses only on the overall improvement of the average throughput in the network, WiFi users would obtain higher throughput at the expense of WiMAX users. This would be unfair in WiFi/WiMAX integrated networks.

To overcome this problem, this paper proposes a fair and efficient spectrum assignment method for such networks.

In the rest of this paper, Section II introduces related work and points out the problematic issues. Section III proposes the fair and efficient spectrum assignment method. It is evaluated in Section IV and V. Finally, Section VI makes some conclusions and indicates future works.

II. RELATED WORK

A. Integrated Wireless Network

Although several wireless systems, such as Cellular, WiFi, and WiMAX, have developed independently, they should be integrated for seamless access by users. Therefore, in recent years, Cellular/WiFi integrated networks [12], [13] and WiFi/WiMAX integrated networks [14], [15] have been researched actively. In particular, a WiMAX/WiFi integrated

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network can achieve high-quality communications by using WiMAX and WiFi as complementary access resources. This integrated network enables load balancing between WiMAX and WiFi by using each system selectively in response to the demands of users and the condition of each system.

However, this integrated network assumes that each wireless system uses the spectrum band prescribed by law, so that, even if the WiMAX system has unused spectrum temporarily, it cannot be used by WiFi systems. As a possible solution to this problem, cognitive radio is receiving much attention.

B. DSA

According to [10], DSA strategies can be categorized in terms of three models, namely, the Dynamic Exclusive Use Model, the Open Sharing Model, and the Hierarchical Access Model, which are described below.

1) Dynamic Exclusive Use Model: This model protects the current spectrum regulation policy, in which spectrum bands are licensed to services for exclusive use. The main idea is to introduce flexibility to improve spectrum efficiency. Two approaches have been proposed under this model, namely, spectrum property rights and dynamic spectrum assignment. The former approach allows licensees to sell and trade spectrum and to choose freely between technologies. The economy and the market will therefore play major roles in driving towards the most profitable use of this limited resource. On the other hand, the latter approach aims to improve spectrum efficiency through dynamic spectrum assignment by exploiting the spatial and temporal traffic statistics of the various services.

2) Open Sharing Model: This model employs open sharing among peer users as the basis for managing a spectral region. Advocates of this model draw support from the phenomenal success of wireless services operating in the unlicensed Industrial, Scientific, and Medical radio band.

3) Hierarchical Access Model: This model adopts a hierarchical access structure with primary users (licensees) and secondary users. The key idea is to open licensed spectrum to secondary users while limiting the interference perceived by primary users. Two approaches to spectrum sharing between primary and secondary users have been considered, namely, spectrum underlay and spectrum overlay. The former approach imposes severe constraints on the transmission power of secondary users so that they operate below the noise floor of primary users. By spreading transmitted signals over a wide frequency band (i.e., using an Ultra-Wideband system), secondary users can potentially achieve short-range high data rates with extremely low transmission power. Alternatively, the latter approach does not necessarily impose severe restrictions on the transmission power of secondary users, but rather on when and where they may transmit. It directly targets spatial and temporal white space in the spectrum by allowing secondary users to identify and exploit local and instantaneous spectrum availability in a nonintrusive manner.

C. The Existing Method for WiFi/WiMAX Integrated Networks and Problematic Issues

A spectrum-sharing method whereby several WiFi APs temporarily use an unused WiMAX band in a WiFi/WiMAX integrated network has been proposed. It is based on the spectrum overlay described above. In this proposal, as shown in Fig. 1, a central control server called the spectrum manager (SM) manages the spectrum assignment and necessary information for assignment in a WiMAX base station (BS) and the WiFi APs inside the WiMAX service area of the BS. In this paper, we abbreviate "WiMAX service area" to "area" and call the hexagonal area accessed by the WiFi AP the "cell".

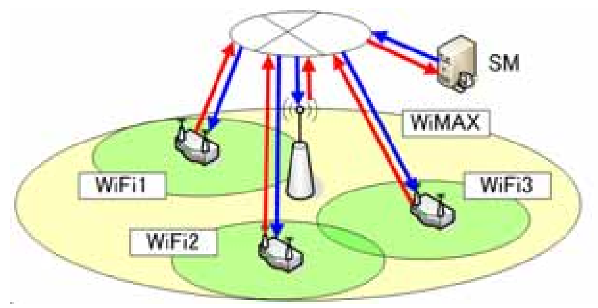

Fig. 1. Network Model

The coverage area of the WiMAX BS, a few kilometers in radius, is so large that it will include some WiFi APs. Therefore, the same spectrum can be used repeatedly by assigning unused WiMAX spectrum to WiFi APs without causing interference between the adjacent WiFi APs. If two or more WiFi APs use some WiMAX BS spectrum, the spectrum utilization efficiency can be enhanced for the whole network.

In [11], a spectrum assignment method to improve the overall average throughput for the network was proposed. In this method, the WiFi APs best suited to receive an additional channel from the WiMAX system are decided by using a genetic algorithm (GA). The sum of the number of users who connect to assigned target WiFi AP is defined as its *fitness value*. As a *constraint*, the method does not assign a certain channel to adjacent WiFi APs simultaneously. In this paper, we call this method the "existing method".

It was confirmed that the existing method improved the overall average throughput in the network compared with a method without spectrum sharing, as shown in Fig. 2. In this graph, the horizontal and vertical axes show the arrival rate for the entire network and the average download time, respectively.

However, because the existing method focuses only on improvements in the average throughput of the entire network, the individual throughput obtained by WiFi or WiMAX is unfairly distributed, as shown in Fig. 3. That is, WiFi users obtain their higher throughput at the expense of WiMAX users. This would be manifestly unfair in a WiFi/WiMAX integrated network.

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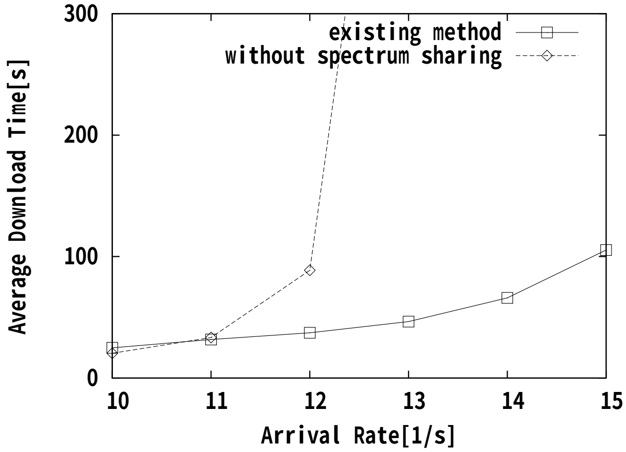

Fig. 2. Throughput Improvement via the Existing Method

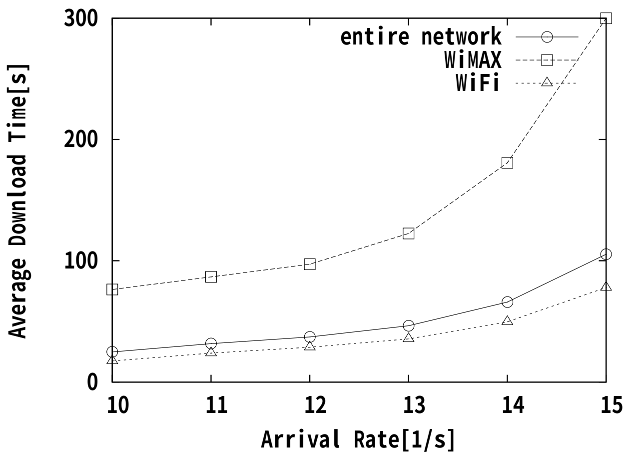

Fig. 3. Performance Characteristics of Existing Method

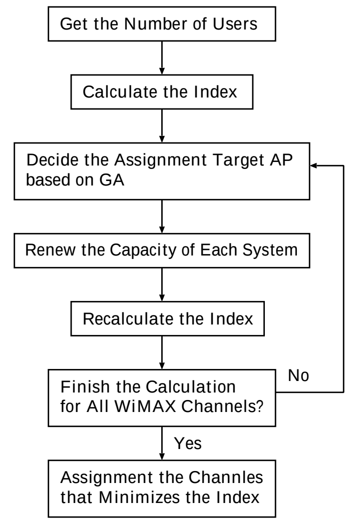

Fig. 4. Flowchart of the Proposed Method

III. Proposed Method

To overcome the problem described above, we propose a spectrum-sharing method that improves fairness in addition to providing higher throughput. The proposed method aims not only to improve total throughput but also to minimize the difference in throughput between WiFi users and WiMAX users. To achieve this, we introduce an *index* to indicate the effectiveness of the spectrum assignment. Here, a smaller value for the index means a better spectrum assignment.

The procedure for the proposed method is shown in Fig. 4. First, the number of users who connect to each system is acquired. Next, the index is calculated for the instant of time of the assignment. In addition, suppose that one channel is assigned from the WiMAX spectrum, and the APs of the assignment target are decided. After the assignment is conducted, the capacity of each system will be changed. Therefore, the capacity of each system is renewed and the index is recalculated.

The index is then calculated for the case of a second additional channel being assigned from WiMAX in the same manner. Finally, the number of assignment channels that minimizes the index is decided.

As mentioned above, after the assignment is carried out, the capacity of both WiFi and WiMAX will be changed. In what follows, "capacity" means the capacity after increasing or decreasing the number of channels.

The average throughput for WiFi users is calculated by Eq. (1).

$$\frac{\sum_{i=1}^{n} p_i u_i}{\sum_{i=1}^{n} \frac{1}{\frac{c_i}{u_i}} \times p_i u_i}, \tag{1}$$

where n, c_i, and u_i are the number of areas, the capacity of the WiFi AP, and the number of connected users, respectively. p_i is an indication function, with $p_i = 1$ indicating that area i contains a WiFi AP, and $p_i = 0$ indicating otherwise.

In the same way, the average throughput of WiMAX users is calculated by Eq. (2).

$$\frac{C}{U}, \tag{2}$$

where C and U refer to the capacity of the WiMAX system and the number of connected WiMAX users, respectively.

The index of the proposed method is defined in Eq. (3) and the proposed method assigns additional channel(s) from WiMAX to WiFi based on the number of channels that minimizes the value of this index.

$$\left| \frac{\sum_{i=1}^{n} \frac{1}{\frac{c_i}{u_i}} \times p_i u_i}{\sum_{i=1}^{n} p_i u_i} - \frac{U}{C} \right| \tag{3}$$

IV. Performance Evaluation

A. Simulation Model

In this section, we evaluate the performance of the proposed method by simulation experiments.

Fig. 5 shows the network model assumed in this simulation. One WiMAX BS and $10 \times 10 = 100$ small areas are allocated to the access area of the WiMAX system. The WiFi APs are allocated to the small areas according to the *distribution rate*. For example, if the distribution rate is 0.75, $100 \times 0.75 = 75$ small areas are selected at random and each has a WiFi AP.

The spectrum of the WiMAX BS is divided into several channels of 20[MHz] each. The WiMAX system is assumed to provide 40 Mbps per channel in accordance with [18] and the WiFi systems are assumed to provide 17.5 Mbps per channel according to our preliminary experiments that used ns2 [19]. In addition, the spectrum utilization, the load status of each system, the control of the spectrum assignment, and the implementation of GA are managed by the SM, as shown in Fig. 5.

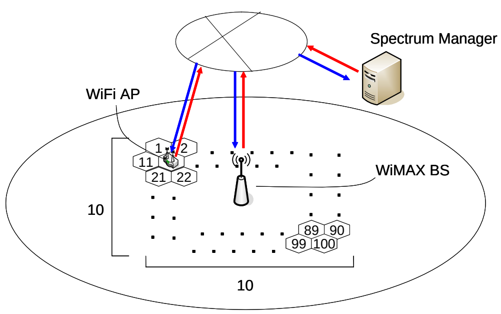

Fig. 5. Simulation Model

In this paper, we focus on best-effort traffic such as data downloading or web browsing. Users are assumed to be downloading a 10[MByte] file. When a new mobile user joins the integrated network, the user connects to a wireless system selected by the spectrum manager and starts downloading data at the allocated throughput. When the downloading is complete, the mobile user disconnects from the wireless system.

If a new user arrives in an area with a WiFi AP, the WiFi connection is used. Otherwise, the WiMAX BS is used. In addition, users stay in the arrival area until the end of their downloading. Calls occur according to a Poisson arrival process, and the arrival rate depends on the existence of the WiFi AP. Because WiFi APs tend to be set up in places where people gather, such as cafes, offices, and rail stations, the call arrival rate in an area with a WiFi AP is assumed to be x times higher than that in an area without a WiFi AP.

We define the arrival rate for the entire network in the case of $x = 1$ as λ_{sys}. To keep λ_{sys} independent of the distribution rate r and the arrival rate ratio x, arrival rates of λ_a (with WiFi AP) and λ_b (without WiFi AP) were selected to satisfy the following equations.

$$\lambda_a = \lambda_{sys} \times \frac{x}{(1-r) \times 1 + r \times x} \tag{4}$$

$$\lambda_b = \lambda_{sys} \times \frac{1}{(1-r) \times 1 + r \times x}. \tag{5}$$

To measure performance, we observe the average time to finish downloading (*download time*) and its coefficient of variance.

Other parameter settings are as shown in Table I.

TABLE I
DEFAULT SIMULATION PARAMETERS

Distribution rate for WiFi APs r	0.5
Spectrum bandwidth for WiMAX	100 MHz
Arrival rate ratio x	5
Interval time T for spectrum assignment	300 seconds

V. Simulation Results

Fig. 6 shows the average download time as a function of the call arrival rate. It indicates that the average throughput of the proposed method is almost equal to that of the existing method.

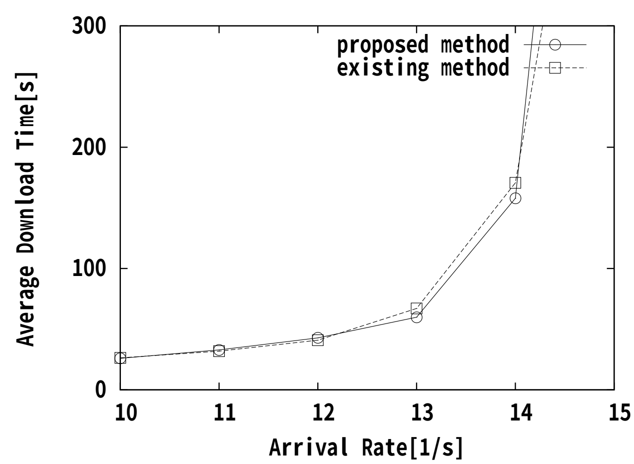

Fig. 6. Mean Dowload Time

Fig. 7 shows the coefficient of variance as a function of the call arrival rate. From this figure, the proposed method is shown to have a lower coefficient of variance than the existing method for heavy-load situations.

Figs. 8 and 9 show the average download time and its coefficient of variance as a function of the arrival rate ratio x, respectively. The call arrival rate was set to 12[1/s].

These results indicate that the proposed method is robust against the arrival rate ratio.

VI. Conclusion and Future Works

In this paper, we have described a spectrum-sharing method that improves the average throughput in a WiFi/WiMAX integrated network and we have shown that there was still room for improvement in the fairness of individual-user throughput. We have therefore enhanced the method to consider fairness in addition to providing higher throughput.

In future work, it will be necessary to propose a spectrum-sharing method that considers QoS issues for network traffic.

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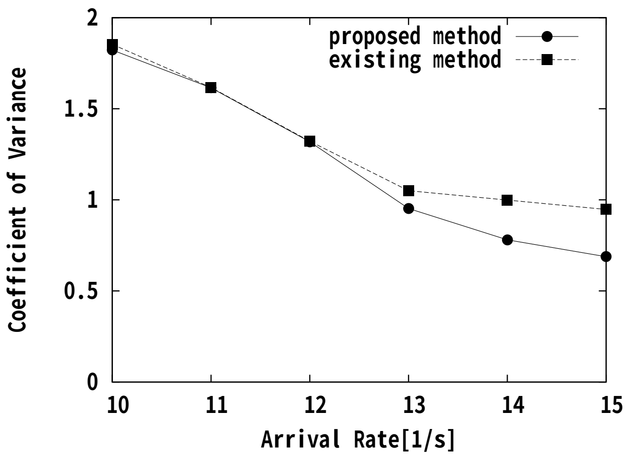

Fig. 7. Coefficient of Variance

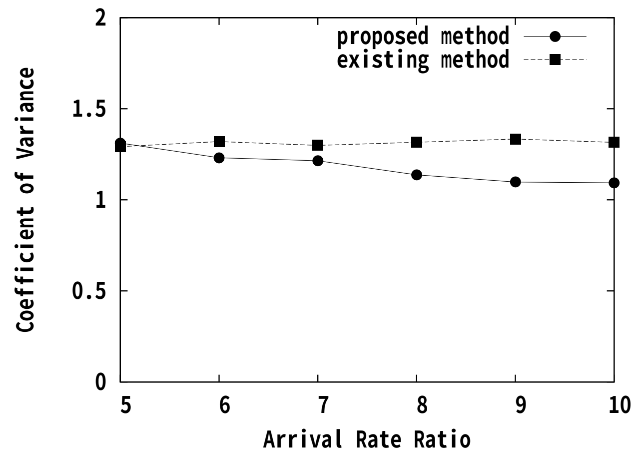

Fig. 9. Coefficient of Variance (variable arrival rate ratio)

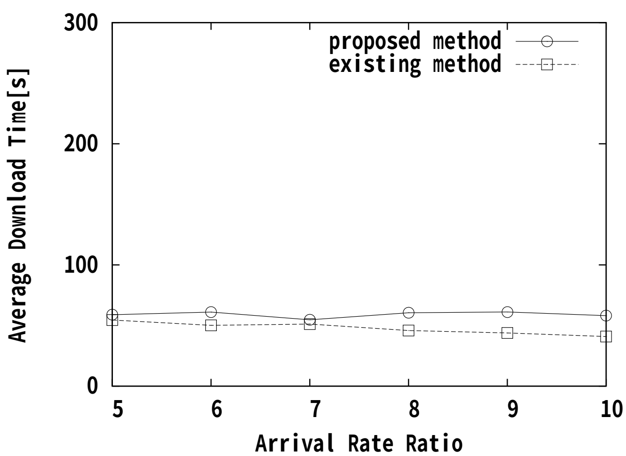

Fig. 8. Mean Download Time (variable arrival rate ratio)

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