A Spectrum Sharing Method Considering Users' Behavior for Uncooperative WiFi/WiMAX Providers

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***Abstract*—The number of wireless network users has remarkably grown by recent advances in wireless communication technologies such as WiFi and WiMAX. This has led to a lack of spectrum resources, which has therefore become an important issue. To overcome this problem, spectrum sharing technology, whereby a WiFi system temporarily uses a spectrum band of a WiMAX system, is receiving much attention. Although existing work assumes that the WiMAX and WiFi providers are cooperative, it may not be realistic. In addition, user behavior model is too simple. In this paper, we propose a spectrum sharing method that behaves properly even if the WiMAX provider, WiFi providers, and users are mutually uncooperative. Finally, we confirm the effectiveness of the proposed method by simulation experiments.**

***Keywords*-spectrum sharing; uncooperative providers; satisfaction; WiFi; WiMAX; user model**

I. Introduction

In recent years, users have had access to various wireless systems such as cellular, WiFi, and WiMAX. With increased bandwidth becoming available, multimedia services via wireless networks are now widely used and the traffic demand is increasing.

However, with available spectrum resources being finite, techniques that use wireless resources more effectively should be considered. As one approach to this problem, cognitive radio [1], [2] is receiving attention. Cognitive radio is a technology whereby wireless devices can select between a number of independent wireless systems according to the condition of each system. The frequency spectrum can then be used more efficiently than by using these systems independently.

For cognitive radio, a spectrum-sharing method has been proposed [3], in which a WiFi system temporarily uses a spectrum band of a WiMAX system. In this method, the WiFi access points (APs) that are to use the additional WiMAX channel are decided according to the "load", where the "load" is defined as the total number of users connecting to the WiFi AP. It was confirmed that this method could improve the overall average throughput for the network compared to a method without spectrum sharing.

However, the proposed method assumed that the WiMAX and WiFi providers cooperated to improve the overall average throughput. Therefore, if the WiMAX provider and WiFi providers do not cooperate and pursue only their own interests, this method might not work.

An alternative auction-based method has been proposed [4], which adopts a pricing model for lending channels. This method can behave appropriately even if the WiMAX provider and WiFi providers do not cooperate. However, because this method focuses on the WiMAX provider's profit, the improvement in the average throughput may not be optimal.

To address these problems, we propose a spectrum-sharing method that behaves properly even if the WiMAX provider, WiFi providers, and users are mutually uncooperative. This is an extended version of[5].

The rest of this paper is organized as follows. In Section II, we introduce some existing methods and point out their problems. In Section III, we elaborate our proposed method. Section IV shows the excellent performance of the proposed method by simulation experiments. Finally, Section V makes some conclusions and indicates future work.

II. Related Work

A. Integrated Wireless Networks

Although several wireless systems such as cellular, WiFi, and WiMAX have been developed, each system is used independently. However, if these were to be integrated, users could access services seamlessly. Therefore, WiFi/WiMAX integrated networks [6], [7] have been investigated recently, aiming to improve quality of service (QoS) and load balancing between the WiFi and WiMAX systems by using each system selectively according to the condition of the systems and the demands of user applications. The coverage area for a WiFi AP is about 100 meters, whereas that for a WiMAX base station (BS) is a few kilometers. As shown in Fig. 1,

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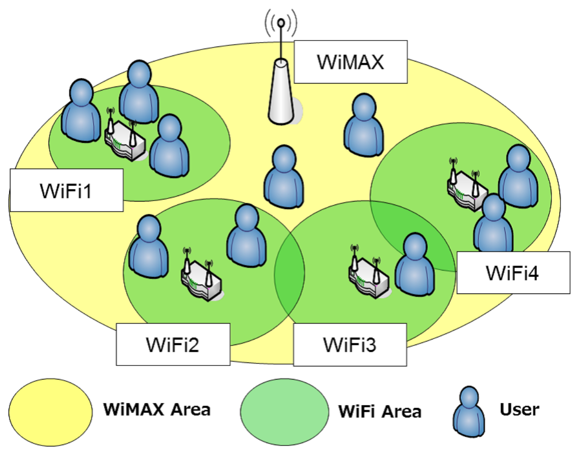

Figure 1. Network Model

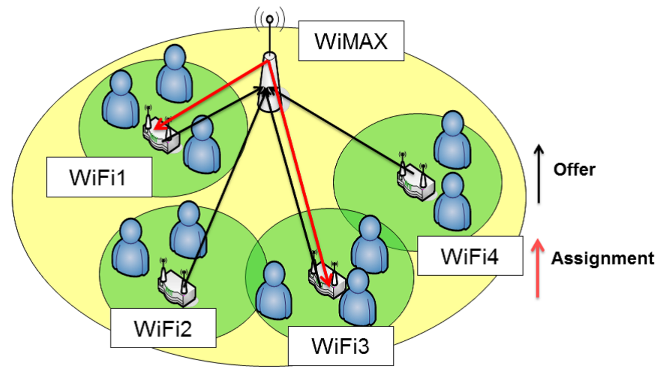

Figure 2. Auction Method

this means that two or more WiFi APs may exist inside a WiMAX service area.

As an alternative, a spectrum-sharing method that temporarily assigns a spectrum band of a WiMAX system to WiFi system APs has been proposed. Here, the same spectrum can be used repeatedly without causing interference between adjacent WiFi APs. This enables more efficient utilization of the spectrum, thereby providing users with higher-throughput services.

B. Spectrum-sharing Method to Improve Overall Throughput

In [3], a spectrum-assignment method for improving the overall average throughput in the network was proposed. In this method, the assignment of a WiFi AP to an additional channel in the WiMAX system is decided by using a genetic algorithm (GA). The number of users who connect to the assigned target WiFi AP is used as the evaluation value and the channel assignment is carried out under the constraint that adjacent WiFi APs cannot be assigned the same channel simultaneously. It was confirmed that this method improved the overall average throughput for the network. Moreover, in [8], a spectrum-assignment method that also minimized the difference in throughput between WiFi and WiMAX users was able to provide higher throughput. This method not only improved the overall average throughput but also reduced the coefficient variance.

However, for these methods, the WiMAX system has to lend channels to WiFi APs without itself receiving any direct reward. This implies that either there is one provider of the WiMAX and WiFi services or that the separate providers are prepared to cooperate. In reality, providers do not always cooperate, preferring to pursue their own profit. Therefore, an effective spectrum-sharing method that behaves properly even if the WiFi and WiMAX providers do not cooperate is needed.

C. Spectrum-sharing Method Based on an Auction

There is a spectrum-sharing method that uses the model of an auction [4]. In this method, if WiFi providers receive an additional channel from the WiMAX provider, they pay for that channel. As shown in Fig. 2, each WiFi provider can make an offer for a channel. By considering these offers, the WiMAX provider selects an assignment pattern that maximizes the WiMAX provider's revenue.

This enables the WiMAX provider to obtain additional profit by lending channels and the WiFi providers to increase their effective bandwidth and user throughput. Furthermore, this method can behave appropriately even if the WiMAX provider and WiFi providers are uncooperative.

However, because this method focuses only on increasing the WiMAX provider's profit, more effective assignment patterns may be overlooked, which implies that the improvement in average throughput is not optimal. Moreover, for some of these proposed methods, the offered prices for an additional channel are decided randomly, which is unrealistic.

III. Proposed Method

A. Summary of the Proposed Method

To overcome the problems described above, we propose a spectrum-sharing method that behaves properly even if the WiMAX provider, WiFi providers, and users are mutually uncooperative. To achieve this, we introduce *satisfaction* as an indicator of users' behavior. In this method, we assume that the user arrival rate at WiFi APs and the WiMAX system varies according to the user satisfaction. Furthermore, given that the WiMAX provider and WiFi providers are not expected to cooperate, the WiFi providers must pay for receiving an additional channel from the WiMAX provider, and must decide for themselves how much they are prepared to pay. The WiMAX provider will select the assignment pattern that maximizes its own profit via a GA method, using the WiFi APs' offered prices and the constraint that

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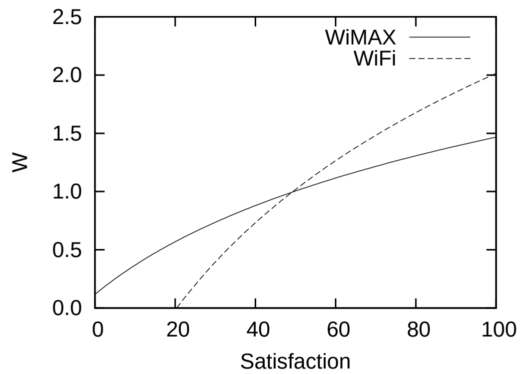

Figure 3. Relation between Satisfaction and Magnification W

adjacent WiFi APs cannot be assigned the same channel simultaneously.

In the following subsections, we first introduce the concept of satisfaction. We then describe how the WiFi APs decide about payments and the algorithm for spectrum assignment.

B. Satisfaction

Satisfaction is associated with each WiMAX and WiFi AP according to the throughput, and may vary from 0 to 100. APs have increased satisfaction as the user throughput increases.

In general, users hope to connect to an AP with as high a throughput as possible. On the other hand, WiMAX and WiFi providers hope to increase the number of connecting users, which increases their profit. Therefore, WiMAX and WiFi providers aiming to increase their profit will improve satisfaction.

The details are as follows. We assume that the user-arrival rate changes as a function of the satisfaction at each AP. Fig. 3 shows the magnification W of the arrival rate as a function of the satisfaction. The arrival rate of APs increases according to the magnification W as the satisfaction increases.

C. Calculation of the WiFi Providers' Offer Price

This subsection explains how WiFi providers calculate the payment for being assigned a channel from the WiMAX provider. As explained in Section III-A, the WiFi providers decide for themselves how much they are prepared to pay. For the WiFi providers, increasing the number of connected users leads to increased profit. Therefore, WiFi providers need to raise their user satisfaction. If WiFi providers receive an additional channel from the WiMAX system, the throughput and the satisfaction will both increase, and an increase in revenue would therefore be expected.

However, WiFi providers must pay the WiMAX provider for the assigned channels. Therefore, WiFi providers must consider both revenue and payment in deciding whether to borrow a channel. If a WiFi provider wants to borrow a single channel, they can calculate the appropriate payment using Eq. (1). For multiple channels, the same calculation will be repeated.

$$P_F * E_i * \alpha, \tag{1}$$

where P_F, E_i and α refer to the price that WiFi providers impose on users, the estimated number of increased users, and the expected profit to the WiFi provider, respectively. E_i is calculated by Eq. (2), assuming that the satisfaction changes from s to s'.

$$E_i = \lambda_F * T * (W_F(s') - W_F(s)), \tag{2}$$

where λ_F and T are the arrival rate at the WiFi AP, and the interval times for spectrum assignment, respectively. $W_F(s)$ is the magnification of the arrival rate, as shown in Fig. 3. Therefore, $W_F(s') - W_F(s)$ indicates by how much the number of users connecting to the WiFi AP will increase by borrowing additional channels. Whenever a WiFi provider judges, using this equation, that it can increase its revenue, it offers the calculated payment for borrowing additional channels. Otherwise, it does not seek to borrow any additional channels.

D. Procedure for Channel Assignment

We now explain the procedure for channel assignment. The WiMAX provider decides on the number of assignment channels and the APs of the assignment targets according to the WiFi APs' offer prices described in Section III-C. However, the assignment of channels to WiFi providers will cause the throughput of the WiMAX provider to decrease. Therefore, the WiMAX provider's satisfaction will change from s to s', which causes a decrease in both arrival rate and revenue. Because of this, the WiMAX provider should perform channel assignment by considering the difference between the revenue decline and the payment from the WiFi APs in terms of Eq. (3).

$$\textit{Estimated Decreased Revenue} = P_M * E_d, \tag{3}$$

where E_d and P_M refer to the estimated number of decreased users and the price that the WiMAX provider imposes on users, respectively. E_d is calculated by Eq. (4).

$$E_d = \lambda_M * T * (W_M(s) - W_M(s')), \tag{4}$$

where λ_M is the arrival rate for the WiMAX system. $W_M(s) - W_M(s')$ indicates the decrease in the number of users connecting to the WiMAX system because of the decrease in available channels.

The APs of the assignment targets and the number of assignment channels are decided according to the following steps.

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1) WiFi APs calculate the payment required to borrow channels.
2) WiMAX provider selects the assignment pattern that maximizes the sum of payments offered by WiFi APs.
3) WiMAX provider calculates the estimated revenue decrease from lending channels.
4) If the revenue from lending channels exceeds the estimated revenue decrease, then perform the channel assignment.
5) Repeat Steps 1 to 4 until all channels are lent or the estimated revenue decrease exceeds the revenue from the target WiFi APs.

Note that, in Step 2, we use the algorithm proposed in [8].

IV. Performance Evaluation

A. Simulation Model

In this subsection, we evaluate the performance of the proposed method by simulation experiments. The network model assumed that WiFi and WiMAX were able to carry out spectrum sharing. There was one WiMAX BS, whose area was divided into $10 \times 10 = 100$ small areas. 50 small areas were selected at random, each having a WiFi AP. The spectrum bandwidth for the WiMAX system was set to 100[MHz] and divided into channels of 20[MHz] each. Each WiFi AP can use one or more additional channels assigned from the WiMAX system. The WiMAX system was assumed to provide 40[Mbps] per channel in accordance with the WiMAX Forum [9]. The WiFi systems were assumed to provide 17.5[Mbps] per channel according to preliminary experiments that used the ns2 discrete-event simulator [10].

In addition, the interval time T for spectrum assignment was set to 300[sec]. The price that the WiMAX provider imposes on its users was 100, and the price that WiFi providers impose on their users was set to 80. The WiFi APs' price was lower because the coverage for WiFi is narrower than that for WiMAX. We considered the example of a user downloading a 10 MByte file.

In this simulation, calls occured according to a Poisson arrival process, with each area having its own arrival rate. Because WiFi APs tend to be set up in places where people gather, such as offices, rail stations, and cafes, the call arrival rate for a WiFi AP was assumed to be x times that for WiMAX. We defined the arrival rate for the whole network as λ_{all}. The initial arrival rate per WiFi AP area (λ'_F) and that for WiMAX (λ'_M) were then calculated by Eq. 5 and Eq. 6.

$$\lambda'_F = \lambda_{all} * \frac{x}{50(x+1)} \tag{5}$$

$$\lambda'_M = \lambda_{all} * \frac{1}{100(x+1)} \tag{6}$$

In this simulation, we set $x = 3$.

Now, as described in Section III-B, the arrival rate would change according to the magnification W of the initial arrival rate. Therefore, the actual arrival rates for WiMAX (λ_M) and per WiFi AP area (λ_F) satisfied the following equations.

$$\lambda_M = \lambda'_M * W_M \tag{7}$$

$$\lambda_F = \lambda'_F * W_F \tag{8}$$

It followed that the arrival rates λ_1 (without WiFi AP) and λ_2 (with WiFi AP) were calculated by the following equations.

$$\lambda_1 = \lambda_M \tag{9}$$

$$\lambda_2 = \lambda_F + \lambda_M \tag{10}$$

If a new user arrived in an area with a WiFi AP, the system with the higher throughput was used. Otherwise, the WiMAX BS was used. In addition, users would stay in the arrival area until the end of their download.

We chose two other methods for comparison. One method was the spectrum-sharing method described in Section II-B, which improved the overall average throughput. In this paper, we call this method the "existing method". The other method did not share any spectrum. As performance measures, we observed the average time to complete the download (download time) and the revenue for the WiMAX and WiFi providers.

Under the same conditions as described above, we ran five simulations with various initial overall arrival rates λ_{all}. The simulation ended after 250,000 calls were completed. We set the parameter α to 0.1. $W_F(s)$ and $W_M(s)$ are logarithmic functions of the satisfaction s. As explained above, with channel assignment, the throughput changes and the satisfaction of the WiMAX and WiFi providers changes from s to s', where s' is calculated from the following equations.

$$s'(WiFi) = s + 190/s \tag{11}$$

$$s'(WiMAX) = s - 25/s \tag{12}$$

Note that, we assume that the satisfaction s is also a logarithmic function of throughput (Tp), as defined in Eq. 13.

$$s = 70 * log((Tp + 5)/5) \tag{13}$$

B. Simulation Results

Fig. 4 shows the average download times as a function of the initial overall arrival rate.

This indicates that both of the existing method and the proposed method improve the average overall throughput, since the capacity of the system increased by assigning one or more channels from the WiMAX BS to several WiFi APs.

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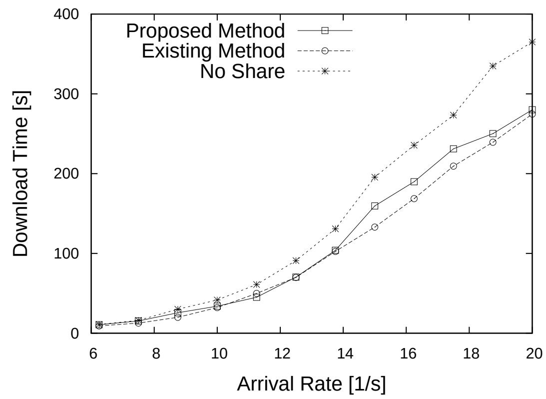

Figure 4. Mean Download Time with Variable Arrival Rate

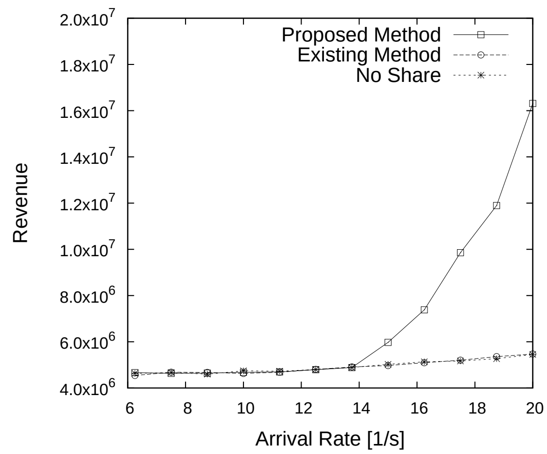

Figure 5. Overall Revenue with Variable Arrival Rate

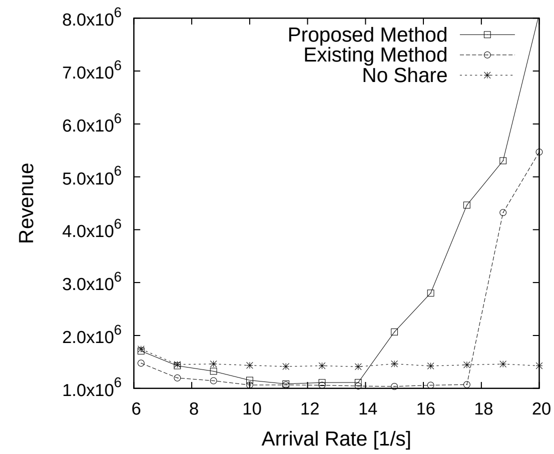

Figure 6. WiMAX Provider's Revenue with Variable Arrival Rate

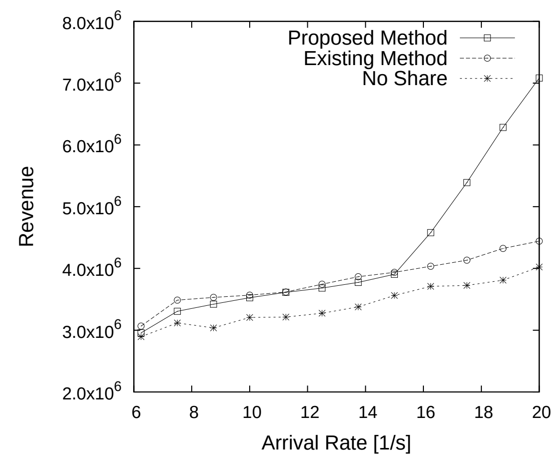

Figure 7. WiFi Providers' Revenue with Variable Arrival Rate

The average throughput of the proposed method is almost equal to that of the existing method. Therefore, this means that our proposed method behaves properly even if the WiMAX provider, WiFi providers and users are mutually uncooperative.

Figs. 5-7 show the sum of the revenues of the WiMAX provider and WiFi providers, the WiMAX provider's revenue, and the WiFi providers' revenue as a function of the initial overall arrival rate, respectively. There is not so much difference between the overall revenue of the existing method and that of the proposed method, when λ_{all} is up to 13.75. However, the overall revenue in the proposed method becomes much higher when λ_{all} is bigger than 15.0. Moreover, Fig. 5 and Fig. 6 indicate that the revenues of the WiMAX provider and that of the WiFi providers are increasing. This is because the proposed method considers the change of the revenue adequately to assign an additional channel assignment based on satisfaction.

However, from Fig. 6, we can see that the revenue of the WiMAX provider is smaller than that of the non-sharing method when the arrival rate is small. In this simulation, when a new user arrives at an area with WiFi AP, he/she chooses a system with higher throughput. In the methods with spectrum sharing, the throughput of the WiMAX users decreases because of the decrease in its available channels. This might cause the situation that more users connect to a WiFi AP rather than WiMAX BS. The proposed method avoids this situation by consideration of the satisfaction. Consequently, when λ_{all} is large, the revenue for the WiMAX provider in the proposed method is higher than that in the existing method.

These results indicate that the proposed method achieves well spectrum sharing even if the WiMAX provider, WiFi providers, and users are mutually uncooperative.

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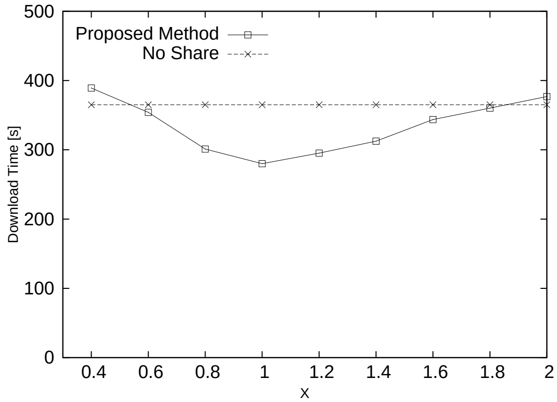

Figure 8. WiMAX: Mean Download Time with Variable X ($\lambda = 20$)

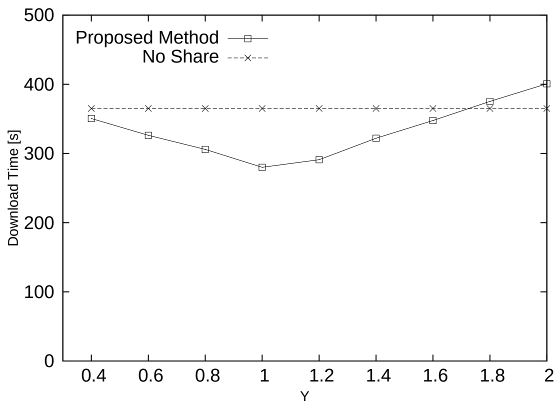

Figure 9. WiFi: Mean Download Time with Variable Y ($\lambda = 20$)

C. Robustness

In this simulation, we assumed that WiMAX and WiFi providers exactly knew the relationship between satisfaction and the arrival rate. Therefore they can expect the change of the number of uses properly. However, this is difficult in fact.

To confirm this robustness, we verified the case where WiMAX (WiFi) provider misestimated the change of users X (Y) times more than the actual value. In other words, if X is 1.0, WiMAX provider can expect the change properly.

Figs. 8 and 9 show the average download times as a function of the parameter X (or Y) compared with the no spectrum assignment method. We set $\lambda_{all} = 20$. Fig. 8 indicates that even if WiMAX provider expects about 50% more or less, the proposed method can improve the average throughput. Similarly, when the differece between what WiFi providers expect and the actual change is less than 60%, the improvemnet of the average throughput is achieved.

V. Conclusion and Future Works

In this paper, we proposed a new spectrum sharing method that works well even if WiMAX provider, WiFi providers, and users are mutually uncooperative. It introduces the satisfaction as an indicator of users' behavior. Furthermore, it was confirmed that the proposed method could keep the average throughput compared with the existing method and improve the revenues.

In a future work, we evaluate the sensitivity of each parameter.

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