A Spectrum Sharing Method based on Adaptive Threshold Management between Non-cooperative WiMAX/WiFi Providers

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***Abstract*—In recent years, the number of portable mobile terminal users is increasing with improvement of the wireless communication environment. In addition, mobile multimedia services also bring the increase of wireless traffic and lack of spectrum resources. As a technique for efficient spectrum use, spectrum sharing receives much attention. It dynamically assigns a spectrum channel from a larger area network such as WiMAX to smaller area networks such as WiFi-based wireless LANs and achieves to increase the total wireless communication capacity of this area. In a case where all providers are cooperative, the spectrum sharing can be realized easily and improve user throughput in average. In another case where providers are not cooperative, some spectrum trading methods based on auction theory had been proposed. Although such an existing method assumes that providers can estimate their gain and loss caused by spectrum sharing, however, it is very difficult in fact since they need to model the users' behavior exactly. In this paper, we propose a spectrum sharing method that works properly between non-cooperative WiMAX/WiFi providers. It is achieved by simple and adaptive parameter management. Finally, we confirm the effectiveness of the proposed method by simulation experiments.**

Keywords- WiMAX/WiFi Integrated Network; Spectrum Sharing; Spectrum Assignment; Cognitive Radio

I. INTRODUCTION

With advances of wireless transmission technology (e.g., WiMAX [1], [2], WiFi [3] and Cellular), mobile communication environment is greatly improved. People can get multimedia services via these networks and the demand will grow as much as in wired networks.

On the other hand, the available radio spectrum resources for a particular wireless systems are getting scarcer. Since radio spectrum is statically allocated to licensed wireless providers, some frequency bands are unused in any time and location. In order to improve the wireless spectrum utilization, effective integration of multiple wireless networks is required.

Utilizing the cognitive radio technology[4], wireless systems can share wireless spectrum in heterogeneous networks. With spectrum sharing, it was confirmed that the frequency usage is improved in WiMAX/WiFi integrated network [5]. However, the existing method assumed that the WiMAX and WiFi providers cooperated to improve mean user throughput. Therefore, in the case where the providers do not cooperate and pursue only their own interests, this method might not work properly.

In such a case, spectrum trading methods had been proposed [6], in which spectrum bands are bought and sold among providers. While most of these works assumes that providers can estimate their gain and loss caused by spectrum trading, it is very difficult in fact since users' behavior has to be modeled exactly.

In this paper, we propose a spectrum sharing method that works properly even between non-cooperative WiMAX/WiFi providers by introducing a threshold to assign an additional channel from a WiMAX base station (BS) to WiFi access points (APs). It is necessary to adapt the threshold of spectrum sharing to the environment. Therefore, we also propose an adaptive threshold management, which is a learning algorithm for the threshold to match the spectrum demand.

The rest of the paper is organized as follows. In Section 2, we introduce spectrum sharing technology and some existing methods. In Section 3, we elaborate our proposed method. Its performance is evaluated by simulation experiments in Section 4. Finally, Section 5 presents some conclusions and indicates future work.

II. SPECTRUM SHARING

A. Integrated Network

Currently, most of wireless systems are independently designed. The integration of those independent wireless systems, however, is able to provide wireless users a seamless access. Therefore, in recent years, integrated network such as the Cellular/WiFi integrated network [7], [8] have been researched actively. As a typical heterogeneous wireless integrated network, we focus on integration of WiMAX and WiFi. The former system whose coverage area is several kilometers wide can achieve Quality of Service (QoS). The latter system can cover only several hundred meters, although, spread widely.

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As shown in Fig. 1, in the integrated network, mobile users are connected to the best wireless systems, which are chosen in terms of user (e.g., application and mobility) and system (e.g., traffic congestion). Therefore, users can have better communications and systems also achieve load balancing [9].

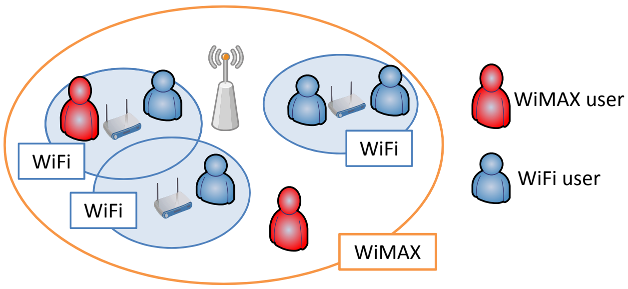

Figure 1: AP selection strategy

B. Spectrum Sharing Model

Spectrum sharing technology has emerged to improve the spectrum utilization in wireless networks. With the aid of cognitive radio, a spectrum owner (or primary system) shares their licensed spectrum for secondary systems, which has no priority to the band [10]. Since two or more secondary systems can use the same spectrum when they are not adjacent, the total wireless communication capacity increases. In the case of WiMAX/WiFi integrated network, spectrum channels of the WiMAX system are temporarily assigned to WiFi APs and it improves the whole network capacity[11].

As shown in Fig. 2, a centralized control server named spectrum manager controls the spectrum assignment and collects necessary information for the assignment from a WiMAX BS and WiFi APs inside the WiMAX BS service area [12]. Also, the server searches for the optimal assignment pattern of WiFi AP.

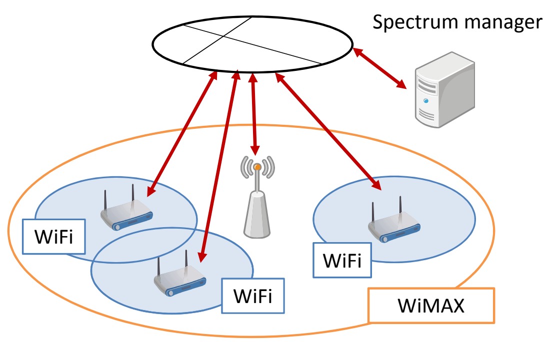

Figure 2: spectrum manager

C. Existing Spectrum Sharing Method

The protocol design for spectrum sharing depends on the relation between WiMAX and WiFi providers (i.e., cooperative or non-cooperative). In a cooperative environment, providers cooperate with each other to improve the average user throughput. On the other hand, non-cooperative providers pursue their own profit.

According to [5], spectrum sharing in cooperative network improves the overall average throughput. In this method, the number of users who connect to the system is used as the evaluation value of Genetic Algorithm (GA). By using GA under the constraint to disallow to assign the same spectrum to adjacent WiFi APs, it is possible to assign channel without interference among selected APs. However, this spectrum assignment method works properly only for a cooperative situation, for example, the same provider owns both WiMAX BS and WiFi APs.

In a non-cooperative environment, spectrum sharing may degrade the WiMAX system throughput due to the decrease of the available WiMAX spectrum. Therefore, spectrum trading method has been proposed. It adopts money trading as a motivation for spectrum sharing [6].

Spectrum trading method based on auction theory is one of the major methods to share frequency band in non-cooperative providers [13], [14]. In this method, each WiFi provider bids for an additional 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. According to the profit which systems will get, providers decide to sell or buy channels. However, it is difficult to guess the right profit due to the difficulty to model exact user behavior, e.g., users may dynamically change to connect to a more comfortable system[14].

III. Proposed Method

A. Concept

We propose a spectrum sharing method based on the auction system with adaptive threshold management between non-cooperative WiMAX/WiFi providers. The proposed method relies on a simple management scheme by utilizing a threshold parameter which WiMAX provider sets as a minimum price per channel. On the other hand, the threshold control is important for an effective spectrum sharing. Therefore, WiMAX provider needs to learn and adapt the threshold parameter to the environment. For this purpose, we also propose a learning algorithm to decide an appropriate threshold. Note that this algorithm does NOT depend on the users' behavior modeling.

B. Network Model

We consider a heterogeneous network, that consists of one WiMAX BS and multiple WiFi APs contained in the BS covered area. Suppose the WiFi APi provides throughput T_i per a contacted user , for $i \in W_{all}$ (a set of all WiFi AP).

On a condition to leave at least one channel for BS, at most N-1 channels of WiMAX are provided to APs, where N is the number of channels primarily allocated to BS.

C. Threshold of Sharing Channel

Each WiFi AP submits a price for an additional channel based on the demand of the spectrum which can be described by provided throughput to each user. When an AP has larger number of connected users, each user receives less throughput. Therefore, price per channel U_i offered by WiFi APi is formulated as

$$U_i = \frac{x}{T_i}. \tag{1}$$

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Since we suppose all APs have basically the same strategy to get an additional channel, x is a constant value.

Meanwhile, WiMAX provider sets the minimum price per channel y. The condition that WiMAX gives its spectrum resource to WiFi is described as

$$\sum_{i \in W_{GA}} U_i > y, \tag{2}$$

where W_{GA} is a set of WiFi APs receiving an additional channel. Though the number of available spectrum channels of the WiMAX BS decreases, this enables the WiMAX provider to obtain additional profit more than y by lending channels.

Since x is constant, x and y can put into one parameter M_{th} (WiMAX threshold) as

$$\sum_{i \in W_{GA}} \frac{1}{T_i} > \frac{y}{x} = M_{th}. \tag{3}$$

D. Channel Assignment

As shown in Fig. 3, a spectrum channel can be assigned to two or more APs which are not adjacent to each other. When a channel is assigned to an AP, the AP can use twice as much bandwidth. Thus, the spectrum demand of an AP which is assigned one or more channels will decrease and the AP will submit lower price for another additional channel. Therefore, WiFi AP changes the price of one channel by the number of the channels it receives.

The target APs for assignment and the number of assigned channels are decided according to the following steps.

1) WiFi APi decides the payment U_i.
2) WiMAX provider selects the assignment pattern that maximizes the sum of payments offered by WiFi APs.
3) If the revenue of lending the channels exceeds y, WiMAX provider performs the channel assignment.
4) Repeat Steps 1 to 3 until N-1 channels are lent or y exceeds the revenue from the target WiFi APs.

Note that, the condition of providing spectrum in Step 3 can be described by (2).

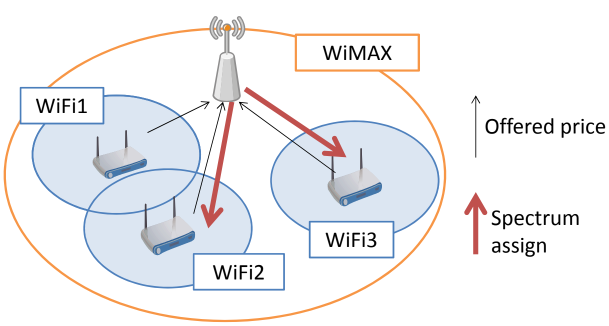

Figure 3: Channel assignment

E. Adaptive Threshold Management

When the threshold of sharing spectrum M_{th} is too small, a large part of the bandwidth is sold at a low price. On the other hand, frequency is not shared when M_{th} is too big. Therefore, it is necessary to set M_{th} to an adequate value in order to share spectrum effectively. Therefore, we propose a learning algorithm to find the appropriate M_{th} value dynamically.

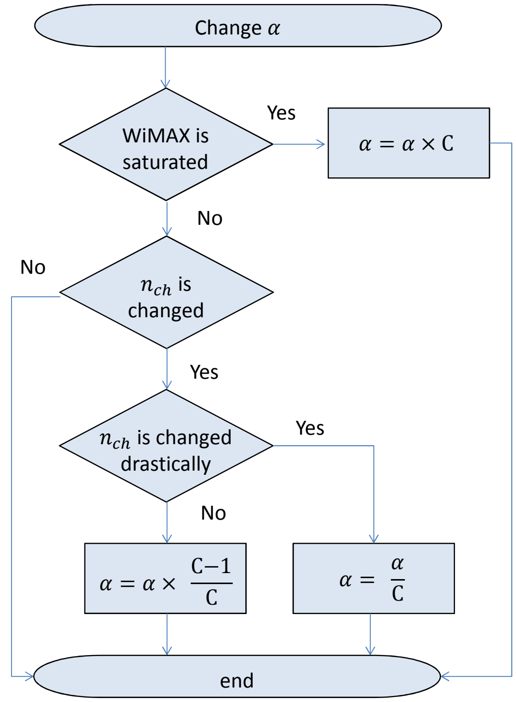

Figure 4: Flowchart of management α

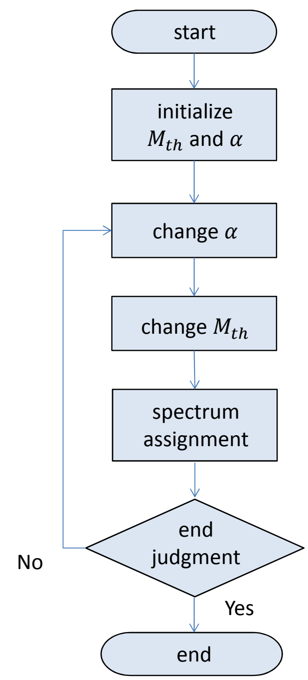

Figure 5: Flowchart of management M_{th}

According to the collected data of M_{th} and average users' throughput T_{all}, α is added or subtracted to M_{th}, where α is a variable. User throughput is given as

$$T_{usr} = \frac{T_{ch} \times C}{U}, \tag{4}$$

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where T_{ch} is the maximum system throughput per one channel, C is the number of available channels for the connected system and U is the number of users connected to the system. M_{th} is varied by α to improve T_{all}. Also, α represents the sensitivity of M_{th}. We define N_{ch} as the number of assigned channels. Larger α leads to a drastic change of N_{ch}, so that M_{th} can be an adequate value quickly. In other words, however, M_{th} may be unstable. In the contrary, smaller α leads to a fine changes and more stable M_{th}, but results in slower adaptation time to reach an adequate M_{th} value. Therefore, we need to adjust α value as well. We propose an algorithm to adjust α value as shown in Fig. 4.

Specifically, when the number of users who connect to WiMAX keeps growing, α is set larger. In the case where the number of assigned channels changes greatly, such as zero to N-1, α is set smaller.

Fig. 5 shows the flowchart of the threshold management.

IV. Performance Evaluation

In this section, we evaluate the performance of the proposed method to show its effectiveness by simulation experiments.

A. Simulation Model

As a network model, which is shown in Fig. 6, we set one WiMAX BS including $10 \times 10 = 100$ cells where randomly selected 50 cells had WiFi AP. APs in adjacent cells interfere with each other.

The spectrum bandwidth of the WiMAX was set to 100[MHz] and each WiFi AP was allocated in units of 20[MHz]. Each WiFi AP could use the one channel of 20[MHz] except any channels assigned from WiMAX. In addition, WiMAX BS was assumed to provide 20[Mbps] per 10[MHz] according to the evaluation in WiMAX Forum [15], and WiFi AP supported 17.5[Mbps] per channel according to our preliminary experiments using ns-2 [16]. We assumed that an AP could use any additional channels with no delay [17].

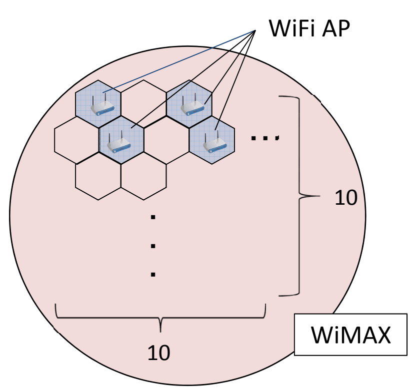

Figure 6: Network model

When a new user arrives at a cell with a WiFi AP, he/she connects to the WiFi and downloads a file. Otherwise, the user connects to the WiMAX. In addition, users were staying in the arrival cell until the end of downloading. Calls occurred following a Poisson arrival process.

We choose two methods for comparison. One is the existing spectrum assignment method [5]: described in section 2.3, this method allocates a spectrum to improve the overall mean throughput in a cooperative network. The existing method is a kind of ideal method in non-cooperative network. The other is the method that does not share any spectrum. As a performance measure, we observed the average throughput.

Moreover, to evaluate the performance of the adaptive M_{th} management, we adopt another compared method called $fixed\ method$ that uses a fixed M_{th}. The fixed M_{th} can be found by several trials and maximizes the average throughput.

The parameters we set are summarized in Table 1. Generally, because WiFi APs are set up in places where people gather (e.g., cafe and office), in order to emulate those environment, we differentiate the arrival rate in a cell with and without WiFi AP.

For M_{th} management, we set M_{th} and α to 0.1 as the initial value. Note that, we found that they are not so sensitive by preliminary experiments.

TABLE I: PARAMETERS SETUPS

interval time of spectrum assignment	300 [sec]
arrival rate in a cell with WiFi AP	λ [1/sec]
arrival rate in a cell without AP	0.1λ [1/sec]
file size	10 [MB]
traffic	best effort
initial M_{th}	0.1
initial α	0.1

B. Simulation Results

The number of assigned channels from WiMAX BS to WiFi APs with fixed M_{th} is shown in Fig. 7. For a smaller value of M_{th}, more and more spectrum channels are shared since WiFi AP can obtain the spectrum with lower cost. In contrast, for a larger M_{th}, it is difficult for APs to get channels. Therefore, M_{th} can control the number of the shared channels WiMAX and WiFi APs.

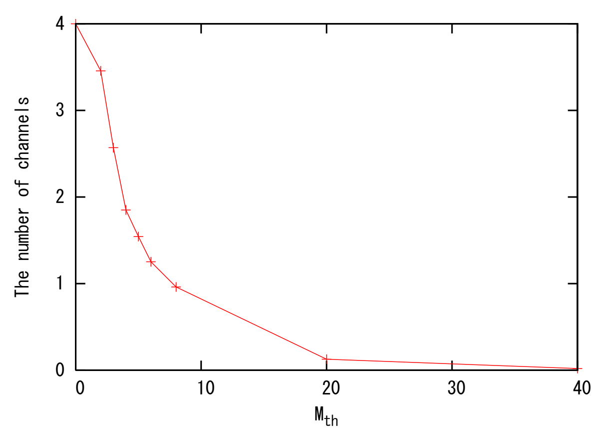

Figure 7: Mean number of assigned channel with variable M_{th}: $\lambda = 0.2$

In Fig. 8 under the condition where λ is fixed, M_{th} converges due to the adaptive M_{th} management. When λ is low, M_{th} is also low since the demand of the spectrum channels from the WiFi APs are low. As the price that the WiFi AP submits increase, M_{th} converge to a higher point to lent a channel at a high price.

Fig. 9 indicates that the existing method and the proposed method improve the average throughput against non-sharing method, since the capacity of the system increased by assigning channels from WiMAX BS to several WiFi APs. For a smaller λ, the average throughput of the proposed method is higher than that of the existing method since we introduce a learning algorithm and obtain feedback of the spectrum assignment interval time. On the other hand, for a larger λ, the average throughput of the proposal method is lower because the bigger λ, results in the higher M_{th}, due to this, the algorithm tries to converges to a smaller value resulting in a longer transient state.

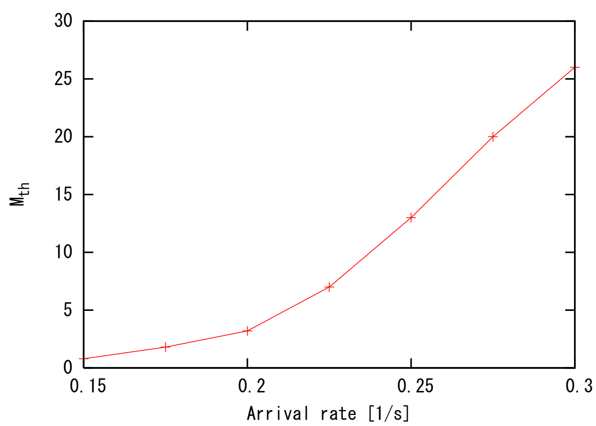

Figure 8: Converged M_{th} with variable λ

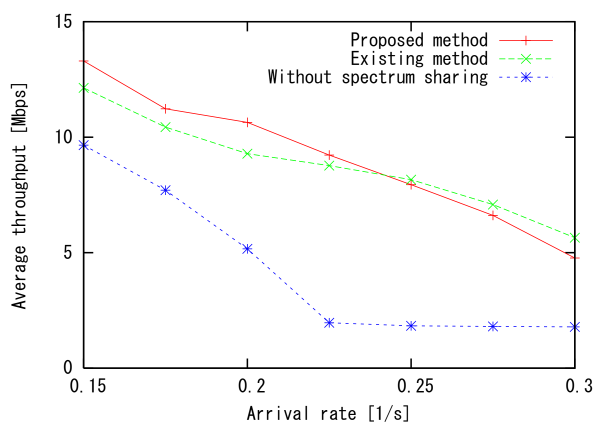

Figure 9: Average throughput with variable λ

The example of transient state of adaptive M_{th} management is shown in Fig. 10. In the transient state, which is soon after the start of spectrum sharing, users' throughput of the proposed method is lower since M_{th} is so small that many frequency bands of WiMAX BS are lent out. After the transient state passes, the overall throughput of the proposed method is as high as that of the fixed method.

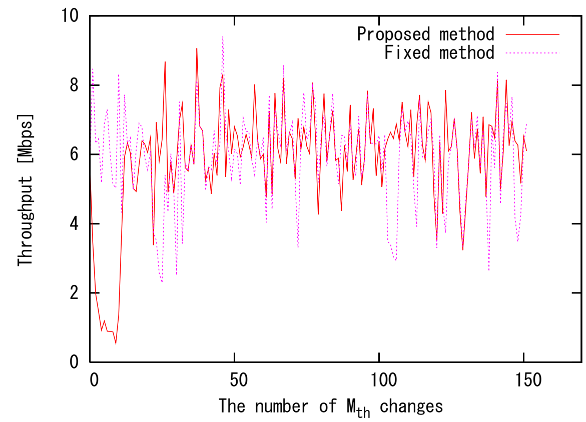

Figure 10: Overall throughput under M_{th} changes : $\lambda = 0.2$, fixed $M_{th} = 3.8$

The result shows that M_{th} can adapt to the environment where λ is fixed. Consequently, it is confirmed that the proposed method can assign spectrum well even if the WiMAX provider and WiFi providers are non-cooperative.

Moreover, according to [18], the mobile communication traffic in a day varies. It states that the traffic reach its peak at 23.00 and then decreases over the early morning. In addition, there is a three times difference in the maximum and the minimum traffic. To conform with this fact, we model the variation of λ as shown in Fig. 11 and observe the average of users' throughput over 30 days.

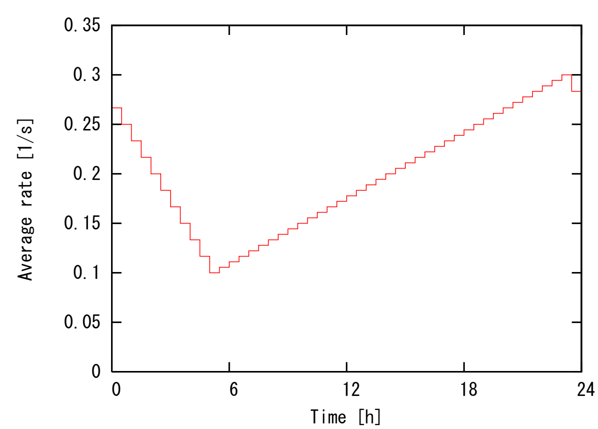

Figure 11: Time-varying λ

Figs. 12 and 13 show the change of M_{th} and the average throughput under time-varying λ. In the morning with a low traffic, M_{th} is low to share spectrum easily. In contrast, the heavier the mobile traffic, the higher M_{th} to refrain from loaning channels out cheaply.

Fig. 13 indicates that although proposed method includes a delay in comparison with the existing method, the users' throughput of the proposed method is much higher than that of the non-sharing method. Therefore, the results confirm that the proposal method can improve throughput in a practical situation.

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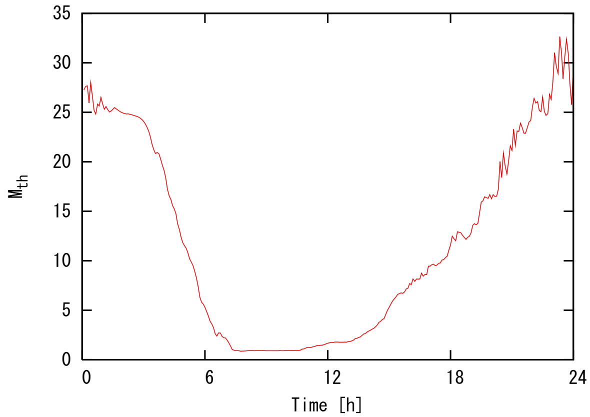

Figure 12: M_{th} with time-varying λ

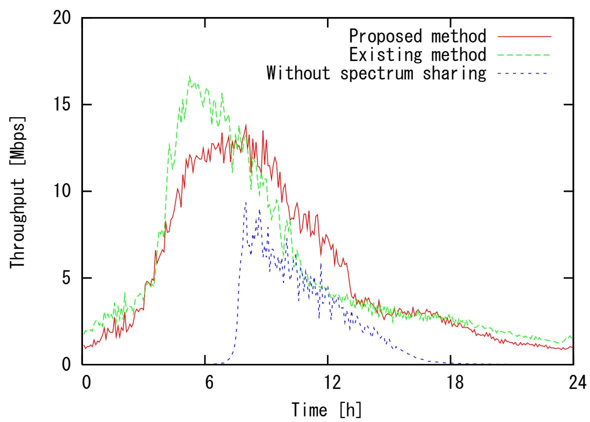

Figure 13: Overall throughput with time-varying λ

V. Conclusions

In this paper, we described the advances in wireless communication technologies and the lack of frequency resources. Next, we introduced integrated wireless network and spectrum sharing technology in heterogeneous integrated network. Different spectrum sharing methods and their problems were outlined. We proposed a spectrum sharing method using a minimum channel price threshold, which enabled WiMAX to control the spectrum sharing between non-cooperative WiMAX/WiFi providers. In addition, adaptive parameter management was proposed. Finally, we showed that the proposed method could assign spectrum efficiently and improve the user throughput by simulation experiments.

As a future work, we consider to improve the adaptation speed of the threshold and enhance the proposed method that supports multiple WiMAX BSs consideration.

Acknowledgements

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