A selection method of optimal channel in wireless network by the dynamic control of the Duty Cycle threshold

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Abstract - Recently, mobile terminals equipped with wireless LAN spread widely. Accordingly, access points such as public Wi-Fi spot or Pocket Wi-Fi come to be used widely. Most wireless LAN is communicated using 2.4GHz bandwidth, but it becomes the problem that the performance of the network decreases because plural terminals use the same channel. This paper intends that access point selects the channel which is most suitable for communication autonomously under the environment where there are a large number of wireless LAN terminals locally. Our proposed method predicts the congestion of the radio wave by analyzing Duty Cycle per each channel and detects the optimal channel. In addition, this method evaluates the quality of communication using expectation of SNR and demanded throughput from SNR. And our method reduces the cost of the channel selection by detecting optimal channel depending on the needs.

Keywords: Wireless LAN, IEEE802.11, FDMA, ISM Band, Duty Cycle, SNR, Cognitive Radio

1 INTRODUCTION

In recent years, many kinds of terminals such as personal computers, laptops, smart phones, tablet terminals, game consoles, and household appliances increasingly become equipped with 802.11 wireless LAN. Therefore Wi-Fi environment to use wireless LAN has been introduced into offices, home, and public accommodations. Furthermore, as measures to 3G line pressure by the spread of mobile phones such as smart phones, mobile phone carriers push the expansion of the public Wi-Fi spot. From these backgrounds, the demand of 2.4GHz bandwidth of radio wave spreads year by year. However, performance degradation by the radio wave interference becomes the problem when multiple wireless LAN apparatuses exist within certain areas.

Wireless LAN is equipped with the CSMA/CA which is a mechanism to avoid the radio wave interference. The more wireless LAN apparatuses exist in certain areas, the more frequently collision avoidance by CSMA/CA is carried out. Therefore, the transmission opportunity decreases, and problems such as the defectiveness of a throughput drop and the connection are caused. The detection of free channel is necessary to reduce this radio wave interference. And there are some existing wireless LAN access points with the free channel detection function. It may be said that the wireless LAN is the autonomous distributed wireless network. But in the autonomous distributed network, the case which all channels are using is assumed. In this case, if we can detect which channel is suitable for communication, we can stabilize and improve throughput of communication.

In this paper, we propose the method to predict the congestion degree and detect the optimal channel, by analyzing Duty Cycle which is the ratio of electric field strength beyond the threshold at the observation time for every channel. The proposed method controls the threshold to distinguish a radio signal from a noise autonomously depending on radio wave environment. However, at the time of the use by access points, the radio wave which the access points transmits and receives for sensing has an influence on the radio wave environment and may not obtain the most suitable result by the method using only Duty Cycle. Therefore, we evaluate the communication quality of access points using S/N ratio and the expectation of throughput calculated from S/N ratio, and detect the optimal channel using Duty Cycle if necessary.

2 RELATED WORK

2.1 Automatic Channel Selection of Wireless LAN Access Point

The item about the channel selection is not standardized in standards of IEEE802.11[1]. Therefore, it is entrusted implementation of each vendor under the present circumstances. In late years, almost all products have channel automatic setting function, and the products characterized by detecting free channel automatically also exist. However, the most of these functions are simple. Some method use a technique to detect the free channel around from channel information put on a beacon of the wireless LAN. This technique provides information such as Fig.1. From this information, an access point selects an unused free channel and uses the channel. However, this method may not select the optimal channel because there may not be free channel substantially, if the usage frequency bandwidth of wireless LAN is considered. Thus the free channel detection by beacon can perform relatively easily without the high-load complicated processing on access points. On the other hand, it becomes the problem that this technique cannot show maximum effect in the case that there are not enough free channels that channel interference does not occur.

2.2 Investigation into Utilization Status of Radio by the Site Survey

When the large-scale wireless LAN environment is built in the offices, the vender investigates the utilization status of

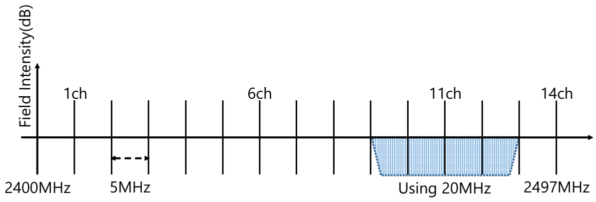

Figure 1: Channel division of the 2.4GHz bandwidth

neighboring radio beforehand to decide channel setting and the setting place of the access point may be used. This method called "site survey". There are some softwares such as Ref.[2] for the purpose of the site survey. By this software, we can analyze the signal intensity of the radio and can check the utilization status of radio for each area with a heat map form in detail. When we analyze the utilization status of channel using radio signal intensity by site survey, we can consider the radio signal of various standards except the wireless LAN in 2.4 GHz. In this way, we can find the optimal channel when all channels are used. However, the decision of the optimal channel depends on knowledge and the ability of the observer because it is entrusted to a human being performing site survey. In addition, it also becomes the problem that it is necessary to find the optimal channel for each time because the radio wave condition, the observation time, and the observation cost always changes after having decided the optimal channel once.

2.3 Effective Utilization of the White Space using DSA

There are some researches to utilize effectively of the radio resource by communicating with the channel which other radio systems do not use in 2.4GHz bandwidth temporarily and locally. These channels are called White Space. The technique to detect existing White Space discretely on a frequency axis, and to select and use the channel on White Space is called Dynamic Spectrum Access (following DSA). Reference[3] proposed the connection method, channel selection method, and data transmission method of the communication system using DSA. This research uses spectrum sensing for carrier sensing method to know the frequency utilization status. It is necessary to expand the carrier sense on not only the time axis, but also the frequency axis, because it is necessary to detect white space occurring discretely on a frequency axis in the DSA system instantly. Based on White Space provided in this way, the use efficiency of the radio resource rises with radio system changing frequency instantly, and using it. It is difficult to apply such DSA system to the wireless LAN of the IEEE802.11 standard that cannot instantly switch frequency in the specifications of the communication standard. Therefore the use with the software radio apparatus by the original communication standard is expected.

2.4 Learning Type Measuring of the Occupancy Rate

Reference[4] proposed the technique to select the optimal channel for radio transceivers establishing communication newly in multichannel autonomous distributed wireless network communication environment by paying its attention to the occupancy rate of the channel. This technique is effective when the occupancy rate of each channel is stable in time axis. However, the precision of this technique may decrease in the situation that the radio wave condition is easy to fluctuate and the situation that the occupancy rates of channels are distributed over uniformly. In addition, when we consider the application of this technique to existing communication standard including wireless LAN, access points and terminals also need expansion.

3 PROPOSED METHOD

In this paper, we propose the method to calculate the occupancy rate of each channel by calculating Duty Cycle and detect the optimal channel. Furthermore, I enable correspondence to the changeable radio wave environment by automatically controlling the threshold of Duty Cycle. And, we examine a method to apply the proposed method to the wireless LAN access point.

3.1 Duty Cycle

Duty Cycle expresses the ratio of electric field intensity beyond the threshold in the observation time by counting the appearance times of the spectrum beyond the threshold of the reception radio signal intensity set beforehand. It is thought to be able to predict the occupancy rate of each channel by calculating Duty Cycle of each channel. Duty Cycle(D) can be calculated as following formula from the number of the samples of a spectrum obtained in observation time(s) and the electric field intensity every chronological order($R[s]$).

$$D = \frac{\sum_0^s R[s]}{s} \tag{1}$$

The proposed method detects the channel with the smallest D as the optimal channel. This method finds the optimal channel using the value that added up values of Duty Cycle of a leading channel and before and after channels in consideration of frequency bandwidth 20MHz, because the method is assumed an application to wireless LAN.

3.2 The Optimal Value of the Duty Cycle Threshold

3.2.1 The Threshold and the Detective Sensitivity

So as to make the threshold of Duty Cycle a large value, this method can detect the weaker electric field intensity. But, it is necessary to consider that it becomes easy to pick up a noise. On the contrary, the removal of the noise is enabled so as to make the threshold a small value, but the weak signal which is not a noise may be overlooked. In other words, the detective sensitivity of the signal and Duty Cycle threshold are in a trade-off relationship, and it is necessary to discover the optimal threshold. In addition, the optimal value of the Duty Cycle threshold varies according to the environment and the situation, because the signal strength changes by various factors such as the transmission output and the distance of the radio apparatus, and the obstacle.

3.2.2 The Optimal Threshold Selection Algorithm

The proposed method supports the changes of radio wave condition by controlling the optimal threshold of Duty Cycle dynamically depending on environment. Figure 2 shows the calculation algorithm of the optimal Duty Cycle threshold. This algorithm is carried out in the state that fixed quantities of measurement data are gathered. The standard deviation of

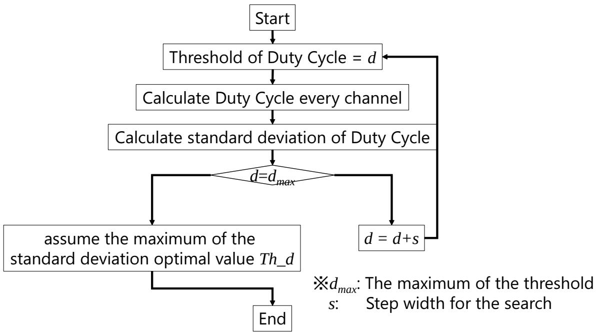

Figure 2: Optimal value search algorithm of the Duty Cycle threshold

Duty Cycle becomes higher so that variation of Duty Cycle is large in the threshold with every channel. Therefore the relative characteristic of each channel appears. We assume that it is in a condition to be able to separate a signal and the noise of the radio system when characteristics appear well. The proposed method adopts a Duty Cycle threshold with maximum standard deviation for the most suitable threshold.

Figure 3 shows the relations of threshold and standard deviation of Duty Cycle on each channel when we measured in the 2.4GHz bandwidth that there are really plural radio systems. Duty Cycle is uniformly low in all channels in the range of the low threshold, and Duty Cycle of all channels becomes the maximum as far as the threshold is high. This shows the trade-off relations of the threshold and the detective sensitivity. We can expect that the relations show similar tendencies in the different radio wave environment. Therefore, by setting the threshold based on standard deviation the measurement accuracy of the congestion degree by Duty Cycle of each channel rises and can detect the optimal channel even in a fluctuating radio wave environment.

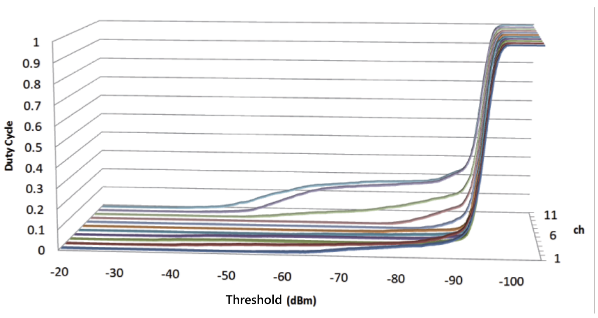

Figure 3: Duty Cycle of each channel in every threshold

3.2.3 The Optimal Channel Detection Method

Figure 4 shows the flow of the optimal channel detection method using the optimal threshold selection algorithm. At first this method performs sensing of the constant time and collects radio signal data. The method carries out the optimal value search algorithm of the Duty Cycle threshold. After obtaining the optimal value of the Duty Cycle threshold, the method calculates Duty Cycle of each channel. Afterward, in consideration of 20MHz that is a usable bandwidth of the wireless LAN, the method calculates the sum of Duty Cycle of a central channel and 2 neighbor channels, and assumes this value as the total value of Duty Cycles.

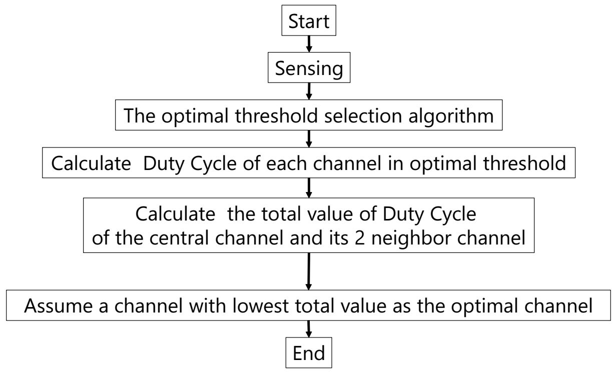

Figure 4: Optimal channel detection method

3.3 Application to the Wireless LAN Access Points

3.3.1 Problems at the Time of the Application

There are some problems at the time of the proposed method application to the wireless LAN access point. At first, in the proposed method with the detection of the optimal channel by Duty Cycle, the own signal of the station is not considered. However, the own radio wave which the station transmits and receives is included in the signal data in the sensing when the method really detect the optimal channel and start communication. In addition, in order to calculate Duty Cycle, we need to observe signal data for some time and collect them. If observation time and frequency increase, the calculation cost also increases. Therefore, it is thought that the number of detections of optimal channel by Duty Cycle has to be suppressed to the minimum. From the above reasons, the following 2 points are the problems when we apply the proposed method to wireless LAN access points.

- The optimal channel detection in consideration of own signal of the base station
- Cost cutting of the optimal channel detection by Duty Cycle

3.3.2 SNR and Data Rate

SNR (Signal-to-Noise Ratio) expresses the ratio of the signal and the noise, and SNR is one index indicating the quality of wireless communication. If SNR is high, the influence of the noise is small. If SNR is low, the influence of the noise is large. When P_s represents signal power and P_n represents noise power, SNR is defined by following expressions.

$$\frac{S}{N} = \frac{P_s}{P_n} \tag{2}$$

If $P_s = -65(dBm)$, $P_n = -87(dBm)$ is provided, SNR can be calculated as follows.

$$\begin{aligned} \frac{S}{N} &= P_s - (P_n) \\ &= -65 - (-87) = 22 \end{aligned} \tag{3}$$

Each wireless LAN device defines necessary signal power for every data rate. Venders selling wireless LAN devices usually show the relations of receiving sensitivity and data rate. We can predict an approximate data rate under the measuring situation that can know the signal power because the data rate rises so that signal power is strong. However, only the signal power is not enough for the prediction of the data rate. This is because it may not satisfy the expected data rate if the noise power is strong even if signal power is strong enough. Therefore recommended SNR and lowest SNR which are required to satisfy the expected data rate are defined to consider the noise. Figure 5 shows each recommended SNR and each lowest SNR. The proposed method knows own quality of communication in the station by predicting data rate in reference to a value of recommended SNR in Fig. 5.

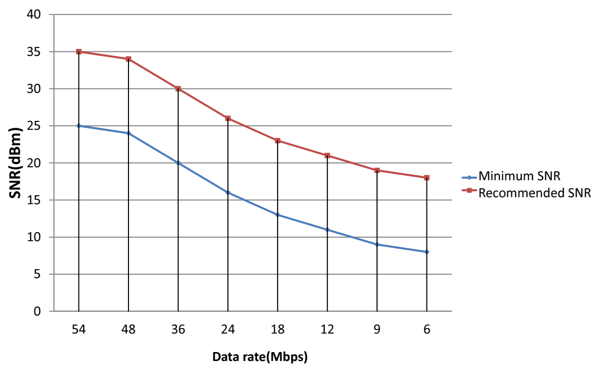

Figure 5: Relations of data rate and SNR

3.4 Channel Switching Algorithm

Figure 6 shows the flow of the channel switching algorithm to apply the proposed method to wireless LAN access points. At first, each base station measures the SNR for its own channel after constant waiting time passed. Then, the station calculates the data rate from provided SNR. Based on this provided data rate, the station judges whether effective throughput is provided in comparison with the real throughput. However, it is necessary to calculate the maximum data rate in the real environment because the data rate shown in wireless LAN is generally a theoretical value.

In the real environment, the access control by CSMA/CA acts firstly, and the waiting time of the ACK reply occurs every one data transmission. Reference [5] calculates effective

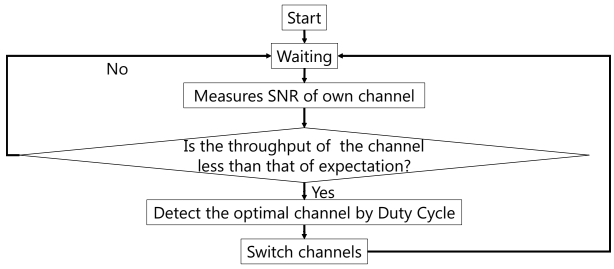

Figure 6: Channel switching algorithm

speed of IEEE 802.11g in the real environment as follows. Reference [5] assumes the fixed waiting time as $35\mu s$, random waiting time as $67.5\mu s$ at the time of the packet transmission. The fixed waiting time of the ACK reply is also assumed as $16\mu s$. Under this condition, if the data packets of $1460byte$ are sent two times at data rate $54Mbps$, and the ACK reply is received one time, the effective speed is calculated by the following expressions.

$$\frac{146(byte) \times 2(packet) \times 8(bit)}{0.0009645(sec)} = 24.2(Mbps) \tag{4}$$

The effective speed becomes $24.2Mbps$ for theoretical value $54Mbps$. Therefore, the realistic effective speed becomes around 45% of the theoretical value. As the terminals using the access point, and other radio devices exisiting in the channel interference zone incerease, the struggles of access privileges by CSMA/CA are frequent, and the effective speed declined further. In this paper, we calculate expectation of the throughput by the following expressions.

$$\begin{aligned} &\text{Expected throughput}(Mbps) \\ = &\frac{\text{Data rate corresponding to SNR}(Mbps) \times 45\%}{\text{\# of the own terminals of the base station}} \end{aligned} \tag{5}$$

The access point compares the measured throughput with the expected throughput. If the measured throughput is more than of expected throughput, it enters the waiting state and measures SNR again. Afterwards it compares the measured throughput with the expected throughput. If the measured throughput is less than the expected throughput, it detects the optimal channel by Duty Cycle, switches channels and enters the waiting state. After that loops do this cycle until finishing the use of the access point. In this way, the proposed method reduces the processing cost of channel detection by repressing the number of optimal channel detection to a minimum by Duty Cycle while considering own signals of stations.

4 PERFORMANCE EVALUATION

4.1 Optimal Channel Detection by the Automatic Control of Duty Cycle threshold

We evaluated following 3 items of evaluation, a throughput evaluation with the optimal channel and other channels, an effective evaluation of automatic threshold control using the standard deviations, and a necessary sensing time evaluation before detecting the correct optimal channel. In addition, the target channels are assumed from channel 1 to channel 11. This is because the channel which wireless LAN can set as central channel is usually assumed. By the calculation processes of the proposed method, the frequency corresponds to channel -1, channel 0, channel 12 channel 13 are included internally. And we used PCATTCP[6] made in Printing Communications Associates for the measurement of the throughput. The parameters of experiments are shown in Table 1.

Table 1: Parameters of experiments

Observation time	$60sec$
Target frequency bandwidth	$2.4GHz$ bandwidth
Target channels	1 - 11
Communication standard	IEEE 802.11b/g
Communication capacity	$16Mbyte$
Number of trials to measure throughput	3
The channels which other devices are using	1,4,6,11

From the results of experiments, the optimal value of the threshold is $-93.5dBm$ and Duty Cycle of each channel is shown in Fig. 7, the throughput of each channel is shown in Fig. 8. The optimal channel of the proposed method is 5

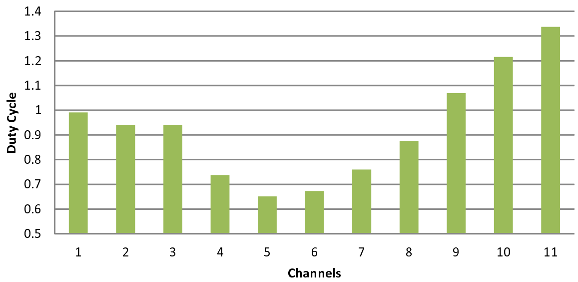

Figure 7: Duty Cycle of each channel at optimal threshold

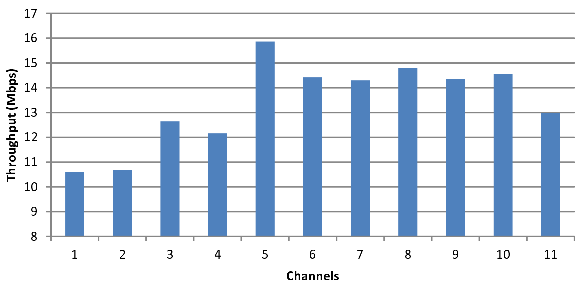

Figure 8: Throughput of each channel

from Fig. 7, and the highest throughput is accomplished in channel 5 from Fig. 8. The best channel of measured throughput accorded with the optimal channel detected by the proposed method and we can show the effectiveness of the optimal channel detection by the proposed method.

Figure 9 shows the variation of the optimal channel every threshold using experimental data. The point where multiple optimal channels are plotted with the same threshold shows that the sum of Duty Cycle is the same, and the judgment of the optimal channel becomes impossible.

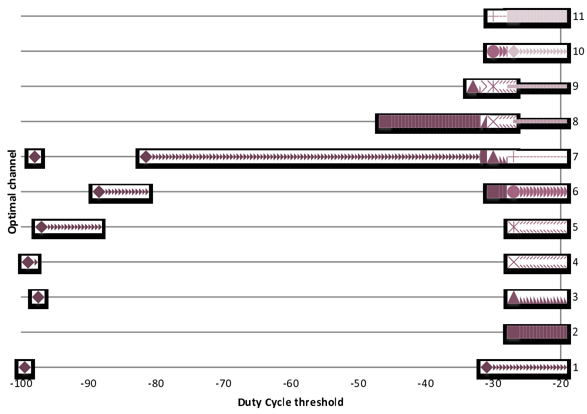

Figure 9: Variation of optimal channel at each threshold

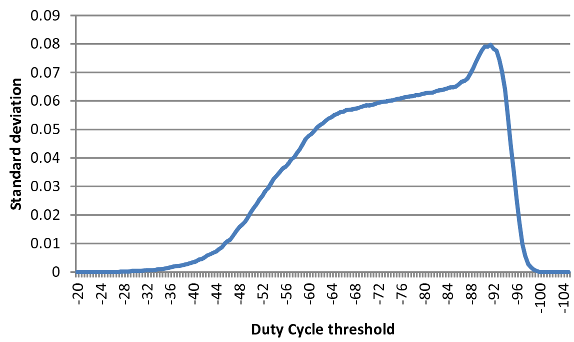

Figure 10: Variation of the standard deviation at each threshold

The signals were not detected in the threshold range lower than $-40dBm$. The proposed method can detect the optimal channel with 5, when the range of the threshold is from $-89dBm$ to $-97dBm$. Therefore, the range of threshold that the optical channel can be detected exists within the uniformity in succession, though there is the change to some extent by the environment.

From Fig. 10, the range where the proposed method can detect the optimal channel is equivalent to the part that standard deviation forms a peak. In other words, corresponding relationship is found between the standard deviation of Duty Cycle and the range of the threshold where the proposed method can detect the optimal channel.

4.2 Application to the Wireless LAN Access Points

Then, we evaluated the proposed method about the application to the wireless LAN access points by the simulations. We compared the average throughput in the simulation time, in a case to apply the proposed method to wireless LAN access point and in a case to detect the optimal channel by Duty Cycle only in the first time before the communication.

Firstly, we evaluated the case that one terminal connects to the access point with 60 minutes simulation under the parameter of Table 2. In this experiment, we used a traffic model to move channel to 2, 4, 6, 8, and 10 every ten minutes. In addition, we used a radio wave environment model based on data of the real environment observed by the experiment of the Sec. 4.1.

Table 2: Simulation parameters

Simulation time	$60min$
Waiting time	$1sec$
Simulation waiting time	$100msec$
Own Duty Cyce	80%
Own signal power	$-40dBm$
# of own terminals	1
Traffic generation channel	$2 \to 4 \to 6 \to 8 \to 10$
Traffic generation interval	$10min$
Duty Cycle of traffic	30%
Signal power of traffic	$-50dBm$

From the result of an experiment, Fig. 11 shows the variations of the channel by the channel switching algorithm. Figure 12 shows the moment throughput at the time of applying the channel switching algorithm in each time, and Fig. 13 shows the moment throughput at the time of the algorithmic non-application. In addition, Fig. 14 shows the average throughput in the case of applying the channel switching algorithm and in the case of not applying the algorithm.

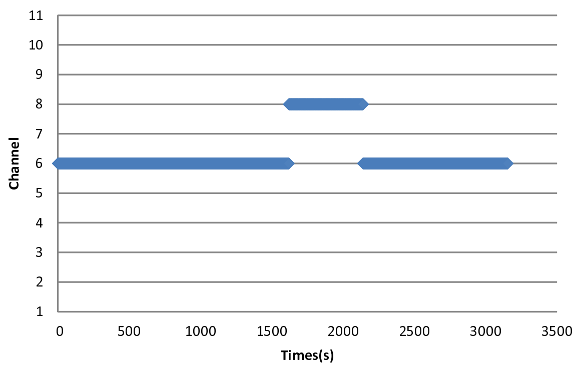

Figure 11: Variation of the channel

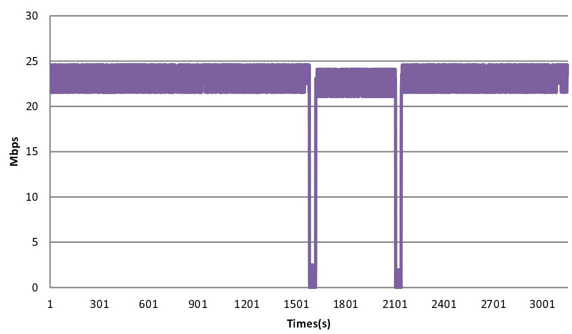

Figure 12: Moment throughput with channel switching

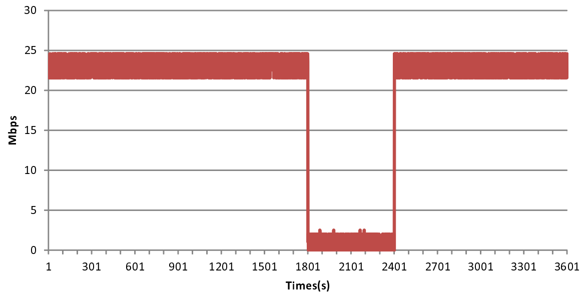

Figure 13: Moment throughput without channel switching

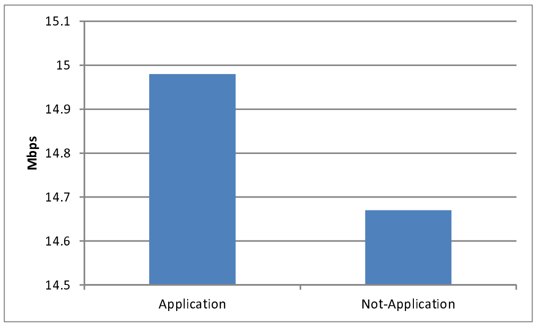

Figure 14: Average throughput

Channel 6 is selected by the first optimal channel detection in both cases, and the change of the channel occurred around $1800sec$ when additional traffic generated on channel 6. At this time, the moment throughput decreases by time lag required for channel switching and by the interference of the traffic increase. And the throughput also decreases sharply at the time when traffic increased on channel 6 in the case of not applying the channel switching algorithm. The average throughput of applying the channel switching algorithm is $0.32Mbps$ more than the throughput of not applying the algorithm.

5 CONCLUSIONS

In this paper, we intended to detect the optimal channel when a wireless LAN system communicated in the radio environment such as 2.4GHz bandwidth. We proposed the detecting method of the optimal channel by measuring the congestion degree of every channel by our performing spectrum sensing and calculating of Duty Cycle. We compared the optimal channel detected by the proposed method with the actual value of the throughput, and showed the effectiveness of the proposed method by the experiments in the real environment. From the relations of the carrier sense time and the detected optimal channel, it is found that the optimal channel might be stable to constant value, when it exceeds the fixed periods of time.

In addition, we applied the proposed method to wireless LAN access point and examined the method to detect and switch the optimal channel when a own channel of the station caught the interference while communicating. We compared the throughput at the time of the non-application of the channel switching algorithm with throughput at the time of the application of the algorithm by simulation under multiple conditions. In each case, the throughput at the time of the application of the algorithm that shows higher values and we can confirm the effectiveness of the proposed method.

For future work, we have to inspect the action in the environment with multiple wireless LAN access points applying proposed method, or in the inferior environment that traffic occurs with multiple channels complicatedly. And it will be necessary to work effectively in such an environment.

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