Channel Assignment and Reallocation Algorithms for Cognitive Radio Systems

Ken Hiraga   Kazunori Akabane   Hiroyuki Shiba   Kazuhiro Uehara

NTT Network Innovation Laboratories

Nippon Telegraph and Telephone Corporation

Yokosuka, Japan

Abstract-**Wireless communication services have been increasing rapidly and this progress has caused a shortage in frequency resources. Cognitive radio technology is expected to enable frequency resources to be used more efficiently. When several wireless communication systems simultaneously use cognitive radio technology, the priority level of each system for frequency use is set and the frequency resource is shared between the systems according to the priority level. In cognitive radio systems, algorithms for channel assignment to access points (AP) have to manage priority levels in frequency use. The conventional dynamic channel assignment (DCA) technology cannot be used in cognitive radio systems without modification since the technology does not have the scheme to manage priority level in the frequency use. We have proposed methods of channel assignment and channel reallocation that are suitable for cognitive radio systems and evaluated our proposed methods using a computer simulation. In addition, we have proposed a new frequency utilization efficiency criterion for cognitive radio systems.**

I.   INTRODUCTION

Wireless communication services, for example, cellular phones and wireless LANs, have been improving and increasing rapidly. This progress has caused a shortage in frequency resources [1]. Actual usage of a given frequency depends on the time and location [2]. Cognitive radio technology is expected to enable frequency resources to be used more efficiently [3].

Cognitive radio is a technology in which wireless equipment recognizes the spectrum environment and uses frequencies effectively by properly selecting the frequency band and the communication method. When several wireless communication systems simultaneously use cognitive radio technology in a given area, the priority level of each system for frequency utilization is set and the frequency resource is shared between these systems according to the priority level.

In cognitive radio systems, algorithms for channel assignment to access points (AP) have to manage priority levels in frequency use. The conventional dynamic channel assignment (DCA) technology used by cellular phones does not have a scheme to manage priority level in the frequency utilization, and cannot be used without modifying the systems that use cognitive radio technology. We propose methods of channel assignment and channel reallocation that are suitable for wireless communication systems that use cognitive radio technology. We have evaluated these methods by computer simulation. In addition, we propose a new frequency utilization efficiency criterion for cognitive radio.

This paper contains the following sections. Section II describes the behavior of a wireless communication system that uses cognitive radio technology. Section III details our proposed methods of channel assignment and channel reallocation that are suitable for cognitive radio systems. Section IV shows the new frequency utilization efficiency criterion and the performance evaluation results. Section V concludes this paper.

II.   COGNITIVE RADIO SYSTEM

In general, cognitive radio systems are classified roughly into two categories [4], and our target is type (ii):

(i) Multimode systems - flexibly use wireless communication systems according to the user's purpose.

(ii) Dynamic frequency sharing systems - dynamically use frequency resources not used at certain times and places.

Frequency usage in a wireless communication system that uses cognitive radio technology is classified as follows.

Primary usage / Primary user (PU) - has high priority level for frequency use and its wireless equipment uses the allocated frequency bands.

Secondary usage / Secondary user (SU) - has low priority level for frequency use and its wireless equipment uses frequency bands not used by primary users. This usage is due to the use of cognitive radio technology.

Fig. 1 shows an example of an operation when two operators that use cognitive radio technology have APs in adjacent areas. Operator "A" uses Ch1 as a *primary user channel* (*PU channel*; a channel on which the operator is allowed primary usage), and uses Ch2 and Ch3 as a *secondary user channel* (*SU channel*; a channel on which the operator is allowed secondary usage). Operator "B" uses Ch2 as a PU channel. AP2 of operator "A" starts up on Ch2 as a secondary user recognizing that Ch2 is not being used by any other APs. When AP3 of operator "B" starts on Ch2 as a primary user, AP2 recognizes the beginning of AP3's primary usage and changes its operating channel to Ch3 as a secondary user.
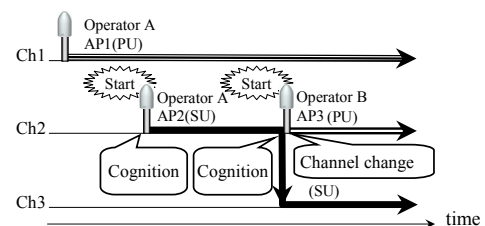

Figure. 1. Example of cognitive radio system operation

A cognitive radio system is able to use frequency resources effectively by secondary usage of frequencies that are not in use. Secondary users, like AP2 shown in Fig.1, change their channel when they recognize the startups of primary users; therefore, secondary users cannot avoid instantaneous interruption of their service for channel change.

In addition, secondary users cannot continue their services when there is no available channel for changing. This means that a channel usage control scheme suitable for cognitive radio systems is necessary.

III. PROPOSED CHANNEL CONTROL SCHEME

A. Channel Assignment Algorithm

In this section, we propose a channel assignment algorithm that enables an AP to stably use channels for cognitive radio systems when an AP starts up. Our proposed algorithm is shown in Fig. 2. First of all, the amounts of interference in all channels are estimated and it is determined whether any of the PU channels can be assigned to the AP that starts up. If there is a PU channel that can be assigned to the AP, the channel with the least amount of interference is assigned. If a PU channel cannot be assigned, an SU channel will be assigned. The SU channels are divided into "*operator-free*" channels, in which the operator who has the right to use it as a primary user has not been decided and "*others*" channels, which can be used by another operator as a primary user. If an AP uses an others channel, the AP has to change the channel when another AP that uses the same channel as a primary user starts up. In this case, an operator-free channel should be given to the AP as a priority over an others channel. As a result, the the number of times that channels change during communication in secondary usage can be decreased, and stable secondary usage can be achieved.
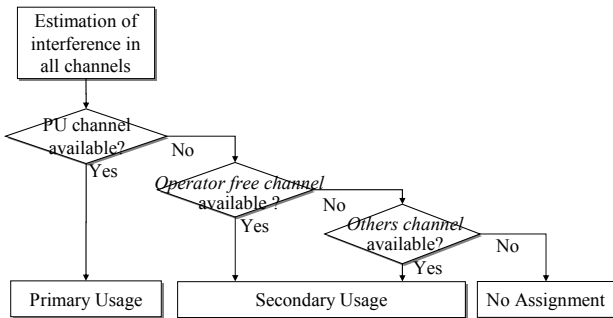

Figure 2. Channel assignment algorithm

B. Channel Reallocation Algorithm

In cognitive radio systems, an appropriate channel allocation for APs can be maintained by reallocating the channel of existing APs that interfere with the new startup AP. An example of a channel reallocation is shown in Fig. 3. Operator "B" can use Ch1 and Ch2 as an SU channel. AP1 and AP2 of the operator "B" use Ch1 and Ch2 respectively. Operator "A" uses Ch1 as a PU channel and starts operation of AP3 in the vicinity. AP1 and AP2 reallocate channels and change their channels to Ch2 and Ch1, respectively, so that AP3 may use Ch1. AP1 and

AP2 are able to continue service by reallocating the channels.

The channel reallocation in a cognitive radio system cannot use conventional DCA technologies because there is frequency usage division of PU and SU. We propose a suitable channel reallocation algorithm for use in a cognitive radio system. Fig. 4 shows our proposed channel reallocation algorithm. First, the APs whose channels have to be reallocated are extracted. Only a secondary user should be extracted because the primary user does not have to be reallocated. Then, the interference to all possible channels of each AP is estimated and the most appropriate channel for each AP is selected. Finally, the channels are reallocated. Here, the appropriate channel selection is based on the following conditions:

(1) *The number of APs that cannot find alternate channels and suspend use of channel is fewer.*

(2) *The number of APs that change channels is fewer.*

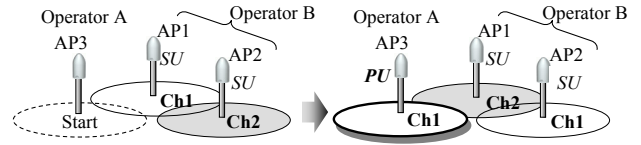(3) *Amount of interference with APs on start up is smaller.*
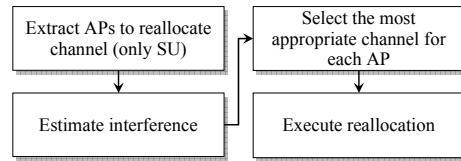

Figure 3. Channel reallocation

Figure 4. Channel reallocation algorithm

IV. PERFORMANCE EVALUATION

A. Definition of Frequency Use Efficiency

Conventionally, the frequency use efficiency of a general wireless system is evaluated by "bit/s/Hz". In a cognitive radio system where two or more wireless systems may share the same frequency band, this evaluation is not valid. Therefore, we defined *cognitive frequency use efficiency* as η_{CR}. The elements of a frequency resource are frequency usage time duration, frequency usage area, and bandwidth. η_{CR} is defined in (1). By using channel usage time duration of each AP, bandwidth, and coverage area, η_{CR} are shown in (2).

$$\eta_{CR} = \textit{frequency use efficiency of the wireless communication system (bit/s/Hz)} \times \textit{utilization factor (time, area, and frequency band)} \tag{1}$$

$$= \sum_{i=1}^{M} \eta_i \cdot \int_{0}^{T} \frac{1}{T} \left\{ \frac{f(t)_i}{F} \times \frac{s(t)_i}{S} \right\} dt \tag{2}$$

Here, M is the number of APs, T is the operating time duration of the entire system, η_i is the frequency use efficiency of AP_i, $f(t)$ is the bandwidth of the channel that

APi uses, F is the frequency bandwidth of the entire system, s(t)$_i$ is the coverage area of AP$_i$, and S is the overall area for evaluation.

An example of calculating η_{CR} is shown below. The frequency usage model is shown in Fig. 5, and the usage conditions are shown in Table 1. The two APs will use Ch1 and Ch2 respectively during time = 0–1 seconds in the evaluation area. Afterwards, an AP that uses Ch1 is established, and a total of three APs operate during time =1–2 seconds. The value of η_{CR} at this time becomes 0.125η, as shown in expressions (3) and (4).

$$\eta_{CR} = \eta \cdot \int_0^2 \sum_{i=1}^3 \frac{1}{2} \left\{ \frac{f(t)_i}{2} \cdot \frac{s(t)_i}{10} \right\} dt \quad (3)$$
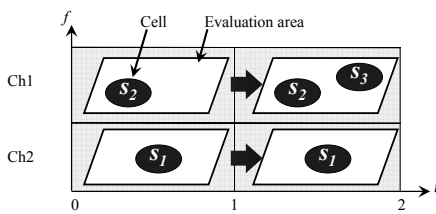
$$= 0.125\eta \quad (4)$$

Figure 5. Frequency usage model

TABLE I
USAGE CONDITIONS

Evaluation area size	$S = 10 \ [\text{m}^2]$
Coverage area (cell) size of AP$_i$	$s_i(t) = 1, 0^* \ [\text{m}^2]$
Total bandwidth	$F = 2 \ [\text{MHz}]$
Bandwidth of Ch i	$f_i(t) = 1 \ [\text{MHz}]$
Freq. usage efficiency (for any AP)	$\eta \ [\text{bit/s/Hz}]$

* zero when the AP does not operate

B. Simulation Results

We assume that cognitive radio technology will be used with fixed wireless access (FWA) systems [6] and have evaluated the performance of our proposed methods in an FWA system. The FWA system provides wireless IP access service to subscribers, as shown in Fig. 6.
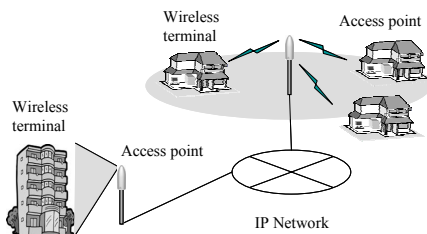

Figure 6. FWA system

The evaluation was performed using computer simulation. The simulation conditions and simulation model are shown in Table 2 and Fig. 7, respectively. The medium-rise buildings are obstacles and are arranged randomly in the 6-km^2 area in order to represent a city in which an FWA system is used.

When an AP is established at an arbitrary position in the evaluation area, η_{CR} is calculated based on the number of APs assigned to a particular channel including secondary users. The amount of interference at each AP that is necessary for a decision on channel allocation is calculated from the amount of distance attenuation between APs and the presence of any obstacles. It is assumed that there is no interference when there is an obstacle between these APs. Each operator can use the channels as a secondary user if the channel is not their own PU channel. For example, the number of channels that operator "A" can use as a primary user is 8, the number of others channels is 4, and the number of free channels is 40. Moreover, the number of AP installations used by both operators is assumed to be the same.

TABLE II
SIMULATION PARAMETERS

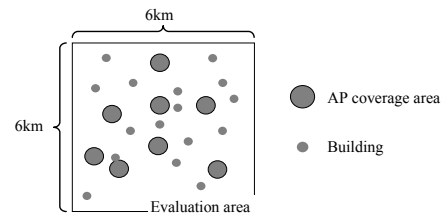| Modulation	QPSK($\eta = 0.77$ bit/s/Hz)
Diameter of coverage area	700 m
Total number of channels	52
PU channel number	Operator A: 8ch Operator B: 4ch
Adjacent channel interference	35 dB
Number of buildings	100
Shape of buildings	Cylindrical, diameter= 20 m

Figure 7. Simulation model

The simulation results are shown in Fig. 8. The number of desired AP installations in which 90% of the APs can actually be set up is 350. When the number of desired AP installations was 350, applying only the proposed channel assignment algorithm without reallocation, η_{CR} was improved 10 times over that of a conventional system. By applying the proposed channel assignment algorithm and channel reallocation algorithm, η_{CR} was improved about 11 times over that of a conventional system.

Fig. 9 shows the probability that channel change will be generated and the probability that service will be stopped because the secondary user cannot find a changeable channel when channels are reallocated. The upper bounds of the number of desired AP installations for which the channel change probability is less than 0.1% is 65 without *operator-free* channel priority assignment and 143 with the assignment. The service stop probability also decreased with *operator-free* channel priority assignment. The results show that a continuous and stable channel usage became possible by allocating an *operator-free* channel prior to *others* channels.
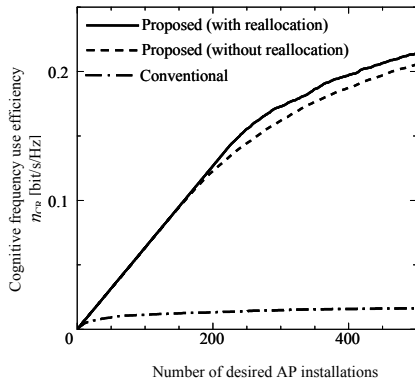
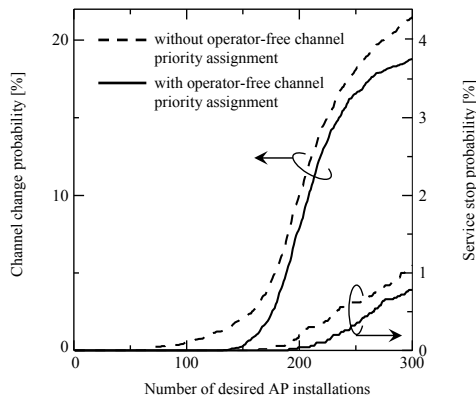Figure 8. Cognitive frequency use efficiency η_{CR}

Figure 9. Effect of operator-free channel priority assignment

V. CONCLUSIONS

We proposed methods of channel assignment and channel reallocation suitable for cognitive radio systems. In addition, we formulated criterion for frequency usage efficiency in cognitive radio systems. The characteristics of the proposed methods when applied to an FWA system that uses cognitive radio technology were evaluated by computer simulation. The results showed that η_{CR} can be improved about 11 times over that of conventional systems and that the frequency resource is efficiently used. Furthermore, it was demonstrated that continuous and stable channel usage is possible by using priorities to determine the allocation of *operator-free* channels and *others* channels. In future work, we will make further evaluations of performance using more simulation parameters and study how to apply our proposed method to other cognitive radio systems.

REFERENCES

[1] http://www.soumu.go.jp/s-news/2006/060216_1.html
[2] http://www.sharedspectrum.com/measurements/
[3] FCC ET Docket No.03-322 Notice of Proposed Rule Making and Order
[4] T. Fujii, 2006 IEICE Society Conference, BP-3-4, Sep. 2006.
[5] K.Hiraga, K.Akabane, and K.Uehara, "A study of an FWA system with cognitive radio and its frequency use evaluation,"2007 IEICE General Conference,B-17-9,Mar. 2007.
[6] K. Nidaira, M. Baba, and T. Saito, "Development of Wireless IP Access System (STEP 2) in the 26-GHz Band," NTT Technical Review, Vol. 1, No. 5, pp. 68–73, 2003.