MASTER THESIS

A Traffic-aware Self-coexistence in Multichannel IEEE 802.22 WRAN

IEEE 802.22 WRAN을 위한 멀티채널에서의 트래픽 기반의 자기공존 알고리즘

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A Traffic-aware Self-coexistence in Multichannel IEEE 802.22 WRAN

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ABSTRACT

IEEE 802.22 is the first worldwide standard for Cognitive Radio Network (CRN) that exploits white spaces of television broadcast. It is a standard for Wireless Regional Area Networks (WRANs) which enables broadband wireless access. In order to coexist between multiple overlapped WRAN cells a single channel self-coexistence mechanism is introduced in IEEE 802.22-2011 standard. Upon the increasing demand for customer promise equipments' (CPE) high throughput, supporting for multichannel operation is inevitable for upcoming 802.22b amendment. In this paper, we propose a traffic-aware self-coexistence for multichannel operation in 802.22 WRAN such that we try to reach CPEs' satisfactions as much as possible.

Keywords: IEEE 802.22, cognitive radio network, WRAN, self-coexistence

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1. INTRODUCTION

1.1 Motivation

The transition from analogue television to digital television (DTV) made some of the spectrum available in the VHF and UHF bands. Such available spectrum is called TV white spaces (TVWS), and it has the potential to revolutionize the way we access the internet. The world of wireless networks suffer from scarce of spectrum while lots of white spaces are remain unused in most location, especially in those rural areas [1]. Such observation have led to FCC regulation which allows cognitive radio (CR) operation in white spaces from 2008 [2].

CR technology enables devices sensing the environment and autonomously adapt its operating characteristics. It utilizes ample free, unlicensed TVWS to enable data transmission with wide coverage and high building penetration. The efficient use of TVWS is therefore very important for utilization of valuable part of the radio spectrum.

One of the solutions to utilization of TVWS is IEEE 802.22-2011 standard. IEEE 802.22 wireless regional area network (WRAN) is the first standard using white spaces based on a cognitive radio where TV channel between 54MHz and 862MHz is used to provide broadband wireless internet access in rural areas without licensed incumbent [3]. The incumbent users refer to the

TV broadcasting or wireless microphones. The unlicensed wireless users refer to IEEE 802.22 entities such as base stations (BSs) and customer premise equipment (CPE) as shown in Figure1.1. To coexist and protect incumbents, 802.22 devices including BSs and CPEs are required to perform spectrum sensing and evacuate immediately upon incumbent detection.

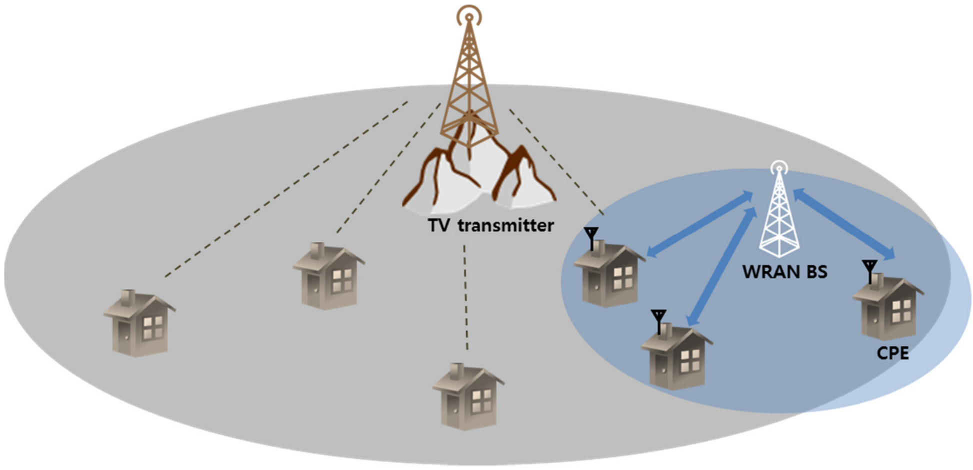

Figure 1.1 Example of IEEE 802.22 WRAN system

Though coexistence between incumbent have been predominantly studied in previous year, tasks still remain on the issue of coexistence between secondary users, in other words, self-coexistence.

A recent paper presented by IEEE802.22b task group for enhancement of broadband services and monitoring applications in TVWS stated that due to the monitoring applications, the maximum achievable throughput is not enough anymore [4]. In the IEEE 802.22-2011, single channel operation is supported as shown in Figure 1.2 with maximum date rate of 22.69 Mbps. In

Figure 1.2, each CPE (CPE 1~CPE 4) is using the operating channel (Ch1) to communicate within the service area of BS where the operating channel (Ch1) is assigned by the spectrum manager (SM) using the available channel list. In the IEEE 802.22-2011 standard, even though there may be several available channels exist in the list, due to the constraint of the single channel operation, those available channels cannot be utilized effectively since multichannel operation is not supported [5].

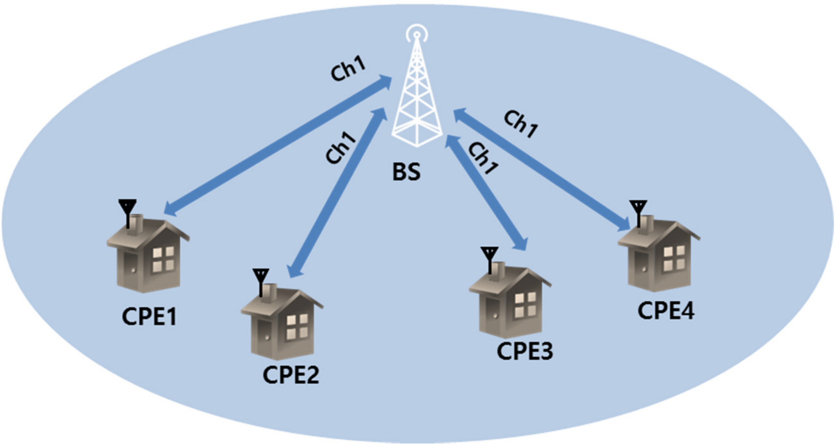

Figure 1.2 Example of 802.22-2011 single channel operation deployment configuration

The IEEE 802.22b standard supports aggregate data rates greater than the maximum data rate supported by the IEEE 802.22-2011 in order to extend its regional area broadband services to a broader range of applications such as real-time and near real-time monitoring, emergency broadband services, remote medical services, etc. which requires higher data rates.

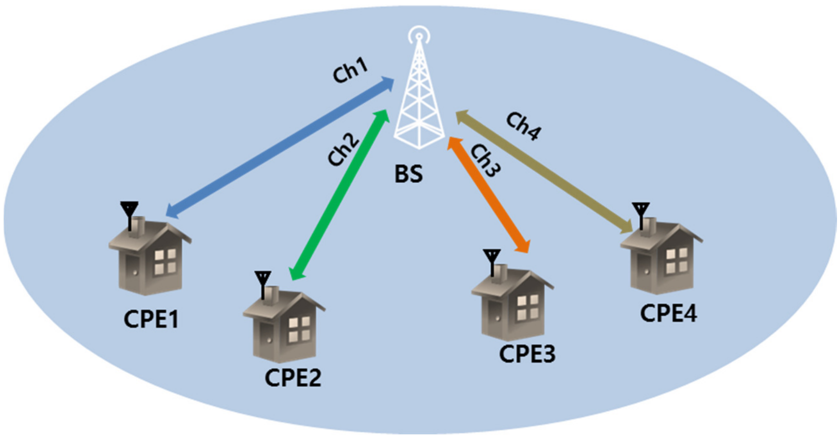

Figure 1.3 Example of multichannel operation deployment configuration

In Figure 1.3, it is assumed that there are 4 available operating channels within the service area of the BS. In this example, multichannel operation on BS is illustrated where BS is capable of receiving and transmitting two or more operating channels and responsible to assign the operating channel to the associated CPEs within its service area. By performing the multichannel operation on BS, the BS can utilize the available operating channels by distributing the operating channels among the associated CPEs. The multichannel operation on BS can improve the individual CPE's throughput by decreasing the total number of associated CPEs per operating channel.

For the improvement of CPE's data rate, multichannel operation s is a feasible solution to achieve throughput greater than the maximum throughput supported by the IEEE 802.22-2011.

Therefore, the issue here is how to deal with self-coexistence mechanism in multichannel environment.

1.2 Objectives and Contributions

The objective of this thesis is to develop a traffic aware self-coexistence algorithm in multichannel IEEE 802.22 network. We focus on the self-coexistence of IEEE 802.22 networks by designing algorithm such that CPEs' service outage is reduced even for the higher traffic load on CPE.

The main contributions of this thesis are the following.

- We proposed a self-coexistence algorithm in multichannel environment which have never done before.
- Applicable to real world scenario since distributed network and channel diversity are taken into consideration.
- We show how the proposed algorithm outperformed the existing one.

1.3 Outline of Thesis

The rest of thesis is organized as follow.

Chapter 2 introduces the basic background, giving an overview of IEEE 802.22-2011 WRAN system architecture and existing self-coexistence. Also it includes a brief discussion on the previous work for what the others have done. In Chapter 3, the problem of existing self-coexistence is discussed and a traffic aware algorithm is proposed. In Chapter 4, MATLAB simulation has been done according to the algorithm described in Chapter 3. Moreover, it is compared with the performance of existing single channel self-existence. Finally, Chapter 5 summarized with conclusion and discusses further work.

2. RELATED WORK

2.1 IEEE 802.22-2011 WRAN

IEEE 802.22 is the first IEEE standard for wireless communication on TVWS published in 2011 by the WRAN working group. This standard provides wireless broadband access over a large area (20km-30km) on the VHF/UHF TV broadcast frequency bands of the range between 54MHz and 862MHz. The standard has specified the physical (PHY) and medium access control (MAC) layers, as well as CR functionalities to operate on the TV bands.

2.1.1 Architecture of IEEE 802.22

The core components of IEEE 802.22 system are the BSs and CPEs as shown in Figure 1.1. A WRAN cell is consists of a single BS and several fixed or portable CPEs, and it allows point-to-multipoint access between the BS and CPEs. In order to provide incumbent protection, WRAN follows a strict master-slave relationship, where a BS is responsible to admit CPEs to be the members of the network, synchronize communications between BS and CPEs, provide different quality of service (QoS) and CR functions such as geo-location capability, database access and self-coexistence as shown in Figure 2.1. If any of the channels used by a WRAN cell is accessed by the licensed incumbent, the primary task of IEEE 802.22 devices is to vacate the channels within the channel move time (2 seconds) and switch to the backup channel.

To get the knowledge of the presence of licensed incumbents and their usage of channels, the BS and CPEs periodically perform channel sensing.

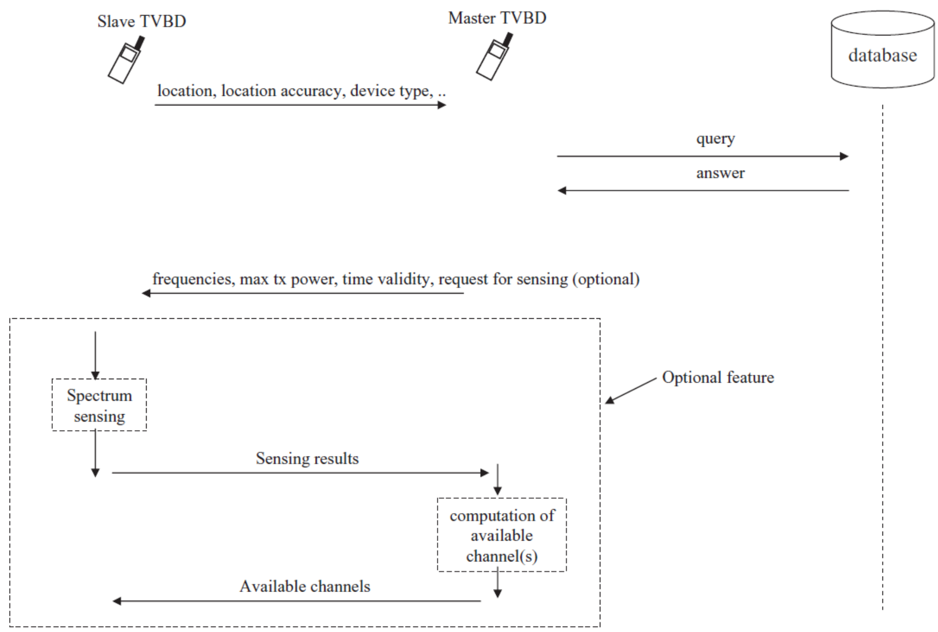

Figure 2.1 Example of master-slave algorithm

2.1.2 Medium Access Control

The standard as detailed in [3] defines both PHY and MAC layers, however, we focus on the MAC layer in this thesis. The MAC provides a medium access method based on connection-oriented and a point-to-multipoint connection. For downstream (DS) from BS to multiple CPEs, time division multiplexing (TDM) is used, while (OFDMA) is used for upstream (US) from multiple CPEs to BS as on-demand multiple access requests from the CPEs as shown in Figure 2.2. A DS subframe is used for frame synchronization and to transmit management information and data frames from BS to CPEs. On the other hand, an US subframe is used for the connection from CPEs to BS that all frames from the CPEs to BS appear within the US subframe. In addition, the US subframe contains contention slots for association and power control, bandwidth request and urgent coexistence situation notification. Furthermore, self-coexistence window (SCW) is allocated in the US subframe to allow transmission of opportunistic coexistence among multiple WRANs on the same channel.

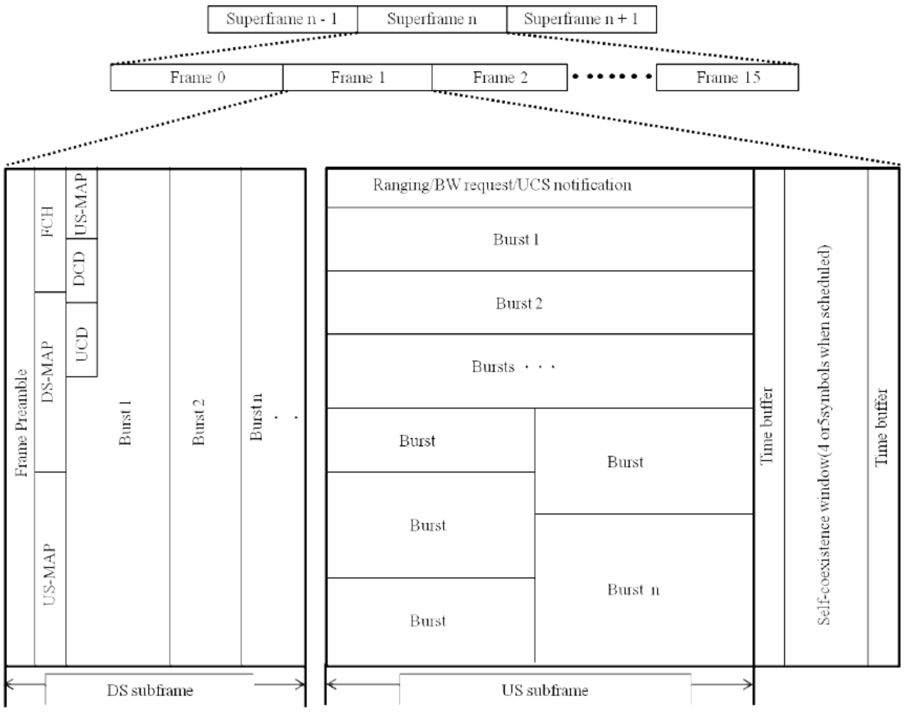

Figure 2.2 IEEE 802.22 superframe and frame structure

2.2 Self-coexistence

Spectrum manager (SM) as a cognitive capability has several main functions which are geo-location, incumbent database service, channel set management, polices, spectrum sensing and self-coexistence.

As shown in Figure 2.3, multiple WRAN cell may operate in the same vicinity. If neighbour cells use the same channel, the interference degrades the system performance significantly. IEEE 802.22 MAC addresses the self-coexistence using mandatory mechanisms which are spectrum etiquette and on demand frame contention (ODFC). Channel selection in a cell follows the self-coexistence mechanism so that the chosen channel may be interference free or interfered with minimum number of channels.

The available channels in the network are classified as follow, and they are managed through the function of channel set management in SM. Operating channel is the current channel used for communication between BS and CPEs within the WRAN cell which is in bold according to Figure 2.4. Backup channels are the channels which have been cleared to immediately become the operating channel in case the WRAN needs to switch to another channel. Backup channels are underlined. Candidate channels are the channels that are candidates to become a backup channel.

Self-coexistence is managed through the coexistence beacon protocol (CBP), which is a transport mechanism for inter-WRAN communications. CBP packets carry key information like channel set list to adjacent and overlapping WRAN cells for self-coexistence handling. CBP bursts are transmitted in the SCW at the end of MAC US subframe. The source of a CBP packet can be a BS or a CPE.

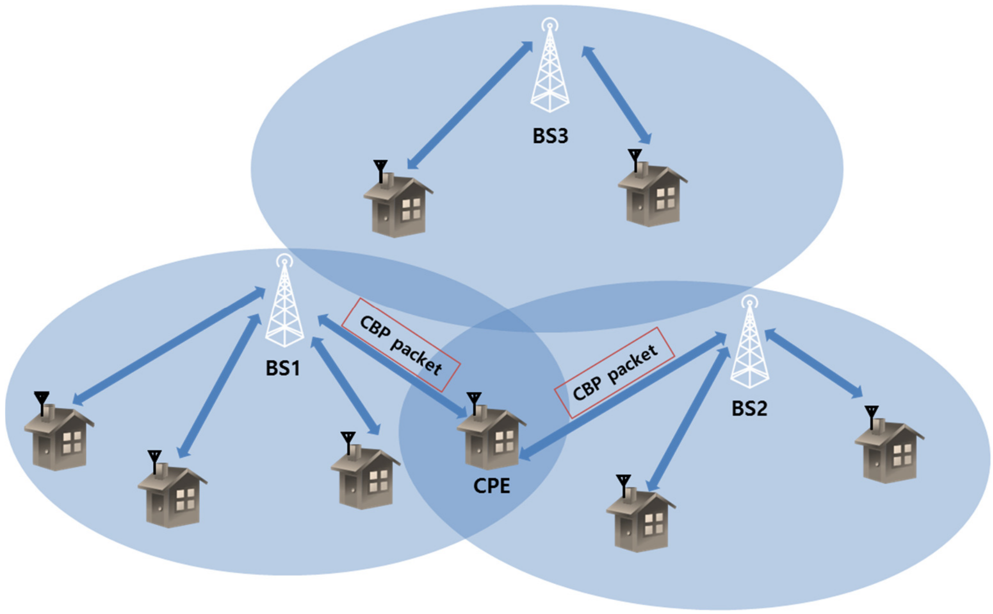

Figure 2.3 Example of multiple WRAN deployment

2.2.1 Spectrum Etiquette

Spectrum etiquette is used where enough available channels and orthogonal operating and backup channels can be found for different WRAN cells. The information on operating, backup and candidate channels of each cell is exchanged through the use of CBP packets among the WRAN cells. Upon reception of CBP packets or incumbent detection control massage, SM updates its information. Spectrum Etiquette is triggered by following events:

- Incumbent discovery
- Neighbour WRAN cell discovery of update
- Operating channel switch demand (i.e., because of interference)
- Contention request received from neighbour WRAN cells

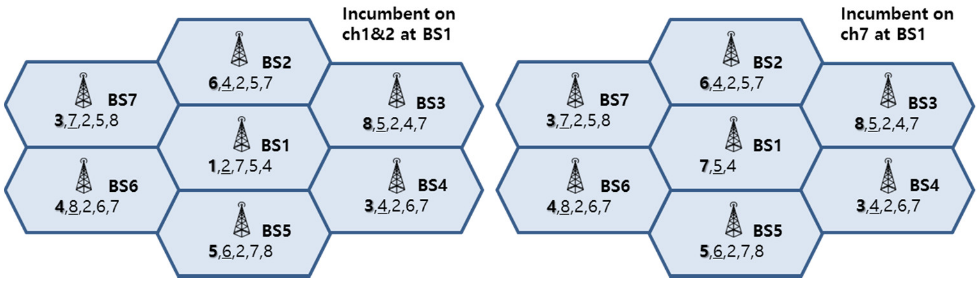

Figure 2.4 Example of self-coexistence

2.2.2 On Demand Frame Contention

The ODFC is used if there are not enough available channels and different WRAN cells must share the same channel, thus working in self-coexistence mode of operation. It is used to resolve contentions of frame resource among the neighbouring WRAN cells. When an operating BS switches from the normal mode of operation to the self-coexistence mode of operation, it initially occupies all 16 frames of the superframe. In self-coexistence mode, the BS shall schedule at least one contention SCW to monitor potential frame requests from new overlapping WRAN cells.

Once the CBP packet which contains neighbour's frame contention request (FC_REQ) message is received, ODFC is applied to determine how to distribute subsequent frames or superframes accordingly. The neighbour BS who sent FC-REQ message is considered as frame contention source (FC_SRC), and the BS who received FC_REQ message is frame contention destination (FC_DST). As shown in Figure 2.5, to win the contention, the randomly generated number N_c1 by FC_SRC should larger than N_c2 generated by FC_DST. In the case of success of contention source, the FC_DST answers to the request with a response message (FC_RES) containing the source identifier and the list of granted frames F1. Then, the FC_SRC replies with acknowledgement (FC_ACK), and will use the granted frame F1 starting from the next superframe. Finally, the release message (FC_REL) notifies the FC_DST that the list of frames F1 will be released to the winning FC_SRC. If N_c1 is smaller than N_c2, the FC_SRC loses contention, and opportunity for access the frame F1 is rejected.

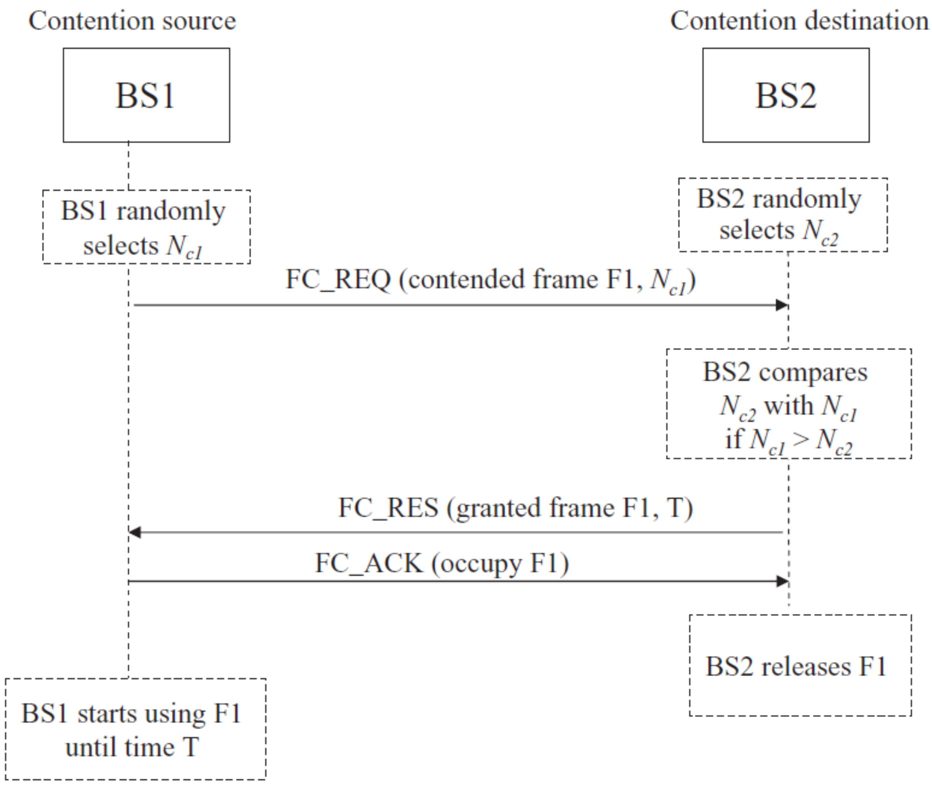

Figure 2.5 Example of ODFC in the case of contention source success

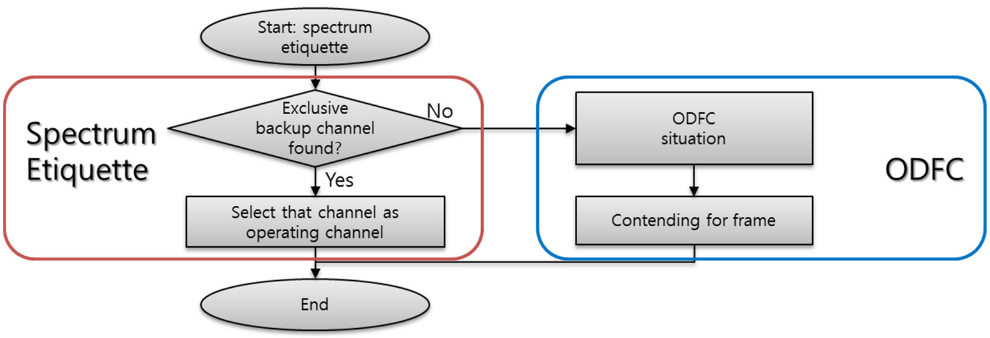

Figure 2.6 Flowchart of IEEE 802.22 self-coexistence mechanism

2.3 Previous Work

2.3.1 IEEE 802.22 self-coexistence mechanism

The Figure 2.6 shows the IEEE 802.22 self-coexistence mechanism. Once spectrum etiquette is triggered, the BS looks into its SM see if there is any exclusive backup channel found. Exclusive backup channel means those backup channels which are not used as neighbours' operating channels. If exclusive backup channel exists, use that channel as operating channel and send updated channel list to neighbour BSs. If none of the exclusive is found, BS is forced to enter ODFC to contend channel access opportunity on certain channel with its neighbour.

With multichannel operation, there are several problems we have to consider. In multichannel operation with objective of reaching CPEs' satisfaction, spectrum etiquette is triggered more frequently. That is, because the network has larger number of channels used as operating channels compared to single channel operation network. That means under the same TV incumbent traffic multichannel operation will encounter more spectrum etiquette.

The problem of spectrum etiquette is that it transits to ODFC easily. The more spectrum etiquette transits to ODFC, the bigger possibility to contend and share channels which leads to degradation on CPEs' satisfaction.

Besides, existing ODFC also has problem. In standard, there is no specific criteria saying which channel to choose to share. Thus, coming up with criteria to reach the CPEs' satisfaction as much as possible is required.

2.3.2 Traffic-aware channel assignment [7]

To overcome the static nature of fixed channel allocation (FCA) method they propose the traffic-aware technique as an alternative method. The main idea of their proposed a cooperative scheme is that the available channels are dynamically redistributed between neighboring WRAN cells, taking into account the prevailing traffic loads at the different WRAN cells (in terms of blocking rate). The detail of our proposed solution is described as below:

- Initially, all available (idle) channels are evenly assigned to the three WRAN cells.
- Then, for the jth time period of length Ts, each WRAN cell computes the blocking rate at time period j-1 as:

$$P_B^{(i)}(j-1) = \frac{NB_i^{(j-1)}}{NB_i^{(j-1)} + NS_i^{(j-1)}}, i = 1,2,3$$

where NB_i and NS_i represent the number of blocking and served requests in the (j – 1) th period, respectively. Based on the computed P_B(j-1) each base station decides whether the blocking probability exceeds the pre-specified system blocking rate value. If one or more base stations have blocking probability that is higher than the threshold blocking probability, the base station(s) request(s) channel redistribution by sending beacons to other base stations. These beacons request channels' redistributing such that the different cells' blocking rate requirements are satisfied as much as possible. At time j, the channels are redistributed according to the following:

$$C_i^{(j)} = \left\lfloor \frac{C_i^{(j-1)} + NB_i^{(j)}}{N + \sum_{i=1}^{3} NB_i^{(j)}} N \right\rfloor, \quad i = 1, 2, 3$$

where C_i(j-1) and N respectively represent the number of already assigned channels in the (j − 1) th period to cell i and the number of all available channels in the system. Note that if the blocking probabilities of all base stations at time j are within the threshold values, the base stations of the different cells continue using the same set of channels (i.e., C_i(j)=C_i(j-1)).

3. PROPOSED SCHEME

2.1 Network Model

We consider a distributed cooperative IEEE 802.22 WRAN, where multiple WRAN BS operates in close proximity in an overlapped region. Both BSs and CPEs are fixed, and they both support multichannel operation. Spectrum is allocated in distributed which means there is no such central coordinator allocating channels. However, since neighbour BSs share exchange information through CBP packet, it is cooperative. Each BS's objective is to reduce the associated CPEs' service outage as much as possible. Network conditions are dynamic in terms of TV incumbent activities and traffic rate of each CPE which will be further parameterized.

We assume that there are N WRAN cells competing for the M available licensed channels. In this thesis, we consider reaching the CPEs satisfaction as objective, proposing a traffic aware self-coexistence supports multichannel operation.

2.2 TV incumbent traffic model

The activity of a TV incumbent in our network is modelled with an On-Off process [6]. We are assuming multiple channels in the system, and TV incumbent selects a particular channel and BS with uniform probability.

Incumbent remains in ON state for a fixed period, and in OFF state for an exponentially distributed period. ON and OFF durations are assumed as independent and identically distributed (i.i.d).

2.3 Channel Allocation in WRAN

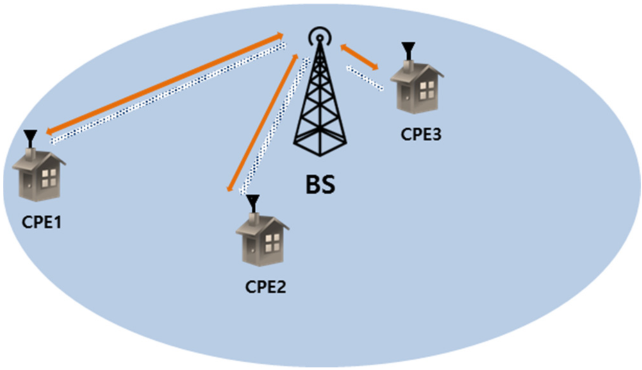

Figure 3.1 Example of channel allocation among WRAN

As shown in Figure 3.1, assume there are three CPEs associated. To avoid starvation issue of CPE, we assume each CPE has even access to the operating channels that BS is using. That is, each CPE can have $\mathrm{N}_{OCH}^{j}/\mathrm{N}_{CPE}^{j}$ channels to access, where N_{OCH}^{j} is the number of operating channel of cell j and N_{CPE}^{j} is the number of associated CPE of cell j. Thus, CPE of example has 2/3 channels.

2.4 Proposed Scheme

In each time, we have

- Traffic arrival rate λ_i for CPE i, and it follows log normal distribution.

- Transmission rate C_i per channel for CPE i which only depends on distance from CPE to BS. Therefore, the aggregated transmission rate is $\frac{N_{OCH}^j}{N_{CPE}^j} * C_i$.

- Satisfaction of CPE (SC) is

$$SC_i = \min(1, \frac{N_{OCH}^j}{N_{CPE}^j} * \frac{C_i}{\lambda_i})$$

When aggregated transmission rate > traffic rate, CPE is satisfied and SC_i=1. Otherwise, $SC_i = N_{OCH}^j * C_i/(N_{CPE}^j * \lambda_i)$.

- Service outage (SO) of cell j is

$$SO_j = 1 - \sum_{i=1}^{N_{CPE}^j} SC_i / N_{CPE}^j$$

Bigger SO means larger portion of associated CPEs are unsatisfied.

Besides, CBP packet is also modified for proposed scheme. In order to compare SO_j value for ODFC procedure, CBP packet contains it.

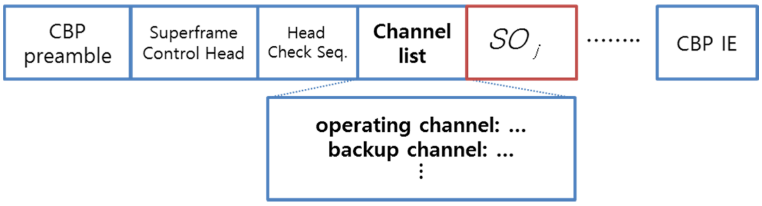

Figure 3.2 Modified CBP packet

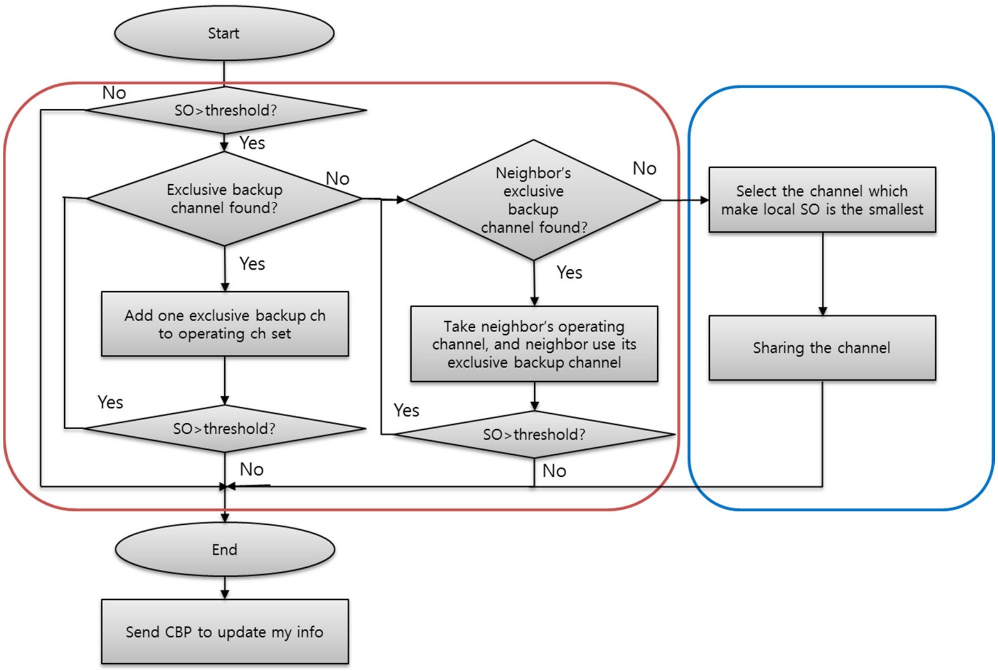

Figure3.3 Flow chart of proposed scheme

Figure 3.3 shows the flow chart of proposed scheme. Red block is the proposed spectrum etiquette, and the blue one is the proposed ODFC.

In proposed spectrum etiquette, cell j checks if its SO is bigger than the threshold. If it is bigger, it means cell j is not satisfied. Thus cell j asks for more exclusive backup channel of its own. One exclusive backup channel is added to operating channel set until the SO is smaller than threshold which indicates the satisfaction of cell j. The reason why cell j only adds one exclusive backup channel at a time is that we do not want selfish behaviour of cell. That's why we want to analyse the traffic of CPEs, and give exact amount to satisfy them. After cell j runs out of exclusive backup channel, it does not transit to ODFC immediately. In the proposed scheme, cell j checks if its neighbours have any exclusive backup channels. For instance, neighbour cell k has its own exclusive backup channel, then cell j takes one operating channel of cell k and makes cell k to fill up with its exclusive backup channel.

Procedure enters ODFC when neighbour of cell j ran out of exclusive backup channel too. In proposed ODFC, cell j must share channels with neighbour cells. Thus, we proposed that cell j select the channel that will minimize the neighbourhood overall SO. Once channel is selected, it is shared in contention based manner.

4. PERFORMANCE EVALUATION

4.1 Simulation Environment

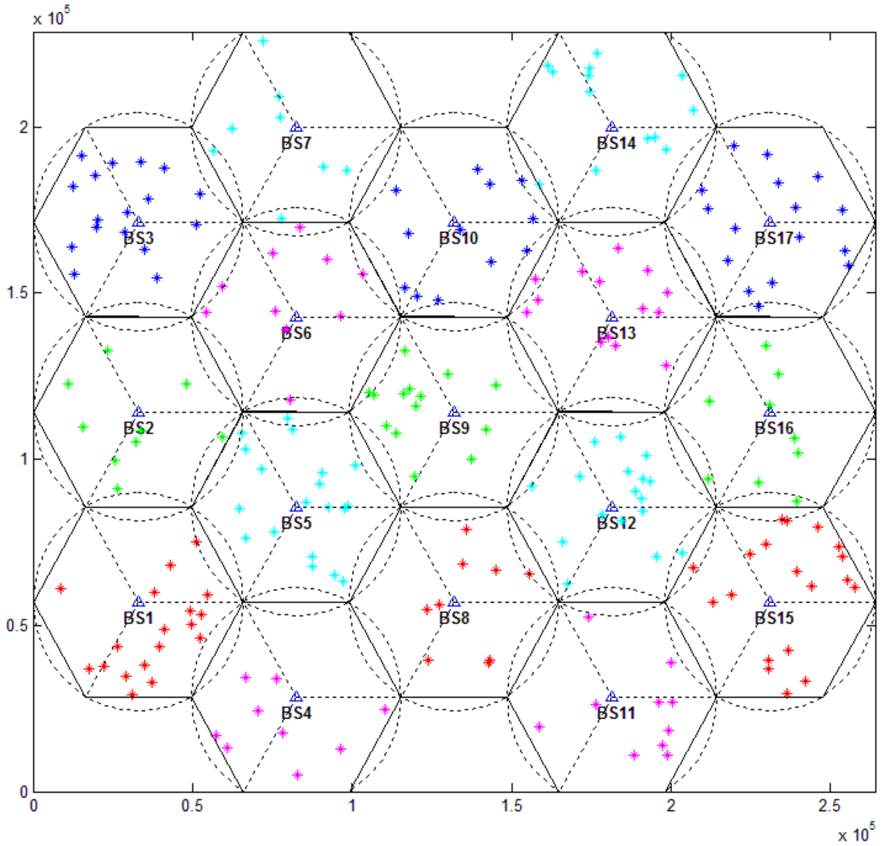

Figure 4.1 Simulation topology

In this section, we describe the network environment and parameter for our simulation. To evaluate our proposed algorithm, the simulation is conducted in MATLAB. To begin with, we carry out a simulation based on IEEE 802.22 WRAN. We suppose that there are 17 WRANs which are overlapped to each other such as Figure 4.1 and CPEs are randomly deployed. Table 4.1 provides parameters used for our simulation.

Table 4.1 Simulation parameters

Parameters	**Value**
Network environment	IEEE 802.22 WRAN
Network range	250km X 250km
Propagation range	33km
The number of WRAN BS	17
The number of available TV Ch.	50
The number of CPEs of each BS	Random from 5~20

4.2 Simulation Results

The objective of our scheme is to reduce the SO as much as possible. To achieve goals, we carry out the simulation in different scenarios. The Figure 4.2 ~ Figure 4.4 presents our simulation results.

In first simulation, we compare our scheme with the existing IEEE 802.22 self-coexistence in standard. Obviously, as the number of available channels in the network increases, the smaller average SO value is. Besides, the reduction between existing and proposed scheme is even larger as the number of available channel increases. That is, with more available channels, the SO has more room to be reduced. In other words, CPEs have more possibility to be satisfied. For the information, standard scheme uses only 1 operating channel, thus, the performance gap between standard and proposed is huge.

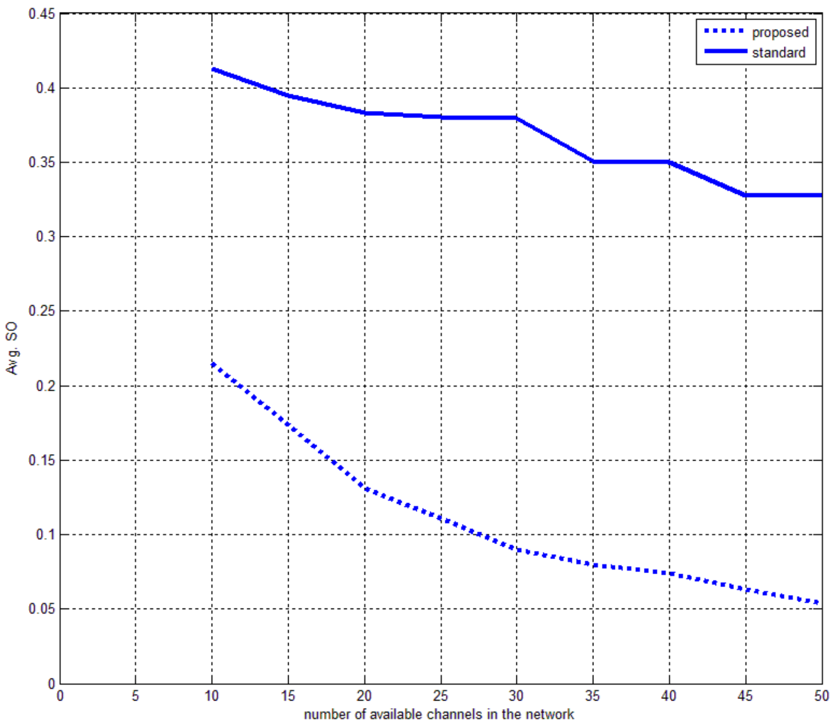

Figure 4.2 Avg. SO when different channels available

To have more in depth study of how our proposed scheme works, different variations of proposed scheme is compared. In scheme 1, only BS's own exclusive back channels are added to operating channels. Once it is ran out, BS transfers to ODFC mode with random selection of channel. It means neighbours' exclusive backup channels are not utilized here. In scheme 2, both BS and neighbours' exclusive backup channels are utilized. Still, random selection of channel is adapted in ODFC mode. Again, proposed scheme is better in the way that it selects the channel which makes local SO the smallest instead of random selection.

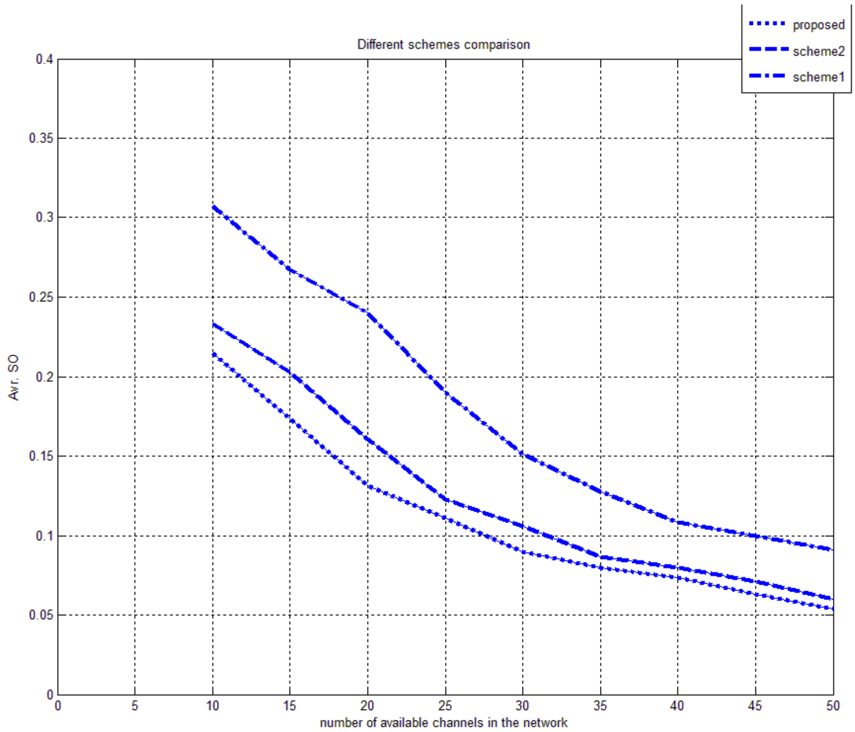

Figure 4.3 Avg. SO with different schemes

According to the result shown in figure 4.3, scheme 2 has better performance than scheme 1. Notice that the gap between scheme 1 and 2 is larger than that of scheme 2 and proposed one. It shows both utilization of neighbours' exclusive backup channel and improved ODFC increase the performance, and former has more impact on performance than latter.

In third simulation, Figure 4.4, we analyse the tendency of average SO as the threshold goes up. Threshold = 0 means all the CPEs should be satisfied if there are enough available channels. It is obvious that as threshold goes up average SO increases. It is because threshold goes up indicates CPEs have more tolerance to dissatisfaction such that more tolerance to SO.

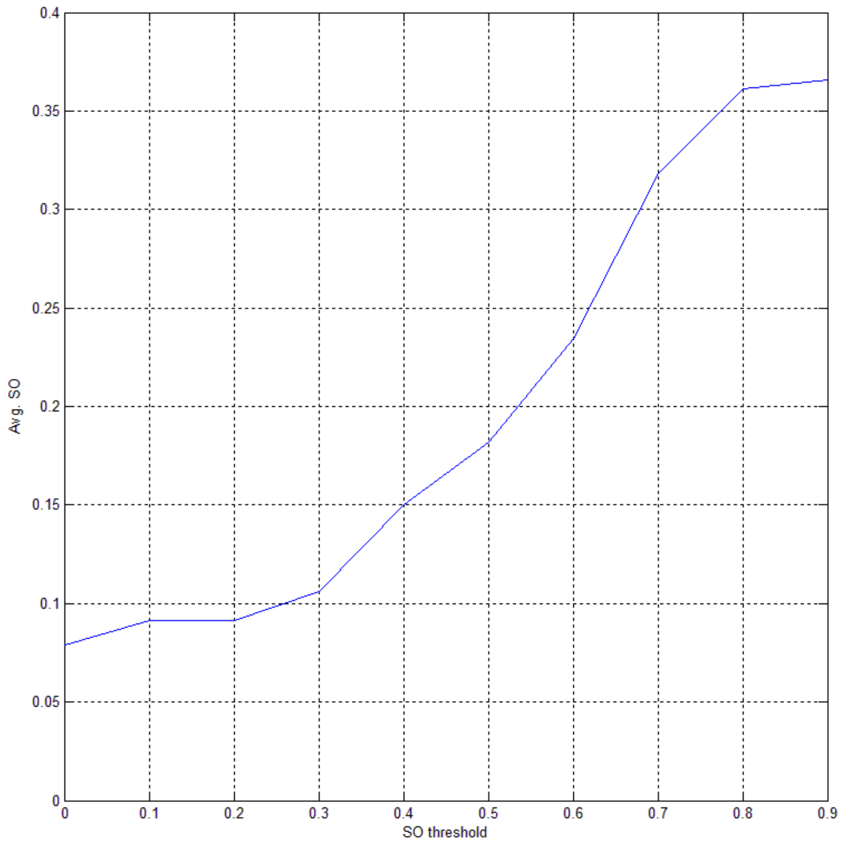

Figure 4.4 Avg. SO when different threshold is applied

5. CONCLUSION

The main objective of CR is to resolve a problem that the spectrum lacks by reallocating the unused spectrum. The existing IEEE 802.22 WRAN has adopted self-coexistence method to efficiently use the unused TV channels.

Self-coexistence has two mechanism. Spectrum etiquette use channels orthogonally among different WRANs, and it guarantees that channels are not shared but use solely by own BS. The other one is ODFC which is an efficient channel sharing method based on contention. It happens when spectrum etiquette is no longer available. Both of them has limitations if we try to adopt them in multichannel environment.

In this thesis, we propose a traffic-aware self-coexistence such that CPEs' service outage is reduced. Simulation results demonstrated that it is more efficient than the existing method.

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초 록

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IEEE 802.22 는 처음으로 TV 주파수 대역의 화이트 스페이스 대역을 인지 무선 통신에 사용한 전 세계적인 표준이다. 인지 무선 기술은 서비스 되지 않는 주파수 자원을 무선기기가 스스로 감지하여 사용하는 효과적인 주파수 공유 방법이다. 따라서 여러 개의 WRAN 셀이 간섭 없이 빈 채널을 공유하는 효과적인 자기 공존 알고리즘이 필요하다.

본 논문에서는 IEEE 802.22 WRAN 들이 멀티채널을 사용하기 위한 트래픽 기반의 자기 공존 알고리즘을 제안한다. 성능평가의 척도로 WRAN 의 서비스 아우티지를 사용하여 사용가능 채널수가 변할 때의 수치를 측정하였다. 제안된 기법의 결과 IEEE 802.22 스탠다드에 나오는 기존의 기법보다 우수성을 입증하였다.

주요어 : IEEE 802.22, 인지무선통신, WRAN, 자기 공존, 멀티채널

학 번 : 2011-24085

MASTER THESIS

A Traffic-aware Self-coexistence in Multichannel IEEE 802.22 WRAN

IEEE 802.22 WRAN을 위한 멀티채널에서의 트래픽 기반의 자기공존 알고리즘

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AUGUST 2014

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
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A Traffic-aware Self-coexistence in Multichannel IEEE 802.22 WRAN

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이 논문을 공학석사 학위논문으로 제출함

2014년 8월

서울대학교 대학원

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이령 의 공학석사 학위논문을 인준함

2014년 8월

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ABSTRACT

IEEE 802.22 is the first worldwide standard for Cognitive Radio Network (CRN) that exploits white spaces of television broadcast. It is a standard for Wireless Regional Area Networks (WRANs) which enables broadband wireless access. In order to coexist between multiple overlapped WRAN cells a single channel self-coexistence mechanism is introduced in IEEE 802.22-2011 standard. Upon the increasing demand for customer promise equipments' (CPE) high throughput, supporting for multichannel operation is inevitable for upcoming 802.22b amendment. In this paper, we propose a traffic-aware self-coexistence for multichannel operation in 802.22 WRAN such that we try to reach CPEs' satisfactions as much as possible.

Keywords: IEEE 802.22, cognitive radio network, WRAN, self-coexistence

Student number: 2011-24085

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1. INTRODUCTION

1.1 Motivation

The transition from analogue television to digital television (DTV) made some of the spectrum available in the VHF and UHF bands. Such available spectrum is called TV white spaces (TVWS), and it has the potential to revolutionize the way we access the internet. The world of wireless networks suffer from scarce of spectrum while lots of white spaces are remain unused in most location, especially in those rural areas [1]. Such observation have led to FCC regulation which allows cognitive radio (CR) operation in white spaces from 2008 [2].

CR technology enables devices sensing the environment and autonomously adapt its operating characteristics. It utilizes ample free, unlicensed TVWS to enable data transmission with wide coverage and high building penetration. The efficient use of TVWS is therefore very important for utilization of valuable part of the radio spectrum.

One of the solutions to utilization of TVWS is IEEE 802.22-2011 standard. IEEE 802.22 wireless regional area network (WRAN) is the first standard using white spaces based on a cognitive radio where TV channel between 54MHz and 862MHz is used to provide broadband wireless internet access in rural areas without licensed incumbent [3]. The incumbent users refer to the

TV broadcasting or wireless microphones. The unlicensed wireless users refer to IEEE 802.22 entities such as base stations (BSs) and customer premise equipment (CPE) as shown in Figure1.1. To coexist and protect incumbents, 802.22 devices including BSs and CPEs are required to perform spectrum sensing and evacuate immediately upon incumbent detection.

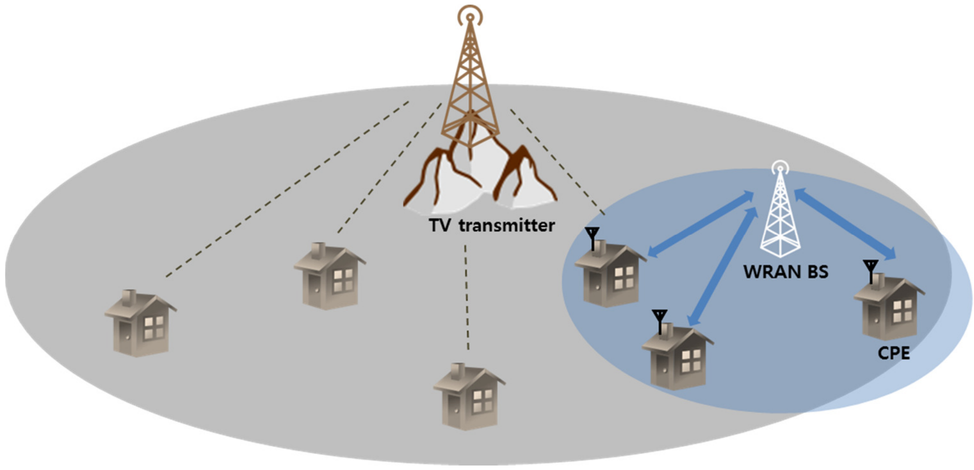

Figure 1.1 Example of IEEE 802.22 WRAN system

Though coexistence between incumbent have been predominantly studied in previous year, tasks still remain on the issue of coexistence between secondary users, in other words, self-coexistence.

A recent paper presented by IEEE802.22b task group for enhancement of broadband services and monitoring applications in TVWS stated that due to the monitoring applications, the maximum achievable throughput is not enough anymore [4]. In the IEEE 802.22-2011, single channel operation is supported as shown in Figure 1.2 with maximum date rate of 22.69 Mbps. In

Figure 1.2, each CPE (CPE 1~CPE 4) is using the operating channel (Ch1) to communicate within the service area of BS where the operating channel (Ch1) is assigned by the spectrum manager (SM) using the available channel list. In the IEEE 802.22-2011 standard, even though there may be several available channels exist in the list, due to the constraint of the single channel operation, those available channels cannot be utilized effectively since multichannel operation is not supported [5].

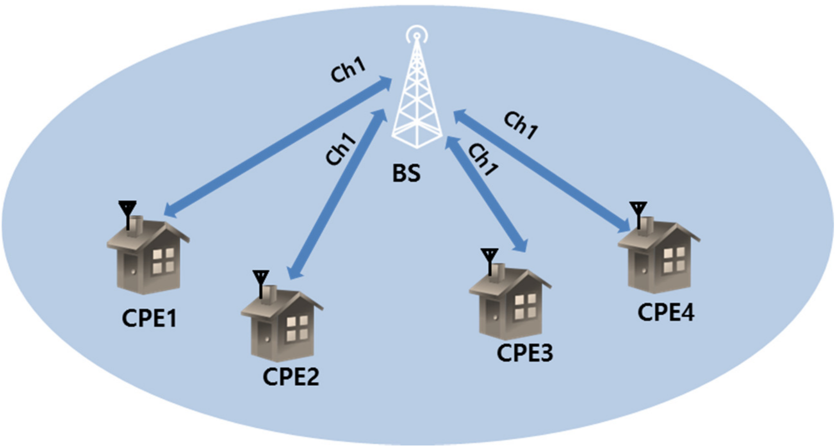

Figure 1.2 Example of 802.22-2011 single channel operation deployment configuration

The IEEE 802.22b standard supports aggregate data rates greater than the maximum data rate supported by the IEEE 802.22-2011 in order to extend its regional area broadband services to a broader range of applications such as real-time and near real-time monitoring, emergency broadband services, remote medical services, etc. which requires higher data rates.

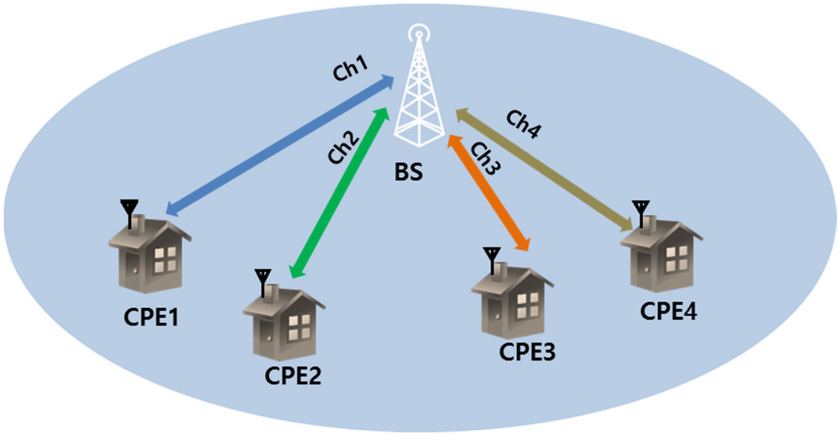

Figure 1.3 Example of multichannel operation deployment configuration

In Figure 1.3, it is assumed that there are 4 available operating channels within the service area of the BS. In this example, multichannel operation on BS is illustrated where BS is capable of receiving and transmitting two or more operating channels and responsible to assign the operating channel to the associated CPEs within its service area. By performing the multichannel operation on BS, the BS can utilize the available operating channels by distributing the operating channels among the associated CPEs. The multichannel operation on BS can improve the individual CPE's throughput by decreasing the total number of associated CPEs per operating channel.

For the improvement of CPE's data rate, multichannel operation s is a feasible solution to achieve throughput greater than the maximum throughput supported by the IEEE 802.22-2011.

Therefore, the issue here is how to deal with self-coexistence mechanism in multichannel environment.

1.2 Objectives and Contributions

The objective of this thesis is to develop a traffic aware self-coexistence algorithm in multichannel IEEE 802.22 network. We focus on the self-coexistence of IEEE 802.22 networks by designing algorithm such that CPEs' service outage is reduced even for the higher traffic load on CPE.

The main contributions of this thesis are the following.

- We proposed a self-coexistence algorithm in multichannel environment which have never done before.
- Applicable to real world scenario since distributed network and channel diversity are taken into consideration.
- We show how the proposed algorithm outperformed the existing one.

1.3 Outline of Thesis

The rest of thesis is organized as follow.

Chapter 2 introduces the basic background, giving an overview of IEEE 802.22-2011 WRAN system architecture and existing self-coexistence. Also it includes a brief discussion on the previous work for what the others have done. In Chapter 3, the problem of existing self-coexistence is discussed and a traffic aware algorithm is proposed. In Chapter 4, MATLAB simulation has been done according to the algorithm described in Chapter 3. Moreover, it is compared with the performance of existing single channel self-existence. Finally, Chapter 5 summarized with conclusion and discusses further work.

2. RELATED WORK

2.1 IEEE 802.22-2011 WRAN

IEEE 802.22 is the first IEEE standard for wireless communication on TVWS published in 2011 by the WRAN working group. This standard provides wireless broadband access over a large area (20km-30km) on the VHF/UHF TV broadcast frequency bands of the range between 54MHz and 862MHz. The standard has specified the physical (PHY) and medium access control (MAC) layers, as well as CR functionalities to operate on the TV bands.

2.1.1 Architecture of IEEE 802.22

The core components of IEEE 802.22 system are the BSs and CPEs as shown in Figure 1.1. A WRAN cell is consists of a single BS and several fixed or portable CPEs, and it allows point-to-multipoint access between the BS and CPEs. In order to provide incumbent protection, WRAN follows a strict master-slave relationship, where a BS is responsible to admit CPEs to be the members of the network, synchronize communications between BS and CPEs, provide different quality of service (QoS) and CR functions such as geo-location capability, database access and self-coexistence as shown in Figure 2.1. If any of the channels used by a WRAN cell is accessed by the licensed incumbent, the primary task of IEEE 802.22 devices is to vacate the channels within the channel move time (2 seconds) and switch to the backup channel.

To get the knowledge of the presence of licensed incumbents and their usage of channels, the BS and CPEs periodically perform channel sensing.

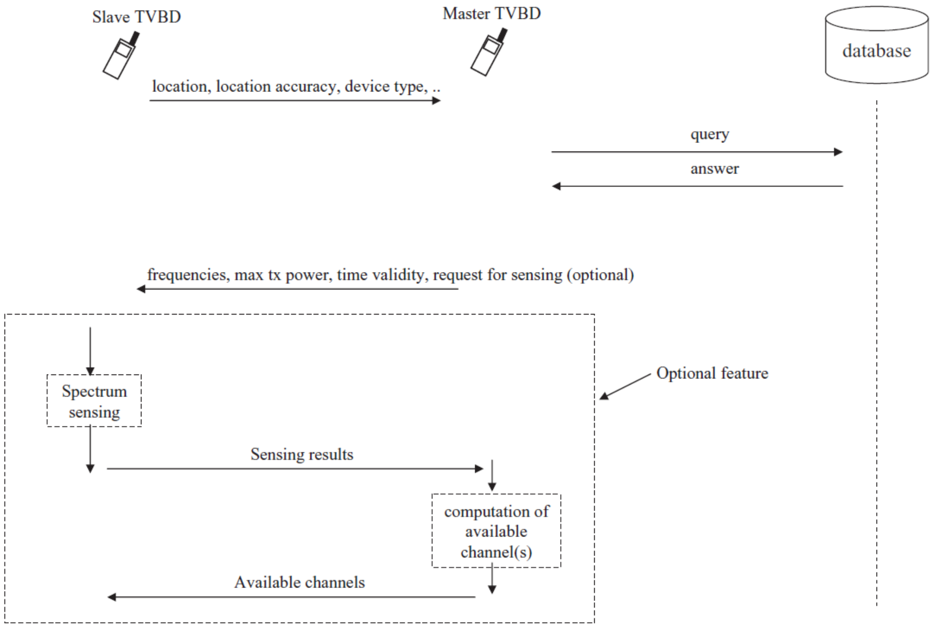

Figure 2.1 Example of master-slave algorithm

2.1.2 Medium Access Control

The standard as detailed in [3] defines both PHY and MAC layers, however, we focus on the MAC layer in this thesis. The MAC provides a medium access method based on connection-oriented and a point-to-multipoint connection. For downstream (DS) from BS to multiple CPEs, time division multiplexing (TDM) is used, while (OFDMA) is used for upstream (US) from multiple CPEs to BS as on-demand multiple access requests from the CPEs as shown in Figure 2.2. A DS subframe is used for frame synchronization and to transmit management information and data frames from BS to CPEs. On the other hand, an US subframe is used for the connection from CPEs to BS that all frames from the CPEs to BS appear within the US subframe. In addition, the US subframe contains contention slots for association and power control, bandwidth request and urgent coexistence situation notification. Furthermore, self-coexistence window (SCW) is allocated in the US subframe to allow transmission of opportunistic coexistence among multiple WRANs on the same channel.

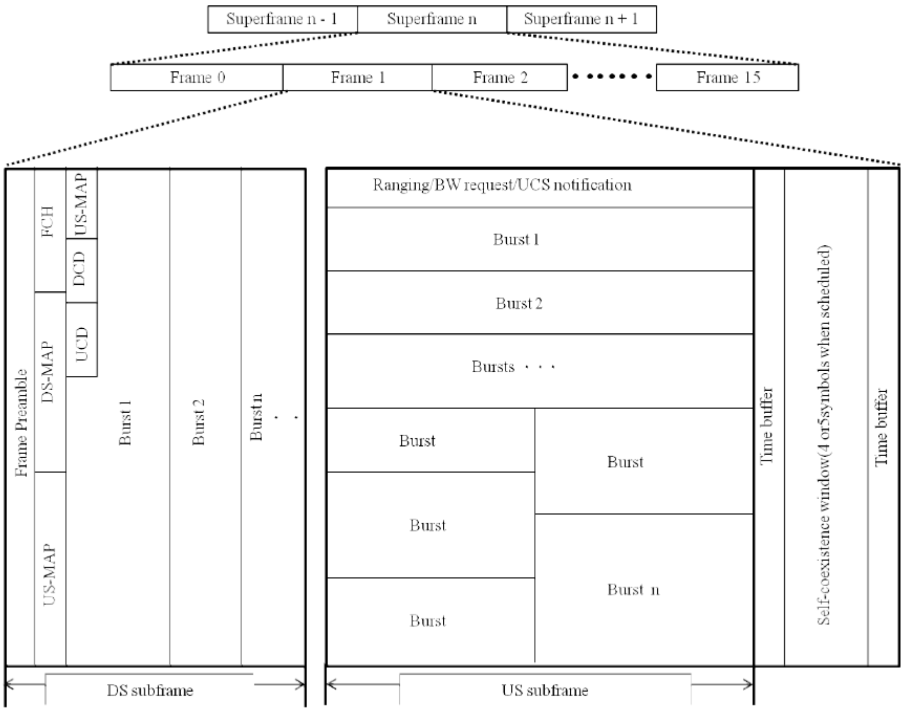

Figure 2.2 IEEE 802.22 superframe and frame structure

2.2 Self-coexistence

Spectrum manager (SM) as a cognitive capability has several main functions which are geo-location, incumbent database service, channel set management, polices, spectrum sensing and self-coexistence.

As shown in Figure 2.3, multiple WRAN cell may operate in the same vicinity. If neighbour cells use the same channel, the interference degrades the system performance significantly. IEEE 802.22 MAC addresses the self-coexistence using mandatory mechanisms which are spectrum etiquette and on demand frame contention (ODFC). Channel selection in a cell follows the self-coexistence mechanism so that the chosen channel may be interference free or interfered with minimum number of channels.

The available channels in the network are classified as follow, and they are managed through the function of channel set management in SM. Operating channel is the current channel used for communication between BS and CPEs within the WRAN cell which is in bold according to Figure 2.4. Backup channels are the channels which have been cleared to immediately become the operating channel in case the WRAN needs to switch to another channel. Backup channels are underlined. Candidate channels are the channels that are candidates to become a backup channel.

Self-coexistence is managed through the coexistence beacon protocol (CBP), which is a transport mechanism for inter-WRAN communications. CBP packets carry key information like channel set list to adjacent and overlapping WRAN cells for self-coexistence handling. CBP bursts are transmitted in the SCW at the end of MAC US subframe. The source of a CBP packet can be a BS or a CPE.

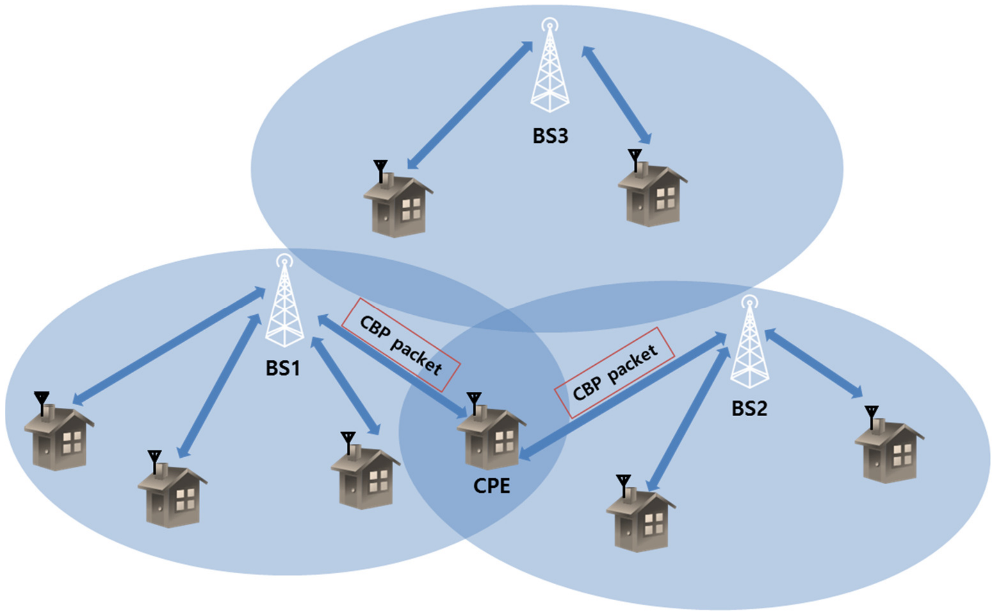

Figure 2.3 Example of multiple WRAN deployment

2.2.1 Spectrum Etiquette

Spectrum etiquette is used where enough available channels and orthogonal operating and backup channels can be found for different WRAN cells. The information on operating, backup and candidate channels of each cell is exchanged through the use of CBP packets among the WRAN cells. Upon reception of CBP packets or incumbent detection control massage, SM updates its information. Spectrum Etiquette is triggered by following events:

- Incumbent discovery
- Neighbour WRAN cell discovery of update
- Operating channel switch demand (i.e., because of interference)
- Contention request received from neighbour WRAN cells

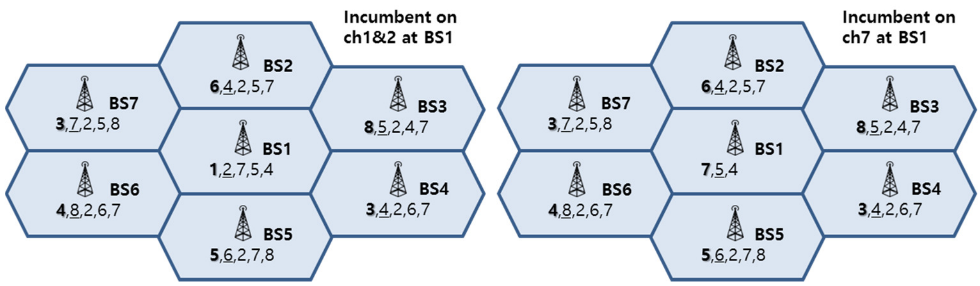

Figure 2.4 Example of self-coexistence

2.2.2 On Demand Frame Contention

The ODFC is used if there are not enough available channels and different WRAN cells must share the same channel, thus working in self-coexistence mode of operation. It is used to resolve contentions of frame resource among the neighbouring WRAN cells. When an operating BS switches from the normal mode of operation to the self-coexistence mode of operation, it initially occupies all 16 frames of the superframe. In self-coexistence mode, the BS shall schedule at least one contention SCW to monitor potential frame requests from new overlapping WRAN cells.

Once the CBP packet which contains neighbour's frame contention request (FC_REQ) message is received, ODFC is applied to determine how to distribute subsequent frames or superframes accordingly. The neighbour BS who sent FC-REQ message is considered as frame contention source (FC_SRC), and the BS who received FC_REQ message is frame contention destination (FC_DST). As shown in Figure 2.5, to win the contention, the randomly generated number N_c1 by FC_SRC should larger than N_c2 generated by FC_DST. In the case of success of contention source, the FC_DST answers to the request with a response message (FC_RES) containing the source identifier and the list of granted frames F1. Then, the FC_SRC replies with acknowledgement (FC_ACK), and will use the granted frame F1 starting from the next superframe. Finally, the release message (FC_REL) notifies the FC_DST that the list of frames F1 will be released to the winning FC_SRC. If N_c1 is smaller than N_c2, the FC_SRC loses contention, and opportunity for access the frame F1 is rejected.

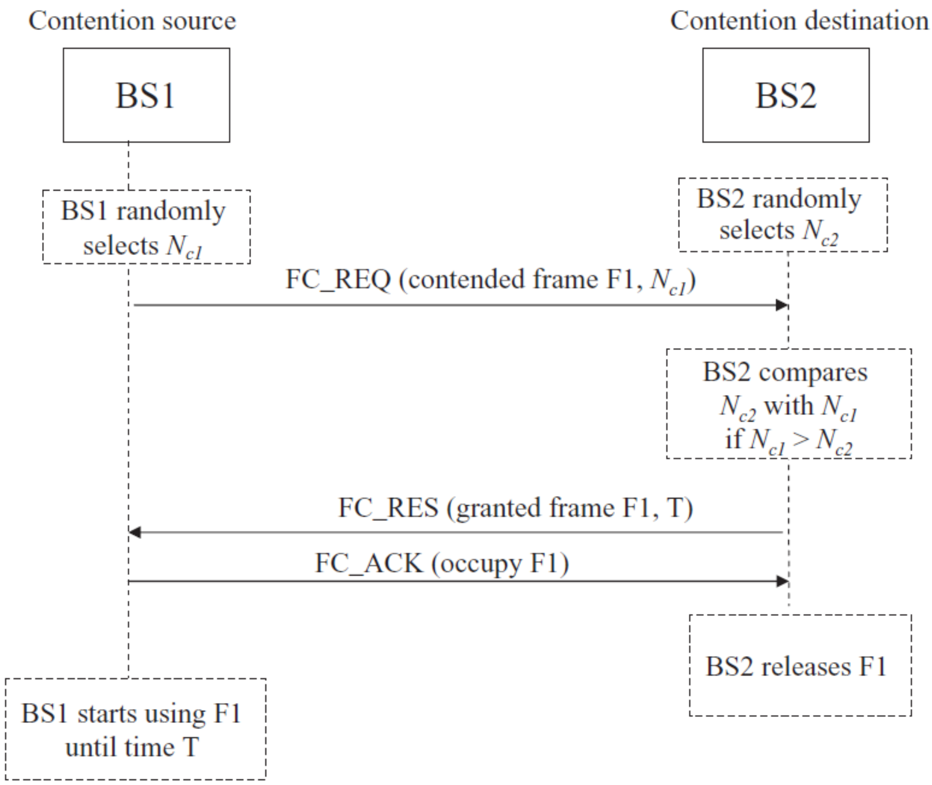

Figure 2.5 Example of ODFC in the case of contention source success

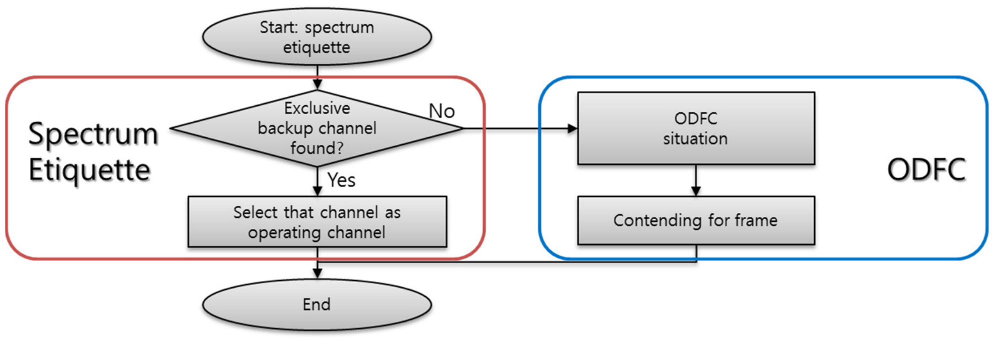

Figure 2.6 Flowchart of IEEE 802.22 self-coexistence mechanism

2.3 Previous Work

2.3.1 IEEE 802.22 self-coexistence mechanism

The Figure 2.6 shows the IEEE 802.22 self-coexistence mechanism. Once spectrum etiquette is triggered, the BS looks into its SM see if there is any exclusive backup channel found. Exclusive backup channel means those backup channels which are not used as neighbours' operating channels. If exclusive backup channel exists, use that channel as operating channel and send updated channel list to neighbour BSs. If none of the exclusive is found, BS is forced to enter ODFC to contend channel access opportunity on certain channel with its neighbour.

With multichannel operation, there are several problems we have to consider. In multichannel operation with objective of reaching CPEs' satisfaction, spectrum etiquette is triggered more frequently. That is, because the network has larger number of channels used as operating channels compared to single channel operation network. That means under the same TV incumbent traffic multichannel operation will encounter more spectrum etiquette.

The problem of spectrum etiquette is that it transits to ODFC easily. The more spectrum etiquette transits to ODFC, the bigger possibility to contend and share channels which leads to degradation on CPEs' satisfaction.

Besides, existing ODFC also has problem. In standard, there is no specific criteria saying which channel to choose to share. Thus, coming up with criteria to reach the CPEs' satisfaction as much as possible is required.

2.3.2 Traffic-aware channel assignment [7]

To overcome the static nature of fixed channel allocation (FCA) method they propose the traffic-aware technique as an alternative method. The main idea of their proposed a cooperative scheme is that the available channels are dynamically redistributed between neighboring WRAN cells, taking into account the prevailing traffic loads at the different WRAN cells (in terms of blocking rate). The detail of our proposed solution is described as below:

- Initially, all available (idle) channels are evenly assigned to the three WRAN cells.

- Then, for the jth time period of length Ts, each WRAN cell computes the blocking rate at time period j-1 as:

$$P_B^{(i)}(j-1) = \frac{NB_i^{(j-1)}}{NB_i^{(j-1)} + NS_i^{(j-1)}}, i = 1,2,3$$

where NB_i and NS_i represent the number of blocking and served requests in the (j − 1) th period, respectively. Based on the computed P_B(j-1) each base station decides whether the blocking probability exceeds the pre-specified system blocking rate value. If one or more base stations have blocking probability that is higher than the threshold blocking probability, the base station(s) request(s) channel redistribution by sending beacons to other base stations. These beacons request channels' redistributing such that the different cells' blocking rate requirements are satisfied as much as possible. At time j, the channels are redistributed according to the following:

$$C_i^{(j)} = \left\lfloor \frac{C_i^{(j-1)} + NB_i^{(j)}}{N + \sum_{i=1}^{3} NB_i^{(j)}} N \right\rfloor, \quad i = 1, 2, 3$$

where C_i(j-1) and N respectively represent the number of already assigned channels in the (j − 1) th period to cell i and the number of all available channels in the system. Note that if the blocking probabilities of all base stations at time j are within the threshold values, the base stations of the different cells continue using the same set of channels (i.e., C_i(j)=C_i(j-1)).

3. PROPOSED SCHEME

2.1 Network Model

We consider a distributed cooperative IEEE 802.22 WRAN, where multiple WRAN BS operates in close proximity in an overlapped region. Both BSs and CPEs are fixed, and they both support multichannel operation. Spectrum is allocated in distributed which means there is no such central coordinator allocating channels. However, since neighbour BSs share exchange information through CBP packet, it is cooperative. Each BS's objective is to reduce the associated CPEs' service outage as much as possible. Network conditions are dynamic in terms of TV incumbent activities and traffic rate of each CPE which will be further parameterized.

We assume that there are N WRAN cells competing for the M available licensed channels. In this thesis, we consider reaching the CPEs satisfaction as objective, proposing a traffic aware self-coexistence supports multichannel operation.

2.2 TV incumbent traffic model

The activity of a TV incumbent in our network is modelled with an On-Off process [6]. We are assuming multiple channels in the system, and TV incumbent selects a particular channel and BS with uniform probability.

Incumbent remains in ON state for a fixed period, and in OFF state for an exponentially distributed period. ON and OFF durations are assumed as independent and identically distributed (i.i.d).

2.3 Channel Allocation in WRAN

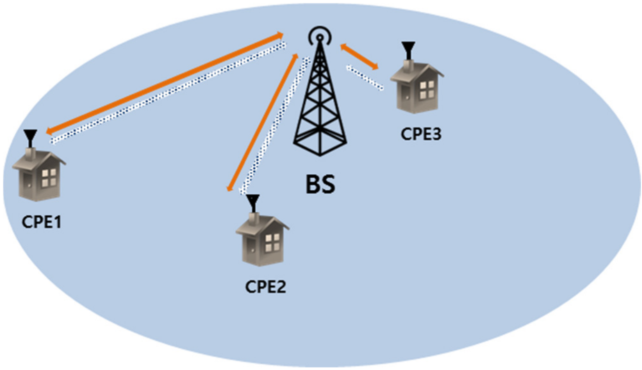

Figure 3.1 Example of channel allocation among WRAN

As shown in Figure 3.1, assume there are three CPEs associated. To avoid starvation issue of CPE, we assume each CPE has even access to the operating channels that BS is using. That is, each CPE can have $\mathrm{N}_{OCH}^{j}/\mathrm{N}_{CPE}^{j}$ channels to access, where N_{OCH}^{j} is the number of operating channel of cell j and N_{CPE}^{j} is the number of associated CPE of cell j. Thus, CPE of example has 2/3 channels.

2.4 Proposed Scheme

In each time, we have

- Traffic arrival rate λ_i for CPE i, and it follows log normal distribution.

- Transmission rate C_i per channel for CPE i which only depends on distance from CPE to BS. Therefore, the aggregated transmission rate is $\frac{N_{OCH}^j}{N_{CPE}^j} * C_i$.

- Satisfaction of CPE (SC) is

$$SC_i = \min(1, \frac{N_{OCH}^j}{N_{CPE}^j} * \frac{C_i}{\lambda_i})$$

When aggregated transmission rate > traffic rate, CPE is satisfied and SC_i=1. Otherwise, $SC_i = N_{OCH}^j * C_i/(N_{CPE}^j * \lambda_i)$.

- Service outage (SO) of cell j is

$$SO_j = 1 - \sum_{i=1}^{N_{CPE}^j} SC_i / N_{CPE}^j$$

Bigger SO means larger portion of associated CPEs are unsatisfied.

Besides, CBP packet is also modified for proposed scheme. In order to compare SO_j value for ODFC procedure, CBP packet contains it.

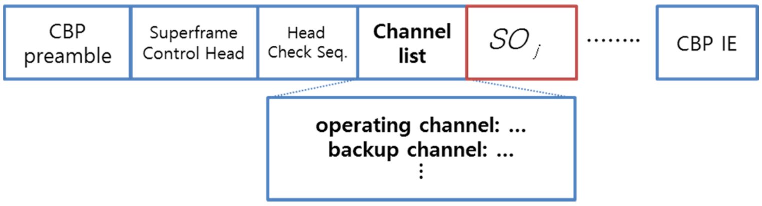

Figure 3.2 Modified CBP packet

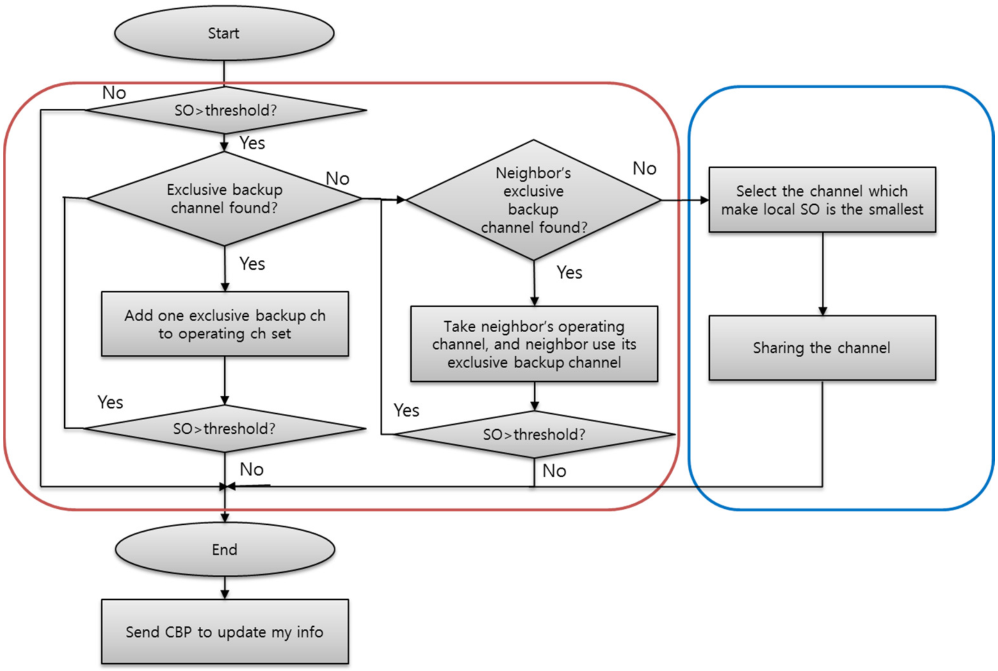

Figure3.3 Flow chart of proposed scheme

Figure 3.3 shows the flow chart of proposed scheme. Red block is the proposed spectrum etiquette, and the blue one is the proposed ODFC.

In proposed spectrum etiquette, cell j checks if its SO is bigger than the threshold. If it is bigger, it means cell j is not satisfied. Thus cell j asks for more exclusive backup channel of its own. One exclusive backup channel is added to operating channel set until the SO is smaller than threshold which indicates the satisfaction of cell j. The reason why cell j only adds one exclusive backup channel at a time is that we do not want selfish behaviour of cell. That's why we want to analyse the traffic of CPEs, and give exact amount to satisfy them. After cell j runs out of exclusive backup channel, it does not transit to ODFC immediately. In the proposed scheme, cell j checks if its neighbours have any exclusive backup channels. For instance, neighbour cell k has its own exclusive backup channel, then cell j takes one operating channel of cell k and makes cell k to fill up with its exclusive backup channel.

Procedure enters ODFC when neighbour of cell j ran out of exclusive backup channel too. In proposed ODFC, cell j must share channels with neighbour cells. Thus, we proposed that cell j select the channel that will minimize the neighbourhood overall SO. Once channel is selected, it is shared in contention based manner.

4. PERFORMANCE EVALUATION

4.1 Simulation Environment

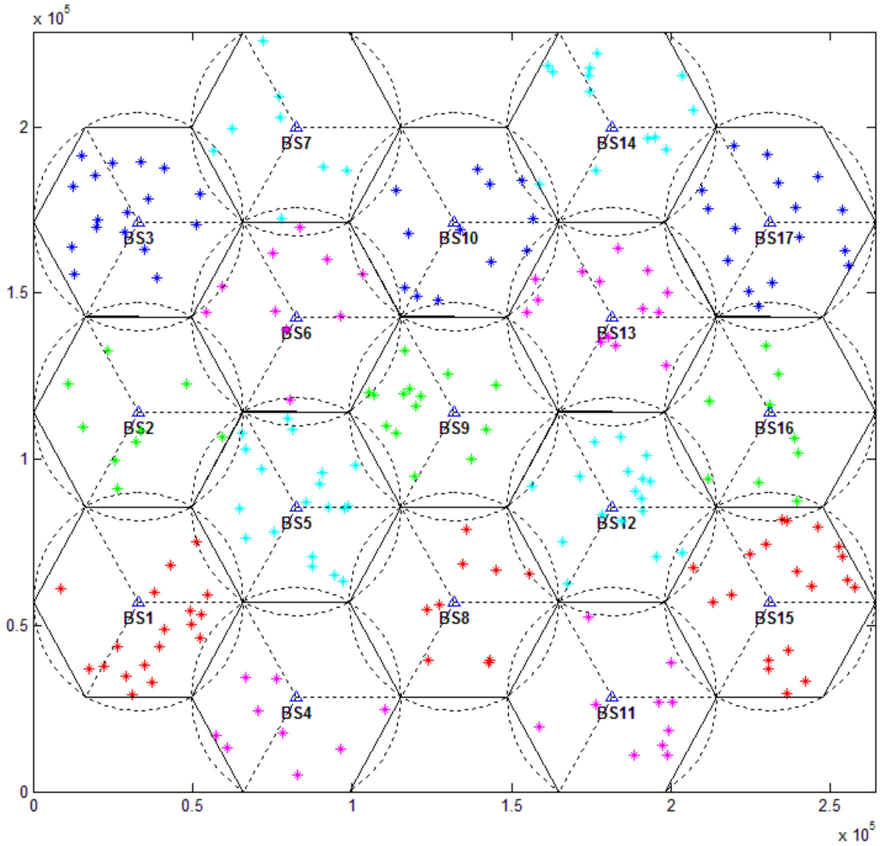

Figure 4.1 Simulation topology

In this section, we describe the network environment and parameter for our simulation. To evaluate our proposed algorithm, the simulation is conducted in MATLAB. To begin with, we carry out a simulation based on IEEE 802.22 WRAN. We suppose that there are 17 WRANs which are overlapped to each other such as Figure 4.1 and CPEs are randomly deployed. Table 4.1 provides parameters used for our simulation.

Table 4.1 Simulation parameters

Parameters	Value
Network environment	IEEE 802.22 WRAN
Network range	250km X 250km
Propagation range	33km
The number of WRAN BS	17
The number of available TV Ch.	50
The number of CPEs of each BS	Random from 5~20

4.2 Simulation Results

The objective of our scheme is to reduce the SO as much as possible. To achieve goals, we carry out the simulation in different scenarios. The Figure 4.2 ~ Figure 4.4 presents our simulation results.

In first simulation, we compare our scheme with the existing IEEE 802.22 self-coexistence in standard. Obviously, as the number of available channels in the network increases, the smaller average SO value is. Besides, the reduction between existing and proposed scheme is even larger as the number of available channel increases. That is, with more available channels, the SO has more room to be reduced. In other words, CPEs have more possibility to be satisfied. For the information, standard scheme uses only 1 operating channel, thus, the performance gap between standard and proposed is huge.

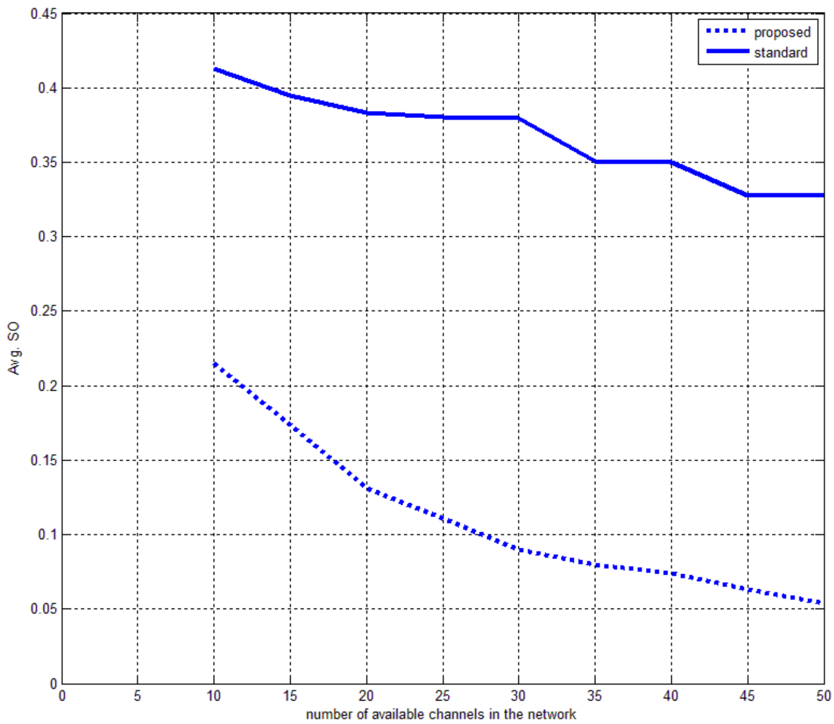

Figure 4.2 Avg. SO when different channels available

To have more in depth study of how our proposed scheme works, different variations of proposed scheme is compared. In scheme 1, only BS's own exclusive back channels are added to operating channels. Once it is ran out, BS transfers to ODFC mode with random selection of channel. It means neighbours' exclusive backup channels are not utilized here. In scheme 2, both BS and neighbours' exclusive backup channels are utilized. Still, random selection of channel is adapted in ODFC mode. Again, proposed scheme is better in the way that it selects the channel which makes local SO the smallest instead of random selection.

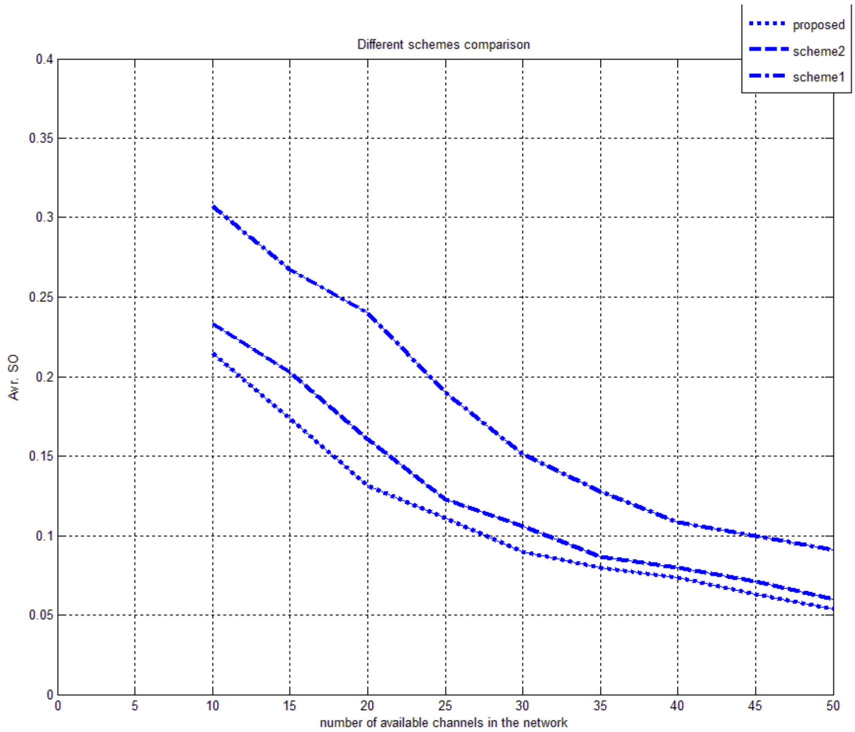

Figure 4.3 Avg. SO with different schemes

According to the result shown in figure 4.3, scheme 2 has better performance than scheme 1. Notice that the gap between scheme 1 and 2 is larger than that of scheme 2 and proposed one. It shows both utilization of neighbours' exclusive backup channel and improved ODFC increase the performance, and former has more impact on performance than latter.

In third simulation, Figure 4.4, we analyse the tendency of average SO as the threshold goes up. Threshold = 0 means all the CPEs should be satisfied if there are enough available channels. It is obvious that as threshold goes up average SO increases. It is because threshold goes up indicates CPEs have more tolerance to dissatisfaction such that more tolerance to SO.

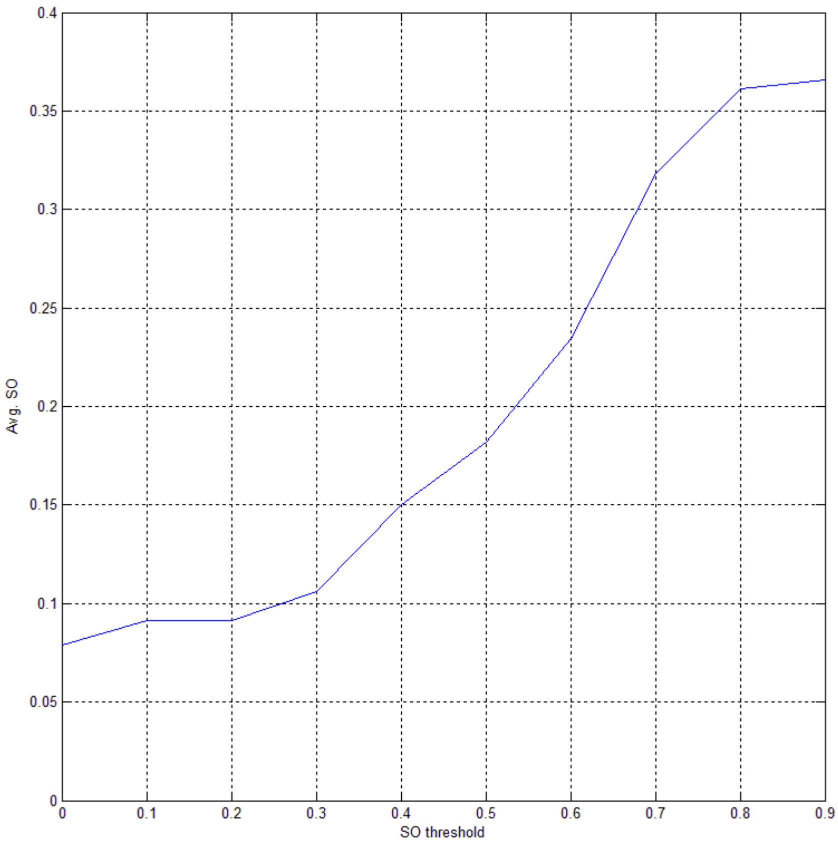

Figure 4.4 Avg. SO when different threshold is applied

5. CONCLUSION

The main objective of CR is to resolve a problem that the spectrum lacks by reallocating the unused spectrum. The existing IEEE 802.22 WRAN has adopted self-coexistence method to efficiently use the unused TV channels.

Self-coexistence has two mechanism. Spectrum etiquette use channels orthogonally among different WRANs, and it guarantees that channels are not shared but use solely by own BS. The other one is ODFC which is an efficient channel sharing method based on contention. It happens when spectrum etiquette is no longer available. Both of them has limitations if we try to adopt them in multichannel environment.

In this thesis, we propose a traffic-aware self-coexistence such that CPEs' service outage is reduced. Simulation results demonstrated that it is more efficient than the existing method.

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초 록

IEEE802.22 WRAN 을 위한 멀티채널에서의 트래픽 기반 자기 공존 알고리즘

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IEEE 802.22 는 처음으로 TV 주파수 대역의 화이트 스페이스 대역을 인지 무선 통신에 사용한 전 세계적인 표준이다. 인지 무선 기술은 서비스 되지 않는 주파수 자원을 무선기기가 스스로 감지하여 사용하는 효과적인 주파수 공유 방법이다. 따라서 여러 개의 WRAN 셀이 간섭 없이 빈 채널을 공유하는 효과적인 자기 공존 알고리즘이 필요하다.

본 논문에서는 IEEE 802.22 WRAN 들이 멀티채널을 사용하기 위한 트래픽 기반의 자기 공존 알고리즘을 제안한다. 성능평가의 척도로 WRAN 의 서비스 아우티지를 사용하여 사용가능 채널수가 변할 때의 수치를 측정하였다. 제안된 기법의 결과 IEEE 802.22 스탠다드에 나오는 기존의 기법보다 우수성을 입증하였다.

주요어 : IEEE 802.22, 인지무선통신, WRAN, 자기 공존, 멀티채널
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