Overview of 802.22 WRAN Standard and Research Challenges

Zaw Htike and Choong Seon Hong
Department of Computer Engineering, Kyung Hee University,
1 Seocheon,Giheung, Yongin, Gyeonggi, 449-701 Korea
htike@networking.khu.ac.kr,
cshong@khu.ac.kr,

Abstract

Cognitive radio technology gets much attention of wireless network research environments as a new way to utilize the precious spectrum efficiently. IEEE 802.22, Wireless Regional Area Network, is the first international standard based on cognitive radio technology which intends to provide broadband access by utilizing unused TV channels, also known as TV white spaces. This standard provides PHY and MAC layers functionalities in an infrastructure-based wireless access network. In this article, we describe overview of 802.22 standard from MAC perspective and discuss research challenges related to it. We mainly discuss for two research issues, QoS and coexistence.

1. Introduction

The interests on cognitive radio technology have been increasing since Joseph Mitola introduced the concept of CR in 1999 [1]. In 2004, the Federal Communications Commission (FCC) indicated that the unused TV channels could be used for fixed broadband access [2] and it enhanced the interests of CR technology of many researchers. Since then, many regulatory bodies around the world have been developing CR based technologies and IEEE 802.22 is the first standard for Wireless Regional Area Network (WRAN) to operate on TV bands [3]. The

standard uses CR techniques to utilize the TV white space (TVWS) while ensuring no harmful interference to incumbents such as TV broadcast and wireless microphones. Although it has already standardized, we believe that there are some functions we can improve to utilize the spectrum more efficiently and to get better performance. Thus, in this article, we describe overview of 802.22 WRAN system from medium access control (MAC) point of view. Then, we discuss two important research issues, enhancing QoS and coexistence with heterogeneous networks. Nowadays, quality of service (QoS) demands have been rapidly increasing and guaranteeing QoS satisfaction for WRAN service while ensuring no interference to incumbent users will not be a trivial task. In order to improve channel utilization, many regulatory bodies have been developing CR technologies to operate on TV white spaces such as 802.11af. Therefore, coexistence issue is expected to be a great challenge in future when emerging CR technology based standards are approved.

2. Overview of 802.22 WRAN Standard

IEEE 802.22 WRAN standard has been developed with the aim of using geographically unused TV spectrum by using cognitive radio technologies while ensuring no interference to incumbent users. This standard specifies an infrastructure -based network, which is point to multi-point, and the network is formed by a Base Station (BS) and Consumer Premise Equipments (CPEs). The BS is fully responsible to control the medium access.

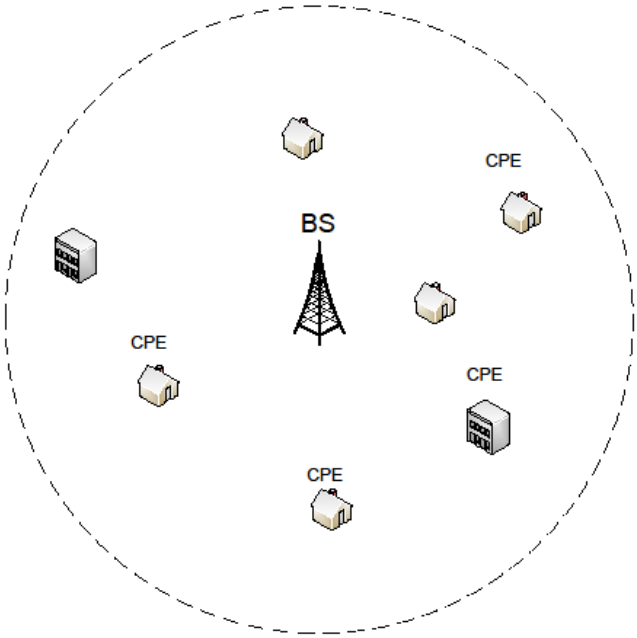

Figure 1: An IEEE 802.22 WRAN cell with a base station and CPEs

2.1 Superframe Structure

In 802.22 MAC frame format, time is divided into superframes and each superframe includes 16 frames and frame duration is 10ms (see Fig.2). Each frame is constructed with two parts: a downstream (DS) subframe and an upstream (US) subframe (see Fig.3). DS subframe is used for BS's transmissions to CPEs and it is based on TDM. US subframe is for CPEs' transmissions to BS and it is shared by CPEs on a demand basis, according to DAMA/OFDMA scheme [3]. At the end of US subframe, a self-coexistence window may be scheduled by BS and it is used for opportunistic coexistence beacon protocol bursts.

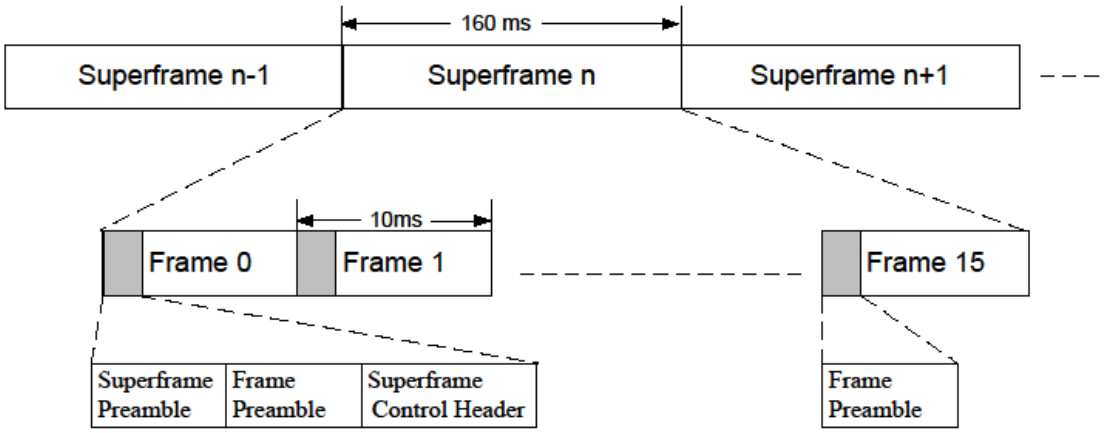

Figure 2: General superframe structure

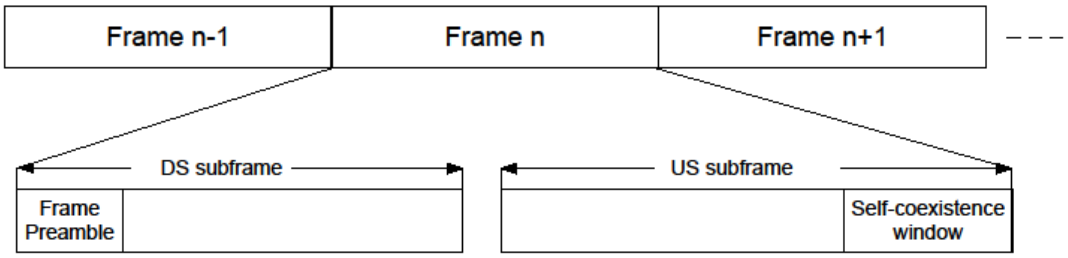

Figure 3: General frame structure

2.2 Channel Management

Channel management policy is one of the most key functions in 802.22 system. Spectrum manager is integrated in BS and the BS manages the channels according to the reports from CPEs. CPEs report channel state, incumbent users activities, coexistence information etc.

2.2.1 Channel Classifications

In 802.22 standard, channels are generally categorized as available channels and unavailable channels. The available channels are classified as:

- Operating channel : currently used by BS,
- Backup channels : potential operating channels in case of incumbents appearance,
- Protected : prohibited by local regulations
- Candidate channels : candidates for backup channels,
- Occupied channels : currently used by other WRANs and
- Unclassified channels.

Channels that are currently used by TV transmitters are classified as unavailable channels. BS maintains all the available channel sets and each CPE maintains only the first three channel sets. These channel sets are updated periodically.

2.2.2 Incumbent Protection

Incumbent protection is one of the most important functions in 802.11. Incumbent users represent licensed users of the spectrum such as analog TV, digital TV and wireless microphones. In order to protect the incumbents users, 802.22 system needs information about the usage of the TV channels. This can be done by two different techniques, incumbent database and spectrum sensing.

Incumbent databases are maintained by regulatory bodies and it contains about information of spectrum usage of incumbent users [4]. This database can be accessed by any 802.22 device. The 802.22 system sends the request with the geo-location of the BS and its associated CPEs and the database provides available channels list. These incumbent databases are also updated periodically.

Spectrum sensing can be done by both BS and CPEs. Normally, spectrum sensing is done within quiet periods which are scheduled by BS. However, BS may request to specific CPEs to perform spectrum sensing in normal operation.

If any CPE detects the incumbent signal on operating channel, it reports to BS. According to these reports, BS manages the channel by choosing some options; (1) perform channel switching or (2) request specific CPE to perform channel sensing or (3) waits more report from other CPEs. If BS decides to switch the channel, it broadcasts the channel switching request and the whole WRAN cell shall switch its operating channel to the first backup channel. Basically, 802.22 support two channel management modes, embedded mode and explicit mode. In embedded mode, the channel management messages are broadcast in every frame to the CPEs. In explicit mode, the channel management messages are sent to specific CPEs and BS dynamically manages the channel operations explicitly.

2.3 Self-coexistence

Self-coexistence means multiple overlapping WRAN cells are operating on the same channel (see Fig. 4). To operate multiple 802.22 BSs and CPEs in the same vicinity, the control information is needed to be exchanged between WRANs cell and this can be done by coexistence beacon protocol (CBP).

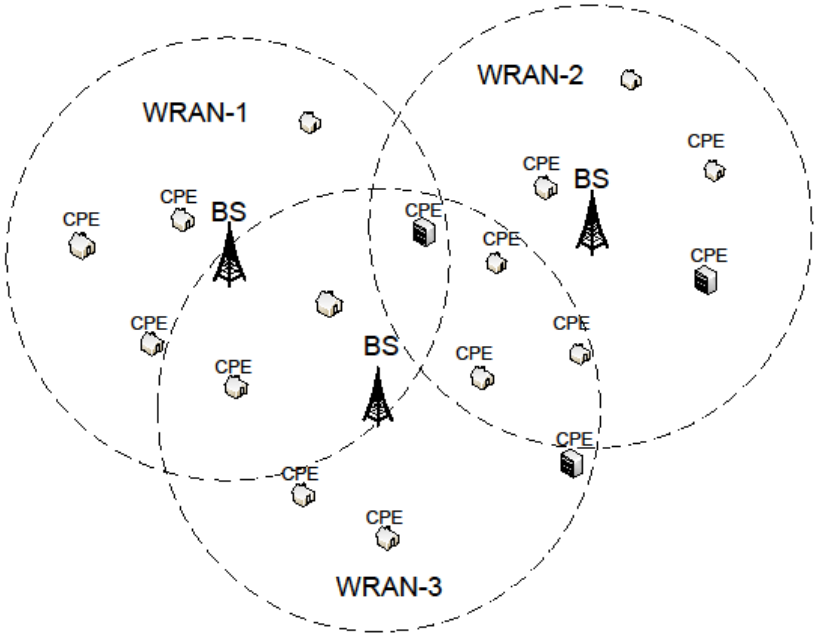

Figure 4: Self-coexistence scenario with multiple WRANS

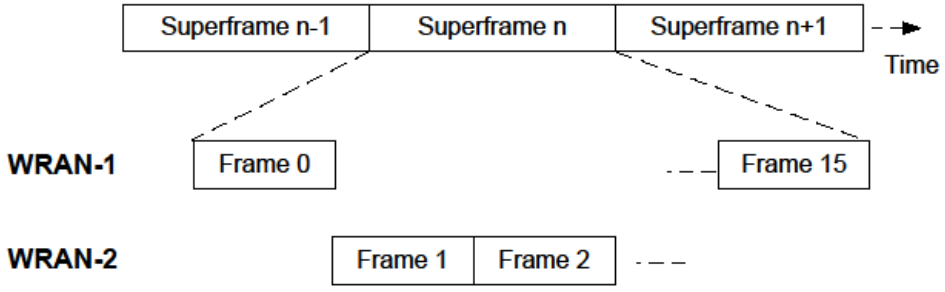

Figure 5: MAC frames allocation in self-coexistence mode

2.3.1 Coexistence Beacon Protocol

Coexistence beacon protocol is used for neighbor discovery, control information exchange among WRANs cells and inner-cell communications. Coexistence beacons are transmitted in self-coexistence window (SCW) and it includes channel information and specific time schedules. If a CPE receives a coexistence beacon from other WRANs cells, it decodes it and reports to its BS. Once BS receives the report, it changes its operating mode from normal to coexistence mode. The overlapping WRANs cell can share the frames by using on-demand frame contention protocol. A WRAN cell can request frames from other WRAN which is currently occupying the frames by using on-demand frame contention protocol and the requests are sent with coexistence beacon in SCW.

3. Research Challenges

Although it has been already standardized, we believe that some functions of 802.22 are needed to improve to utilize the spectrum more efficiently and to get better performance.

3.1 QoS

One of the most challenges in 802.22 is providing QoS requirement while ensuring no harmful interference to incumbent users. Most of CR technologies are based on multi-channel operation which means more than one data communication can be done simultaneously and it significantly enhances the throughput of the network [5][6]. However, 802.22 MAC is based on signal channel operation. Data transmission between BS and CPEs is scheduled by BS and CPEs are only allowed to transmit in allocated time slots. Moreover, if the operating channel is shared by multiple WRANs in coexistence mode, the time frames are also shared and transmission opportunities for WRANs users will be much lower than normal mode. In this situation, ensuring QoS satisfaction for WRANs services is great challenge.

In order to protect the incumbent users, 802.22 system needs to sense the channels and detect the incumbents signals. In 802.22 systems, channel sensing is done by both BS and CPEs within quiet periods which are carefully scheduled by BS. To get the reliable and accurate channel sensing results, no transmission is allowed in quiet periods and only channel sensing must be performed. So that, any signal which is detected in quiet periods can be determined as incumbent signals. However, in order to get more accurate and reliable sensing, the quiet periods need to be scheduled quite frequently and significantly long. On the other hand, scheduling the quiet periods significantly affects the throughput of network. Therefore, optimizing the trade off between throughput and reliable channel sensing will be a great research issue for 802.22 system. In [7], the authors considered to perform data transmission and spectrum sensing simultaneously to improve the throughput and satisfy the QoS requirements.

One possible solution to enhance the throughput is developing the multichannel concepts and apply in 802.22 WRAN system since many multichannel technologies for CR networks have been developed. In 802.22 system, all transmission are done only in operating channel, but in the available channel set, backup channels are also free. Therefore, data transmission can be accomplished in other channels such as backup channels. To apply the multichannel techniques, BS may needs more transceivers to support parallel transmission and receiving. Moreover, more sophisticated channel management mechanism, scheduling and sensing algorithms will be required. However, from the CPEs' point of view, only fast channel switching may be required.

3.2 Coexistence with Heterogeneous Networks

Many research efforts are currently ongoing to enable secondary access to TV white spaces (TVWS) such as IEEE 802.11af and 802.19.1 Task Groups [8]. Any CR based technology that aims to operate in TVWS should consider coexisting with not only incumbent users but also other secondary networks. 802.22 system addresses self-coexistence issue, but no mechanism for coexistence with other heterogeneous secondary networks is supported. We will mainly discuss on coexistence of 802.22 system and 802.11af which has been developing to operate the Wi-fi

(WLAN) on TVWS. Fig.6 represents the coexistence scenario of heterogeneous secondary networks especially 802.22 and 802.11af.

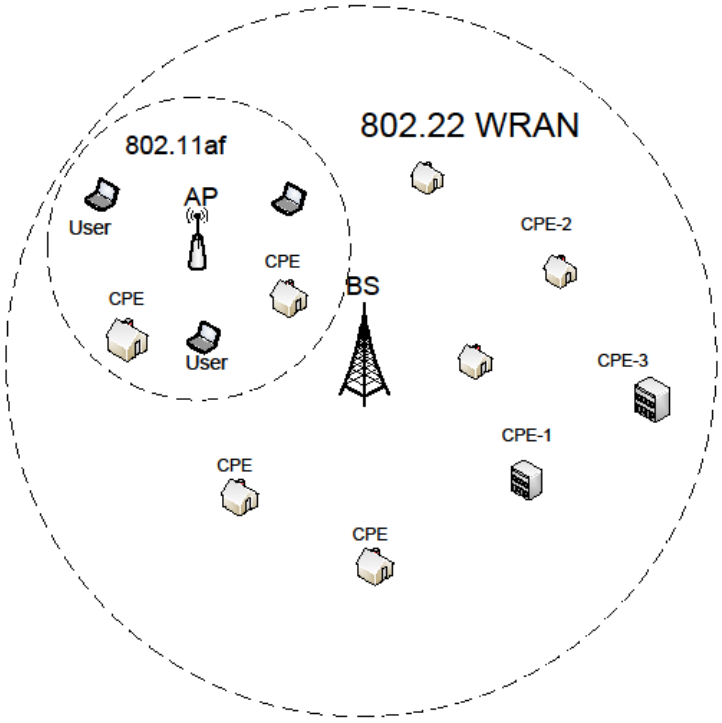

Figure 6: Heterogeneous coexistence scenario of different secondary networks

3.2.1 Network Discovery

The first challenge to coexist with different networks is secondary network discovery. Among multiple 802.22 WRAN systems, network discovery can be done by coexistence beacon protocol. Any CPE receives beacon from other WRANs, it will decode the beacon and report to its BS. Then BS changes the network operation into self-coexistence mode. Upcoming WLAN standard like 802.11af may use the beacons for network discovery. However, the problem is different standards may use different MAC frame formats and different PHY modulations. Although CPE or WLAN user receives the beacon of other networks, it may not be able to decode it and it may be confused with incumbent signal. Therefore, developing reliable network discovery mechanisms and sophisticated incumbent detection algorithms will be great challenges.

3.2.2 Spectrum Sharing

The most efficient way to utilize the spectrum is operating different networks on different channels independently. However, this might not be always possible especially when available channels are not sufficient. Spectrum sharing between different secondary networks must be considered in advance.

One of the most great challenges in spectrum sharing is different CR technologies might use different MAC strategies. 802.22 MAC is TDM-based with resource allocation while 802.11af will possibly use contention based protocols such as CSMA. CSMA mechanism is based on listen before talk, so that 802.11af users can back off if they sense the spectrum is occupied by a 802.22 system. But, 802.22 users do not need to listen before transmission and it can cause harmful interference to WLAN users [9].

Spectrum sharing among heterogeneous networks in the time domain was proposed in [9]. This mechanism has already developed for sharing the spectrum among multiple overlapping 802.22 systems (see Fig.5). As shown in Fig.7, certain time slots are allocated for 802.22 system and others are reserved for WLAN.

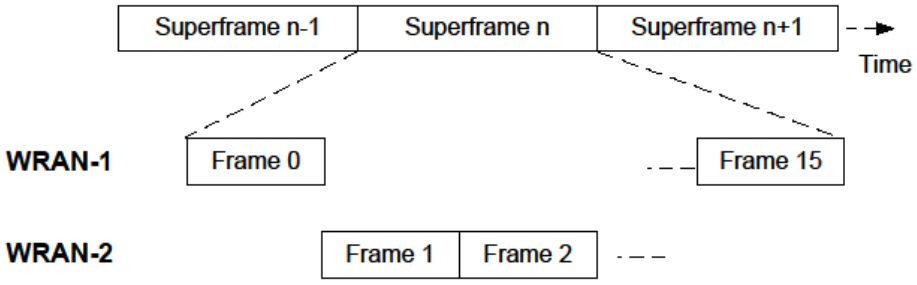

Figure 7: Spectrum sharing between 802.22 WRAN and 802.11af WLAN

Let us consider a sharing mechanism based on the above approach. Coverage area of WLAN system is much smaller than that of WRAN system, so there might be a lot of CPEs (WRAN users) that are not in the vicinity of WLAN system. Allocating the whole time frame to WLAN system and staying the rest of the 802.22 system quiet in this frame might not be necessary. 802.22 BS can schedule upstream transmission to specific CPEs that are not in the vicinity of currently operating WLAN system. In Fig.6, some CPEs , such as CPE-1, CPE-2 and CPE-3, are not in the vicinity of 802.11af WLAN system. While WLAN is operating on allocated time frame, 802.22 BS can schedule upstream transmission to these CPEs and it can cause no interference to current transmission of WLAN system.

The challenges for this approach are synchronization among different networks and internetwork communication. Synchronization among WRAN users can be obtained by Global Positioning System (GPS)[3], but this facility might not be available for WLAN users. To allocate time frames to different networks, it will require communication and negotiation among networks. The use of common control channel has been proposed for network discovery, internetwork communication and negotiation [10]. However, upcoming CR standards are not expected to use this concept [9].

4 Conclusions

The concepts of CR technologies are transforming to realities with the standardization 802.22 WRAN standard. Although it has already been standardized, we believe that the performance of

802.22 can still be improved and there are some problems to be solved. In this article, we described an overview of 802.22 WRAN standard from MAC perspective and we discussed two research issues, enhancing the QoS and coexistence heterogeneous networks.

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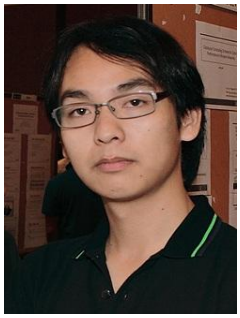

Zaw Htike received Bachelor of Computer Technology from University of Computer Studies, Mandalay, Myanmar. Since 2008, he has been working towards the Ph.D. degree at Department

of Computer Engineering at Kyung Hee University, Korea. His research interest includes cognitive radio networks, cooperative communication, MAC protocols for wireless ad hoc networks.

Choong Seon Hong received his BS and MS degrees in Electronic Engineering from Kyung Hee University, Rep. of Korea, in 1983, and 1985, respectively. In 1988 he joined KT, and worked on Broadband Networks as a member of the technical staff. Since September 1993, he joined Keio University, Japan, and received his PhD degree in March, 1997. He had worked for the Telecommunications Network Lab, KT as a senior member of technical staff and as a director of the networking research team until August 1999. Since September 1999, he has been working as a professor of the College of Electronics and Information, Kyung Hee University. He has served as a Program Committee Member and an Organizing Committee Member for International conferences such as NOMS, IM, APNOMS, E2EMON, CCNC, ADSN, ICPP, DIM, WISA, BcN and TINA. His research interest includes ad-hoc networks, network security and management. He is a member of IEEE, IEICE, IPSJ, KIPS, KICS and KISS.