Study of Protection Criterion and Signal Detections based on Cognitive Rado Techniques for IEEE 802.22 Wireless Regional Area Network (Rural FWA) in Japan

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1 Background

Currently, the radio spectrum is becomming scarcity. The scarcity of radio spectrum is mostly caused by the spectrum access technique that was so far not allowed the different systems to share the same radio resources even though they are not in use at specific location or time.

In order to improve the spectrum usage, the Federal Communications Commission (FCC) Spectrum Policy Task Force (SPTF) has proposed a new rule permitting unlicensed devices to operate in the low usage bands but without interference to the incumbent services [1].

Taking advantage of FCC proposal into account, in November 2004, the IEEE 802.22 Working Group (WG) has proposed the Fixed Wireless Access (FWA) for rural area which is called IEEE 802.22 Wireless Regional Area Network (WRAN) to operate in the TV broadcast bands [2, 3]. Notice that, the TV band has been observed as the one of the potential candidate for permit unlicensed devices to share the radio spectrum, since in the sparsely populated area there are many TV channels are unused over large geographical area [1].

The IEEE 802.22 WRAN system aims at providing the wireless broadband access to rural areas where the need for broadband service is not being met due to the physical limitations and economic realitie of wireline solutions.

However, the IEEE 802.22 WRAN system must operate without causing any harmful interference to the TV receivers. To archieve this, the Cognitive Radio (CR) technique is required to incoporate into its system in order to detect the presence or absence of TV signals and utilize only the vacant television channels.

Indeed, the major push towards the commercial deployment of IEEE 802.22 WRAN mostly comes from the U.S. In Japan, the IEEE 802.22 WRAN is just becomming interested. We expect that the usages of radio spectrum in the TV bands seem not so high and will be even after the digital TV transition, although the population density is much higher than in United States (U.S).

Our study has started from the investigation of the applicability of this system to Japan [12]. We are considering the IEEE 802.22 system to coexist with the analog TV (NTSC) and digital TV (ISDB-T) that operates in the band of 90 MHz to 770 MHz and 470 MHz to 770 MHz, respectively.

In this paper, we introduce the concept of CR technique that will be employed in IEEE 802.22 WRAN. Various signal detections based on CR are also described here. Moreover, the protection criterion of TV system from IEEE 802.22 WRAN are also described, since the IEEE 802.22 WRAN's operation coexist with the TV system.

We divide the rest of this paper as follows. In Section 2, we provide the concept of cogitive radio. The IEEE 802.22 WRAN system is presented in Section 3. In Section 4, we introduce the IEEE 802.22 WRAN issues and our research directions in Japan. The protection criterion and signal detections based on CR are presented in Section 5 and Section 6, respectively. Finally, the summarize of our work is presented in Section 7.

2 Cognitive Radio

A cognitive radio is the path of evolution from Software Defined Radio (SDR). There are at least 4 definitions of CR.

Firstly, from Joseph Mitola, CR is a radio domain model-based reasoning about radio etiquette which is the set of RF bands, air interfaces, protocols, and spatial and temporal patterns that moderate the use of radio spectrum [5].

Secondly, from Simon Haykin, CR is a smart radio that is aware of its surrounding environments and uses the methodology of understanding by building to learn from the environment and adapt its internal RF stimuli by making corresponding changes in certain operating parameters (transmit power, carrier frequency, modulation strategy etc.) in real time [4].

Third, from FCC, CR is a radio that can change its transmitter parameters based on the interaction with the environment in which it operates [1].

Lastly, from IEEE 802.22 Working Group (WG), CR is a radio frequency transmitter/receiver that is designed to intelligently detect whether a particular segment of the radio spectrum is currently in use, and jump into the temporarely unused spectrum very

rapidly, without interfering with the transmission of other authorized users [2].

From the above definitions, we see that the CR technologies hold tremendous promise in helping to facilitate more effective and efficient access to spectrum by opening opportunities for spectrum use in space, time, and frequency dimensions without interference to the incumbent users. Figure 1 shows the concept of cognitive radio system.

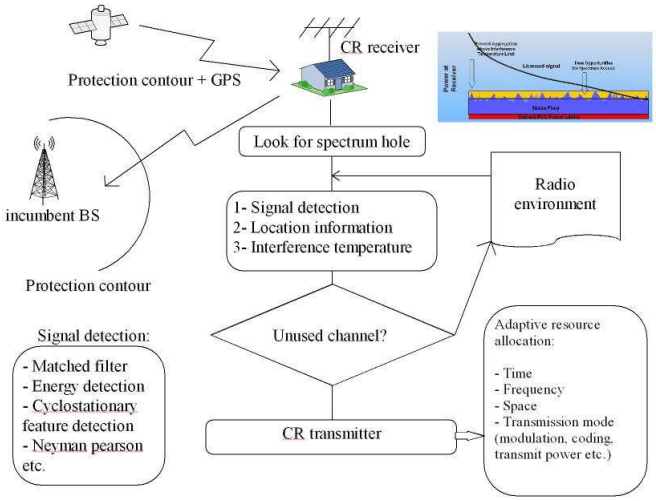

Figure 1 Concept of Cognitive Radio System

From Figure 1, a cognitive radio receiver performs the spectrum sensing to look for the spectrum hole (unused channel). This is can be done by various techniques such as signal detection methods, location awareness, and interference estimation. After complet the spectrum measurements, the CR receiver reports the results to its cognitive radio BS. The CR BS, in turns, peforms spectrum management and will decide whether the CR receiver is allowed to transmit or not.

Moreover, the CR BS shall perform adaptation over time, frequency, space, and transmit power and transmission mode.

3 IEEE 802.22 System

IEEE 802.22 WRAN system [2, 3] is a fixed point-to-multipoint wireless air interface for rural and remote area. It aims at providing the wireless broadband services (data, voice and video) to a single-family residential, multi-dwelling units, small office/home office (SOHO), small business, multi-tenant building, and public and private campuses etc.

The structure of IEEE 802.22 WRAN is composed of base station (BS) and consumer premise equipment(CPE) [7]. Figure 2 shows the deployment scenario of IEEE 802.22 WRAN in rural area.

The system parameters of IEEE 802.22 WRAN are shown in the Table 1.

In gerneral talk, the IEEE 802.22 WRAN BS manage

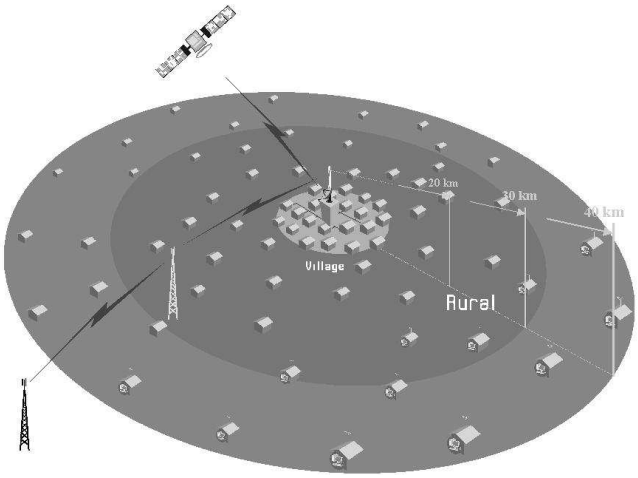

Figure 2 Deployment Scenario of IEEE 802.22 WRAN

its own cell and its asscociated CPEs. The IEEE 802.22 BS controls all the RF characteristics such as modulation, coding and frequencies operation of its CPE. Moreover, IEEE 802.22 BS shall instruct various CPEs to perform the distrubuted measurement activities and report the results to the BS. Based on the interaction results from the CPE, the BS will decide whether CPE is allowed to transmit or not. With these concepts, the interences from IEEE 802.22 WRAN to the TV systems will be reduced. Now, it is clearly seen that the IEEE 802.22 BS and CPE must rely on cognitive radio techniques.

An alternative means, the IEEE 802.22 BS should consult the database of television broadcaster to calculate the protection contour of each TV stations [1]. With this aspect, the CPE is supposed to aware about its location. If the CPE is located inside the protected contour of the TV station, it is not allowed to transmit on the co-channel or first adjacent channel of that TV station. However, if the CPE is located outside the protected contour of the TV station, it is allowed to transmit on the co-channel or other channels if its location far enougth from the protection distances.

Table 1 IEEE 802.22 system parameters

Frequency operation	617 MHz (54 to 862 MHz)
Channel bandwidth	6 MHz (6/7/8 MHz)
Spectral efficiencies	0.5 bit/s/Hz
	to 5 bit/s/Hz
Data rate	1.5 Mbps (downstream)
	384 Mbps (upstream)
BS EIRP	100 W
CPE EIRP	4 W
BS Height	75 m
CPE Height	10 m
Sevice coverage	33 Km

4 Issues and Research Direction

4.1 Issues

Unlike U.S, the Ministry of Internal Affair and Communication (MIC) in Japan is not yet to release any rules for unlicensed operation of the cognitive radio.

However, in Japan, the IEEE 802.22 WRAN is being attracted among the accademic researchers. We expect that the MIC would allow this system to implement in Japan, if there is no inteference to the TV systems.

The IEEE 802.22 will employ either signal detection mechanism or employ the geographical location informations to look for the vacant TV channels. However, in Japan, the usage of geolocation information is very difficult because the informations of each TV station as well as its protection contour are not disclosed at all. Unlike U.S, all the informations about varoius TV stations are opend to public.

4.2 Research Direction

The purpose of our research are, firstly, to study about the interference protection of TV system from the IEEE 802.22 WRAN system. We investigate whether this system can be applied to Japan. Secondly, we are seeking for some algorithms for signal detection of analog and digital TV channels to look for the unused channel for use by IEEE 802.22 WRAN system.

5 Analog and Digital Protection Criterion

Once again, the IEEE 802.22 WRAN operates in the analog and digital TV band. Therefore, the protection of analog and digital TV from the IEEE 802.22 WRAN system must be highly considering.

In our initial study, the separation distance from the IEEE 802.22 BS/IEEE 802.22 CPE to digital/analog TV is used as a protection criterion, to consider the possibility of interference avoidance.

For analog TV, the separation distance will be computed based on Noticed Proposal Rule Making (NPRM) of FCC and ITU-R recommendations as decribed in [6].

For digital TV (ISDB-T), the separation distance will be computed based on, firtsly, similarity approach to the impact study of ultra-wideband (UWB) systems [6], which is conservative to the existing system. Secondly, based on the protection criterion within ISDB-T system [8, 9].

The protection criterion for digital TV (ISDB-T) are summarized in Table 2.

In our study, we also consider two propagation models for computing the separation distances. One is the free space model and the other is spherical earth model [10].

Table 2 Protection Criteria for ISDB-T

Criterion I [6]	INR	-20 dB
Criterion II [8, 9]	Co-channel INR	0 dB

Table 3 Separation Distance

[km]	Free space		Diffraction	
	BS	CPE	BS	CPE
Criterion I: INR=0dB	4,900	1,000	73	31
Criterion II: INR=-20dB	49,000	10,000	98	54

Considering the IEEE 802.22 system model, protection criteria, and the propagation model, the separation distance is determined to satisfy the required SIR [13].

Figure 3 shows the scenario between IEEE 802.22 WRAN and ISDB-T, used for compute the separation distances between IEEE 802.22 WRAN BS/CPE and the ISDB-T receiver.

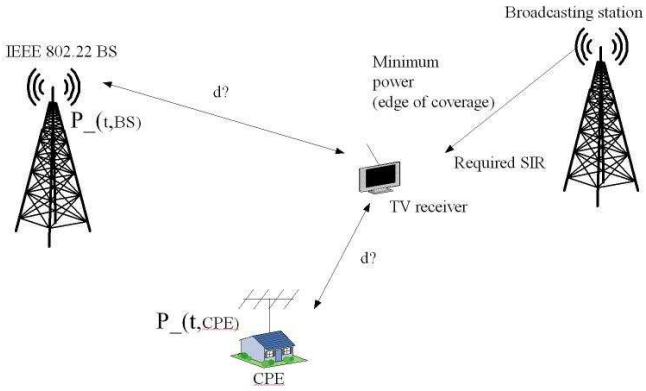

Figure 3 Protection scenario

In our study, we consider the rural application with low user density, only a single-entry case is treated.

Particularly, the separation distances between BS and ISDB-T receiver has been calculated as show in Figure 4. We suppose that the TV station brodcasts on the frequency of $617MHz$ and the IEEE 802.22 WRAN BS intends to use also the same frequency as that TV station. By using the spherical earth model, the BS must be located at least $98Km$ from the ISDB-T receiver in order to avoid interference to ISDB-T system.

Table 3 summarizes the separation distances for two protection criterion and two propagation models.

6 Signal Detections

Signal detection methods are very important for the cognitive radio system. To share the frequency resources in the same band with the existing sytems, the CR must be able to identify the unused channel of the existing systems in low signal to noise ratio (SNR).

Various detectors that have been considered in the IEEE 802.22 WRAN are matched filter, energy detec-

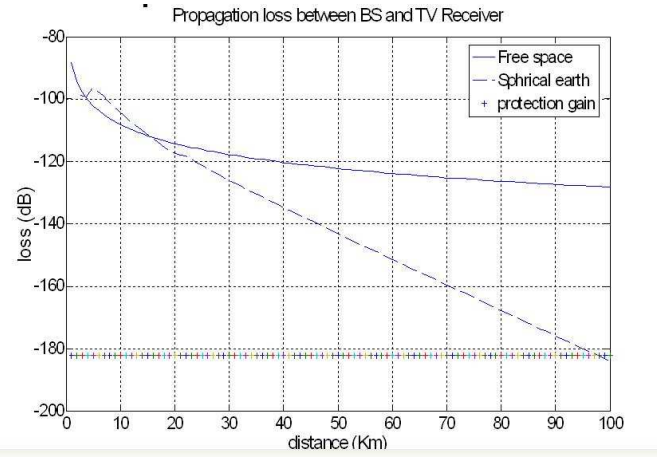

Figure 4 Separation distance between IEEE 802.22 BS and ISDB-T Rx

tor, cyclostationay feature detector etc.

In the followings, we review briefly about those detectors:

- Matched filter can maximize the received signal-to-noise ratio (SNR) but it requires the knowledge of primary user signals.
- Energy detector measures the energy around the peak area in the received signal spectrum and the decision on the absence or presence of the primary user signal is to compare with the predetermined threshold. However, it is difficult to measure the peak signal especially in the low SNR.
- Cyclostationary feature detection searches the unique cyclic frequency of different modulated signals. It does not require decoding of the primary signal and is robust to random noise and interference.

Our initial study about the signal detectors are Monte Carlo simulation and Neyman-Pearson theorem [11]. We explore those signal detectors to identify the given TV channel as either occupied by a TV signal or vacant. Based on Neyman-Pearson theorem, there are two errors can happend. First error is to decide the channel is occupied when it is vacant which is called the probability of false alarm. The second error is to decide the channel is vacant when it is occupied which is called the probability of misdetection.

We need to maximize the probability of detection while minimize the probability of misdetection. With serveral channels and signal models, the probability of detection and false alarm are studied as a function of signal to noise ratio (SNR).

7 Discussion

In this paper, we introduce the concept of cognitive radio system which is the new technology to affort the use of spectrum more efficiently and more flexibility. Moreover, the fixed wireless regional area network which is based on the cognitive radio technique is described. We see that the IEEE 802.22 WRAN system will provide the broadband services in the rural area with low cost and high speed. Various techniques of signal detections based on the cognitive radio are also introduced.

Because of the cognitive radio operate in the TV band, importantly, the separation distances between the IEEE 802.22 WRAN and the ISDB-T have been calculated.

We see that, from Table 3, free space model is too conservative considering the curvature of the earth surface. However, the spherical earth model seem to be resonable for evaluation.

Our future work is to apply the various signal detection mechanisms for detect the analog and digital TV signals. We will also study the separation distances between the IEEE 802.22 WRAN and ISDB-T system, when the adjacent-channels are attempted to use by IEEE 802.22 WRAN system.

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