Protection of Digital TV from Cognitive Radio Interference

Young-Keun Yoon, Heon-Jin Hong, and Ik-Guen Choi

ABSTRACT—Analytic modeling and computational simulation for the protection of DTV from cognitive radio interference are performed. Protection is achieved by using the protection ratio, which is derived through system modeling and its analysis. On the frequency coordination between digital TV and cognitive radio, an analysis in a co-channel environment, in a rural area in Korea, is performed.

Keywords— OFDM, ATSC DTV, vestigial sideband, protection ratio, cognitive radio.

I. Introduction

Allowable interference for protecting an incumbent service is known as the protection ratio (PR). In previous studies [1]-[3], the PR among TV broadcast services using exclusively TV bands was obtained by measurement. Such measurement requires prototype hardware, an investment of time, and other costs. In the near future, TV bands may be used for other kinds of communication systems, such as cognitive radio (CR). CR technology is attracting growing interest from academics, regulation and standardization bodies (such as IEEE 802.22), and industry. Regarding coexistence feasibility, PR was assumed in [4], and it was further assumed that the impact of CR signal on digital TV (DTV) broadcasting would be similar to that of DTV signal. However, few studies have suggested how to protect TV broadcast services. Also, the required PR has not yet been determined through measurement or simulation.

In this letter, we present analytic modeling and computational simulation for the protection of DTV from CR interference. The calculation of the PR through simulation would be a more time efficient approach than measurement. In addition, we studied co-channel DTV-to-DTV PR calculation using the proposed analytic approach. The result is similar to the PR of 15 dB based on measurement in [5]. The proposed scheme is also used to analyze the protection of DTV from CR. Several results are presented as a guide for the initial planning of frequency coordination between DTV and CR.

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II. Analytic Modeling Approach

1. System Modeling

In [6], ATSC DTV system modeling is given. The analysis of DTV protection from CR based on orthogonal frequency division multiplexing (OFDM) was proposed in [7]. A full block diagram is shown in Fig. 1. Key OFDM parameters were given in [8].

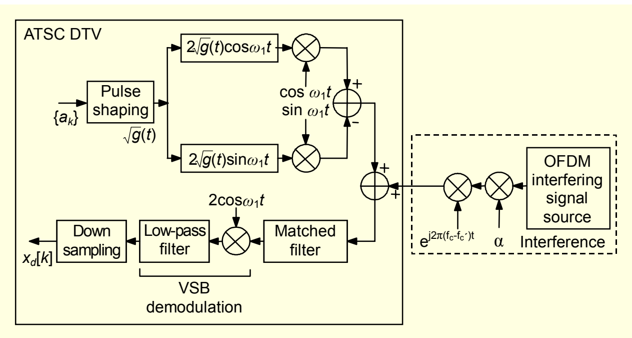


Fig. 1. Block diagram for protection of DTV from CR interference.

At the DTV transmitter, let $\{a_k\}$ be an information symbol sequence and $s(t)$ a discrete-time signal comprised of the information symbols:

$$s(t) = \sum_{k=0}^{\infty} a_k \delta(t - kT), \tag{1}$$

where T is the symbol duration of 0.093 μs in the ATSC DTV. In order to avoid inter-symbol interference (ISI), a pulse shaping filter is used at the transmitter. The pulse-shaped signal $x(t)$ is given by

$$x(t) = s(t) * \sqrt{g}(t). \tag{2}$$

The pulse-shaped signal is filtered by the vestigial sideband (VSB) filter and then up-converted with the frequency of 5.38 MHz. The resulting complex signal $x_v(t)$ can be obtained as

$$x_v(t) = [x(t) * 2\sqrt{g}(t) e^{j\omega_1 t}] e^{j\omega_1 t}. \tag{3}$$

In Fig. 1, taking the real part of $x_v(t)$ produces the real signal for transmission.

At the DTV receiver, the signal distorted by OFDM interfering signal as the real part of $x_{\text{inf}}(t)$ is first down-converted prior to matched filtering. Here, we obtain the base-band received signal $x_r(t)$ given by

$$x_r(t) = \text{Re}\{x_v(t)\} + \text{Re}\{x_{\text{inf}}(t)\}, \tag{4}$$

$$x_{\text{inf}}(t) = (1/\alpha) \cdot x_i(t) \cdot e^{j2\pi(\Delta f)t}, \tag{5}$$

where $x_i(t)$ denotes the OFDM interfering complex signal, α the ratio of DTV signal power over OFDM signal power, and Δf $(=f_c - f_c')$ frequency spacing. Here, f_c denotes the center frequency of DTV and f_c' the center frequency of CR. Under the white noise condition, matched filtering maximizes the signal-to-noise ratio (SNR) of the received signal. We demodulate the matched filtered signal by down-converting to baseband and low-pass filtering. The down-converted signal is obtained by multiplying the matched filtering signal by $2\cos\omega_1 t$. At the ATSC DTV receiver, the raw symbol error rate (SER) before trellis decoding is 0.2. This error rate has been determined by subjective testing to be the threshold of visibility (TOV) for an HDTV picture in [9].

2. DTV Protection Derivation

The PR is defined as a minimum requirement of the desired (ATSC DTV signal)-to-undesired (OFDM interference) signal power ratio.

The steps in deriving the PR are as follows.

Step 1. Set frequency spacing Δf.

Step 2. Set the relative OFDM signal power gain ratio α, and calculate the SER of the ATSC receiver.

Step 3. If the SER of step 2 is equal to the target SER (=0.2), then the value of α of step 2 is the required protection ratio; otherwise, go back to step 2 and increase or decrease the value of relative OFDM signal power gain ratio α.

III. Results

We obtained two results; the PR for the protection of DTV from CR interference and the CR requirement for frequency coordination.

1. Protection of DTV from CR Interference

Figure 2(a) shows the SER at the DTV receiver according to the relative OFDM signal power gain ratio, α. The SER gradually decreases as α increases. The PR on co-channel CR interference is 14.71 dB in case of $\Delta f = 0$, when SER is 0.2. This PR value of 14.71 dB is similar to that of DTV-to-DTV co-channel interference in [5]. Therefore, it seems a reasonable assumption that CR impact on DTV will be similar to the impact of DTV on DTV as discussed in [7]. Figure 2(b) shows the expected DTV PR according to frequency spacing (Δf), when the SER is 0.2. As shown in Fig. 2(b), the DTV PR in the co-channel when $\Delta f = 0$ is

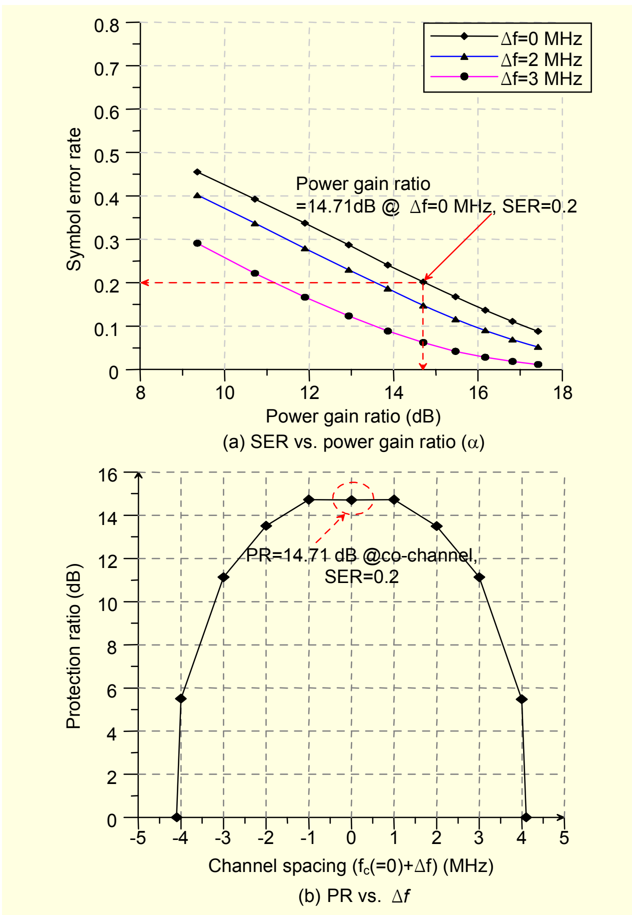


Fig. 2. Protection of DTV from CR.

14.71 dB, and the DTV PR in the second adjacent channel when $\Delta f = 2$ is 13.5 dB. These results show that the DTV PR in the co-channel must be limited much more than that in the adjacent channel.

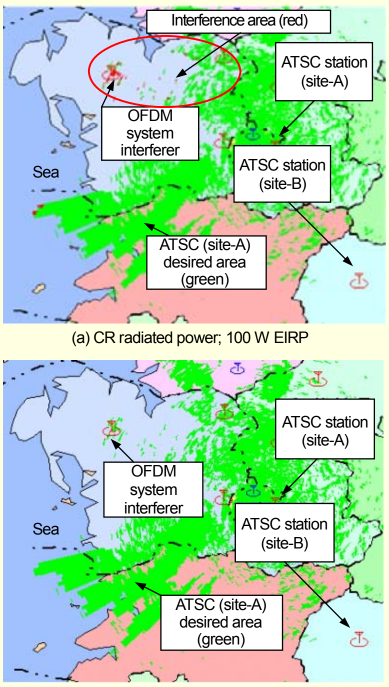
2. Frequency Coordination between DTV and CR

The DTV station parameters are summarized in Table 1, along with the parameters for the CR system [4]. The DTV station used is located in Korea, where stations are located in rural areas. Also, CR antennas should be polarized orthogonally to DTV antennas to provide additional isolation through cross-polarization discrimination [7]. Moreover, the antenna height of the CR transmitter is 75 m. Figure 3 shows only one CR system (OFDM system interferer) and site A, which is one of several ATSC stations. We considered and defined these for frequency coordination.

For frequency coordination between DTV and CR using a co-channel frequency, the CR interfering signal level should be less than the desired DTV signal level by as much as the expected PR value of 14.71 dB. Otherwise, the DTV stations of some regional areas would be affected by CR interference. Figure 3(a) shows the effect of CR interference (red) in the ATSC service area (green) when the CR transmit power is 100 W EIRP. The CR interfering signal level is much higher than the desired DTV signal level when the desired DTV signal level is 38.72 dBμV/m in the ellipse region. Therefore, the CR transmit power must be limited to less than 4 W EIRP, as shown in Fig. 3(b) for CR coexistence with DTV.

Table 1. Parameters for frequency coordination.

CR (interferer)		ATSC DTV station
Parameter	Values	Values
Center frequency	473 MHz	473 MHz
Radiated power	100 W /4 W (EIRP)	2.5 kW (conducted power)
		10.3 dBi (antenna gain)
Service availability	F(50, 99.9)	F(50, 90)
Required minimum field strength	28.8 dBμV/m	38.72 dBμV/m
Polarization	Vertical	Horizontal



(a) CR radiated power; 100 W EIRP

(b) CR radiated power; 4 W EIRP

Fig. 3. CR interference effect into DTV.

IV. Conclusion

This letter presented analytic modeling and computational simulation for the protection of DTV from CR interference. As a result, we concluded that the DTV PR on CR co-channel interference should be at least 14.71 dB.

Regarding frequency coordination between DTV and CR, an analysis on the possibility of regional coexistence in a co-channel interference environment was performed. The CR transmit power would need to be rigidly restricted in rural areas in Korea.

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