Spectral Efficiency of WRAN Spectrum Overlay in the TV White Space

Cha Sik Leem, Sang Won Kim, Chang-Joo Kim, Sung-Chul Kang, and Jaiyong Lee

ABSTRACT—In this letter, we investigate the spectral efficiency of IEEE 802.22 wireless regional area network (WRAN) spectrum overlay when it is used in TV white space. Since 2004, when the FCC published the notice of proposed rule making 04-186 to make use of unused TV spectrum, the IEEE 802.22 working group has been standardizing specifications for WRAN operations. There have been a few papers investigating the spectral efficiency of this, but their analyses were limited to the cases for various guard distances between WRAN base stations. Since WRAN base station (BS) power for WRAN service may differ from country to country, it is important to analyze the spectral efficiency for various WRAN BS powers. In this letter, we analyze the spectral efficiency of WRAN spectrum overlay as a function of the power of WRAN BSs. The simulation results show that spectral efficiency decreases as the power of WRAN BSs and guard distances increase.

Keywords—WRAN, spectral efficiency, white space.

I. Introduction

In the past, most of the radio spectrum has been managed by government by "command and control" mechanisms. This management method was effective when radio technology was immature and the demand for the spectrum was low. However, demand for the radio spectrum has grown with advances in radio technology while radio resources have remained limited. On the other hand, spectrum measurement data shows that some bands of the spectrum are heavily used while others are not [1], resulting in an overall spectrum usage of less than 15%. Thus, dynamic spectrum access technology, such as cognitive radio (CR) should play an important role in the efficient use of the radio spectrum.

In 2004, the FCC published the notice of proposed rule making 04-186 to utilize the unused spectrum in the TV band [2]. There were two types of devices recognized for CR applications in the TV white space. One type is fixed access devices with 4 W EIRP, and the other type is personal/portable devices with 100 mW peak transmitter power.

The IEEE 802.22 wireless regional area network (WRAN) working group was formed in November 2004 to develop a standard for fixed access service in TV white space and completed its functional requirements in September 2005. WRAN networks aim to provide wireless broadband service with capability close to ADSL or cable modem, as shown in Table 1, in rural areas where the population density varies from 1.25 people/km^2 to 60 people/km^2 using vacant TV channels.

Figure 1 shows a WRAN service scenario. The WRAN

Table 1. Characteristics of the WRAN system.

Parameter	Values
Capability	Close to ADSL or cable modem (1.25 to 60 people/km^2)
Service range	30 km typically (max. 100 km)
User terminal characteristic	Fixed
Serivice type	Point to multi-point (P-MP)
Frequency range	42 MHz to 862 MHz (VHF/UHF TV band)

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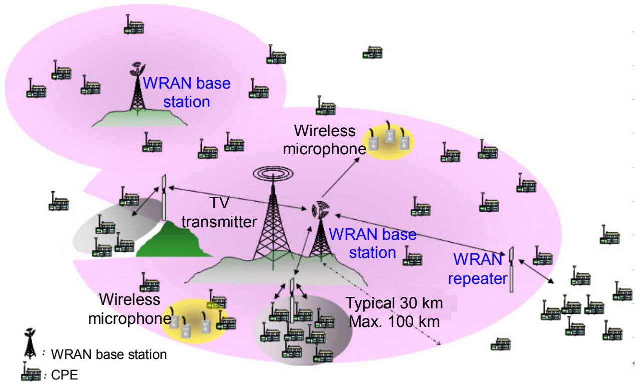

Fig. 1. WRAN service scenario [3], [4].

Table 2. Parameters used in the simulation.

Parameter		Values
Interference region (W_a)		400 km $\leq W_a \leq$ 800 km
Bandwidth		6 MHz
DTV system	Radius (r_d)	135 km (57,256 km^2)
	Protection range (p_d)	16 km for 4 W CPE EIRP
	Data rate	19.4 Mbps/6 MHz
WRAN system	Radius (r_c)	16.7 km for 4 W BS EIRP, 30.3 km (3,421 km^2) for 100 W BS EIRP
	Data rate	18 Mbps (@6 MHz, downlink)

system makes use of TV white space in the frequency ranges from 42 MHz to 862 MHz [3] in an opportunistic way but depends on the radio regulations of the country for the WRAN service. Thus, WRAN spectrum overlay is very important for the efficient use of a limited radio spectrum. However, there have been few analyses of how much spectrum efficiency can be achieved when WRAN spectrum overlay is used. Leem and others [5], [6] analyzed spectral efficiency when the guard distance of the WRAN system varies from $0r_c$ to $2r_c$, where r_c is the radius of a WRAN cell. Note that WRAN coverage is typically 30 km up to a maximum of 100 km. WRAN service is of the P-MP type, and the maximum EIRP for both WRAN base station (BS) and WRAN CPE is 4 W, which leads to an imbalance in the downlink and uplink coverage. The downlink coverage is much shorter than the uplink coverage because the WRAN BS power has to be shared among all the active CPEs. For these reasons, some countries are considering 100 W EIRP for the WRAN BS power to correspond to the 4 W EIRP of the CPEs, and many countries may be using a BS power between 4 W and 100 W EIRP. Hence, we need to investigate the effects of WRAN cell size. In this letter, we analyze the spectral efficiency of WRAN spectrum overlay as a function of WRAN cell size in TV white space.

II. Model Descriptions

To evaluate the spectral efficiency of WRAN spectrum overlay, we made the following assumptions. The target area for evaluation of spectral efficiency is $W_a^2 (W_a \times W_a)$ km^2, where W_a is a distance on the x- and y-axes and is greater than or equal to $2(r_d+p_d)$, where r_d is the radius of the TV service coverage, p_d is the DTV protection range, r_c is the radius of WRAN service coverage, and k_w is the guard distance between WRAN BSs. The parameters used in this simulation are described in Table 2.

Figure 2 shows the target area for the evaluation of spectral

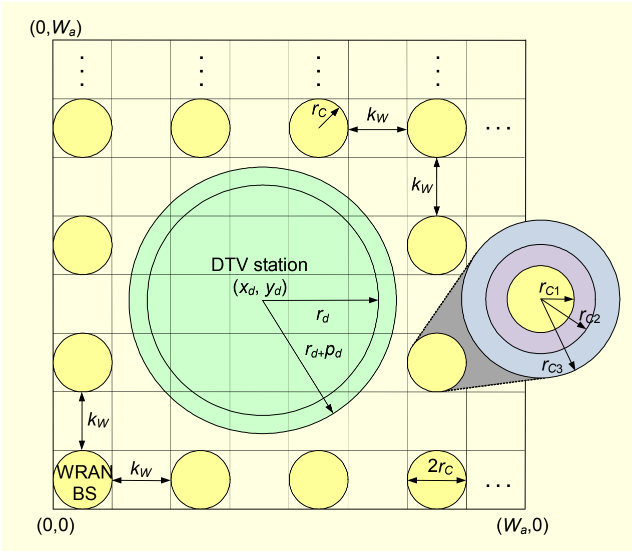

Fig. 2. Evaluation model of WRAN spectral efficiency in the white space.

efficiency. Service coverage of the DTV station is located inside the target area. The WRAN BS is deployed according to the tier-by-tier scheme [5], [6].

III. Simulation and Discussion

The BS power of WRAN systems can vary depending on the radio regulations of the country for the WRAN service. For example, it can be 4 W EIRP on an unlicensed basis in some countries, while it can be 100 W EIRP under licensed conditions in other countries. Therefore, it is important to take the power effects into consideration for analysis of the WRAN spectral efficiency. We investigate the spectral efficiency of our model for a variety of WRAN BSs, operating from 4 W EIRP to 100 W EIRP. The ITU P.1546 path-loss model is used to calculate both the protection range (p_d) for a DTV system and service coverage (r_c) for a WRAN BS as shown in Table 2 [7].

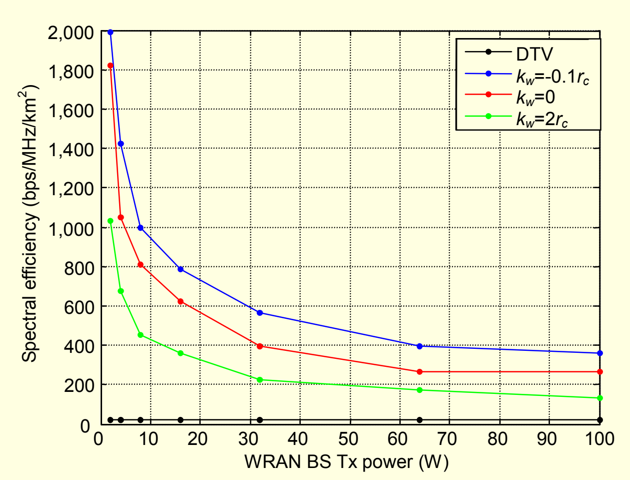

Fig. 3. Spectral efficiency as a function of WRAN BS power (W_a = 400 km).

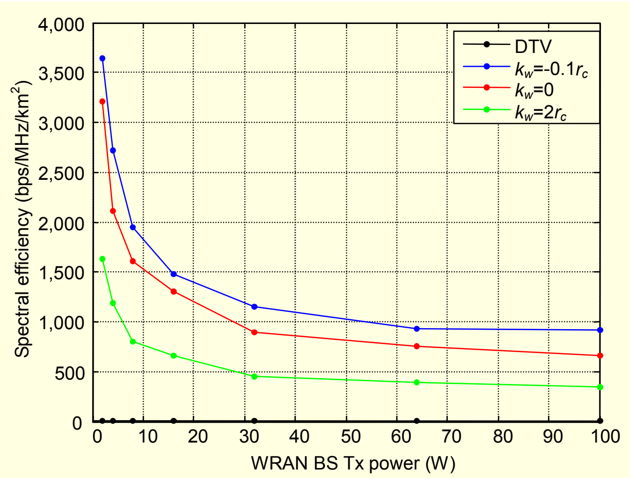

Fig. 4. Spectral efficiency as a function of WRAN BS power (W_a = 800 km).

In Fig. 2, W_a varies from 400 km to 800 km to see the effects of target area size. As a performance measure, spectral efficiency is defined as

$$SE = \frac{R_{\text{DTV}} + \sum_{i=1}^{N} R_{\text{WRAN},i}}{S \times BW} \quad \text{bps/MHz/km}^2, \qquad (1)$$

where R_{DTV} is the DTV transmission rate, $R_{\text{WRAN},i}$ is the i-th WRAN transmission rate, N is the number of WRAN BSs, and S is the target area.

Figure 3 shows the spectral efficiency of WRAN spectrum overlay as a function of WRAN BS power which varies from 4 W EIRP to 100 W EIRP when W_a=400 km. Spectral efficiency with WRAN spectrum overlay is at least 100 times higher than DTV alone in this simulation. Also, the lower the power of a WRAN BS is, the higher the spectral efficiency. The spectral efficiency of a WRAN BS with 4 W EIRP is five times higher than it is with 100 W EIRP. Also, the spectral efficiency with k_w= 2r_c is lower than when k_w= - 0.1r_c because it has less space for the WRAN BS. Spectral efficiency generally decreases with the size of the guard distance.

Figure 4 shows the spectral efficiency of WRAN spectrum overlay as a function of WRAN BS power which varies from 4 W EIRP to 100 W EIRP when W_a=800 km. The general trend in spectral efficiency is similar that shown in Fig. 3. The overall spectral efficiency in Fig. 4 is higher than that with W_a=400 km because the number of WRAN BSs in this case is higher.

IV. Conclusion

In this letter, we have analyzed the spectral efficiency of WRAN spectrum overlay in TV white space. Simulation results show that WRAN spectrum overlay improves the spectral efficiency drastically by reusing TV white space. Moreover, the lower the power of a WRAN BS is, the higher the spectral efficiency. Comparison shows that the spectral efficiency of a WRAN BS with 4 W EIRP is five times higher than it is with 100 W EIRP. The overall spectral efficiency with W_a=400 km is lower than that with W_a=800 km because the number of WRAN BS in this case is reduced compared to that of W_a=800 km. Also, spectral efficiency generally decreases with the size of the guard distance.

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