

Transmit Power Control Scheme for TV White Space Wireless System

Sang Yun Lee, Mee Kyong Kwon, Seung Hun Lee

Office of Policy Research, Korea Radio Promotion Agency

78 Garak-dong, Songpa-gu, Seoul, 138-803, Korea

sylee76@korpa.or.kr

Abstract— White space means spatially (or temporally) unused spectrum and this can be used on a unlicense basis. Since protecting primary users from harmful interference is the most important issue in unlicensed spectrum access on a secondary basis, regulatory authorities mandate the use of geolocation and DB (database) access capability as interference avoid scheme. The main role of this white space DB is to notify white space device of information required to use spectrum e.g. available channel or maximum transmit power level. Therefore, it is important to devise optimum allocation scheme in order to fully exploit scarce spectrum resources. In this paper, we investigate how DB allocates transmit power in a sense that maximizes total system uplink throughput. There are transmit power constraints in this system, i.e. sum of transmit power of all users are should be controlled so as not to make harmful interference to primary users. With this constraint, we consider optimization problems which maximize total system uplink throughput and show the solution of the optimization problem becomes well known water-filling algorithm.

Keywords— TV white space, power control, constraint optimization, water filling problem

I. INTRODUCTION

Geographically unused spectrum in TV broadcasting band, called ‘TV White Space’, is authorized by FCC in 2008 to be accessed on a unlicensed basis. TV white space is considered as good candidate for CR based spectrum sharing technology for some reasons [1]. First, spectrum usage behaviour is relatively static in respect of location of radio station, transmit power, and frequency since these bands are mainly used for TV broadcasting service. With the fact that the channel bandwidth is wide of 6 or 8MHz, this facilitates spectrum sensing. Relatively low UHF band enables economical system deployment because of good propagation characteristics. Furthermore, the fact that 80% of TV subscribers receive DTV signal through CATV lower the possibility of suffering harmful interference from white space devices (WSD).

Since protecting primary users from harmful interference is most important issue in unlicensed spectrum access on a secondary basis, regulatory authorities mandate the use of geo-location and database access capability as a supplemental measure of spectrum sensing [1], [2]. In this scheme, first, WSD notifies its location information getting from geo-location capability, e.g. GPS, to white space database

(WSDB), then WSDB informs WSD of available channels (or possibly maximum transmit power level) in order to protect incumbent users from harmful interference induced by WSD. When WSDB notifying available channel, maximum transmit power of WSD can also be controlled by informing possible maximum power level while keeping interference to an acceptable level for the purpose of making spectrum efficiency increased rather limiting maximum transmit power to a fixed level.

In [3], area spectrum efficiency of TV white space wireless system with transmit power control is studied. However, power control scheme is not presented. In this paper, we investigate transmit power control scheme which maximizes total uplink system spectral efficiency while keeping interference at TV service contour to minimum level. The remainder of this paper is organized as follows. The next section introduces geolocation and DB access scheme and describes channel and system model. Section III presents transmit power control by solving optimization problem and numerical result is shown in section IV. Finally, conclusion will be drawn in section V.

II. SYSTEM MODEL

A. Geolocation and DB Access

As interference avoid scheme for TV white space spectrum, several schemes are considered including spectrum sensing, beacon signal, and geolocation and DB access. However, regulation authorities who permit unlicense based use of TV white space mandate the use of geolocation and DB access scheme or decided it is most practical scheme since spectrum sensing technology is still in early stage.

In this scheme, WSDB which contains information of radio stations (e.g. frequency, location, Tx power) operating in certain area performs critical role in interference protection. The scheme work as follows. First, WSD notifies its location information getting from geo-location capability, e.g. GPS, to white space database (WSDB), then WSDB find available channels (or possibly maximum transmit power level) in order to protect incumbent users from harmful interference induced by WSD and WSDB informs WSD of result.

When WSDB decides available channel or Tx power level, WSDB may use propagation model using GIS to estimate interference level at TV service contour.

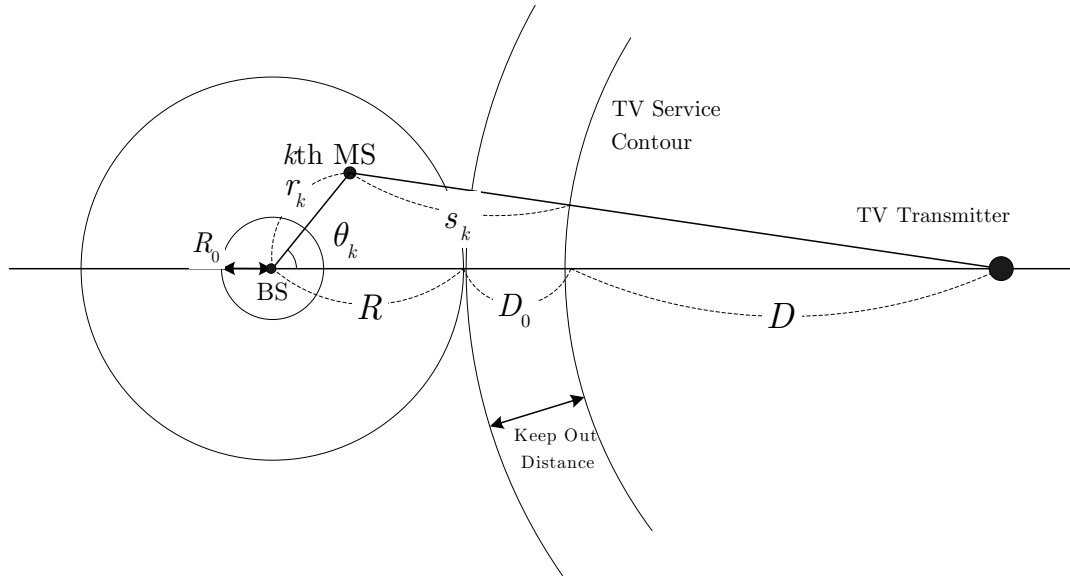


Figure 1. System Arrangement

When WSDB notifying available channel, maximum transmit power of WSD can also be controlled by informing possible maximum power, i.e. WSDB can control transmit power of WSD. Specifically, since TX power can be increased while protecting incumbent users, system throughput (or spectral efficiency) also can be increased.

B. Channel and System Model

Though signal propagation in radio mobile environment is affected by deterministic path-loss variation with distance, random slow shadowing, and random fast multipath fading, we consider only path-loss for the simplicity of analysis. Path loss in TV broadcasting band is modelled by F-curves, which are statistical propagation models derived from actual measurements, and are fully specified by operating band, effective radiated power (ERP), antenna height above average terrain (HAAT), location (l), and time (t) percentage reliability requirements in the format of $F(l, t)$ [4]. The FCC has proposed utilizing $F(50,10)$ propagation curves for modelling WSD co-channel interference levels, and $F(50,50)$ curves for modelling adjacent channel interference model. However, $F(50,10)$ curves are generally ill-defined for propagation distances of less than 15km, and both $F(50,10)$ and $F(50,10)$ curves are undefined for transmit antenna height below 30m, which corresponds many WSD use cases. Therefore, computationally simple but relatively correct two-ray propagation model is proposed [4].

According to this model, the average received signal power from the k th mobile with Tx power $P_{t,k}$ is given by

$$P_{r,k} = G(d_{BW}^2 / r_k^4) P_{t,k} \quad (1)$$

where G is constant, r_k [m] is distance between the k th mobile and BS, The parameter d_{BW} [m] is break-point

between square-law and fourth-law path-loss curve and is given by $d_{BW} = 2h_{TX}h_{RX} / \lambda_c$, where h_{TX} [m] is the transmit antenna height, h_{RX} [m] is the receive antenna height, and λ_c [m] is the wavelength of the carrier frequency.

Consider white space system whose coverage area is located at close to the co-channel TV service contour as shown in Figure 1. This arrangement can be considered as extreme situation, where the system spectrum efficiency can be maximized by using multiple frequency reuse cell. In Figure 1, D and R represent TV service contour radius and cell radius of white space system, respectively. D_0 represents TV service contour radius and keep-out distance for protecting TV receivers from harmful interferences.

Transmit power of MS's in the cell for white space service can be controlled through accessing WSDB. WSDB files radio station permission records including location, carrier frequency, transmit power, etc. In order to protect wireless microphone or camera used in arena or venue, sporting or performance events information is also filed in DB. Based on these information, WSDB can determine maximum transmit power level so as not to increase CIR level of incumbent user above required interference protection ratios which is specified in terms of desire-to-undesired (D/U) signal levels as shown in Table 1.

TABLE 1. REQUIRED INTERFERENCE PROTECTION RATIO

Type of Service	Channel Offset	Interference Protection (D/U)Ratio (dB)
Analog TV	Lower Adjacent	-14
	Co-Channel	34
	Upper Adjacent	-17
Digital TV	Lower Adjacent	-28
	Co-Channel	23
	Upper Adjacent	-26

III. TRANSMIT POWER CONTROL

In this section, we formulate constraint optimization problem for TV white space wireless system considered in this paper and show that optimum transmit power control algorithm becomes well known water-filling algorithm.

A. Problem Formulation

The aim of the optimum transmit power control scheme considered in this paper aim is to maximize uplink system throughput while protecting incumbent TV band users.

First, using Shannon capacity formula, uplink system spectrum efficiency to be maximized can be written as

$$\eta = \frac{1}{W} \sum_{k=1}^K W_k \log_2 \left(1 + \frac{P_{r,k}}{I} \right) \quad (2)$$

where W_k is band bandwidth of k th MS, total bandwidth $W = \sum_{k=1}^K W_k$, and interference power to BS, I is given by $I = G \left(\sqrt{d_{B,T}} / (D + D_0 + R) \right)^4 P_t$.

Denoting D_p as signal level received from TV broadcasting transmitter with power P_t and U_p as signal level received from the k th MS with power $P_{t,k}$, in order to protect TV band users in TV service contour, transmit power of MS's $P_{t,k}$ should satisfy following constraint

$$D_p / U_p > \beta \quad (3)$$

where β is protection ratio. Using propagation model of (1), signal level is given by $D_p = G \left(d_{B,T}^2 / D^4 \right) P_t$. Since undesired signals are resulted from transmit signal from K mobile stations, referring system arrangement of Figure 1, aggregated undesired signal power is obtained from the sum of arrived signal power from MS's at TV service contour as

$$U_p = G \sum_{k=1}^K \left(d_{B,W}^2 / s_k^4 \right) P_{t,k} \quad (4)$$

where $s_k = \sqrt{r_k^2 + (R + D_0 + D)^2 - 2r_k(R + D_0 + D) \cos \theta_k} - D$. Using definitions of D_p and U_p , we can rewrite (3) as

$$\sum_{k=1}^K \bar{P}_{r,k} < \delta \quad (5)$$

where $\bar{P}_{r,k} \triangleq \gamma_k P_{r,k}$, $\gamma_k \triangleq r_k^4 / (G d_{B,W}^2 s_k^4)$, and $\delta \triangleq \left(d_{B,T}^2 P_t \right) / \left(\beta d_{B,W}^2 D^4 \right)$. By using the same manner, we can rewrite uplink system spectrum efficiency (2) as follows

$$\eta = \frac{1}{W} \sum_{k=1}^K W_k \log_2 \left(1 + \frac{\bar{P}_{r,k}}{\gamma_k I} \right). \quad (6)$$

Since we are to maximize uplink spectrum efficiency η by increasing transmit power of MS, the constraint of (5) can be rewrite as

$$\sum_{k=1}^K \bar{P}_{r,k} = \delta. \quad (7)$$

B. Optimum Transmit Power

The optimum transmit power can be obtained by finding $\bar{P}_{r,k}$ which maximize (6) subject to (7) and the constraint optimization problem can be solved by using Lagrangian multiplier method. Set up objective function that incorporate constraint (7)

$$J = \frac{1}{W} \sum_{k=1}^K W_k \log_2 \left(1 + \frac{\bar{P}_{r,k}}{\gamma_k I} \right) + \lambda \left(\delta - \sum_{k=1}^K \bar{P}_{r,k} \right) \quad (8)$$

where λ is Lagrange multiplier. Thus, differentiating (8) with respect to $\bar{P}_{r,k}$, then setting to the result zero, i.e. $\partial J / \partial \bar{P}_{r,k} = 0$ and assuming that all MS's are allocated the same bandwidth $W_k = W / K$, we can see that the optimization problem becomes well known water-filling problem as

$$\bar{P}_{r,k} + \gamma_k I / K = 1 / (\lambda \ln 2). \quad (9)$$

By solving $K + 1$ equations of (7) and (9), we can find $\bar{P}_{r,k}$, $k = 1, \dots, K$ and transmit power can be obtained from the relation of $P_{t,k} = s_k^4 \bar{P}_{r,k}$. In practical system, various loading algorithms can be applied to find $\bar{P}_{r,k}$, $k = 1, \dots, K$ and s_k can be calculated directly since WSDB knows location of MS's, TV service contour. By the same reason, r_k and γ_k also can be obtained easily.

IV. NUMERICAL RESULT

In this section, we evaluate average uplink spectral efficiency. Since, as shown in (6), uplink spectral efficiency varies with the location of MS, the average uplink spectral efficiency can be obtained as

$$\bar{\eta} = \frac{1}{K} \sum_{k=1}^K \int_0^{2\pi} \int_{R_0}^R \log_2 \left(1 + \frac{\bar{P}_{r,k}(r_k, \theta_k)}{\gamma_k(r_k, \theta_k)I} \right) p_{r_k}(r_k) p_{\theta_k}(\theta_k) dr_k d\theta_k \quad (10)$$

where we assume that $W_k = W / K$, $p_{r_k}(r_k)$ and $p_{\theta_k}(\theta_k)$ are PDF of mobile location in polar coordinates (r_k, θ_k) relative to their BS's. MS's are assumed to be uniformly distributed in the cell, i.e, PDF of mobile location is given by

$$p_{r_k}(r_k) = 2(r_k - R_0) / (R - R_0)^2, \quad R_0 \leq r_k \leq R \quad (11)$$

$$p_{\theta_k}(\theta_k) = 1 / (2\pi), \quad 0 \leq \theta_k \leq 2\pi \quad (12)$$

where R_0 corresponds to the closest distance the mobile can be from the BS antenna, and is approximately equal to 20 m for microcellular systems and 80 m for macrocellular systems. Since it is hard to express (10) in a closed form, numerical results are obtained by Monte-Carlo simulation as in [5]. Table 2 shows simulation parameters.

TABLE 2. SIMULATION PARAMETERS

Parameter	Number
Carrier frequency	600 MHz (CH 35)
Keep-out distance (D_0)	15 km
Antenna height (h_{TX}, h_{RX})	MS : 9 m, BS : 30 m, TV transmitter : 450m, TV receiver : 10m
TV transmit power (P_t)	5 kW
TV service area (E-field strength over 41dBu)	168 km
Interference protection ratio (β)	Co-channel : 23 dB Adj-channel : -28dB

Figure 2 shows the plot of average uplink spectral efficiency versus number of mobiles in cell. Figure 2 quantifies how spectral efficiency varies as the number of mobiles increases. In this figure, it is shown that average spectrum efficiency is high when interference protection ratio is low. Since transmit power of each user is controlled while keeping aggregated interference power level below interference protection ratio, transmit power can be increased when interference protection ratio is low and system throughput also can be increased.

It is also shown that average spectrum efficiency decreases as the number of user increases. This is because transmit power of each user should be decreased in order to decrease interference power resulted from increased user number. On the contrary, when interference protection ratio is high ($\beta=23\text{dB}$ in figure 2), average spectrum efficiency increases as the number of user increases. In this case, interference protection ratio is very high and transmit power is restricted at relatively low level. Thus, contribution of transmit power decrease is lower than that of user increase.

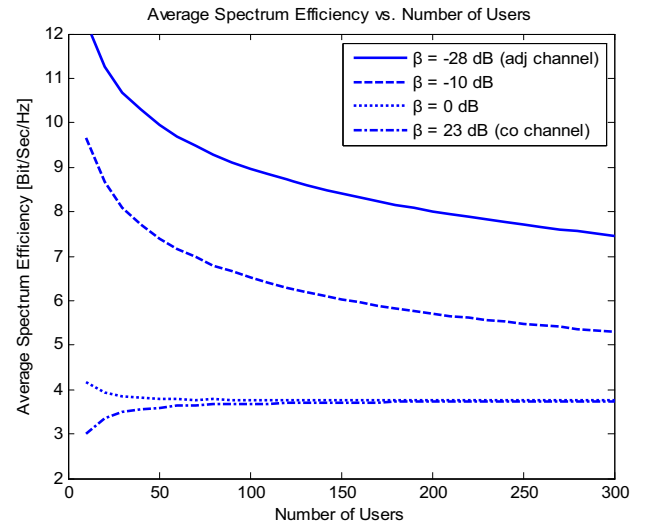


Figure 2. Average Uplink Spectral Efficiency vs. Number of Mobiles in Cell

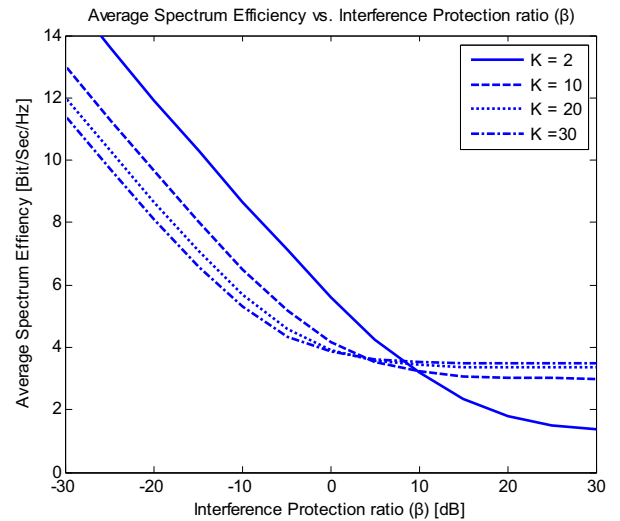


Figure 3. Average Uplink Spectral Efficiency vs. Interference Protection Ratio(β)

Figure 3 depicts the effect of interference protection ratio to average spectrum efficiency. As explained before, as user increases, the contribution of transmit power decrease is dominant at low interference protection ratio region (corresponding to adjacent channel) but vice versa at low interference protection ratio region (corresponding to co-channel).

V. CONCLUSION

We introduce transmit power control scheme for TV white space wireless system using geolocation and DB access as interference avoid scheme. DB informs users of available channel and allowable transmit power. Thus, DB can control transmit power of each user. However, since TV white space spectrum is used without licence, WSD should not cause interference to incumbent users. With this constraint, we proposes power control scheme which maximize spectrum

efficiency and the resulted scheme is same as well known water-filling problem. By simulation, it is shown that average spectrum efficiency increases as the number of user increases when using co-channel but vice-versa when using adjacent channel.

In that primary role of WSDB is to notify users of available channel, WSDB may perform bandwidth allocation as in [6]. Thus, joint resource (bandwidth and power) allocation scheme also can be studied.

REFERENCES

- [1] FCC, "Second report and order and memorandum opinion and order," ET Docket No. 08-260, Nov. 2008.
- [2] Ofcom, "Digital Dividend: cognitive access," Statement, July, 2009.
- [3] S.Y. Lee et al, "Area spectral efficiency of TV white space wireless system with transmit power control, " in *Proc. of ICACT 2010*, pp. 1061-1066, Feb. 2010.
- [4] D. Gurney, et al, "Geo-location database techniques for incumbent protection in the TV white space," in *Proc. of IEEE DySPAN 2008*, pp. 1-9. 2008.
- [5] M-S. Alouini and A. J. Goldsmith, "Area spectral efficiency of cellular mobile radio systems," *IEEE Trans. Vech. Tech.*, vol. 48, no. 4, pp 1047-1066, 1999.
- [6] D. Niyato, E. Hossain, and Z. Han, "Dynamic spectrum access in IEEE 802.22 based cognitive wireless networks: A game theoretic model for competitive spectrum bidding and pricing," *IEEE Wireless Commun.*, vol. 16, pp.16-23, April, 2009.