Reserved Distance and Significant Parameter Determination in Incumbent and TV White Space System Coexistence

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Abstract. In the bandwidth demanding world, TV white space is becoming one of the promising options. Its use as a secondary system with incumbent system must be managed in order not affect the primary users. This can be done by determining first the incumbent coverage and then the spatial variation that should be kept in order to maintain unaffecting region. Our primary concern is keeping the incumbent users safe. This is accompanied by different methods to keep the secondary device non interfering. The interference can be avoided by efficient cognitive radio technique or spatial variation between the two systems. The later technique requires efficient signal modeling and planning. The secondary system should be deployed in an area that is out of primary coverage. This is done by first determining the incumbent coverage. To determine this coverage, different factors must be taken in to account. Frequency and antenna height are of the significant factors. After the signal range of primary transmission with receivable quality is determined, we have determined another reserved distance that a secondary device should be kept away in its active status, without affecting the incumbent system. This is what is known to be reserved distance. From the significant factors in determining the spatial variations, we have found transmitter antenna height to be the most significant factor in white space system planning.

Keywords: Antenna height · Contour coverage · Reserved distance · Secondary system

1 Introduction

The TV white space is a vacant space in time or space of the terrestrial TV transmission channels. It is part of the radio communication spectrum, which is vacant at a given time in a given geographical area on noninterfering basis with regard to primary and other services [1]. These vacant portions of spectrum became available as a key research topic

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and future technology and business development area. There have been different standards developed to manage this availability of free channels for secondary use [2]. It is a very effective technological option in providing a broadband internet with advantage of good bandwidth quality, large bandwidth, long distance coverage capability and greater signal penetration [3]. To gain these advantages, there must be a good management of the secondary system deployed to exploit the free bands. To have effective management then, efficient cognitive radio technique must be guaranteed which include time or spatial variation of use [4].

The spatial variation uses to keep the secondary device some place out of the signal range of the incumbent system at its minimum receivable signal quality. For this placement determination, signal quality and propagation characteristics are necessary. Using the propagation models, we can calculate the coverage area and hence the range of primary signal [5]. Determining the primary coverage is insufficient in planning the secondary system deployment. The secondary device must be some distance away from the coverage range of the primary system, called reserved distance. This is because the secondary device is transmitting, so that it causes interference [6]. So, the reserved distance must exist between the contour coverage of the primary system and secondary device in order to give sufficient working area in its full transmission power [7]. Different factors determine this distance [6]. Assuming the white space device (WSD) is operating with its maximum power, 36 dBm [8], frequency and transmitter antenna height are the most significant factors. In the deployment of secondary system, the vendor must take care of providing non interfering system to the primary user. Therefore, the most significant factor must be known in determining the coverage and reserved distance. Which one is most significant? Operating frequency or antenna height? We have tried to identify it. Different researchers tried to find different ways to determine the coexistence of the two systems [4, 6–12]. They have shown ways to manage the coexistence. Denkovska et al. [9] used Monte carlo simulation method to calculate the separation distance that should be kept between the LTE mobile technology and Digital Video Broadcasting-Terrestrial (DVB-T) without interference to the television system. Suh et al. [10], studied ways to determine the minimum receivable field strength which in turn is used to determine the protection ratio and reserved distance. K. Kang [11] on the other hand provides a methodology to calculate the reserved distance as well. It implements the geolocational database technique. However, these are not researches made to determine the most significant factor in determining the coverage and reserved distance.

The main purpose of this study resides on determining the reserved distance for the separation of the secondary device (white space device) and the primary or incumbent system (Digital Terrestrial Television). And we studied the most significant factors in determining this reserved distance and separation distance, where this in turn helps during secondary system deployment to protect the primary system from unwanted signal interference. To determine this, we have used geolocational database implementation method, among the three cognitive radio techniques. It works on spatial variation basis. The most significant factor which determines these parameters in secondary system planning and deployment is determined by taking test points. The rest of this paper is arranged in a way like, after the introduction System Model and Problem Formulation follows. Section 3 focuses on Results and Discussion. Finally, a conclusion is given in Sect. 4.

2 System Model and Problem Formulation

The secondary system or TV white space system must be non-interfering to the incumbent system. The licensed user, who pays for the national regulatory body, should not be affected by the secondary system. This is the guiding principle in TV white space system installation. One way to protect the incumbent system is by providing sufficient spatial variation between the primary and the secondary systems. This spatial variation is supported by installing the white space device (WSD) out of the incumbent coverage. In other words, there must be a separation distance from the digital terrestrial TV (DTT) transmitter that the WSD must be kept away. The contour coverage of incumbent system is affected by different factors [1]. These factors include DTT transmitter antenna height, frequency of operation and the minimum allowable field strength value for the DTT receiver below which the receiver can't have acceptable quality of signal. Each of these factors, on the other hand, may be dependent on other factors. In some cases, different selected propagation models may depend on the terrain coverage around the transmitter; this implies the antenna height is better described by Height Above Average Terrain (HAAT). The minimum median field strength is the value which is limited by the national authorized body by considering different factors. These factors contribute in determining the minimum receivable signal quality of the DTT receiver. For one country, the limiting equation is given by [6, 8].

$$E_{min} + F_D + G_D + F_{Da} - L_1 - N_t - N_F = C/N \quad (1)$$

Where E_{min} is the minimum field strength and in this equation, FD is dipole factor with its formula [6]:

$$F_D = -75.05 - 20 log f_c \quad (2)$$

Here fc is the channel mid frequency. G_D is dipole antenna gain of the incumbent transmitter. F_{Da} is dipole antenna gain adjustment factor which is given by:

$$F_{Da} = 20 log(615/f_c) \quad (3)$$

where in this case f_c is the channel midfrequency. According to Ethiopian Broadcast Authority, the geometric mean frequency is given by 69 MHz for low VHF, 194 MHz for high VHF and 615 MHz for UHF. F_{Da} has the value as defined in the formula for UHF frequencies only; otherwise, it is zero [2]. L_l is the downlead line loss of the transmitter antenna to its receiver antenna. N_t is thermal noise given by:

$$N_t(dBm) = 10 log(kTB) \quad (4)$$

where k is Boltzmann constant given by $k = 1.38 \times 10^{-23} J/K$, T is system temperature and B is the bandwidth of the channel. N_F is the noise figure and *C/N* is carrier to noise ratio. With these values identified, the planning is done to limit the contour coverage of the primary system. The figure below represents the sample system arranged in such a way that a TV white space device is placed not to affect the primary system. The primary system is kept non-interfered by the WSD if it is placed at a certain reserved

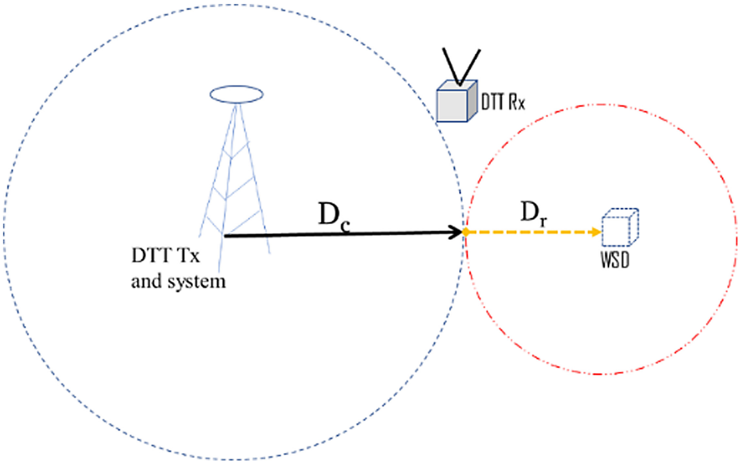

Fig. 1. TV white space device placement and reserved distance

distance, *Dr*. As shown in Fig. 1, the DTT receiver is assumed to be put at the edge of the incumbent contour coverage. It is to receive the minimum receivable signal quality.

Dc is the contour coverage distance when measured from the center of the DTT transmitter, and Dr is reserved distance between the white space device and the DTT coverage contour. Each of these distances must be determined well in order the two systems to coexist. So, the coexistence of the TV white space system with the incumbent system is determined by designing the system which separates the WSD at sufficient distance from the incumbent coverage contour [4, 6]. To determine the contour coverage radius, we have to limit the minimum field strength value, E_{min} from Eq. (1). After the E_{min} value is calculated, appropriate propagation model is used to find at which distance the E_{min} value is met. For this analysis, we have selected Okumura Hata model.

2.1 Okumura Hata Model

It is a propagation model designed to cover a distance up to 100 km. The operating frequency ranges from 150 MHz up to 1.5 GHz [3]. The loss for urban areas is given by:

$$L_{urban} = 69.55 + 26.16log(f) - 13.82log(h_t) - a(h_r) + (44.9 - 6.55log(h_t))log(d) \tag{5}$$

Where L_{urban} is signl loss for urban areas, f is operating frequency, h_t and h_r are transmitter and receiver antenna heights above the ground in m, and correction factor $a(h_r)$ for middle and small cities is given by:

$$a(h_r) = (1.1log(f) - 0.7)h_r - (1.56log(f) - 0.8) \tag{6}$$

For open or rural areas, it become:

$$L_{rural} = L_{urban} - 4.78(log(f))^2 + 18.33log(f) - 40.94 \tag{7}$$

The pathloss for a given minimum field strength is given by a formula:

$$E_{min}\left(dB\mu\frac{v}{m}\right) = P_t(dBm) - P_l(dB) + 20logf(MHz) + 77.2 \tag{8}$$

Where E_{min} is the minimum receivable field strength. This value is what is determined in Eq. (1). F is the working frequency and others are transmitted and loss powers respectively. By equating the loss calculated from the pathloss model and this loss, we will find coverage radius.

Also, for the D_r, we have a field strength value given by:

$$E_r = E_{min} - P_{WSD} - D/U + G_{Dis} + 64.25 \tag{9}$$

Where E_r is the field strength which is at a location where a white space device should be located away from the primary system transmitter. P_{WSD} is the transmitted white space device power, mostly it is given to be 36 dBm. G_{dis} is the offset antenna discrimination factor. D/U is the desired to undesired signal ratio. It has a different value for adjacent and co-channels [4]. Also, for this field strength, we can find the pathloss by using Eq. (8). The parameters set for these calculations are set as in Table 1.

From the factors which affect the coverage and reserved distance, and hence the coexistence, we have selected the two main factors i.e. coverage radius and frequency. In designing a TV white space system, there must be a good management to avoid interference. This management is guided by spatial variation of the secondary and primary system. For this comparison we have selected five different test points with different frequency. These points are from different locations of terrestrial TV transmitters in Ethiopia, with an assumption that they represent the ranges of frequency used for the terrestrial TV transmission.

Table.1. Parameters for reserved distance determination [6]

Parameters	Values
f_c	610 MHz
G_D	10 dB
L_l	4 dB
NF	7 dB
P_{WSD}	36 dBm
C/N	23 dB
$D/U_{co\text{-}channel}$	23 dB
$D/U_{Adjacent\ channel}$	−33 dB
G_{Dis}	14 dB
N_t	−104.95 dBm

3 Result and Discussion

The minimum field strength is calculated to be $E_{min} = 49.74$ dB(μV/m). For this field strength value and other given parameters, the coverage contour will be at a radius of 36.28 km. For reserved distance calculation antenna height of 10m is used for the same frequency, 610 MHz. The field strength value is calculated to be 69 dB(μV/m) for co-channel. Then the reserved distance is 5.396 km for co-channel. For adjacent channel, the field strength is 104 dB(μV/m). This value declares that the distance from the contour coverage for adjacent channel is 140 m. It is very near to the coverage contour of the DTT transmitter. The values show that to use a co-channel by the white space device, it must be separated with larger separation distance than adjacent channels. As shown in the coverage map, there is sufficient gap for the WSD and DTT transmitter coverage contour. Thus, their coexistence is determined by the reserved distance which should be calculated as in the formula above. For the primary transmitter site taken as a test point at Bedi, which is operating at frequency of 610 MHz, and located near Addis Ababa, Ethiopia, the WSD should be placed at 5.396 km and 140m away from the contour coverage of 36.28 km, in order to reuse the adjacent channels of channel number 38 and the channel 38 itself respectively. These distance values of keeping the WSD are the least allowed distances, below which the WSD causes interference to the incumbent system, as shown in Fig. 2. The figure shows the SPLAT software analysis result of the signal coverage range and reserved distance.

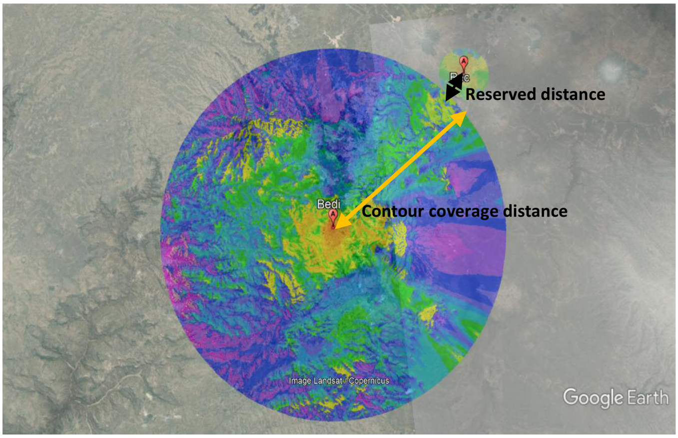

Fig. 2. Contour coverage and reserved distance (adapted from Google Earth)

For different frequency values, the adjacent and co-channel reserved distances from the incumbent system is found as tabulated in Table 2. The site names are incumbent transmitters or the terrestrial TV transmission sites selected based on their different operating frequency.

Table 2. Reserved distances of DTT transmitters for different test points

Site name	Frequency (MHz)	Co-channel D_r(km)	Adjacent channel D_r(km)
Furi	178	7.9684	0.1515
Assosa	220	7.8614	0.1495
Kebridhar	498	7.8096	0.1485
Tendaho	650	7.9155	0.1505
Debark	762	8.0086	0.1523

From Table 2, the variation of reserved distances, with variation of frequency from channel 5 to channel 57 or 178 MHz to 762 MHz, doesn't show a big difference. The difference is in a range of decimal points. For the frequency difference from 178 MHz to 762 MHz, the percentage variation in the reserved distance is only 5%. There is also a non-linear variation, where for co-channel reserved distances it is 7.9684 km for 178 MHz and decreases to 7.8096 km for 498 MHz and this again increases to 8.0086 km for 762 MHz. This characteristic is also noticed in the graph of frequency versus keep out distance for different height values. Keeping the frequency and other parameters constant and varying the antenna height from 1.5 m to 30 m gives a reserved (keep out) distance variation of 5 km or 250%. This analysis indicates that the deployment of TV white space system should be more concerned for antenna heights of the WSD than operating frequency. As it can be seen from Fig. 3, the most significant factor in TVWS system deployment is antenna height. The iterations made for this graphing is in the basis of 0.01.

a)

b)

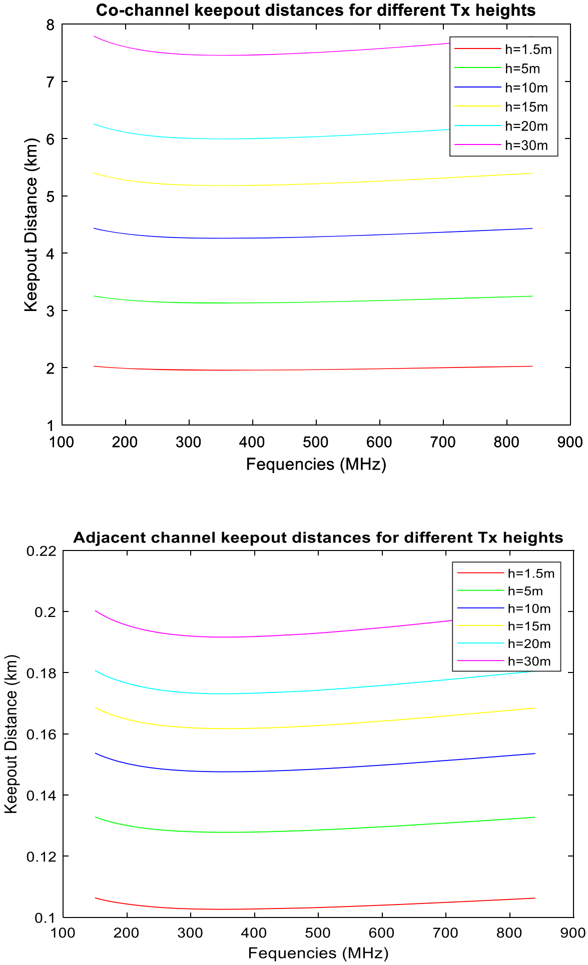

Fig. 3. Reserved (keep out) distance for different antenna heights (a) & (b)

4 Conclusion

In this work, it is tried to analyze the separation distance that a white space device should be kept away from the contour coverage of the primary system. It is the reserved distance to keep the device non interfering to the incumbent system. In the planning of the secondary white space system different factors are taken in to account. Among them, antenna height and operating frequency have been compared in order to identify the most significant factor. Hence, antenna height is found to be the most influencing factor in TV white space system planning and design. So, the planning body must take care of the transmitter antenna heights more than other parameters to have non-interfering and stable system coexistence.

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