IMPACT OF EMPIRICAL PATH LOSS MODELS ON SPATIAL TV WHITE SPACE UTILIZATION

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Abstract

Regulatory bodies have called for alternative spectrum management models and techniques that would allow efficient utilization of the TV white space since the proposed cognitive radio technique may not be realized in the nearest future. For effective utilization of the spatial TV white space, and coexistence between the primary and secondary users, a reliable prediction technique is required to accurately estimate the service contours of the primary users. In this article, we present the effects of empirical path loss propagation models in predicting the TV service contour using optimized model which is based on measurements of path loss in the study area and other conventional models such as the ITU-R, COST 231, HATA, Egli and CCIR models. Results of simulations show that measured path loss models' prediction deviates significantly from the other models that provide large protection zone around the primary cell and, thus reduce the spatial utilization of the spectrum. It was also found that the -114 dBm FCC rule for empty white space is highly conservative and significantly affects the availability of the white space.

Keywords: TV white space, path loss models, service contour, protection contour, cognitive radio

Introduction

Spatial TV white space represents geographical locations where there is no TV signal and the broadcasting frequency can be used for secondary purposes without causing any interference to the performance of the TV broadcasting in the remaining areas and other incumbent services anywhere [1]. Technically, this represents locations where the signal level is less than -116 dBm for digital TV (DTV) and -94 dBm for analogue TV [2].

Although, FCC defined -114 dBm as the criteria of the empty spaces for TV white space. Developed countries like USA have conducted analytical studies of the white space and its management and, also, determined what kind of services could reuse the white spaces. The idea of deploying cognitive radio networks to utilize the available white spaces in developing countries like Nigeria may not be realized in the nearest future, and hence, the call for alternative methods and techniques for exploiting the underutilized spectrum. In view of these, recently, researchers adopted the conventional propagation models to predict the TV coverage and keep-out distances and consequently the white spaces for safe and peaceful coexistence between the primary and secondary networks. The service area (TV coverage) of a primary user will however depends on the transmit power, height, operating frequency and propagation characteristic of the area. Several models have been employed by researchers to predict these service contours. The general trend is that, field strength vary with distance, this is true is some cases but most of the wireless devices operate in complex environment and this makes accurate modelling of the actual environment difficult. It is expected that prediction errors will be high when these models are deployed in a different environment for which the model was not intend since the models are not restricted to the environment to which they were built for. This makes the models not too accurate when apply for another environment. It has been proven that, the most widely used empirical models developed are not compatible with the tropical regions in Nigeria. For example [3][4] provide error bounds for nine widely used empirical models based on measurement conducted in Kwara State, Nigeria. The work concluded that no single model provides good fit consistently, however Davidson model gives better performance amongst the models used. The work presented in [5] provides optimized Davidson model in which minimal errors was achieved. In this work, the effect of empirical path loss propagation models in predicting the TV service contour is presented. In the work, optimized model which is based on local measurement conducted in Kwara State, Nigeria and the Hata, COST231, ITU-R 5293, ECC, Egli and CCIR models were used to predict the service contour (coverage distance) of primary users.

System Model and Simulation

Consider a licensed primary transmitter (TV Broadcast system) mounted on a tower with height, $h_{T(m)}$, transmitting with power, P_T (kW), on UHF band as shown in Fig 1. The secondary user can reuse the same frequency near the cell border of the primary user if it meets the required condition specified by FCC for empty white space. The TV service contour is the TV service area which is within the grade B contour, i.e. where received signal strength for channels 14 through 69 exceeds 64 dBu and 41 dBu for analog and digital TV systems respectively. The service area is illustrated in colour blue. These contours are calculated in accordance with specific procedure described in Section 73.622 and 73.625 of the FCC Rules and Regulations [6].

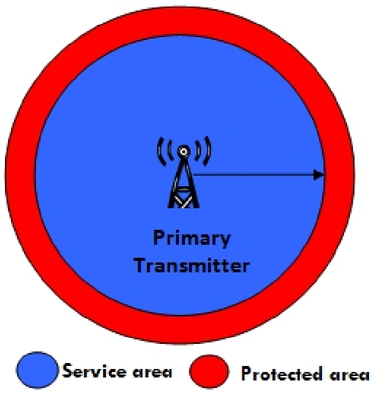

Fig. 1. TV service and protection contour

In order to have safe coexistence between the primary and secondary users, the incumbent TV services must be protected from excessive interference from the secondary transmitter. For such protection to be guaranteed, the secondary users must be located outside the contour of the TV transmitter for a minimum distance (keep-out-distance) as described by FCC [7] (see Table 1). Fig 1 shows the protection radius in RED. Therefore, it is necessary to know the service contour of the primary user for effective utilization of the white space.

TABLE 1FCC RULES ON REQUIRED SEPARATION DISTANCES [8]

Antenna Height of Unlicensed Device	Required Separation [km] From Digital or Analog TV Protected Contour	
	Co-channel	Adjacent channel
Less than 3 meters	6.0	0.1
3 - Less than 10 meters	8.0	0.1

10 - 30 meters	14.4	0.74

Results and Discussion

In the first scenario, we consider a lower power 150 m height primary transmitter operating on channel 21 (470 MHz). Fig 2 shows the coverage level for the model described in Fig 1. FSPL, COST 231, Hata, ITU-R, ECC, CCIR and optimize model (measured) were used in the simulation.

Considering the ITU regulation of 41 dBu for service contour for digital TV systems, the minimum received signal strength was found to be -87.46 dBm. This value is obtained using equation (1). Now, if this threshold is put into considerations, we can see that the estimated coverage radius for the DTV transmitter is 95 km, 60 km, 38 km, 33 km, 31 km, 18 km and 26 km for Egli, ECC, ITU-R, Hata, COST 231, CCIR and measured respectively. Meaning, other models except for CCIR model over estimate the service contour.

$$P(\text{dBm}) = E(\text{dBu}) - 130.8 + 20 * \log_{10}(615 / f_{mid}) \quad (1)$$

where, f_{mid} is the channel mid frequency in MHz.

TABLE 2SIMULATION PARAMETERS

Parameter	Values
Center frequency of DTV Transmitter	CH 21 (470 MHz), CH 31 (550 MHz), CH 41 (630 MHz), 51 (710 MHz) 60 (782 MHz)
Transmit power of DTV Transmitter	1, 2.5, 5, 10, 100 kW
D/U ratio at noise-limited contour	15.5 dB
Field strength at grade B contour	41 dBu
Path Loss model	COST 231, HATA, ECC, Egli, CCIR, ITU-R and Measured model
Height DTV receiver	10 m
Path loss exponent (n)	2.8
Height of DTV transmitter (m)	100, 150, 200, 300, 400, 500 m

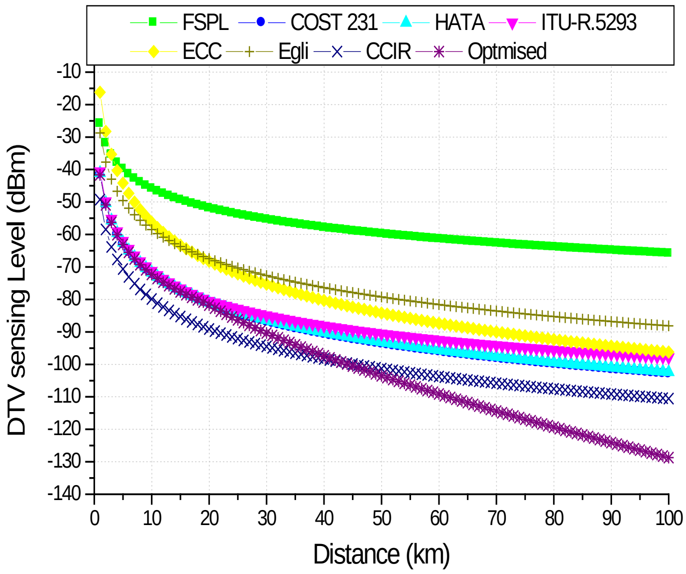

Fig 2. Received signal strength with distance for optimized and other models for 1kW 150m 470 MHz antenna

The models provide a large protection zone around the primary cell and hence reduce the spatial utilization of the spectrum. In the other hand, CCIR model under-estimates the service contour and consequently, lower the protection zone. This in turn maximizes the spatial white space but transmission of secondary users will degrade the QoS of the primary system. Knowing that the optimized model has impact on the DTV service coverage, we further investigate how frequency could possibly affects the availability of the white space. In this scenario, operating frequencies were randomly selected from the UHF band; Table 2 shows the simulation parameters used. Fig 2 provides plot of DTV service contour with distance for channels 21 (CH 21), CH 31, CH 41, CH 51 and CH 61.

TABLE 3DTV SERVICE COVERAGE FOR OPTIMIZED AND OTHER MODELS FOR 1kW 150m TRANSMITTER FOR 41 dBu COVERAGE LEVEL LOW POWER TRANSMITTER

Path Loss Model		*HATA*	*COST 231*	*ITU-R.5293*	*Egli*	*ECC*	*CCIR*	*OPT*
DTV service Coverage (km)	CH 21	32	33	38	61	95	18	27
	CH 31	31	31	37	61	97	18	26
	CH 41	30	29	36	61	98	17	26
	CH 51	28	27	35	60	98	15	25
	CH 60	26	125	34	60	98	14	25

TABLE 4 DTV SENSING LEVEL FOR OPTIMIZED AND OTHER MODELS FOR 100 kW 150m TRANSMITTER FOR 41 dBu SENSING LEVEL FULL POWER TRANSMITTER

Path Loss Model		HATA	COST 231	ITU-R 5293	Egli	ECC	CCIR	OPT
DTV service Coverage (km)	CH 21	141	147	265	192	-	80	57
	CH 31	137	137	269	192	-	77	57
	CH 41	133	129	274	192	-	75	56
	CH 51	130	122	282	192	-	74	55
	CH 60	127	117	191	192	-	72	55

Tables 3, 4, 5, 6 and 7 show the DTV coverage distance for the optimized model and the conventional models. Table III provides coverage distance for lower power transmitter for channels 21-60 using seven empirical path loss models. In this work, 41 dBu service criterion was used. For CH 21, the minimum signal strength using the criterion is -87.46 dBm. The optimized model predict the coverage radius as 27 km. Hata, COST 231, ITU-R, Egli and ECC models over-estimate the radius by 5 km, 6 km, 11 km, 34 km and 68 km respectively. In the other hand, CCIR model under-estimates the coverage distance by about 9 km. For Ch 41 the threshold value is -90 dBm this decreases the coverage radius for all the models. Hata model gives results that are closer to the measured model. But for the fact that prediction error for Hata becomes more, when the transmission exceeds 20 km, the height may not be the limiting factor since is still within the validity range.

TABLE 5DTV COVERAGE LEVEL FOR OPTIMIZED AND OTHER MODELS FOR 2.5 kW AND FIXED TRANSMITTER HEIGHT OF 150m AT 41 dBu SENSING LEVEL LOW POWER TRANSMITTER

Path Loss Model		HATA	COST 231	ITU-R 5293	Egli	ECC	CCIR	OPT
DTV service area (km)	CH 21	43	45	55	77	130	24	32
	CH 31	41	42	54	77	132	24	31
	CH 41	40	39	53	77	134	23	31
	CH 51	39	37	53	77	130	20	30
	CH 60	38	36	51	76	128	18	28

Similar results were obtained for full power transmitter except for ECC model which produces the worst case with no result in all the channels as shown in Table IV. This distances covered by the transmitters are the protected distance of the incumbent users or licensed owner and no TVWS devices must transmit or operate within this territory. When 15.5 dB D/U (desired –to-undesired) ratio rule is applied, the coverage distance increase from 32 km to 57 km for CH 21as shown in Tables V and VI. This implies that, the protection margin will increase and subsequently decrease the availability of the white space. However the coverage distance increases furthermore when FCC rule of -114 dBm for empty white space is used. The protection margin increase by about 48 km as shown in Table 7. This shows that the FCC rule would surely under-estimate the available white spaces for secondary use.

TABLE 7DTV SENSING LEVEL FOR OPTIMIZED AND OTHER MODELS FOR 2.5KW 150m FIXED TRANSMITTER HEIGHT AT -144 dBm SENSING LEVEL

Path Loss Model		HATA	COST 231	ITU-R 5293	Egli	ECC	CCIR	OPT
DTV service area (km)	CH 21	311	324	-	351	-	176	78
	CH 31	272	273	-	324	-	154	74
	CH 41	242	235	-	303	-	137	71
	CH 51	230	215	-	285	-	122	68
	CH 60	210	195	-	263	-	105	65

Conclusion

In this article we have shown that a reliable prediction technique is required to accurately estimate the service contours for effective utilization of spatial TV white space. It was found through simulation that, when considering -114 dBm FCC regulation of empty TV white space, the service contour increases from 69 km for low power transmitter (1kw) to 112 km for high power transmitter (100 kW). It was also found that there where divergence in coverage prediction between the measured model and the conventional models. Therefore transmit power and heights of the TV transmitter would in the same way affects the service contour, which will ultimately affect the availability of the white space.

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