Performance Evaluation of Power Control Algorithm for TV White Space Resource in UK

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Abstract — **The digital switchover plan in the UK, expected to be completed in 2012, is capable of freeing up a total of about 240MHz TV bandwidth. This includes the license-exempt access to TV White Spaces (TVWS) as defined in IEEE 802.22 standards for Wireless Regional Area Network (WRAN). In our previous studies [12], a simulation model based on the existing keep-away region algorithm is first established and verified to explore the potential TVWS resources with the Cognitive Radio technology at any given location in the UK. Then, the newly proposed power control algorithm based on the maximum allowed transmission power is to replace the keep-away region algorithm and improve the availability of a cognitive radio (CR) operation. In this paper, both of these two algorithms' performances are evaluated and compared with the results obtained from Digital UK [13] and a third-party company Wolfbane [14]. Finally, the correctness of the proposed power-control algorithm is validated and proved to have a better performance than the traditional keep-away region algorithm in terms of numbers of available channels.**

Finally, a comparison between these two algorithms is made in terms of system capacity.

Keywords: Cognitive radio, Geo-location database, TV White Space, Digital TV, Keep-away region, Power control, National Grid Reference

I. INTRODUCTION

Cognitive Radio (CR) technology, first presented by Joseph Mitola III and Gerald Q. Maquire, Jr in 1999[1][2], has been viewed as an emerging novel approach being capable of allowing unlicensed users to opportunistically exploit the spectrum holes temporarily unoccupied by the licensed users without interferences [3]. With the advance Digital TV (DTV) technology, large portions of the VHF/UHF TV spectrum will become entirely vacant on a geographical basis after the digital switchover plan. Reforming the analog TV spectrum could make the vacant spectrum a prime candidate for the opportunistic spectrum access cognitive radio technology. In the UK, a consultation on the feasibility of cognitive access to the interleaved spectrum (White Space) carried out by Office of Communications (Ofcom) indicates that over 50% of UK's locations are likely to have more than 150MHz interleaved spectrum, and 90% of the locations might be available for 100MHz cognitive access [4]. Furthermore, the IEEE 802.22 standard for Wireless Regional Area Networks (WRAN) has started to apply the CR technology in the unused TV bands and this could be the first worldwide CR-based standard to the unlicensed operation in TV bands [5].

The successful operation of CR in TVWS relies on its ability to detect the surrounding spectrum bands, provided it does not cause harmful interference to incumbent users, such as the TV broadcasting and wireless microphones [3]. A number of methods are proposed to achieve this purpose such as sensing only and geo-location database techniques. The geo-location database method based on the keep-away region algorithm was proposed in [6]. However in this algorithm, the CR station is required to keep a minimum distance away from DTV transmitter's coverage edge to avoid the interference to DTV transmitter's edge users. The keep-away region is typically 5 to 10 Km away from the edge [5], therefore the secondary users within this region cannot benefit from the great advantages brought by CR techniques and thus result in lower spectrum efficiency. In order to utilise the available spectrum more efficiently, a power control algorithm is proposed [12]. By using the power control algorithm, CR station can determine not only DTV channel's availability at its current location but also the associated maximum allowed transmission power to avoid causing interference to the licensed incumbents, e.g. DTV stations' edge users. In this paper, the correctness of the proposed power-control algorithm is validated by a further comparison with the results obtained from Digital UK [13] and a third-party company Wolfbane [14]. Such results amply justify power-control algorithm's strong outperformance of the conventional keep-away region algorithm.

The remainder of this paper is organised as follows: The conventional geo-location based keep-away region algorithm is described in Section II. This is followed by the proposed power control algorithm in Section III. A comparison between these two algorithms' performance with the results obtained from Digital UK and Wolfbane is discussed in IV. The conclusions and further work are drawn in Section V.

II. KEEP-AWAY REGION ALGORITHM

In this section, a MATLAB simulation model based on the keep-away region algorithm is implemented according to the parameters in [6]. The model is also verified to be able to obtain the available DTV channels of a specific location in the UK. The keep-away region algorithm assumes that there are two DTV transmitters located schematically within a given region as shown in Figure 1. A CR station is planning to be built at a nearby location, where it can make use of the DTV transmitter's operational channels. The CR station is required not to cause harmful interference to licensed TV receivers locating at DTV transmitter's coverage edge. Consequently, the CR station must keep a minimum distance - keep-away

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region, away from the edges of these two DTV transmitters' coverage area [7].

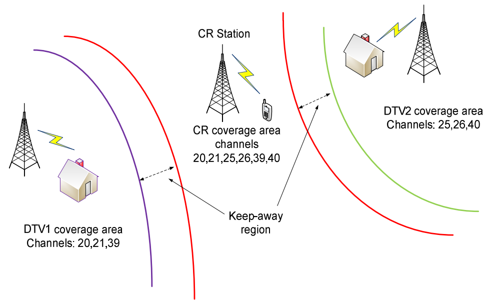

Figure 1 Keep-away region scenario.

III. THE PROPOSED POWER CONTROL ALGORITHM

In the keep-away region algorithm, it is assumed that there is no power control strategies built into the CR station. In order to minimise the interference received by DTV transmitter's edge user, the position of the CR station should be a certain distance away from the edge (typically 5 to 10 km) [5]. On the other hand, if a power control strategy is applied to the CR station to determine its maximum allowable transmission power, more available channels could be obtained. This would be more efficient for the CR station to make use of the white space spectrum instead of having to be located outside the keep-away region from DTV transmitter's coverage edge. Figure 2 shows a scenario for the proposed power control algorithm.

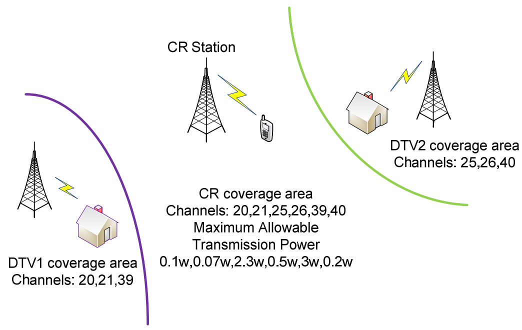

Figure 2 Power control scenario.

The set-up of the proposed power control algorithm is the same as that of the keep-away region algorithm. There are two DTV transmitters located schematically at a given region, along with their respective operational DTV channels, as shown in Figure 2. A CR station is planning to be built at a nearby location, where it can use these operational DTV channels on a secondary basis. Instead of having to be a certain distance away from DTV transmitter's coverage edge, the CR station equipped with the power control mechanism will allocate a maximum allowable transmission power to each channel it is currently using. Therefore, it is critical for the CR station to know how to compute this maximum allowable Effective Isotropic Radiated Power (EIRP).

By referring to the computationally simple but relatively accurate two-ray propagation model defined in [8], the maximum allowable White Space Device (WSD) transmission power EIRP can be given by equation (1) with the associated parameters in Table 1:

$$EIRP_{WSD} = \frac{4\pi d^4}{d_{BP}^2}\frac{E_{CR_{\max}}^2}{\eta} \quad (1)$$

Table 1 Equation parameters

Parameters	Descriptions
d	Distance between the CR station and DTV transmitters' coverage edge.
$d_{BP} = KH_{TX}H_{RX}/\lambda$	Break-point distance between square-law and fourth law propagation, where K is a constant value, and H_{TX} is the height of the transmit antenna, H_{RX} is the height of receive antenna, and λ is channel's wavelength.
$E_{CR_{\max}}$	CR station's maximum allowable E-field strength received at DTV transmitter's edge user.
$\eta = 120\pi$	Intrinsic impedance.

As shown in equation (1), the power control algorithm relies on the computations that take into account each licensed incumbent's specific interference protection requirements. This allows varying levels of CR transmission power to be applied to maximize the utilization of the spectrum. The flowchart of the proposed algorithm is exhibited in Figure 3

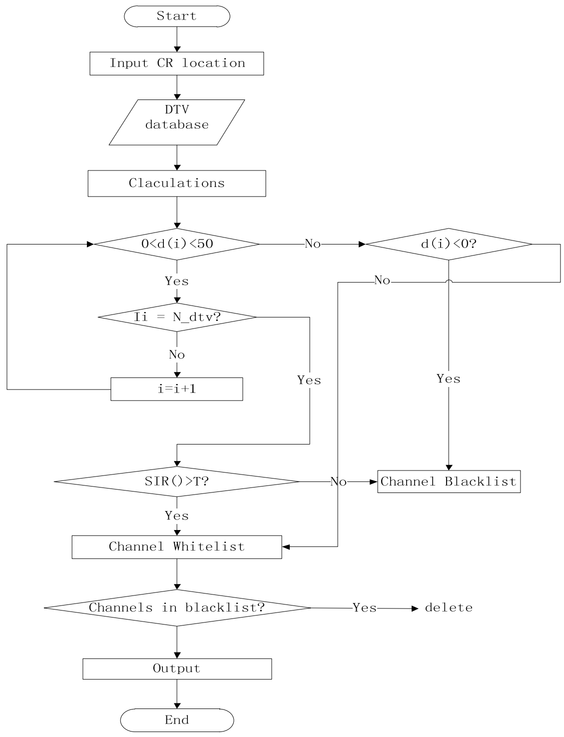

Figure 3 Flow chart of the power control algorithm.

The National Grid Reference (NGR) geo-location coordinate is first obtained by the CR station. This is followed by the computation of the distance array $d(i)$ $(i = 1, 2, ... N\_dtv)$ that stores all the N_dtv different distances from a CR station to the coverage edge of N_dtv DTV stations in the UK. In UK there are N_dtv DTV stations; each DTV station normally operates on 6 DTV channels. Some stations can share the same DTV channels as far as they are sufficiently apart. The system then begins to check whether each element of the array d contains a distance that is greater than $d_{min\_threshold}$. The threshold $d_{min\_threshold}$ is defined as the minimum distance from a DTV station to be allowed to transmit, below which transmitting is not allowed (typically 100m) [9]. If the distance between the CR station and the i^{th} DTV station is less than $d_{min\_threshold}$, all the 6 operational channels being used by station i will be added to the blacklist, and the DTV station i will be tagged as black listed. Otherwise, the 6 channels will be added to the white list and the DTV station tagged as white listed [10].

However, because some DTV stations can share common DTV channels, it is possible that some of the channels of a black listed station are in the white list. This can be illustrated from Ofcom's newest digital switchover transmitter details [11]. In other words, for the same channel, it may appear both in the black and white list. Therefore, in order to avoid co-channel interference, the channels appearing in both lists (black and white) are eliminated from the white list. The power control algorithm is finally applied to the remaining available channels in the white list to obtain its corresponding maximum allowable transmission power. The higher transmission power is allocated to CR station located far away from DTV transmitter's coverage edge, and lower power is allocated to the devices nearby the edge. Therefore, the proposed power control algorithm provides better spectrum utilization for a secondary system through the flexible power allocation scheme.

IV. SIMULATION RESULTS AND COMPARISONS

The conventional keep-away region algorithm was first established and simulated in MATLAB. Using this algorithm, we can get the number of available DTV channels in a specific location in the UK by entering its NGR coordinates. It is proved that the obtained results are almost the same with those obtained in [6] by entering the same NGR coordinate. Furthermore, the proposed power control algorithm was realised and integrated into a verified MATLAB model. The details about the verification can be found in our previous studies [10] [12].

In order to make a comparison with the results obtained from Digital UK and Wolfbane, the same 12 locations of UK are selected along with their NGR coordinates for the simulations as presented in [6] in Table 2.

Table 2 List of 12 locations of UK

No.	Locations	NGR	No	Locations	NGR
1	Glasgow	NS595655	*7*	Brighton	TQ315065
2	Southampton	SU425135	*8*	London	TQ315815
3	Bristol	ST065755	*9*	Birmingham	SP095875
4	Plymouth	SX475565	*10*	Edinburgh	NT275735
5	Cardiff	ST185765	*11*	Swansea	SS645945
6	Newcastle	NZ255645	*12*	Manchester	SJ835985

In [12], the power-control algorithm can detect more available TV white space channels than the keep-away region algorithm when entering the NGR coordinates of Glasgow, Plymouth, Cardiff, Brighton, London, Birmingham, and Manchester. An example of Glasgow is shown in Table 3 and Table 4. As is shown in Table 3 and Table 4, the keep-away region algorithm cannot provide results for very low transmission powers. However the proposed power control algorithm provides results whatever the theoretical maximum allowable EIRP is. In other words, the power control algorithm can allow more DTV channels to be used by the CR station, provided that they do not exceed the maximum allowable transmit power 4w [9]. Consequently, this is a more power efficient way to make use of the White Space channels compared to the conventional keep-away region algorithm.

Table 3 Available TVWS channels of Glasgow (Keep-away region)

Glasgow (NS595655)			
Channel No.	**Max EIRP (w)**	**Channel No.**	**Max EIRP (w)**
5	4	31	4
32	4	34	4
51	4	63	4
64	4	65	4
66	4	68	4
100	4		

Table 4 Available TVWS channels of Glasgow (Power-control).

Glasgow (NS595655)			
Channel No.	**Max EIRP (w)**	**Channel No.**	**Max EIRP (w)**
5	4	30	4
31	4	32	4
34	4	41	0.24876050
44	0.23094478	47	0.21497660
51	4	63	4
64	4	65	4
66	4	68	4
100	4		

Since both Digital UK and Wolfbane always produce the same results when entering the same NGR coordinate. Here we take Wolfbane's result as an example. The available digital

TV transmitters and their associated available transmitting channels within the "distant" range of Glasgow (NS595655) are illustrated in Figure 4.

Transmitter	1 (PSB 1): BBC A		2 (PSB 2): D 3 & 4		A (COM 1): SDN		B (PSB 3): BBC B		C (COM 2): Arqiva A		D (COM 3): Arqiva B		Gp	Pol	OS grid ref.
	UHF	ERP W	UHF	ERP W	UHF	ERP W	UHF	ERP W	UHF	ERP W	UHF	ERP W			
Black Hill	**46**	100k	**43**	100k	**41**	100k	**40**	100k	**44**	100k	**47**	100k	B	H	NS831645
Glasgow West Central	**50**	6	**59**	6			**55**	6					CD	V	NS565682
Cathcart	**60**	2	**57**	2			**53**	2					CD	V	NS565616
Netherton Brae	**27**	2	**24**	2			**21**	2					A	V	NS581575
Darvel	**22**	20k	**25**	20k	**23**	10k	**28**	20k	**26**	10k	**29**	10k	A	H	NS557341
Kelvindale	**52**	2	**56**	2			**48**	2					CD	V	NS555692

Figure 4 DTT Transmitters within "distant" range of Glasgow (NS595655)

Before the comparison, we should make it clear that all the available channels obtained from Table 3 and Table 4 are the available TV white space channels. These channels should be utilised by the secondary users. However, the results from Figure 4 should only be used as a rough indication as to which transmitters might be available at Glasgow (NS5950655) [14]. In other words, these available channels from Figure 4 should only be used by the licensed digital TV users.

Therefore, channels appeared in Table 3 and Table 4 should not exist in Figure 4, for the purpose of protecting licensed digital TV users' normal operation in Glasgow. Clearly, the results computed by the conventional "keep-away" region algorithm in Table 3 satisfy this condition. Hence, the correctness of the keep-away region algorithm established in our simulation is first verified.

However, compared with the results obtained from Wofbane in Figure 4, we found that most of the channels in Table 4 also satisfy the above mentioned non-overlap condition except channel number 41, 44, 47. Actually, these three channels in this way only make sense if their transmitted powers are restricted under the maximum allowable value. Otherwise, they are still not allowed to be used by the secondary users. Consequently, the correctness of the proposed power-control algorithm is also verified.

In the case of Glasgow, we may also notice that the proposed power control algorithm could always provide more available channels than the keep-away region algorithm. Consequently, the system throughput could be further improved by considering the additional available channels compared to the conventional keep-away region algorithm.

V. CONCLUSION

In this paper, the power-control and conventional keep-away region algorithm's performance are evaluated and compared with the results obtained from Digital UK [13] and a third-party company Wolfbane [14]. NGR coordinate of Glasgow was selected to make a comparison between these two algorithms. Finally, the correctness of the proposed power-control algorithm is validated and proved to have a better performance than the traditional keep-away region algorithm in terms of numbers of available channels. The improvement of system throughput results in greater spectrum efficiency and therefore the proposed power control algorithm could be a strong contender for future TV white space standards.

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