Design and Implementation of A TV White Space Channel Allocation System

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***Abstract*—This paper describes a white space channel allocation method which aims on calculating the quality of the available channels and the possible inference introduced by the new node. The implementation and analysis of the system are also discussed.**

Keywords: Cognitive Radio, White Space, Channel Allocation

I. INTRODUCTION

White space technology is a cognitive radio communication method that uses unlicensed bands as well as avoids the interference to the ordinary communications between existing users, so the spectrum efficiency can be largely improved. As with the use of digital television broadcast system gradually grows, there will be more free bands available for such technology.

In this paper, a white space channel allocation system is designed and implemented for a given environment. The UK digital switchover program is taken as the background setting, and the system focuses on avoiding the interference between the peer user nodes inside the field of interest. Some assumptions and approximations are made due to simplicity. A web-based front end serves as user interface, and a background database is used to store all the node data and channel data. Tables used in the database are fully described here, and a time-to-live (TTL) field is introduced to ensure a node will only occupy the channel for a limited time.

After description, the system is tested using some samples, and some thoughts and discussions for future studies of this field are given.

II. INTRODUCTION OF TV WHITE SPACE

A. Cognitive radio technologies

Cognitive radio is a new approach for increasing the utilization of the spectrum. In most cases, the cognitive radio will be a software defined radio to keep its flexibility over different environments. With appropriate spectrum-sharing process, the spectrum utilization will be improved under the vast changing conditions. With appropriate development, such an intelligent radio may be able for autonomous reconfiguration by self-learning process in the future. Dynamic spectrum access on TVWS is one of the most important applications of cognitive radio.

B. Introduction of TVWS

As for a general definition, white spaces refer to those frequency bands that may be idle over time or space. Since the white spaces are in both time and space domains, they can be sorted into two types: Temporal white spaces arise from the idle time periods when the devices do not emit electromagnetic signals. For example, mobile phone calls usually become more frequently in the daytime compared to the night time, so there will be possibly more white spaces at night in such mobile bands. On the contrary, spatial white spaces come from the area where there is no coverage of transmitters operating on certain bands. TV bands can be a typical example of spatial white spaces: the channels allocated for TV are interleaved, so for a certain location, only a few parts of the whole bands will be put in use for television broadcast. The term "white space" we are discussing in this paper is mainly spatial white spaces. In this paper, the example taken as example is the TV spectrum undergoing a digital switchover in UK.

C. Digital switchover progress in UK

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D. The band feature of TV White Space (TVWS)

Thanks to the Digital Switchover (DSO) approach in UK and US, a big portion of TV White spaces (TVWS) are freed for unlicensed cognitive access. In UK, there is significant possible capacity in TVWS: Modelling studies by Ofcom reveals that around 50% of locations in UK possibly have 150MHz of interleaved spectrum, and 90% might have around 100MHz for cognitive access [1]. As is shown by the figure below, TV bands lie between 470MHz to 862MHz, which is within the range of VHF and UHF. Besides that, it would also be easier for power control and signal coverage in such a lower frequency mode.

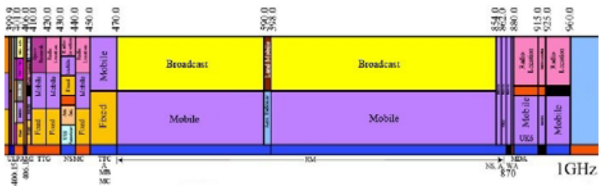


Fig. 1. Frequency allocation in UK (part), by Roke Manor research Ltd.[2]

Research by S. Kawade and M. Nekovee [3] compared the performance of TVWS spectral with 2 widely used industrial, scientific and medical (ISM) bands, 2.4GHz and 5GHz. The result shows TVWS performs better than other bands better on low to medium load situations. And in such a scenario, the power consumption by the transmitter can also be cut down significantly. These features have made TVWS a very attractive band for community-scaled Internet access or complementary access methods when it is hard to gain wired connections, like in rural or mountainous area.

III. ENVIRONMENT SETTINGS

A. *Environment settings and assumptions*

The system is assumed to work in the environment that can be described as below:

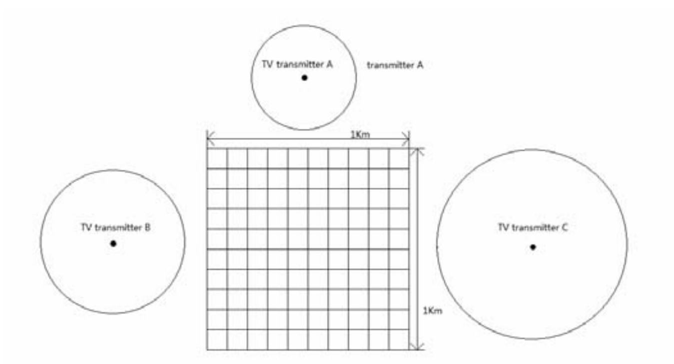


Fig. 2. System environment preset

1) The area in which the system applies is a 1000*1000m^2 square, surrounded by 3 different TV transmitters.

2) The transmitting power of each white space device (node) is set to 100mW, which is seen as the typical transmitting power of license-exempt cognitive radio devices.

3) The connection between nodes will be an exclusive point-to-point link. That is to say, each channel can only occupied by one pair of nodes at the same time.

4) The attenuation model is free space path loss model. The path loss formula is:[4]

$$\text{Loss (dB)} = 20\log10(d) + 20\log10(f) - 27.55 \qquad (1)$$

Here d and f are measured in units of meters and megahertz, respectively.

5) The technical details of the 3 transmitters in this environment can be converted from real-world TV transmitters in London area. They are[1]:

a) High Wycombe transmitter: Transmitting power 100 watts, uses channel 55, 59 and 62;

b) Hertford transmitter: Transmitting power 500 watts, uses channel 54, 58 and 61;

c) Forest row transmitter: Transmitting power 24 watts, uses channel 50, 56 and 58;

6) Each channel is being allocated as a whole. That is to say, it is 8MHz per channel as well as in the case of TV bands. According to the recent channel allocation methods, the channels available in this scene will be channel 21-30, 39-49, 51-53 and 57 (25 available channels altogether). The frequency range of such bands is 470MHz to 766MHz. Here the maximum frequency will be used for the loss calculation later.

7) As is depicted below, the whole 1,000,000m^2 field of interest is divided into 10,000 square cells, and each node is a 10*10m^2 square. To make the problem simple, we assume that there can only be 1 active station (node) in each square cell, and any node that falls into the range of the cell will be seen as being situated in the center of it. If a node falls into the common border of 2 cells or the common vertex (through these two circumstances are very rare) of 4, it will be randomly assigned into any of those cells. The error being brought by such simplifications will be discussed in the next subchapter.

8) The interference calculation method will apply the Signal to Interference Rate (SIR). From the works by Sang Yun Lee, Mee Kyong Kwon and Seung Hun Lee[5], the digital TV interference protection ratio in adjacent channel condition could be around 50dB better than co-channel. For simplicity, in this system the channel cannot be multiplexed. That means each channel can only be occupied by one node at the same time. Besides that, the worst Interference protection ratio (Desired by Undesired, D/U. It can also be seen as SIR) in Digital TV can be chosen from here for interference calculation.

TABLE 1: INTERFERENCE PROTECTION RATIO IN ANALOG TV AND DIGITAL TV.[5]

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

B. *Guard space calculation*

The guard space is to prevent the TV receivers from being interfered by the white space devices (nodes). As is mentioned above, a channel cannot be used by more than one node at the same time. Because there are at most 25 available channels, so the strongest interference will be made by 50 nodes altogether. For a single node, when it is on the border of the square field and the line between the node and the TV transmitter is perpendicular to the border, the interference to the outer space is at its peak.

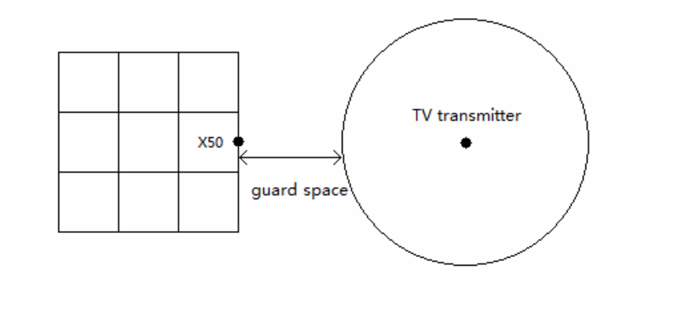


Fig. 3 the extreme condition used to calculate the guard space

For simplicity, I suppose the 50 nodes are all in such situation (while it is impossible according to the discussion earlier, but the interference caused in reality will always be less, so such calculation can still keep a safe margin). So according to the free space path loss model:

$$\text{Loss (dB)} = 20\log10(d) + 20\log10(f) - 27.55 \quad (1)$$

$$[Tx(TV)-Loss(TV)]-[50*Tx(node)+Loss(guard)]=-26dB \quad (2)$$

Since 50*Tx(node)=36.99dbm, Tx(TV) is given in the Table 1:

guard=50.1m

That is the length of the guard space that protects the TV transmitter being interfered by the nodes.

C. System design

1) System operation pattern

According to the discussion above, we can obtain the work flow of the system:

a) When an incoming request is received, the system firstly begins to check whether the data type and value is reasonable. If so, the data will be processed and sent to the judgment subsystem.

b) Then, the system checks if the incoming request is for the registration of a single node or attempting to set up a connection with a registered node.

c) If the request is for a single node registration, the system will make sure there are still available channels for allocation. If so, the interference of the new node to those existing node pairs will be calculated. The accumulative interference of each paired node will be retrieved from the database, then added with the new interference and divided by the power of the paired node to form a Signal to Interference Rate (SIR). If any of them exceeds the threshold, all the accumulative interferences will be rolled back, and the channel request will be rejected. If not, the channel request will be accepted. The system will randomly select a channel from the available channel pool, and the node data will be registered in the database along with the channel data.

d) If the inquiry is for a connection with a certain node, the channel number will be given along with that request. The system will check whether the channel is used for a pair of channels. If so, the channel will not be able to join the existing connection, so the request will be rejected. If not, the system will begin to calculate the interference. Not like the previous situation, this time the interference from all other registered nodes to the both nodes forming a pair will be calculated and summed up separately as well as the interference from the new node to the other node pairs. Then the SIRs will be calculated and compared with the threshold. If all the interferences fall below the threshold level, the request will be accepted successfully. The data of the new node will be registered in the database, and the data of its paired node will be updated.

e) For each result, the system will give some feedbacks to the requesting user. If the request is rejected, the reason will be shown on the front-end; if the request is accepted, the message including the registration details will be sent back.

2) Design of the judgment subsystem

The system is mainly used to calculate the interference between existing nodes and the new node, see if it is feasible to introduce the new node. If all the accumulated interference can be kept within the threshold, and there are still available channels for allocation, the system will register the node data along with its assigned channel data on the database. The process will be discussed here in detail:

a) Pre-check

Some of the constraints can be used to determine the result of request before the interference calculation procedure. Quite a lot of time and resources can be saved according to such a pre-check. They are:

i. Check if there are any free channels available for allocation. If not, the request will be rejected.

ii. Check if there are any registered nodes in the 8 adjacent square cells of the incoming node. If so, the request will be rejected.

b) Interference calculation and comparison

The following judgments will require the interference between the nodes. Below shows the procedure of the interference calculation:

i. Each cell in the grid has a set of relative coordinates (x, y). As is shown in the graph, we can get the distance L_0 between two cell centres as:

$$L_0 = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2} \quad (3)$$

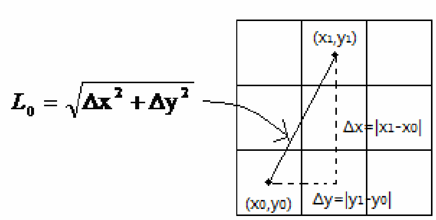


Fig. 4. calculation of the distance between nodes

To compensate the inaccuracy of the node placement within the cells, the distance used for interference calculation will be $L=L_0-d$. For the case that the nodes taken into consideration is a new pair, the resulting distance will be

$$L' = L_0 + \lceil L_0 / d \rceil \sqrt{2} d - \lfloor L_0 / d \rfloor d \quad (4)$$

ii. Using the free space loss calculation formula:

Loss (dB) = 20log10(L) + 20log10(f) -27.55 (1)

Since f=766MHz, the formula can be rewritten as:

$Loss_i$ (dB) = 20log10(Li) + 30.13 (5)

Loss’ (dB) =20log10(L’) + 30.13 (6)

Here $Loss_i$ (dB) denotes the Loss from the destination node to the i th node in the field. Loss’ (dB) denotes the loss from the destination node to its paired node.

Given the node power is 100mW (20dbm), the interference power in the distance L will be:

Inti (dbm) = -10.13-20log10(Li) (7)

Inti (mW) = 10exp(int(dbm)/10) (8)

And the signal strength of the paired node in the situation of the current node is:

Tx’(dbm) = -10.13-20log10(Li) (9)

Tx’(mW) = 10exp(int(dbm)/10) (10)

iii. For the new node requesting for a connection with another node: calculate the interference between this node and each of the existing nodes, and add them together to get the total interference to this node. Calculate the Signal to Interference Rate (SIR), using:

$$SIR = \frac{Tx'(mW)}{\sum_i Int_i(mW)} \quad (11)$$

If the SIR exceeds the tolerance threshold of the node, the request will be rejected. The similar procedure applies for another node in the pair.

iv. For all the existing nodes: In this case, the transmitting powers of all the nodes are equal, so the interference between two nodes is the same. When the interference between an existing node and a new node is calculated in (iii), the interference is added to the accumulative interference of this node, and the result is stored in a cache and used to calculate SIR:

$$SIR = \frac{Tx'(mW)}{Int(mW) + \sum_{i-1} Int_i(mW)} \quad (12)$$

v. Here Int(mW) denotes the interference brought by the incoming node, and $\sum_{i-1} Int_i(mW)$ denotes the previously accumulated interference, and T_x’(mW) denotes the signal strength of the paired node at the situation of current node. If any of the resulting SIRs exceeds the threshold, the request will be rejected.

vi. Channel allocation and node registration: Now the request is accepted. A random free channel will be assigned to the node, and the node data will be inserted into the background database. Besides that, the accumulative interference of all the existing nodes will also be updated.

IV. IMPLEMENTATION AND FURTHER DISCUSSION

The system is implemented by MySQL and web-based Java. The system consists of 3 parts: a web-based front end, a Java-based decision making subsystem and a background database. The front end serves as the user interface, the decision making subsystem calculates the interference introduced along with the new node then makes the decision, and the background database stores the data of the channels as well as the registered nodes.

The system running result is shown below:

If the channel request is successfully accepted, the system will switch to another notification page as is shown in Fig.5. Here the details of the registered node will be displayed along with the success message.

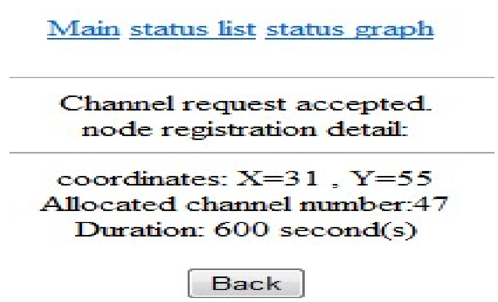
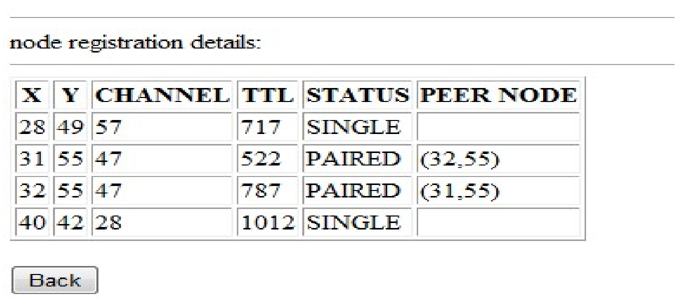


Fig.5. success image

The detail of the registered nodes will be available in the status list page. Here you can obtain the placement data, channel number, TTL, status and its peer node (if there is any).


node registration details:

X	Y	CHANNEL	TTL	STATUS	PEER NODE
28	49	57	717	SINGLE	
31	55	47	522	PAIRED	(32,55)
32	55	47	787	PAIRED	(31,55)
40	42	28	1012	SINGLE	

Back

Fig. 6. The status list page

The system works well on the low load situation, but when the grid is filled with nodes, it would be very hard for a new node to join – the interference of the existing nodes are quite large, and the dense distribution of nodes makes it hard to find a place having no nodes nearby. To help with such a problem, the precision of the system could be alleviated to avoid the error introduced from the approximations and assumptions.

V. ACKNOWLEDGEMENT

I shall firstly offer my gratitude to London South Bank University, the university where I had spent a year as an exchange student. The main ideas and researches are done in that period. And all the students and professors in my lab located on Beijing University of Posts and Telecommunication also deserve my thankfulness. They offered me a lot of help as well as care , which helped me find my way in those postgraduate years.

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