Reducing load of geo-location database by querying with secondary user's preferred channels

Ha Nguyen Tran, Yohannes D. Alemseged, Chen Sun, Hiroshi Harada
Wireless Network Research Institute, NICT
3–4 Hikarino-oka, Yokosuka 239–0847, Japan

Abstract—**Consulting to geo-location database is one of the approaches for secondary user (SU) to obtain the list of available channels for its operation. Each regulator may require the SU to send different types of information to the geo-location database in order to calculate the channel availability. However existing methods consume time and introduce heavy load to the database due to the procedures of checking overlapping between protected contours and SU's operation areas in order to protect primary users (PU) from harmful interference. By submitting SU's preferred channels to database the calculation time and database's load will be reduced significantly. The additional information can also help the database manages spectrum usage so that it can provide recommendation to other SUs.**

Index Terms—**geo-location database, white space, cognitive radio, available channel, preferred channel**

I. Introduction

Accessing to geo-location database (GDB) is an approach for secondary user (SU) to obtain available channels for its operation. This is the main approach in the TV White Space (TVWS) related regulations or technical requirements of many countries and areas e.g. [1], [2].

The GDB approach is based on the following conditions: a) protected operating areas of primary (or incumbent) users (PU) are clearly defined and can be calculated from information stored in the GDB, b) SU's identification and specifications (e.g. transmission power, antenna type, mobility etc.) are known and can be verified by the GDB, and c) SU can provide geo-location information within a pre-defined accuracy.

Since there are measurement uncertainties in the geo-location, each location information in a 2D plane is represented as a rectangular. In some cases the mobile device is permitted to send multiple locations or information of an area where it may move and operate (e.g. a stadium, a shopping mall, or a university campus). In general the shape is considered a closed curve which is called "operation area" of the SU. The problem of determining available channels include the test in order to determine if the operation area of SU and the protected contours (plus additional separations if required) are overlapped or not. Note that the GDB must check for all contours corresponding to all PUs, and the same operation is repeated for every request message from each SU. These operations introduce overhead to the GDB and make the proccess time in the second step longer.

In this paper a novel method of determining available channels is explained and evaluated. Our proposal is to utilize the operation channels information as preferred channels information from SUs. This information is used in other purposes for example to populate the sensing database or coexistence database, however it is currently not required by regulators. By utilizing operation/preferred channels information, the number of necessary tests of overlapping polygons can be reduced significantly. As a result the computational time in GDB for each request is shorter, and the load of GDB can be reduced.

The rest of this paper is organized as follows. Section II introduces detailed technical requirements of current rules and recommendations. Section III analyses the cost of determining available channels. Section sec:db-workload shows the proposed method of determining available channels. Numerical evaluation results are given in Section V. Section VI concludes the paper.

II. Regulations and technical requirements

The Federal Communications Commission (FCC) is an independent United States government agency. In September 2010 the FCC released an updated set of rules for devices operate in TV White Spaces [1]. According to FCC rules, TVWS devices shall rely on the geo-location and database access mechanism to identify available television channels. The FCC has specified the use of F(50, 50) curves when computing analog Grade B service contour levels, and F(50, 90) curves when computing digital Noise Limited Contour (NLC) levels [3]. An implementation method of the protection contour has been proposed as follows. "Contours shall be defined as 360 straight lines connecting 360 calculated contour vertices. Vertices shall be calculated at one degree increments around the station location, using the Radial HAAT." [4] Further separation distances are added to the contour according to the antenna's height, e.g. when the antenna height is less than 3 meters the distance requirement is 6 km for co-channel and 100 m for adjacent channels [1].

The Electronic Communications Committee (ECC) within the Central European Post and Telecommunications (CEPT) is an organization which considers and develop policies on electronic communications activities in European context. ECC published a report in January 2011 to provide technical and operational requirements for cognitive radio systems (CRS) in the 'white spaces' of the frequency band 470-790 MHz in order to ensure the protection of the incumbent radio services [2]. According to this report, the SU will be providing information to the GDB which will then be used by the GDB to calculate and output information containing a list of allowed frequencies and their associated maximum transmit powers to the device.

The information sent from SU to GDB is shown in Tab.I. According to Tab.I, current methods do not use channel information provided by SU to calculate the list of available channels.

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TABLE I
INFORMATION EXCHANGE, FROM SU TO GDB

Information element	FCC 10-174	ECC Report 159
Device ID	Required	Optional
Device type/model	Not included (can be identified by FCC ID)	Required
Location information	Required	Required
Location accuracy	Not included (by default ±50 m)	Required
Expected operation area	Optional	Optional
Operating channel (or Preferred channel)	Not mentioned	Not mentioned

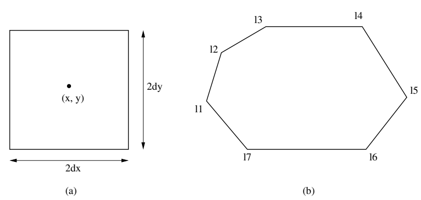

Fig. 1. Submitted locations

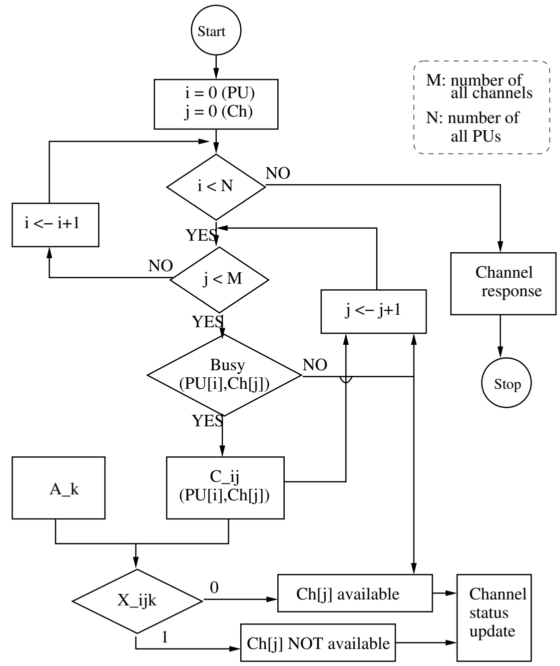

Fig. 2. Existing procedures

III. SYSTEM MODEL

The following model is used to analyze the computational cost in the GDB in order to determine channel availability corresponding to each request from the SU. The analysis is based on common information shown in Tab.I.

Each SU submit its identification information and current geo-location information to the GDB. Submitted geo-location information is considered as a polygon (for example a rectangular corresponding to a single point and the uncertainty of two dimensions, or a polygon which represents a service area of SU). After verification and authentication the GDB will check all potential channels in the bands allowed by regulator. An available channel is the channel which is not being used by any PU, or being used by a PU but the service area submitted by SU is not overlapped with the protected area.

A. SU's location submission

Depending on how the SU submits its geo-location, the area to be checked by the GDB can be expressed by one of the following two methods.

1) a single point with measurement uncertainty: (x, δx, y, δy)
   The geo-location information is represented as (x, δx, y, δy), where x and y are latitude and longitude coordinates respectively, δx and δy are accuracies in meters. The area to be checked is a rectangular as shown in Fig.1a.
2) multiple points: (l_1, l_2, ..., l_n)
   The geo-location information is represented as (l_1, l_2, ..., l_n), where l_i is current location, or a nearby location to which the device may move in future. The area to be checked is shown in Fig.1b.

Let us denote the area bounded by the above polygon as $\mathcal{A}$.

B. Protected service contour

The protected service contour of each PU is assumed to be represented as a 360-polygon, which is defined as 360 straight lines connecting 360 calculated contour vertices. The vertices are calculated at one degree increments around the PU's location according to a pre-defined function. Additional separations may be required according to the SU's antenna height and channel's status (co-channel or adjacent channels). Let us denote the area bounded by the protected service contour (and separations) as $\mathcal{C}$.

C. Available channel determination

In order to determine whether or not a channel $ch[i]$ is available for an SU U which forms a service area $\mathcal{A}$, the GDB will check if $\mathcal{A}$ and $\mathcal{C}$ are overlapped or not by performing the following test.

$$\mathcal{X} = \begin{cases} 0 & \text{i.e. non-overlapped, if } 0 \le \mathcal{A} \cap \mathcal{C} \le th \\ 1 & \text{i.e. overlapped, if } \mathcal{A} \cap \mathcal{C} > th \end{cases} \tag{1}$$

where th is the threshold and $th = 0$ by default.

The test in Eq.(1) is equivalent to the test if two polygons are overlapped or not.

For each request from any SU the GDB must check for a certain area which is specified by regulation. Assume that inside the target area the number of PUs is $N = \mathrm{N_{St}}$ and the number of channels to be checked is $M = \mathrm{N_{Ch}}$. The flowchart in Fig.2 shows the steps to be performed by the GDB.

IV. DATABASE WORKLOAD AND THE EFFECTS OF CHANNEL FEEDBACK

This section analyzes the workload of GDB when it performs necessary operations to determine available channels corresponding to a query from SU. Necessary operations are as follows.

At first the GDB will list up all PUs that could be interfered by the SU. Then it will check all channels if they are being used by each PU. If a channel is being used, the GDB will locate 360 points around the PU, form a protected area and perform the test according to Eq.(1). Previous studies have proved that finding the overlapping area of two polygons is a problem which has complexity $\mathcal{O}(V \log V)$, where V is the number of virtices [5]. If the channel is used by any PU the test will be performed for every query. Therefore we focus on the number of overlapping tests and propose a query method which reduces this number.

A. Workload corresponding to normal operations

Let us denote N_{PU} as the number of PUs, N_{Ch} as the number of channels to be checked, $P_{\text{con}}(i, j)$ as the probability to perform the test Eq.1 for the submitted area and the protected area of the PU number i regarding channel j according to existing methods, and $O(\text{polygons})$ as the required calculations to check if two polygons are overlapped or not.

The required calculations in GDB side corresponding to each request is as follows.

$$\mathcal{L}_{\text{con}} = \sum_{i=1}^{N_{\text{PU}}} \sum_{j=1}^{N_{\text{Ch}}} P_{\text{con}}(i, j) \times O(\text{polygons}) \tag{2}$$

B. Utilizing preferred channels information

In Eq.(2) N_{PU} is fixed and $O(\text{polygons})$ is necessary and sufficient for the test Eq.(1) which is also fixed [6]. The load of GDB can be reduced by reducing the number of channels to test, or reducing the probability of performing Eq.(1) per channel.

Based on this observation we propose the following method to identify available channels. The first query of each SU will follow existing methods, however in subsequent queries each SU will also submit the list of preferred channels based on the initial list. For subsequent queries instead of checking all channels with each PU, the GDB checks only preferred channels.

The cost of this method is as follows.

$$\mathcal{L}_{\text{new}} = \sum_{i=1}^{N_{\text{PU}}} \sum_{j=1}^{N'_{\text{Ch}}} P_{\text{new}}(i, j) \times O(\text{polygons}) \tag{3}$$

The message sequence between SU and DB is shown in Fig.5.

C. Probability to have overlapping check

Let us denote p_1, p_2, p_0 where $0 \leq p_1, p_2, p_0 \leq 1$, as the probability that a channel is not used by the selected PU, is used by the selected PU but is available for SU's location(s), and is not available for SU's location(s), respectively.

For any channel, the probability of running the overlap test is

$$P_{\text{con}}(i, j) = p_{\text{con}} = \frac{p_0 + p_2}{p_0 + p_1 + p_2} \tag{4}$$

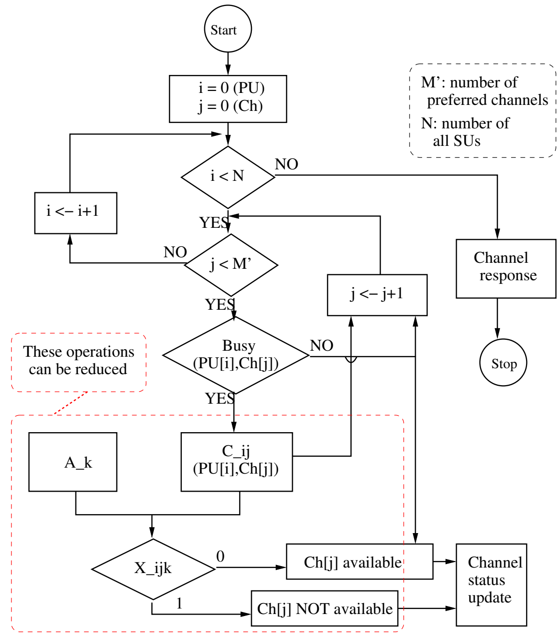

Fig. 3. Proposed procedures with channels feedback

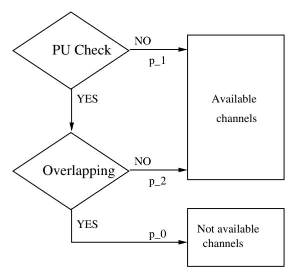

Fig. 4. Overlapping test probability

For a channel from preferred list, which were the results of channel availability check of the first query, the probability of running the overlap test is

$$P_{\text{new}}(i, j) = p_{\text{new}} = \begin{cases} p_{\text{con}} & \text{in general} \\ \frac{p_2}{p_1 + p_2} & j \in \text{available channel} \end{cases} \tag{5}$$

$$\Delta P = \frac{p_0 + p_2}{p_0 + p_1 + p_2} - \frac{p_2}{p_1 + p_2} \tag{6}$$

$$= \frac{p_0 \times p_1}{(p_1 + p_2)(p_0 + p_1 + p_2)} \geq 0 \tag{7}$$

The meaning of Eq.(7) is that, the probability of performing overlap test corresponding to a channel in the available list is smaller than the probability of performing overlap test of an arbitrary channel.

D. Workload comparison

From Eq.(2) and Eq.(4) $\mathcal{L}_{\text{con}}$ is expressed as follows,

$$\mathcal{L}_{\text{con}} = N_{\text{PU}} \times N_{\text{Ch}} \times p_{\text{con}} \times O(\text{polygons}) \tag{8}$$

Also from Eq.(3) and Eq.(5) $\mathcal{L}_{\text{new}}$ is expressed as follows,

$$\mathcal{L}_{\text{new}} = N_{\text{PU}} \times N'_{\text{Ch}} \times p_{\text{new}} \times O(\text{polygons}) \tag{9}$$

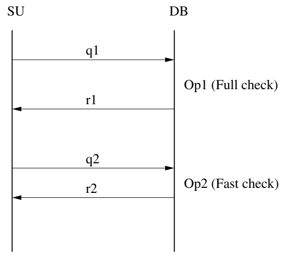

Fig. 5. Message sequence between SU and DB

TABLE II
SIMULATION PARAMETERS

Parameter	Value and Unit
N_{SU}	100
N_{Ch}	30
N'_{Ch}	1 – 8
Area size	2000 m × 2000 m
DB access trigger	60 s or 100 m
Mobility model	Gauss-Markov mobility model
Speed mean	2.0 m/s
Randomness parameter α	0.75
Simulation time	100 – 6000 s

The rate of workload is reduced as follows,

$$R = \frac{\mathcal{L}_{\text{new}}}{\mathcal{L}_{\text{con}}} = \frac{N'_{\text{Ch}}}{N_{\text{Ch}}} \times \frac{p_{\text{new}}}{p_{\text{con}}} \tag{10}$$

If all preferred channels can be reused the rate is as follows,

$$R_{\text{min}} = \frac{N'_{\text{Ch}}}{N_{\text{Ch}}} \times \frac{p_2(p_0 + p_1 + p_2)}{(p_1 + p_2)(p_0 + p_2)} \tag{11}$$

If all preferred channels need to be check, the rate is as follows,

$$R_{\text{max}} = \frac{N'_{\text{Ch}}}{N_{\text{Ch}}} \tag{12}$$

E. Comparison of message traffic

According to existing query methods, the payload of a data packet from SU to GDB contains device's identification, device's type, geo-location information and accuracy, and expected operation area as shown in Tab.I. The proposed query messages include channel information in the payload which will increase the size of the packet.

$$\frac{S_{\text{new}}}{S_{\text{ref}}} = \frac{S_{\text{ID}} + S_{\text{type}} + S_{\text{geo}} + S_{\text{area}} + S_{\text{ch}}}{S_{\text{ID}} + S_{\text{type}} + S_{\text{geo}} + S_{\text{area}}} \tag{13}$$

where $S_{\text{ID}}, S_{\text{type}}, S_{\text{geo}}, S_{\text{area}}, S_{\text{ch}}$ are the size of device ID, device type, geolocation, area, and preferred channels information elements, respectively.

For example, if 14 octets are used for ID, one octet is used to represent device's type, 16 octets for geo-location (cf. IETF RFC 6225), 4x16 octets for other 4 points to specify the operation area, and 8 octets to represent 8 preferred channels, the payload size increases about 8.4%. However the amount of traffic sent to global network can be reduced by other technologies e.g. [8].

V. SIMULATION AND PERFORMANCE EVALUATION

A. Simulation environment

The parameters in Tab.II are used to verify the proposed model and to evaluate the performance of the proposed query method. The values are selected according to the following considerations. In case of TV white spaces the channels to be checked is from channel 21 to channel 51 in UHF band (channel 37 is excluded in some regulatory domains) therefore $N_{\text{Ch}} = 30$. In this simulation the number of preferred channels N'_{Ch} varies from 1 to 8. Note that the SU may keep some channels from N'_{Ch} in the back-up list as specified in the IEEE Standard 802.22-2011, or it may use all channels simultaneously. For example the use of multiple contiguous or non-contiguous channels simultaneously is technically supported by the PHY design of the IEEE P802.11ac TG. The SU will check its geo-location for every 60 s, and issues a new query to GDB if it has moved more than 100 m. This trigger is similar to the FCC rules for Mode II device. Regarding mobility the Random Walk is a widely used model however it is a memoryless mobility pattern and it can generate unrealistic movements such as sudden stops and sharp turns. Therefore this simulation adopts the Gauss-Markov model which can eliminate the unrealistic movements of the Random Walk model by allowing past velocities/directions to influence future velocities/directions with the turning parameter α [7]. According to this model, the value of velocity and direction of the mobile SU at the n^{th} instance is calculated based on the value of its velocity and direction at the $(n-1)^{\text{th}}$ instance and a random variable using the following equations

$$s_n = \alpha s_{n-1} + (1-\alpha)\bar{s} + \sqrt{1-\alpha^2}\, s_{x_{n-1}}$$
$$d_n = \alpha d_{n-1} + (1-\alpha)\bar{d} + \sqrt{1-\alpha^2}\, d_{x_{n-1}}$$

where s_n and d_n are the new velocity and direction of the SU at time interval n, $\bar{s}$ and $\bar{d}$ are constants representing the mean value of velocity and direction as $n \to \infty$, and $s_{x_{n-1}}$ and $d_{x_{n-1}}$ are random variables from a Gaussian distribution.

Two scenarios are considered in this simulation. In the first scenario (DB1), most of the available channels in neighbor locations are different. In the second scenario (DB2), available channels are the same for all locations in the target area. For any scenario in real environment the performance of proposed method will be better than DB1, but worse than DB2.

B. Simulation results

The number of overlapping tests are counted. The ratio between proposed method and existing methods when the number of tests of the first query is included, is denoted as FR. Also, when the first query is not included the ratio is denoted as HR.

Figure 6 shows that after operating for 3000 seconds the difference between HR and FR (due to the first query) is negligible, and the ratio become stable. Based on this result 3000 s is chosen as simulation time for other evaluations.

The effect of including preferred channels into the GDB query corresponding to a system with 100 SUs after operating for 3000 s when there are maximum 10 available channels in each location is shown in Fig.7. The ratio is always less than 1 therefore the number of overlapping tests of the proposed method is always smaller compare to other methods which do

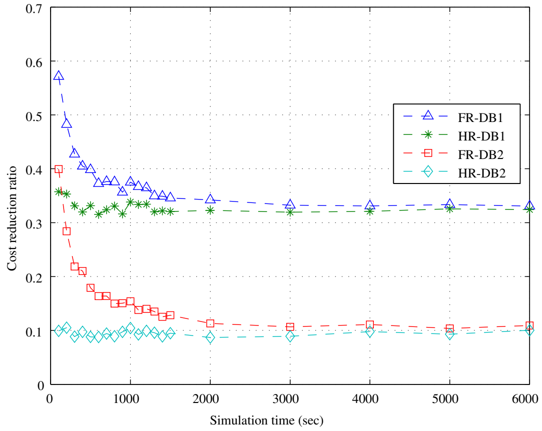

Fig. 6. Time required to achieve stable results

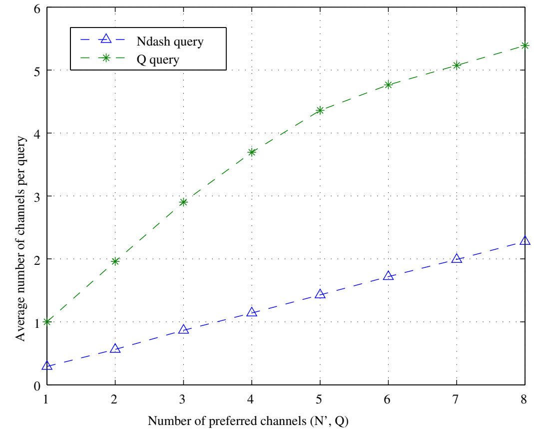

Fig. 8. Channels obtained per query

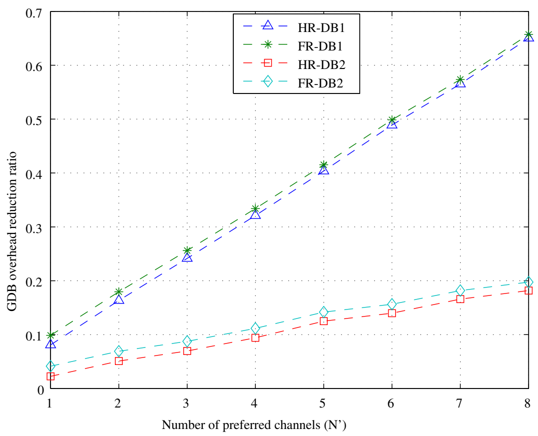

Fig. 7. Cost reduction rate compare to existing methods

not include preferred channels. When the number of preferred channels becomes larger the ratio also becomes bigger (i.e. the cost is closer to existing methods). Since the payload of query message also becomes larger to carry more channels information it is not recommended to include many preferred channels. If each SUs include less than 6 preferred channels to each query the number of overlapping tests will be reduced by more than half in any case.

We have also compared two methods of query, the "N' query method" just reduces the number of channels, and the the "Q query method" which includes preferred channels in the query message. Figure 8 shows the average number of available channels obtained for each query. If each SU sends the number of channels to be checked by GDB (the "N' method"), only 2 available channels were obtained after checking for 8 channels. If each SU also sends the available channels obtained from previous queries (the "Q method"), they can obtain up to 5 available channels.

VI. Conclusions

In this paper we have analyzed the GDB operation which is used to determine the list of available channels. We have identified that the step which performs overlapping test of two areas requires large computation complexity, and proposed a new query method by adding preferred channels to the query messages. Since the number of channels to be checked is smaller, and the probability of overlapping checked is also smaller for operating channels, the load of GDB will be reduced. Simulation results showed that when the number of preferred channels is properly selected (about 4 or 5) the number of overlapping test can be reduce by more than half. Also, the "Q method" outperforms the "N' method" in term of number of channels obtained per query. Based on this observation we have proposed a message sequence to be implemented between PU and DB for obtaining available channels.

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