Operations for Citizens Broadband Radio Service (CBRS); GAA Spectrum Coordination (GSC) Technical Report-Approach 3

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TERMS, CONDITIONS & NOTICES

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1 Introduction

FCC part 96 allows up to 150 MHz of spectrum to be used by General Authorized Access (GAA) users in the areas where higher tier users (incumbents and PAL users) are not using the spectrum. Sharing spectrum between several users in the same band is not an easy task, especially when the different users can deploy different technologies. In some existing unlicensed bands, the sharing of the spectrum is done by mandating a common radio spectrum access procedure, like for example Listen Before Talk (LBT). However, for CBRS band, while no common radio spectrum access procedure has been defined, the Spectrum Access System (SAS) could take the role of coordinating the GAA spectrum access.

This document describes a SAS GSC solution that can be used by SAS administrators to coordinate the use of GAA spectrum channels with the main goal of reducing interference among the GAA users, while fulfilling the secondary goals of maximizing continuous GAA spectrum assignments and minimizing power constraining factors.

2 References

2.1 Normative References

The following referenced documents are necessary for the application of the present document.

[n.1] WINNF-TS-0112, "Requirements for Commercial Operation in the U.S. 3550-3700 MHz Citizens Broadband Radio Service Band", Wireless Innovation Forum

[n.2] Electronic Code of Federal Regulations, Title 47, Chapter I, Subchapter D, Part 96, https://www.ecfr.gov/cgi-bin/text-idx?node=pt47.5.96

[n.3] WINNF-SSC-0010, "WInnForum Recognized CBRS Grouping Parameters", Wireless Innovation Forum

[n.4] WINNF-SSC-0002, "Signaling Protocols and Procedures for Citizens Broadband Radio Service (CBRS): WInnForum Recognized CBRS Air Interfaces and Measurements", Wireless Innovation Forum

[n.5] WINNF-TS-0016, "Signaling Protocols and Procedures for Citizens Broadband Radio Service (CBRS): Spectrum Access System (SAS) – Citizens Broadband Radio Service Device (CBSD) Interface Technical Specification", Wireless Innovation Forum.

[n.6] WINNF-TS-0096, "Signaling Protocols and Procedures for Citizens Broadband Radio Service (CBRS): Spectrum Access System (SAS) – SAS Interface Technical Specification", Wireless Innovation Forum.

[n.7] WINNF-SSC-0011, "Spectrum Sharing Committee Policy and Procedure, SSC Abbreviations and Definitions", Wireless Innovation Forum

2.2 Informative References

The following referenced documents are not necessary for the application of the present document, but they assist the reader with regard to a particular subject area.

[i.1] West, D. B. (1996), Introduction to Graph Theory, Prentice-Hall.

3 Definitions and Abbreviations

3.1 Definitions

CBSD Interference Graph: A CBSD Interference Graph is an undirected graph [i.1] in which the vertices are represented by registered CBSDs and an edge between a pair of CBSDs indicates either or both of the CBSDs experience interference from the other CBSD above a given threshold.

Connected Set: A set of CBSDs whose members only have potential to cause radio interference with the operation of other members of the set.

Coexistence Manager (CxM): A logical entity responsible for managing coexistence among CBSDs within a specific CxG.

GAA Spectrum Coordination (GSC): GAA Spectrum Coordination refers to assignment of GAA Resources to different Coexistence Groups with the goal to mitigate interference among them.

GAA Resource: GAA Resource is the set of frequency ranges available for assignment to CBSDs as GAA grants.

3.2 Abbreviations

CxG	Coexistence Group
CxM	Coexistence Manager
GSC	GAA Spectrum Coordination
GSC	GAA Spectrum Coordination
IBW	Instantaneous Bandwidth
OBW	Occupied Bandwidth

4 Functional Description of GSC Solution

4.1 GSC Solution Overview

The GSC solution, described in this document, takes into account the WInnForum requirements captured in [n.1]. The solution recognizes that CBSDs can be grouped in Coexistence Groups (CxGs) where each group will handle the interference between its CBSD members.

The GSC makes the assumption that the interference between the CxG members is either handled separately by a Coexistence Manager (CxM) or the CxG members have agreed on a common radio spectrum access procedure that will resolve the interference issues among members. If a CxG employs the services of a CxM, then this can be viewed as a hierarchical spectrum management where the GSC will manage the interference between CxGs (inter-CxG) and the CxM will further manage the interference within the CxG (intra-CxG).

In the case a CBSD does not declare its membership to a CxG, the CBSD is placed in a "Default" CxG group. Members of the "Default" CxG group will be assigned a GAA spectrum frequency range, but that spectrum will be potentially shared by all the members of the "Default CxG", hence there will be no intra-CxG interference protection; however, the members of the "Default" CxG group will be protected from inter-CxG interference from members of other CxGs. **CBRS GAA spectrum users are strongly encouraged to avoid their CBSDs being placed in the "Default CxG" by declaring their membership to a CxG and making sure that their managing SAS communicates the CxG membership to other SASs.**

The proposed GSC solution contains several stages:

A. Determine and quantify the interference between overlapping CBSD deployments

B. Determine the maximum continuous GAA spectrum that can be used by each CBSD without creating interference towards un-coordinated neighbors, i.e. towards neighbor CBSDs belonging to different CxGs

C. Assign the frequency ranges (channels) that can be used by each CBSD

D. When more than one SAS collaborate towards a unified GAA solution, determine the final common solution that maximizes the GSC goals

4.2 Stage A - Determine and quantify the interference between CBSDs

For stage A, the SAS will examine the interference relationships between the CBSDs. If two CBDSs are deemed to interfere with each other, then the two CBSDs are considered to be linked by an interference edge. A CBSD can have interference edges with several of its neighbor CBSDs. The interference relationship can be estimated by the SAS using propagation models and determining if the CBSDs have overlapping coverage.

Once a set of interference edges are determined, they will create an interference graph. The interference graph will have several groups of CBSDs that are inter-connected, and they will form the Connected Sets. Each Connected Set is considered to operate independently of the other Connected Sets, since there is no interference generated between the Connected Sets.

The GSC will operate at the Connected Set level.

4.3 Stage B: Determine how much continuous GAA spectrum can be used by each CBSD

In Stage B, the GSC will determine how much continuous GAA spectrum can be assigned to each CBSD, in a Connected Set, without creating inter-CxG interference. The GSC assumes that neighboring CBSDs (i.e. CBSDs connected with an interference edge) belonging to different CxG will require a non-overlapping frequency range assignment.

A recursive clustering method is proposed for determining the fair spectrum bandwidth that can be used by each CBSD.

The idea behind the clustering algorithm is to identify clusters of nodes in the Connected Set that only have connections to nodes that belong of a subset of CxGs. For example, identify cluster of nodes in the graph that belong to CxG_x and only have connections to nodes of the graph that also belong to CxG_x. This is denoted as a cluster of size 1 since it has nodes belonging to one CxG. For those clusters of nodes of size 1, the entire 100% of GAA spectrum can be allocated, since it will be up to the CxM, managing that particular CxG, to further divide the spectrum intra-CxG.

The algorithm can be applied recursively by increasing the number of CxGs that are part of the cluster. For example, after identifying all the single CxG clusters, the next step would be to identify the dual CxG clusters, i.e. the clusters of nodes that belong to CxG_x or CxG_y and only have connection with nodes from CxG_x and CxG_y. Those clusters are considered to be of size 2, since they contain nodes belonging to two CxGs. The nodes in the clusters of size 2 can be allocated 50% of GAA spectrum for nodes belonging to CxG_x and 50% for nodes belonging to CxG_y.

A special consideration has to be given to the “link nodes”, i.e. the nodes that connect these identified clusters with nodes belonging to CxGs that are not part of the cluster.

In general, if there are N CxGs in the connected set, then the clusters can be identified recursively, starting with single CxG clusters of size k=1 for which 100% of spectrum can be allocated, up to clusters of size k=N, for which $(\frac{100}{k})$% of spectrum can be allocated to the nodes belonging to the cluster.

An example is provided to illustrate the recursive clustering algorithm results. Let’s assume that a connected set contains CBSDs from three CxGs: CxG_1, CxG_2 and CxG_3, as depicted in the following figure, and that there are 150 MHz of available GAA spectrum:

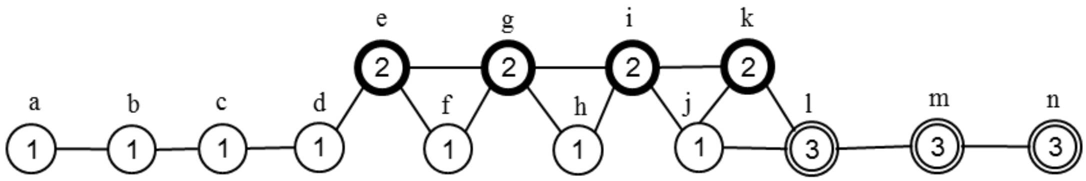

Figure 1: Example of Connected Set containing 3 CxGs

In step 1, the algorithm identifies the clusters of nodes that only have connections with nodes from the same CxG. The identified clusters, highlighted in the figure below, are:

- Cluster C_1 with nodes *a*, *b*, *c* which belong to CxG_1
- Cluster C_3 with nodes *m* and *n* which belong to CxG_3

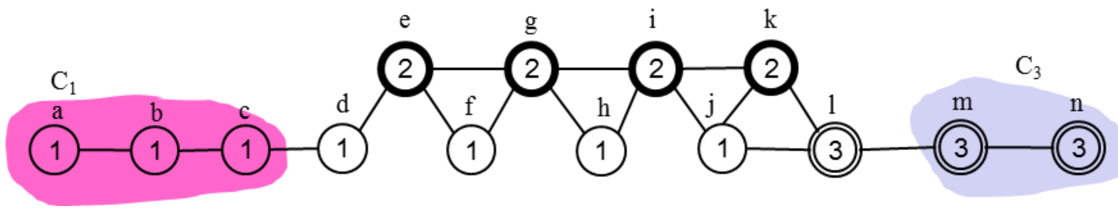

Figure 2: Clusters of size 1

The nodes from clusters C_1 and C_3 will be assigned 100% of the available GAA spectrum, (0 MHz – 150 MHz).

In step 2, the algorithm identifies the clusters of nodes that only have connections with nodes from two CxGs. The identified cluster, is:

- Cluster C_{1-2} with nodes *e*, *f*, *g*, *h* and *i* which belong to CxG_1 and CxG_2

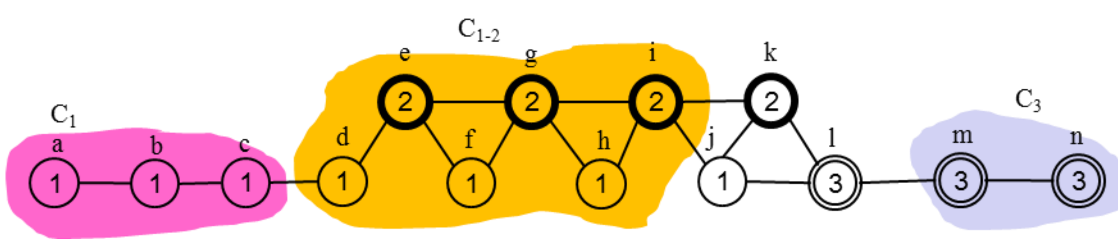

Figure 3: Clusters of size 1 and size 2

The nodes from cluster C_{1-2} will be assigned 50% of the available GAA spectrum, nodes *d*, *f*, *h* will be assigned (0 MHz – 75 MHz), and nodes *e*, *g*, *i* will be assigned (75 MHz – 150 MHz).

In step 3, the remaining three nodes, *j*, *k*, *l*, belonging to a cluster C_{1-2-3} with 3 CxGs, will be assigned 33% of the GAA spectrum.
This time the assignment has to be done carefully so that the spectrum assigned to node *j* overlaps with spectrum assigned to CxG_1 within the C_{1-2} cluster, and spectrum assigned to node *k* overlaps with CxG_2 spectrum within C_{1-2} cluster. The node *j* will be assigned (0 MHz – 50 MHz), node *k* (100 MHz – 150 MHz) and node *l* (50 MHz – 100 MHz).

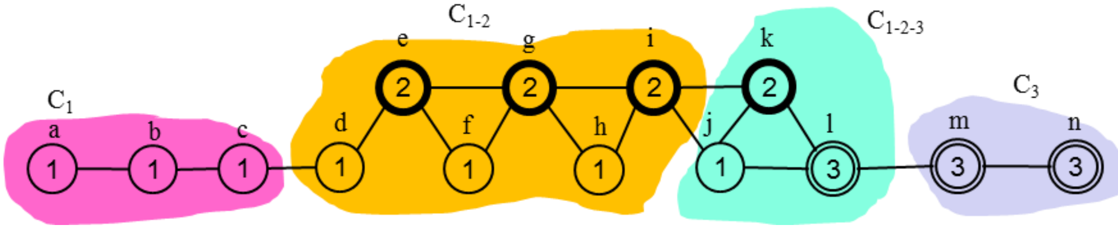

Figure 4: Clusters of size 1, size 2 and size 3

To finalize the example, assuming that there are no channel constraints, the result of the Stage C spectrum assignment is represented in the figure below:

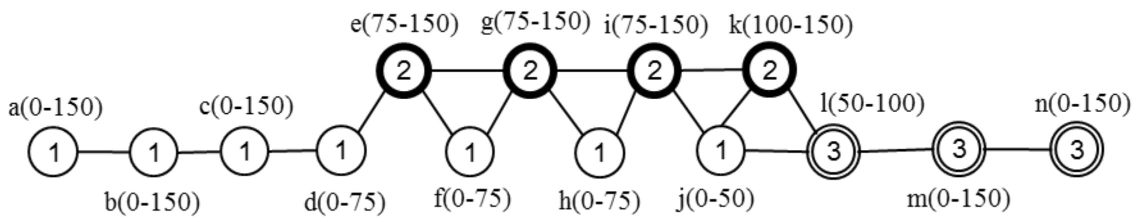

Figure 5: Spectrum assignment for CBSDs in the Connected Set

Where (0-150) is the full 150 MHz available spectrum between 3550 and 3700 MHz; (0-75) is the lower half of the spectrum; (75-150) is the upper half; (0-50) is the lower third; (50-100) is the middle third; and (100-150) is the upper third

4.4 Stage C: SAS level - Assign frequency ranges (channels) to CBSDs

The following principles can be considered by the SASs for assigning GAA frequency ranges to CBSDs:

- **Maximize channel usability and avoid or minimize channel constraints**
  - Assign channels in a way that will allow CBSDs to operate close to the desired power level
- **Contiguous (preferably) or proximal spectrum allocation to meet Instantaneous Bandwidth (IBW) constraints of the CBSD**
  - Assign channels that are close to each other to fit within the CBSD IBW
  - Consider also the CBSD capability in terms of Occupied Bandwidth (OBW)
- **Long term spectrum allocation stability**
  - Consistently assign the same channels to the CBSDs/CxGs
  - Avoid, as much as possible, changing channel allocation after CPAS unless there is major change in connected set or incumbent activity
- **Provide High User Value (i.e. high channel quality)**
  - SINR used as an approximation to user value
  - Augment computed user value with measurement data collected by SAS from CBSDs
- **Fairness** – for future consideration
  - Potential use of different fairness metrics – based on gained field experience
  - Reward CBSDs that have features to minimize interference

- **Continuity of service** – for future consideration
  - Assignment of backup channel in case of channel becoming unavailable due to DPA activation

Since the algorithm for finding an optimal channel assignment has to take into account different aspects as showcased above, SAS Administrators are encouraged to provide their proprietary implementation for Stage C.

4.5 Stage D: Unified GSC solution: Assign final channels to CBSDs

In case there are several SASs participating in the GSC solution, a process is needed to find a unified consistent solution for CBSD frequency range assignments that will be applied across all participating SASs.

The easiest way to reconcile the frequency assignments done by different SASs is to objectively compare the assignments and to select the best one to be applied by all SASs. An Objective Function has to be defined for this purpose.

4.5.1 Frequency Range Assignment Objective Function

An Objective Function is introduced to compare channel assignments. The objective function is based on a channel quality estimate.
Let *CQ(x, ch)* function be an indication of the channel quality for channel *ch* if it has been assigned to CBSD *x*. The channel quality function is based on a points systems where different amount of points are assigned for different aspects of the channel assignment:

- Points allocated for the CBSD opportunity to transmit at the desired power level:
  - Subtract 10**(Desired_power – IAP_power)* points if [*Desired_power – IAP_power* <= 10 dB]
  - Subtract 500 points if [*Desired_power – IAP_power* > 10 dB]; this is done to discourage power back-off more than 10 dB
  - Alternatively, to avoid the step function corresponding to 10 dB power reduction, the formula can be changed to subtract the number of points equal to $20*(10^{(Desired\_power-IAP\_power)/10} - 1)$, which will provide a smoother transition for power reductions greater than 10 dB

- Points allocated for channel allocation stability:
  - Add 10 points if the channel *ch* was also assigned to CBSD *x* the day before
- Points allocated for contiguous allocation:
  - Add 25 points if the adjacent channel *ch-1* is also assigned to CBSD *x*
  - Add 25 points if the adjacent channel *ch+1* is also assigned to CBSD *x*
  - Subtract 25 points if the adjacent channel *ch-1* is assigned to a different CxG
  - Subtract 25 points if the adjacent channel *ch+1* is assigned to a different CxG

- Points allocated for the channel quality estimated by the User Value
    - Add 100 points if estimated User Value > 10 for CBSD *x* in channel *ch*
    - Add 50 points if estimated User Value is between 5 and 10 for CBSD *x* in channel *ch*
    - Add 10 points if estimated User Value > 0 for CBSD *x* in channel *ch*

Different weights can be applied when summing up the points for the *CQ* function:

$$CQ(x,ch) = w_1 * P_{power} + w_2 * P_{stability} + w_3 * P_{continuous} + w_4 * P_{quality}$$

Initially, $w_1 = w_2 = w_3 = w_4 = 1$, and it will be adjusted later based on field experience.

The points above are awarded to channel *ch* that is 10 MHz wide. 5 MHz channels do not get any awarded any points.
For a channel assignment *m*, the objective function used to compare the quality of channel assignment is:

$$OF(m) = \sum_x \sum_{ch} CQ(x, ch)$$

The goal is to maximize the objective function *OF*. SASs will select a channel assignment *m* that has the maximum *OF(m)*

The estimated User Value expresses the quality of a channel. The estimated User Value is based on the SINR:

$$SINR = \frac{S}{I + N}$$

where the *S* is the useful signal received by the EUD, *I* is the interference received by EUD and *N* is the noise level.
The same formula can be expressed in dB as:

$$SINR_{dB} = S_{dB} - N_{dB} - log_{10}\left(1 + \frac{10^{\frac{I_{dB}}{10}}}{10^{\frac{N_{dB}}{10}}}\right)$$

The SINR is calculated on a grid of points within the coverage of the CBSD. It includes interference received from the CBSDs within a radius of 40 km from each grid point (only CBSDs that are part of the same connected set are considered) operating in same channel as well as adjacent and alternate channels. For CBSDs operating in adjacent and alternate channel, the Tx power is adjusted based on the transmission mask specified by the FCC Part 96 [n.2].

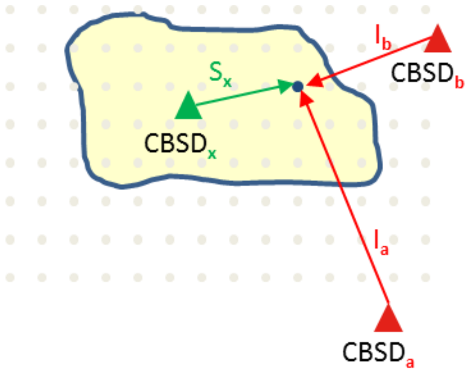

Figure 6: Example of Useful Signal and Interference used to calculate SINR for a point *p* in the grid

The final estimated User Value is computed by averaging the SINR values

$$UV(x,ch) = Average(SINR_{dB}(p, x, ch))$$

where *p* are the grid points within the coverage of the CBSD.

Using the grid of points is very similar with the PPA protection approach.

5 Document History

Document history		
V1.0.0	16 May 2019	Initial Release