CBRS Protocols Technical Report

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TERMS, CONDITIONS & NOTICES

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CBRS Protocols Technical Report

1 Scope

This technical report provides an informative explanation of the use of the CBRS protocols in the context of particular use cases and functions. The information provided is intended to be helpful as an illustration of how the mechanisms used in the protocols can be employed in particular situations, but is not intended to be normative or complete.

Sections 2 and 3 of the document contain examples of protocol interactions between CBSDs and the SAS. The heartbeat interaction described in section 2 is central in governing the transmission authorization of CBSDs. The spectrum inquiry process described in section 3 is the mechanism by which CBSDs get information from the SAS about available channels at the CBSD's location.

Sections 4 and 5 describe the registration process whereby the SAS collects required information about a CBSD's identity, capabilities, and installation parameters prior to spectrum grant interactions.

Section 6 provides an overview of the various error codes which can be returned from the SAS to a CBSD and gives examples of how a CBSD can handle such error codes.

Section 7 provides an explanation of how the protocol is used to provide support for Priority Access Licensee CBSDs.

1.1 References

[n.1] "Spectrum Access System (SAS) - Citizens Broadband Radio Service Device (CBSD) Interface Technical Specification", WINNF-16-S-0016 V1.1.0, 2017.

[n.2] "Report and Order and Second Further Notice of Proposed Rulemaking," FCC-15-47, GN Docket 12-354, 21 April 2015.

1.2 Acronyms and Definitions

See [n.1] for a full list of acronyms and definitions.

CBSD	Citizens Broadband Radio Service Device
Grant	A Grant is a reservation for a contiguous frequency allocation. A CBSD uses the Grant procedure in the protocol to obtain a spectrum allocation from the SAS.
Heartbeat	The heartbeat is a temporary authorization ticket that allows the use of the Grant. It is provided by the SAS to the CBSD following a request by the CBSD on an ongoing basis.
PAL	Priority Access Licensee
SAS	Spectrum Access System

2 Heartbeat Timing Diagrams

2.1 Introduction

This section provides an informative description of the operation of the SAS-CBSD Heartbeat procedure and its application to various use cases in CBSD management.

A PAL Grant provides a spectrum reservation in a manner that prohibits any other SAS from granting any other user permission to use any subset of the spectrum allotted to the PAL Protection Area (PPA). This includes areas within the designated PAL Protection Area (PPA) as well as adjacent areas determined by the SAS to achieve adequate stand-off distances and adequate interference protection from other co-channel users. The SAS considers all CBSD Grants in its interference calculations as well as considering protection of other higher tier users, viz., Tier 1 incumbents and Tier 2 PAL users.

The Grant period is expected to be quite long relative to the authorization period. There is minimal cost for the CBSD to ask for a Grant extension. The expectation is that the CBSD will get this extension well before the expiry of the Grant. (e.g., Grants are around a year or so and Grant renewals would be at about half that cadence).

Grants are long-lived by design, but a CBSD is allowed to transmit using the Grant only in limited time intervals under the control of the Heartbeat procedure. Each Heartbeat provides continuing authorization for a short time interval before which the CBSD will have to secure a new period of authorized activity by sending another heartbeat request to the SAS and receiving another response.

The heartbeat cadence is much, much faster than the Grant cadence (typically a few minutes as opposed to months). CBSDs therefore need not worry too much about Grant renewal. They can expect continued authorization to operate on the channel without needing to renew the Grant often. The mere act of sending a heartbeat will almost always extend the authorization to operate on the channel, and a Grant that is due to expire can be renewed using the heartbeat procedure. The heartbeat is intended to guarantee that the connectivity between the CBSD and its authorizing SAS is maintained and verified.

2.2 Basic Heartbeat Anatomy

The diagrams in this section follow the schema described in Figure 1.

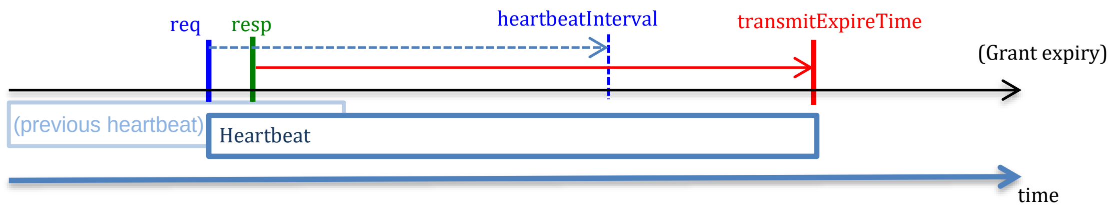

Figure 1: Basic Heartbeat Anatomy

The *heartbeatInterval* is a recommended value for the CBSD to use for re-authorization requests. Ordinarily it will be smaller than the *transmitExpireTime*. The heartbeat response from the SAS *can* update the *heartbeatInterval* as part of the heartbeat process.

The *heartbeatInterval* field is specified as a timer interval (in seconds) relative to the time the previous heartbeat was sent. The first heartbeat after the Grant is ordinarily expected to be sent right after the Grant is given to the CBSD, regardless of the value of *heartbeatInterval*.

The *transmitExpireTime* (transmit authorization expiration time) parameter is set in every heartbeat response and indicates to the CBSD the time at which it must begin to hand off traffic and stop all transmission, unless it receives a re-authorization in a subsequent heartbeat. The CBSD has 60 seconds from the time indicated by the *transmitExpireTime* to discontinue use of the radio resources represented by the Grant. Thus, it represents the maximum heartbeat period, including the time for receiving a response to the heartbeat request.

Ordinarily the difference between request and response times ('req' and 'resp') will be very small compared to the *transmitExpireTime* distance from the response time and the *heartbeatInterval* (10s of milliseconds as compared to 100s of seconds). Therefore, most of the diagrams ignore this and just draw the heartbeat periods as boxes. There is in general a possibility of delivery delays between the SAS and CBSD, and to manage this the *transmitExpireTime* is provided in an absolute time reference rather than relative to delivery time of the message.

2.3 Expected Heartbeat Operation

The normal operation of heartbeats is shown in Figures 2 to 5.

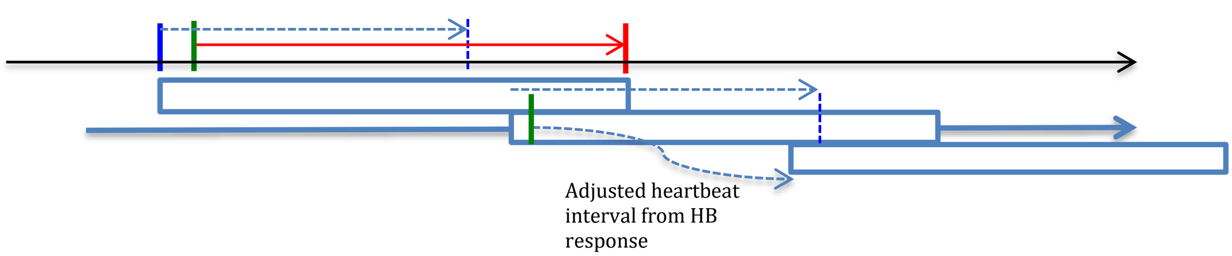

Figure 2: Expected Heartbeat Operation

Figure 2 illustrates the CBSD sending a heartbeat request on an interval timer, and getting overlapping *transmitExpireTime* authorizations that extend the original authorization. There are no interruptions of service. Denials of authorization status by the SAS are expected to occur very infrequently. When they do the CBSD can expect to be able to find an alternative spectrum allocation.

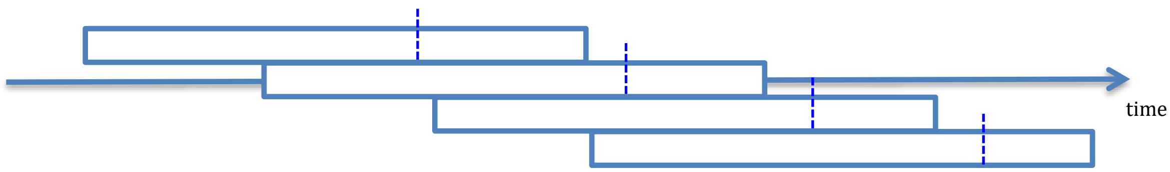

Figure 3: Successive Heartbeats.

The boxes in Figure 3 represent the times of successive heartbeat requests and the corresponding re-authorization times provided by the SAS

It is also acceptable for the CBSD to send heartbeats in advance of the suggested interval timer (that is, to use a shorter interval timer than the one suggested by SAS) to provide a longer interval in which the CBSD can perform handover if needed, thus improving performance. Figure 3 illustrates this kind of behavior. *Heartbeat interval is advisory, not mandatory*.

Sending a heartbeat request too often could result in the request being ignored by the SAS for load management reasons. It is expected that CBSD vendors and SAS administrators will establish prudent guidelines for heartbeat interval choices.

It is suggested that the heartbeat is carefully chosen to provide the CBSD with a desirable lead time before having to react to incumbent activity or other administrative action by the SAS, avoid overloading the SAS with traffic, and account for possible message loss (e.g. 80 to 90 percent of the re-authorization time indicated by *transmitExpireTime*). The exception to the rule is if multiple heartbeat requests from the CBSD do not receive a response from the SAS; the CBSD might then rapidly attempt to complete a heartbeat exchange. The decision regarding when a CBSD must prepare to vacate the Grant is left to the discretion of the implementation, subject only to the relevant Part 96 requirements.

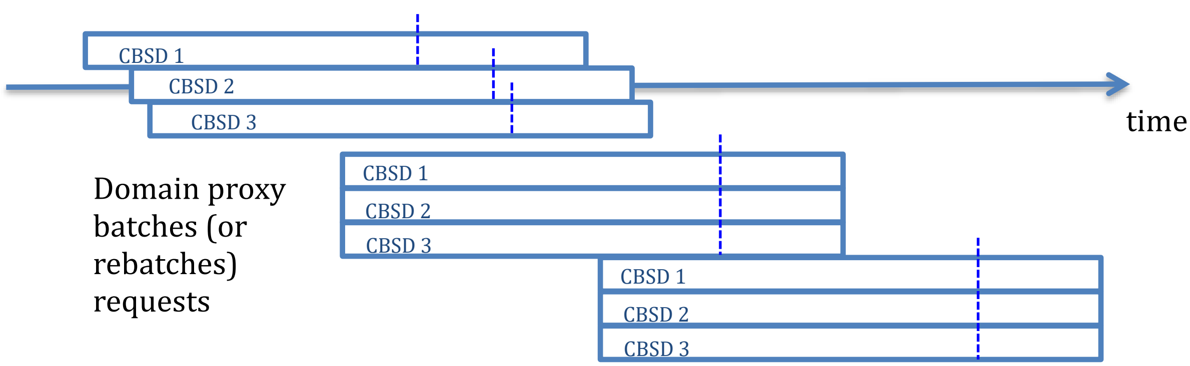

Figure 4: Domain Proxy Batching of Heartbeat Requests

Figure 4 illustrates that the CBSD can re-frame heartbeat requests according to its own preferences, e.g. to align with other requests by a domain proxy or for other reasons.

2.4 Extreme Situation: Multiple heartbeat requests

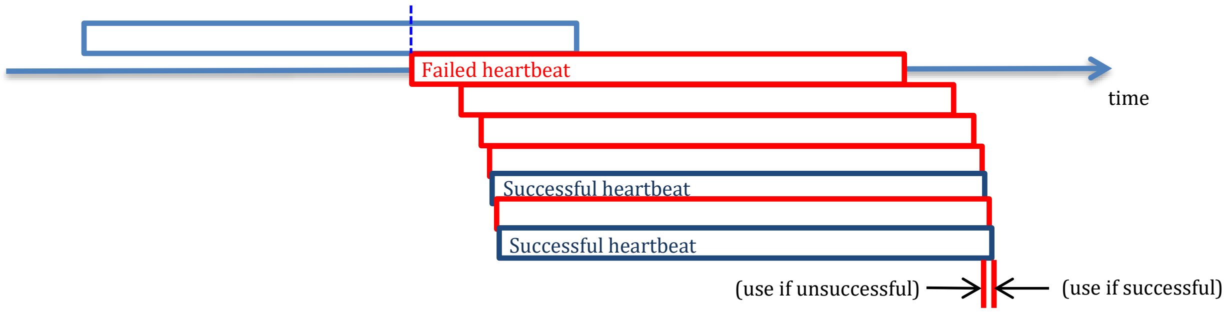

Figure 5: Use of Repeated Heartbeat Requests to Ensure Continued Transmission

If a CBSD is nearing the transmitExpireTime and has not received a successful heartbeat response from the SAS it can repeat heartbeat requests in short intervals in an effort to successfully contact the SAS. Retransmission must be done carefully to avoid overloading the SAS.

In such a case, if there are multiple successful heartbeat responses, the CBSD can use the **last** *transmitExpireTime* it received.

HOWEVER, if the CBSD receives any unsuccessful (suspend or terminate) Grant indication *responseCode,* it must obey the most **conservative** *transmitExpireTime* it has received.

If a CBSD can only remember the most recent value of heartbeat response it has received, it ought not send simultaneous heartbeat requests.

2.5 Suspension or Termination of a Grant

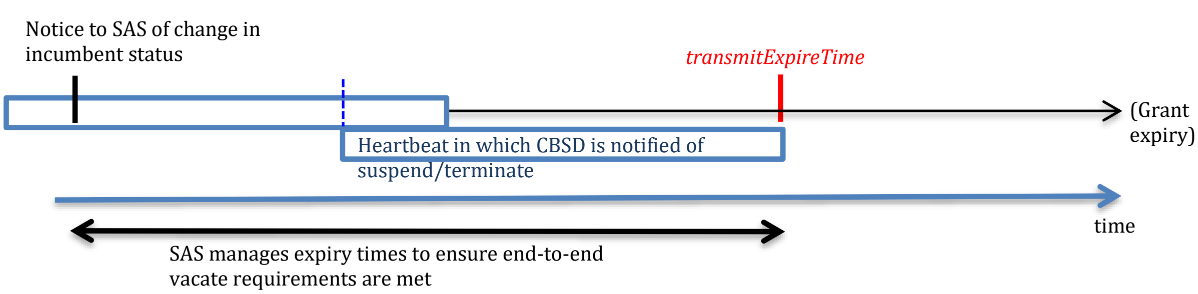

Figure 6: Heartbeat Response Indicating Suspension/Termination

Figure 6 shows the ordinary termination of a Grant. After the SAS is notified about a change in incumbent status (or other event warranting a Grant change), the CBSD is notified in the subsequent heartbeat response message. The SAS manages the *transmitExpireTimes* such that the full time from the notice to the SAS to the device change in operational parameters implementing the requirement satisfies the protection timelines.

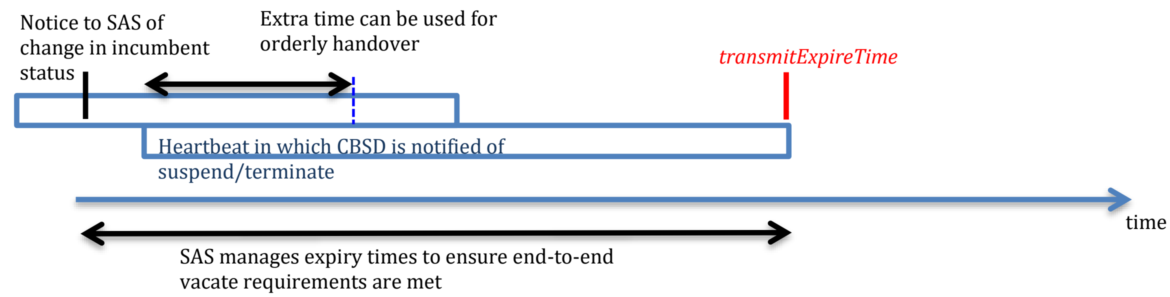

Figure 7: Advanced Heartbeat Scheduling

Figure 7 shows how an advanced heartbeat scheduling can provide extra time for orderly handover in the case of a change in Grant status.

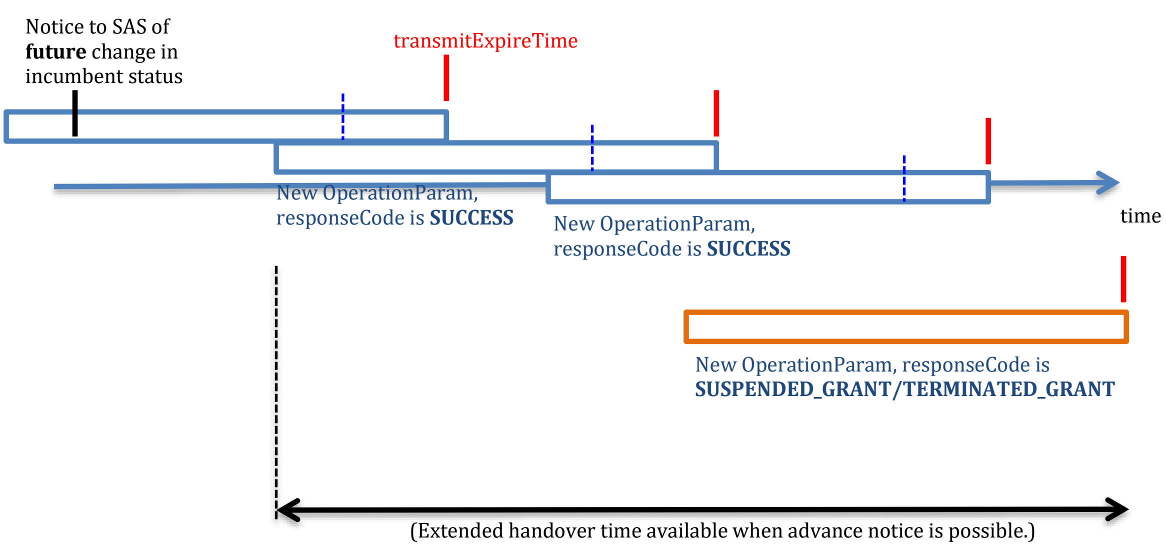

Figure 8: Use of Advanced Heartbeat Scheduling to Provide Advance Warning

Figure 8 shows how this can be extended to provide significant advance warning when the SAS knows of a future change to incumbent status. In this case, new operational parameters are provided to a CBSD in advance of a required change in Grant. The CBSD then has an extended period in which to request a new Grant and perform an orderly handover. The last heartbeat response message before the required change will have the suspend/terminate code indicating the CBSD is required to implement the change. If the CBSD cannot store alternate operational parameters from earlier heartbeat responses, it can always choose to use the most recent alternate operational parameters it receives, and decide to wait until the suspend/terminate notice. If the CBSD receives a termination notice, it is recommended that it explicitly relinquish the grant using a relinquishment message. If the notice is for a grant suspension, it is up to the CBSD whether to continue to heartbeat the grant waiting for it to become available for transmission again or relinquish it and seek an alternative grant.

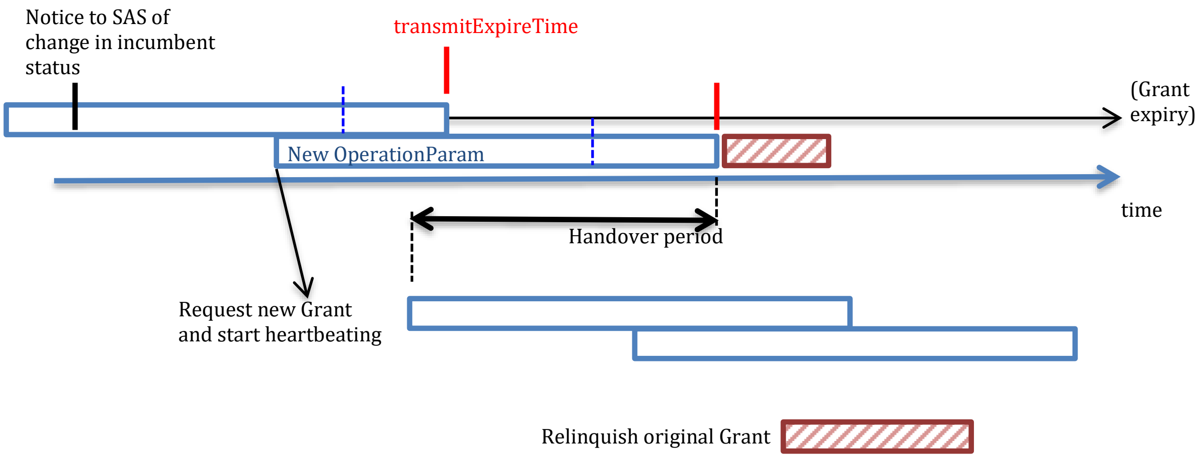

Figure 9: Use of a Handover to Switch Between Grants

Figure 9 includes a diagram of how the handover period can be managed by the CBSD to implement a make-before-break function using multiple Grants. That is, when one Grant is being suspended, the CBSD can request a new Grant, then handover end-user functions into the new Grant, then relinquish the original Grant.

2.6 Emergency Shutdown

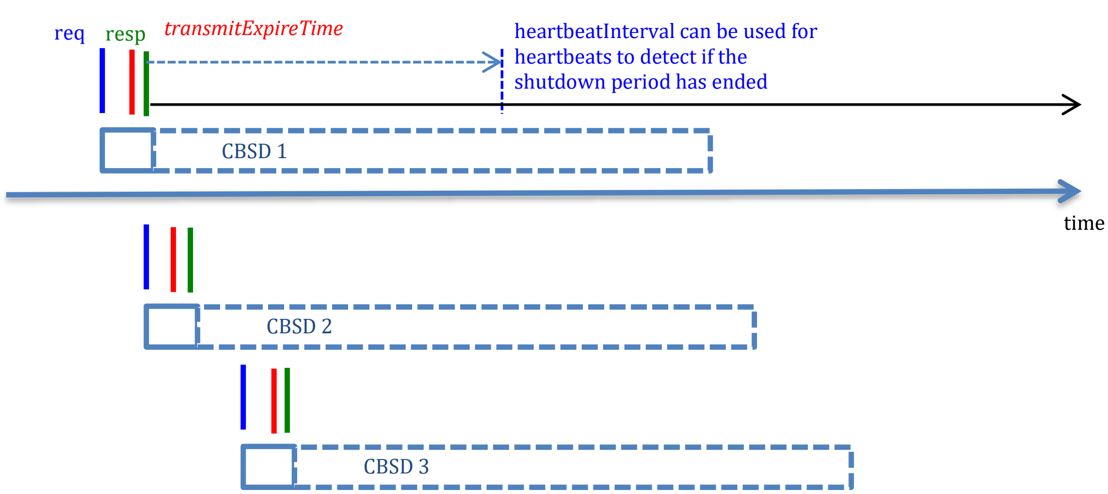

Figure 10: Emergency Transmission Shutdown

Figure 10 illustrates the procedure the SAS can execute for signaling the CBSDs to shut down immediately. In this case, the *transmitExpireTime* is set to a value 60 seconds in the past, *before* the time the response is received by the CBSD. In this eventuality, the CBSD (which looks at the *transmitExpireTime* + 60s as the limit for transmission) must cease operations immediately, without any orderly handover.

In the case of any suspension of a heartbeat such as this, the CBSD can continue to heartbeat on the suspended grant until the conditions causing suspensions have reversed, or it can relinquish the grant and seek unimpaired spectrum resources.

2.7 Initial Grant extended heartbeat interval

Figure 11 illustrates the situation for an extended *heartbeatInterval* provided in the first heartbeat response after a Grant request to signal to the CBSD explicitly that the Grant is approved but transmission is not yet authorized (SUSPENDED_GRANT). For example, this situation can happen if there are pending power level adjustments elsewhere in CBRS to be able to admit the CBSD and maintain incumbent protection constraints.

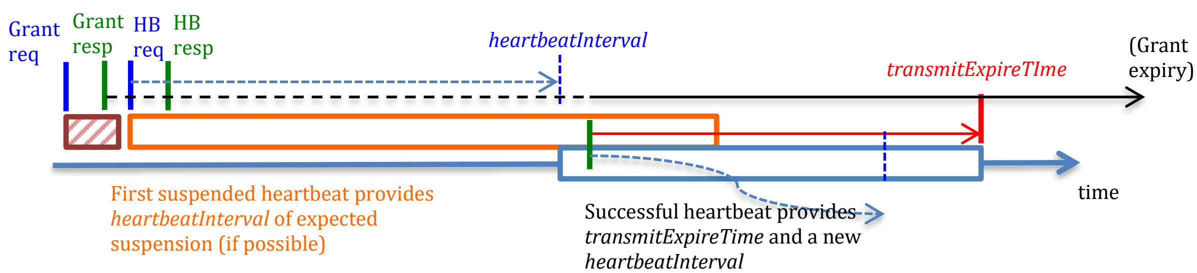

Figure 11: Use of Extended Heartbeat Interval

Here the first heartbeat request is sent immediately after the Grant response, as usual. The first heartbeat response indicates the suspended nature of the Grant with a *responseCode* of SUSPENDED_GRANT, with a heartbeat interval which can express to the CBSD a hint about when the Grant will become available for use. The CBSD is free to check ahead of that interval about availability, as with all *heartbeatInterval* advice.

2.8 Grant Renewal

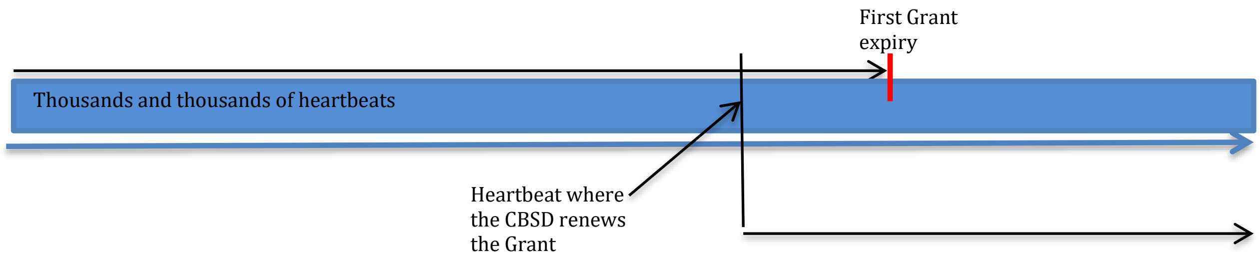

Figure 12: Grant Renewal

At some point an internal CBSD threshold is met and the CBSD includes a Grant renewal request in a heartbeat request. This operation is cheap, so the CBSD can feel free to send an extra heartbeat request to renew the Grant if desired.

2.9 Timing synchronization

The units in which the SAS sends the *transmitExpireTime* timer value is in absolute time. This requires the SAS and CBSD to have good synchronization between their clocks. The SAS-CBSD protocol requires the SAS to send an HTTP Date header with responses, which the CBSD can use to help synchronize its relevant clock to the SAS time basis.

For instance, if a particular heartbeat request latency is less than a second, the CBSD can be confident that the Date header time is correct to within one second, and use that fact to discipline its own relevant clock.

There can be unpredictable network latencies between the CBSD and SAS which produce more unpredictable latencies for exchanged packets. In such cases, the CBSD can use other mechanisms such as an NTP service or other non-SAS-CBSD mechanism, such as GPS if available, to achieve clock synchronization. It is expected that SAS-CBSD protocol latencies for heartbeats will frequently be quite small; however, so the Date HTTP header will typically provide sufficient information to perform adequate synchronization.

Complex network topologies where latencies are higher are likely to be correlated with the availability of other synchronization schemes such as NTP, so a reasonable approach for a CBSD would be to rely on SAS-CBSD timing sync unless there is a specific manager-provided alternative supplied.

3 Spectrum Inquiry Process

3.1 Spectrum Inquiry Process

A CBSD can initiate a spectrum inquiry process any time after it has successfully registered with a SAS. The Spectrum Inquiry procedure is used by a CBSD to learn what frequency ranges are available to it for a future Grant. This procedure is not mandatory for a CBSD to operate. For example, if a CBSD already knows (through some out of band communication) that a channel is available, it can request a grant for that channel without performing spectrum inquiry. Note that even if a CBSD learns that a frequency range is available through spectrum inquiry process, it is not guaranteed that if the CBSD sends a Grant Request for that frequency range, it will be successful. This can happen, for example, because an incumbent became active just after the spectrum inquiry response and before the grant request process.

We illustrate the spectrum inquiry process with some numerical examples. Let us assume that for the location of a CBSD making Spectrum Inquiry Request, the availability of the frequencies is as shown in Figures 13-14 below.

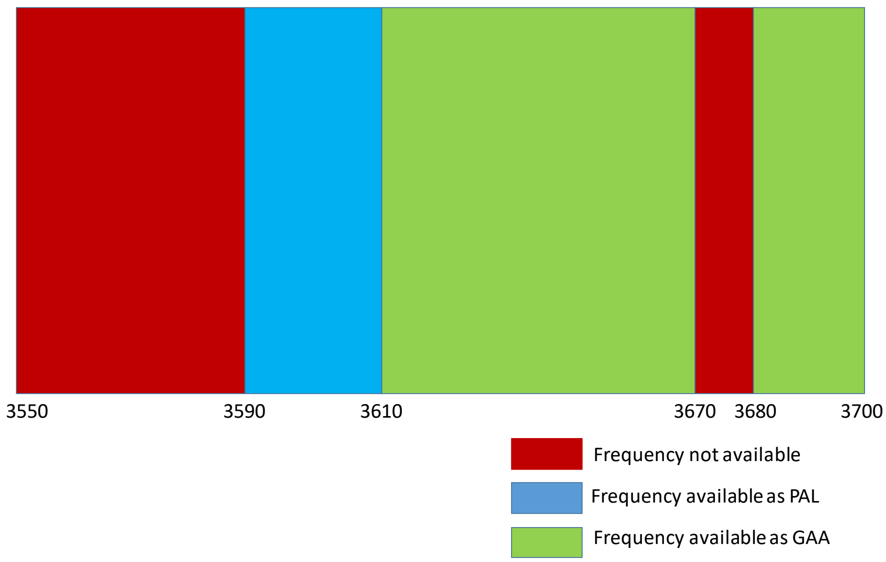

Figure 13: Frequency Availability

Spectrum Inquiry requests will return indications matching the availability of channels within the indicated frequency ranges. For example, a full-band request could return something like the following:

3590-3600	3600-3610	3610-3620	3620-3630	3630-3640	3640-3650	3660-3670	no response for unavailable channel	3680-3690	3690-3700
PAL	PAL	GAA	GAA	GAA	GAA	GAA		GAA	GAA

Figure 14: Frequency Availability Report

Note that unavailable frequency ranges are not included in the reply.

Partial-band requests (e.g. requests for information on only some channels) will receive back responses with the desired subset of this information. CBSDs can expect to receive channel rasterization information from the SAS spectrum inquiry process aligned with the channel grants that, if used, will provide them with the largest spectrum allocation.

3.2 Spectrum Inquiry ResponseCode Handling

The Spectrum Inquiry procedure provides a means for the CBSD to learn from the SAS what spectrum ranges are available for a Grant. A *responseCode* of 0 (SUCCESS) on the Spectrum Inquiry Response message indicates that the SAS was able to process the Spectrum Inquiry Request. Usually one or more available spectrum ranges are indicated in the Spectrum Inquiry Response message; however, it is possible that even though the request was successfully processed, no channels are available in the requested range(s). In such a case, the CBSD can submit another Spectrum Inquiry Request message specifying different or additional spectrum ranges.

When a CBSD receives a successful Spectrum Inquiry Response message with one or more available spectrum ranges, the CBSD usually selects the spectrum range most closely fitting its needs and submits a Grant Request indicating that spectrum range. Note that even though the spectrum range was indicated as available on the Spectrum Inquiry Response message, there is no guarantee that it will still be available at the time the Grant Request is made. It is also possible that the SAS has the spectrum range available, but cannot accept the power level (maxEIRP) specified by the CBSD in the Grant Request.

Other possible *responseCode* values that can be given on a Spectrum Inquiry Response message are:

- BLACK_LISTED
- MISSING_PARAM
- INVALID_VALUE
- CERT_ERROR
- DEREGISTER
- UNSUPPORTED_SPECTRUM

See the section on error code handling for more detail on these *responseCode* values.

4 CBSD Identifiers and the SAS

The SAS-CBSD protocol depends on several identifiers exchanged between the CBSD and the SAS. This table summarizes those IDs, their uniqueness scope, and who assigns them. In practice, some uniqueness scopes can be larger than indicated due to best practices engaged in by participants (e.g., manufacturers could agree to a common assignment practice which would make serial numbers globally unique).

Table 1: CBSD Identifiers

Identifier	Minimal Uniqueness Scope	Assigned by
FCC-ID	Global	FCC

Serial number	Per FCC-ID	OEM Manufacturer, which must guarantee uniqueness for any duplication of FCC-ID across OEMs or models, and may include a suffix (e.g. to identify sectors in a multi-sector piece of equipment)
CBSD-ID in SAS-CBSD exchange	Global	SAS
CBSD Reference ID in SAS-SAS exchange	Global	Computed from FCC-ID and Serial number
Grant-ID	Per CBSD-ID	SAS
User Id (UR-ID)	Global	SAS (e.g. for PAL users, this can be "license@FRN" to ensure uniqueness and correspondence to the PAL shared database)
Call Sign	Global	FCC (if applicable)
Air Interface and Measurement Identifiers	Global	Administered by WinnForum
Interference coordination Group-ID	Per userId (Note: subject to change in v1.1.0 of SAS-CBSD Protocol)	User

Before a CBSD can begin automated channel allocation requests with the SAS, the CBSD must be registered with the SAS. This is a rather complex process where the following separate registrations or enrollments might be required:

- User Registration: CBSDs must be associated with a user; the user is required to pre-register (enroll) with the system. The user can be an organization or an individual. The user may be the owner, the deployer, or the manager of the CBSD(s).
- Certified Professional Installer (CPI): A person who is certified to install CBSDs.
- Certified Professional Installer Device Information (CPIDI): Some CBSDs will be installed by a CPI. The CPI is to be pre-registered with a Professional Installer accrediting body and its database. This certification database must be accessible by the SAS. *Note: Category B CBSDs must be setup by a CPI.*

- CBSD Registration: The CBSD must register with the SAS and also provide installation details.
  - User installed CBSDs: Category A CBSDs can be installed by a user or an authorized associate or employee of the user. Such CBSDs will initiate registration with the SAS. A user-installed CBSD must be capable of automatically calculating (GPS) its location (as per the FCC Rules) and provide that location information as part of the CBSD registration process.
  - Professionally installed CBSDs: All Category B CBSDs must be installed by a CPI. Category A CBSDs unable to automatically determine their location (GPS) accurately enough to meet the FCC Rules must be installed by a CPI [Ref N.2 FCC-15-47 ¶ 208]. Any Category A CBSD requiring antenna information (gain, pointing direction) must also be installed by a CPI. Category A CBSDs might not be capable of automatic determination of their location (either by design or due to disadvantaged placement); such CBSDs will be installed in a fixed location so as to be attached to a permanent structure (e.g. pole, ceiling, or wall), and the location of such a CBSD's antenna will be provided by the CPI.
  - Note that in a multi-sector piece of equipment (transmitting independent waveforms, so not MIMO), every sector is considered a separate CBSD with its own unique serial number (e.g. with a suffix designating the sector) and registration. Implementation details are determined by the manufacturer.
- PAL Registration: For CBSDs using PAL spectrum, the PAL identifier (PAL-ID) and the specific must be pre-registered.

4.1 User Registration / Enrollment with the SAS

The User is a person or company who owns, deploys or manages, and is responsible for, one or more CBSDs. User registration with a certified SAS is expected to be a manual process (likely via a Web Interface).

After the User has provided necessary User contact information, the system must provide the User with:

- A User Registration Identity (UR-ID),
- A method to authenticate the User when accessing the User account (e.g., password),

TBD: Information exchanged between the CBSD User and the SAS Administrator will in the future establish a secure mechanism to associate CBSD(s) and User identity. This mechanism will be used to allow the SAS to properly associate a registering CBSD with its User. This is to ensure the CBSD is linked to a valid User and to ensure registration occurs with the User's permission. The mechanism will allow the owner to create sub-groupings of CBSDs which can be useful for large networks.

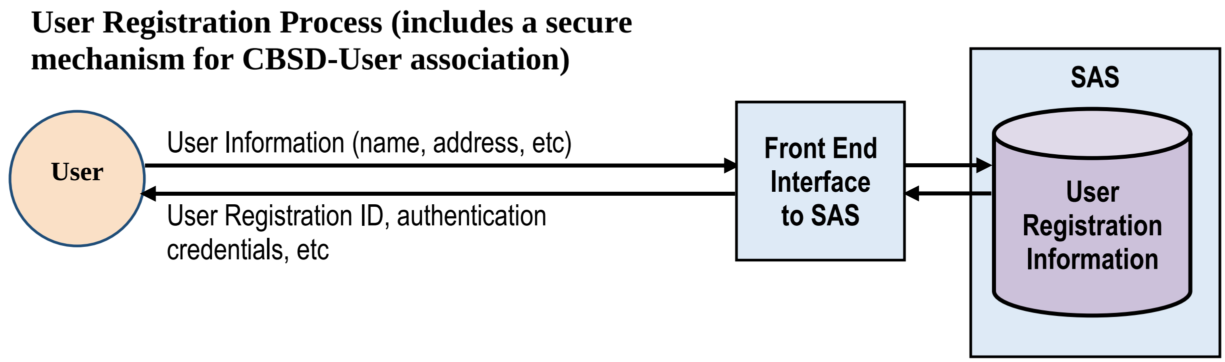

Figure 15: User Registration Process

4.2 CBSD Registration

Category B CBSDs are required to be setup by a CPI and require the installer to provide additional information about the CBSD. The information can be entered into the CBSD (to be relayed to the SAS) or entered by the CPI via a mechanism provided by the SAS administrator.

Category A CBSDs which are unable to automatically calculate their location adequately to meet the FCC requirements need to have their location entered by a CPI.

The information provided by the CPI is site specific.

The figure below is high level and does not imply any specific message sequencing.

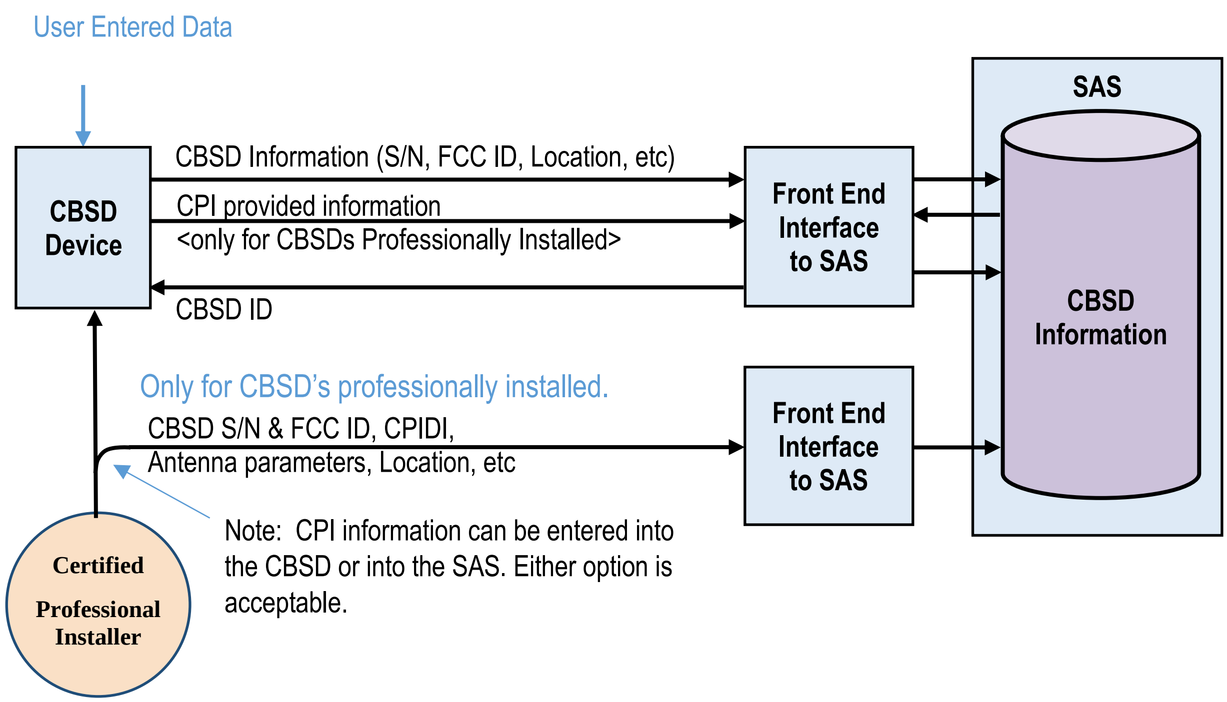

Figure 16: CBSD Registration Process

4.3 CPI Registration

The FCC Rules require Category B CBSDs and Category A CBSDs that cannot identify their locations to be installed by a CPI, while other Category A CBSDs can be installed by a CPI [96.45(b)]. CPIs must pass a certification program to be registered in a centralized database, which is accessible by all SASs. This will provide the installer with a system wide unique CPI Identifier and a method to authenticate the Installer when accessing the CPI account. This information will be used by the installer when they enter the Device Installation Record into the CBSD or provide it to the SAS Administrator.

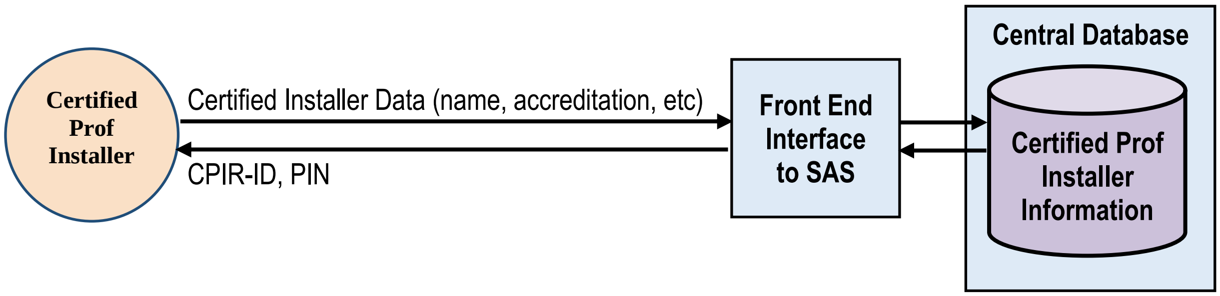

Figure 17: Installer Registration Process

5 Examples of Single- and Multi-Step CBSD Registration Procedures

There are several variations in the CBSD Registration procedure which are supported as a way of achieving the goal of having a fully registered CBSD, which can then engage in automated grant management and heartbeat exchanges with the SAS. The different entities relevant to the different registration variants are:

CBSD: the radio node transmitting in the CBRS band.

Domain Proxy: an optional system communicating with the SAS on behalf of a CBSD (or group of CBSDs).

Manufacturer (or OEM): the entity which created the CBSD itself, and most likely undertook the certification process whereby the CBSD was authorized by FCC for operation in the CBRS band (Original Equipment Manufacturer).

Registered User: the CBRS Registered User which has a SAS account and is responsible for the day-to-day operation of the CBSD.

Certified Professional Installer (CPI): a conditionally-involved individual who has received professional training in the CBSD Registration procedure has been certified by an accredited body, and is qualified to supply to the SAS details relevant to the RF performance of a CBSD. (Note that CPI involvement is required for Category B CBSDs and for Category A CBSDs that do not provide sufficiently accurate location measurements automatically).

SAS: the registering Spectrum Access System with which the various operational parameters required by the rules for operation of the CBSD are registered.

Single-Step CBSD Registration: The CBSD registration which is done by one-time Registration Request containing all the “Required” and “REG-Conditional” parameters.

Multi-Step CBSD Registration: The CBSD registration which is done by one or more Registration Requests containing all the registration parameters and/or by other means to provide REG-conditional parameters to the SAS.

The SAS depends upon data which in a multi-step registration process can be supplied by multiple entities. There are a wide range of possible use cases in which one or more of these entities can provide partial registration parameter data needed for the SAS to consider a CBSD successfully registered. As part of its function, the SAS must connect up the information provided by various sources about a CBSD to form a complete set of registration parameters. The way the SAS does this is by joining this data based on CBSD identification information provided by the various sources. The CBSD must have permanent identification information which identifies it uniquely to the SAS in the case of single-step registration (FCCID, model (if required for uniqueness), and Serial Number that can form the basis of a globally unique CBSD-ID). That same information is to be used by other parties providing registration data to the SAS on behalf of that CBSD, and thus can be identified to the SAS even if the CBSD has not even contacted the SAS yet.

The final step in all of these procedures is for the CBSD, or Domain Proxy acting on its behalf, to communicate with the SAS in machine-to-machine format and receive a successful Registration Response including an assigned CBSD-ID. When and only when that step is completed is the CBSD regarded as Registered.

Note that to perform these multiple Registration Request scenarios, the CBSD or Domain Proxy must be designed to recognize and support them.

5.1 Basic Machine-to-Machine Registration

Figure 18: CBSD-to-SAS Registration on the SAS_CBSD Interface

In the simplest case, all registration parameters are supplied once by the CBSD. This is the easiest case to understand, in that the SAS can respond with a success code to signal the CBSD that it is fully registered after a single exchange. This case applies to Category A CBSDs that can determine their location, and to both Category A and B CBSDs that have the remaining information installed in them by a CPI.

When the CPI first provides necessary data to the CBSD (or the Domain Proxy) itself, even cases (such as Category B installation) requiring CPI support can be accommodated in single-step registration. Parameters entered by a Professional Installer at the CBSD or Domain Proxy are securely signed by the CPI to guarantee integrity to the SAS.

5.2 Multi-step CBSD Machine-to-Machine Registration

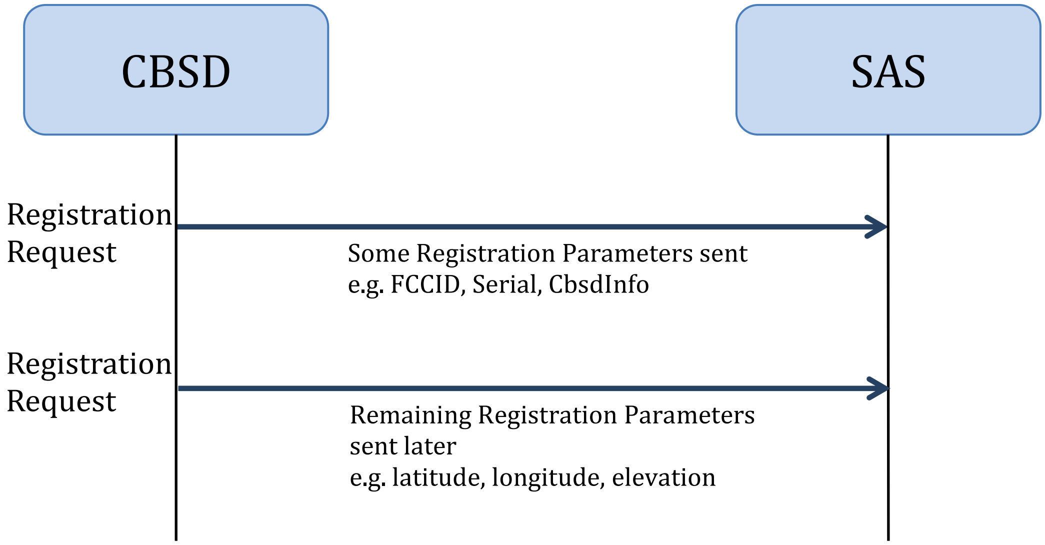

Figure 19: Multi-step CBSD Registration

This figure shows a more complex example, where a CBSD uses multiple requests to register with the SAS. All requests are still machine-to-machine, but the CBSD can be configured so it uses multiple steps to fully register. For instance, it could send global parameters in one request (e.g. FCC ID, Model (if required for uniqueness), Serial Number, CBSD Metadata information), and then send another request registering its current location (latitude, longitude) once those values become available.

In such a case the CBSD would receive a REG_PENDING response code after the initial Registration Request, and when it had supplied all required registration parameters, the SAS will respond with a SUCCESS response code.

Note that a CBSD could use an arbitrary number of registration requests to communicate the required parameters to the SAS. On each Registration Request the SAS checks to see whether all required parameters have been supplied. This could happen, for example, if a CBSD is being installed and moved from location to location, or is perhaps supplying parameters resulting in an unsuccessful registration and is then managed by the User into a successful registration condition. In such cases the CBSD can issue many Registration Requests before successfully registering.

5.3 CBSD Manual Pre-Registration

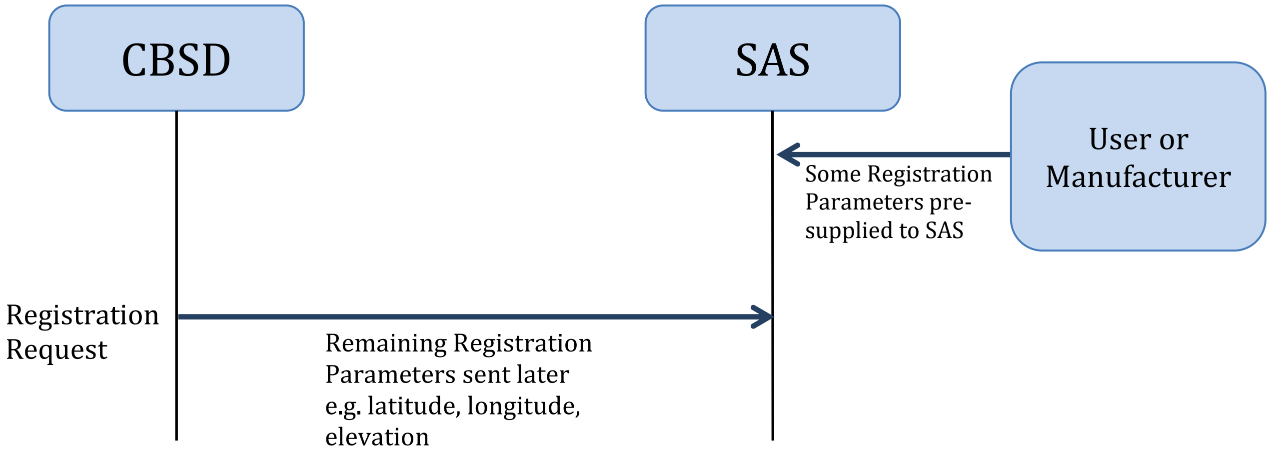

Figure 20: CBSD Registration Including Manual SAS Pre-Configuration

This figure illustrates another possibility for multi-step registration. In this situation, the SAS is manually pre-configured to contain some registration parameters for the CBSD. For example, the SAS can have a relationship with the CBSD manufacturer so that for a particular FCC ID, the SAS already has the required parameters related to measurement capability and air interface supported by the CBSD. In such a case, it is allowable for the CBSD to not provide those parameters to the SAS directly. Instead, they are provisioned in a separate process (perhaps a SAS accessible private database provided by the CBSD manufacturer) out of scope of the SAS-CBSD protocol.

In such a case, when the CBSD engages in a machine-to-machine Registration Request, it can only supply partial data but can still be approved by the SAS on the first request if the missing registration parameters which are required by Part 96 have already been supplied by this manual process. (Such parameters are marked as REG-Conditional in the protocol specification.)

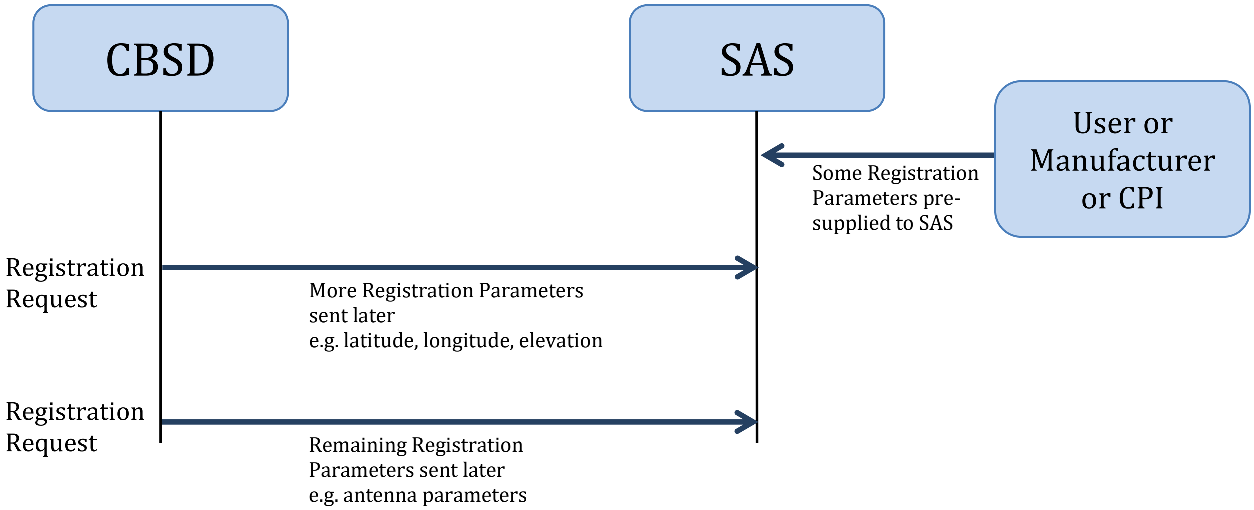

Figure 21: Variant A - Multi-step CBSD Registration Process

This figure shows a yet more complicated variant of this pre-registration process, wherein the CBSD has some parameters pre-registered by, e.g., the operator or manufacturer, and then again uses multiple registration requests to supply the SAS with all the required registration parameters.

5.4 Multi-Step Registration With Multiple Manual and Machine-to-Machine Steps

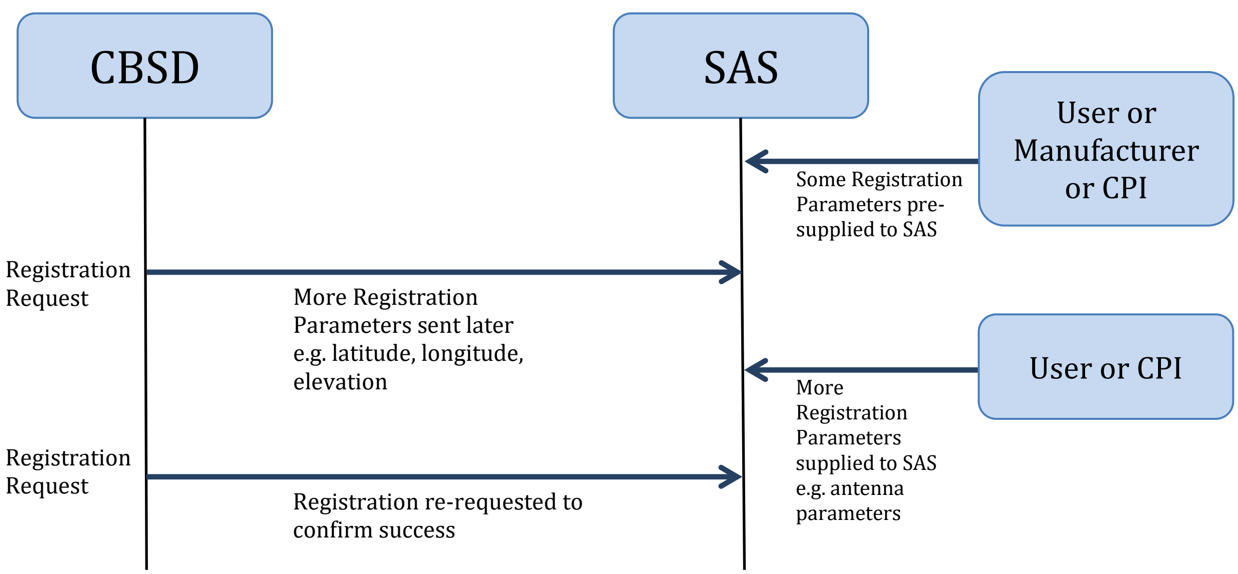

Figure 22: Variant B - Multi-step CBSD Registration Process

It is possible for not only the machine-to-machine provisioning of registration parameters to use multiple steps, but for the manual supply of registration parameters to use multiple steps as well.

Figure 18 shows such a case. Here there are some pre-registered parameters. (For instance, the manufacturer can supply general antenna characteristics and device characteristics to the SAS.) The CBSD engages in a machine-to-machine registration providing some general parameters. Then a CPI can supply yet more registration parameters to the SAS (e.g., regarding antenna gain, orientation, and the location of the CBSD). During and after that manual process, the CBSD can send more Registration Requests (or be triggered by the CPI to do so), ending with a confirmation that all parameters have been supplied, which is signaled by a SUCCESS response code returned to the CBSD.

5.5 The SAS REG_PENDING Response Code

The SAS uses the REG_PENDING (registration pending) response code to signal to the CBSD in a machine-to-machine way that not all required registration parameters have yet been received. There are a wide range of possibilities in multi-step registration, as well as different registration parameter requirements for Category A CBSDs and Category B CBSDs, some of which cannot be known by the CBSD engaging in machine-to-machine registration before the registration attempt is begun. Due to this fact, the SAS uses the REG_PENDING response code as a generic indication that more registration work is required, supplying details on the nature of the remaining parameters the CBSD registration process needs to supply.

This response code does not mean that the CBSD necessarily must supply the indicated registration parameters: in some cases that will not be possible, as a CPI will need to supply them. The indication is a guide to the CBSD as to what registration parameters are still required, which can be supplied either by the CBSD in subsequent Registration Requests, or through other means.

5.6 Merging partial registration data

When the SAS receives partial registration data from various sources (CBSD, Domain Proxy, CPI, User, Manufacturer), it will need to merge those data into a complete set of registration parameters. This will be done using the two identifying fields relevant to a particular CBSD device class and device identity: FCC ID, model (if required for uniqueness), and serial number.

When device data is supplied generically for a class of devices, that data will be keyed by the FCC ID and model (if required for uniqueness). This covers, for example, generic data supplied about a class of devices by the manufacturer of that CBSD device type or model. When registration data is supplied for a particular CBSD device, it will be keyed by the FCC ID, model (if required for uniqueness), and serial number of the device. (If a physical device serves more than one sector, each sector counts as a separate CBSD, and the hardware serial number may require a suffix for uniqueness.) These parameters are sufficient to identify the CBSD to the SAS using machine-to-machine communication, and so are necessarily sufficient to identify the CBSD to the SAS from other sources such as CPIs or CBSD users as well.

6 CBSD Error Code Handling

6.1 Introduction

This section provides an informative explanation of the various *responseCode* values which can be returned by the SAS to CBSDs during the SAS-CBSD Protocol exchanges. It also provides guidance on recommended responses by CBSDs to the various error conditions which can be communicated through these *responseCode* values.

In this document, the "CBSD" is described as responding to the various error conditions, but if a Domain Proxy is communicating with the SAS on behalf of a CBSD, any corresponding response can equally well be undertaken by the Domain Proxy itself, in connection with its administrator.

A *responseCode* value of SUCCESS (0) indicates successful completion of the applicable operation.

6.2 BLACKLISTED Response Code (101)

This *responseCode* value is returned by the SAS when the CBSD has been determined to be in violation of CBRS rules, and has been the subject of a manually-reviewed intervention which bars the CBSD from further operation until the problem is corrected.

An example of such conditions includes enforcement actions by the FCC if the equipment is found to be in violation of Part 96 rules.

The action the CBSD ought to take when receiving such a *responseCode* value in any message is:

1. Ensure that all transmission ceases as soon as technically possible.
2. Relinquish any outstanding Grants with the SAS.
3. Deregister from the SAS.
4. Using locally-available means, attract the attention of the User or operator of the CBSD, who can contact the SAS to correct the problem. Perhaps there is a fundamental problem with the CBSD hardware which requires it to be replaced, or perhaps there is a missing or invalid set of paperwork which the User needs to provide to the SAS before service can be restored.

Because this condition results only from manual intervention and is identified as a problem with Part 96 compliance, the only recourse of the CBSD is to attract the attention of someone who can make the corrections needed to enable service to be restored.

6.3 MISSING_PARAM Response Code (102)

During CBSD development, such a *responseCode* value from a SAS can indicate problems with the format of a SAS-CBSD message needing debugging. For properly operating CBSDs, this message is only related to severe protocol negotiation errors. In such a case, the *responseData* parameter in the response message indicates to the CBSD which parameters are missing. If the error results from stale or corrupt local information, it can be possible for the CBSD to recover from this error by resetting its state and retrying.

This responseCode value can also be issued by SAS when one or more "Required" parameters are missing.

6.4 INVALID_VALUE Response Code (103)

This *responseCode* value is issued by the SAS when the value of a parameter supplied in a message is invalid. If this occurs during CBSD deployment, it can simply be a case of incorrect formatting and require debugging.

6.4.1 Context: Grant-related procedures

In the field, a certified CBSD receives this *responseCode* value related to an ongoing Grant communication (Grant, Heartbeat, and Relinquish requests) only when the CBSD has fallen out of sync with the SAS related to that specific Grant. For instance, if the *grantId* value is notified as invalid, the Grant can be expired due to a connection problem between the SAS and CBSD.

In this case, the CBSD must immediately terminate any ongoing transmission under the authorization of the Grant it identified with the invalid grantId as soon as technically possible. (A certified CBSD ought not have any such ongoing transmission to terminate, but as a fail-safe it must ensure this is the case.)

The CBSD also ought to attempt to resynchronize with the SAS by relinquishing Grants it has recorded, and requesting new ones. There will probably be timestamp information available to the CBSD related to the last successful heartbeat procedures which enable it to detect that it has desynchronized. These relinquishment requests can also return INVALID_VALUE errors, but the CBSD will then be confident the SAS also reflects these Grants as no longer active.

6.4.2 Context: Registration procedure

If this *responseCode* value is returned as part of a registration procedure, there is a fault in one or more of the parameters supplied by the CBSD. The *responseData* parameter associated with the *responseCode* will indicate which parameters have problems.

In this case, the CBSD ought to notify the CBSD User/operator/installer to alert them to the invalid values. For example, this could happen in the case of a data entry mistake by a professional installer, or if a Category B device is mistakenly installed operating Indoors (such devices can only be operated Outdoors). The specific response to an invalid value during registration will be specific to the kind of error, but will require manual intervention by the person managing the installation. In this context, it is unexpected for the CBSD to retry such a registration request before the error has been addressed by the installer.

6.5 CERT_ERROR Response Code (104)

This *responseCode* value is returned by the SAS to indicate that the certificate presented during the SAS-CBSD protocol is invalid. An invalid certificate can also be identified if the SAS refuses the TLS session with a corresponding error condition.

This condition might be able to be automatically remedied by the CBSD if it is the result of, for instance, an expired certificate or obsolete firmware which can be refreshed automatically. In many cases, however, the CBSD will need to bring this condition to the attention of the CBSD

User or operator, as there might be maintenance to the CBSD required. For instance, if the security specifications evolve to disallow particular connection methods, the CBSD firmware would need to be upgraded to remain in compliance with the evolving specification.

6.6 DEREGISTER Reponse Code (105)

This *responseCode* value can be provided by the SAS if it detects the CBSD is in a badly desynchronized state. For instance, the CBSD can issue Grant-related requests and not be registered. In such a situation, the CBSD ought to reset itself and start over with initial registration. It is recommended that the CBSD also do any automated checks it has available to update its software and firmware in response to receiving this *responseCode* value. The SAS can have out-of-band information that the CBSD needs to be updated to continue to receive service, and is using this *responseCode* value to notify the CBSD of this fact.

It is expected that the CBSD is probably able to handle this *responseCode* value automatically, and it is expected that the CBSD will immediately re-attempt registration after performing whatever internal reset and update mechanisms it has at its disposal.

6.7 REG_PENDING Response Code (200)

A REG_PENDING *responseCode* value is only given on a Registration Response message. It indicates that the information provided on the Registration Request message was acceptable to the SAS; however, the SAS is still missing REG-conditional registration parameters. The list of those parameters that are still needed can be found in the *responseData* parameter.

The likely cases in which this could happen are:

1. Partial registration of a Category B CBSD requiring certain data to be provided by a CPI.
2. Missing User identification, which requires the CBSD to prompt the User or installing party to provide the required information.

Such errors will mainly occur during installation, and can be inspected by the CBSD and notified to the party installing it for correction. In general, it is acceptable for a CBSD to retry a request after a REG_PENDING error. Details will depend on the characteristics of the installation process for different CBSDs, but the CBSD ought to be informed that the required parameters either have been indicated to the installer for out-of-band provisioning to the SAS, or have been provided to the CBSD by the installer or otherwise gathered by the CBSD. It is acceptable for the CBSD to repeat registration requests while the information is being gathered – it will receive REG_PENDING errors until the full set of required Part 96 data has been collected by the SAS.

The missing parameter values need to be provided to the SAS prior to the CBSD achieving a successful registration. If the CBSD is a Category A CBSD that is normally installed without the help of a CPI, the method for providing the additional information is an administrative matter. If a CPI is involved in the installation of the CBSD, they can provide the information to the SAS directly and then cause the CBSD to reattempt the registration.

6.8 GROUP_ERROR Error Code (201)

This *responseCode* value can be provided by the SAS if an error in the group membership parameters supplied by the CBSD is detected. For instance, a CBSD can specify group memberships which the SAS determines as mutually contradictory, or for which the CBSD does not present the proper authorization.

It is not expected that the CBSD is likely to handle this *responseCode* value automatically. The CBSD can notify the CBSD User/operator/installer to alert them to the error condition.

6.9 UNSUPPORTED_SPECTRUM Response Code (300)

This *responseCode* value is returned by the SAS if a CBSD issues a Grant request or spectrum inquiry request which falls outside the CBRS spectrum range which can be allocated to it by the SAS.

It is expected that this *responseCode* value could be handled in a fully automated way, and that the CBSD will immediately re-try Grant-related requests with frequency ranges that are within the range the SAS can respond to.

6.10 INTERFERENCE Response Code (400)

The SAS uses the INTERFERENCE *responseCode* value to signal to the CBSD that a requested Grant will violate protection conditions. This *responseCode* value can occur even if the SAS has responded to a prior spectrum inquiry request indicating that the spectrum is available. The reason for this is that an incumbent (or, in the case of a GAA Device, a PAL) has possibly entered the band and requires protection in the interval between spectrum inquiry and Grant requests.

In this situation, the CBSD can handle the *responseCode* value automatically by continuing to seek a Grant according to its pre-existing algorithm. It can choose to return to the spectrum inquiry process and re-request available spectrum, or if it recently performed such an inquiry and has a prioritized list of channels to ask for, it can just continue on to ask for the next channel in its prioritized list. The details of the CBSD handling of this condition are not specified, but it is expected that ordinarily the resolution of the condition will be automatic. That is, the CBSD will issue further SAS-CBSD Grant-related requests.

In the case that a CBSD finds no available spectrum after sustained automated efforts, it can notify the person responsible for the CBSD that it is encountering difficulty. That person can then investigate and determine whether there is a transient condition blocking spectrum availability or something more permanent. For example, a transient condition can exist when there is a broad range of incumbent activity, which combined with the presence of other incumbents, drastically limits the temporary availability of spectrum. On the other hand, there can be a more permanent condition where the CBSD is located so close to an incumbent that it is unlikely to ever receive a Grant of spectrum because any operation will produce interference. The person responsible for the CBSD will need to manually intervene in such a case to decide how to handle it.

6.11 GRANT_CONFLICT Response Code (401)

The GRANT_CONFLICT *responseCode* value is used by the SAS to signal to the CBSD that there is a construction problem with the Grants it is requesting. For instance, the CBSD can be requesting a Grant which overlaps a Grant it already has.

It is expected that the CBSD handles this condition by resynchronizing itself with the state of its Grants. For instance, it can relinquish the conflicting Grant and then re-request the original Grant. In the worst case, the CBSD could relinquish all Grants it has if there is more desynchronization detected, and then start over in seeking a spectrum allocation.

6.12 TERMINATED_GRANT Response Code (500)

The TERMINATED_GRANT *responseCode* value is a response to ongoing heartbeat re-authorization, and notifies a CBSD that the Grant it has is being terminated. The CBSD must respect the accompanying *transmitExpireTime* indications about when the Grant termination occurs, and cease transmissions within 60s of that value.

The use of this *responseCode* value is an indication that the SAS has reason to believe the CBSD will not be able to re-acquire the terminated Grant, and so can therefore re-enter the process of looking for a Grant. Thus, the CBSD must relinquish the Grant after receiving this message and cease transmission in the associated spectrum range.

It is expected that the CBSD will immediately begin to seek another Grant. CBSDs can do this even before the *transmitExpireTime* has passed and it has ceased transmission, in order to be able to do a more graceful handover to another channel. The CBSD can use the information in the heartbeat response in which the SAS has suggested another alternate channel as a guide for this procedure.

The CBSD ordinarily ought to be able to handle this condition automatically, and the SAS expects it to immediately begin to seek a new Grant.

6.13 SUSPENDED_GRANT Response Code (501)

This *responseCode* value is very similar to TERMINATED_GRANT, but with the difference that the SAS has reason to believe that the use of the spectrum requiring the Grant to be interrupted is only temporary. That is, the CBSD can choose to maintain the Grant as it exists, sending heartbeats periodically to be notified when transmission on the Grant is allowed again.

The CBSD can choose to relinquish a suspended Grant, in which case it treats it very similarly to a TERMINATED_GRANT condition. If it does not, it must still honor the *transmitExpireTime* timer and cease transmission within 60s of that value.

The SAS expects the CBSD to handle this condition automatically. It does not impose a requirement on CBSD behavior (whether to maintain the Grant or relinquish it), and can immediately respond to any CBSD Grant-related requests to procure alternate spectrum.

6.14 UNSYNC_OP_PARAM Response Code (502)

If the heartbeat response indicates UNSYNC_OP_PARAM, the CBSD interprets it as an indication that the CBSD is out of sync with the SAS on operational parameters or Grant state. The CBSD immediately terminates radio operation by turning off its radio transmission and relinquishes the Grant by sending a *RelinquishmentRequest* object. The CBSD can subsequently request a new Grant.

If the CBSD has multiple grants assigned, it can analyze the state of its grants and decide to relinquish all the grants or relinquish only the grant which has received the heartbeat error. In case the CBSD decides to keep the other grants, it will trigger a *HeartbeatRequest* for those grants to make sure that the states of the grants are in sync between the CBSD and SAS.

The following example illustrates one possible scenario where UNSYNC_OP_PARAM error code is returned by SAS:

- CBSD has a grant in AUTHORIZED state and it is transmitting
- CBSD sends a normal *HeartbeatRequest* to SAS with the grant in AUTHORIZED state
- SAS is busy and takes a long time to respond
- CBSD sends a second *HeartbeatRequest* with the same info
- SAS finally replies with GRANT SUSPENDED to the first *HeartbeatRequest*
- Then SAS processes the second *HeartbeatRequest*, and replies with error code 502 (UNSYNC_OP_PARAM) since it expected the grant to be in the GRANTED state and not in the AUTHORIZED state

7 Support for PAL Operations

A PAL holder can receive a PAL license through participation in an FCC auction or by leasing such a license, in whole or in part, from an entity which obtained it in such an auction. This section describes how a particular CBSD is provided with the association to that license such that when it receives a grant from the SAS, the *GrantResponse* indicates that the grant is of *channelType* “PAL”.

7.1 Step 1: PAL channel assignment

Behind the scenes, there is a process by which SAS administrators collaborate to provide consistent channel assignments to particular PAL licensees, based on the results of the PAL auction and other considerations. [ref 96.59, 96.63] This process results in each SAS having a map of what the primary channel assignments are for CBSDs which are operating under all PAL licenses. This is illustrated in a simplified geography below where the cells in the table represent a grid of census tracts:

Table 2: Example PAL Channel Assignments

A : 3560-3570 B : 3570-3580	A : 3560-3570 C : 3590-3600	D : 3550-3560 C : 3590-3600	C : 3590-3600
A : 3560-3570	A : 3560-3570		
A : 3560-3570	A : 3560-3570	E : 3580-3590	

The table respresents a simplified geographical map with rectangular census tracts.

The color codes and letters correspond to specific PAL holders. For the purposes of this section, the process which assigns the frequencies to each block is opaque, but the end result is that a database containing information necessary for drawing maps similar to this example is shared among all SASs.

Geography is seldom so simple, but for the purposes of the example, the end result is the same: for specific PAL license areas, the SAS has information like:

Census tract FIPS code: 4034.02
PAL holder userId: "Teal"
Assigned Frequency range: 3590-3600

7.2 Step 2: CBSD registration

The next step is for the "Teal" (C) PAL license holder to be able to identify its own CBSDs as belonging to its network. This is done at the time of registration of the CBSD, when the PAL holder provides the CBSD attribute *userId* = "Teal" to the SAS. The PAL holder can use SAS account security features to ensure that CBSDs it does not control cannot simply identify themselves with the "Teal" *userId* and gain access to the PAL spectrum. For example, PAL holders could register the CBSD certificate fingerprints used by their devices with the SAS [ref ComSec spec], which can then check specific requests to ensure they come from authorized CBSDs.

Now that the CBSD is registered with the SAS and correctly associated with a PAL holder account, the PAL holder can include it in a PPA definition (the cluster list of CBSDs within that PPA).

7.3 Step 3: PAL Protection Area definition

A PAL holder can use registered CBSDs to form PPAs which will receive PAL protection from all SASs. [ref 96.25, 96.41(d)(1)] This will be done using SAS-specific tools accessed through the PAL holder's SAS account. The resulting contours are shared among SASs so that PAL holder operations within PPA boundaries are protected from harmful interference from other co-channel CBSDs.

As part of the PPA definition process, the PAL holder provides to the SAS a list of CBSDs which the PPA protects (the cluster list). [See 0112 doc, R2-SPU-04] Once the PPA is defined, the SAS has a cluster list of the *cbsdId*s of the CBSDs which are entitled to protection within the PPA.

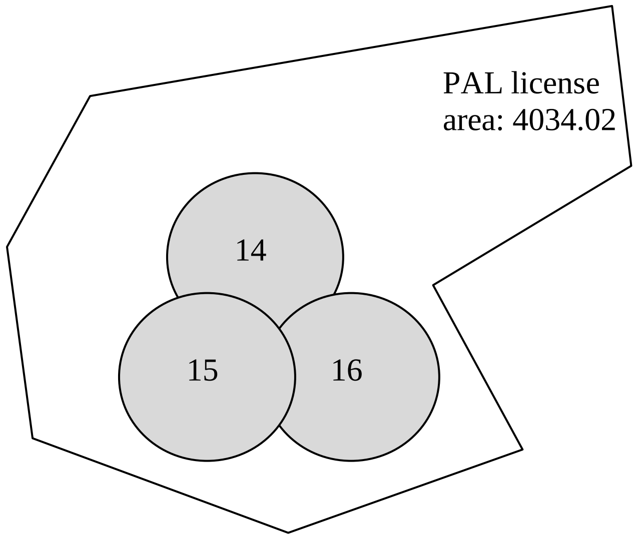

Figure 23: Simplified PPA Definition

This figure illustrates a simplified PPA definition process. Three CBSDs form the PPA, with *cbsdId*s “14”, “15”, and “16”. The CBSDs are registered in the “4034.02” PAL license area, which the SAS can validate against the PAL license database to ensure that the PPA registrant has permission to create a PPA in this license area (i.e. the PPA registrant is in fact the PAL license holder). (More complicated scenarios in which multiple license areas form a geographically compact “service area” are also possible.)

7.4 Step 4: Discovery of PAL rights by CBSDs

Now that PAL rights are configured for the CBSDs comprising the PPA cluster list, those CBSDs will see the rights reflected in Spectrum Inquiry Requests they issue to the SAS. When a CBSD in the cluster list does a spectrum inquiry, it will receive a Spectrum Inquiry Response containing the frequency ranges in which it will have PAL protections. For example, this might look like the following:

```
{ cbsdId: "14",
  availableChannel: [
    {
      channelType: "GAA",
      frequencyRange: {
        lowFrequency: 3580000000,
        highFrequency: 3590000000
      },
      ruleApplied: "FCC_PART_96"
    },
    {
      channelType: "PAL",
      frequencyRange: {
        lowFrequency: 3590000000,
        highFrequency: 3600000000
      },
```

```
      ruleApplied: "FCC_PART_96"
    },
    {
      channelType: "GAA",
      frequencyRange: {
        lowFrequency: 3600000000,
        highFrequency: 3610000000
      },
      ruleApplied: "FCC_PART_96"
    }
  ],
  response: {
    responseCode: 0
  }
}
```


Figure 24: Example Frequency Ranges in Spectrum Inquiry Response

This response indicates that 3590-3600 is available for PAL use, and other channels are available for GAA use by the CBSD. The SAS uses the PPA definition to validate the CBSD's membership in a proper PPA cluster list, and uses the PAL channel assignment database to provide the CBSD with the consistent PAL channel on which it can use the PAL rights. Aggregation of PAL licenses means there can be more than one such PAL channel available to a CBSD.

At this point, the CBSD can choose to use PAL spectrum, GAA spectrum, or both. It cannot request a grant including both PAL and GAA spectrum, but it can hold simultaneous grants with any mix it chooses of PAL and GAA spectrum.

Note that this step, like spectrum inquiry generally, is optional. That is, the PAL holder might already know it has created the PPA, and know the frequency range assigned for that PAL spectrum, since it is part of the PAL channel assignment output, and so configure the CBSDs to simply request spectrum within the PAL range it already knows. Since transient incumbent operations or other factors can impact the availability of PAL spectrum, it is recommended that CBSDs expecting to use PAL spectrum (or domain proxies operating on their behalf) use a Spectrum Inquiry Request to confirm PAL channel assignment.

7.5 Step 5: Requesting a Grant for PAL spectrum

Since the CBSD has discovered it has access to PAL spectrum, it can request a grant for spectrum within the *frequencyRange*(s) indicated in the Spectrum Inquiry Response. It does this identically to a request for GAA spectrum. The differentiating factor is that the CBSD is part of a PPA cluster list and so will receive protection for its operations in the indicated spectrum. This means that a CBSD can be brought into operation in GAA spectrum (opportunistically). The PAL holder can then acquire PAL rights and define PPAs, and the CBSD can continue to use the same spectrum using the same protocol functions throughout this process – the only difference is that the SAS will now be providing PAL protections.

When the CBSD requests the grant, it will receive confirmation in the Grant Response that the grant was for PAL spectrum. If the *channelType* field in that message is set to "PAL" then the grant is operating in PAL spectrum. If it is set to "GAA" then the grant is operating in GAA spectrum.

Note that transient incumbent activity could require a CBSD to cease operations on PAL spectrum. In such cases, the SAS will attempt to relocate the CBSD to other PAL spectrum and enforce PAL protections in the relocated spectrum. Under some conditions, however, this is not possible (e.g., transient incumbent operations which span the entire PAL spectrum). In such cases, the recourse for the CBSD will be to use GAA spectrum if available until the condition is reversed.

8 Document History

Document history		
V1.0.0	1 August 2017	V1.0.0 Released