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Optimization of Citizen Broadband Radio Service Frequency Allocation for Dynamic Spectrum Access System

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Abstract: With the increase in mobile broadband utilization, more spectrum release is recommended by the Federal Communications Commission for spectrum sharing under a three-tire system called Citizens Broadband Radio Service. The standardization, functional and operational necessities of this framework are defined by the Wireless Innovation Forum. If an unavoidable shipborne radar appears on the channel, the channel must be vacated by the lower tier users. The timing constraints on CBRS is also stringent. Wireless stations transmit short beacon frames termed as heartbeat signals. These signals consist of the wireless channel encryption data, Service Set Identifier (SSID) and other credential data. These signals also transmit commands to vacate a channel. The heartbeat interval, timing constraint and domain proxy features are analyzed in this paper. CBSD renunciation and spectrum acquisition is performed with the help of domain proxy based communication. The CBRS-SAS channel allocation algorithm is further investigated. The communication interoperability and network robustness can improved with the introduction of secondary SAS and secondary domain proxy respectively.

Keywords: Citizens Broadband Radio Service, Spectrum Access System, Spectrum Sharing, Generalized Authorized Access, Dynamic Capabilities;

1. Introduction

Mobile broadband allocation of 1000Mz is suggested by the President's Council of Advisors on Science and Technology (PCAST) out of the government-held spectrum in the United States [1]. The Spectrum Access System (SAS) is used for creation of Citizens Broadband Radio Service (CBRS) along with a set of rules proposed by the Federal Communications Commission (FCC). Several commercial applications are accommodated on a shared basis by the authorization framework of three-tiered spectrum in the CBRS. The dynamic spectrum access system manages the operation and access to the service [2]. General Authorized Access, Priority Access, and Incumbent Access are the three tires of CBRS. A large potential user group is exposed to the flexible, open access licensed-by-rule General Authorized Access tier. The unused priority access channels offer opportunistic operation of the bandwidth by General Authorized Access users. Creative bidding is used for encompassing Priority Access Licenses (PALs) in the Priority Access tier. The band at 3550-3650 MHz range is used for this purpose. A single applicant may receive from four PALs and any census tract may be assigned with a maximum of seven PALs [3]. A 10MHz channel can be used for non-renewable authorization by a PAL. During the first auction, in any specific license area, a maximum of two consecutive PAL terms may be acquired by the applicants.

3.5 GHz band fixed satellite service and authorized federal users fall under the category of incumbent access users [4]. General Authorized Access and Priority Access users will be prevented from causing harmful interference. The US Navy radar operators use this band and follow the rules set by the FCC. The transmission data cost is reduced and the need for spectrum licenses is eliminated in using the CBRS band. Instead of depending an deals and auctions for acquiring spectrum licenses, shared airwaves are used for easier and faster deployment of 5G using these carriers [5]. Care must be taken that the CBRS band does not interfere with the satellite receiver station, military radar station and other surrounding nearby airwave bands as these frequencies are used for government applications traditionally [6]. The spectrum allocation fee must be paid through a server by the end users inhabiting the property or individual building owners where CBRS equipment is deployed. This is similar to the deployment of Wi-Fi. The Commission approved CBRS devices (CBSD) and SAS is represented in CBRS scheme as show in in figure 1. Based on their preferences, customers are categorized into Generalized Authorized Access (GAA), Priority Access group (PAL), and Incumbent Access (IA).

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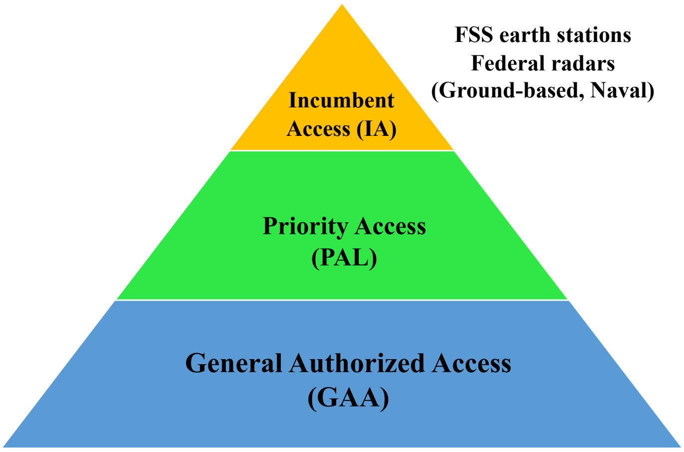

Figure 1: Three-tiered architecture of CBRS

CBRS provides several framing elements for business opportunities that may be categorized under enablers, limiters and challenges [7]. The enablers include internet domain with analytical capabilities and big data, offloading capacity provision for GAA, increase in business in dense urban areas with better QoS spectrum and so on. The limiters include the necessary technologies in 3GPP ecosystem for SAS functionality standardization, missing or unclear federal incumbents with real incentives, and limited MNO business opportunities with limited spectrum availability. Further, the challenges include low transaction costs, dynamic market spectrum, spectrum license model, increased operational and technical complexity, network optimization and management with new capabilities and competencies [8].

2. SAS-CBSD protocol simulation

The grant state machine and registration state machine are the two state machines involved in the SAS-CBSD protocol. Initially an unregistered state is used for establishing the CBSD. Further, it passes through the registration state machine when it registered with the SAS [9]. Transition occurs into the registered state on successful registration. Spectrum grants may be requested by the CBSD on entering the registered state. The grant state machine is entered after obtaining the spectrum grant where specific transmission power and frequency range can be used for transmission by the CBSD as approved by the SAS [10]. During operation in idle state, the SAS is sent grant request by the CBSD. The grant is checked for causing any unsafe interferences to other users. Permission is granted to the CBSD if it is free of such interferences and goes to the granted state. Idle state is reached by the CBSD if grant request fails. Transmission is restricted for CBSD in granted state.

Wireless stations transmit short beacon frames termed as heartbeat signals. These signals consist of the wireless channel encryption data, Service Set Identifier (SSID) and other credential data. These signals also transmit commands to vacate a channel. Information is transmitted by the heartbeat request message in granted state. The SAS provides the heartbeat response on successful reception of request at the CBSD. Further, CBSD moves to authorized state and data transmission is enabled [11]. Until successful reception of heartbeat responses, heartbeat requests are sent continuously at the authorized state of CBSD. Transmission can be stopped by the SAS when heartbeat response fails at the CBSD. In this case, the authorized state is changed to granted state. Harmful interferences may be experienced if the CBSD channel has incumbent appearances [12]. The SAS is sent a relinquishment request of no further transmission is to be done on the channel by the CBSD.

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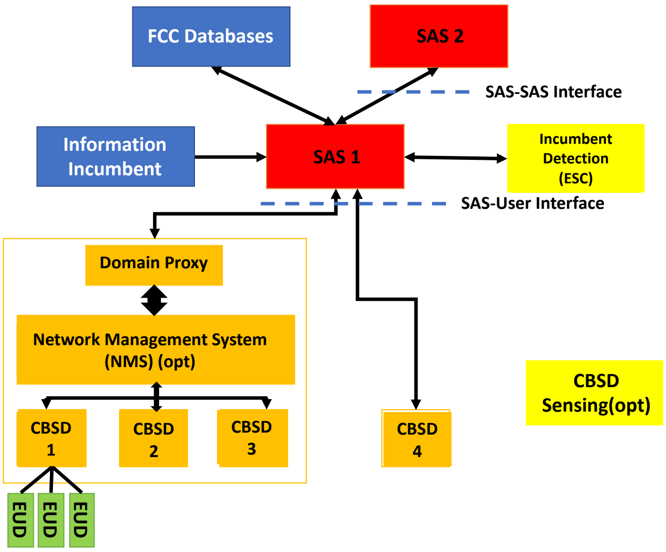

Figure 2: Key domains and functional architecture of CBRS

Figure 2 represents the key domains and functional architecture of CBRS. A centralized FCC chosen SAS is required for management and authorization of operation of the networks, access points and base stations of the fixed or portable CBSDs. Network management functionality and domain proxy is incorporated in the CBSD network as in Mobile Network Operator (MNO) case. The domain proxy may be a smart mediation function that combines individual cells of a sports arena or mall into a sports arena or complete mall as a virtual base station entity or a routing engine that allows completely bidirectional data processing. The network interference optimization and flexible self-control may be obtained by this feature. The system consists of end user devices, CBSD access networks, spectrum access system, national regulatory authority and incumbent access system for management, utilization and spectrum provisioning [13]. They dynamic capabilities framework consists of resources for providing key inputs for activities, operative capabilities required for performing necessary activities, core capabilities required for competitiveness and dynamic capabilities required for renewal.

3. Simulation and Results

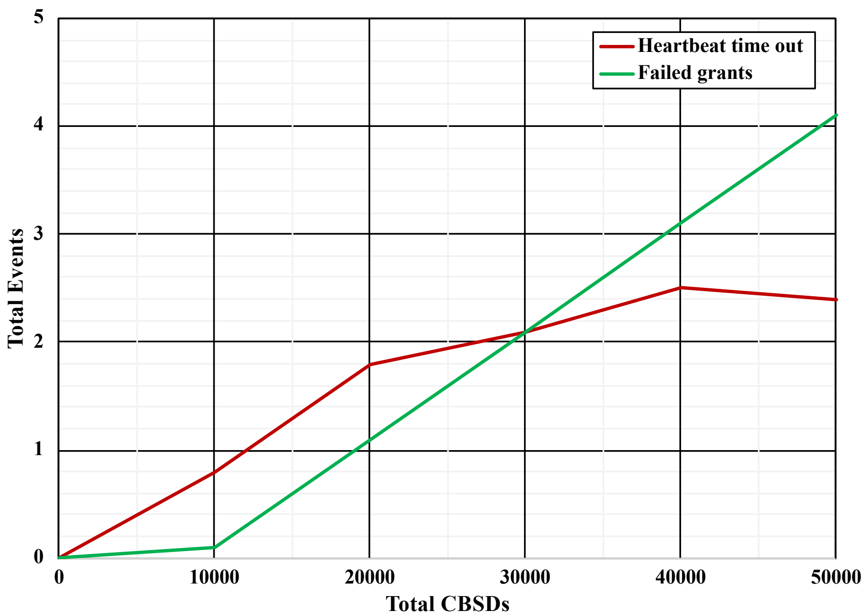

Figure 3: Total events vs total CBSD at 50 requests per second service rate

The experimental simulation and results are presented in this section. Multiple experiments are run at the primary stage. Message handling is performed with overloading effect in the first type. The incumbent radar is not simulated as SAS message handing is the major focus area of this experiment. On appearance of incumbent

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radar, the speed at which the CBSD can vacate the channel is studies such that the FCC specified timing constraints are satisfied by the channel. At a 50 requests per second (rps) SAS service rate, the total CBSDs vs unnecessary failed grants caused by SAS overload and heartbeat timeout is represented. Uniform distribution of heartbeat interval is provided between 150 to 200 seconds. The simulation of CBSD is executed for a duration of 24 hours. Until 5000 CBSDs, the heartbeat timeout is low and increases rapidly post the value. The value tapers off beyond 20000. There is a rapid increase in the failed grant count at 10000 CBSDs. If the total number of grants in the system is less it leads to grants fail. This results in maintaining a moderate heartbeat failure despite the increase in the grant request fail.

An incumbent radar is simulated in this experiment for analysis. The CBSDs are instructed towards suspension of grants through the heartbeat response messages and 90% of the grants are randomly selected by the SAS in the same channel as that of the radar. When the grant in heartbeat response message is suspended based on the CBSD command, the transmit expiry time timer is set to zero by the SAS. The channel is vacated by the CBSD within a duration of 60 s. At different mean heartbeat intervals, the CBSDs vacating the channel are analyzed for their Cumulative Distribution Function (CDF) as represented in figure 4. Grant or heartbeat request message loss is avoided by providing adequate amount of processing power to the SAS. During message arrival, message drops must not occur in the SAS. This criteria is used for calculation of the total CBSDs for any specific mean heartbeat interval. There is a uniform distribution of heartbeat interval between 150 to 200 seconds. The service rate is set at 50 requests per second at the SAS for handling of 1500 CBSDs. When the limit is close to 300 seconds, it is evident that more grants vacate the channel and mean heartbeat Interval increases.

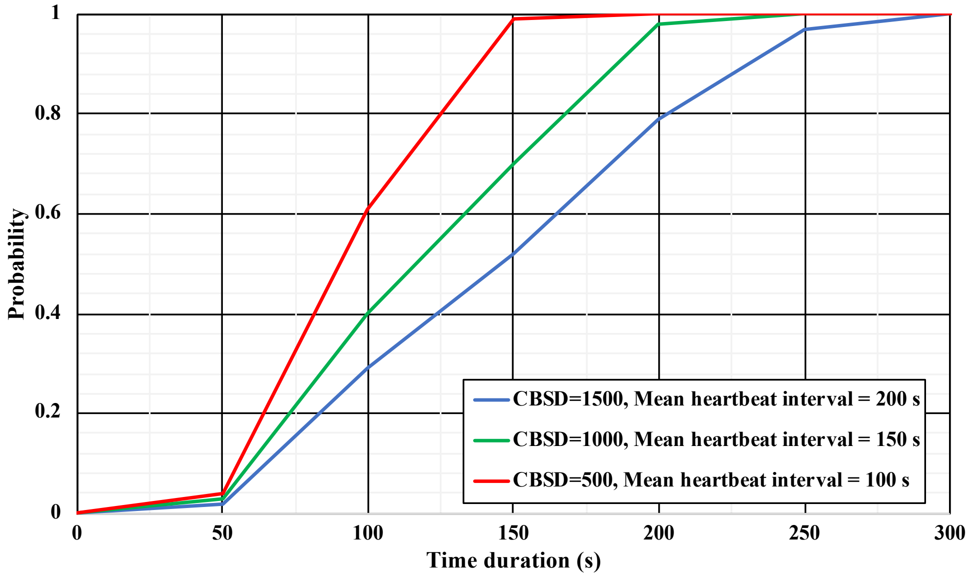

Figure 4: Channel vacating parameters at 50 requests per second service rate

For a specific service rate, lesser CBSDs can be served when heavy load is exerted on the SAS by shorter heartbeat interval. The channel vacating time for CBSDs can be managed by the SAS for achieving reasonable balance by setting the heartbeat interval at 150 seconds. Figure 5 represents the GAA user assigned channels and its corresponding channel reuse distance cumulative distribution function (CDF). The analysis is performed for one and two channel models. When single channel is used, channel reuse distance is lesser by a factor of 0.2, while it is 0.4 for dual channel model. Domain proxy provides a backup database for uninterrupted communication. Direct communication of messages from CBSD to SAS takes place without redundancy when there is no direct proxy.

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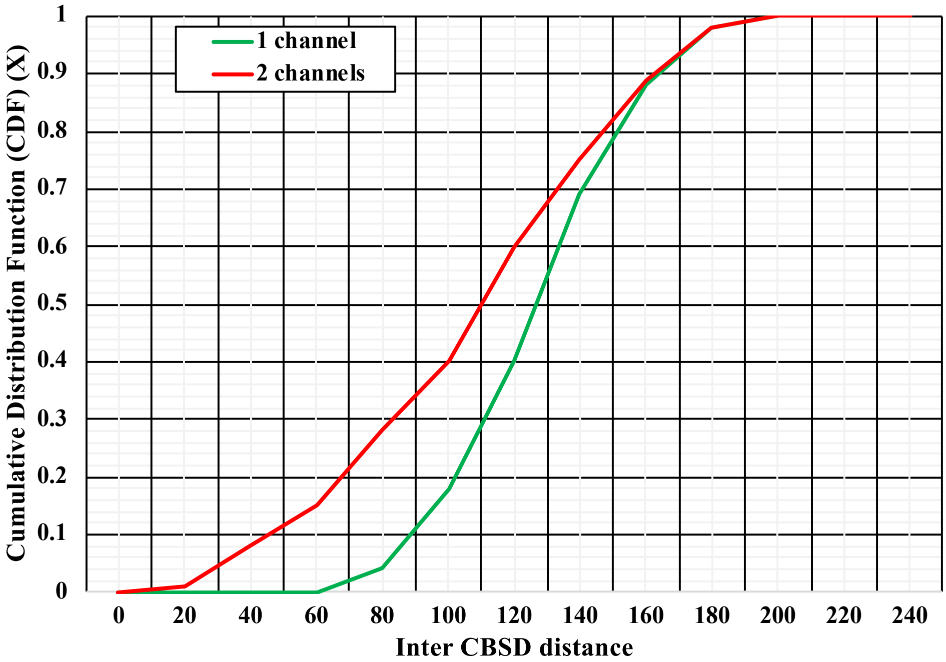

Figure 5: Cumulative distribution function Vs Inter CBSD distance for GAA users

4. Conclusion

The FCC rules to meet the end to end timing constraints in the CBRS system is satisfied by analyzing the impact of heartbeat interval and by developing an SAS-CBSD protocol simulator. The spectrum utilization is reduced by suspension of CBSD transmission by the ExpireTime timer that causes unnecessary transmit timeout due to the message overload on a SAS. This concept is analyzed by the simulator. The heartbeat interval, timing constraint and domain proxy features are studied. The tradeoff between CBSD count and time constraint is represented graphically. In order to attain a good balance between the tradeoffs, the heartbeat interval may be set to around 150 seconds. Lesser number of CBSDs can be served by a SAS quicker meeting of end to end timing constraint of vacating a channel can be performed if the heartbeat interval is less. Future work is focused on providing a better solution to the channel vacating protocol while a higher order device requires access to the channel using novel algorithm.

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