DYNAMIC SPECTRUM MANAGEMENT USING OPERATIONAL SPECTRUM COMPREHENSION, ANALYTICS, AND RESPONSE (OSCAR)

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ABSTRACT

Increasing demand for spectrum resources has introduced the need for intelligent and dynamic spectrum management systems. To address this need, Peraton Labs is developing the Operational Spectrum Comprehension, Analytics, and Response (OSCAR) system. OSCAR provides a simple automated dynamic spectrum planning capability that enables sharing between military and commercial systems in shared bands including AWS-3, AMBIT, and future shared bands. OSCAR provides spectrum managers with a unified interface and automated workflow tools to plan spectrum usage, deconflict spectrum requests for multiple concurrent test and training missions, and push those plans to radios, while also dynamically reacting to and avoiding interference in real time with a mature and flexible RF sensor network. This paper discusses how OSCAR can dramatically improve spectrum planning and enable dynamic in-mission spectrum agility. We describe how OSCAR can streamline current spectrum management duties and enable more advanced spectrum management activities including informed spectrum sharing, DSA radio management, real-time spectrum situational awareness, increased spectrum utilization, and more.

1. INTRODUCTION

Dynamic spectrum sharing is an increasingly urgent objective as additional frequency bands are auctioned for commercial usage. AWS-3, AMBIT, and future shared bands from EMBRSS will impose a requirement for shared spectrum usage between military and commercial system, reinforcing the need for advanced planning tools that incorporate automated deconfliction functionality and features to support future DSA radios. The current process that dominates spectrum management at test and training ranges is largely exclusive frequency use, but this is a luxury that simply will not withstand growing spectrum congestion. To address this need, Peraton Labs is developing OSCAR, which is a web-based application intended to improve and automate the current spectrum management workflow and incorporate advanced features for spectrum sharing including frequency deconfliction and DSA policy generation, management, and enforcement. OSCAR not only fits within the current spectrum management workflow to aid in planning but also provides new capabilities such as command and control of over-the-air managed (OTAM) radios and an RF sensor network to support in-mission situational awareness, frequency deconfliction, and DSA policy enforcement.

2. OPERATIONAL SPECTRUM COMPREHENSION, ANALYTICS, AND RESPONSE

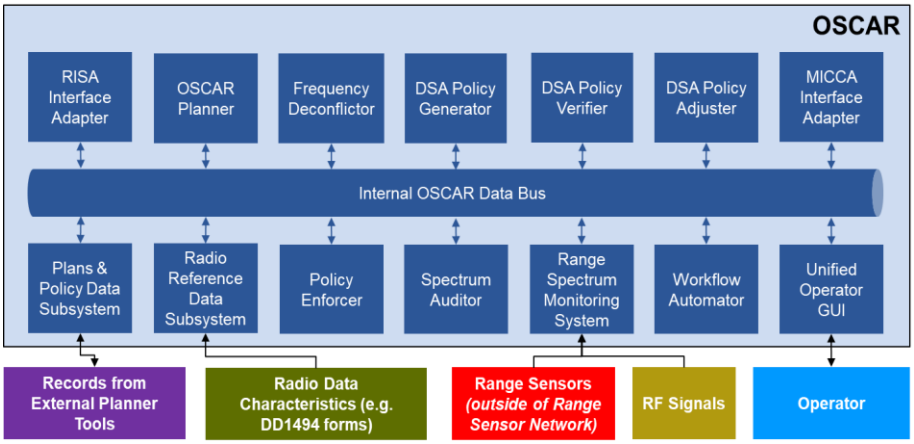

Figure 1: OSCAR Architecture and Inputs

The OSCAR system was developed as a solution to current and future needs for efficient spectrum management and utilization, including support for shared spectrum use cases in congested or contested environments. OSCAR provides an integrated portal for Spectrum Managers to streamline and simplify their daily activities, such as making and approving frequency authorization requests, refining mission plans, verifying planned spectrum sharing policies without interference, monitoring spectrum usage during mission execution, and auditing spectrum utilization over time. OSCAR is designed with a microservice-centric architecture, facilitating the inclusion of multiple services as shown in Figure 1. These microservices work in concert to produce the functionality described further in this paper. Of specific interest is that OSCAR works within the current spectrum management workflow, incorporating inputs from external planning and management tools (e.g. SXXI, SPEED, UNO Planner) and standard record forms as its core source of authoritative information. In addition to software-based microservices, OSCAR additionally includes a Range Spectrum Monitoring System with distributed networked passive RF sensors that are used for spectrum monitoring, spectrum auditing, data acquisition for spectrum utilization metrics, and detection of unexpected spectrum usage.

Core OSCAR functions support the overall objective of enabling efficient spectrum management in congested environments. OSCAR incorporates map-based visualization to inform frequency assignment decisions as well as indications of identified conflicts or expected interference between concurrent plans through automated multi-mission conflict detection. Visualization of the Electromagnetic Operating Environment (EMOE) facilitates the responsibilities of both Unit and Installation Spectrum Managers, providing context to decision making. OSCAR automates the generation of recommend deconfliction both in planning and during mission execution, while retaining workflow for responsible personnel to approve changes to frequency assignments. Workflow automation further prompts user with alerts and notifications to support faster execution of frequency request and approval processes. Lastly, OSCAR automates the generation of complex DSA policies to facilitate inclusion of advanced radios into current and future test and training missions, as well as for tactical usage. Additional details on these functions are described in the sections below.

3. SPECTRUM PLANNING

OSCAR provides enhanced decision support and reduces manual effort for human planners by mechanizing routine tasks, while retaining key oversight and approval authority with authorized

personnel. OSCAR serves as a portal for stakeholders—the System Owners, Unit Spectrum Managers, and Installation Spectrum Managers—who, depending on their role, can create, delete, approve, manage, and visualize the status of planning requests. OSCAR not only orchestrates the workflow, but also provides situational awareness of the workflow status of each planning request during its entire lifecycle from creation, analyses, modifications, approval, deployment, situational awareness updates to other systems as applicable, and archival.

Authorized users interact with OSCAR for spectrum planning by means of an integrated dashboard using an interface that is similar to those used in enterprise business process automation systems. The purpose of this dashboard is to alert the users of tasks that require their attention, while also providing overall situational awareness of the status of workflow instances associated with them. This has the effect of streamlining the frequency request and approval process, which otherwise can significantly slow down spectrum planning and authorization. The interface provides customized screens and views depending upon the user's role and ability to approve or authorize spectrum usage.

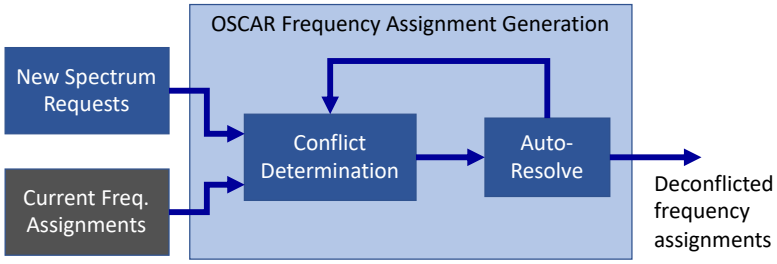

Figure 2: Frequency Assignment Generation with Auto-Conflict Detection and Resolution

To facilitate efficient spectrum sharing, OSCAR automatically performs multi-mission frequency deconfliction once spectrum requirement requests are imported or entered into the system. Conflict detection is run on all plans that intersect with each other in time; that is, if a newly entered mission is disjoint from all other missions in time, then there is no need to run a simulation to predict interference. The conflict detection calculation uses RF propagation modeling to determine if two sets of activities using the same frequency will interfere with each other, leveraging specific information from each mission plan including the geographic area of operation and characteristics of equipment being used. SINR is calculated in spatio-temporal bins for each stage of the mission plan to determine expected interference effects from transmitters to victim receivers. Isolation requirements for equipment used in each mission profile are used to trigger conflict identification.

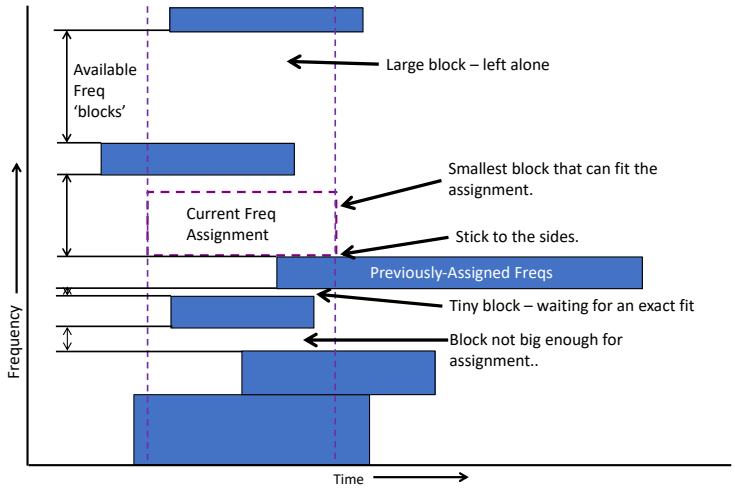

Figure 3: SMT-Solver Based Allocation and Conflict Resolution for Minimizing Spectrum Fragmentation

Once identified, OSCAR facilitates conflict resolution by attempting to identify an optimal position in time and frequency to fulfill the frequency assignment requests without introducing interference between mission transmissions and/or commercial or fixed transmitters in the area of regard. As a brute force optimization approach is an NP-complete problem, OSCAR uses a Satisfiability Modulo Theories constraint solver (SMT-solver) with well defined constraints to quickly identify appropriate solutions.

Constraints were defined from feedback from DoD Spectrum Managers to ensure suitability to OSCAR's objectives. The SMT-solver results in one, several, or all of the frequency assignments being adjusted. The revised mission plan(s) are presented to a user with approval authority, such as the Installation Spectrum Manager, prior to any distribution to radios during exercises.

OSCAR's use of workflow automation, notifications for required action, and recommended deconfliction during frequency assignment has the effect of streamlining spectrum planning and authorization, facilitating efficient and shared spectrum usage in congested environments.

4. DYNAMIC DECONFLICTION

Dynamic deconfliction during mission execution is increasingly necessary in congested and contested EMOEs as unexpected interference becomes more likely to occur. Real-time deconfliction additionally is necessary due to error, human or otherwise, where emitters do not follow their specified frequency assignments. The capability to dynamically react to changes in the EMOE is necessary to adjust spectrum utilization, accommodating unanticipated conflicts to minimize debilitating interference during mission execution.

As the spectrum environment changes, the original static spectrum plan will need to be updated accordingly. For example, if OSCAR detects signal energy that is not coming from an authorized source (one not planned nor identified as a type of authorized radio for the range), replanning of the spectrum with this new interference-blocking constraint in place will be necessary in order to mitigate and/or minimize any disruption. Once this happens, this additional constraint is added to the original plan and the auto-resolve algorithm described in the previous section is executed. These spatial and frequency constraints are added to the original planning task just as another spectrum reservation would be added. That is, the interference is treated as additional spectrum activity that cannot move in frequency or space and the same algorithm is run to determine the best frequency plan with the minimal disruption to the original plan, and within the constraints of what mission equipment is capable of supporting. Here again, the revised mission plan is presented to a user with approval authority prior to any distribution to radios during exercises. Additionally, the approval authority is notified of the unauthorized spectrum usage and provided with metadata (e.g. frequency, bandwidth, TDOA-based geolocation) to enable the user to take action and resolve the unauthorized usage.

Note that the current process for detecting and resolving interference is both reactive and time-consuming. A radio operator experiencing issues may troubleshoot for an extended period including adjusting the radio configuration and swapping antennas as well as eventually leveraging a spectrum analyzer and directional antenna to measure the electromagnetic background. In some cases, the approval authority is also engaged to tediously track down unauthorized usage. This process can sometimes take hours and significantly delay training operations. Additionally, sometimes unauthorized usage can impact nearby commercial operations (e.g. cellular, aviation). In either of these scenarios, OSCAR's sensor network is able to provide near real-time visualization of the EMOE to limit impact and enable rapid resolution.

OSCAR's dynamic deconfliction is enabled by near-real-time measurement of the spectrum through a distributed network of passive RF sensors. These measurements enable OSCAR to orchestrate access to the spectrum and monitor spectrum usage for interference and policy compliance during execution of real-time training missions. The RF sensors within the OSCAR Range Spectrum Monitoring System are automatically tasked based on the frequency and spatial

extents of a particular set of missions occurring at the time of mission execution for spectrum monitoring. Sensors perform signal detection and classification at the edge to minimize data backhaul requirements. OSCAR's sensor network employs various energy detection and signal classification algorithms. OSCAR also employs cyclostationary processing (CSP) algorithms to detect and characterize low SNR signals as the majority of communication signals exhibit the CSP property (Napolitano, 2012). In particular, OSCAR's sensors incorporate the Strip Spectral Correlation Analyzer (SSCA) function, which is one of the most efficient implementations of an exhaustive CSP algorithm (Brown & Loomis, 1993). This data can be combined with measurements from other range sensors and telemetry systems as available. OSCAR compares sensed spectrum data and detected signals against approved mission plans to audit the spectrum for an area of regard, notifying cognizant users of unexpected or unauthorized spectrum usage. Interference sources or unauthorized transmitters can be geolocated using the sensor network, providing users with actionable information to resolve the source of detected issues. This would occur in parallel with the deconfliction auto-resolve process described above.

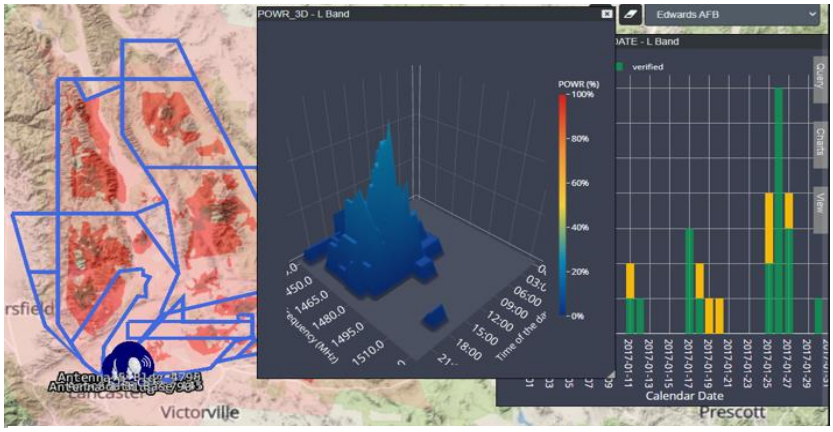

Figure 4: Representative Spectrum Usage Map and Associated Metrics

5. ENABLING DYNAMIC SPECTRUM ACCESS

As spectrum becomes further congested, interest in DSA radios that can dynamically adjust their behavior is growing quickly. Such hardware is capable of self-tuning based on a DSA policy which is effectively a set of rules or constrains that dictate what the radio can and cannot do. DSA radios also include the ability to sense the electromagnetic environment during operation to more intelligently identify open or unused channels. However, the command and control of DSA radios can become complicated especially when compared to simply configuring a legacy radio with a particular loadset. As such, OSCAR incorporates multiple microservices and an intuitive interface for generating and managing DSA policies in a simple and automated fashion. Furthermore, OSCAR also provides the capability to enforce policies for OTAM legacy radios. Although OTAM legacy radios are not policy-based, OSCAR's policy reasoner enables a centralized DSA behavior for such devices. This particular feature is of great interest as DSA radios are not expected to be widely available until further proven and accepted by the community. In the interim, OSCAR can provide the advantages of DSA with existing radio hardware.

OSCAR's methodology for DSA policy generation includes multiple modeling and analysis steps to account for regulatory policy, coordinated policy among nearby ranges or commercial emitters, concurrent test and training exercises, equipment capabilities, frequency authorizations, and more. To manage each of these unique data inputs, OSCAR's policy generation process relies heavily on an ontology as a semantic data model and an associated knowledge graph.

Given that DSA policy generation represents a new process within the existing spectrum management workflow, automation and ease-of-use is critical. OSCAR should not unnecessarily

introduce new tasks and terminology for existing spectrum managers but rather generate DSA policies *within* the existing process. As such, OSCAR's automation features include smart filters that enable the operator to create a DSA-capable network for a given radio equipment type by intelligently restricting the frequency set, bandwidth, power output, etc. of the selected equipment based on the transmitter's tuning range parameters and RF channeling capabilities. This feature leverages the equipment inventory and radio hardware characteristic database that OSCAR maintains by ingesting data from existing tools and databases such as SPEED and JSDR. This process is also followed by additional automated constraint checking prior to assessing the impact of other concurrent exercises.

Following equipment constraint checking, OSCAR determines the Area of Potential Interference (AoPI), i.e., the area where the non-DSA Radio may be affected by energy emanating from the DSA radios. The AoPI is a function of the application Quality of Service (QoS) requirements and communication and security constraints. The AoPI may be larger than Area of Operation (AO) and is determined by considering the interference distance from the boundary of the AO. It depends mainly on the propagation conditions (urban vs. rural, flat vs. mountainous, etc.), type of platform hosting the DSA radios (ground vs. air), etc. Once the AoPI is determined, OSCAR automatically finds all the non-DSA radios that have assignments within the AoPI and identifies the frequencies previously assigned to these systems. OSCAR then performs a series of propagation modeling and assesses interference between concurrent training missions. At this point, the Spectrum Manager is provided information on impact to concurrent missions and presented with options to guide the policy generation process. For example, the Spectrum Manager may choose to completely eliminate any sharing with non-DSA radios. In this case, the list of frequencies available to DSA radios will be additionally constrained to only those that do not interfere with non-DSA radios, given their current configurations and locations within the AO. On the other hand, the Spectrum Manager may approve sharing, in which case OSCAR will automatically embed constraints within the policy based on the interference analysis. For example, OSCAR may restrict sharing to a certain geospatial region, whereby if the DSA radio leaves the designated region, sharing will not be allowed. This provides greater flexibility to the DSA radio while still mitigating any risk of interference to non-DSA radios.

OSCAR will assist Spectrum Managers in the generation of diverse types of DSA policies as part of an automated workflow. The automation will include both algorithms that derive allowable policy parameters (e.g., location, frequency, time, BW) and context sensitive GUI menus showing only relevant policy and radio parameters at a given point in the workflow. OSCAR's DSA policies allow fully dynamic spectrum sharing by combining frequency-based, time-based, and geospatial-based policies with spectrum sensing capabilities.

Once policies are automatically generated or generated in an assisted way, they need to be verified for consistency with other previous existing policies, including the fixed frequency assignments generated using the automated deconfliction process. OSCAR's policy verification satisfies this requirement by employing first-order logic reasoning suitable for dynamic, complex policy sets. This process provides policy verification for consistency, conflict, completeness, etc. For example, consistency verification ensures that a given configuration is either permitted or denied but not both. These features within OSCAR enable Spectrum Managers to confidently use emerging DSA technology without introducing untenable risk into operations.

CONCLUSION

Dynamic spectrum conditions in congested and contested environments require the deployment of advanced capabilities both in spectrum management, from planning through mission execution. Workflow automation and process streamlining is needed to increase the pace of frequency requests, authorization, and deconfliction while maintaining strong standards for safety in avoiding interference. Spectrum monitoring during a mission enables the detection of unexpected conditions which can then be dynamically resolved through intelligent decisions guided by available information. OSCAR has been designed to provide these capabilities to be a next-generation tool for the cognizant personnel in order to support current and future needs in dynamic spectrum management.

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