Software Tool for Assessing Secondary System Opportunities in Spectrum Whitespaces

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***Abstract*—The prospect of increasing wireless capacity via secondary access to spatio-temporally underutilized chunks of spectrum, so-called *whitespaces*, has been proposed as a central aspect of emerging radio systems in response to the imminent spectrum scarcity problem. In this demonstration we present a novel software tool that helps researchers, industry, and regulators in assessing the feasibility and value of secondary spectrum access beyond simple whitespace availability calculation. Whereas existing software applications merely provide visualization of estimated secondary spectrum over a geographic area, our tool uniquely enables a holistic evaluation of the realistic potential of whitespace technologies, by modelling the performance of entire secondary systems in the envisioned eco-system of dynamic spectrum access policy and technology. Our tool provides a unified and flexible software framework and assessment methodology to conduct such studies, and is composed of an extensive primary spectrum usage database, a graphical interface for user interaction, and an interface to an extensible MATLAB backend for numerical calculations. We showcase the deployment scenarios of cellular and Wi-Fi-like secondary networks in TVWS (TV whitespaces). We also compare the impact of employing FCC-type of regulatory rules (with a fixed power/no-talk distance configuration) against European WG-SE43 regulatory proposals (with probabilistic access and power control). The case studies we will demonstrate are based on real network configuration data of European and US TV networks.**

I. INTRODUCTION

The prospect of increasing wireless capacity by secondary, or opportunistic, access to spatio-temporally underused frequency bands has raised expectations of overcoming the imminent spectrum scarcity problem. The UHF bands for broadcasting digital TV have drawn particular attention due to attractive propagation characteristics and low primary spectrum exploitation. Other bands are also being evaluated to find more potential whitespaces. The effects of interference from a single secondary transmitter on primary performance have been widely studied. Regulatory policies, e.g. in the US by FCC [1], have subsequently defined the rules for acceptable coexistence between primary and secondary devices and limited test trials suggest that whitespace operations are technically possible. However, ascertaining the scalability of entire whitespace networks, composed of thousands whitespace devices, is challenging and still largely unaddressed.

In this demonstration we present a software tool to explore the feasibility and performance of secondary networks operating in whitespaces. We argue that regulatory policy, scenario, and the deployed secondary technology need to be studied in a holistic manner in order to properly understand and maximize the utility of secondary operation while maintaining sufficient primary protection. Existing tools [2], [3] are limited to merely visualizing and simply calculating raw whitespace availability in terms of the allowed areas for secondary transmission given the coverage of the primary system, as would be stored in a rudimentary TVWS database. By contrast, our software tool uniquely enables a holistic analysis of real whitespace *utility* by combining primary and well-defined secondary system models, applying different regulatory rules, taking into account aggregate secondary interference, and estimating performance indicators of primary and secondary network operation.

Developing such a systems modelling framework and implementing it efficiently in a real-time software tool is a highly non-trivial task, due to the requirement of handling multiple levels of abstraction and the need to iteratively evaluate the mutually-dependent interactions of desired secondary network service and secondary-primary wireless interference effects. Ours is the first comprehensive tool available that allows detailed joint analysis of the technological, regulatory, and economical value issues in secondary spectrum access within a systematic and robust framework. Our tool facilitates in-depth analyses on a number of key pertinent questions, e.g.:

- Is there a superior regulatory policy for specific envisioned secondary deployment types?
- Will current primary protection measures suffice when whitespace operations become more common (i.e. given aggregate secondary interference effects)?
- Can secondary networks provide sustainable coverage and performance to their users?

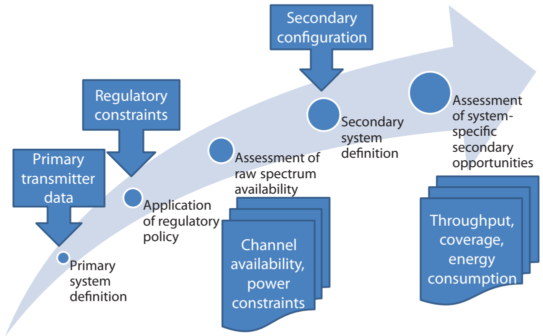

Figure 1. Workflow of system-driven whitespace spectrum utility assessment.

In the following, we provide a technical description of our software tool and whitespace utility assessment methodology, and give a brief outline of our proposed demonstration.

II. Technical Description

Our tool provides a unified framework for conducting studies on the performance of secondary systems with dynamic spectrum access. The overall workflow of the application is aligned to the spectrum assessment methodology in Fig. 1. Beyond application design, this workflow serves as a valuable guide for future studies on whitespace networks, as a consistent methodology for complex techno-economical analysis. The overall architecture of our software tool (Fig. 2) is composed of:

- an extensive **Primary Spectrum Resource Usage Server** (PSRUS) that stores results from propagation modelling and measurement campaigns;
- a **graphical user interface** (GUI) with mapping and export functionalities for user interaction (Fig. 3); and
- a **MATLAB backend toolkit** for numerical calculations, with generic and open interfaces and a prototypic spectrum policy and secondary systems implementation.

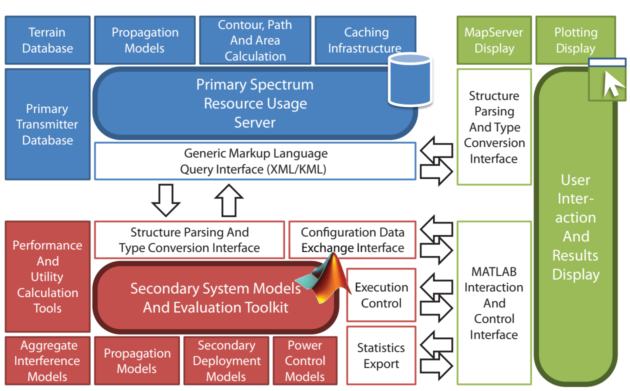

Figure 2. System architecture of spectrum assessment tool.

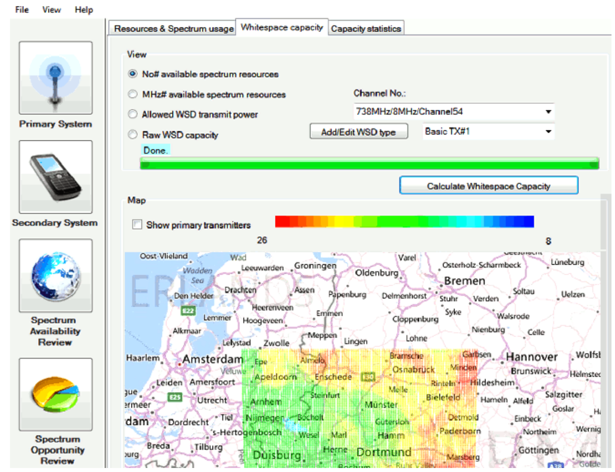

Figure 3. Screenshot of GUI, showing a heatmap result of calculated secondary network capacity and various configuration tabs.

In order to extend the original architecture of whitespace databases, we have developed the novel PSRUS for primary system modelling. The server design separates those metrics which relate to the primary system usage, and those relating to the applied regulatory policy. The PSRUS offers a web-based control interface via an HTTP server. Our new tripartite XML schema describes queries to the server. The *primary model definition* comprises information for predicting primary propagation; the tool currently supports terrain-aware pathloss estimation with the Longley-Rice ITM model and the more generic ITU P.1546-3 model. Entries to the *primary system specification* define transmitters to be included in the signal strength calculation, in terms of their location, transmit power, and antenna height and pattern. Along with the primary model definition, this information is applied to calculate primary coverage in a specified study area, as the first step of the spectrum assessment workflow. *Queries* can request contours of the signal power or signal strength for particular spectrum resources and fixed areas.

The next step in the assessment is to derive the constraints to secondary operation based on the applied regulatory policy. The PSRUS connects to a MATLAB-based toolkit for the application of user-specified regulatory policy and secondary system configuration. The toolkit comprises the core of the assessment, as it calculates the constraints to secondary exploitation of whitespace spectrum resources. By default, our tool determines the spectrum resource availability assuming an FCC-type of constraint set, with a predefined minimum distance to co-channel and adjacent channel resources and a fixed power limit per secondary transmitter [1]. Unlike fixed TVWS databases, the parameters of the model can be adjusted to test different options for regulatory rulings. We have also implemented the alternative policy framework proposed by ECC SE43-WG [4], where the expected degradation of primary signal quality determines the secondary's permitted power budget. The aggregate interference of multiple secondary transmitters is calculated via Monte-Carlo simulations or analytical models where available.

Secondary channel constraints and power budgets provide the basis for deriving the performance and characteristics of actual secondary network deployments. Our MATLAB toolkit currently features two secondary system models: a cellular network with planned transmitter locations [5] and an opportunistic high-density model representing Wi-Fi-like deployments for in-home or hotspot use [6], [7]. Our tool enables derivation of their key performance metrics, such as coverage, achievable throughput, and carrier aggregation capabilities, which are also provided to the GUI for visual review. We thereby derive the actual technical opportunities of an entire secondary network deployment.

III. Demonstration Outline

Using our software tool's holistic approach to assessing the utility of secondary spectrum access, we will demonstrate that merely calculating raw whitespace availability is insufficient and misleading; the real-world value of spectrum whitespaces for secondary networks deployments strongly depends on:

- the regulatory policy ruling,
- the assumed propagation and terrain model,
- the envisioned secondary system,
- aggregate secondary interference considerations.

Firstly, the user will be able to select from two prototype implementations of regulatory policy, namely the FCC rule-set (with a fixed power/no-talk distance configuration) and the European SE43 proposal (with probabilistic access and power control). Beyond simply implementing the currently perscribed parameter settings in these rule-sets, our tool allows the user to fully configure all parameters in these two archetypal regulatory policy models; this enables the user to rapidly explore and evaluate the effects of varying the model parameters when defining white space device regulatory rules, in terms of the resulting raw whitespace availability and permitted secondary power budgets. Our demonstration thus clearly illustrates how even minor changes in policy rule-set parameters affect the exploitation potential for a whitespace device.

In addition to the applied regulatory policy, the raw whitepace availability that is calculated is determined by the assumed propagation model. Our tool allows the user to select between two propagation models (ITU P.1546-3 and Longley-Rice ITM). By changing the propagation model, the user will again observe a large local variation in the calculated raw whitespace availability. Our demonstration thus underlines the importance of carefully modelling the radio environment in the context of a whitespace database granting channel access to a secondary device.

Once the user has selected a regulatory policy and propagation model, our software tool calculates in real-time a map of raw whitespace availability, as a preliminary estimate of the exploitation potential for a single secondary device. Uniquely, our tool then goes beyond this basic step of calculating and visualising raw channel availability (as would be stored in a rudimentary TVWS database), by considering the resulting performance of an entire network of secondary devices operating in these whitespaces. In our demonstration, the user will be able to select between two candidate secondary system models (cellular and Wi-Fi-like). Given the raw whitespace availability in the region of the envisioned secondary network, our tool then calculates in real-time several key performance metrics of the whitespace network deployment, such as coverage and achievable throughput.

Our tool thereby enables the user to evaluate the actual *utility* of the available whitespaces for a particular envisioned secondary network deployment. Our demonstration in particular illustrates the effects of aggregate secondary interference on the achievable secondary network performance, given the constraint of maintaining sufficient primary protection. The demonstarted software tool and holistic spectrum assessment methodology is thus of benefit to spectrum regulators, industry, and researchers, as a means of properly understanding and maximizing the real-world value of spectrum whitespaces for secondary operation.

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