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Economic and Market Design Challenges for Spectrum Zone Management Systems

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***Abstract*—Facilitating the market adoption of Dynamic Spectrum Access (DSA) mechanisms is a joint technical and economic challenge. In this poster, we discuss ongoing efforts to address fundamental economic questions associated with DSA. These efforts are linking core economic theory of market performance into a multi-tier contracting model to support spectrum sharing across heterogeneous networks. Specifically, we focus on three interrelated tasks. The first task is the design of spectrum sharing contracts based on the Spectrum Consumption Model (SCM) framework standardized in IEEE 1900.5.2. SCMs provide a way of characterizing the spectrum and interference protection needs of heterogeneous wireless systems. Second, we are specifying and evaluating the performance of different market structures for managing spectrum sharing contracts. Finally, we investigate the implications of these market designs on industry structure and communications policy.**

I. Introduction

The future of wireless systems requires expanded technical and economic capabilities to automate dynamic sharing and management of spectrum resources. Dynamic Spectrum Access (DSA) technologies offer a promising solution. A main technical challenge in DSA is the development of resource allocation mechanisms that can dynamically orchestrate spectrum sharing among heterogeneous uses, users, and devices. Facilitating the market adoption of DSA is a joint technical and economic challenge. Whereas the agile radio technologies needed to enable DSA have advanced impressively, incentive-compatible economic mechanisms for managing spectrum access rights (including interference protection) are necessary for DSA technologies to facilitate resource sharing and succeed in today's complex and crowded wireless markets.

In this poster, we discuss ongoing efforts to address fundamental economic questions associated with DSA. Our goal is to advance work towards building the needed complementary economic mechanisms to support DSA for local management of spectrum resources in competitive markets. To frame our ongoing efforts, we briefly summarize a related project from our collaborators engaged in the COSMOS-NRDZ project [1] that are working to develop a prototype DSA platform to enable automated spectrum management called the Zone Management System (ZMS) for a Radio Dynamic Zone (RDZ). To coordinate spectrum use, the ZMS uses Spectrum Consumption Models (SCMs), as defined in the IEEE 1900.5.2 standard [2]. SCMs provide: (i) a mechanism for RF devices to declare how they intend to use the spectrum and/or their needs in terms of spectrum protection; and (ii) a computational method to arbitrate compatibility (i.e., non-interfering co-existence). The COSMOS-NRDZ project is developing techniques for efficiently generating SCMs for use in a large-scale ZMS [3]. The ZMS will be prototyped and evaluated via real-world experimentation at the NSF COSMOS testbed [4] and the NOAA-CESSRST center, both residing in an FCC Innovation Zone in a dense urban area in NYC.

We build on the ZMS framework to address fundamental economic research on the use of DSA technology by focusing on three strongly interrelated tasks, as illustrated in Fig 1. **Task 1** aims to design marketplace/incentive-compatible and technically-sound spectrum access contracts based on SCMs which we refer to as Spectrum Access Agreements (SAAs) [5]. These contracts will serve as viable mechanisms for transferring spectrum usage rights dynamically among heterogeneous users. Therefore, such contracts must be incentive compatible and enforceable. Questions being addressed include defining the economic terms of the spectrum contracts and enforcement mechanisms that may be needed to support diverse usage and co-existence scenarios. **Task 2** involves specifying representative frameworks for market-based management of the SAAs, building on prior work extending economic models for market-based resource allocation to spectrum [6], [7]. This will allow us to evaluate the theoretical performance of alternative market design specifications and to investigate stakeholder incentives and enforcement challenges. **Task 3** aims to analyze the implications of advancing the SCM/SAA ZMS approach on business models and communications policy. Although significant earlier techno-economic multidisciplinary research has focused on top-down efforts to advance spectrum sharing [8], [9], the SCM/SAA work embodies a bottoms-up approach. In economist terms, the SCM's provide the accounting primitives needed to craft the incentive compatible contracts to facilitate automated sharing in DSA-enabled secondary markets for trading spectrum usage rights.

The remainder of this poster briefly discusses the research agenda associated with these three tasks. Section II describes SAAs. Section III discusses market modelling. Section IV explores policy challenges and implications.

II. Spectrum Access Agreement Design

Our first task focuses on the design of SAAs. Similar to a Service Level Agreement (SLA) between Internet providers,

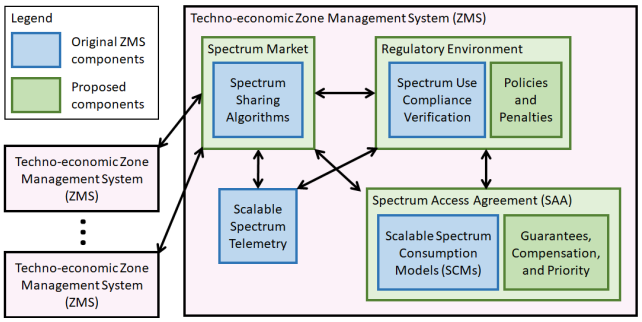

Fig. 1. Main components of the proposed DSA mechanism. We distinguish the technical components from the original ZMS architecture (being developed by our collaborators as part of the COSMOS-NRDZ project) from the economic components proposed in this poster.

an SAA will document a common understanding of the aspects of spectrum use and the roles and responsibilities of all parties in maintaining shared and non-interfering spectrum use. An SAA will use SCMs to define the boundaries (e.g. power/bandwidth/location) that each party agrees to for their use of spectrum, as well as the terms governing a failure to comply to those boundaries.

Some basic economic issues being studied with regard to SAAs include the following. (i) Would these be bilateral or multilateral agreements? What provisions for SAA negotiation/bargaining would be enabled? (ii) Would these be direct contracts or mediated by third-parties (e.g., a spectrum band manager)? (iii) How can SAAs accommodate the coexistence needs of diverse users (e.g., radioastronomy, mobile broadband, and public safety)? (iv) To render SAAs/SCMs cost-effective and computationally manageable, the parameters available for an SAA (and the underlying SCMs) should be parsimonious, so what is the right complexity balance for different contexts and to support ZMS adaptability? (iv) How might SCM/SAA designs vary with contract duration, geospatial specificity, interference protection guarantees, and RF band? We are exploring these issues with input from both the ongoing work on the COSMOS-NRDZ platform and the literature on contract design and bargaining.

III. Market Modeling and Design

In our second task, we are extending standard economic models of congestible resource-allocation to tackle the market-design issues of sustaining secondary markets based on SAAs. Issues being considered include the following. (i) Understanding how the initial assignment of usage rights and alternative market designs may impact economic and technical efficiency and equilibrium redistribution of resources; (ii) The potential for competition and interaction among multiple ZMSs in a market, the granularity (in time, space, bandwidth) for SAA-based management, and market dynamics (e.g., contestability); and (iii) the role for third-party governance (e.g., regulation) to render ZMS participation incentive compatible and efficient.

To answer these questions, we begin with adapting basic competitive market models to understand the competitive equilibria that may arise in these settings and the resulting welfare achieved. This builds on our prior work that considered models for both unlicensed sharing [6] and tiered sharing as in the CBRS [7]. In this work, we are building on these approaches to develop models under different abstractions of SAAs and then use these to evaluate the competitive equilibria and the implications for the design of markets for secondary spectrum trading in different usage contexts (e.g., government-commercial, communications-sensing, overlapping contract durations and asymmetric information contexts, etc.).

IV. Institutional and Regulatory Trajectories

In our third task, we are investigating the implications of advancing the SCM/SAA-enabled ZMS work for deployment in real-world wireless markets and regulatory policy making, and its potential for advancing the broader agenda of enabling more dynamic management of spectrum in any location and band. This requires thinking about how regulations, institutions, and market structures may need to change to support a transition to a more liquid, dynamic, and efficiency-promoting market-based spectrum management environment. In other words, how to build toward secondary market trading of usage rights and congestion management for heterogeneous users and networks including both active and passive users of spectrum.

The goal of the expanded research agenda articulated above is to facilitate the expansion of market-based spectrum sharing across other RDZs in other geographic markets and spectrum usage contexts (rural, emergency provisioning, etc.). That will require addressing a number of evolutionary considerations for how the ZMS insights might propagate and evolve in the real world and in the face of legacy regulatory, technology, and market contexts. It is fundamentally a joint techno-economic challenge.

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