The Path to Market Success for Dynamic Spectrum Access Technology

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Abstract

Rapid progress is being made in the technology for Dynamic Spectrum Access (DSA) radio systems. However, the structure and dynamics of the wireless services market must also evolve for DSA to succeed, due to the unique attributes of DSA radios. This paper examines the interlinked technical and economic issues of markets for DSA-based wireless services. We use this analysis to make technical and policy recommendations that facilitate the success of DSA technology and to suggest directions for further research.

1 Introduction

Dynamic Spectrum Access (DSA) radio technology promises to help overcome the lack of available spectrum for new communication services by increasing spectrum sharing. Currently, spectrum sharing is limited to simple approaches such as low power unlicensed devices. New types of spectrum sharing enabled by DSA include higher-power transmission at times when the primary users of a band are inactive, real-time trading of spectrum access rights, and collaboration among unlicensed users to more efficiently share spectrum resources.

DSA will only provide significant economic and social benefits if it becomes widely available and utilized; that is, if wireless services based on DSA are successful in the market. For this to occur, the wireless services market itself must evolve. New value chains, market incentives, and ways of managing risk must grow up around the new features of DSA radios. Product features and technical capabilities that support this market evolution are just as important as the core spectrum access features of DSA radios.

In this paper we analyze the interactions between DSA technology and the wireless services market. We make recommendations for how the technology, markets, and regulations ought to co-evolve to overcome potential barriers to the success of DSA.

Our recommendations fit within current regulatory and policy frameworks, making them realistic short-term steps. There are also fundamental policy reforms that can accelerate and help maximize the benefits of DSA. We do not have room in this paper to address fundamental policy topics in detail; however, we briefly discuss some of the possibilities in the last section.

1.1 Definitions

Before proceeding, we define the key terms used in our discussion .

A *band* is a contiguous range of frequencies subject to the same regulatory treatment. Traditionally, most commercial bands have been allocated via *static spectrum licenses*, which specify a band and grant the licensee protection against in-band interference from third parties. For example, both over-the-air broadcasters and commercial cellular service providers operate in specified bands under restricted use licenses administered by the government.

Dynamic Spectrum Access is defined in draft standard IEEE 1900.1 as "a technique by which a radio (system) dynamically adapts to select operating spectrum to use available (in local time-frequency space) spectrum holes with limited spectrum use rights." Thus, DSA technology encompasses a wide range of radio system capabilities. A DSA radio may be *agile*—able to operate in many different bands—and may be *flexible*—capable of supporting many different transmission standards or waveforms. However, neither of these features are necessary for DSA. Many DSA devices will support only one waveform and operate in a single band.

DSA technology includes Cognitive Radio (CR) technology which may be used to control dynamic spectrum access. IEEE 1900.1 defines CR as "communication systems that are aware of their environment, internal state, and location, and can make decisions about their radio operating behavior based on that information." Whether AI techniques are used or not to make these decisions is not important for our analysis.

There is a hierarchy of spectrum access rights. A *primary rights holder* (or *primary user*) is an entity who holds a spectrum access right that is protected from interference. Most commonly these rights are assigned to a single entity, although there are *co-primary users* in some bands who must coordinate with each other. A *secondary user* is any entity accessing a band who must avoid causing interference to its primary rights holders. There will often be multiple secondary users contending for access to a single band.

There are two main frameworks for sharing spectrum between primary and secondary users, *cooperative DSA* and *noncooperative DSA*. In cooperative DSA a secondary user may only use a band with permission of the primary rights holder of that band. Normally the parties will enter into a contract involving payment for access rights. In noncooperative DSA the secondary user does not require permission from the primary rights holder. By analogy to property law, *easements* created by regulatory authorities specify the conditions and requirements for noncooperative spectrum access in a given band. Low power ultrawideband (UWB) devices are an example of non-cooperative spectrum sharing via an easement.

Spectrum access rights are traded in a *secondary spectrum market*. What is traded may include primary (exclusive use) rights; "secondary" in this context refers to trading subsequent to the initial assignment of rights by regulators. In noncooperative DSA, secondary access opportunities are discovered and exploited rather than traded, but it is still useful to consider it as a spectrum market subject to supply and demand behaviors.

In any DSA context, whether cooperative or noncooperative, a policy or procedure called a *spectrum etiquette* controls secondary access to each shared band. This may specify only low-level transmission features such as output power, as in the case of current unlicensed bands, or it may require higher level behaviors such as listen-before-talk. The etiquette in force in a given band may be established by industry standards, by regulators, or by cooperative DSA contract.

2 Market dynamics

DSA significantly increases opportunities for shared use of spectrum. One way it does this is to stimulate trading in the spectrum market, because the primary rights holder need not vacate a band before offering access rights to someone else. Shared use is also increased by the coexistence of secondary users with (noncooperative) primary rights holders, and by the increased number of situations where spectrum managers can safely allocate co-primary licenses.

An obvious result of greater trading and more shared spectrum is that spectrum access gets cheaper. This is of course the major driver for the wide interest in DSA. What is not so widely discussed is the way that cheaper spectrum and an active secondary spectrum market will reshape the radio services market and industry value chain.

Smaller scale, lower cost entry becomes feasible, which enhances competition in data communication services, driving down service prices. As a result, incumbent business models built around spectrum scarcity will be less viable. Incumbents will need to introduce more value-differentiated services to justify price margins. Thus, DSA will stimulate innovation in wireless communications even from operators who do not exploit it.

Lower entry costs will increase the pace of product and business model lifecycles, through faster entry and exit in the marketplace. Furthermore, DSA allows new services to replace legacy services more gracefully. A new entrant can begin with inexpensive, limited spectrum access rights, then scale its usage rights to match its capacity needs as business grows.

Finally, increased lifecycle speed makes it more challenging to recover the fixed costs associated with introducing new technologies, services, or business models. It also increases the likelihood that successive generations of technologies will overlap. Both effects raise the importance of radio design techniques that reuse hardware designs across multiple waveforms, such as device modularity and software radio.

The effects of DSA just described will only develop if there is sufficient liquidity in the spectrum market to enable the deployment of DSA based services. There are three enablers for market liquidity: available spectrum, customer demand, and low transaction costs. The next sections describe mechanisms for making progress in each of these areas. These mechanisms are summarized in Figure 1.

3 Available spectrum

The first enabler for success of DSA-based wireless services is that sufficient spectrum must be available for secondary access. The conditions required for this to occur are roughly the same whether DSA is cooperative or noncooperative.

First, the perceived risk of interference due to DSA radio operation must be reduced to an acceptably low level. This can best be achieved through demonstrated safe operation with initial deployments in simpler bands. A “simpler” band is one where the spectrum access etiquette

Figure 1. Feedback loops for growth in use of dynamic spectrum access. The multiple cause/effect chains diagrammed in this graph can proceed independently.

required for noninterfering operation is less complex, due to characteristics of the incumbent services. An "acceptably low" level of risk also varies by band, according to that band's function and users.

Second, the value of services based on DSA radios must be established, in order to support the pricing of leases in the secondary spectrum market, and/or provide economic justification for regulatory creation of the easements. Initially the perceived value is likely to be lower than its eventual equilibrium level, due to concerns about the quality of service that can be delivered without guaranteed spectrum rights. The paths to overcoming this concern are discussed in the next section.

Finally, incumbent service providers must be weaned from reliance on spectrum scarcity as a barrier against competition. Ideally this will occur naturally over time as DSA proves viable and new entrants begin to exploit it in limited bands. However, this may also be a place where market development is chilled. If the amount of available spectrum remains artificially limited after the other barriers of risk and value have been addressed through initial deployments, regulators may have to jumpstart the market. This can be accomplished through offering secondary access to a significant amount of spectrum. This step will create the expectation of future competition in communication services and convince incumbents that a spectrum hoarding strategy is no longer effective. Spectrum availability will then rise to equilibrium levels: in the cooperative DSA case, because primary rights holders seek to earn a share of the access revenues, or in the noncooperative case, because they spend less political capital fighting the creation of new easements.

Each of the above conditions suggests that the supply of spectrum available for secondary access will increase in a stepwise, iterative manner over time.

4 Customer demand

Success of DSA-based wireless services also requires sufficient customer demand in the secondary access spectrum market. The notion of customers applies to both cooperative and noncooperative DSA. In the cooperative case, the market requires players who will pay for secondary spectrum access. In the noncooperative case, the market requires players who back the creation of easements, and who will use those easements for sufficiently valuable purposes to justify regulatory action.

The initial customers in the secondary spectrum market are the companies whose products depend on DSA, whether equipment vendors (e.g. manufacturers of WiFi access points) or service providers (e.g. cellular carriers). Over time, as DSA-enabled devices become more successful, we expect to see end-users seeking to acquire spectrum access directly. For example, a hotel might expand the capacity of its wireless network when hosting a convention, through temporarily exploiting secondary access to additional spectrum; or, a community of users might acquire spectrum as needed to support a broadband local access mesh.

The level of demand by customers in the secondary spectrum market is highly dependent on the quality of service (QOS) vs. price tradeoff achievable with DSA. That is, a communications service with lower QOS may still generate significant end-user demand if it is cheap enough. Such price/QOS tradeoffs are a hallmark of competitive markets.

At first glance, it appears that DSA based services would have a strictly lower QOS than radio services that enjoy guaranteed spectrum access. However, it is better to say that DSA-based services will offer a different QOS, in the same way that the Internet offers a different QOS from traditional telephone networks, one that is more desirable for some applications. Furthermore, DSA based services may be dramatically better in some contexts. For example DSA can be used to build networks that communicate more effectively through building walls than WiFi, by exploiting VHF frequencies with better propagation characteristics than the 2.4 GHz and 5 GHz unlicensed bands.

Therefore, the QOS/price challenge is as much about finding the right novel applications as it is about improving the communications capability of DSA radio technology itself. One example new application is a service that keeps the entertainment system in a user's car automatically updated as new media is loaded on the user's home PC. An occasional delay in updating may be acceptable, if the cost savings relative to using cellular network services for the high volume of data that is transferred are sufficient. Of course, as with many prior innovations, the "killer apps" for DSA are likely to be unforeseen. The chance that one or more will emerge is enhanced by the lower entry costs for new service providers that is enabled by DSA.

When it comes to supporting legacy applications, the perceived reduction in QOS associated with DSA may impede market success. To address this concern, it may make sense to deploy such DSA systems initially in bands where the primary usage is so low that secondary access rights are tantamount to guaranteed access to spectrum. For example, there are 6-MHz wide UHF TV channels in large urban areas in the USA where the license holder has not transmitted for years. Making such spectrum available for DSA-based wireless services will require regulatory reform to create easements or to permit secondary access contracts.

In the longer term, even such desirable bands may suffer from QOS challenges due to competition among multiple secondary users. Techniques to improve QOS for DSA systems therefore are an active and important area for research. This includes such techniques as running etiquettes simultaneously on multiple bands, coordinating independent secondary users geographically to support the QOS requirements of each, and bringing spectrum availability information into network level decisions in order to route around congested areas.

There are also non-technical ways to improve QOS. A derivative securities market (e.g., options and futures contracts for spectrum access rights) could enable operators to hedge the risk of losing spectrum access. Alternatively, service providers may choose to bundle a DSA-based service together with one that has guaranteed spectrum access, perhaps as two operating modes of a single end-user device, so user needs are met despite the QOS limitations of DSA for these legacy applications.

5 Low transaction costs and risks

Assuming we have a willing spectrum provider and customer, the final requirement for success of DSA-based wireless services is acceptably low transaction costs and risks in the secondary spectrum market. There are obvious transaction costs such as searching for an opportunity and satisfying government red-tape. These costs can be reduced by spectrum brokers, who will evolve naturally as the DSA market begins to operate. Regulatory reforms to streamline procedures for transferring rights will also help. There is no fundamental reason why it should not be efficient to trade spectrum rights for short time blocks (minutes) and small bands, under either cooperative or noncooperative DSA regimes.

In addition to the obvious transaction costs, there are also less-obvious costs due to risks encountered by offeror and customer. The risks are different for cooperative and noncooperative DSA regimes.

Cooperative DSA

The offeror counts as a transaction cost the risk of reduction in the value of their spectrum access rights. There are three main ways the primary rights holder could be harmed.

First, there is the risk of interference caused by the secondary user. The main way to reduce this risk is of course testing of DSA devices, either as specified by regulatory mandate or contractual agreement. However, at least in the early stages of DSA deployment, testing is likely to only imperfectly address this risk. Mechanisms are needed to reduce the cost of resolving interference when it does occur. One approach would be a requirement that all DSA devices transmit their make/model/software version on (authenticated) demand. Also, DSA devices could be required to keep a log of the bands where they have recently operated, similar in function to an airplane's "black box," permitting post-interference analysis.

In cases where the secondary user deploys a large number of devices, perhaps distributed to consumers, there is the risk that devices will remain in the field after the access contract expires, continuing to exploit the band without authorization. This risk can be addressed through a time limit on operation that is enforced by a trusted subsystem in each device. These time limits are called *leases*. The straightforward technical implementation of leases is to use cryptographically signed certificates to send lease extensions to the device. Failure to receive a lease extension causes the device to cease operating in that band after the specified deadline.

Finally, there is the risk that authorities will retract some of the rights assigned to the primary user. Sharing with secondary users offers evidence that the primary user does not need all of the existing spectrum allocation. To reduce this risk, policymakers must make credible commitments to procedures that protect primary rights holders from subsequent loss of rights on the basis of their activity in the secondary spectrum market.

There is also risk for the customer in a cooperative DSA arrangement, which must be mitigated for the transaction to be worthwhile. The primary user may seek to expropriate the value of the secondary user's business once its viability has been demonstrated. For example, the primary user can threaten to modify its usage patterns in a way that reduces the secondary user's access below the level needed for acceptable end-user QOS, and thereby force the secondary user into unfavorable additional contracts. Creative contractual arrangements will need to be developed to protect the rights of both parties to cooperative DSA transactions, for example including limits on the primary user's access patterns.

Noncooperative DSA

In noncooperative DSA, the secondary user must characterize the primary user's spectrum use well enough to avoid causing interference. There are both direct costs associated with doing this—monitoring, analysis, communicating data among multiple secondary nodes—and risks of making a mistake and incurring legal liability. Due to both the cost of the characterization task and the associated risk, secondary users are motivated to be conservative. The simple etiquettes that secondary users decide to implement are likely to achieve a lower level of spectrum utilization than is technically possible in a band.

The cost and risk of characterizing spectrum use can be reduced through establishing an information registry, which could be governmental or private, for authoritative data about primary users. Posted information could include for example geographic locations of transmitters and receivers, waveform characteristics such as modulation and bandwidth, or times of day when the system does not operate. This type of information enables secondary users to execute more aggressive spectrum access algorithms at acceptably low risk. Notification of secondary users when registry data is updated would assure quick response to changes in primary user behavior. One of the primary challenges of a registry is to assure that the information posted is correct; both regulatory and market mechanisms that assist this are worth exploring.

An effective registry mechanism can reduce the interference risk of DSA, compared to a regime where secondary users operate without external information. As a result regulatory authorities can establish more liberal easements. This effect is synergistic with the benefits of a registry: both lead to higher spectrum utilization. The policy and technical issues associated with the registry approach are a valuable area for further investigation.

6 Value Chain

DSA-enabled opportunities to share spectrum in new ways will create opportunities for innovation in business/service models, asset ownership/control and contracting (firm structure), and value chain relationships. A classic industry value chain describes the production flow process downstream from raw materials through intermediate goods production (sub-components) to final goods producers/distributors and ultimately to final consumption by end-users. In wireless services, one may think of the raw material as the spectrum access rights which must be bundled with radio equipment (intermediate goods) devices into networks (downstream producer/distributor) to deliver finished communication services to the end-user. DSA makes it possible to redefine how these essential elements are organized in the market.

The traditional model of static spectrum access supports an industry structure in which wireless services are segregated into distinct, well-defined value chain *silos*. Each service is provided by purpose-built networks employing equipment dedicated to that narrow class of applications and operating in dedicated spectrum bands. The result is a number of distinct radio system architectures. Thus, over-the-air broadcasters, mobile system operators, and end-user-deployed wireless LANs (WiFi) are each based on distinct and incompatible radio system architectures, service/business models, and spectrum management regimes.

DSA technology promotes both the *vertical disintegration* and *horizontal integration* of the existing wireless service market silos, driving the same sort of platform convergence that has been occurring in wired communication services. DSA facilitates vertical disintegration by enabling new types of business models and wireless architectures for delivering services. For example, under the traditional *service provider/subscriber* model for cellular telephone services, there is a mobile network operator which makes the capital investment in network equipment and spectrum rights, then sells services to end-customers who pay monthly recurring fees for usage. DSA makes it possible to unbundle the investment in spectrum rights, the operation of a mobile network, and the offering of mobile services. New types of intermediaries may emerge to exploit these opportunities, including an MVNO that operates a service in multiple bands; spectrum brokers that specialize in managing the transference of access rights in secondary markets; or vendors of customer-equipment that supports the viral deployment of end-user provisioned ad hoc or cooperative, mesh networks.

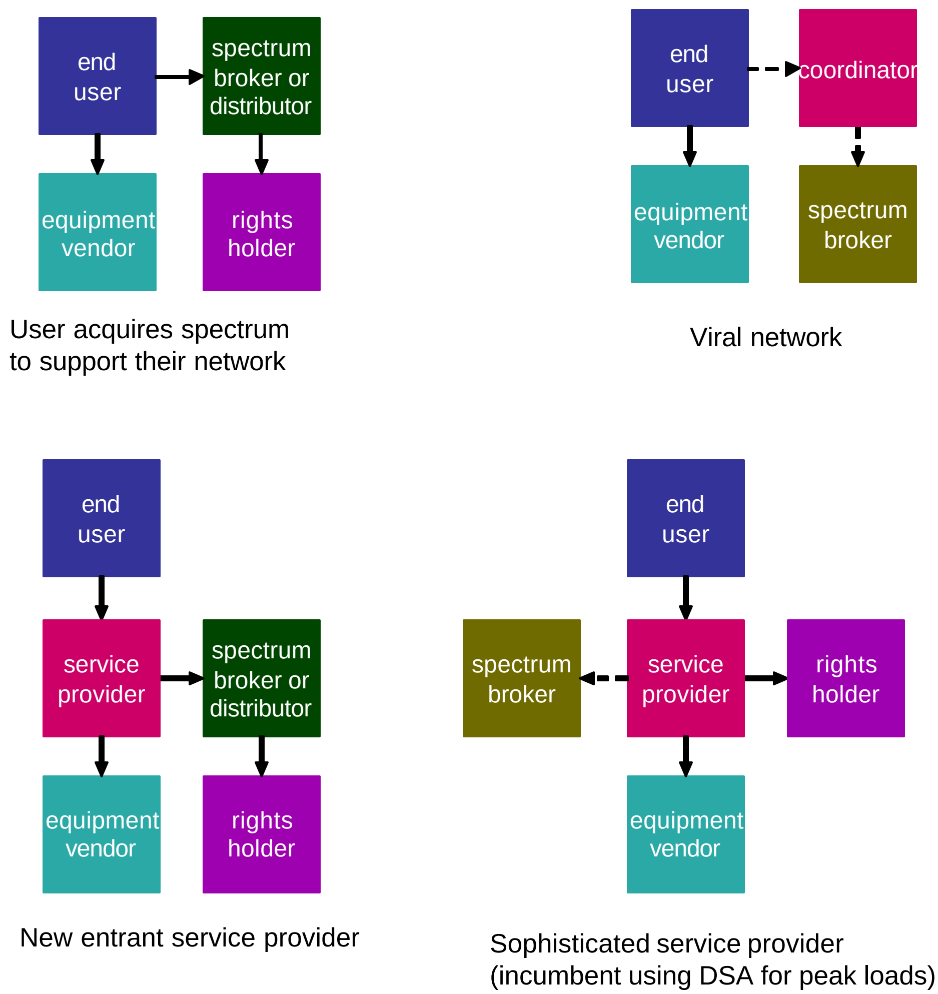

Figure 2. Potential value chains for DSA-based wireless services. In the case of noncooperative DSA, the rights holder is removed but the rest of the chain is unchanged. Dotted arrows indicate small revenue flows.

Horizontal integration occurs when a single product competes across silos and thereby breaks down the barriers between sub-markets. With DSA, a radio device or system can scale its spectrum use to reflect changing application needs and local network conditions. As a result it may more effectively support a larger range of end-user applications than devices based on static spectrum access, if QOS challenges can be overcome. Manufacturers and service providers exploiting these more flexible system architectures will be more resilient against setbacks in any particular sub-market, making them competitive against silo incumbents.

The spectrum access algorithms or etiquettes used to implement DSA are expected to be complex, difficult to get right, and even more difficult to get certified by regulatory authorities. There will be strong incentives for device manufacturers to acquire and reuse etiquette implementations. This will promote the componentization or modularization of radio system design. Software radio technology, which is distinct from DSA but is likely to be used to support the system design opportunities created by DSA, also promotes the vertical disintegration of traditional vertically-integrated equipment manufacturers. For example, third-party software providers may provide customizable baseband processing software that could run on common hardware and can be sold to diverse network operators.

Perhaps the most obvious new type of intermediary that DSA gives rise to are firms that specialize in the spectrum trading function itself, seeking to ensure adequate market liquidity and low transaction costs. Such a *spectrum distributor* could operate as a sophisticated variant of a spectrum broker, adding value by aggregating and partitioning spectrum access rights. The distributor could contract with end-users to deliver QOS-differentiated spectrum access, while acquiring the spectrum rights through contracts with primary rights holders or through exploiting easements. The distributor could also install and operate the monitoring and analysis systems needed to decide when secondary operation in a given band at a given location is safe. Provision of this monitoring and decision service by a responsible entity will reduce the cost of end-user devices and the risk of interference to primary rights holders.

It is not clear what business models will prove most valuable in a DSA-enabled market. There are end-user equipment models in which end-users purchase devices and then assemble mesh networks that scale using DSA-enabled spectrum to form provider-less networks. There are disaggregated radio equipment manufacturing models offering separate hardware and software components. There are also new types of MVNO models that unbundle retail services, network ownership and spectrum rights. The market will need to experiment with which arrangements of the value chain (and new intermediaries) make the most sense. Regulatory policy needs to allow such experimentation to occur, and should not artificially bias the market toward choosing one value chain structure over another. (Figure 2 illustrates some of the novel value chains DSA makes possible.)

7 Conclusions

We have described a number of wireless communication service market developments that are linked to dynamic spectrum access, either as required enablers or as potential effects. The underlying enablers are those regulatory steps and technical innovations that improve liquidity in the secondary spectrum access market, by boosting spectrum availability, increasing QOS and hence customer demand, and reducing transaction costs and risks. We have identified a virtuous cycle of innovation leading to widespread use of DSA-based services. Once DSA technology is widespread, we can expect reduced entry costs for new service providers to speed up product and business lifecycles. The technology will also enable new value chains and business models for providing communication services.

The market developments analyzed in this paper can occur within existing regulatory frameworks. However, proactive regulatory reform could accelerate the evolution of the market. The desirable fundamental policy reforms shift away from traditional command and control mechanisms toward more market-based mechanisms. This means increased reliance on market-based contracting to address interference concerns, industry instead of government-mandated standardization, and lightweight regulatory rules that clearly specify the property rights of primary and secondary users. Current regulatory trends toward further deregulation, technology-neutral rules, and further reforms to enable secondary market trading are all encouraging. Progress will depend on demonstrating the safety and market-value of DSA-based services and the new architectures DSA enables. In the early years, regulatory structures will need to be flexible to adapt to the lessons learned as the technology matures.

We have identified a set of potential new entities, such as spectrum use registries and spectrum distributors, as well as product features such as black boxes and leases, that may play important roles in facilitating growth of the market for dynamic spectrum access based wireless services. Research on how these entities and features can work is just as important as research on basic questions of safety in dynamic spectrum access, if the technology is to fulfill its promise of significant increases in overall spectrum use efficiency and thereby deliver its full potential social and economic benefits.

For further reading

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