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An Overview of the U.S. and Japanese Approaches to Cognitive Radio and SDR*

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SUMMARY "Cognitive radio" and "software-defined radio" (SDR) are today an important consideration in major spectrum debates in the United States. The U.S. drafted its first SDR rules in 2001, and since has continued efforts to resolve potential regulatory concerns and facilitate the benefits of the technology. At the same time, Japan has had a very rich experience in the lab with SDR, with significant achievements on many engineering topics. However, the regulatory state of SDR in Japan has not kept pace with the United States. Likewise cognitive radio, while a topic of inquiry, betrays a different focus. The paper explores why the paths for these technologies have diverged in the U.S. and Japan.

key words: *software defined radio, cognitive radio, spectrum regulation, spectrum policy*

1. Cognitive Radio and the SDR General Background Introduction

Cognitive radio and SDR are complex topics with evolving definitions and applications. Nevertheless, these technologies are real with current applications and legal status in the regulatory law[**]. These come at a crucial time as exploding demand for spectrum makes the regulators job of improving access to spectrum increasingly difficult. The technical aspects of the technology are the topic of many excellent papers and conferences. The focus here is on examining the regulatory course in U.S. and Japan.

While the regulatory focus of SDR has been on how to certify devices under the relevant spectrum regulations the device operates under, Cognitive Radio represents the set of technical and regulatory considerations introduced by the possibility for a new highly dynamic, efficient, and flexible spectrum environment enabled by adaptive radios using advanced "cognitive" processing techniques. Where SDR's regulatory focus is primarily on preserving the integrity of devices to prevent interference, the Cognitive Radio focus is on improving spectrum management process' allocation, service, and licensing rules. Cognitive Radio is the hard look at how spectrum is used and regulated and what improvements are possible using adaptive, aware, and learning features. The approach to SDR can affect the treatment of Cognitive Radio, and can be seen as the source of difference in policy approaches in the U.S. and Japan, as discussed in Table 1.

2. SDR and Cognitive Radio — The U.S. Experience

"We neither wish to have our processes inadvertently be a barrier to the development and deployment of these technologies nor wish to permit the widespread deployment of radios easily susceptible of being misused to cause harmful interference to others." [1].

The U.S. experience has fundamentally been a proactive one with a strong commitment to exploring benefits

Table 1 Overview of use of SDR and cognitive radio with problems of spectrum's increasing demand and scarcity.

U.S.	Japan
➢ Focus on Access as Problem	➢ Focus on New Technology Allocations (3G, 4G, WiFi)
➢ Concern for SDR device integrity ▪ Study in TAC ▪ Direct Regulatory Action ▪ Change to Rules	➢ Concern for SDR device integrity concerns ▪ Commissioning Studies and Research ▪ Comments Sought and Rule Change
➢ SDR as flexible platform for new approaches	➢ Narrow Approval for Specific Application
➢ Identify and utilize Cognitive Radio technical features to derive regulatory benefits wherever useful	➢ Exploration of CR For Ubiquitous Aspects
➢ Provide incentives for use of new technology by creating new regulatory approaches	➢ Identify Specific Business Model and Player ➢ Budgeting for Research and development

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**The FCC approved the first SDR in 2004, a base station by Vanu, but 802.11 Access Point devices and others are also today in the marketplace.

while protecting against potential harms. Interest in SDR as a regulatory topic can be traced to the Federal Communications Commission (FCC) directing its Technological Advisory Council (TAC) to assess the state of the art and propose directions for SDR and Cognitive Radio [2]. The FCC pursued the topic aggressively initiating several initiatives to vet any changes to the FCC rules necessary to accommodate SDR technology, and in September 2001 adopted rule changes defining SDR in the law for the first time and adopting various new "certification" procedures for approval of SDR devices [3]. The FCC adopted procedures for obtaining approval for software changes to a radio, and required devices certified as SDRs to incorporate a means to prevent unauthorized modifications. The FCC created the "class 3 permissive change" which made it easier to make subsequent changes to the software of an approved SDR. Additionally, the new procedure required some security measures to prevent third-party modifications to approved software that could potentially result in interference. Under the rule, a SDR is defined as:

"A radio that includes a transmitter in which the operating parameters of frequency range, modulation type or maximum output power (either radiated or conducted), or the circumstances under which the transmitter operates in accordance with Commission rules, can be altered by making a change in software without making any changes to hardware components that affect the radio frequency emissions."[†]

Four years later in the Cognitive Radio Order, the FCC made additional changes to the SDR security and certification requirements so that any SDR that could reasonably be viewed as open to modification by other than the manufacturer must comply with the SDR rules and have security protections in place to prevent unauthorized modifications to the SDR software[††] [1].

Both times it changed its rules the FCC took steps to preserve the integrity of the SDR approval process, but decided against specifying implementations, instead providing developers flexibility to craft their own solutions. Manufacturers craft their solution but must supply a high-level operational description of the SDR's software controlling RF characteristics, and software security measures. In this way the FCC demonstrated its commitment to assuring a balance between the flexibility to develop and deploy SDR while preventing radios from being misused to cause harmful interference.

2.1 Regulatory Flexibility and the FCC's "Marketing" Rules

The FCC policy of balancing flexibility and protections is central to its approach to regulating new technologies and depends on its legal authority to ensure that radio devices comply with rules preventing interference before they are sold, marketed or imported[†††]. When the rules are not followed the FCC has authority to impose severe penalties[††††]. For example, the FCC has authority to assess a "forfeiture" of $11,000 for each violation, or each day of a continuing violation, up to $87,500 for any single continuing violation, and is specifically authorized to assess a baseline forfeiture amount of $7,000 for each violation involving the marketing of unauthorized equipment.

However, this was not the case in the late 1960's when the U.S. Congress took up the serious problem of how to combat the increasingly burdensome and dangerous problem of harmful interference emitting from malfunctioning or manipulated devices [4]. One example discussed in the Senate involved serious interference problems to air-safety-related emergency communications coming from 58 garage door openers–RF devices subject to technical standards in the "unlicensed" Part 15 FCC rules. Congress took action and amended the Communications Act giving the FCC greater authority to address interference problems. The FCC modified its regulatory framework to ensure that before RF devices are sold, marketed or imported in the U.S., they must be checked for compliance with the appropriate technical rules they will operate under — in Japanese a "hanbai kisei"[†††††]. The statute and subsequent rules thus created a "pre-check" on the harmful interference potential of devices shifting much of the risk of enforcement from the field to the laboratory. This "pre-check" authorization rules work together with the technical rules to prohibit the use of equipment or apparatus which may cause interference giving the U.S. Regulator significantly more comfort to be flexible in defining its technical and other rules[††††††].

2.2 Cognitive Radio's Value as Tool for Regulatory Flexibility in Allocation and Technical Policy Making

The FCC next turned from the benefits of SDR as a platform to the potential benefits of "Cognitive Radios," capable of adapting spectrum use to the real-time conditions of the operating environment. The FCC considered how the capabilities of such radios could help achieve more flexible, efficient, and comprehensive use of available spectrum while reducing the risk of harmful interference. After first conducting a workshop on the topic, the FCC began a rulemaking seeking comment on various exciting proposals for application of Cognitive Radio features [1], [5]. Among other things, the FCC sought comments on: The capabilities of cognitive radios; Permitting higher power by unlicensed devices in rural or other areas of limited spectrum

[†]See 47 C.F.R. §2.1.

[††]Cognitive Radio R&O para. 20, at 8.

[†††]47 U.S.C. 302a(b) (codifying section 302 of the Communications Act of 1934, as amended); 47 C.F.R. §§2.1201, 2.801 et seq.

[††††]47 U.S.C. §503(b)(2)(D); 47 C.F.R. §1.80(b)(4).

[†††††]Proposals to revise Japanese law in this regard have surfaced repeatedly in the past but ultimately failed.

[††††††]Readers interested in this subject may find the deliberations on the need for expanding the FCC's regulatory authority to address harmful interference from non-complaint devices in the field discussed in the Senate Report at page 2486-89.

use; Enabling secondary markets, including interruptible spectrum leasing; Dynamically coordinated spectrum sharing; and SDR and cognitive radio equipment authorization rule changes.

At the same time, Cognitive Radio had emerged as a topic in important spectrum proceedings on Rural Wireless Policy, Secondary Markets, Unlicensed Use in Television Bands, and others [7]–[9]. In 2005 the FCC adopted its first "Report & Order" on Cognitive Radio and expressed its intent to continue to explore new and evolving applications of Cognitive Radio [1].

2.3 Cognitive Radio's Value in Both Licensed and Unlicensed Policy Making

While, FCC spectrum regulatory policy is complex and a complete introduction is beyond the scope of this paper, broadly speaking there are two regulatory approaches. The license-based or "exclusive use" approach permits use of spectrum based on a license issued by the FCC and governed by its service and technical rules. In general these rules, the commercial mobile radio services (CMRS) for example, give licensees significant technical flexibility. Thus the rules typically accommodate new technical approaches without significant revisions.

Nevertheless the FCC has applied Cognitive Radio capabilities to many new regulatory approaches such as the "private commons" leasing technique [7], [8]. Under this approach, a licensed spectrum user could choose a set of "technical rules" for use of his licensed frequencies, and permit people using a peer-to-peer device that conforms with those rules to operate on his licensed frequencies, consistent with the applicable technical requirements and use restrictions under his own license.

For example a licensee, such as a CMRS, with an existing network infrastructure could offer an existing service offer in tandem with a "piggy-backed" new low-power services that would operate not in the 2.4 Ghz band under FCC license-exempt rules, but instead in the licensee's own band. Because the service provider ultimately would control the technologies and services involved, he could deploy new technologies, simultaneously offering new services supported by the reliability of his exclusively licensed spectrum environment. Leveraging technical features to create new spectrum market opportunities is a valuable benefit of treating Cognitive Radio in the regulatory context.

The FCC has explored other interesting synergies between the technical features of Cognitive Radio and new spectrum regulatory techniques. For example, the FCC explored in the Cognitive Radio proceeding how the technology could be used to promote Spectrum Leasing by creating dynamic "interruptible" markets in spectrum access [1], [11], [12]. Such new techniques are backed by enforcement authority against licensees, should the need arise, giving the spectrum policy planner a degree of comfort. Nevertheless the FCC's use of cognitive radio not only as a technical vehicle, but also as a regulatory vehicle for new spectrum management techniques is significant.

The FCC also has an extensive "unlicensed" or commons-based spectrum regulatory environment that dates back to 1938 — recently discussed in some detail in an FCC order on ultra-wide band unlicensed applications [6]. Under this regime, use of spectrum isn't individually licensed but permitted for non-interfering devices that have been confirmed to comply with the technical rules to prevent interference. Devices operating under this regime are generally sold in large quantities to users lacking any specialized spectrum knowledge. These considerations might require a more conservative approach to crafting technical rules, but for the incorporation of Cognitive Radio capabilities. Together with the strong device authorization regime, "unlicensed" technical rules can take account of the highly adaptive real-time cognitive capabilities available today, to craft new approaches that would otherwise be impossible. The proposals for unlicensed use in TV-bands and others are profound examples of how utilizing the benefits of Cognitive Radio can expand the scope of possibilities in the regulatory context [7]–[13].

Thus the FCC's legal authority to regulate the sale, marketing or importation of devices that don't comply with their rules or take action directly against an offending licensee is important to understanding the overall approach. The FCC's enforcement authority derived from a climax of concerns at the Congress today can be seen to provide the regulator an opportunity to be more liberal in crafting policy. In this regard, the significant legal issue can be seen to influence the culture of the regulatory environment.

3. SDR and Cognitive Radio — The Japanese Experience

"*The Ministry of Communications, referencing the submitted comments in this proceeding, will proceed by monitoring the direction of R&D for SDR and international activity at the ITU and elsewhere.*" [14] (trans. Miller)

The research community in Japan has shown strong interest in SDR and related technologies for ten years or more. Numerous excellent technical papers and projects in the area have come from Japan [15]–[19]. The Ministry of Communications (MIC) has also explored the topic. Nevertheless, except for software to control selection of frequency for a class of wireless LAN's in the 5 GHz, SDR is not permitted in Japan.

Beginning in December 2003, MIC sought comments on security, certification and other aspects of SDR and related technologies, garnering significant interest [22]. In 2005, MIC released a summary of the comments and proposed use of SDR with 5 GHz wireless LAN [14], [21]. While MIC adopted the proposed changes to allow limited SDR use with wireless LAN operations in the 5 GHz band in April of 2005, MIC's stated intent to follow the development state of the technology and work at the ITU, may reveal a less proactive stance to incorporating these techni-

cal features into its spectrum regulatory environment.

3.1 Enforcement of Technical Rules and Flexibility in the SDR Regulatory Environment

The Japanese regulatory stance regarding SDR is easily understood in light of how critically equipment authorizations must be considered. While the specific rules and procedures for equipment authorization in Japan and the U.S. may differ on various points, the crucial difference is not in how radio emissions are measured or the kinds of filling required or system for approved testing bodies [22]. The important difference lies in what authority the U.S. and Japan have to enforce their rules.

Where revisions to the U.S. Communications Act provided the FCC authority to combat interference potential through equipment authorizations before they enter the stream of commerce, MIC lacks this regulatory authority. Lacking this authority, a regulator might feel more concern for devices that are designed under broad definitions, and prefer to allow new approaches only under tightly defined standards. Looking at the 2005 actions on SDR, it could be said MIC is paying very close attention to the role of security and device integrity, opting for a "wait and see" approach–perhaps until more concrete implementations emerge [14].

3.2 Equipment Authorization and Spectrum Planning

Uncertainty naturally influences a regulator's comfort level with flexibility in the "licensing" as well as technical standards for spectrum use. This discomfort together with other factors may contribute to regulators reluctance to explore new licensing and unlicensed regulatory choices. This may be the case in Japan.

Generally speaking the Japanese approach to allocations is to vet with key players in various research committees and advisor boards what new technologies should be employed in what bands. In light of this approach, many Japanese regulators view with significant discomfort (if not hostility) the "U.S. approach" marked by volatile market changes regarding entry and exit of players, technologies, and service offerings. There has not been a significant outcry for Cognitive Radio and SDR rule changes in these traditional policy setting fora. One might reasonably conclude, until someone comes to the table with something specific, it's likely difficult for the regulator to see Cognitive Radio and SDR as a "solution" in someone's service and business model.

There are several recent indications that interest in Cognitive Radio and SDR is beginning to pique. The first is of course the first step of permitting wireless LANs in the 5 GHz to use software in implementing interference avoidance and frequency selection schemes [14]. Also Cognitive Radio has been raised in the context of recent MIC requests for comments regarding the digital-analog TV transition [23]–[25].

In October 2005 MIC also issued a request for proposals regarding improved spectrum efficiency research funded by spectrum usage fees [26]. Among the many research topics available for proposals, MIC included substantial funding for a 3-month 1.4 Billion Yen (@$1.4 mil.) project for R&D on cognitive radio technology directed at shared mobile technology. This clear commitment to the potential of Cognitive Radio is very encouraging, and at the same time quite predictable under the Japanese approach. It is not uncommon for Japanese regulators to fund research to bring technology to a higher level of implementation, where the regulator can be more comfortable going forward in the regulatory context.

4. Conclusions and Future Directions

In conclusion, the author fundamentally does not see the U.S. and Japan on a different course, but simply proceeding at a different pace and in different lanes of the same road. Many of the same issues and problems emerge and are being discussed in tandem. Nevertheless the answer to why Japan and U.S. approaches do differ, is part law and part culture. The most decisive regulatory difference may be in the underlying legal authority for how devices are certified. Even with a change to the Japanese law regarding certification though, U.S. and Japanese regulators have different comfort levels regarding technical and regulatory "flexibility" that will effect their pace and direction. However, a higher level of comfort regarding enforcement does influence to what degree the spectrum allocation and licensing system will take advantage of the flexibility of SDR to harness new engineering techniques and novel spectrum management techniques. This suggests it may be time for a discussion in Japan on legal authority to regulate wireless devices.

Two points should be observed from the U.S. experience. Preliminary exploration of SDR and Cognitive Radio topics in the TAC and through inquiries was important to framing the debate, as has been the case in Japan. However, progress has been made by seriously exploring the topic in the context of changing laws to harness the technical features. Such leadership has been evident at all levels of the FCC, from staff comments in such documents as the Spectrum Policy Task Force Report all the way to remarks by Commissioners and the Chairman. The benefits of SDR and Cognitive Radio are numerous, but a commitment to working through potential problems is necessary. In the U.S. where flexibility is highly valued these benefits are compelling, but whether Japanese regulators appreciate these benefits in the same way may influence the future course in Japan.

Given the MIC's intent to follow the state of R&D and international situation, leadership in this area may ultimately come from elsewhere. The Japanese technical community will continue to play a critical role in providing policy makers examples of how technical features can enable more flexible, efficient, and interference resilient regulatory approaches. Cognitive Radio research on highly adaptive and dynamic physical layer (particularly MAC) improve-

ments are of particular interest but also focus on problems above the physical layer offer significant promise.

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