CR: Cooperative Radio or Confrontational Radio

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***Abstract*—Two basic approaches to cognitive radio systems are discussed. One is based on passive observations of spectrum use and the other requires cooperation of other spectrum users. The two approaches are compared from the technical and policy viewpoints and suggestions are made for testing them in a future spectrum testbed.**

***Index Terms*—cognitive radio, dynamic spectrum, spectrum policy**

I. INTRODUCTION

CR, of course, really stands for "cognitive radio" although people disagree on what exactly cognitive radio is really defined as. For most people, cognitive radio includes concepts like selecting frequency and other transmitted signal parameters based on estimates of location and the spectrum use of others in the area. 5 GHz band Dynamic Frequency Selection (DFS) is probably the first significant cognitive radio standard, although simpler systems like cordless phones have had some cognitive aspects for more than a decade. DFS is particularly notable in that it is actually an international standard not just a national one. But in the US, DFS implementation has been delayed for several years while parties argued over technical details.

Cognitive radio suggestions of the US Federal Communications Commission's (FCC) Spectrum Policy Task Force and more recently "TV whitespace" proposals in FCC Docket 04-186 have met with significant opposition from established industry and are making slow progress, if any. This paper explores the promise of cognitive radio, the concerns it has raised among more traditional spectrum users, and possible realistic paths for introducing cognitive radio into routine spectrum use.

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II. BASIC APPROACHES TO COGNTIVE RADIO

A. The Dichotomy

There are two basic approaches to designing cognitive radio systems that both meet the basic definitions of selecting spectrum parameters on local conditions. We will call these spectrum sensing access (SSA) and cooperative market-based access (CMA). In SSA the cognitive radio system estimates current spectrum use from a combination of present observations (possibly at multiple networked locations), past observations, and regulatory data and then selects frequency and other parameters to minimize the likelihood of interference to other users. CMA, on the other hand, involves direct interaction with other spectrum users in the area who explicitly consent to the cognitive radio user's use of spectrum that the other users have some previously established rights, e.g. licenses and primary allocations, for.

Both CMA and SSA achieve one basic goal of cognitive radio – increasing the intensity of spectrum use – although they do it in very different ways involving very different business plans of the participants.

B. Spectrum Sensing Access (SSA)

This is, perhaps, the best known approach to cognitive radio and is the approach used in the 5 GHz DFS systems and in two of the three options in the FCC Docket 04-186 proposals. A cognitive radio system selects frequencies, power, and other RF parameters by estimating what the likelihood of interference to conventional users and then selecting those parameters that either minimize this likelihood or which meet a regulatory standard. For DFS the regulatory standard is stated in terms of a limit of received power from the radar systems that share the band.

The FCC Docket 04-186 proposals deal with unlicensed or "lightly licensed" devices using "white space", spectrum which is unused at a given locations, in the TV broadcast band. The FCC proposal deals with three possible options to enable access to the white space: 1) listen-before-talk technology, 2) geolocation

followed by a database lookup to see what frequencies can be used, and 3) use of localized beacon transmitters to indicate what frequencies are available. The FCC proposal mentioned that the third option beacons might be controlled by the local broadcasters so if could be a type of CMA systems, but the other two would fit the SSA definition.

Finally, the DARPA xG project[i] exploring cognitive radio use in the military context is a SSA approach. Indeed, SSA appears to be the only alternative for sharing spectrum in hostilities as multiparty cooperation would be unrealistic.

C. Cooperative Market Access (CMA)

CMA involves the active agreement between the cognitive radio user and the original licensee of the spectrum in question. Because there is explicit agreement on spectrum use between spectrum users, the likelihood of interference is generally less than in SSA and the original user has mainly himself to blame in case of interference.

CMA spectrum use decisions can involve complete information on actual spectrum use that would not be available from passive observations, *e.g.* what frequencies are being used at what locations and at what powers and trend information on trunked traffic loads. It can even involve future information that is impossible to derive passively, *e.g.* what frequency will be assigned next by the system controlled is when a new frequency is needed.

In the US, agreements for CMA are specifically allowed now under the FCC's secondary market rules[ii] and such agreements are under consideration in Europe under the terminology "spectrum trading". CMA concepts are also being explored as a technological issue in the European Commission's End-to-End Reconfigurability (E^2R) program[iii] which is considering how networks can cooperatively share resources[iv] - including spectrum resources.

Today, many mobile radio systems are either cellular in structure or use the older trunked technology. In both cases there are system controllers that have real time knowledge of spectrum use and some information about near term future use. If this real time information could be made available or sold to prospective spectrum users it could be used to create new types of spectrum utilization and benefits all involved.

III. Comparison of SSA and CMA

In SSA applications the cognitive radio system must make observations and estimates of the spectrum use of others. Obstacles, multipath propagation, and radio noise all make such observations difficult and imperfect. By contrast CMA systems can conceptually have perfect knowledge of current spectrum use as well as possibly knowledge about traffic trends and future frequency usage.

A. Comparative Effectiveness

SSA systems could approach, but never reach, the knowledge of CMA systems of spectrum use if there are multiple internetworked observation platforms with individual observations made from carefully sited locations. For example, an cognitive radio infrastructure system sited like cellular radio towers could make much better observations and estimates of spectrum use than observations by mobile users at or near ground level. This would not be practical for military users, but is possible in a civil context. Indeed, cellular operators may find that operating such networks would build on their experience and that selling the real time information from such networks might create a new product line and new cashflow.

The key immediate advantage that CMA has over SSA is the issue of consent and the prospect of low controversy. As the FCC docket filings in Docket 04-186 have shown, SSA systems at this time create great fear of the unknown in large businesses that depend, or at least feel they depend, on spectrum. (FCC studies actually show that only 14% of US homes depend solely on over-the-air reception of VHF/UHF TV signals.[v] TV broadcaster may be more concerned about their "must carry" rights that create 86% of their viewing audience and are indirectly related to actual over-the-air viewing potential.)

But regardless of the reasons for opposition to SSA and the ability of opponents to withstand detailed scrutiny of their technical arguments, the fact remains that strident opposition is a major obstacle to cognitive radio implementation and increasing the intensity of spectrum use through the use of this new technology.

Continued focus by the advocates of cognitive radio on only SSA approaches raises the potential of major confrontations with traditional spectrum users who have some legitimate concerns about unproven technology negatively impacting their livelihood and important operations.

B. "Unjust Enrichment"

In the US context the economic jargon "unjust enrichment" often arises in contexts analogous to CMA. This refers to concerns that licensees who both received their license at no charge or at a minor costs and have not been using the spectrum efficiently might receive

financial benefits from leasing or otherwise transferring he spectrum to others. In a sense this is true. In the US and most other countries there is no direct private ownership of spectrum. Section 304 of the US Communications Act of 1934 even states,

> "No station license shall be granted by the Commission until the applicant therefor shall have waived any claim to the use of any particular frequency or of the electromagnetic spectrum as against the regulatory power of the United States because of the previous use of the same, whether by license or otherwise."[vi]

But another issue that has to be considered is the cost to society and national economies of letting spectrum lie fallow, for spectrum is today a key input to a wide variety of economic activities. While in theory governments can "take back" or "refarm" spectrum that is underutilized, in practice in functional democracies this is difficult and time consuming to do.

If one wants to use a land analogy, much of the land in the US outside the original 13 states went into private ownership at no cost to the first owners under the provisions of the Homestead Act of 1862.[vii] This land often sells at high values and no ones ever complains about "unjust enrichment" when such land is sold.

From the pragmatic viewpoint it may be better to get underutilized spectrum back "in circulation" faster by giving its licensees financial incentives to increase its usage intensity than to engage in lengthy legal proceedings determining whether its present intensity of use is consistent with some ill defined public interest standard.

IV. Proposed FCC/NTIA Spectrum Testbed and SSA/CMA Comparison

FCC and its counterpart for US federal government users, the National Telecommunications and Information Administration (NTIA), are exploring creation of a joint testbed[viii] to try new spectrum sharing concepts. The author has filed comments[ix] at FCC advocating that this testbed be instrumented for objective testing of SSA and CMA and for comparing them. This could be done by selecting a geographic area and spectrum band for the testbed and instrumenting the area with transmitters sending dummy traffic for the selected band. Receivers could then be placed in the area in order to detect the intended signals or harmful interference and record the observations. Such receivers could also quantify the amount of cognitive radio use occurring in the testbed so it could be correlated with the amount of observed interference.

Including in the testbed equipment to simulate trucked/cellular radio systems would allow both SSA and CMA to be evaluated. The simulated controllers for the trunked/cellular transmissions could make data available to CMA systems information on current spectrum use and near term expectations and the CMA systems could use this to try to "squeeze" more spectrum transmission capacity into the testbed while the receivers recorded the results. In such a testbed, CMA and SSA could be fairly tested and evaluated against each other.

V. Conclusions

Near term focus on SSA as the only approach to nonmilitary cognitive radio is likely to result in growing opposition to all cognitive radio use from other spectrum users. The TV spectrum proposal in FCC Docket 04-186 may well be the easiest application of SSA due to its technical characteristics such as high transmit antennas, high power systems, near continuous transmissions, and well defined wide band signal amenable to cyclostationary detection[x] below the ambient noise level. But even this proposal has resulted in formidable opposition. Pending successful implementation of this concept, additional SSA use elsewhere is unlikely.

But CMA systems achieve many of the same long term benefits in terms of increasing spectrum utilization probably without raising as much opposition from traditional spectrum users. Increased focus on CMA approaches would complement SSA approaches and will likely speed the introduction of cognitive radio concepts overall.

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