Operational Challenges for Emerging Cognitive Radio Technologies - Wireless Devices Utilizing TV White Spaces

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Abstract

Cognitive radios are finally emerging in the form of White Space devices capable of accessing spectral resources allocated for communication systems but not actually in use. Temporal and geographical information on existence of White Space is obtained from dedicated database through Internet access. In this paper, technological advancements enabling commercial utilization of wireless White Space devices are analyzed. However, before full scale commercial deployment is possible regulatory and techno-economical challenges exist. Here, current research and development, regulation, and standardization activities to overcome remaining obstacles are surveyed. Scientific community should turn attention to providing contributions for regulatory authorities in order to facilitate positive administrative decisions for cognitive radio technologies.

Index Terms: cognitive radio, white space, geolocation database.

I. Introduction

Cognitive radios have been under intensive study since Joseph Mitola III published his vision on context-aware and adaptive wireless device in 1999 [1]. Mitola envisioned device, which would emulate human cognition cycle – observe, orient, plan, decide/learn, and act.

There are many definitions and interpretations what the cognitive radio actually is. Currently, cognitive radio is used as a generic name for all radio technologies that provide improved and flexible spectrum utilization by analyzing the surrounding radio environment and adapting its operation based on the result.

ITU-R has given the following definition for cognitive radio, which may considered as “official” definition [2]: “Cognitive radio system (CRS): A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained.”

Driving force behind huge R&D investments to cognitive radio technologies is due to spectrum shortage. The huge growth of consumer mobile data utilization has showed that current spectrum allocations for cellular networks are inadequate.

The transition from analog TV transmissions to digital TV frees up large amounts of frequencies in VHF and UHF bands. This is also called as digital dividend. The competition for digital dividend is hard and for example mobile operators are demanding more spectral resources to provide mobile broadband services. Regulators may allow also cognitive radio technologies to access digital dividend.

Frequencies in VHF and UHF bands are very attractive from network point-of-view. Propagation properties are good, since attenuation of signal is slower than with high frequencies. This makes possible to cover large areas with small amount of base stations, which lowers network building costs.

Traditionally, frequencies are strictly regulated to guarantee that wireless communication systems do not cause interference to each other. But, frequency bands have been also allocated for unlicensed operation. For example, ISM band at 2.4 GHz frequency is used by WLAN and Bluetooth transmissions among other systems. All these systems must be able to cope with interference caused by other wireless transmissions.

Wireless systems operating in regulated frequencies can assume that other systems are not causing interference. Drawback is that the spectrum utilization is not optimal. Depending on wireless system there can be substantial temporal and geographical differences how spectral resources are utilized during communications. These locations where spectrum is un-utilized appear as white areas in system coverage maps. Therefore they are referred to as White Spaces. Another terms used in the literature are spectral holes or spectrum gaps.

TV white space (TVWS) is the unused spectrum on TV broadcasting frequencies (UHF and VHF bands) in an arbitrary location. TV White Spaces are created especially by efficient spectrum utilization of the digital broadcasting. TVWS is currently the first area that is considered for White Space devices (WSD). The reason is that due to the network planning strategies there exists relatively good amount of White Spaces. Also, TV signal and its coverage area is more stable than for many other communication systems. Wireless microphones are also operating in TVWS and they should not interfere TV signals. White Space devices have to protect both incumbents: TV and wireless microphones.

Further in this paper the term WSD is used instead of cognitive radio. The main characteristic of these devices is not in emulating human cognition cycle [1] or brain-like computing [3], but instead the flexible spectrum use in available White Spaces. The implementation of cognitive radios envisioned by Mitola and Haykin are still far in the future.

This paper concentrates on emerging technologies which may be commercially available within a few years. The aim of the paper is to survey efforts and R&D resource allocations globally aimed to provide commercial enablers for cognitive radios, and to support building trust towards regulating organizations so that devices exploiting the White Space would be granted operating licenses.

Current factors delaying the deployment of TVWS cognitive radio devices come from the uncertainty how to protect incumbents (TV, wireless microphones) in optimal way while guaranteeing maximum White Space availibility. Also, many operators are opposing as cognitive radios are seen as additional interference for their existing operating wireless systems. There might be also fear for losing profit with changed value networks.

Therefore, in this paper, current status of TVWS utilization is discussed. That includes regulation activities in Northern America and Europe, standardization activities in different organizations and current R&D challenges that are required to solve. Activities in Asia, the most notably in Japan, are also underway, but they are left for further study.

The paper is organized as follows. First, methods to access White Spaces are described in Section II. Then, design challenges for White Space databases are discussed in Section III. In Section IV, possible network deployment scenarios are given and possible applications are discussed. In sections V and VI, regulation and standardization efforts are described. Finally, summary is given.

II. Flexible spectrum use with white spaces

The prerequisite for cognitive radio system is that wireless devices are aware of surrounding radio environment. The most commonly referred means to learn about the radio environment are queries in a frequency database and spectrum sensing. The third option is utilization of dedicated beacon signal to assist sensing operation.

Sensing has been under extensive study [4, 5] and in scientific community it has been seen as primary means to implement cognitive radio technologies. Even though significant progress has been accomplished, several technical research challenges has to be solved before stand-alone sensing is reliable enough. These include for example the sensing of very low power signals and so called hidden node problem [6].

Sensing can be assisted with dedicated beacon signal, which will reveal White Space locations and available timeframes for wireless devices. However, constructing for example nation-wide network of beacons is very expensive. Other drawbacks are reserved frequency for beacon signal and possible interference caused by beacon signal to other communication systems.

Third option is geolocation database approach [7, 8]. The database contains information on terrain properties, incumbent information and regulatory protection policy for incumbents. Incumbents in TVWS are digital TV transmissions and wireless microphones used in programme making and special event (PMSE) sector. This paper focuses on database approach as regulators such as FCC and Ofcom see it as the best possibility to start commercial utilization of White Spaces in the near future.

III. Design challenges for TVWS databases

The role of White Space database is to protect incumbent systems, search for available White Space frequency for White Space devices, and possibly also control interference between them. Interference scenarios that must be taken into account are co-channel interference outside the service area of primary system, and adjacent channel interference inside and outside the service area of primary system. Database algorithms must calculate all these interference options when determining available White Space frequency band and maximum transmitting power for them. White Space databases are often called geolocation databases to emphasize the importance of geographical information in controlling the utilization of White Space spectral resources.

Accuracy and precision of database algorithms are essential in determining frequency channel and transmitting power. The closer is the database output to optimal value for given location input, the better is the White Space utilization. Optimal value means that White Space communications uses maximum allowable transmission power, where incumbent systems can still be operated normally.

If incumbent system users are over-protected, the amount of White Space diminishes rapidly. The amount of available White Space is critical factor in business decisions that will be done in industry [9, 10]. If it seems that White Space areas would be available only for very limited number of potential customers, there will not be investments in industry to produce dedicated wireless White Space devices or to implement White Space functionality in other wireless communication devices such smart phones, tablets or laptop computers.

With geolocation databases also additional information security issues must be taken into account from different point-of-view than in traditional wireless communication. This is due to the Internet access between WSD and database. Device and database must perform mutual authentication. Database has to know if device is allowed to access White Space. On the other hand, device has to which database is certified by regulatory authorities. Naturally, data transfer has to be encrypted and the integrity of geolocation data has to be secured. Database may be also a target for Denial of Service (DoS) attack. If information security fails it can cause the collapse of also the incumbent systems in addition to White Space network due to the incorrect or inaccurate information on allowed White Space areas or maximum transmitting powers.

IV. WHITE SPACE NETWORK CONFIGURATIONS

Geolocation database is accessed through Internet. On the other hand, White Space device has to obtain permission from the database to access White Space frequencies. Thus, White Space device has to be multimode radio, which can connect to database with some other communication system such as 3G or WLAN.

Another option is to build White Space network with fixed master device. Depending on service and application the master device can operate as WLAN-type access point or cellular-type base station. The master device has LAN connection to Internet, which is used to connect to geolocation database. After obtaining the list of available frequency channels, the master device forwards this information to wireless White Space devices.

In the first phase, the scenario described above seems to be probable. This opportunity has been taken into account also in development in new WLAN (see Table 1) and cellular network standards. In the more distant future it is probable that also autonomous mobile ad-hoc networks will emerge, where at least one wireless device has Internet connectivity. This device will then assume master role in the network and other wireless radios in the network will be slave devices.

It is hard to predict which will be actual applications that will eventually utilize White Space. One option, and maybe the most probable, is rural area wireless broadband access. WLAN networks could find more frequencies from White Space as ISM band at 2.4 GHz is getting congested in densely populated areas. Personal wireless networks are getting more common in homes and public areas. Cellular operators might offload heavy data traffic to White Space frequencies. Also, machine-to-machine (M2M) connections are anticipated to emerge. Business models and value networks are still evolving. Regulatory decisions will shape the business landscape, and interesting question will be, for example, which role has geolocation database operator in the value chain.

TABLE I
REGULATORY AND STANDARDIZATION ACTIVITIES FOR TVWS UTILIZATION

Organization	Group	Goal
CEPT EEC	SE43	Regulatory work for European TVWS access
ETSI	RRS	Reconfigurable radio systems and their applications for public safety
IEEE	802.22	Rural area wireless broadband (Super Wi-Fi)
IEEE	802.11af	White Space access withWLAN
IEEE	802.16h	White Space access with WiMAX
IEEE	802.19.1	Co-existence in White Space frequencies
IETF	PAWS	Protocol for Database and White Space device communication

V. STANDARDIZATION AND REGULATION ACTIVITIES

The USA has been the first the country to make a decision on the utilization of White Spaces. Federal Communications Commission (FCC) has adopted rules to allow unlicensed radio transmitters to operate in the broadcast television spectrum when that spectrum in not used by a licensed service [11]. FCC has appointed ten database operators. First nine, including Google, were selected early 2011. Microsoft was added later to the list of approved database operators. Trial period of 45 days is required for all database operators and the first such trial with Spectrum Bridge's database began 2011, September 19th. FCC is aware of possible coordination problems between different database operators but it is anticipated that the creation of new business models will be more efficient when several companies are involved.

Second country to make a decision is UK when Ofcom announced September 2011 that they will start actions to support commercial utilization of White Spaces using geolocation databases [12]. It should be noted that either FCC or Ofcom do not require sensing capability in White Space devices. Ofcom is supporting harmonized European approach, but is not willing to stop the development of new business opportunities while waiting European-wide regulatory decisions.

At European Union level, Radio Spectrum Policy Group (RSPG) operating under European Commission published in February 2011 RSPG Opinion on Cognitive Technologies [13] and results to requested consultations from stakeholders. Fig. 1 shows predicted model for Europe, which connects different stakeholders related to White Spaces utilization.

Current European regulation activity is performed by CEPT ECC group SE43 [14]. They have published the first report Technical and operational requirements for the possible operation of cognitive radio systems in the "white spaces" of the frequency band 470-790 MHz [15], which describes technical requirements for cognitive radios in Europe. But the first report contained more research questions than actual specifications. Thus, a lot of European-wide work is required before harmonized flexible spectrum utilization in White Spaces is possible.

Table 1 presents a few active regulatory and standardization organizations that are working with White Space utilization.

VI. FINNISH APPROACH

In Finland, legislation allows White Space communication in frequencies 490 MHz – 790 MHz, and Finnish Communications Regulatory Authority (FICORA) has granted a few test licenses for limited duration and limited geographical area.

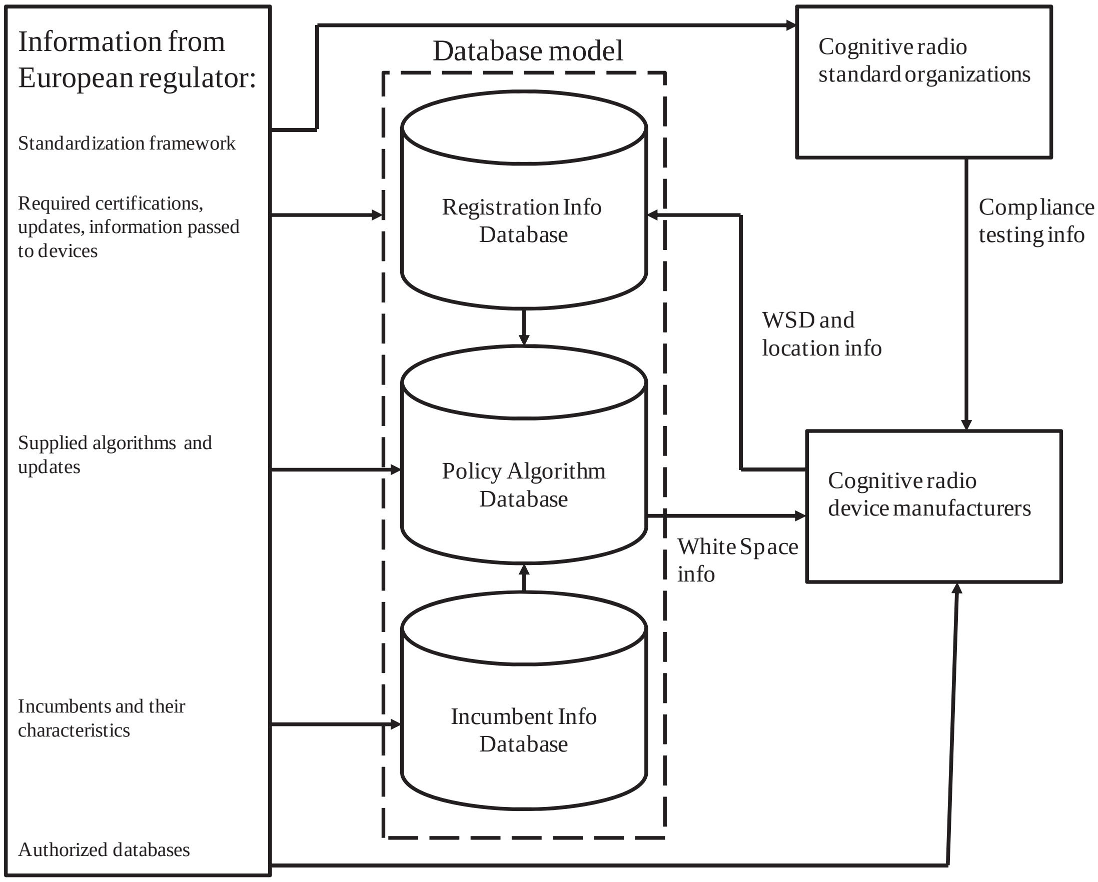

Fig. 1. European model for White Space utilization with geolocation databases. Modified from [13].

To support cognitive radio technology development Tekes (the Finnish Funding Agency for Technology and Innovation) has launched technology program *Trial Environment for Cognitive Radio and Networks 2011-2014* [16]. The aim of the program is to transform Finland into a globally attractive cluster of expertise and unique trial environment for cognitive radio and networks. Tekes is the main public funding organization for research, development and innovation in Finland.

One of the projects in Trial program is WISE [17]. The objective of the WISE project is to construct a testbed for studying the use of cognitive radios on television broadcast bands allowing practical studies of the usability, algorithms, and interfaces of cognitive radio. The operation of geolocation database will be verified using a measurement and simulation platform developed in the project. Data from the measurement and simulation platform can be utilized in studying the functional characteristics of cognitive radio devices.

VII. SUMMARY

In this survey paper, geolocation database assisted cognitive radio access to White Spaces has been described and analyzed. Current regulation and standardization activities aimed for starting up commercial operation in White Spaces have been discussed for Europe and Northern America. The time for cognitive radios has come and they are emerging in the form White Space devices utilizing geolocation databases for flexible spectrum use.

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