The effective and innovative way to use the spectrum: focus on the development of the "interleaved/white space"

1. Prologue

Flexible and collective usage of spectrum is the mainstream in the modern times. Julius Genachowski, chairman of the Federal Communications Commission, delivered the keynote address to the CTIA-Wireless Association convention on Oct. 7, 20091. He said the U.S. government has been tripling the amount of spectrum available for commercial uses. The problem is that many industry experts predict wireless traffic will increase 30 times because of online video and other bandwidth-heavy applications. Accordingly, he warned that the shortage of spectrum would be a crisis for the on-going evolution of mobile broadband communication. Therefore, it's critical for using precious spectrum effectively. Now, with the breakthrough of ICT, there is an alternative solution to this crisis: "application of interleaved/white space".

2. The cure for shortage of the spectrum

To solve the shortage and ineffective use of scarce spectrum, developed countries have innovated technology to overcome the dilemma. Accordingly, the cognitive radio (CR) network with OFDMA (Orthogonal Frequency Division Multiple Access)2 systems, namely "spectrum sensing", to use the interleaved/white space is the therapy nowadays, especially after digital switchover (DSO).

CEPT (European Conference of Postal and Telecommunications Administrations) identified "white space" as a part of the spectrum, which is available for a radio-communication application (service, system) at a given time in a given geographical area on a non-interfering / non-protected basis with regard to primary services and other services with a higher priority on a national basis. Specified clearly, the wording of "White Spots" or "White Spaces" or "Interleaved Spectrum" applied by CEPT has been used to introduce a concept of frequency spectrum which is potentially available at a given time for further utilization within frequency spectrum originally planned for broadcasting in GE063. The current CEPT view is that any new white space applications should be used on a non protected non interfering basis.

Further studies are required into the framework needed to enable the use of CR devices within white space spectrum.

Meanwhile, Millions more — both rural and urban — couldn't afford computers and internet access in the United States. Yet big telephone and cable companies won't bring broadband internet to rural America. Therefore, U.S. administration takes it seriously and considers to bridge the "digital gap" via CR networks for using white space to high-speed wireless internet access in rural area. Moreover, innovative way to use the spectrum after DSO could also satisfy the demand of band immediately with National Broadband Plan which proposed by President Barack Obama.

3. The definition and function of "white/interleaved space"

In a word, the spectrum licensed to commercial use or public safety is not always occupied totally all the time. Accordingly, some bands are vacant just like "white" or "interleaved". If communicators use these interleaved and fragmented bands temporally, the spectrum-usage will be more effective and the cost of the spectrum now we used will be much lower. Not only U.S but also UK regulator Ofcom has published a discussion document to explore the possibility of using interleaved spectrum to wirelessly link up different devices and offer enhanced broadband access in rural areas. The idea is based on the development of technology that could search for unoccupied radio waves between TV channels to transmit and receive wireless spectrum.

Take DSO in U.S. for example, when TV goes digital in June, 2009, TV broadcasters will use only a small portion of the public airwaves they are allocated.4 This is because digital transmissions can be packed into adjacent channels, while analog ones cannot. This means that the band can be "compressed" into fewer channels, while still allowing for more transmissions, which could result in a kind of "white space" (or so-called digital dividend) mentioned above.

In most rural areas, 60 to 70 percent of these digital airwaves will be vacant. It goes without saying that those bands will be idle, which will also increase the cost the spectrum-usage. However, the TV band can carry a broadband signal that penetrates buildings, travels great distances, and penetrates heavy foliage. If people could search the "spectrum hole", off course, with CR or DSA (Dynamic Spectrum Sensing), and then link up those unoccupied band for wireless communication, the compelling needs of spectrum will be eased. Most important of all, this innovative way fits the trend of collective and flexible spectrum usage in 3G/4G era.

4. The key to open "white space"

Undoubtedly, the WSD (White Space Devices) is the key to open the new gate. FCC issues some R&O to test WSD for welcoming white space. On October 5, 2007, OET (the Office of Engineering and Technology) of FCC issued a public notice inviting submittal of additional prototype devices for further tests (Phase II). On February 24, 2010, OET selected Wilmington, North Carolina, for the test market for the DTV transition, and unveiled a new municipal Wi-Fi network, after a month of testing. OET permitted that TV Band has an 18-month experimental license.5

For the goal of "smart city", the network has used the white space made available by the end of analog TV transmission. Spectrum Bridge (a famous company devoted to working out WSD and solution to white space)6 has worked to make sure TV stations in the market do not receive interference (no interference issues have been reported), and the company hopes to do the same if similar service becomes nationwide. The "smart city" network will not compete with cell phone companies but will instead be used for "national purposes", including government and energy monitoring (i.e. Smart Grid). TV Band Network, made up of private investors, has put up cameras in parks, and along highways to show traffic. Other uses include water level and quality, turning off lights in ball parks, and public Wi-Fi in certain areas.7 This success has promptly encouraged those have eyed unlicensed band/devices for wireless broadband internet access, especially the White Spaces Coalition8.

The White Spaces Coalition consists of eight large technology companies that originally planned to deliver high speed broadband internet access beginning in June 2009 to United States consumers via existing white space in unused television frequencies between 54-698 MHz (TV Channels 2-51). The coalition expects speeds of 80 Mbps and above, and 400 to 800 Mbps for white space short-range networking9.

Therefore, the Coalition hasn't only pushed FCC to free up the band, namely unlicensed-band approach, but also eagerly innovated the WSD and advanced IT technology (i.e. Geo-Location, CR, DSA, OFDMA and IEEE 802.2210 …etc.) to promote the awareness of white space.

5. How to use the key to unlock the door ?

First of all, Geo-Location technology is the threshold to use the white space. Geo-Location is the identification of the real-world geographic location of Internet-connected computers, mobile devices, website visitors or others. In avoidance of band-interference and public safety communication, users mustn't interfere with the prior ones, or s/he couldn't access the band via WSD. Thus, Geo-Location can assist WSD users, just like a beacon, to avoid the occupied band and keep them away from nearby transmissions.

Second, a spectrum database that contains Geo-Location information about devices using the free channels in the radio spectrum and some strong database managers are needed. Frankly speaking, the original idea was that WSD would detect existing users and switch frequencies to avoid them, but that's technically dubious and hasn't been demonstrated to FCC's satisfaction. So the proposed solution requires devices to locate themselves then connect to a database which will allocate a frequency along with a timeout, after which the device will have to repeat its request. For example, the followings are the necessary information in the TV database.

• Transmitter coordinates (latitude and longitude),
• Effective radiated power (ERP),
• Height above average terrain of the transmitter (HAAT),
• Horizontal transmit antenna pattern (if the antenna is directional),
• channel number,
• Station call sign.

In a word, in order to protect existing broadcasters, FCC mandated the creation of a Geo-Location database that details what spectrum is in use and where. Furthermore, the idea is that unlicensed broadband devices will tap this database before sending or receiving data, using the info in tandem with spectrum sensing technologies to avoid interference. Accordingly, White Spaces Database (WSDB) was introduced, a DB which would permit public access to register and discover devices and the frequencies used based on their location11. This database would be used in conjunction with local device discovery to avoid contention between devices. FCC has worried about that no one has ever run a radio system like this, so no one can really claim experience in the area (though most of the proposals try).

The FCC commissioner Robert McDowell has raised an eyebrow at Google's request to serve as an administrator of a national database detailing the use of white-space spectrum. Google proposes the operation of a WSDB for at least five years, promising to "transfer to a successor entity the Database, the IP addresses and URLs used to access the Database, and the list of registered Fixed WSD" in case they cannot live up to it. Google does not plan to "implement per-query fees"12 , but they are considering a per-device fee. No decision has been made yet, but the FCC allows a WSDB administrator to charge such fees.13

Finally but innovating initially, it's the Cognitive Radio system (CR). There are various definitions of CR. Herewith the paragraph 10 of the FCC 03-322 NPRM, the definition of Cognitive Radio could be specified as a radio that can change its transmitter parameters based on interaction with the environment in which it operates.

The following figure shows how the Cognitive Radio System does work.

Figure 1.Cognitive Radio System

Let's explain it more clearly and vividly. Imagine a radio which autonomously detects and exploits empty spectrum to increase your file transfer rate. Suppose this same radio could remember the locations where your calls tend to drop and arrange for your call to be serviced by a different carrier for those locations. These are some of the ideas motivating the development of cognitive radio. In effect, a cognitive radio is a software radio whose control processes leverage situational knowledge and intelligent processing to work towards achieving some goal related to the needs of the user, application, and network.

Although cognitive radio was initially thought of as a software-defined radio extension (Full Cognitive Radio), most of the research work is currently focusing on Spectrum Sensing Cognitive Radio. In other words, the focus on CR has been switched into "DSA" (Dynamic Spectrum Access) nowadays.14 Therefore, some fellows replace Cognitive Radio with "Cognitive Systems" for accurate description.15 The following is the figure to show the function of DSA to detect "spectrum hole" that could be used as TV white space.16

Figure 2.The sensing of the spectrum hole

"Digital dividend", one kind of interleaved/white space, has been viewed as precious band in Unite Kingdom, too. In U.K., its regulatory body, Ofcom, has also published a discussion document to explore the possibility of using these "dividend" to wirelessly link up different devices and offer enhanced broadband access in rural areas. Ofcom has predicted that could enable the use of the spectrum in this way would take at least three years to develop. Possible applications include mobile broadband, the transmission of home media such as photos from cameras to a computer wirelessly and the ability to control appliances in the home. Moreover, Ofcom firmly contended that if there was evidence that interference could be avoided, it would allow the use of interleaved spectrum without the need for individual licenses, the same as the FCC's policy.

However, local TV coalition United for Local Television (ULTV)17 has strongly criticized the Ofcom's current proposal to appoint a band manager to "control" interleaved spectrum (and make it available to applications such as wireless microphones for special events) and to ensure that the spectrum is made available to local TV groups on fair, reasonable and non-discriminatory terms. According to current proposals, Ofcom's "band manager" would be required to allocate spectrum to special event organizers on fair and non-discriminatory terms but not to local TV groups. ULTV has protested this unfair condition. In contrast, FCC has clearly issued the "2nd report" to mandate the bidder of upper 700 MHz D block should apply to fair and non-discriminatory terms.

6. Technological challenges for accessing white space

In November 2008 the FCC issued an R&O on the unlicensed use of TV white space.18 The FCC regulated some vital requirements to rule

the usage of TVWS in this document. These requirements impose technical challenges for the design of devices operating in TV white space spectrum, which brings new tough task for the innovation and production of WSD.19

These new rules provide an opportunity but they also introduce a number of technical challenges. The challenges require development of cognitive radio technologies like spectrum sensing as well as new wireless PHY and MAC layer designs. For example, the development of spectrum sensing techniques involves RF (Radio Frequency) design, robust signal processing, pattern recognition and networking protocols… etc.

The choice of RF architecture is no longer merely a hardware issue, but will directly affect the upper layer performance. Furthermore, these challenges include spectrum sensing of both TV signals and wireless microphone ones, frequency agile operation, geo-location, stringent spectral mask requirements, and of course the ability to provide reliable service in unlicensed and dynamically changing spectrum.20

In addition, the FCC has strict out-of-band emission (OOBE) requirements to prevent interference with licensed transmissions in other channels. A detailed description of these out-of-band emission requirements and their impact on the transmission spectral mask for WSD is provided in Section VII of the R&O.

Unfortunately, there are still other hurdles to be overcome. While the frequencies used by television stations do have a long reach and easily penetrate walls, it is important to remember that these signals are one-way communications, often broadcast from giant antennas at megawatts of power. For gadgets and computers, a much lower transmission power would be used, greatly decreasing the range of the White Space devices. So are we talking the Wi-Fi-like ranges here or 3G-like ranges? The National Association of Broadcasters has also questioned the ability of WSD to operate without interfering with television broadcasts. In addition, wireless microphones could be affected, although Google has proposed a "beacon" that could be utilized alongside existing wireless microphone equipment that would alert WSD not to operate on the same channel.

Last but not least, how to ensure QoS of WSD users is implicit trouble. The Cognitive Radio system should provide that fast, robust, coordinated sensing and quite periods and to protect incumbents as well as provide QoS. It will be a dilemma faced by the regulatory bodies and ICT industry. Another real-world problem is that there are no WSD for consumers and even if someone comes out with a new product, it will likely be very expensive since it isn't widely produced,21 although Spectrum Bridge has proven one example mentioned above.

Nevertheless, some people still criticized what Spectrum Bridge has done probably could have used 5 GHz for the point-to-point backhaul connections. "The Smart City" is using Wi-Fi for the last mile rather than white spaces because there are no white space devices on the consumer end. Rick Rotondo, chief marketing officer for Spectrum Bridge argued Spectrum Bridge tried using Wi-Fi at 2.4GHz, 5GHz would never have made it; 2.4 didn't make it. However, Spectrum Bridge did use Wi-Fi for the last hundred feet, not the last mile, but for the last hundred feet because there are Wi-Fi receivers built into laptops and smartphones and that's who we wanted to be able to connect to this network. It sounds like a tautology.

7. What's beyond the white space ?

What kind of ICT could people apply to after getting the white/interleaved space? "Super Wi-Fi" is the first application connected with white space. As Larry Page, co-founder of Google, has described that white spaces are like "Wi-Fi on steroids" linked up wireless internet with much faster speeds, stronger signals and more affordable costs. Besides, there are other advanced ICT could function via white space, such as LTE, IPTV, MediaFLO, DVB-H, ISDB-T, MVNO, ITS (DSRC) and so on.

8. Vision: Legal challenges for accessing white space in Taiwan

Although not mentioned above, FCC indeed allows the secondary-market of spectrum boosting in U.S. That's an important reason, or motivation, to develop white space applications and regulations. In other words, the spectrum, not the license, could be auctioned, leased, retailed, weaved and so on. However, the regulatory mode of communication in Taiwan is "Vertical Regulatory Framework", which would be an obstacle to evolve the spectrum-usage in contrast to U.S and EU.

Under the interpretation of Legal Positivism, Taiwan Budget Act Article 94 states, "Unless otherwise provided for by law, grant of quota, frequency, or other limited or fixed amount special licenses shall be conducted by open auction or public invitation to tender and the proceeds of which shall be turned in to the national treasury." Hereby, the administration could really fulfill the legal assignment via public invitation to tender or auction for the "license", not the band. Nevertheless, the administration does not apply auction process to issue the licenses, but approaches the frequency licenses with "Radio and Television Act" and "Administrative Regulations on Radio Waves" which is promulgated under the Telecommunications Act in accordance with the first paragraph of 48, Section 1 of said Act instead.

Step closely, Radio and Television Act Article 4 firmly states, "The frequencies used by radio/television businesses are owned by the state and their allocation shall be planned by the MOTC in conjunction with the regulatory agency. The frequencies mentioned in the preceding paragraph **may not be leased, loaned, or transferred**. (emphasis added)". This article has resulted in inflexible use of spectrum, and dragged the collective use of spectrum, too. Undoubtedly, only we have to do is to amend the article for accessing white space in accordance with Legal Positivism.

Second, according to Administrative Regulations on Radio Waves, the National Communications Commission shall be responsible for the overall coordination and regulation of radio waves including radio frequencies, power, emission method and radio station identification call sign etc., which shall not be used or altered without approval. Thus, under the justice of legal system, NCC should revise the spectrum policy/regulations in harmony with Administrative Regulations on Radio Waves. For example, the Article 6 and 10 separately regulates, "**The radio equipment shall adopt the latest technical advances** to limit the number of frequencies and the frequency bandwidth used to the minimum essential for the necessary services. The frequency assigned to a station of a given service shall be separated from the limits of the band allocated to this service in such a way that, taking account of the frequency band assigned to a station, **no harmful interference is caused to services to which frequency bands immediately adjoining are allocated**." Therefore, WSD indeed, even necessarily, should be applied to band management and revolution of ICT industry.

Moreover, Central Regulation Standard Act Article 5 (embodied the principle of constitutional requirement of a specific enactment) also requires, "The following objects shall be stipulated by a statute: 1. It is required to stipulate by a statute as the Constitution or a statue expressly stipulated. 2. Stipulation concerns the rights or obligations of the people. 3. Stipulation concerns the organization of a government agency at national level. 4. Other objects with substantial importance shall be stipulated by a statute." The Legislative Yuan must consider to promote the status of Administrative Regulations on Radio Waves to Statue, which conforms to Constitutional requirement.

To sum up, Taiwan administration should take white space seriously, or ICT in Taiwan will be doomed as if getting lost in "space".

9. ad hoc Conclusion :Do not lock the door of white space

"Open access" is the most important canon in the usage of white space. In this meaning, there are two dimensions for open access. One is unlicensed band-usage, the other is unlicensed WSD which is also unlicensed and interlocks into different operators' networks. The later is a big task in America. FCC's decision was contested by the TV broadcasters who fear using the freed channels would interfered with TV signals and live singers who are using the same wave spaces.22 Larry Page also argued that unlicensed white spaces offer a way for the U.S. to catch up with the rest of the world in broadband access. Today, 10% of Americans still don't have access to DSL or cable broadband, according to consultancy Parks Associates.

Fortunately, the first steps towards white space communications have already been taken and FCC has approved unlicensed use of the spectrum, but FCC requires a database of all known licensed users to be deployed in order to prevent from interfering with the existing broadcasts and devices already using the space, such as licensed TV broadcasts and some wireless microphones

The second dimension is unlicensed WSD to compatible different network architecture. At first, the unlicensed devices must fit the criterion which could guarantee that they will not interfere with assigned broadcasts can use the empty white spaces in frequency spectrum. In order not to harm nearby transmission, the best way is to set a standard for WSD in one network built by certain operator. For example, if WSD users want to connect to Verizon Wireless' network, s/he has to buy/use Verizon Wireless' WSD. However, out of Verizon Wireless' network, WSD users have to purchase/use another WSD. It will be inconvenient and raise the cost, but quench people's desire to use WSD. As a result, FCC issued the R&O to prevent devices-locked, so-called "discriminatory QoS", from deploying the white space proposal. Accordingly, the mandatory rule indeed slows down the innovation of WSD.

Obviously, unlicensed use of the vacant TV channels is an economic and social revival waiting to happen in rural areas. In addition, white/interleaved space will manage to fit the core principle of modern spectrum-development, "collective and effective use". There are so many merits to share the "dividend", but at this time, we are still far away the real "white space". The situation in Taiwan is much worse unfortunately.

1.See FCC official document,http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-293891A1.pdf (last visited 03/05/2010)

2.OFDMA is a multi-user version of the popular Orthogonal frequency-division multiplexing (OFDM) digital modulation scheme. Multiple access is achieved in OFDMA by assigning subsets of subcarriers to individual users. This allows simultaneous low data rate transmission from several users.

3.See Final Acts of the Regional Radio-communication Conference for planning of the digital terrestrial broadcasting service in parts of Regions 1 and 3, in the frequency bands 174-230 MHz and 470-862 MHz (RRC-06).

4.In the United States, the abandoned television frequencies are primarily in the upper UHF "700-megahertz" band, covering TV channels 52 to 69 (698 to 806 MHz).

5.See http://spectrumbridge.com/web/images/pdfs/smart_city-spectrumbridge.pdf visited on 2010/2/27.

6.http://spectrumbridge.com/web/

7.See http://showmywhitespace.com/portals/1/Spectrum%20Bridge%20Launches%20White%20Spaces%20Network%20In%20Wilmington-New%20Hanover%20County.pdf visited on 2010/2/27.

8.The group includes Microsoft, Google, Dell, HP, Intel, Philips, Earthlink, and Samsung Electro-Mechanics.

10.The standardization is another crucial issue but will not be discussed in detail hereunder.

11.In February 2009, Google joined Comsearch, Dell, HP, Microsoft, Motorola, and Neustar to form the White Spaces Database Working Group (WSDG), an effort to build such a database..

12.Actually, the database host will know where users are and the kit they're using, both of which are commercially valuable pieces of information. Google thinks that data will pay for the database, and Google is very good at extracting value from information; but even if it can't turn white space into gold, it will have five years to drive the competition out of business.

13.See generally Google's proposal to FCC, http://www.scribd.com/doc/24784912/01-04-10-Google-White-Spaces-Database-Proposal visited on 2010/2/28.

14.Specifying clearly, the main mechanism of CR is including, but not limited to DSA.

15.Evolution of Cognitive Radio toward Cognitive Networks is under process, in which Cognitive Wireless Mesh Network (i.e. Cog-Mesh) is considered as one of the enabling candidates aiming at realizing this paradigm change.

16.Test conducted in the rural sector west of Ottawa, Canada. See C. R. Stevenson, G. Chouinard, W. Caldwell,Tutorial on the P802.22.2 PAR for :"Recommended Practice for the Installation and Deployment of IEEE 802.22 Systems," IEEE802, San Diego, CA, 7/17/06 http://grouper.ieee.org/groups/802/802_tutorials/july06/Rec-Practice_802.22_Tutorial.ppt.

17.United for Local Television ("ULTV") is a coalition of groups and campaigners who together lobby the government to recognize local TV as a public service. ULTV argues that all citizens should have access to local TV, no matter where they live, without having to subscribe to pay-TV or broadband. ULTV proposes that the government reserve capacity for local TV services on the most popular television platform in the UK today – digital terrestrial television (commonly known as "Freeview"). ULTV anticipates that local TV channels will provide local news and sport,

together with a range of other local and networked programming. ULTV envisages local TV services would also provide local advertising, for the first time offering a cost-effective option for many local businesses seeking to advertise on terrestrial TV in their target market.

18.See Second Report and Order and Memorandum Opinion and Order In the Matter of Unlicensed Operation in the TV Broadcast Bands, Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band, Federal Communication Commission, Document 08-260, Nov. 14, 2008.

19.In detail, the FCC distinguished fixed WSD from portable one. There are different restrictions and requirements between them.

20.See http://ita.ucsd.edu/workshop/09/files/paper/paper_1500.pdf visited on 2010/2/20.

21.See http://www.digitalmediabuzz.com/2010/03/broadband-debate-white-space/ visited on 2010/3/17.

22.See http://lasarletter.net/docs/nabpet4review.pdf visited on 2010/2/25.

Release : 2013/04

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