TV White Spaces

Unlicensed Access Spectrum in Sub-700 MHz Band

WHITE PAPER

INTRODUCTION

The transition from analog to digital TV transmission has brought about important developments in a prime band of spectrum spanning from 54 MHz to 806 MHz. First, 108 MHz of spectrum in the 700 MHz band has become available for mobility services among other applications[1]. Second, the compactness of digital TV signals and fragmented broadcast band plan have made fairly large amounts of 'white spaces' available.

White spaces refer to frequencies in the sub 700 MHz range that are available for use on an unlicensed basis. The band between 54 MHz and 698 MHz is reserved for TV broadcasting as shown in Figure 1, but also includes other unlicensed applications for low power devices such as wireless microphones used in permanent locations or for temporary events[2]. To limit adjacent channel interference between TV channels, the bandplan contains 'white spaces,' frequencies where no transmission is allowed to protect the integrity of TV signals.

The FCC ruling[3] to make these bands available for unlicensed use has opened a new and very promising market for broadband wireless services and products. This is because these frequencies have good non-line of sight propagation characteristics as well as low industrial noise and reasonable antenna sizes for fixed and nomadic broadband applications. Moreover, although the amount of unused spectrum varies from area to area, large amounts of white spaces are available outside the metropolitan centers because there are fewer TV stations. Table 1 shows a sample of cities and townships in the United States and the corresponding amount of available white spaces: large amounts of spectrum (100 MHz) are available in many medium and relatively large cities (between 1-2 million inhabitants), while small cities and townships (a few hundred thousand inhabitants) have around 150 MHz available and rural areas feature yet higher amount of available spectrum.

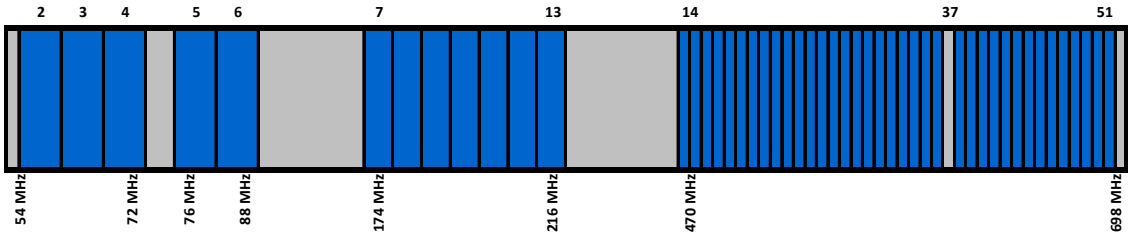

FIGURE 1 BROADCAST DIGITAL TV AND WHITE SPACE CHANNELS.

White space has generated significant interest from different companies, not the least of which are telecom equipment vendors who see a new potential to deliver products to these market segments:

1- Wireless Internet Service Providers (WISPs): service providers' business centers on providing DSL-type connectivity in rural areas. Thousands of such entities exist in the United States. White spaces provide

[1] The band between 698 MHz – 806 MHz, traditionally allocated to TV channels 52-69 is now divided into a 'lower 700 MHz band' from 698 MHz – 746 MHz which comprises three 2x6 MHz paired channels (A,B,C) and two unpaired channels (D,E). The 'upper 700 MHz band' from 746 MHz – 806 MHz includes bands C (2 x 11 MHz) and D (2 x 5 MHz; band associated with Public/Private Partnership), two guard bands (A, B; each 2x 1 MHz) and a paired band (2 x 12 MHz) designated for public safety use.

[2] There are 13 metropolitan markets where Commercial Public Land Mobile Service is operational on one to three channels in the range of channels 14-20. Medical telemetry equipment is allowed to operate in on unlicensed basis on any vacant TV channels in the range of channels 7-46. Unlicensed remote control devices are allowed to operate on any TV channel above 70 MHz except channel 37 which is allocated for radio astronomy and wireless medical telemetry service.

[3] U.S. FCC, ET Docket 08-260, "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," Nov. 14, 2008.

access to 'clean' unlicensed spectrum unlike current bands in 2.4 GHz (which is considered highly 'polluted' due to WiFi access points) and 5.8 GHz.

2- Enterprises: including manufacturing plants, warehouses, and industrial installations as well as electric, oil & gas and water utilities. Enterprises can own their independent networks for different applications that include internet access & email (DSL-type services) as well as video surveillance and security.

3- State and local governments: including school boards and educational institutions, municipalities and other local governing entities, many of which rely today on unlicensed products in the 2.4 GHz and 5.8 GHz bands.

White Spaces have been dubbed as 'WhiteFi' as they promise longer range in a cleaner spectrum than WiFi (which is based on IEEE 802.11 standard). The unique requirements for unlicensed products in this band have opened the door for implementation of dynamic spectrum access algorithms and cognitive radio concepts. The IEEE has designated the 802.22 task group with standardizing equipment for use in white spaces, although the FCC does not mandate a standard.

TABLE 1 AVAILABLE WHITE SPACE SPECTRUM FOR SELECT UNITED STATES CITIES AND TOWNS.

Location	Population*	Total Available Channels	Total Available Spectrum (MHz)	Channels For Portable Devices	Spectrum for Portable Use (MHz)
New York, NY	19,006,798	2	12	1	6
Los Angeles, CA	17,786,419	0	0	0	0
Chicago, IL	9,785,747	10	60	4	24
Boston, MA	7,514,759	9	54	5	30
Philadelphia, PA	6,385,461	7	42	3	18
Dallas, TX	6,300,006	4	24	0	0
Houston, TX	5,728,143	7	42	1	6
Miami, FL	5,413,212	2	12	0	0
Washington, DC	5,300,000	5	30	1	6
San Francisco, CA	4,203,898	5	30	2	12
Seattle, WA	3,344,813	18	108	10	60
Denver, CO	2,506,626	6	36	4	24
Pittsburgh, PA	2,462,571	13	78	8	48
Cleveland, OH	2,250,871	20	120	12	72
Kansas City, MO	2,053,928	27	162	13	78
Knoxville, TN	1,029,155	21	126	12	72
Grand Rapids, MI	776,833	28	168	20	120
Boise, ID	587,689	16	96	10	60
Eugene, OR	343,140	20	120	12	72
Evansville, ID	342,815	21	126	12	72
Amarillo, TX	226,522	12	72	9	54
Bangor, ME	148,000	25	150	15	90
Alexandria, LA	145,035	31	186	19	114
Sioux City, IA	143,157	25	150	14	84
Casper, WY	66,533	26	156	18	108
Great Falls, MT	56,690	29	174	16	96
Fairmont, WV	19,024	28	168	22	132
Alliance, NE	8,959	43	258	28	168

* Population of metropolitan area or combined statistical area (CSA) if defined for particular location.

FCC Requirements and Characteristics of White Spaces

This spectrum between 54 MHz and 698 MHz is divided into 5 sub-bands: 54-60 MHz, 76-88 MHz, 174-216 MHz, 470-608 MHz, and 614-698 MHz. It comprises traditional TV channels 2-13 (VHF) and 14-51 (UHF). Each broadcast TV channel is 6 MHz in width.

The FCC allows two classes of unlicensed devices to operate in white spaces: fixed devices and personal/portable devices. Each has certain characteristics and requirements which are detailed below. For all device types, the FCC will closely test for certification and monitor the introduction of systems for this market.

It is required that devices operating in unlicensed white spaces not interfere with existing broadcast TV and other unlicensed devices. Therefore, white space devices must detect existing broadcasts and not operate within 6 MHz of incumbent users. To control interference to existing incumbent licensed users, the FCC has mandated that a database will be the controlling mechanism for interference with broadcast TV[4]. This requires the implementation of geo-location capabilities whereby devices need to determine their location and match that against the database for incumbent licensed user transmitter location, power and channel assignment. Spectrum sensing capabilities are mandatory as well for fixed and portable devices as a further means to protect against interference to wireless microphones and further protection for broadcast TV.

To protect unlicensed wireless devices such as microphones, the FCC has limited the operation of personal/portable devices to channels in the range 21-51. Only fixed systems can operate in channels 2-20.

Operation of Fixed Devices

Fixed devices can operate on any channel between 2 and 51 except channels 3, 4, and 37 and are allowed to communicate with other fixed and personal/portable devices. The allowed transmit power is up 4W EiRP with 1W maximum transmitter output power. It is mandated that antennas for fixed devices be mounted outdoors. All fixed devices must implement a power control feature to limit interference to broadcast TV and other devices.

Fixed devices are mandated to register their location with the FCC and must transmit identifying information. Spectrum sensing of signals as low as -114 dBm is required.

Portable/Personal Devices

Portable devices can operate on any channel between 21 and 51 except channel 37. This is intended to control interference to wireless microphones[5]. They are allowed to communicate with fixed devices and with other fixed and/or portable devices in two modes: a) client mode, where a portable device is controlled by a fixed device or another portable device that operates in an independent mode; and b) independent mode, where a portable device has determined channel availability using its own geo-location and database access capabilities in which case it is allowed to control other portable devices.

Portable/personal devices are allowed to transmit up to 100 mW EiRP except when operating in an adjacent channel, where they are limited to 40 mW. Power control is mandatory.

Portable/personal devices are not required to register with the FCC database.

[4] Devices that do not support the geo-location and database access capability may still get certified by the FCC but it involves a more stringent testing and certification process and are limited in transmit power (50 mW EiRP)

[5] Wireless microphone locations can also be registered in the national database to receive protection similar to broadcast TV.

THE BUSINESS CASE FOR WHITE SPACES

The business case for white spaces center on the following premises:

1- Unlicensed use of spectrum: this opens the door for a number of different applications by different types of entities that include private enterprises, service providers and state and local government agencies as outlines.
2- Amount of available spectrum: as stated, it is estimated that up to 25 channels (150 MHz) is available in rural areas and 10 channels (60 MHz) is available in suburban areas. This compares favorably with about 80 MHz available in the 2.4 GHz ISM band for WiFi use. Furthermore, this spectrum is relatively 'clean' when compared to the congested 2.4 GHz and 5.8 GHz bands.
3- Good propagation characteristics: the coverage range for white space frequencies is large due to lower propagation loss than in 2.4 GHz and 5.8 GHz bands. This is particularly attractive in rural areas where subscriber density is low. Therefore, a better return on investment can be generated by wireless service providers who intend to use white spaces for commercial applications.

To illustrate the improvement in coverage over existing unlicensed band systems, Table 2 shows the range and number of cells required to build a 100 square kilometer market for non-line-of-sight coverage (as is the case for a Wireless Internet Service Provider). It is demonstrated that 4 and 12 times less sites are required in 700 MHz than in 2.4 and 5.8 GHz.

TABLE 2 COVERAGE PERFORMANCE FOR DIFFERENT UNLICENSED SPECTRUM BANDS.

Frequency of Operation (MHz)	698	2,400	5,800
Cell Radius (m)	1,989	955	565
Path Loss at 4,380 m (dB)	130	144	154
Site Count for 100 km^2 Market	10	43	121
Relative Site Count	1.0	4.3	12.1

Assumes a maximum allowable path loss of 130 dB typical for a potable broadband wireless system device. Cell radius was calculated using the Erceg Type B model with 30 m base station height and 2 m subscriber station height. Added 6.5 dB for 75% contour confidence interval resulting in 90% area confidence interval. Path loss dependency on frequency is $20 \times \log_{10}(f) + 6 \times \log_{10}(f/1900)$. The latter term is a correction factor to account for the fact that the model parameters were based on measurements taken at 1900 MHz. Hexagonal cells are assumed for cell count calculations.

IEEE 802.22 STANDARD FOR WIRELESS REGIONAL AREA NETWORKS (WRAN)

The IEEE 802.22 has undertaken the task of writing a standard for wireless devices operating in white spaces. The standard implements cognitive radio techniques to enable dynamic spectrum access in compliance with the rules and regulations the FCC has set for operation in this band. Cognitive radio observes its environment (i.e. spectrum sensing/interference detection) and adjusts its transmission behavior (e.g. frequency of operation, power) to accommodate its environment. Dynamic spectrum access implies the ability to access unused parts of the spectrum by other systems on a time and frequency basis. Television white spaces are considered 'frequency white space' since they are available for particular frequencies in certain geographic areas as determined by TV broadcasts. However, 'time white space' is also relevant to avoid other applications such as wireless microphones that can start transmitting at any time.

The IEEE 802.22 implements two techniques for spectral awareness: geo-location and spectral sensing. Geo-location entails knowledge of the geographic coordinates of the unlicensed white space device (WSD) and access to a database of licensed users and available channels for unlicensed use. Spectral sensing entails monitoring the spectrum and identifying existing channels occupied by licensed users.

The IEEE 802.22 focuses on providing wireless broadband access in rural areas for a distance up to 30 km from the base station with extension of service to a distance up to 100 km. The throughput targets for cell edge are 1.5 Mbps in the downlink (base station to CPE) and 384 kbps in the uplink (CPE to base station). While currently the standard focuses on 54-862 MHz band, there is a plan to extend the operation range to 41-910 MHz to accommodate additional international regulatory requirements.

The 802.22 standard, as in other IEEE 802 standards, details the physical and medium access control layers. The physical layer is based on carrier orthogonal frequency-division multiple access (OFDMA) with 2048 carriers to provide reliable non-line-of-sight operation. Time division duplex (TDD) is the main mode of access with future provisions for frequency division duplex (FDD). The channel bandwidth is 6, 7, and 8 MHz. Multiple-input multiple-output (MIMO) or beamforming techniques are not supported in 802.22 because of the relatively large antenna size at these frequency bands[6].

TABLE 3 IEEE 802.22 ACCESS INTERFACE KEY PARAMETERS.

Air Interface	OFDMA
Number of Carriers	2048
Channel Bandwidth (MHz)	6, 7, 8; according to regulatory domain
Cyclic Prefix	1/4, 1/8, 1/16, and 1/32
Access Mode	TDD
Sub-channels per Symbol	60
Sub-carriers per Sub-channel	28; 24 data sub-carriers, 4 pilot sub-carriers
Frame Size (msec)	10
Burst Allocation	Linear (downlink bursts are allocated progressively across sub-channels in the frequency Domain, no time diversity due to slow fading channel)
Modulation	QPSK, 16 QAM, 64 QAM
Coding Rates (Data)	1/2, 2/3, 3/4, 5/6 (for each modulation)
Coding Type	Mandatory: Convolutional coding Optional: Convolutional turbo code (CTC), shortened block turbo codes (SBTC), and low density parity check (LDPC) codes

TABLE 4 IEEE 802.22 MODULATION AND DATA RATES.

PHY Mode	Modulation	Coding Rate	Peak Data Rate in 6 MHz (Mbps)	Spectral Efficiency
1*	BPSK	Uncoded	4.54	0.76
2**	QPSK	1/2; repeat 3	1.51	0.25
3	QPSK	1/2	4.54	0.76
4	QPSK	2/3	6.05	1.01
5	QPSK	3/4	6.81	1.13
6	QPSK	5/6	7.56	1.26
7	16-QAM	1/2	9.08	1.51

[6] Furthermore, the main application for 802.22 is for outdoor CPE at 10 m height, which in a rural area, implies limited multipath characteristics of the transmission channel which limits the effectiveness of spatial multiplexing MIMO techniques.

8	16-QAM	2/3	12.10	2.02
9	16-QAM	3/4	13.61	2.27
10	16-QAM	5/6	15.13	2.52
11	64-QAM	1/2	13.61	2.27
12	64-QAM	2/3	18.15	3.03
13	64-QAM	3/4	20.42	3.40
14	64-QAM	5/6	22.69	3.78

* Applies to CDMA ranging and bandwidth requests.

** Applies to coexistence beacon protocol.

The MAC layer implements several mechanisms for avoiding interference to existing incumbent license users and for coexistence among 802.22 devices. One of these mechanisms is coexistence beacon protocol (CBP) which sends a packet at the end of some frames with information to facilitate network discovery, coordination and spectrum sharing.

Another mechanism is a quiet period where the base station and CPEs cease transmission to sense the spectrum for existing transmitters. Two types of sensing are defined:

1- Fast sensing: a fast algorithm (under 1 msec per channel) is used to detect electromagnetic energy.
2- Fine sensing: if energy above threshold is determined in the fast sensing stage, fine sensing is employed for each single frequency channel to look for particular signatures of transmitted signals. The fine sensing algorithms can take up to a few milliseconds to execute.

Spectrum sensing is performed at both the base station and CPE using a 0 dBi omni-directional antenna mounted at a height of 10 m.

Satellite-based geo-location technology (e.g. GPS) is used to determine location of unlicensed devices. Access to a database of incumbent licensees that includes both broadcast TV as well as other registered device locations is searched to avoid transmission on occupied channels. A CPE must locate its coordinates before it associates with a base station. Operating parameters of CPEs such as antenna patterns, EiRP, location (latitude and longitude), and height are reported to the incumbent database to generate a list of available frequencies and EiRPs at which the CPEs can operate without interference.

CONCLUSIONS

The transition from analog to digital TV broadcasting has freed up new frequency bands. White spaces are available in the sub 700 MHz band for broadband wireless access and backhaul applications on an unlicensed basis. White space devices have to comply with strict FCC requirements to prevent interference with incumbent TV broadcasters and other users of TV band frequencies. This is accomplished by a number of safeguards that include geo-location awareness and access to a database to determine WSD frequency of operation. Cognitive radio techniques that apply to spectrum sensing are also mandated to further safeguard against interference. White spaces provide a good business case for different type of applications because of good propagation characteristics in the sub-700 MHz frequency band. The IEEE 802.22 is in the process of developing a standard based on cognitive radio techniques and dynamic spectrum access to speed up the commercialization of white space devices and spectrum.

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