TV Whitespaces: Promises and Actions

Using the Thunder SDR Waveform Development Platform to Develop a Flexible TV Whitespaces Test Bed

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Point of Contact:

Amy Corman
SDR Business Developer
DataSoft Corporation
1275 W. Washington St., Suite 106
Tempe, AZ 85281
Phone: (480) 763-5777 x447
email: amy.corman@datasoft.com

1 Executive Summary

TV Whitespaces are the unused TV broadcast channels made available by the recent transition from analog to digital TV in June 2009. On November 4, 2008, in anticipation of the digital TV transition, the FCC adopted rules to allow unlicensed new, sophisticated wireless devices to operate in the broadcast television spectrum on a secondary basis at locations where that spectrum is open ("TV Whitespaces"). This action will make a significant amount of spectrum with very desirable propagation characteristics available for new and innovative products and services, including broadband data and other services for businesses and consumers. [1] It also allows the public to use spectrum that would otherwise be inefficiently used or entirely unoccupied. A clarification of the rules and reconsideration of petitions regarding the TV Whitespaces use was issued by the FCC on September 23, 2010. This set of rules clarified questions regarding sensing of spectrum and protection of wireless microphones left open with the November 2008 ruling. [2]

The white space devices (WSDs) present new opportunities for consumers to efficiently use currently unused and underutilized spectrum. In this way, America's technology sector will have new avenues to promote ubiquitous, more affordable broadband deployment – particularly in underserved rural areas – as well as stimulate new innovations in consumer products, services, and applications. With the growing use of Wi-Fi and other unlicensed devices in everything from laptops to next-generation PDAs and cell phones, WSDs provide much-needed additional capacity for broadband connectivity, home and community networking. [3]

This paper presents an overview of TV Whitespaces, the realm of possible applications and a solution, using Software Defined Radio (SDR) technology, to create a flexible TV Whitespaces (TVWS) test bed with access to the real-time Spectrum Bridge TV Band database.

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2 TV Whitespaces Technical Features

TV White Space Defined:

TV Whitespaces are the vacant frequency bands between occupied (licensed) broadcast channels or broadcast auxiliary services like wireless microphones. Figure 1 shows the TV broadcast spectrum and channel assignments. The amount of available unlicensed spectrum significantly increased with the transition to Digital TV in 2009. In fact, the New America foundation estimates the amount of white space in most of the nation's 210 local TV markets will greatly exceed the amount of occupied spectrum, even in most major cities. [4]

Every geographical region in America has a large quantity of low-frequency spectrum that is unoccupied at any given time. Although the particular empty channels vary in each local market, in most parts of the nation a majority of local TV frequencies are not being used, but could be, for affordable broadband access. Spectrum Bridge, one of the companies that has filed petitions with the FCC to provide a TV band database, offers a free online service to check the channels available for white space spectrum. For example, using Spectrum Bridge's www.showmywhitespace.com tool, and as shown in Figure 2, Scottsdale, Arizona has limited vacant channels, while Dodge City, Kansas has many vacant channels. [3]

Another attractive feature of the Whitespaces is the propagation characteristics of the 500 MHz to 700 MHz band. Transmissions in this band are attractive for the same reasons TV broadcast used this band – the transmissions can easily penetrate obstacles such as buildings, weather or trees and can reach longer distances than higher frequencies that millions of WiFi devices are currently sharing in a smaller, less desirable band of unlicensed spectrum (2.4 or 5 GHz).

The ability to provide broadband coverage is a straightforward process: a Whitespace channel is 6 MHz wide; multiple channels may be combined to create higher bandwidth channels – thus allowing the expansion of wireless broadband spectrum.

TV Band Devices:

The FCC has designated the use of TV Whitespaces would be made available on an unlicensed basis as long as the device operating in the space does not interfere with the incumbents (i.e. wireless microphones, remaining licensed TV broadcasts, public safety, etc.)

	Channel	Frequency (MHz)	
VHF Low	2	54	60
	3	60	66
	4	66	72
	5	76	82
	6	82	88
VHF High	7	174	180
	8	180	186
	9	186	192
	10	192	198
	11	198	204
	12	204	210
	13	210	216
UHF Band	14	470	476
	15	476	482
	16	482	488
	17	488	494
	18	494	500
	19	500	506
	20	506	512
	21	512	518
	22	518	524
	23	524	530
	24	530	536
	25	536	542
	26	542	548
	27	548	554
	28	554	560
	29	560	566
	30	566	572
	31	572	578
	32	578	584
	33	584	590
	34	590	596
	35	596	602
	36	602	608
	37	608	614
	38	614	620
	39	620	626
	40	626	632
	41	632	638
	42	638	644
	43	644	650
	44	650	656
	45	656	662
	46	662	668
	47	668	674
	48	674	680
	49	680	686
	50	686	692
	51	692	698

Figure 1: TV Broadcast Frequencies

Dodge City, Kansas Vacant TV Channels

Fixed TVBD

2	✓ (blue)	19	✓ (blue)	36	✓
3	X	20	mic	37	X
4	X	21	X	38	✓
5	mic	22	X	39	✓
6	X	23	✓	40	✓
7	mic	24	X	41	✓
8	X	25	X	42	✓
9	mic	26	X	43	✓
10	mic	27	X	44	✓
11	X	28	X	45	✓
12	mic	29	X	46	✓
13	X	30	X	47	✓
14	mic	31	✓	48	✓
15	X	32	✓	49	✓
16	mic	33	✓	50	✓
17	✓ (blue)	34	✓	51	✓
18	✓ (blue)	35	✓		

Portable 40mW

2	X	19	X	36	✓
3	X	20	mic	37	X
4	X	21	X	38	✓
5	mic	22	✓	39	✓
6	X	23	✓	40	✓
7	mic	24	✓	41	✓
8	X	25	X	42	✓
9	mic	26	X	43	✓
10	mic	27	X	44	✓
11	X	28	✓	45	✓
12	mic	29	X	46	✓
13	X	30	✓	47	✓
14	mic	31	✓	48	✓
15	X	32	✓	49	✓
16	mic	33	✓	50	✓
17	X	34	✓	51	✓
18	X	35	✓		

Scottsdale, Arizona Vacant TV Channels

Fixed TVBD

2	✓ (blue)	19	X	36	X
3	X	20	X	37	X
4	X	21	X	38	X
5	✓ (blue)	22	X	39	X
6	✓ (blue)	23	X	40	X
7	mic	24	X	41	X
8	X	25	X	42	X
9	mic	26	X	43	X
10	X	27	X	44	X
11	X	28	X	45	X
12	X	29	X	46	X
13	mic	30	X	47	X
14	mic	31	X	48	X
15	X	32	X	49	X
16	X	33	X	50	X
17	X	34	X	51	X
18	mic	35	X		

Portable 40mW

2	X	19	X	36	X
3	X	20	X	37	X
4	X	21	X	38	X
5	X	22	X	39	X
6	X	23	X	40	X
7	mic	24	X	41	X
8	X	25	X	42	X
9	mic	26	X	43	✓
10	X	27	✓	44	✓
11	X	28	X	45	X
12	X	29	X	46	X
13	mic	30	X	47	X
14	mic	31	✓	48	X
15	X	32	✓	49	X
16	X	33	X	50	X
17	X	34	✓	51	X
18	mic	35	X		

X	Your location is within the service area of a TV station or other licensed user and this channel cannot be used by a TVBD
✓	This channel is vacant in your location, and can potentially be used by your TVBD
✓ (blue)	This channel is vacant in your location, and can potentially be used by your TVBD, but personal portable devices may not be used on channels 2-20.
mic	This channel is reserved for wireless microphone use.

Figure 2: Available Channels in Scottsdale, Arizona for TVBD Operation

The FCC has proposed classifying the unlicensed devices into two functional categories: "Fixed" and "Personal/Portable" as described below:

a. "Fixed", Higher Power, unlicensed devices: These devices will be allowed to communicate with other fixed devices and with personal portable devices (see next section).

The current FCC rules for "Fixed" unlicensed devices (as of September 23, 2010) are as follows:

- Must determine their geographic location through an incorporated geo-location capability or from a professional installer and have access to a TV Bands Database.
- Must transmit identifying information such that they may be identified if interference occurs and be registered with a database system that contains records of protected services and receive a list of the available channels at their location.
- Fixed TVBDs are required to re-check the database, at a minimum, on a daily basis. If a device fails to make contact with its database on any given day, it is required to cease operating at 11:59 pm the following day.
- May operate with transmitter output power up to 1 W with a maximum antenna gain of 6 dBi. The transmitter power must be reduced by the same amount of dB that the

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maximum antenna gain exceeds 6 dBi. This equates to the fixed devices operating at 4 W EIRP.

- May operate on any channel between 21 and 51, except channel 37 and may be subject to other restrictions such as co-channel operation or operation to adjacent TV channels. Fixed devices that only communicate with other fixed devices will be permitted on channels 2 and 5-20, except that they must avoid operation on channels used by private land mobile radio service (PLMRS).
- Two channels nationwide will be set aside for wireless microphone use and other LPAS (light weight portable amplification systems) operations. These channels will be the first channels on either side of channel 37 that are unoccupied by broadcast television stations.
- May not operate on channels that are immediately next to the channel of a TV station.
- Out of band emissions in the first adjacent channel must be > 72.85 dB below the channel they occupy as measured with a 100 KHz bandwidth relative to the total in-band power in a 6 MHz channel (bandwidth radio of 6 MHz/100 KHz or 17.8 dB).
- Will operate from an installed outdoor location that does not change.
- The transmit antenna must be outdoors and be mounted no more than 30 meters above ground. Further, TVBDs are restricted from operation at locations where the HAAT (height above average terrain) of the ground is greater than 76 meters. This limits the total antenna HAAT to 106 meters. Fixed devices must submit the antenna height above ground to the database when querying for available channels. (Requirements for sensing antennas have been removed from the rules).
- Must include adaptive power control so that they use the minimum power necessary to accomplish communications.
- Conducted output power must comply with power spectral density (PSD) limits. This will prohibit high power concentrations in a single channel. PDS limits in a 100 KHz bandwidth are 16.7 mW (12.2 dBm) for fixed devices.
- Sensing: The recent FCC rules were changed from requiring sensing to “Some forms of spectrum sensing may be included in TVBDs on a voluntary basis for purposes such as determining the quality of each channel”. The TVBD must sense signals to a -107 dBm threshold. Applications for certification of sensing only devices will be accepted and will be approved under a “proof-of-performance” standard. The rules further clarify that sensing only devices may initiate and participate in a network of TVBDs and may communicate with fixed, Mode I, Mode II, and other sensing-only TVBDs but may not provide a Mode I device with a list of available channels.

b. “Personal/Portable”, Lower Power unlicensed devices: These are wireless portable devices such as laptops, smart phones, wireless home and local area networks and other short range applications. They generally transmit with very low power and are used indoors or within a

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small localized area. These devices will be allowed to communicate with fixed devices and with other personal/portable devices. They will be operated either in a client-like Mode I topology or an access point-like Mode II topology.

Mode I (Client-like) - A personal/portable device that may only transmit after receiving a list of available channels from a fixed or Mode II TVBD that has contacted the database and verified the FCC ID of the Mode I device is valid. A Mode I device will operate only on the available channel identified by the fixed or Mode II device. A device in Mode I must either (1) receive a special signal from the Mode II or fixed device that provided its current list of available channels to verify that it is still in reception range or (2) contact a Mode II or fixed device at least once per minute to re-verify/re-establish channel availability.

Mode II (Access Point-like) – A personal/portable device which determines the available channels using its own internal geo-location/database access capabilities. The Mode II device must use its geo-location capability to check its location at least once every 60 seconds, except when in “sleep mode”. Mode II devices are required to re-check/re-establish contact to the database and obtain a list of available channels at least once per day. In addition to the daily re-check, the device must re-check/re-establish contact with the database (1) if it is moved more than 100 meters from the location at which the last re-check was performed or (2) if it loses power. If the Mode II device loses power and obtains a new channel list, it must signal all Mode I devices it is serving to acquire the new channel list.

The current FCC rules for personal/portable unlicensed devices (as of September 23, 2010) are as follows:

- May operate with transmit output power up to 100 mW EIRP, with 0 dBi antenna gain. If the device is operating in a channel adjacent to a TV station or another licensed station/service, operations are limited to 40 mW EIRP. Personal/Portable devices that rely on spectrum sensing without the use of geo-location and a TV bands device database are limited to 50 mW EIRP.
- If a Mode II device fails to make contact with its database on any given day, it is required to cease operating at 11:59pm the following day.
- May operate on any channel between 21 and 51, except channel 37.
- Out of band emissions in the first adjacent channel must be > 72.85 dB below the channel they occupy as measured with a 100 KHz bandwidth relative to the total in-band power in the occupied 6 MHz channel (bandwidth radio of 6 MHz/100 KHz or 17.8 dB).
- Conducted output power must comply with power spectral density (PSD) limits. This will prohibit high power concentrations in a single channel. PDS limits in a 100 KHz bandwidth are 1.67 mW (2.2 dBm) for personal/portable devices, 0.7 mW (-1.8 dBm) for

personal/portable devices operating in adjacent to occupied channels and 0.83 mW (-0.8 dBm) for sensing-only personal/portable devices.

- Must include adaptive power control so that they use the minimum power necessary to accomplish communications.
- All antenna(s) shall be permanently attached.

Fixed and personal/portable operations may be used together and can use the TV spectrum if they comply with the rules to ensure they do not interfere with incumbent devices. Both devices will be allowed to transmit broadband data and other types of communications.

3 TV Whitespaces Applications

TV Whitespaces innovations will reach all of us in most areas of our life – there is a huge market potential for unlicensed applications operating in the TV Whitespaces frequencies. The highly desirable characteristics of the TV frequency band could fundamentally change the wireless provider model by greatly increasing the amount of wireless bandwidth available to unlicensed devices. New devices will emerge taking advantage of the increased range and penetration ability. The new devices will allow providers to supplement existing cellular networks and will open markets for disruptive new entrants. Some potential areas of development are as follows:

Rural Broadband Deployment:

The chairman of the FCC set an aggressive goal of delivering 100-Mbit/s broadband service to 100 million Americans by the year 2020. This is a challenging goal for unserved and underserved areas of the country, especially in rural areas with limited or no broadband communications options.

A broadband system using TV Whitespaces could provide a cost-effective solution – In an article released by Cambridge Consultants, Rural Broadband was identified as a key growth opportunity triggered by the TVWS opportunity. There are around 3000 wireless internet service providers in the US, mostly serving rural communities. “By upgrading to Whitespace radio these providers will be able to extend the range of their access points at least 300 percent, and remove the need for a line of sight between subscriber premises and the access point. The overall result will be to greatly reduce the number of access points needed to cover a particular community, reducing the cost of installing a network by up to 75 percent. Spectrum Bridge already has a rural network set up in Claudville, VA, a small rural community lacking broadband connectivity.” [9]

Whitespaces LAN:

For the same reasons TV Whitespaces are interesting to a rural deployment, they also make effective LAN networks. TV Whitespace propagation characteristics provide a LAN solution with improved coverage and indoor penetration over those of current 2.4 GHz and 5 GHz systems currently in use.

Public Safety:

Possible uses include providing high speed data networks for public agencies or providing a secure communications channel for disaster efforts. Data networks could stream video for surveillance and disaster response provide for fast access to suspect data, building blueprints, and public safety databases. “Public agencies argue that access to more and better spectrum in the TV band will improve the capacity and quality of their networks, as well as facilitate their expanded use for e-government and consumer services.”[4] Disaster rescue efforts could be enhanced by having a common communications channel available for both voice and data for all agencies to communicate. In an article referencing the broadband plan, PC World magazine states “Public safety officials and U.S. lawmakers have been calling for a nationwide mobile broadband network since the Sept. 11, 2001, terrorist attacks on the U.S., during which the multiple public safety agencies responding to the attacks couldn't talk to each other.”[5]

Power Grid:

In the National Broadband Plan released March 16, 2010, the FCC stated 6 major goals for the project. Goal Number 6 reads “To ensure that America leads in the clean energy economy, every American should be able to use broadband to track and manage their real-time energy consumption.” [6] The Smart Grid as defined by the National Institute of Standards and Technology (NIST) is the “two-way flow of electricity and information to create an automated, widely distributed energy delivery network.” [7]

To fully implement and utilize the vision of the Smart Grid, two-way communications, power sensors, and software need to be added to homes and the electrical systems. Communications are vital to everything associated with the Smart Grid – power generation, transmission, distribution, and consumption.

Mesh/Sensor Networks:

Many ideas for sensor networks have been published in the past two years since the FCC announcement of the opening of the TV Whitespaces Frequencies. A sensor network monitoring traffic, weather, or even emergencies in a community is one such application that would benefit from the characteristics of the TVWS (broadband for video, good penetration through buildings and weather, and improved power delivery.)

Home Networks:

The TV Whitespaces frequency has the building penetration and low power requirements that make an ideal environment for a home management network. A vision of the “Smart Home” is a home with home computing networks, entertainment, appliance/device management and power consumption via the Smart Grid, seamlessly integrated in a broadband wireless system. Smart Home users will want a network in which they can link home computers and peripherals such as printers to each other for data transfer. They will want broadband access to share connections between devices; they will want to have streaming video capability; and they will eventually want appliances and power meters connected to the Smart Grid. These requirements could easily be satisfied even today with a system taking advantage of the WiFi enabled devices communicating with a "home command" system operating in the TV Whitespaces frequency band.

Unknown Applications:

Perhaps the most exciting application of TV Whitespaces is the unknown. The unlicensed aspect means innovators will think of applications that we cannot even imagine. Think of the last unlicensed frequency release in 1985 of the 2.4 MHz "junk" spectrum. At that time Wi-Fi was not even a word in our vocabulary and today is a multi-billion dollar industry.

4 Proposal for TV Whitespaces Experimental System

The promise of available spectrum through the use of TV Whitespaces is exciting. However, as shown in Figure 3, the status of using the spectrum is in the process of rule making, standards developments, and test procedures for certification – in other words, a lot of churn is occurring while innovators are waiting to make solutions, create new markets and generate profit. So the obvious question in this situation is: What can be done during this waiting period?

The answer is easy – experiment with hardware test beds, waveform development and network deployments – all using the flexibility of software defined radio (SDR).

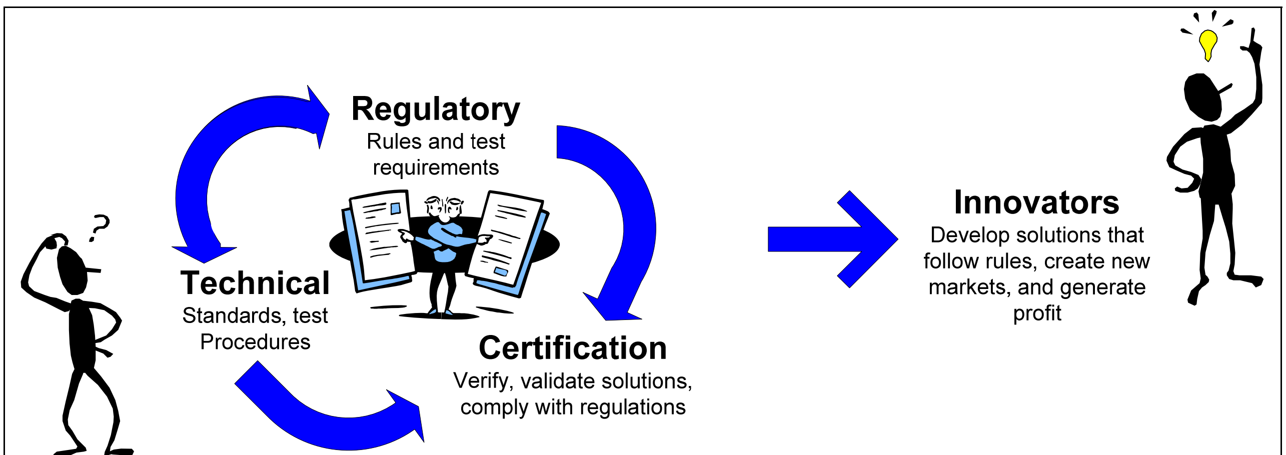

Figure 3: TV Whitespaces Status

An experimental system must be capable of supporting the current FCC rules (including accessing a working TV Whitespaces Database) and IEEE standards and must support the evolution of these rules and standards. DataSoft has developed a TV Whitespaces System test capability starting with a hardware test bed, moving to a waveform development and test environment, and finally evolving the system to network testing and deployment.

Test Bed for System and Waveform Development

The TVWS test bed using the Thunder SDR waveform development platform is shown in Figure 4. The test bed represents a typical application of accessing the internet via TV Whitespaces.

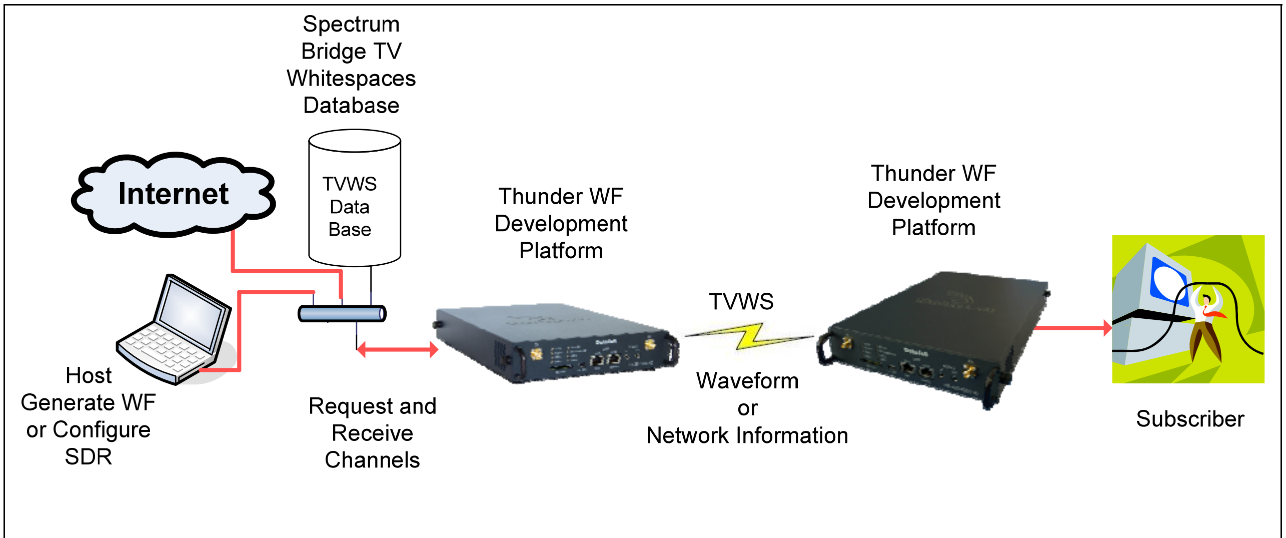

Figure 4: TVWS Test Bed using the Thunder Software Defined Radio Development Platform

The first step is configuring one Thunder SDR to act as a fixed or portable/personal Mode II TVBD and the other to act as the portable/personal Mode I TVBD. The GPP processor is programmed to adhere to all FCC rules for TVBDs relating to their power levels, database access requirements, re-check requirements and others as listed previously in section 2. With the test bed, one can verify the TVBD rules are met; the system receives the appropriate channels and correctly transmits and receives the required data and information.

An advanced use of this test bed is waveform development for TV Whitespaces. The standards are evolving, so a flexible system capable of meeting and adapting to the evolving standards is valuable. The Thunder SDR has a variable, programmable bandwidth of 40 KHz to 40 MHz, a variable, programmable frequency range of 400 MHz to 4 GHz, or 30 MHz to 1600 MHz, and high data rate D/A and A/D converters. This system can vary the modulation types, coding techniques, sample rates, bandwidth, frequency hopping and power. A test waveform based on today's standards can be deployed, "what-if" scenarios can be applied, and future requirements changes can be accommodated.

This TVWS test system is capable of providing a simple rules verification system, a waveform and application development platform, and finally a test platform for spectrum management techniques in other bands beyond the TV Whitespaces.

A detailed layout of the Thunder SDR is shown in Figure 5. The Thunder platform is the heart of the Whitespaces test bed and provides the flexibility to start early development of systems using new waveforms and spectrum utilization techniques for TV Whitespaces systems. Some key features of the Thunder SDR are:

- Affordable, wide-band, high performance baseband and RF development and test platform.
- 400 MHz to 4 GHz RF System interfaced to the Mistral TI OMAP EVM providing advanced SDR Development on the OMAP platform.
- Fully programmable 40 KHz to 40 MHz Signal Bandwidth.
- Open source Linux Operating System hosting GNU radio applications for Cognitive, Frequency Agile or 802.x applications.

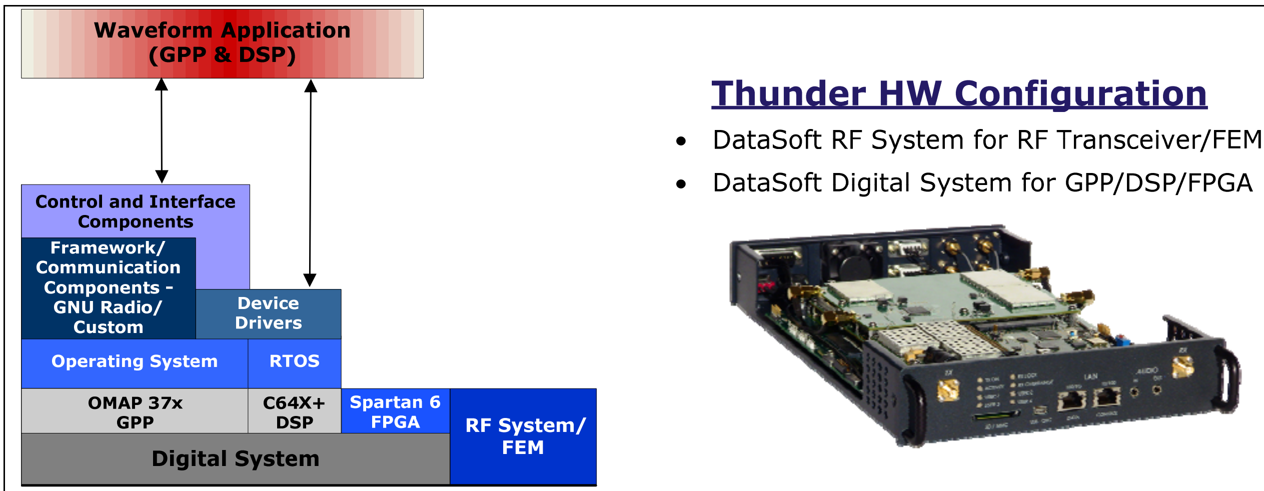

Figure 5: Thunder SDR – the Heart of the TVWS Test Bed

Network Development and Test Environment

Once a TVBD and its waveform are known, developers will want to move to system and network development and test. Having a test-bed capability for testing in the intended network will reduce risk and implementation expenses due to unknown network issues. Through internal IR&D funding and SBIR awards, DataSoft has developed an extremely capable Waveform and Network Development and Test Environment, well suited for new, emerging networks like the TV Whitespaces. This environment is adaptable to evolving rules and standards. Figure 6 shows the tools and process for waveform development and network testing. As shown in Figure 6, waveform development starts with the Thunder SDR test bed and the Probe Toolbox – a tool for porting and debugging waveforms.

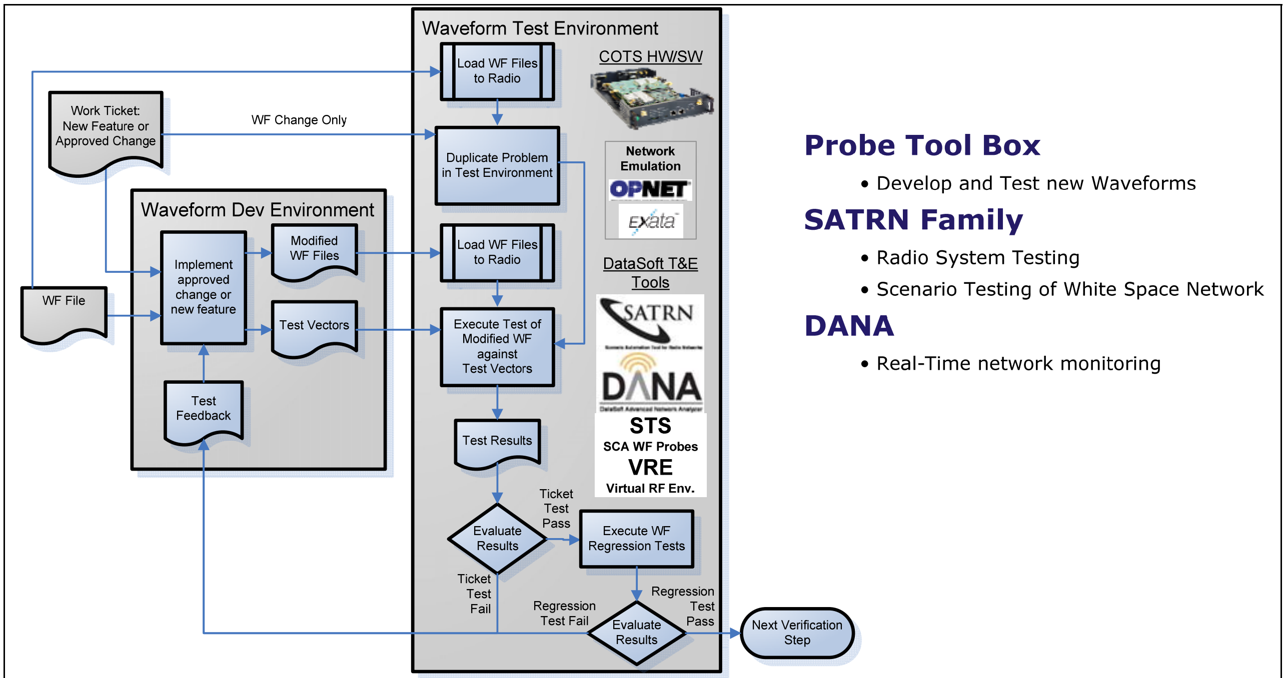

Figure 6: Waveform and Network Development and Test Environment

Once the TVBD performance is known, the SATRN family is used for radio system testing, providing a virtual test environment for the TVBD. A diagram of the SATRN tool and features is shown in Figure 7.

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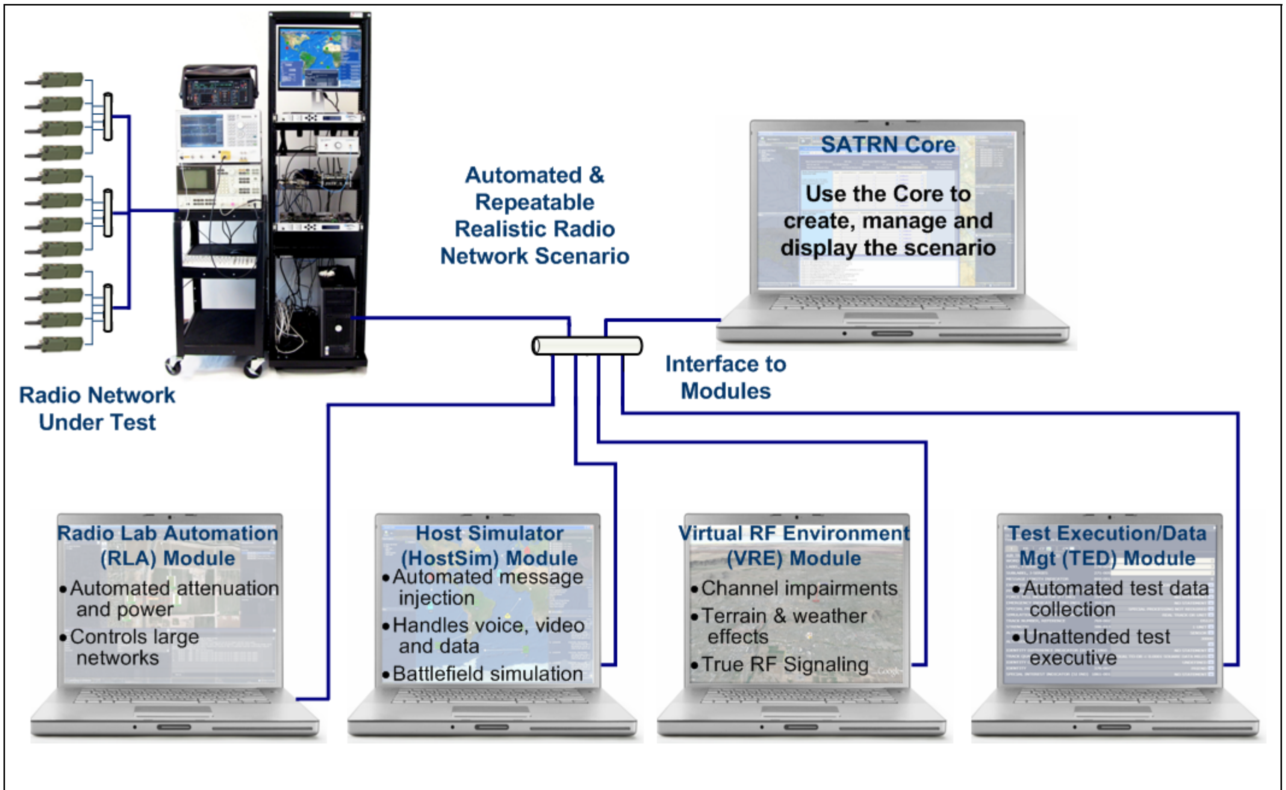

Figure 7: SATRN Family: Tools for Radio Network Testing

Using SATRN, the TVBD network is set up in a lab environment and tested for environmental, messaging, channel impairments and power loss scenarios before going through the expense of deploying the network and finding these issues in the field.

Finally, as referenced in Figure 6**,** the DANA tool provides real-time network monitoring of either a system under test in the lab or a fully deployed network. DANA will monitor network connectivity, capacity, and health with end-to-end response time visualization and drill down capabilities.

5 Summary

With the transition to digital TV in 2009, new and highly desirable frequencies vacated by analog TV have become available to use for unlicensed applications. Because of their excellent propagation characteristics, these newly available TV Whitespaces frequencies are considered 'beachfront property', and there is no lack of enthusiasm to use them to test new ideas. [7]. The TV Whitespaces frequencies offer an efficient and effective strategy to support the future growth of broadband communications technologies. These technologies include Rural Broadband access, Whitespaces LAN networks, expanded Public Safety communications networks, Smart Power Grid networks, Mesh/Sensor Networks, Home networks and yet to be discovered Innovations. Development of products and applications in the TV Whitespaces offers exciting promise with a near term issue of evolving regulatory, technical and certification standards leaving the innovator waiting for resolution.

The proposed TVWS test bed, Waveform Development environment, and Network Analysis tools will provide a path to efficiently deploy an adaptable, affordable TVWS network with flexibility to adapt to future rule changes. The TV Whitespaces vision could quickly become reality with the proposed solution.

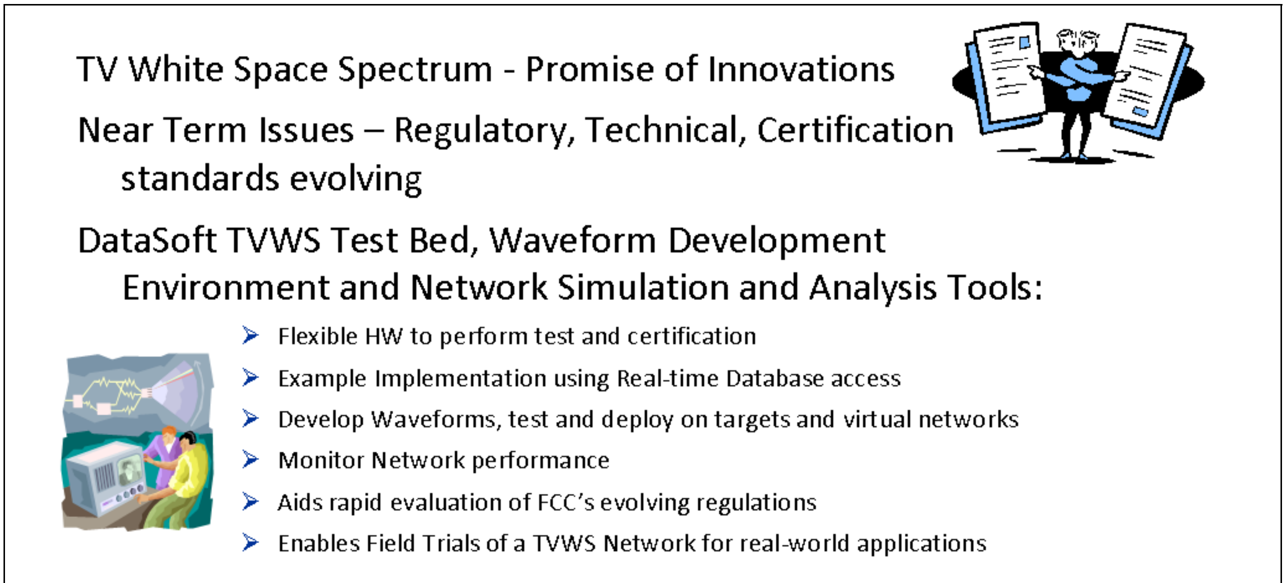

Figure 8: The DataSoft TV Whitespaces Development Test Bed

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