16-Mar-10

Open Spectrum: New Standards Big Prospects

This white paper contains an overview and analysis of the open spectrum regulations and their impact on mobile business and technology. The paper was sponsored by xG Technology, but the opinions expressed here are the author's alone.

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At the turn of the 20th century spectrum was, much like the Wild West, unregulated and free, but things have changed. Dramatic advances in wireless technology have spurned elaborate regulations from the FCC and its international counterparts. But spectrum regulations have traditionally lagged the evolving needs of the wireless world.

TV broadcasting, the dominant wireless technology of its time, gave way to cellular and wireless broadband communications. And now the FCC regulations designed for the broadcasting age must evolve to meet the needs of mobile users.

Today's TV service is mostly distributed via satellite and cable, causing valuable segments of the VHF/UHF broadcast spectrum to remain unused, while modern mobile communications bands are gasping for capacity, burdened with billions of dollars in spectrum licensing costs.

Funded by the National Science Foundation (NSF), a recent study of spectrum usage under 3 GHz determined that the average occupancy over various locations studied was 5.2% and the maximum occupancy was 13.1% (in New York City) [ssc]. Another study [snider] found that only 10% of Americans receive their television signals via terrestrial broadcasts, while the rest of us rely on satellite and cable.

Such inefficient use of spectrum is an issue in a mobile world. To resolve it, international regulators are working with the industry to optimize their rules for modern wireless technology. With today's sophisticated processors and software, wireless devices no longer require dedicated channels as did their analog predecessors. A natural migration for spectrum regulations is to enable opportunistic use of spectrum according to its availability at a particular time, location and frequency band [pickard].

Where allowed, the use of unlicensed spectrum has been phenomenally successful, giving birth to multi-billion dollar industries such as Wi-Fi and Bluetooth. And recently, an innovative voice over IP (VoIP) architecture, xMAX, was successfully demonstrated in the 902-928 MHz unlicensed band by xG Technology [xg]. Both Wi-Fi and xMAX enable affordable data and voice services in the unlicensed bands and their ability to capture vast commercial interest indicates that the story of open spectrum is just beginning to unfold.

Overview of unlicensed spectrum

The use of open spectrum by amateurs and by the scientific community goes back to the dawn of wireless communications in the early 1900s when ham radios were used to transmit Morse code and later voice in the frequency band under 30 MHz. Today's open spectrum includes Industrial Scientific (ISM) and Unlicensed National Information Infrastructure (UNII) bands with allocations at 915, 2450 and 5800 MHz (Figure 1).

In 2005 the FCC allocated 3650-3700 MHz lightly regulated band, opening the door for new wireless operators unable to afford billions of dollars in licensing fees. This 50 MHz band allows multiple services to share spectrum via contention-based access protocol compatible with 802.11y. The licensing is nearly free: $300 per license for 10 years.

The industry has yet to make productive use of the unlicensed Ultra Wide Band (UWB) with 7.5 GHz of spectrum between 3.1 and 10.6 GHz. Operation in this band turned out to be technologically challenging as the UWB devices must operate in the noise floor of the co-located traditional wireless services, at transmit levels below -41 dBm/MHz EIRP.

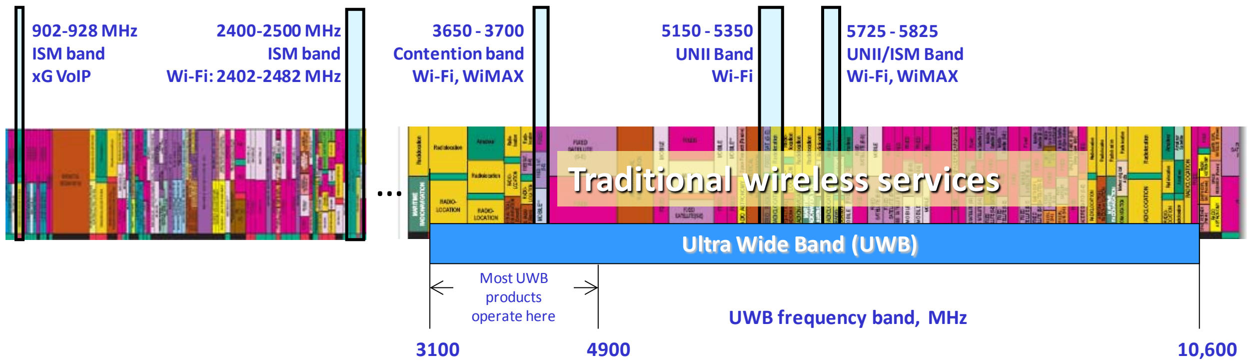


Figure 1: Key unlicensed wireless bands in the US

The 902-928 MHz ISM band, commonly used indoors by cordless phones, garage openers and baby monitors, has recently been re-invented by xG Technology for indoor and outdoor use of VoIP. With range measured in miles and capacity of hundreds of simultaneous calls per base station, xG's xMAX is the first open spectrum VoIP application to challenge the expensive business model of traditional wireless operators like Verizon and ATT.

And while operators who have invested billions in spectrum licensing may deride open spectrum as 'junk bands', Wi-Fi and xMAX prove that that these bands can deliver impressive cost/performance alternatives to licensed services.

So, how much better is the user experience on licensed spectrum vs. unlicensed?

Attention to detail when it comes to architecture and management of unlicensed wireless services can deliver robust performance [Motorola]. My direct assessment of quality of experience (QoE) on the unlicensed xG VoIP network is that it is high and indistinguishable from QoE of my ATT service. And although the answer to licensed vs. unlicensed QoE lies in statistics on blind spots and dropped calls, such statistics are difficult to find since carriers consider them confidential.

But how important are elaborate QoE studies? The early adopters of Wi-Fi, back in the mid 1990s, weren't concerned with statistics. They liked the price of a Wi-Fi router and network card, both of which they could buy at Staples. They liked being able to watch TV on a couch while responding to email without being tethered to a desk. And because Wi-Fi was affordable, accessible and worked well enough, it became a resounding market success.

By the same token, open spectrum can bring about low cost and availability of voice service to wireless users unable to afford mobile connectivity from traditional carriers.

As suggested by the aforementioned studies [ssc, snider] showing spectrum utilization under 10% in most locales, we will likely find that unlicensed services can deliver acceptable performance for VoIP, data and M2M (machine to machine) traffic to most users and that multiple operators can efficiently share hundreds of MHz of TV band white space spectrum.

TV band – a game changer for the wireless operator business?

A recent study from Perspective Associates estimates the economic potential of TV band at $100 Billion [thanki] for a variety of data and VoIP services.

The concept of opening up the unused broadcast spectrum to wireless data services was born at around the time the FCC started planning for a transition from NTSC (National Television System Committee, aka analog TV) to ATSC (Advanced Television Systems Committee, aka digital TV). Companies such as Google, Microsoft, Dell and others, desiring to break into the private club of wireless service providers, formed the Wireless Innovations Alliance (now dissolved) with the goal of petitioning the FCC to allow sharing of the broadcast TV channels by unlicensed wireless services.

The first step in TV band white spaces regulations was the FCC Notice of Proposed Rule Making (NPRM) on May 25, 2004 [nprm]. On November 4, 2008 the FCC approved Report & Order 08-260, allowing unlicensed use of TV band spectrum [rno]. On February 17, 2009, the FCC released the final rules for "Unlicensed Operation in the TV Broadcast Bands".

Regulatory efforts to enable sharing of the TV broadcast band by unlicensed devices are also underway internationally. Ofcom, the UK counterpart of the FCC, is in the process of opening up its TV band, referred to as "Digital Dividend" band, to unlicensed services [Ofcom]. ECC (Electronic Communications Committee) of CEPT (European Conference on Postal and Telecommunications) in Europe is also conducting consultations on sharing of the TV broadcast bands. The first report on this effort from ECC is due in May of 2010. Chinese TV band regulations are expected in 2015.

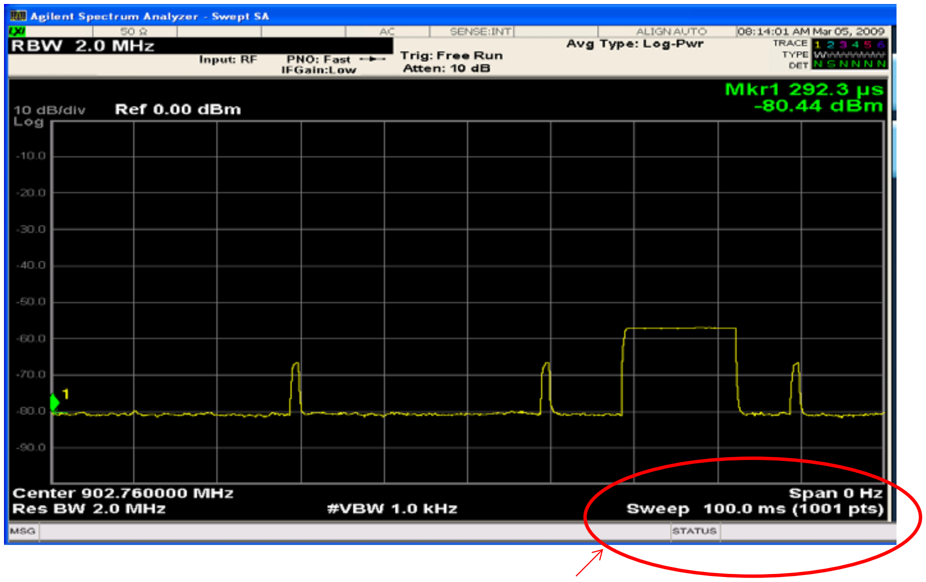
Quality of Service in the open spectrum

We have so far mentioned two examples of today's open spectrum usage: Wi-Fi and xMAX. The popularity of Wi-Fi speaks to its adequacy for data services. Wi-Fi, however, falls short in supporting VoIP and despite WMM™ (Wi-Fi Multi Media) [wmm], has yet to be widely employed for this lucrative application. A white paper extensively analyzing the theoretical VoIP bounds of the 802.11 protocol [mlin] demonstrates that 802.11b running WMM cannot exceed 22 VoIP calls and 802.11g/a cannot exceed 68 calls. In real networks, though, the number of calls will be less than a third of these theoretical boundaries and even less when mixed with data traffic. Furthermore, Wi-Fi has yet to be deployed outdoors to any meaningful degree and is in no position to replace cellular voice.

Thus, until the recent emergence of xMAX, unlicensed networks were unable to rival traditional carrier networks for voice services.

Operating in a low-loss 902-928 MHz band, xMAX offers long range and high capacity VoIP and data service. The xMAX medium access control (MAC) protocol was designed from the ground up to provide utmost efficiency for synchronous services such as VoIP.

And although the unlicensed 902-928 MHz band cannot guarantee 100% availability, it appears to be lightly used in most locations. A representative scan of this band vs. time (Figure 2) demonstrates significant available capacity.



Span of 0 Hz shows measurement of power vs. sweep time of 100 msec at a frequency in the 902-928 MHz band

Figure 2: Typical level of activity in the 902-928 MHz band vs. time in the Fort Lauderdale, FL area. This is a 100 msec trace of airlink activity performed by xG Technology. The trace shows significant available capacity.

Clearly, more thorough studies of the 902-928 MHz band are needed to quantify capacity vs. locale vs. time. But as often happens, pioneers get going without elaborate studies and create successful industries. Examples of these are Wi-Fi and Cable modem. Even the now overwhelmingly successful Ethernet at the time of its birth was considered too unpredictable by those advocating guaranteed access protocols such as time domain multiple access (TDMA).

With its xMAX radio access network (RAN) saving billions of dollars by eliminating spectrum licensing costs, xG Technology is lowering the entry barriers for a new class of mobile service providers: competitive local exchange carriers (CLECs), multiple service operators (MSOs), such as cable and satellite companies, and other new entrants.

Although a mobile network must provide both data and voice services, the challenging part is to meet the stringent latency and jitter requirements of VoIP. If VoIP can be made to work well, data delivery will also work well. For this reason xMAX was architected around the stringent QoS requirements of a VoIP network.

Revenue is another important reason for optimizing the service architecture around VoIP. Mobile voice revenues currently exceed mobile data revenues 5-fold and these services are not expected to achieve revenue parity for at least another decade [xG]. Thus, xMAX, having been optimized for VoIP delivery, is an attractive offering for new entrants into the mobile broadband operator business.

While the RAN architecture of xMAX is carefully optimized for sharing the airwaves with other traffic in the unlicensed environment, the backhaul and core components of xMAX leverage commercial off the shelf (COTS) solutions such as SIP Proxy Servers, Media Gateways, voicemail, inter-network call signal routing and other basic voice services [xG].

And as the 902-928 MHz band gradually reaches its optimum capacity under the increasing use of VoIP, more spectrum will be freed up as mandated in the FCC national broadband plan [fcc_plan]. The VoIP delivery architecture will have to remain flexible and adaptable to coexist with or to conform to the emerging TV band standards from the IEEE and other organizations.

Open spectrum standards

Early uses of open spectrum, including cordless phones, garage openers and baby monitors, were required to comply only with the FCC regulations. However, with the increasing importance of unlicensed wireless networks, new generations of radio devices will be expected to coexist with the industry standard protocols, such as 802.11 and its TV band derivatives.

Open spectrum today (Table 1) does not yet include hundreds of MHz of TV band spectrum (Table 2) since the FCC Final Rules [final] are still being challenged by the incumbents [court] and petitioned for refinement by numerous companies [petitions] developing products for the TV band.

Table 1: Key unlicensed bands in the US

Frequency	Band	Uses	Notes
902-928 MHz (26 MHz)	ISM	xMAX VoIP Cordless phones Garage openers Military radar	xMAX VoIP is a brand new application for this band
2.4-2.5 GHz (100 MHz)	ISM	802.11b,g,n Microwave ovens	
3.65-3.7 GHz (50 MHz)	Contention band	802.11y 802.16h	Lightly licensed, $300 for 10 years
5.150-5.350 GHz (200 MHz)	UNII band	802.11a,n	
5.725-5.825 GHz (100 MHz)	ISM/UNII band	802.11a,n, ac 802.16	802.11ac is under development
57-64 GHz (7 GHz)	60 GHz	802.11ad WirelessHD	802.11ac is under development

The TV band spectrum (Table 2) at VHF/UHF frequencies, below 1 GHz, offers longer reach and better propagation through walls than the traditional Wi-Fi bands located at 2.4 and 5 GHz. The term “Wi-Fi on steroids” has been coined to convey the expected longer reach of TV band Wi-Fi. The IEEE 802.11 Task Group af (TGaf) was formed in January of 2010 to adapt 802.11 to TV band operation.

Table 2: White Spaces spectrum

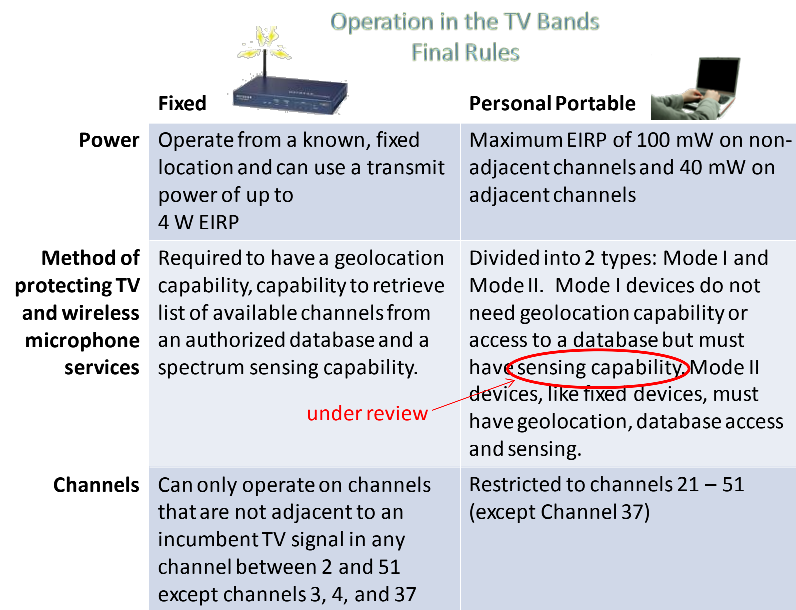
	Channel #	Frequency Band	
Fixed TVBDs only	2-4	54-72 MHz	VHF
	5-6	76-88 MHz	
	7-13	174-216 MHz	
	14-20	470-512 MHz**	UHF
	21-51*	512-692 MHz	

** Devices classified as personal portable (PP) are only allowed to operate in channels 21-51. Channel 37 (608-614 MHz) is reserved for radio astronomy; ** Channels 14-20 are shared with the public safety services.*

In the WiMAX camp, the IEEE 802.16h task group, originally formed to adapt 802.16 to the 3650-3700 MHz contention band, is also working to enable TV band operation of 802.16.

But the origins of TV band standardization go back to the IEEE 802.22 Working Group formed in 2004 to enable operation of Regional Area Networks in the available TV spectrum. Many of the regulations currently found in the FCC Final Rules [final] were developed by the 802.22 committee [eet].

The FCC TV band regulations [final] specify two types of TV band devices (TVBDs): fixed and personal portable (PP). Both types of devices must protect the licensed services, including TV broadcasting and wireless microphones (Figure 3).



	Fixed	Personal Portable
Power	Operate from a known, fixed location and can use a transmit power of up to 4 W EIRP	Maximum EIRP of 100 mW on non-adjacent channels and 40 mW on adjacent channels
Method of protecting TV and wireless microphone services	Required to have a geolocation capability, capability to retrieve list of available channels from an authorized database and a spectrum sensing capability.	Divided into 2 types: Mode I and Mode II. Mode I devices do not need geolocation capability or access to a database but must have sensing capability. Mode II devices, like fixed devices, must have geolocation, database access and sensing.
Channels	Can only operate on channels that are not adjacent to an incumbent TV signal in any channel between 2 and 51 except channels 3, 4, and 37	Restricted to channels 21 – 51 (except Channel 37)

Figure 3: Summary of the TV Band Final Rules [final] and device classifications. Sensing capabilities for PP devices is currently deemed impractical and is under review by the FCC.

Protection mechanisms include spectrum sensing and geolocation to determine whether given transmit frequencies and power levels will cause harmful interference to licensed services. As the TGaf standardization effort progresses, the IEEE will be working with the FCC to amend some of the TV band regulations that may be impractical for the industry to implement (spectrum sensing, for example) or to add rules that would enhance the standard.

The current direction of the IEEE architecture is to enable access points and base stations (fixed devices) with geolocation capability and to let PP devices be guided by their respective APs or base stations in setting the channel. Fixed devices, required to be connected to the Internet, communicate their geolocation coordinates in a query to the FCC database in order to obtain information on the TV band channels available at their location.

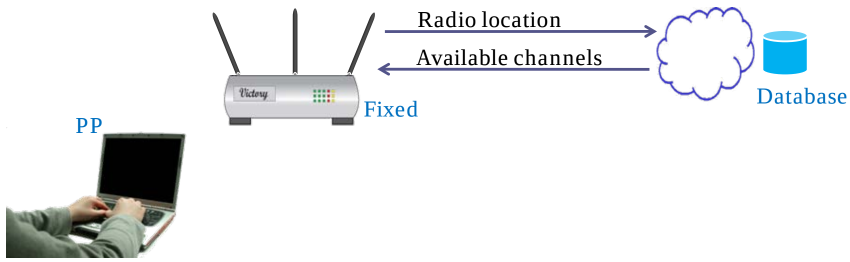


Figure 4: Operation of the TV band database. Fixed TVBD reports its geolocation to the database and receives information on available channels at its location PP TVBD sets its channel to that of the fixed device with which it associates.

Google, Spectrum Bridge and other companies are working with the FCC to refine the specifications for the TV band database. Some of the novel capabilities being considered include the ability of such a database to assist in dynamic auctioning of the unused spectrum as a function of time, space and frequency.

With such capabilities, the brave new world of open spectrum will enable users to reserve, for example, an hour of wireless access in the middle of NYC at a specific time on a specific channel. This unprecedented flexibility has the potential of unleashing a torrent of wireless services currently being blocked by the rigidity, complexity and cost of spectrum access.

Conclusion

Existing regulations originated back in the days when radio was young and TV broadcasting dominated the airwaves. Today these outdated regulations are poorly serving modern mobile users of voice and data services. Unlicensed wireless services have already built multi-billion dollar industries such as Wi-Fi and Bluetooth. And innovations in open spectrum continue to create opportunities for affordable wireless services capable of narrowing the Digital Divide.

The latest example of open spectrum innovation is the xMAX VoIP service operating in the 902-928 MHz unlicensed band. The xMAX architecture, designed from the ground up to operate in the unlicensed spectrum and to coexist with other services, has demonstrated excellent performance, on the par with licensed networks.

And with hundreds of MHz of VHF/UHF TV band spectrum being promised by the FCC mandate [fcc_plan] for unlicensed use, the opportunity for services like xMAX in the open spectrum is just beginning to unfold.

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[database] Fixed TVBDs require geolocation capability and Internet access to a database of protected radio services. White Spaces Database Group was started by Google and other companies to create and standardize the database. Database related proposals to the FCC: http://fjallfoss.fcc.gov/ecfs/comment_search/execute?proceeding=04-186&applicant=&lawfirm=&author=&disseminated.minDate=&disseminated.maxDate=&recieved.minDate=1%2F6%2F09&recieved.maxDate=&address.city=&address.state.stateCd=&address.zip=&daNumber=&fileNumber=&submissionTypeId=&__checkbox_exParte=true

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