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A CRITIQUE OF FCC'S TV WHITE SPACE REGULATIONS

Broadband access constitutes the "oxygen" for the Internet Era, to which end, the issue of spectrum management is foundational. In this position paper, we present an overview of FCC's pioneering work framing TV white space rules that allows unlicensed access by secondary users while protecting licensed primary users. The core contribution of this paper is an in-depth analysis of FCC's TV white space regulations (often treated as a global template). We argue that FCC's current white space regulations does not achieve the desired balance between effectively promoting unlicensed secondary access and providing adequate protection of the primary. As more countries around the world look at framing white space regulations, we argue for incorporating a more flexible design that can catalyze a white space device ecosystem to flourish, similar to Wi-Fi.

INTRODUCTION

Broadly speaking, spectrum allocations can be classified under two principles/approaches:

a) granting of exclusive licenses, usually via a suitably designed auction mechanism, to operators for an explicitly identified purpose of service (that may not be changed) and

b) setting aside "unlicensed bands" for technology neutral usage, whereby compliant devices do not need a license to operate (but must nevertheless be certified), akin to a public "commons."

The first scenario conforms to a single primary network in the licensed band whereas the latter maps to multiple (co-located) networks. The exclusive license model is the operative one for all cellular network services, based on the operators belief that exclusive rights to spectrum enables them to offer/tailor desired services, as well as optimize the network/delivery mechanisms so as to extract maximum revenue. The unlicensed model is used by standards, such as Wi-Fi, where the fundamental issue is managing interference, specifically a) secondary unlicensed interference to primary licensed users and b) interference between unlicensed secondary users. FCC Part 15 rules [FCC 01-58] that govern unlicensed bands have mostly focused on "transmit power" centric rules to ensure limited interference from secondary unlicensed users to primary users (e.g. limits on average transmit power over the band, maximum power spectral density and on out-of-band emission limit using transmit spectral mask) while encouraging the use

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of "etiquettes," such as listen before talk (LBT) for managing interference between unlicensed secondary users.[1]

Spectrum license auctions, such as those by the FCC, typically generate several billion USD as a one-time revenue to the U.S. treasury (e.g. 2006 auction of 90 MHz netted USD 14 billion [BULOW]). However, a multibillion dollar industry has also grown in the use of "unlicensed" spectrum [THANKI 1]; a recent analysis suggests that the value generated from unlicensed spectrum use is $140 billion per annum in the U.S. alone [THANKI 2]. Because users of unlicensed spectrum enjoy economies of scale and do not pay for expensive spectrum licenses, unlicensed networks typically offer a less expensive and more readily deployable form of wireless service than licensed spectrum – albeit at a trade-off for quality of service and protection from interference.

Wi-Fi carried about 70% of all mobile Internet data traffic in 2014 and Wi-Fi's share is expected to rise to 85% by 2018 [WI-FI-TRENDS]. The global success of Wi-Fi even with the relatively small ranges of frequency allocated for unlicensed use has led many spectrum advocates to press for *more* unlicensed spectrum, leading to a more equitably *mixed* ecosystem of licensed and unlicensed approaches that combines the relative strengths of both. While the original notion of (pure) unlicensed usage corresponds to a "commons" scenario where all networks are treated on-par and must accept interference from each other, rule making can readily accommodate provisioning of *priority* for any sub-set operating in co- or adjacent channels.[2] This is precisely the notion of Cognitive *White Spaces* (WS), whereby the identified *primary* services are to be protected from unlicensed usage, as we discuss next.

TV WHITE SPACES & RULES OF "COGNITIVE USAGE"

After the transition from analog to digital TV broadcasting, TV broadcast in the U.S. is limited to channels 2-51; the *unused spectrum* within channels 2-51 at any location is designated as **TV White Spaces** (TVWS). The FCC, in a series of pioneering notices and regulations starting from 2004, effectively allowed Part 15 like (unlicensed) operation in TV White Space frequencies subject to cognitive usage rules for protecting the primary users, i.e. requiring unlicensed or secondary TV Band (TVBD) devices to incorporate "smart radio" features to protect the primary users [FCC 04-113, FCC 08-260, FCC 10-174, FCC 14-144].

General Requirements on TV Band Devices (TVBDs) [FCC 14-144]

The unlicensed TVBDs were classified into two functional categories: a) lower power "personal/portable" devices, such as Wi-Fi–like cards in laptop computers and b) higher power "fixed" devices that could be used to provide services such as 802.22 Base station/CPEs providing a backhaul for broadband client access.

The personal/portable TVBDs were further sub-divided into Mode I and Mode II operations with somewhat different rules applying as detailed below. Fixed devices are intended to operate at a fixed location (e.g. an outdoor access point) while personal/portable devices can operate in unspecified locations based on user mobility. A (secondary) network can only be initiated by a fixed or Mode II TVBD, not a Mode I TVBD.

Fixed Devices: Fixed devices can initiate a network by sending enabling signals to one or more fixed and/or personal/portable TVBDs. Fixed devices can use any available WS frequency but may not operate above 512 MHz (above TV channel 20) if those available channels are adjacent to occupied TV channels. Fixed TVBDs can utilize an external antenna up to 30 meters above the ground and are allowed a higher transmitter power of 1W or up to 4W EIRP with a 6 dBi gain antenna. These devices are not allowed to be located at a site where the ground height above the average terrain (HAAT) exceeds 250 meters, so use in hilly areas may be restricted.

Personal/Portable Devices: Personal/portable device transmissions are restricted to available channels in the frequency bands 512-608 MHz (TV channels 21-36) and 614-698 MHz (TV channels 38-51). These devices are limited to a maximum EIRP of 100mW or 40mW if the device is operating on a channel adjacent to an occupied TV channel.

Mode I Personal/Portable Devices: A Mode I device is not required to use geo-location or have access to the TV bands database. Instead, it obtains a list of available channels from either a fixed or Mode II personal/portable device. A Mode I device may not initiate a network nor may it provide a list of available channels to another device.

Mode II Personal/Portable Devices: A Mode II device uses its own geo-location capability and access to the TV bands database, either through a direct connection to the Internet or through an indirect connection by way of a fixed TVBD or another Mode II TVBD. A Mode II device may select a channel itself and initiate and operate as part of a network of TVBDs, transmitting to and receiving from one or more fixed or personal/portable TVDBs. It may provide a list of available channels to a Mode I device.

Interference Avoidance Methods: Channel availability for a TVBD is determined based upon *geo-location* and *database access* but

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[1] This is in contrast to EU regulations that mandate LBT use in unlicensed spectrum.
[2] For example, in the upper 5 GHz band, Wi-Fi devices share the band with military radar subject to the condition that the Wi-Fi devices are capable of spectrum sensing and if radar is detected, the unlicensed user must immediately vacate the channel.

spectrum sensing can also be used. For fixed and Mode II devices, geographic coordinates need to be determined to an accuracy of +/- 50 meters by utilizing incorporated geo-location capability. Fixed devices that are professionally installed do not need geo-location capability if the coordinates are provided at time of installation. All devices must register their coordinates with the database and must re-establish their position each time it is activated from a power-off condition. Fixed devices shall access and update their database at least once every day and personal/portable device must check its location at least once every 60 seconds. Operation on a channel must cease immediately if the database indicates the channel is no longer available. Mode II personal/portable devices also must re-check its position if it changes location during operation by more than 100 meters. A Mode II device can also establish a bounded area in which a channel is available at all locations within the area and operate on a mobile basis within that area.

TV Bands Database: A TV bands database maintains records for all authorized (primary) services that operate in the TV bands and contains the following information: transmitter coordinates, effective radiated power (EIRP), antenna height above terrain (HAAT), antenna pattern, beam tilt, channel number and call sign. A TV bands database administrator (DBA) may charge a fee for the provision of lists of available channels and other associated information and for registering fixed TVBDs. However, the FCC OET has stipulated that all DBAs in any region must provide *exactly* the same output (WS channel listing etc.) in response to a TVBD client query. In effect, this is achieved by requiring all DBAs to use exactly the same input formation, i.e., the official and publicly available CDBS database of broadcast stations along with a common FCC OET specified algorithm TV coverage area estimation.

Spectrum Sensing: Spectrum sensing *may* be used *in lieu of geo-location and database access* but devices must submit an application for certification and demonstrate with a high degree of confidence that they will not cause harmful interference to

FIGURE 1. One of the first FCC-approved white spaces device is a 1.5-lb radio from KTS Wireless.

incumbents [SHELL 11]. TVBDs that meet the spectrum sensing requirements for personal/portable devices are limited to a maximum EIRP of 50mW. All fixed and personal/ portable TVBDs must be capable of detecting ATSC digital TV, NTSC analog TV and wireless microphone signals at the following detection thresholds:

- ➤ ATSC digital TV signals: -114 dBm, averaged over a 6 MHz bandwidth
- ➤ NTSC analog TV signals: -114 dBm, averaged over a 100 kHz bandwidth
- ➤ Low power auxiliary & wireless microphone signals: -107 dBm, averaged over a 200 kHz bandwidth.

FCC TVWS RULES: A CRITIQUE
As with any new rule making to promote the commercial use of TV White Spaces, the FCC sought to achieve the reasonable "median" of balancing the incentives/opportunities for proponents seeking to develop viable new unlicensed networks based on TV band devices (TVBDs) with measures necessary to ensure that any co-located licensed or primary services are protected. A clear measure of the success of any policy is whether vendors move into the market subsequently with WS transceivers and the rate of uptake into consumer devices. To date, more than ten years after the first FCC notice for proposed ruling making in TV white spaces [FCC 04-113], the only WS devices available on the market resemble those in Figure 1, i.e., intended for high power, point-to-point backhaul segment and manufactured by

a handful of small startups [TVBD]. The integration of embedded WS devices into consumer portable/handheld devices has not yet occurred, stalling the onset of any virtuous market cycle based on increasing adoption volume. As a result, the future of WS technology under the regulations proposed by FCC looks bleak.
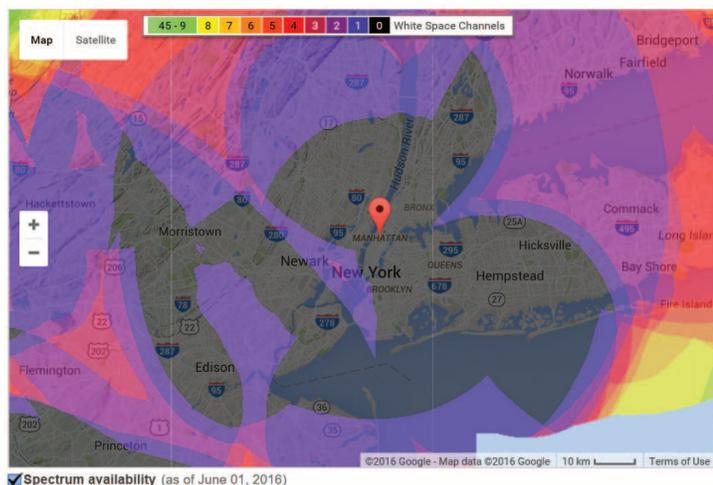
In this section, building upon some preliminary observations in [TCCN 2015], we provide an in-depth assessment for this state-of-affairs and suggest alternate designs that could allow a large white space device ecosystem to develop, similar to that of Wi-Fi.

ISSUES WITH FCC TVWS RULINGS
1. Database showing little or no white space availability in dense metro areas: The WS predictions in the database are based on *assumed* radio propagation (path loss) models that are used to determine the coverage or service region of any primary (DTV) broadcast source and an additional no-talk region for protecting the TV receivers from interference. Needless to say, even the best RF propagation models accurately fit only a specific set of scenarios, and no one model can fit the wide variety of topological conditions (urban, sub-urban, rural; open, obstructed, indoor, etc.). It has been demonstrated that *current database predictions of available WS are almost always conservative, erring on the side of protecting the primary incumbents* [CHAKRABORY]. For example, the database predicts zero or very little WS availability in several U.S. metro areas as of this writing (e.g., Figure 2). At the national level, the availability of white spaces in the U.S. decreases significantly with increasing density of users as shown in Figure 3 (see [ROY15]). This situation severely limits the market size for potential manufacturers, resulting in the reluctance of big manufacturers to enter the white space device market.

A **two-tier architecture** that integrates *targeted spectrum sensing along with a Database **is necessary*** to improve the accuracy and availability of WS channels, especially in densely populated areas where few white space channels are available. For example, a recent study shows that, in the New York City Metro

FIGURE 2. Google white space spectrum database showing zero white space channels available in Manhattan, NY, USA.
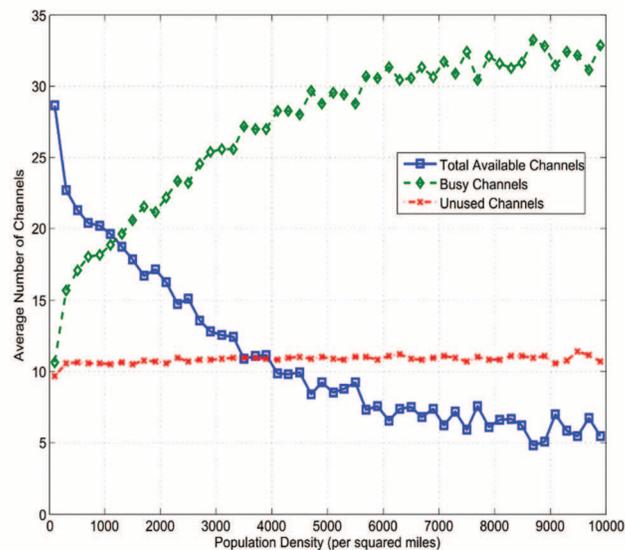

FIGURE 3. Available white spaces, occupied TV channels and unused TV channels versus population density in the U.S.

Area, about 40-75% of white space spectrum is "lost" due to the conservative database, most of which can be recovered by targeted sensing augmentation [CHAKRABORTY]. Thus, *local spectrum information generated by client-side (targeted) sensing can be effectively fused with prior information (such as predictive primary coverage regions) to obtain more accurate WS prediction accuracy.* In other words, channel access by TVBDs should always require the kind of authorization as in current TVWS database architecture, but assisted by client-side information.

Such an architecture also addresses another deficiency in today's white space market, namely, the inability of database providers to differentiate themselves. Today, all WS database providers report identical channel availability information (since this information is computed based on the FCC authorized models). Allowing the database to be augmented with local sensing information can incentivize different database providers to place sensing nodes at various locations (e.g., metros) in order to provide a richer, more accurate channel availability information, thereby differentiating their database product, while simultaneously increasing the available capacity for

TVBDs. This architecture is consistent with a) optimizing channel allocation to various secondary users and b) promoting better secondary co-existence (discussed next).

2. No consideration of secondary-to-secondary coexistence: In our opinion, another oversight is the complete omission of any consideration of secondary co-existence in FCC TVWS rulings that exclusively concentrates on protection of the primary. As mentioned earlier, unlike the EU, FCC typically does not mandate techniques like LBT for secondary co-existence in unlicensed spectrum. However, secondary co-existence will be a bigger challenge in TV white spaces compared to 2.4GHz and higher frequency ISM bands given that propagation and thus interference is spread over larger distances in TV UHF spectrum. While IEEE 802.19 defines standards for co-existence between different secondary networks, most TV white space products in the market today do not support the standard. As a result, TVWS rulings are unable to provide an assurance that TVBD networks can scale effectively, wherein the secondary-to-secondary interference becomes the fundamental performance limiter. An effective solution to the secondary co-

existence problem may include LBT, perhaps augmented with additional database support.

3. Lack of alternatives for Indoor Operations: Per the Second Report and Order (that allowed for two classes of TV bands devices – fixed and personal/portable), Mode II personal/portable devices must incorporate a geo-location capability that self-locates device coordinates to within +/- 50 meters accuracy. With current state-of-art of indoor location technology where GPS does not work (especially in urban areas where concrete buildings are common), this level of accuracy cannot be achieved reliably. As a result, a significant class of mass market Mode II devices are precluded from indoor use, dealing a significant blow to their market uptake. The FCC initially did not consider potential alternatives tailored to *indoor use* – a significant market in dense metro areas where the need for an alternate to the crowded Wi-Fi spectrum is severe.

A recent update to the white space rules by the FCC in 2015 has resulted in the inclusion of an option of specifying the location *uncertainty* by devices to the database [FCC 15-99]. This addresses the strict location accuracy requirements of the previous regulations and could perhaps
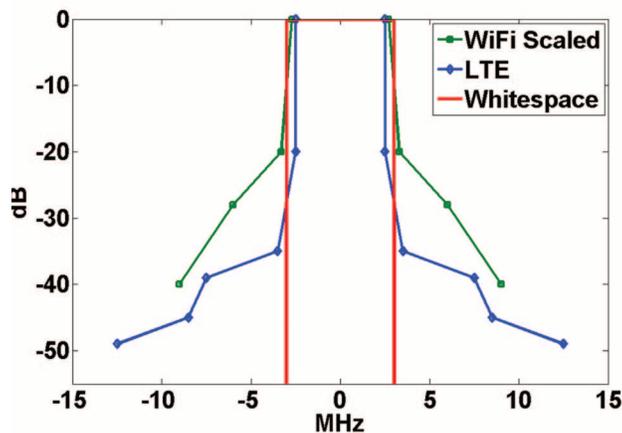
FIGURE 4. Spectrum masks (scaled) for Wi-Fi, LTE and FCC white space device.
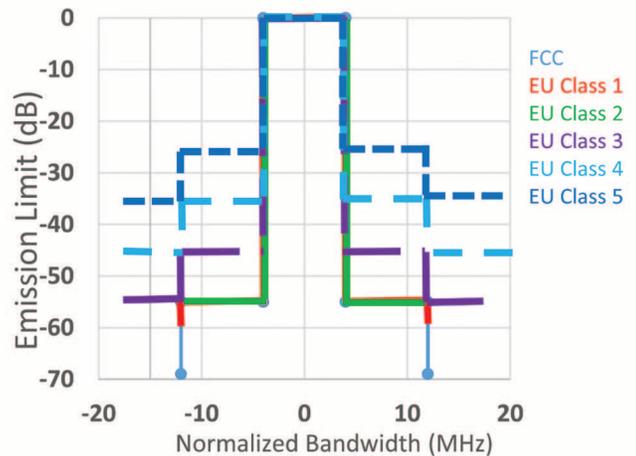

FIGURE 5. Spectrum masks (scaled) for FCC and ETSI Class 1 through Class 5.

spur the development of indoor white space products.

However, the propagation models that are utilized by FCC are still based on outdoor propagation and do not consider major factors, such as building penetration loss. Measurements have shown that indoor white space channel availability can be significantly higher than outdoors [YING]. Given the lack of white space channels in dense metro areas, taking building penetration loss into account will result in the availability of a few channels for indoor use, providing an impetus to the indoor white space device market.

4. Inflexible Settings for Various System Parameters

a) Transmit Spectrum Mask/Out-of-Band Emissions: The transmit mask adopted by the FCC for TVBDs sets extremely stringent limits on out-of-band emissions. The allowed channel emission limit for each of the four maximum power levels at which TV bands devices can operate is simply the maximum power minus 72.8 dB. The rules allow TVBDs to operate at the maximum permissible power in a bandwidth of 5.5 MHz (instead of 6 MHz), with 250 KHz for roll-off for in-band signal. As shown in Figure 4, this emission mask for TV band devices is 35 dB more stringent than the industry standards for Wi-Fi and about 20 dB more stringent than

4G cellular technologies, such as LTE and results in equipment costs for fixed customer premises equipment that are 65% higher compared to comparable equipment operating in other frequency bands. As a result, expensive and complex analog filtering must be added to device front-end to meet the out-of-band emission limits, and essentially rules out a low-cost, lower power solution necessary for integration into client-side portable devices.

Besides the negative impact on device cost, the above exemplifies another key issue with FCC TVWS rule making – specifying fixed parameter values that negatively impact the potential of secondary (WS) networks.

An alternative to the FCC approach is the approach adopted by U.K.'s Ofcom for white space device regulations [ECMA 392, ECC 2011]. Instead of insisting that all white space devices implement a single sharp spectrum mask, Ofcom allows white space devices the flexibility of choosing from a variety of spectrum masks, for example, ETSI class 1 to class 5 [ETSI 301 598] (Figure 5) while controlling their maximum transmit power. Thus, a less stringent ETSI class 5 mask device will only be able to transmit at a much lower power than an ETSI class 1 mask device, which may very well be fine if the former is a low-cost Internet of Things (IoT) device. Thus, instead of a

strict mandate, incorporating flexibility in system parameters, such as spectrum masks can enable a variety of new applications for white space devices.

b. Spectrum Sensing System Parameters: Portable TVBDs that incorporate spectrum sensing are limited to a maximum EIRP of 50 mW (lower than the 100 mW maximum for devices that consult a database), while being required to detect DTV signals at a sensitivity of -114 dBm. Fixing these values without considering any DTV receiver characteristics[3] results in further sub-optimality of secondary network designs.

Spectrum sensing at a sensitivity of -114 dBm is not only overly conservative [MISHRA] but also very challenging. For a 6 MHz TV channel, noise floor is around -100 dBm considering a 6 dB noise figure; this translates to an SNR of -14 dB. For a portable device with smaller antenna size, effective SNR will be in the range of -20 to -18 dB. Signature detection techniques become unreliable and energy detection methods are fundamentally flawed at such low SNRs,

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[3] FCC rule making is entirely focused on transmitters and does not incorporate any receiver-side recommendations. This represents another missed opportunity since pushing for improved DTV receiver design would inevitably also improve capacity (and market size) of TVBD devices.

due to uncertainty of noise power. Thus, sensing is not implemented by white space devices in the market today.

c. Height above Average Terrain Limit:
The range at which a TVBD can cause interference to licensed users increases with the height of the device's antenna. Thus, FCC adopted a maximum antenna height limit of 30 meters above ground level (AGL) for fixed devices. However in scenarios where a TVBD is located at high point, the relevant parameter to measuring interference to the primary is the antenna height above average terrain (HAAT). Thus, while the AGL limit is kept at 30 m, a HAAT limit of 250 m was added. Unfortunately, this decision has the side-effect of unnecessarily limiting TVBD coverage for several scenarios in hilly areas, notably for a high-elevation transmitter and low-elevation receiver. Again, a more flexible regulation, such as setting TVBD transmit power limits as a function of key scenario parameters (AGL, HAAT) or setting (AGL, HAAT) parameters as a function of location of the TVBD would have been a more desirable approach.

In summary, perhaps as a result of being a pioneer in crafting TVWS regulations, we believe that FCC has been conservative and rigid in their regulations. As a consequence, the desired *balance* between effective *promotion* of unlicensed secondary access and providing adequate *protection* of the primary was not achieved, resulting in a white space product ecosystem that is yet to take root, let alone flourish, like Wi-Fi.

CONCLUSION

The above critique suggests some inescapable conclusions – first and foremost, adopting FCC TVWS regulations as they stand by other countries is undesirable. In fact, strategically rethinking white space regulations represents a welcome *opportunity,* especially for developing nations where billions of users still do not have broadband access to the Internet. Towards this end, we have presented alternative design options that promote flexibility, such as a) augmenting the white space database with targeted spectrum sensing to create a more accurate spectrum availability map and

b) allowing flexibility in choice of white space device spectrum masks and other system parameters, to better promote development and growth of a diverse and vibrant white space device ecosystem while still preserving protection of the primary licensed user. ∎

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