
Spectrum Policy for Innovation

BY RICHARD BENNETT | SEPTEMBER 2011

Spectrum incentive auctions are an important policy tool with the clear capability to increase opportunities for innovation.

Ten times more Americans use mobile phones than watch over-the-air television, yet TV broadcasters have exclusive rights to more spectrum than the four largest mobile networks. No less than other countries, the United States economy is hamstrung by out-of-date spectrum policies that retard mobile innovation. The nations that are first to update their spectrum policies will reap an innovation windfall and those that lag will suffer economically. The stakes in spectrum policy are high, but the solutions are straightforward.¹

The National Broadband Plan delivered to Congress by the Federal Communications Commission (FCC) last year recommended the reallocation of 500 MHz of spectrum from current uses to wireless broadband networks. The Plan proposed to reallocate some of this spectrum through an incentive auction that would compensate local TV broadcasters for the release of the spectrum licenses they currently hold.

In his February 2011 State of the Union address, President Obama called for a National Wireless Initiative (WIN) to make 4G wireless services available to at least 98 percent of Americans with a spectrum allocation consistent with the Plan and with an additional allocation for a nationwide public safety network. In June 2011, the Senate Commerce Committee passed S. 911, the "Public Safety Spectrum and Wireless Innovation Act," consistent with WIN. In July, the House Republicans offered a discussion draft titled the "Spectrum Innovation Act of 2011" that addresses the incentive auction and public safety issues in a somewhat different way.² Spectrum incentive auctions should be employed immediately to transfer spectrum from legacy television to innovative mobile broadband, but the proposed public safety network requires further study.

When users of smart mobile devices such as the iPhone and Droid communicate with other people or connect to web sites, a radio in the smartphone communicates with another radio in a wireless base station. In the United States, commercial radio communication uses radio frequency (RF) spectrum allocated by the FCC. The more spectrum smartphone users can use the more data they can transfer in any given period of time. Spectrum policy is therefore a key enabler of mobile broadband and mobile innovation.

The historical practice in spectrum policy has been for regulatory authorities around the world to assign rights to specific radio frequencies to applications according to their

judgment regarding the “best and highest use” of each frequency. This system enabled regulators to harmonize assignments around the world, an important imperative given the fact that radio waves don’t recognize international borders. It worked well until all of the most useful frequencies were assigned.

Technology never stops progressing, however. We’re now in a situation where many of the initial assignments of spectrum are obsolete, so the task of spectrum regulation has become one of reassigning already utilized spectrum to new uses that have more social and economic utility than old ones. Spectrum incentive auctions are a quick and practical means of reassigning spectrum, so it’s important that Congress expeditiously grants the FCC liberal authority to conduct them.

Spectrum reassignment should not be viewed as a one-time event. Spectrum reassignment will become the normal activity of spectrum regulators for years to come, as we can expect that the uses we currently regard as “best and highest” today will be less attractive in the future as the menu of spectrum usage choices expands. In the ultimate future, advances in technology may make regulatory spectrum allocation unnecessary; systems may evolve that will enable broad scale self-regulation, negotiation, and inter-regulation of spectrum use; “smart radios” would be one major component of such a system. These systems don’t exist yet, so policymakers must become adept at the practical means of spectrum reassignment.

Administrative agencies are not effective at evaluating competing demands for a single resource such as spectrum; U.S. policy has recognized since the mid ‘90s that market mechanisms such as spectrum auctions are better, more effective means. Incentive auctions that effectuate the transfer of particular blocks of spectrum from one application and rights holder to another are the best and most practical tool currently available for ensuring that spectrum is used in a way that’s consistent with the public interest. In today’s most pressing case, television broadcasters hold valuable licenses to spectrum that could be used more effectively for mobile broadband, simply because over-the-air (OTA) TV is an older technology with a small audience. If regulators were starting with a clean sheet of paper today, it’s unlikely that they would judge the current allocation of spectrum to OTA TV to be in the public interest.

The incentive auction authority granted to the FCC by S. 911 brings spectrum license assignment up to date and should be supported. The planned public safety network is a step backward, however, because it retreats from forward-looking, multi-purpose networking to the old application-specific spectrum allocations of the past that led to fragmentation of the spectrum map. There are ways to provide public safety with robust networking capabilities without fragmenting the spectrum map, however.

Policy Recommendations

1. Congress should grant permissive incentive auction authority to the FCC.
2. Broadcasters who don’t participate in the incentive auction should be reassigned to digital TV channels shared with other non-participating broadcasters.
3. The FCC should phase out existing application-specific licenses and work toward the goal of creating a single network with multiple components.
4. The FCC should plan for a second DTV transition that redefines DTV as an application provided by multi-purpose networks.

5. The FCC should regard unauthorized spectrum use as the violation of the law that it is.
6. Free spectrum licenses issued in the future should be subject to review and revocation on a five to ten year basis to allow for the ultimate deployment of Dynamic Spectrum Allocation systems when practical and beneficial.
7. Congress should clarify the rights of spectrum license holders relative to their neighbors and authorize the FCC to adjudicate such disputes in a rule-driven, case-by-case procedure.
8. The NTIA should develop a plan to privatize most of the spectrum currently assigned to government agencies at the federal, state, and local levels.
9. The national public safety network proposed by S. 911 should not be built as currently conceived. Instead, it should be a Mobile Virtual Network (MVN) running over commercial spectrum funded in part by auction proceeds and serving first responders.
10. The FCC should develop an empirical means for determining the relative value of exclusive spectrum licensing versus non-exclusive use.

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BACKGROUND

The FCC and similar agencies around the world divide radio frequency spectrum (spectrum) into distinct blocks (ranges), and then allocate each block to a particular application. This process of “divide and allocate” began in an era in which spectrum was viewed as a super-abundant resource that would never be exhausted. Indeed, when the FCC was founded by the Communications Act of 1934, the demands for radio frequency spectrum were minimal, the rate of technological change was slow, and it was appropriate for the agency to take an application focus. According to former FCC chairman William Kennard: *The FCC was founded on the simple notion that each technology was a distinct market with a separate regulatory framework.*³

Allocation by Application

Applying this notion to the technologies that use RF spectrum, the FCC further concluded that each wireless technology warranted a distinct spectrum allocation. This perspective has essentially led the agency to allocate distinct blocks of spectrum directly to applications. In effect, the FCC’s initial approach to spectrum was to create something similar to a modern-day “app store” on the principle that each application (AM radio, broadcast TV, radio taxis, ship-to-shore radio, satellite TV, etc.) requires its own network, and each network requires its own allocation of spectrum.

With the advent of general-purpose mobile broadband networks based on 3G and 4G technologies, technology has made it possible to fully distinguish applications from wireless networks in much the same way that the Internet decouples applications from networks in the wireline space. The modern 4G network is capable of supporting a wide range of applications from text messaging to web browsing to video conferencing.

Emerging technologies such as Dynamic Spectrum Access (DSA) suggest that someday it will be practical to further subdivide wireless networks from long-term spectrum

assignments through systems of inter-network negotiation ranging from spectrum trading to opportunistic access, but these systems are not fully developed.⁴

As the United States and other nations revise spectrum policy to reflect the realities of general purpose networks, they confront a policy dilemma regarding DSA and similar technologies that promise more flexible spectrum use: Do we fully embrace the claims of DSA advocates to the effect that long-lasting spectrum assignments are counter-productive according to the (largely unproven) capabilities of emerging technologies, or do we tread more moderately in order to make the best use of today's technologies today?

The most prudent course is to review specific forms of flexible spectrum allocation for practicality and to specifically endorse the methods with proven or highly probable utility today, such as incentive auctions, while leaving more speculative systems such as DSA for future review as verifiable facts warrant.

Costs of Not Reallocating Spectrum

The refusal of regulators to reallocate spectrum rights from legacy applications with low utility and low demand to more socially beneficial ones slows the rate of innovation and harms the economy. The drag on the economy that such a practice represents is multiplied when other countries are acting quickly; “do nothing and hope the problem will go away” is not a productive strategy in these instances.

In the case of the spectrum currently used for TV, the problem of allocating to best and highest use is compounded by the particular means by which Digital TV (DTV) is currently assigned. The FCC unfortunately requires United States broadcasters to use a system known as ATSC/8VSB instead of the more spectrally efficient DVB-T/OFDM system adopted in Europe and Asia. Therefore, there are two compelling reasons to reallocate the spectrum rights currently granted to broadcasters:

1. To satisfy the greater demand for mobile broadband evidenced by the growing demand for mobile bandwidth and the shrinking demand for over-the-air TV; and
2. To minimize the waste in the current system caused by an incorrect technical standard.

This is a difficult problem to correct. Converting the current United States DTV system to the global standard would allow for more efficient reassignment of the spectrum allocated to DTV at the cost of another TV set and/or converter box transition for OTA TV viewers. Sticking with the current system puts the United States 200 MHz behind our rivals in terms of mobile broadband spectrum, and leaves us with an inferior DTV system. The most palatable option is to reduce the DTV allocation through band sharing (multiplexing) and leave the inferior ATSC/8VSB technology in place. Consumers are effectively organizing a second DTV transition of their own toward Internet-mediated TV services such as Netflix and Hulu Plus.⁵ The FCC should monitor to the shift toward Internet TV and adjust the DTV spectrum allocation accordingly.

POLICY ISSUES

Wireless networks have a well-established history of improving interpersonal communication through narrowband applications such as text messaging and voice. Broadband wireless networks enable richer forms of interpersonal communication such as

video calling and High Definition (HD) voice, and also provide access to content stored on the Web or streamed through the Web by video content services. Emerging mobile broadband applications such as Mobile Augmented Reality hold the promise of improving our interaction with the physical world as well, through improved navigation capabilities and enhanced social networking options.

Mobile broadband improves productivity, quality of life, education, healthcare, and energy efficiency by providing all the benefits of broadband as well as the additional benefits of mobility and location awareness. A fuller account of the benefits of mobile broadband applications is provided in ITIF's reports *Going Mobile: Technology and Policy Issues in the Mobile Internet* and *Opportunities and Innovations in the Mobile Broadband Economy*.⁶

Spectrum Allocation by Application

Historically, the FCC allocated spectrum to specific applications. For example, it allocated the following frequencies to broadcast applications:

- 535 – 1605 KHz to AM radio
- 88 – 108 MHz to FM radio
- 54 – 72 MHz to TV channels 2 – 4

When making these assignments, the FCC not only determined a place for the application in the spectrum map, it determined the amount of spectrum that each particular application required. Each TV broadcaster is assigned 6 MHz; each AM radio broadcaster is allowed to use 10 KHz (Europe assigns 8 MHz for TV and 9 KHz for AM radio.) If the application required more bandwidth than the FCC could find after several assignments had been made, it was allocated more than one place in the frequency range: Conventional terrestrial TV has five distinct allocations, and additional assignments were made for satellite TV.

Limited Value of First-Time Allocations

Most spectrum allocations that have been made by the FCC and similar agencies around the world were “Greenfield” assignments made at a time when no competing uses for the spectrum were envisioned. Hence, assignments were relatively generous and the process was largely non-contentious. And indeed, in most cases the process was largely a giveaway with the receiving party getting to use this valuable resource for free, subject to a few minor public interest concessions. The rights to use the spectrum that's most useful for mobile broadband (300 MHz – 2 GHz) have already been assigned to a number of applications, so the additional 500 MHz recommended by the President and the National Broadband Plan can only come from existing uses rather than by greenfield allocation. Greenfield was the old norm and reallocation is the new norm.

The useful lifetime of most technologies is limited, and this is no less the case for radio-based applications than for any others. Every allocation of spectrum made by a regulator is based on some degree of speculation, which may or may not prove correct over time and has a limited lifetime even in cases where it is initially correct. Therefore, spectrum rights need to be transferred between applications from time to time in any case, as they were when TV was changed from analog to digital. Accelerating rates of progress with wireless

technologies suggest that application-to-application transfers will need to take place more frequently in the future.

Unfortunately, it's extremely difficult for the FCC to alter current spectrum allocations without overturning apple carts. Even the least successful applications attract some users, each of whom has had to invest in the ability to use the spectrum. The 10 percent of Americans who watch OTA TV are a small and declining population now that most Americans watch TV over cable, satellite, DSL, or fiber optics; most of them watch standard definition programming at that. The broadcasters who serve this minority paid no license fees to access their customers, but they did purchase transmission equipment and sign talent to contracts based on their reasonable assumption that their rights of access to the whole market would continue for at least the term of their licenses.

While the FCC has the legal power to unilaterally transfer licenses between applications, the exercise of this power can have unpleasant political consequences, especially when the loser of the spectrum license is armed with a megaphone aimed at the electoral process, as is the case with TV broadcasters.

The speed of technical progress and the consequent increase in competing demands for spectrum requires faster and less political mechanisms for the transfer of spectrum rights.

Just as the legacy rights of real property owners are not absolute, neither are the rights of legacy spectrum users. Like all rights, they need to be balanced against the competing rights of the citizens who would like to use TV spectrum for such things as mobile broadband. The periodic transfer of spectrum licenses should be understood as an inevitable consequence of the development of new applications and ever more sophisticated technologies for radio use. The speed of technical progress and the consequent increase in competing demands for spectrum requires faster and less political mechanisms for the transfer of spectrum rights. Unless nations can do this, they are confining themselves to much slower rates of mobile broadband innovation.

Spectrum Auctions

Spectrum auctions are a politically neutral way of expressing the public's will with respect to spectrum usage. When the right to use spectrum is offered to bidders on equal terms, the market expresses itself in the form of bids that represent expert judgments of spectrum's economic value to application providers. Auctions have largely replaced competing mechanisms such as administrative assignment ("beauty contests") in which the regulator assigns spectrum according to subjective judgment regarding the most appealing proposal for its use. Spectrum auctions are less corruptible than beauty contests, and over time, the FCC and similar agencies have become very good at administering them. Moreover, they have the benefit of enriching the treasury, although this is not a primary goal.

Economist Ronald H. Coase invented the notion of the spectrum auction in 1959, but the FCC didn't implement them until 1994.⁷ They're now widely used around the world, as regulators in other countries have followed the FCC's lead. A number of refinements have been added to the basic notion of spectrum auctions concerning ways of making bids, the hiding or sharing of information among bidders, dealing with aggregation risk, and weighting factors that allow policymakers to steer auctions in particular directions. Such specialized auction formats are known as Simultaneous Multiple-Round Auction (SMRA), sealed bid auction, and Combinatorial Clock Auction (CCA).⁸

Spectrum auctions aren't an unbridled free market activity, however. While the auction leaves the question of the ownership of spectrum rights to the market, the regulator nevertheless restricts the uses to which rights holders may put the spectrum he wins at auction, so auctions don't yet take regulators out of the app store business. There are technical reasons to limit the ways in which spectrum can be used at the present: For example, spectrum doesn't respect national boundaries, so there's a need for international harmonization. Advances in technology may render these considerations moot one day, but we aren't there yet.

Incentive Auctions

An incentive auction is a special kind of spectrum auction in which the seller is the current license holder. In the standard spectrum auction, the government is the seller, but the government's role in an incentive auction is that of an auction manager. In the particular instance that's before us now, spectrum licenses are held by the TV broadcasters who serve specific markets. Although they paid nothing for their licenses, they were issued for a specific term. The incentive auction is meant to motivate them to relinquish these licenses to high bidders who will use the spectrum to provide mobile broadband services. The general proposition is for the government to split the proceeds of the incentive auction between the current license holder and the treasury, with the bulk of the proceeds going to the current license holder.

Broadcasters who relinquish their spectrum in a DTV incentive auction will continue to distribute their programming over the wired cable TV network and its Telco equivalent, over digital broadcast satellite (DBS,) and through video streaming services operated over the Internet. As cable and satellite serve 90 percent of the American television audience today and the popularity of Internet streaming is growing rapidly, loss of over-the-air (OTA) terrestrial broadcasting will not significantly affect the size of the potential audience for television. Some analysts have proposed a voucher system that would allow low-income families to obtain free basic cable if their local OTA broadcast is suspended, but the argument for such a system is weak because basic cable is very inexpensive, on the order of \$12-15 per month.

The risk of the incentive auction scheme is that the current license holder may choose not to accept the amount bid. If this happens on a broad scale, bidders face the so-called "aggregation risk" of ending up with patchwork of spectrum that's sufficient for their purposes in some areas but not in others. This problem affects the detailed design of the auction and doesn't undermine its basic utility.

"Unlicensing"

An additional method for allocating spectrum among applications that don't require exclusive use simply discards licenses altogether. Bluetooth and Wi-Fi are the most widely used unlicensed systems. Manufacturers of Wi-Fi devices are required to pass a certification procedure to ensure that their devices conform to regulations for transmit power levels and other technical characteristics so they don't interfere with licensed users, but Wi-Fi users aren't licensed. TV white spaces (TVWS) are also unlicensed frequencies with similar terms of use as Wi-Fi, plus the additional requirement of gaining daily permission to operate from a White Spaces Database (WSDB) to be operated by firms approved by the FCC.

Unlicensed use doesn't provide users with any sort of guarantee that they can use their devices successfully, however. Each unlicensed user has equal transmission rights, and in some areas and at some times, the number of contenders for a particular unlicensed frequency can exceed the technology's capacity. The allocation for some unlicensed frequencies is extremely generous: As much as 600 MHz is available in the United States for Wi-Fi use, more than the current allocation for all licensed mobile broadband services combined.⁹

Because Wi-Fi enjoys such a spectrum bounty and most users don't expect Wi-Fi signals to propagate outside the walls of their residences, instances of congestion are relatively rare outside densely populated apartment buildings. Similarly, the instances in which Wi-Fi has been successfully used to blanket the outdoors of a densely-populated urban area are also rare. TVWS is in its infancy, so it's too soon to say how well it will perform under load.

Licensed and Unlicensed Allocations

Auctions of various kinds can, in principle, arrive at an allocation of spectrum licenses that closely approximates maximum social utility, and they can reallocate licenses as technology and other conditions change. Conventional auctions and incentive auctions don't provide regulators with much guidance regarding appropriate licensing rules, (the correct amount of spectrum to allocate to licensed and unlicensed uses) however.

The National Broadband Plan recommends the reallocation of 300 MHz to mobile broadband and 200 MHz to fixed wireless use, presumably under a traditional exclusive licensing arrangement.¹⁰ The Plan also recommends additional research on non-exclusive opportunistic use, as well as "a new, contiguous nationwide band for unlicensed use" but doesn't tackle the question of how best to balance exclusive licensed uses against non-exclusive and unlicensed uses.¹¹

FCC Office of Strategic Planning and Policy Analysis (OSPP) Working Paper 43 notes that "identifying the most desirable set of licensing rules for a given band of spectrum" remains an "administrative procedure."¹² The working paper develops a novel set of auction rules that would allow for a marketplace determination of appropriate licensing rules in which some firms seek spectrum for non-exclusive use and other seek exclusive use. An important issue that such an auction must address after the primary question is answered is how to prevent free-riding on non-exclusively licensed spectrum. The authors recommend a hybrid system in which those firms who enter bids for the non-exclusive license would have the right to exclude non-payers from access. The FCC points out that the final determination of the spectrum's status is still an administrative one, although the auction would supply the agency with empirical information that would allow this decision to be made rationally.

The House "Spectrum Innovation Act of 2011" discussion draft proposes to adapt the Working Paper 43 method as a precondition to the allocation of additional unlicensed spectrum:

(17) ALLOCATION OF SPECTRUM FOR UNLICENSED USE—

The Commission may only exercise its authority under this Act to allocate a portion of the spectrum for unlicensed use if—

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- (A) the Commission conducts a system of competitive bidding under this subsection in which bids may be placed—
 - (i) for the allocation of such portion for unlicensed use; and
 - (ii) for a license for the use of such portion; and
 - (B) the bids for unlicensed use, in the aggregate, exceed the highest bid for such license.¹³

This provision has drawn considerable negative commentary from “Open Spectrum” advocates, much of it incorrect. Public Knowledge insists that the discussion draft requires a higher bid for unlicensed in order for it to prevail in the auction, while the bill text actually requires only that unlicensed bids *in the aggregate* exceed the highest *single* licensed bid.¹⁴

Clearing away the distortions, it’s evident that the method proposed by the discussion draft has merit in relation to the problem of deploying non-exclusive usage rights for fixed-location wireless networks. The auction details require additional work, but it’s reasonable to task the FCC with designing such an auction as a means of making high power non-exclusive use a feature of some future spectrum allocation. Forward-looking methods such as this one are keys to the practical use of DSA techniques in real-world conditions and therefore are not at odds with the ultimate aims of Open Spectrum advocates.

The Wrong Way to Assign Spectrum

While S. 911 gives the FCC authority to conduct inventive auctions, it also proposes to construct a special-purpose, nationwide public safety network using dedicated spectrum allocated for the purpose. This network would correct the interoperability and functional shortcomings of the current hodge-podge of disconnected public safety networks that dot the American landscape. Public safety would be the operator of this unified network, hence the jobs of the current operators would be secure.

The arguments in favor of such a special purpose network are unpersuasive.¹⁵ Proponents set a low bar for themselves by touting the interoperability benefits of this new network over the existing systems that don’t interconnect and don’t support the same range of devices. The more relevant comparison puts the creations of public safety network vendors alongside the common cellular network or the Internet, two systems that have achieved complete interoperability and a common set of applications and attached devices without a technology mandate or any other direct intervention by the FCC and without an application-specific spectrum allocation. The White House notes that general-purpose networks, handsets, and applications are more advanced than public safety systems. At a recent hearing before the Senate Commerce Committee, New York City Police Commissioner Raymond Kelly remarked that a 16-year-old with a smartphone has “more advanced communications capability than a police officer or deputy carrying a radio.”¹⁶

This situation is easily remedied by converting public safety to the same commercial network used by America’s teenagers. Public safety insists that it has special applications such as “push-to-talk,” “talk around” (network bypass), and group calling, but these features can (and probably will) be provided as applications running on network-attached devices rather than as special in-network features whether public safety gets its own physical

network or not. The plan for this network is for it to run standard Internet Protocol (IP) over Long Term Evolution (LTE) networks, and very many examples prove that innovative voice services can be provided over IP.

Public Safety does have legitimate needs for priority in times of emergency, but these can be met by functioning as a Mobile Virtual Network Operator (MVNO) running over the commercial system within a contract that grants the necessary access rights when needed.

We don't build special roads for ambulances and other emergency vehicles; we give them priority over the public roads. The same logic holds in the case of public safety networks. We should require public safety to lease or auction its spectrum, using the proceeds to transition to a common technology with specialized applications, if indeed there are any. This is only way to prevent an even larger functionality gap from emerging between teenagers and the police in the future.

What Other Countries are Doing

Other countries are generally moving faster than the United States in making spectrum available for mobile broadband. They are able to do this because they use more efficient DTV systems, they haven't reserved as much spectrum for government use, and they've embraced the auction model for spectrum reallocation.

The FCC standard for DTV, ATSC/8VSB, is less spectrally efficient than the DVB-T/OFDM system adopted in Europe and Asia. In countries where the more up-to-date standard is employed, broadcasters are able to use "Single Frequency Networks (SFN)" of repeaters that cover greater ranges, use less power, and require less spectrum bandwidth to operate. The countries that use the more advanced system have reaped (or will reap) larger "digital dividends" from the phase-out of analog TV.

As a general rule, other countries also haven't assigned as much spectrum to government use as the United States. Because the United States has over-allocated spectrum to government (primarily to out-of-date military systems,) it is reasonable to critically examine government spectrum use and to reallocate unused or poorly used government spectrum to the commercial pool, as recommended by the National Broadband Plan.

THE NATURE OF SPECTRUM

The term "spectrum" is used in policy discourse as a short hand for "radio frequency (RF) spectrum usage rights." By way of illustration, when the FCC assigned digital channel 44 to KTVU in 2009, it simply granted the broadcaster the exclusive right to transmit ATSC-formatted video information using the 8VSB encoding at a given maximum power level from the Sutro Tower in San Francisco. This spectrum block was previously assigned to KBCW for analog TV broadcasting, so a handoff had to be coordinated between the two broadcasters which caused the frequency to go dark for a day.

KTVU's programming is also transmitted by the two satellite systems that serve the United States, and will soon be broadcast over an additional "translator" frequency on channel 48. The additional translator frequency is needed because 8VSB does not support the Single Frequency Network (SFN) model explained previously. Part of the KTVU allocation on both frequencies is used to transmit a duplicate program stream in the mobile DTV (ATSC-M/H) format for handhels and other mobile devices.

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KTVU is the license holder for the transmissions that take place over DTV channels 44 and 48, and DirecTV and Dish Networks are the license holders for the satellite transmissions at 12 and 19 GHz. KTVU, like most broadcasters, is also carried by law over cable and other pay TV systems such as AT&T U-verse and Verizon FiOS.

Spectrum Physics

The duplicate spectrum assignment for DBS illustrates one of the properties of radio frequency spectrum as a physical phenomenon, *free-space path loss*. When RF energy is transmitted into the air from a common omnidirectional (isotropic) antenna, it spreads in a spherical pattern. This pattern of propagation disperses the energy of the signal by the square of the distance from the transmitter. In common sense terms, the farther the signal travels the larger the ball it must fill and therefore the weaker the signal becomes at any single reception point. The larger the balloon, the more water it takes to fill it.

Antennas can be designed to produce various propagation characteristics depending on the application, just as beams of light can be focused in the narrow spot light pattern or a broad flood light pattern. The antenna that sends a TV signal from an earth station to a satellite is highly focused to strike the satellite and only the satellite, but the antenna that sends the programming back to earth is more broadly focused because its signal must cover a vastly larger area.

The energy level at the satellite transmitter is therefore much higher than the energy level at each receiver, but the information carried by the transmission must be received at a level considerably higher than background noise in order to be useful.

The combination of the transmit power level, the antenna propagation angle and area, background noise, and signal processing efficiency determines the minimum power level to satisfy the information needs of an application. Making assumptions about antenna propagation allows for free space path loss to be calculated by an alternate formulation in which the signal degrades at the square of the frequency. This method explains the belief that lower frequencies are more power-efficient than higher ones. Power is limited by battery life in mobile applications; hence they prize lower frequencies and directional antennas. Power is less limited when antennas are in fixed locations, so non-mobile wireless applications can make better use of high frequencies. In a free market scenario, mobile applications would naturally gravitate toward frequencies in the range of 300 MHz – 2 GHz where factors such as power efficiency, propagation, and reflection are ideal.

DBS prefers to use 250 – 750 MHz and 1650 – 2150 MHz within the home because these frequencies suffer less loss within the cable that carries them from the satellite dish to the consumer's tuner than the higher satellite frequencies would. This translates into smaller and less expensive cables and higher picture and sound quality. In-cable use of these frequencies is permitted on an unlicensed basis by the FCC's Part 15 rules, in the same way that computers are allowed to leak radio frequency energy from their circuits at very low energy levels. RF propagation is impaired to varying degrees by reflection and absorption from and by physical obstacles such as hills and building materials, as well as by atmospheric effects. RF spectrum is a form of electromagnetism, and the earth itself is a magnet that emits the low power polarized signals that we detect with the compass. Early space exploration determined that higher power magnetic fields emanate between the earth and the sun known as the *magnetosphere*.¹⁷ As we see during lightning storms, the

ionosphere is electrically charged by solar radiation, and the combination of the earth's radiation and that of the ionosphere combine to form a *wave guide* that limits dispersion of radio waves transmitted at 30 MHz and below.

Apart from electromagnetism, physical conditions such as water vapor impair RF transmissions at specific frequencies. Consumer microwave ovens produce RF energy at 2.4 GHz because this frequency is absorbed by water molecules. The transfer of energy to the water molecules inside food is the principle that makes these ovens work. This same phenomenon limits the propagation of Wi-Fi signals, which enables each channel to be reused several times within the same residential neighborhood without interference; think of this as small geographically separate “pools” of the same spectrum that don't overlap with each other.

Spectrum and the Mobile Broadband Ecosystem

Spectrum is the primary enabler of mobile bandwidth, and is therefore the enabler of bandwidth-intensive and reliability-sensitive mobile applications. There is not an inevitable connection between high appetites for network capacity and innovation, because many of the most popular network applications are very modest in their capacity demands: SMS text messaging places negligible load on networks, and standard resolution voice doesn't load them much more. High capacity and high resilience do, however, open doors to particular application categories that are proving attractive to mobile users, such as on-demand video streaming and high resolution conferencing, as well as preserving the ability to enjoy good old-fashioned web surfing at reasonable speeds.

The utility of high network capacity presents itself in two ways on mobile networks, one way that's shared with wireline networks and one that isn't. In common with wireline networks, high network capacity is necessary for mobile networks that host high resolution video streams. While the overall size of mobile screens is much smaller than those on conventional computers and TV sets, the resolution of these screens is increasing and their size is growing as well. The Apple iPhone 4 boasts four times as many pixels as previous iPhone models, 326 per inch.¹⁸ This high pixel density enables a higher quality viewing experience for text, still images, and video streams which in turn creates higher network load for many applications than the previous standard. High-end smartphones from Apple competitors such as Motorola and Samsung also feature higher resolution displays. Tablet computers such as the iPad and its competitors also sport larger physical displays, although their 132 pixel/inch density is not currently as high as the iPhone standard. Tablets have large enough displays to enable the viewing of 720p HDTV streams, which translates into high network capacity load. Netflix streaming was one of the first iPad applications ever created, available to customers on the iPad's initial release date. Personal video streaming is one of the “killer apps” for tablet computers, most of which lack a wireline connection option.

The load that HDTV streaming imposes on mobile networks is so high that some companies have limited its use to Wi-Fi connections in order to prevent congestion of their licensed frequencies. The lifting of such restrictions can only come about by the allocation of more spectrum to mobile broadband networks.

Aside from its role in enabling high load applications, spectrum also has value to mobile broadband with respect to a problem that mobile networks don't share with wireline

Physical impairments such as water vapor impair RF transmissions at specific frequencies.

networks: Resiliency or network quality of service. Bits travelling across any network have some probability of becoming damaged in transit, calculated in network engineering as the *bit error rate* or *packet error rate* of the network. For wireline networks, this figure is very low; the Ethernet standard is no more than one damaged packet in every 10,000,000. For unlicensed Wi-Fi, the typical observed error rate is one damaged packet in 100 under good conditions, but one in 10 is not uncommon. Damaged packets are discarded by network interface hardware, and are therefore experienced by software as “lost packets.” Wi-Fi compensates for packet loss through an acknowledgement and retransmission protocol, but this procedure increases the delay between successful packets, which can impair time-sensitive applications. Another means of reducing the packet damage is to employ *redundant coding* containing information that allows damaged packets to be corrected on the receiving side. *Forward error correction* (FEC) codes are extra bits transmitted with packets of data to allow such correction to take place without retransmission, but FEC codes add overhead that consumes spectrum, so there’s no free lunch. This form of network load is important because it’s likely to be needed by high resolution conferencing applications that are becoming popular on mobile broadband networks.

Consequently, the need for network capacity is not only dictated by the amount of data that applications transfer, but by the nature of the data itself. Time-sensitive information places greater demands on a network per byte transferred than archived information.

Meeting the Need for Network Capacity

Increasing spectrum allocation is one means of increasing wireless network capacity, but there are others, such as improved signal processing efficiency and better protocols. Wireless networks employ fairly mature technologies, so gains that come from the application of these techniques tend to be fairly small. 802.11n Wi-Fi is much more efficient than previous versions because it uses Multiple Input-Multiple Output (MIMO) signal processing and an improved error correction protocol, but roughly half its performance improvement comes about from its ability to use more spectrum through channel bonding, a technique that is also used in DSL and DOCSIS cable modem systems.

In fact, many of the practices that critics of spectrum auctions have proposed as solutions to the spectrum crunch actually require more spectrum to be effective, such as antenna sectorization and the deployment of additional antenna towers.¹⁹ The reason that these techniques require additional spectrum is straightforward.

Sectorization is simply cutting a pie into smaller slices. Instead of each cell tower containing a single antenna covering the entire cell, a sectorized cell would use three or six antennas, each aimed at a portion of the cell. In order to understand why this technique requires additional spectrum, we have only to consider the fact that radio waves aren’t as controllable as geometric shapes. When a cell is sliced or sectorized, an area of overlap is created at the boundary between each pair of sectors. In order for this area of overlap not to become a dead zone, it’s necessary to use signals on either side that don’t interfere with each other, something that is most typically and efficiently done by deploying distinct frequencies in each sector. This process is more like slicing a hot cherry pie than a cold pizza.

Building more cell towers creates a similar scenario. In theory, only three frequencies are needed to create a complete cell map in which all areas of overlap are served by different

As cell sites become smaller and more numerous, network cost increases and spectrum efficiency actually declines, which creates the need for more spectrum by itself.

frequencies. In this theoretical map, each tower propagates a circular pattern. When each cell is composed of six sectors, a much larger number of frequencies are needed in the overall map to prevent overlap, the precise number of which is determined more by the physical topography than by Cartesian geometry. The following diagram illustrates radio wave propagation in a real-world case where the Cartesian model would predict six distinct circles. The irregularities are a consequence of topography.

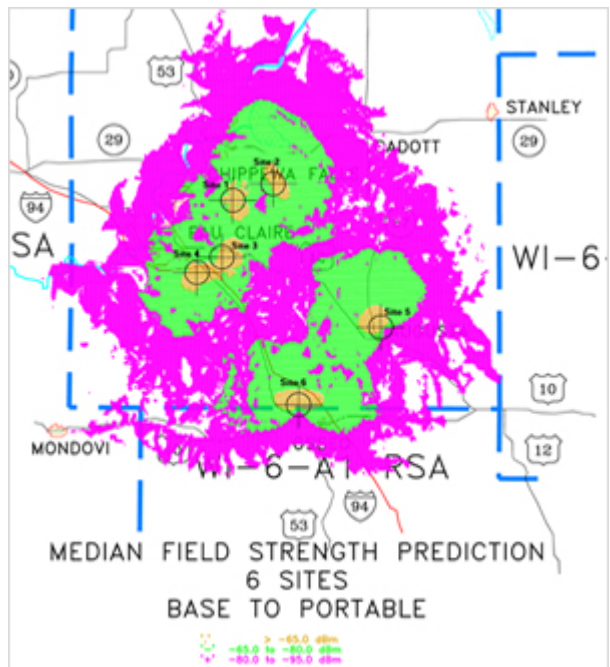


Figure 1: Real-world propagation of an omnidirectional antenna.
Source: http://www.gl.com/consulting_designtools_radio_tool1.html

As cell sites become smaller and more numerous, cell splitting reaches a point of diminishing returns, after which network cost increases and spectrum efficiency actually declines, which creates the need for more spectrum in order to achieve any positive effect.

HISTORICAL PRACTICES IN SPECTRUM POLICY

The era of Greenfield spectrum allocation gave rise to the myth of the omniscient regulator. The operating assumption of the time had it that the FCC was an expert agency tasked with implementing the mere technical details of the Communications Act. Its method of operation was to accept petitions from supplicants beseeching the agency for spectrum rights, in much the same way that a feudal shepherd might have petitioned his lord for access to drinking water. The agency reviewed the petition with all its wisdom, and if it found merit in it, allocated some previously unused spectrum for the supplicant's use. The FCC was able to continue operating in this way even after all the spectrum had an initial allocation because it discovered that it could reassign the same frequencies in different places by limiting power levels, and could even assign blocks of spectrum of different sizes at the same frequencies, such as Ultra Wideband.²⁰ This system has reached an impasse, however.

The current controversy between LightSquared, a satellite-based broadband provider that wishes to use its existing spectrum rights for a new purpose (a terrestrial LTE network) and incumbent GPS users who complain of interference has brought the issue to a head.²¹ The issues in the LightSquared controversy are complex, but they illustrate the pitfalls in changing not just the ownership of a spectrum right but also the application. At least part of the problem that the GPS users have encountered is the result of engineering decisions they made in the design of low-cost equipment as a result of their assumption that most GPS receivers would sense frequencies alongside very low power satellite signals, a sensible, cost-reducing assumption they had no moral right to make as it amounted to using spectrum to which they held no license. At the same time, they had every *legal* right to make this leap, since the FCC establishes no guidelines for receivers, only for transmitters.

Allocation by Application

The NTIA’s Radio Spectrum map illustrates spectrum assignments by application. Note that many frequency ranges are assigned to multiple applications. This is because assignments take location and other transmitter characteristics into account, not just frequency; some allocations (shown in upper case) are deemed “primary” and others (mixed case) are “secondary.” For example, 110 – 130 KHz is assigned to Maritime Mobile as a primary service on the oceans, to fixed data as a primary service on land, and to Radiolocation as a secondary service. Details of the allocation logic are explained the NTIA’s Red Book, but they generally reflect the limitations of legacy technologies.²²

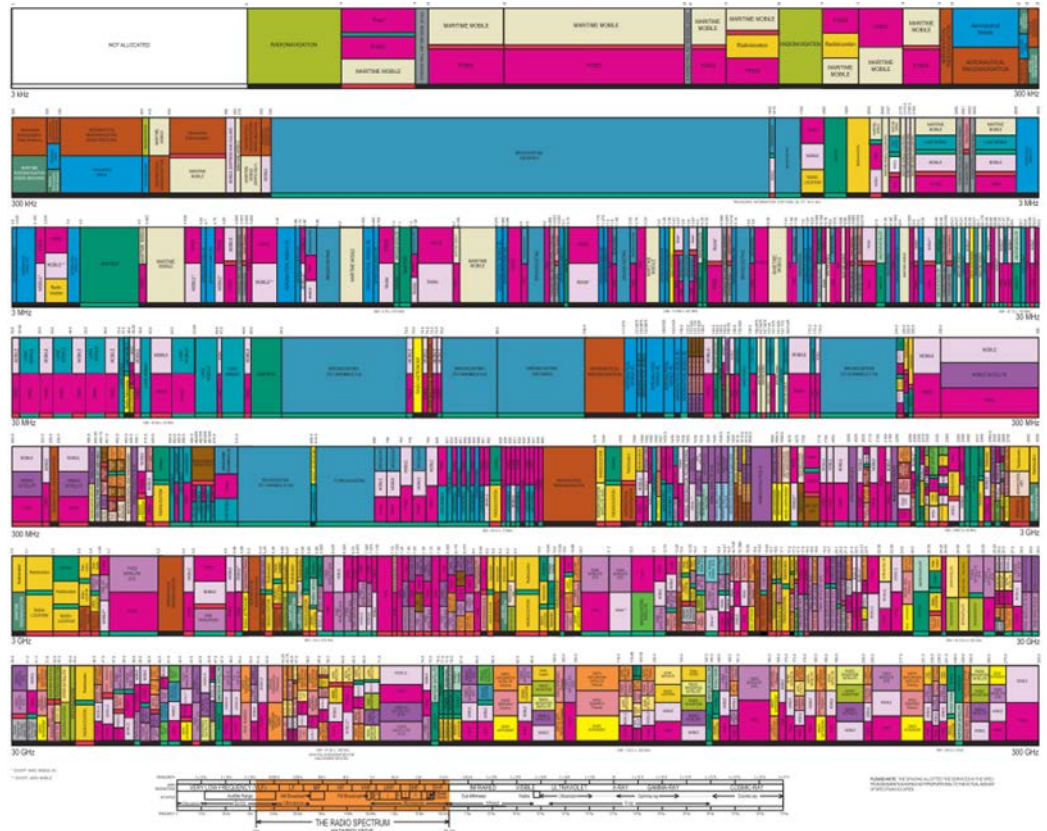


Figure 2: United States Radio Frequency Allocations²³

The overall application set consists of a number of land-based services with satellite counterparts:

- Aeronautical Mobile
- Aeronautical Mobile Satellite
- Aeronautical Radionavigation
- Amateur Radio
- Amateur Satellite
- Broadcasting (radio and TV)
- Broadcasting by Satellite
- Earth Exploration Satellite
- Fixed (non-mobile data)
- Fixed Satellite
- Inter-Satellite
- Land Mobile
- Land Mobile Satellite
- Maritime Mobile
- Maritime Mobile Satellite
- Maritime Radionavigation
- Meteorological Aids
- Meteorological Satellite
- Mobile
- Mobile Satellite
- Radio Astronomy
- Radiodetermination Satellite
- Radiolocation
- Radiolocation Satellite
- Radionavigation
- Radionavigation Satellite
- Space Operation
- Space Research
- Standard Frequency and Time Signal
- Standard Frequency and Time Signal Satellite

It's arguable that the FCC has been overly enthusiastic with satellite allocations, even

though most are on frequencies that are shared with other applications. Satellite was once viewed a much more promising vehicle for communications-oriented applications such as voice than it is today.

One of the primary challenges with application-oriented spectrum allocation is that many allocations have been made on the basis of speculation about the value of the application to society. While many of these speculations are confirmed as well-founded, others are not; many more are well-founded for a limited time (terrestrial TV) but become less compelling as wireline infrastructure develops to do the job better (cable TV and Internet TV.)

The major reason to transition from application-specific spectrum assignments to general-purpose network assignments is to allow the inevitable progress of technology to dynamically reallocate spectrum between applications without repeated visits to the regulator as fashions change.

COMPETING DEMANDS FOR SPECTRUM

Competing demands for spectrum and the rapid rate of technological progress have reshaped the set of issues that demand resolution by spectrum policymakers. The key issues are reallocating spectrum, forecasting demand, transitioning from a system of one-time allocation to a dynamic system that reallocates on demand, correcting innovation-limiting side-effects of previous spectrum allocations, and preparing for an even more dynamic future scenario.

Incentive Auctions

Incentive auctions are a means of reassigning spectrum from a legacy application that no longer has broad appeal to a more compelling and more flexible use. Very few Americans watch TV over the air any more, since 90 percent of those of us who watch TV get our programming from a cable company, telephone company, or DBS provider. At the same time that Americans have dropped over the air (OTA) TV, we've also started to use smartphones capable of accessing Internet-based content and services, including TV programming. According to comScore, 51 percent of Americans had 3G or 4G phones in December 2010.²⁴ The shift in usage patterns motivates a reallocation of spectrum,

The Nature of Incentive Auctions

As we've noted, an incentive auction is a special kind of spectrum auction in which the seller is the current license holder and the government functions as the auction manager. The voluntary TV incentive auction is meant to motivate broadcasters to relinquish their licenses to mobile broadband service providers. The general proposition is for the government to split the proceeds of the incentive auction between the current license holder and the treasury, with the bulk of the proceeds going to the current license holder.

Incentive auctions are a new and untried system that may not produce the desired result in terms of the reassignment of spectrum, so the FCC and Congress must be prepared for more than one incentive auction cycle to perfect the design. Many people find the concept of the incentive auction dubious. One set of critics object to paying broadcasters to relinquish spectrum that was assigned to them for free, and others fear that incentive auctions are too restrictive because they don't open reallocated spectrum to any and all uses. It's important to understand that spectrum reassignment has costs for current

licensees and users, and basic notions of fairness dictate reasonable efforts to mitigate these costs in most cases.

The argument that incentive auctions are too restrictive is more significant. The reason that reassignment is necessary is that the legacy application has declining social value. The day may come when the new user, mobile broadband service provided by a commercial carrier, may be less appealing as well. Rather than create a new way to implement government control over spectrum allocation, it may be beneficial to explore alternate means of more flexible allocation such as spectrum trading or dynamic unlicensed use. These options are discussed in the following portion of this report.

TV After the Incentive Auction

90 percent of Americans who watch television today get their programming from pay TV systems operated by cable companies, telephone companies, DBS satellite companies, or Internet video streaming services such as Netflix. Except for a slight increase in OTA television viewing following the DTV transition, OTA viewership has been steadily declining for twenty years because pay services provide more choice and better quality. Programmers prefer cable distribution to OTA because it allows for better ad targeting and for subscription-based services such as HBO. The fastest-growing segment of the TV distribution business is Internet streaming. Currently four times as many Americans watch TV from the Internet sources such as Netflix and Hulu as watch over-the-air.²⁵

Local broadcasters who relinquish their spectrum in an incentive auction will continue to distribute their programming over pay TV services. As cable and satellite serve 90 percent of the American television audience today and the popularity of Internet streaming is growing rapidly, loss of over-the-air (OTA) terrestrial broadcasting will not significantly affect the size of the potential audience for television. In fact, more aggressive pursuit of Internet delivery may well increase the market for locally-produced programming, and the capital broadcasters will raise from the auction will enable them to develop this distribution system.

Local broadcasters are primarily concerned about losing the “must carry” guarantee currently provided to them by law. Under this provision, pay TV services are required not only to make local programming available to their customers, they are also required to pay local broadcasters for the privilege. “Must-carry” is troublesome in many respects, primarily because it allows local franchise holders to price gouge pay TV service providers, and some alteration of this system is inevitable for reasons of basic fairness. There is no plan to alter it for the purposes of the current incentive auction. This may change if broadcasters refuse to participate in the incentive auction, however. The potential suspension of the FCC’s “must carry” mandate is a powerful negotiating tool, but probably more useful as a threat than as an actuality.

Forecasting Demand

The 500 MHz benchmark for new spectrum allocations for wireless broadband is based on a careful analysis of usage projections prepared for the Cisco Visual Networking Index (VNI) and other projections.²⁶ The VNI has historically lagged actual usage by an average of seven percent, but some critics have charged that other more conservative projections should be used instead.²⁷ Onyeije Consulting cites a blog criticism to the effect that the authors of the VNI have a conflict of interest:

[t]here is overlap between the people who prepare the forecast and the people responsible for marketing Cisco's line of core-network hardware to service providers. The forecast is used to help sell that hardware. Put simply, it's a sales brochure.²⁸

Put simply, this criticism is nonsense: Cisco doesn't sell mobile broadband products, so it has no interests to be conflicted over. While Cisco certainly is the major supplier of IP routing and switching equipment, it has no history of offering inflated projections in the VNI. Other projections for mobile data growth differ from Cisco's in the way we would expect, with some higher and some lower. For benchmarking purposes, it's important merely to define a goal that can be adjusted year after year as more information becomes available.

Cisco explains the VNI methodology in great detail.²⁹ The forecast is based on a seven step model:

1. Number of Users: Obtained from various sources such as Nielsen, IDC and Ovum and validated.
2. Application Adoption: Obtained by region and by application from comScore and other data.
3. Minutes of Use: Obtained from the Cisco Connected Life Market Watch survey and comScore.
4. Bitrates: Calculated from observed data and application characteristics.
5. Rollup: Calculated by multiplying bitrates, MOU, and users together to get average petabytes per month, and then cross-checked against VNI Usage.
6. Traffic Migration Assessment: Reconcile of Internet, managed IP, and mobile segments of the forecast, chiefly subtracting data usage projections from one portion as users migrate to other portions.
7. Validation with Actual Data: Comparing the results of the forecast with actual broadband traffic data from the dozen worldwide service providers who share data with Cisco.

Within the limits of any exercise in predicting the future, the Cisco Visual Network Index's methodology is sound.

Within the limits of any exercise in predicting the future, the VNI's methodology is sound. We don't know which applications will emerge in the future, but for the applications that currently exist, a model that includes numbers of users, device and network characteristics, minutes of use per application, and network capacity gets as close to the truth as possible.

Perhaps the most important feature of the VNI is that it seeks to estimate both the supply of network capacity as well as the demand. The more conservative forecast from the Yankee Group confuses supply with demand, because of its authors' belief that Internet capacity is never a limiting factor on application adoption.³⁰ In fact, high-capacity networks don't fall out of the sky, they're built one piece at a time out of expensive equipment in response to demonstrated demand.

Once built, high-capacity networks have historically promoted the development of high-quality applications, which in turn create demand for further network enhancements. This process is one of the virtuous cycles of innovation.³¹

During the short lifetime of the commercial Internet, from 1994 to the present, a new technology with rapidly improving price/capacity characteristics has met consumer demand almost seamlessly: Fiber optics. Mobile broadband technology is much further along and much less capable of performing a similar economic miracle without new spectrum. Consequently, forecasts that ignore the contingency of spectrum capacity are likely to miss the mark.

Allocation to Applications is Out of Date

One lesson from the controversy over usage forecasts concerns the fundamental impossibility of predicting application use in the future, one of the key variables in any model of future network utilization. Two major shifts are underway in the application space:

1. A migration from broadcast radio and TV programming to personalized content such as Pandora and Netflix; and
2. A shift from fixed location devices such as desktop computers to mobile devices such as smartphones and tablets.

Netflix is single most popular application on the Internet in North America in terms of traffic volume.³² The fourth quarter of 2010 was the first time that more handheld devices were sold (101 million) on a global basis than personal computers (92 million,) and the trend line for handhelds is strong.³³ It's therefore reasonable to believe that the VNI projections are sound unless a new application emerges that requires an upward adjustment, but the more important point is that neither of these trends was visible when the initial allocations of TV, radio, and cellular spectrum were made. In fact, none of them could have been visible to a responsible regulator, but they are now upon us.

The VNI predicts that wireless data usage will ultimately exceed wireline usage:

In 2015, wired devices will account for 46 percent of IP traffic, while Wi-Fi and mobile devices will account for 54 percent of IP traffic. In 2010, wired devices accounted for the majority of IP traffic at 63 percent.³⁴

This prediction would be surprising if the methodology behind it weren't so diligent and if it weren't shared by other responsible forecasters such as IDC.³⁵

This combination of factors—the growth of mobile broadband and the transition from news and entertainment broadcasting to personalized delivery—suggests that the traditional approach whereby the omniscient regulator assigns spectrum by application is out of date and out of touch with marketplace dynamics. The most responsible correction is to begin the process of reallocating spectrum away from single application systems toward general purpose systems that can provide access to a number of applications. Rather than carving the spectrum into the application niches already mentioned, it's more sensible to divide it into technology niches for modes of communication such as mobile, satellite, and backhaul. Rather than creating a discrete number of distinct networks, the goal should become one pervasive and interoperable network with a number of components.

Resolving the Reallocation Uncertainties

The fifteen year transition from analog TV to digital TV offers a number of lessons to policymakers. The transition was unnecessarily long because it was unprecedented and

regulators were uncertain about the disruption it would cause; it was delayed at the very last minute by regulatory hand-wringing. Yet the transition was much less troublesome than many feared, in large part because so many Americans were completely unaffected by it. The 90 percent of the American television audience that subscribes to cable or DBS didn't have to do a thing to watch TV after the transition because the shift from analog to digital was accomplished by their service providers. There is little doubt that the transition could have been accomplished in five years or less without additional disruption.

If future spectrum reallocations are to take place on a timeline closer to five than to 15 years, it will become necessary to better clarify the nature of spectrum rights. Currently, all RF spectrum rights within United States borders is owned by the federal government. Some spectrum is used by the Defense Department and other federal agencies, but the portion used for commercial purposes is assigned by law to the FCC. The FCC leases it to various users in the form of time-limited licenses or makes it available on an unlicensed basis to users of particular transmitting devices that it has certified as conforming to general rules. An expectation has developed that once issued, a license must be automatically renewed indefinitely, but this expectation is not grounded in law. Additional expectations have arisen to the effect that unauthorized spectrum use by unlicensed services such as wireless microphones should be treated as an authorized use after some time as well. Clarifying that these expectations are unreasonable is one step toward speeding up the reallocations that will be necessary in the next few years to rationalize the spectrum map.

The dispute between satellite broadband provider LightSquared and consumer GPS equipment manufacturers illustrates the need to clarify the rights granted by a spectrum license. LightSquared wants to change its business plan and repurpose the spectrum license it currently holds in order to become a wholesaler of LTE services. The single most important impact of this pivot is the use of higher power transmission from very many locations in the United States (Satellite ground station transmitters also emit high power, but only at a single point). Testing indicates that this new mode of operation will certainly have an adverse impact on LightSquared's spectrum neighbors that they can only mitigate by replacing some number of GPS receivers with more robust alternatives.³⁶

If repurposing spectrum from low power to high power uses is to become the norm, receivers need more robust designs in order to be "future-proof." Because the LightSquared spectrum was originally used for low-power satellite transmissions, there was no need for GPS makers to add radio filters to consumer devices to protect against a form of interference that didn't exist under the rules in place at the time the GPS receivers were built. In addition to the problems created by the LightSquared's transition from low power to high power services, there are aspects of this dispute that relate to potentially unauthorized use of spectrum adjacent to the GPS band for high precision GPS systems.

The dispute highlights the fact that RF receivers need to be constructed in way that's tolerant of changes in adjoining frequency bands. In a regime in which spectrum assignments are static and unchanging, there was a temptation for manufacturers to cut corners by leaving out filters and signal correlation logic that best practice guidelines require. The LightSquared/GPS testing indicates that some consumer GPS receivers and some commercial high-precision GPS receiver manufacturers have taken design shortcuts

that smartphone manufacturers have not taken, and these shortcuts have implications for device reliability.

DTV's Technical Errors

The DTV standard adopted by the FCC some fifteen years ago has a number of technical drawbacks that make it inefficient in terms of spectrum requirements. Because of these shortcomings and policy errors, excessively large blocks of spectrum were assigned to local broadcasters in the course of the DTV transition.

- United States broadcasters are forced to use a modulation system known as 8-level Vestigial Sideband Modulation (8VSB) that is less efficient in terms of bits/hertz and less robust in terms of multipath distortion than more modern systems such as the Orthogonal Frequency Division Multiplexing (OFDM) used overseas and in such American systems as DSL and Wi-Fi.³⁷
- Broadcasters are assigned enough bandwidth for several program streams instead of the one stream that was permitted under analog rules. This is why most over-the-air stations broadcast channel “multiplexes” such as channels 7.1 and 7.2, where secondary programming is usually of poor quality. Channel assignments are separated by unused “white spaces” that serve as “guard bands” between transmitters following an analog convention, but modern systems of modulation do not require such large guard bands. Wi-Fi’s guard band overhead is roughly five percent, while American DTV is two-thirds guard band and one-third signal.³⁸

Rather than creating a discrete number of distinct networks, the goal should become one pervasive and interoperable network with a number of components.

The 8VSB mandate makes it more difficult for American television broadcasters to operate Single Frequency Networks (SFN.) In the SFN, relays operate on the same frequencies as primary antennas and therefore don’t require additional spectrum for the same content. This problem arises because 8VSB lacks the ability to deal with multipath interference in a rational way. The global system (used in most of the rest of the world) captures useful information from time-synchronized OFDM signals coming from different transmitters that would degrade the TV experience in the United States. Global DTV doesn’t permit SFNs of unlimited size, but it does enable spectrum rights to be assigned more parsimoniously.

The failure of the current DTV system to adopt an efficient standard suggests that the planning should begin for a second DTV transition. This transition can be accomplished in one of two ways:

1. We can once again require over the air television receivers to convert to a new standard; or
2. We can reassign existing TV broadcast rights to multiplexed channels shared among each other. Instead of each broadcaster using an entire “multiplex” for both high-demand and low-demand programming, a single multiplex such as 7.1, 7.2, 7.3, and 7.4 could carry the programming of the four major networks in a market.

The fastest and least disruptive course is the second. As long as broadcasters retain their retransmission mandate with respect to cable and DBS, their only rational objection to a multiplex arrangement for their most popular over-the-air content will be alleviated.

Spectrum usage rights must have the dynamic character of markets in order for rational patterns of valuation and use to develop.

Continually Evolving Technical Landscape

The fact that the recently-completed DTV transition needs to be reviewed so soon after it was accomplished and the evident changes in spectrum use patterns exhibited by smartphone and tablet users underscores the inability of traditional spectrum allocation policies to keep pace with advances in technology. For every trend that we can predict in the wireless future, two or three others will probably appear that we're unprepared to handle. The accelerating rate of wireless application progress suggests that deregulatory, market mechanisms will achieve even greater prominence in the future.

The incentive auctions proposed by the FCC, the Congress, and the President have been criticized by some as too conservative because they continue to invest application power with the regulator rather than the market. The incentive auction would retain the FCC's traditional power to assign spectrum to applications, even if it assigns some blocks to multiple uses. George Mason University economics professor Thomas W. Hazlett, a former FCC chief economist, proposes a more liberal scheme called "Overlay Auctions" that would eliminate the requirement to use specific blocks of spectrum for particular applications.³⁹ Hazlett's system has a number of forward-looking features, particularly the assignment of larger blocks of spectrum. This is valuable because emerging technologies perform best with large, contiguous blocks than with more numerous smaller ones, and large blocks minimize out-of-band interference with neighboring spectrum blocks.

Overlay rights are too large a step at present in view of the limitations of existing technology. They may well be the future of spectrum allocation because their freedom from application bias offers the ultimate in utility. Before transitioning from the application-based system of the past to such an advanced system, however, it will be necessary to alleviate the interference concerns that have arisen in the 700 MHz auctions and White Spaces proceedings, and yet again in the re-purposing of LightSquared. The application-centric system has allowed the FCC to get by without specifying boundary rights for the more recently assigned blocks of spectrum. All RF transmissions at a given frequency produce effects in adjacent frequencies; in general, they decay into energies at higher frequencies. Clarification of adjacent usage rights will require the adoption of receiver standards that the FCC has been loath to specify.

Enabling Technical Progress through Spectrum Policy

A spectrum policy that enables reallocation of spectrum rights from a narrow application to a broadly-purposed network that enables multiple applications is a step in the right direction, even though it's not the last word. A general grant of authority to the FCC to conduct incentive auctions that reward rights holders for releasing spectrum licenses before the expiration of their terms is a practical means of achieving this goal. Consequently, it would be wise for Congress to grant this authority to the FCC and to follow it up with a plan that will encourage government agencies to release their under-utilized spectrum as well.

Spectrum usage rights must have the dynamic character of markets in order for rational patterns of valuation and use to develop. Means of resolving rights disputes between license holders are also important, and are not at all well developed. While receiver standards are important, the problem of cross-channel interference (RF signals centered on a frequency erode into harmonics at multiples of that frequency, producing small amounts of

interference in neighboring spectrum blocks that affect some applications) is much larger than the effects that can be mitigated by a simple rule for receivers. Cross-channel interference manifests differently for each pair of applications: A terrestrial radio network will produce much more visible interference in an adjacent satellite block than vice versa, owing to different power levels, for example. Similarly, digitally encoded signals are generally more robust than analog ones, and can produce interference on an analog application while not experiencing interference itself, even when power levels are the same. Rights issues such as these are not easily resolved, and policy thinkers have only just begun to explore them. An event sponsored by ITIF and Silicon Flatirons undertook a preliminary examination of this issues in November 2010, and a great deal more needs to be done on this front.⁴⁰

The reassignment of spectrum from applications to networks and the clarification of usage rights are two key problems that can either advance or retard innovation.

ALTERNATE MEANS FOR REASSIGNING SPECTRUM

The utility of spectrum auctions in general and incentive auctions in particular are well understood, but these are not the only tools available for spectrum reassignment. Additional mechanisms include unlicensing, secondary uses, secondary markets and spectrum trading.

Unlicensing

Unlicensing has been used successfully to create millions of Wi-Fi networks around the world. These networks make use of unlicensed spectrum in specified blocks at 2.4 GHz and 5.8 GHz. Wi-Fi assignments are fairly uniform around the world, although each regulatory region has slightly different rules. Wi-Fi products use a combination of location information—a user-settable country code—and a system of dynamic sensing known as Dynamic Frequency Selection (DFS) to conform world-wide products to local regulations.

A study commissioned by the UK regulator Ofcom in 2009 found that Wi-Fi networks suffer from interference from non-Wi-Fi applications and from each other.⁴¹ In the more rural parts of the UK, the most common form of interference was from systems such as baby monitors that tend to stream analog information at the same power levels and on the same frequencies (2.4 GHz) as the most common Wi-Fi channels. As baby monitors have the same spectrum rights as Wi-Fi, there's no limiting their use under the unlicensing regime, except when the owner of the baby monitor is also the owner of the Wi-Fi network suffering the interference.

In Central London, a different problem arose. Wi-Fi access points typically announce their presence every tenth of a second for technical reasons. These announcements, known as Beacons, are sent at the lowest data rate the channel supports and often include 200-400 bytes of data.⁴² Beacons are transmitted whether the network is otherwise actively used or not. A large number of nearby Wi-Fi networks send so many Beacons that their entire capacity can be consumed by them; a similar phenomenon occurs at network industry trade shows.

These problems have been known in the Wi-Fi engineering and standards community for a very long time and remain unresolved. There are potential solutions to Wi-Fi overuse and to Wi-Fi corruption by both technical and policy means. Similar issues will certainly arise

with respect to other unlicensed services such as the TV White Spaces (TVWS,) and a partial solution to the corruption problem is in place in the form of a White Spaces database (WSDB) that must be checked for permission to use TVWS frequencies. TVWS are a long way from overuse, so potential solutions may emerge for coordination between TVWS users before such problems become critical. The important point is that the WSDB is a form of pseudo-licensing or hybrid licensing that can be used to mitigate problems that would otherwise arise—and have arisen—in purely unlicensed scenarios.

The special auction proposed by the House *Spectrum Innovation Act* discussion draft is another method of hybrid licensing that's more permissive than the exclusive license and more robust than unlicensing (see discussion above at *Licensed and Unlicensed Allocations*.)

Secondary Use

TV White Spaces are a secondary use of spectrum whose primary use is DTV. Their primary appeal is potentially better propagation in rural areas than unlicensed alternatives such as outdoor Wi-Fi can produce. Their shortcoming is the higher potential for interference that comes with greater propagation and the greater need for coordination in real systems.

Ultra-wideband (UWB) is another form of secondary use. Unlike TVWS, UWB is designed to co-exist with active primary users. It occupies a very large block of spectrum, typically 500 MHz and transmits at a very low power level. By comparison, a TVWS channel is only 6 MHz wide. UWB is intended for Personal Area Networks (PAN) confined to a single room. UWB was created by regulation permitting its use after testing indicated it caused no discernible interference with incumbent systems, but it has yet to make a significant market appearance due to its limited utility with respect to Wi-Fi. UWB is a significant attempt by regulators to follow-up the successful Wi-Fi system with a second unlicensed system.

Secondary uses are most practical when the characteristics of both primary and secondary systems are well-known. To achieve maximum utility, primary and secondary users require a degree of coordination that's more easily achievable in commercial arrangements between actual parties than in nebulous standards-setting arenas or regulatory scenarios.

Secondary Markets and Spectrum Trading

Secondary markets and spectrum trading are systems tailored for the coordination that secondary uses require. A primary rights holder is free to negotiate under such systems for additional uses that don't impair the primary spectrum right, and as these are market transactions executed by contract, the parties are able to specify coordination requirement in as much detail as necessary.

Two practical examples that exist today are Mobile Virtual Network Operators (MVNO) and roaming agreements. An MVNO such as TracFone buys usage rights to a facilities-based mobile network on mutually agreeable terms. TracFone is then free to sell its service through the retail outlets it develops under terms it defines, which currently consist of pre-paid calling and data plans.

Roaming agreements are typically made between network operators to provide service to customers in areas of poor coverage or high congestion. Roaming agreements require compatible networks, and are quite common among the large national carriers and between

national networks and regional ones. These arrangements will be easier to implement after the conversion to LTE, a common technology base.

Spectrum trading is more complete transfer of rights than either MVNOs or roaming agreements. In the trading scenario, a rights holder transfers his right to another party for full use for a specified period of time. Spectrum trading will become an important tool for network operators as they transition to LTE.

Emerging Technologies and Spectrum Policy

Licensed spectrum use, secondary use, and spectrum markets presuppose the ownership of spectrum usage rights, however granted. Advocates of Dynamic Spectrum Access (DSA) propose an alternative system of free reign to access all frequencies according to rules similar to those applied to Wi-Fi. The argument for DSA asserts that technology will someday enable pairs or groups of radios equipped with sophisticated signal processors to detect and avoid active users and rendezvous on free blocks of spectrum that would otherwise go to waste. This is a promising vision.

*Dynamic Spectrum
Access offers a promising
vision.*

It has given rise to features in the current generation of Wi-Fi and cellular equipment that enable limited forms of spectrum shifting, and motivated the FCC's enquiries into UWB and TVWS. Its promise remains unfulfilled for a number of technical, regulatory, and economic reasons that are as yet not well understood. According to the DSA vision, the NTIA's multi-colored spectrum map will one day become all white. Whether this happens, and when it happens if it does are unclear, but the existence of the DSA vision suggests that spectrum policy should retain enough flexibility to enable it to become reality should technical and economic developments permit.

One means of securing a path to the colorless spectrum map is to ensure that all free spectrum allocations are time-limited and that paid ones can be resold. Allocating free licenses for a span of time in the general range of five to ten years will allow regulators to review the state of technology as the term of the license nears its end and make a judgment regarding the efficacy of their renewal. At some point, many licenses will no longer need to be issued on an exclusive basis. This is a prudent course to follow to permit the use of any new technology that enables more effective use of spectrum.

POLICY RECOMMENDATIONS

1. Congress should grant permissive incentive auction authority to the FCC. Permissive auction authority would allow the FCC to decide which bands of spectrum to offer up, how to set the reserve price (if any), and how to divide the proceeds between the legacy user and the Treasury. Permissive authority will allow the FCC to fine-tune successive auctions (those that follow the one-time TV incentive auction) as necessary in order to obtain the desired result, and obviate the need to go back to Congress time and time again before auctioning additional bands. If the FCC abuses this authority in the future, it's within the power of Congress to revoke it.
2. Broadcasters who don't participate in the TV incentive auction should be reassigned (or "repacked") to digital TV channels shared with other non-participating broadcasters. The current allocations for TV broadcast spectrum are overly generous, as each station has been allocated enough spectrum to broadcast a "multiplex" of several programs. Each of these overly-generous allocations is

sufficient to carry the primary programs for three to five stations simultaneously. Non-participating stations should be multiplexed over a single allocation to free most of the spectrum they're currently using for low-demand programming in markets with extremely high demand for mobile broadband capacity. At some point in the future, it may be desirable to eliminate OTA DTV entirely, but we don't propose to take this step immediately.

3. The FCC should phase out existing application-specific licenses and work toward the goal of creating a single network with multiple components. The one lesson that emerges most clearly from the history of spectrum allocation is that every use we can imagine for spectrum today will be obsolete within a generation or two of technology. The reason we need incentive auctions today is to bring policy up to date with the relentless advance of technology. Therefore, the allocations of spectrum that regulators make today and tomorrow should favor flexible, multiple use networks over single applications such as broadcast television, ship-to-shore radio, and paging.
4. The FCC should plan for a second DTV transition that redefines DTV as an application provided by multi-purpose networks. Digital television is the last of the single application networks, and as such it should be eventually phased out along with all the other single application systems in favor of multi-purpose networks. DTV is little more than an application that the networked citizen runs on a flexible platform such as a mobile handset or docking device attached to a femto-cell that also supports a variety of other content and communication applications. The second DTV transition should enable the creation or expansion of multi-purpose networks and phase out TV as an application that owns its own network. This doesn't imply that DTV should become an application exclusively for mobile broadband networks, but does imply that at a minimum DTV should become part of a broadcast platform that supports mobile receivers, audio-only broadcasting formats, and possibly audio broadcasting combined with still images.
5. The FCC should regard unauthorized spectrum use as an unauthorized use that does not establish squatter's rights. A number of unauthorized uses of licensed spectrum, such as wireless microphones, are impeding the transition from TV to digital networking in the 700 MHz band and elsewhere. The TVWS system has been required to accommodate these uses even though they've never conformed to the law in any meaningful sense (they rely on the Part 15 loophole for radiated emissions from consumer devices that were meant for random emissions from computers.) Such applications should be clearly labeled as contingent on regulatory approval so that buyers know they're assuming risk of using them.
6. Free spectrum licenses issued in the future should be subject to review and revocation on a five to ten year basis to allow for the ultimate deployment of Dynamic Spectrum Allocation systems when practical and beneficial. In the future, the whole activity of formal spectrum allocation by a radio regulator may become unnecessary. Whether this happens in five years, ten years, 50 years, or not at all is open to question, but spectrum policy should allow for the phase-out of free licensed spectrum if it does come to pass.
7. Congress should clarify the rights of spectrum license holders relative to their neighbors and authorize the FCC to adjudicate such disputes in a rule-driven,

case-by-case procedure. The LightSquared transition plan has opened a host of issues on both sides of the dispute. The GPS makers have, in some cases, effectively appropriated spectrum that was never assigned to them to make their systems better and cheaper; the original siting of LightSquared next to a satellite-based service makes their proposal for a massive increase in transmit power at thousands and perhaps millions of locations very troublesome. The property rights model for adjudicating spectrum disputes doesn't capture the nature of spectrum physics, and is therefore in need of refinement. Congress and the spectrum policy community need to add clarity by defining reasonable expectations for spectrum users relative to each other.

8. The NTIA should develop a plan to privatize most of the spectrum currently assigned to government agencies. This plan may resemble the incentive auction system, with proceeds to cover the costs of transitioning government systems and in some cases developing new technologies to accommodate government applications on multi-purpose networks.
9. The national public safety network proposed by S. 911 should not be built as planned because it's an unnecessary fragmentation of spectrum for a special purpose that's not as special as its advocates believe. Public safety has failed to demonstrate a single application that can't be implemented over a general-purpose LTE network running standard IETF protocols. Push-to-talk, group calling, and talk-around are simply specialized versions of VoIP that can be accommodated by apps running over LTE or Wi-Fi. Instead of building and operating its own network, public safety spectrum should be leased or auctioned and the proceeds used to contract with mobile network service providers for a virtual network. This would allow public safety to function as a Mobile Virtual Network Operator (MVNO) similar to TracFone. The proper contractual arrangement can provide public safety with priority access when it's genuinely needed without taking valuable spectrum out of service at other times.
10. The FCC should develop an empirical means for determining the relative value of exclusive spectrum licensing versus non-exclusive use. Historical allocations of non-exclusive usage rights have taken place under a wide open "unlicensing" regime, but there is a middle ground that is more permissive than exclusive use and more controlled than unlicensed use. The development of this middle ground is important to the development of high power non-exclusive networks and the practical use of DSA techniques for networks larger than the Wi-Fi wireless local area networks (WLANs) and Bluetooth wireless personal area networks (WPANs) that are the best examples of non-exclusive spectrum rights today.

CONCLUSIONS

A regime of spectrum rights based on the property model was initially proposed by Coase in 1959. While a great deal of progress has been made in this direction, regulatory bodies retain control over the assignment of spectrum to applications and currently use auctions simply to choose among potential providers of a chosen application. Under this system, priority should be given to the building of multi-purpose networks over single-use applications. Recent experience teaches that application creators are much more imaginative and faster-moving than spectrum regulators. Regulators would very much like to be relieved of the task of predicting the value that society will place on future applications, and citizens stand to benefit from such a shift in policy.

The incentive auction system proposed by the FCC, the Congress, and the President is an important spectrum policy initiative that will enable the United States to satisfy its immediate interest in making more network capacity available to users of smart mobile devices. There is no practical alternative to transferring the 500 MHz from low-value incumbent uses to multi-purpose networks. Responsible forecasts demonstrate a clear need for at least this much spectrum, and the assertion that network capacity can be increased as needed without additional allocations is technically and economically naïve.

In the distant future, it may very well be the case that spectrum ownership and use according to property models will become obsolete as all of our wireless devices negotiate an ideal sharing of the pervasive commons. Practical spectrum policy needs to deal first with today's requirements, while leaving the door slightly ajar for the development of tomorrow's technologies. A system of spectrum free licenses of limited terms and free trading of spectrum rights satisfies both objectives.

[Editor's note: Minor errors in the original version of this report were corrected September 19, 2011.]

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ABOUT ITIF

The Information Technology and Innovation Foundation (ITIF) is a Washington, D.C.-based think tank at the cutting edge of designing innovation strategies and technology policies to create economic opportunities and improve quality of life in the United States and around the world. Founded in 2006, ITIF is a 501(c) 3 nonprofit, non-partisan organization that documents the beneficial role technology plays in our lives and provides pragmatic ideas for improving technology-driven productivity, boosting competitiveness, and meeting today's global challenges through innovation.

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