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Hearing on Spectrum Policy:

Avoiding the Spectrum Crunch: Growing the Wireless Economy through Innovation

Before the Subcommittee on Technology and Innovation

of the Committee on Science, Space, and Technology

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Summary of Testimony

Computing is undergoing a dramatic shift from fixed-location desktop and nomadic laptop systems to mobile devices, networks, and applications. *In 2011, the number of smartphones sold worldwide exceeded the number of personal computers sold for the first time.* Only half of Americans have smartphones so far, so the trend will continue for some time. One day appliances and other devices will come to have smartphone capability built in, so the number of "smartphones" will exceed the population many times over.

New users will use mobile social networks, among other applications. Last week, Facebook acquired Instagram, a photo sharing service with only 13 employees, for a billion dollars because Instagram had acquired 40 million users in only 16 months of operation. "Mobile Augmented Reality" is a new application category that extracts information from massive databases in the Cloud relevant to a user's location, activity, and preferences; it moves video streams between the user and the Cloud. *All of these applications require spectrum – the more the better – and as they're truly mobile there are limited opportunities to offload their spectrum needs to short distance Wi-Fi networks.*

Spectrum assignments by regulators around the world have produced a highly fragmented system of relatively small assignments for a relatively large number of applications, as we see in the NTIA's spectrum allocation chart. *We need to realign spectrum into a smaller number of larger allocations for general-purpose commercial networks because such networks have the proven ability to manage the demands of competing users and applications*. In order to do this – a process akin to putting Humpty-Dumpty back together – we need to shift most government applications and all low-value commercial applications onto general-purpose commercial networks. This is where the 500 MHz recommended by the National Broadband Plan will come from, and the only way to get to a more realistic allocation of commercial spectrum. All spectrum assignments ultimately come from a common pool.

Many government applications are critical for first-responders during periods of crisis. We have technologies that permit certain applications to get high-priority treatment on commercial networks. But commercial users also desire more spectrum during such events, so we have a policy conflict. This conflict was resolved by Congress through the creation of FirstNet, the public safety network operated by NTIA, but this is not a satisfactory solution. *Ultimately, FirstNet operations should be commercialized, as soon as devices have been developed that allow trusted priority access policies*. When we have such devices, the balance between public and government use can be specified by contract rather than by spectrum fragmentation.

Striking a balance between commercial and government use will remain a difficult policy problem until mobile network technology advances to the next stage. *Ultimately, technology will enable reliable networks to support multiple simultaneous transmissions (many speakers at once) in the same spectrum, at the same time, and in the same location*. Commercial network operators are motivated to solve this problem, but with the decline of America's R&D giants – such as Bell Labs– funding for basic research is highly dependent on government's contributions. Taxpayer money is better spent on such research problems than on building duplicate network facilities such as FirstNet. *Advanced sharing will have tremendous military benefits as well, since it does not depend on cooperative regulators abroad.*

Detailed Testimony

Chairman Quayle, Ranking Member Edwards, and members of the Subcommittee, I appreciate the opportunity to appear before you to discuss the role of spectrum in the development of the mobile economy.

I am a Senior Research Fellow with the Information Technology and Innovation Foundation (ITIF). ITIF is a nonpartisan research and educational institute whose mission is to formulate and promote public policies to advance technological innovation, productivity and competitiveness. Before joining ITIF three years ago, I enjoyed a thirty year career in network engineering and standards, where it was my good fortune to contribute to the initial standards for Ethernet over Twisted Pair and Wi-Fi.

We at ITIF believe the spectrum challenge is critical to the economies of our nation and the rest of the world because computing is undergoing a dramatic shift from fixed-location desktops and nomadic laptop systems to mobile devices, networks, and applications. In 2011, the number of smartphones sold worldwide exceeded the number of personal computers sold for the first time.[1] Only half of Americans have smartphones so far, so the trend toward rapid smartphone and tablet adoption will continue for some time. One day appliances and other devices will come to have smartphone capability built in, so the number of smartphones will exceed the population by several times. This will change the both the Internet and the cellular networks quite dramatically.

The Internet is used by some two billion people, but we can expect that number to triple within the next three to five years. The growth in the use of smartphones and the mobile Internet is even more rapid than the boom we saw in Internet growth at the turn of the century.[2]

Smartphone users use many of the same applications that we use on laptop and desktop systems for personal productivity, information browsing, education and entertainment, but they also use applications that are enabled by mobility itself. We've already seen a shift in shopping habits during the holiday buying season as smartphone users share information about products, stocks in local stores, lines, and prices.[3] Thanks to web sites such as Zillow and Redfin, shopping for housing is a completely different experience today than it was even two years ago, as we can drive a neighborhood, see which houses are for sale or rent, view pictures of their layout, and even analyze their purchase history without leaving the car. Those who walk, run, or cycle for exercise can map their routes, monitor their speed, distance, and heart rate, and estimate calorie burn with mobile exercise apps such as Endomondo and RunKeeper that connect to social networks.

Last week, Facebook acquired Instagram, a photo sharing service with only 13 employees, for a billion dollars, largely because Instagram has acquired 40 million users in only 16 months of operation.

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[1] Henry Blodget and Alex Cocotas, "The Future of Mobile" (presented at the IGNITION WEST: Future of Mobile Conference, San Francisco, CA, March 22, 2012), http://www.businessinsider.com/the-future-of-mobile-deck-2012-3.

[2] Mary Meeker, "Internet Trends 2011" (presented at the Web 2.0 Summit, San Francisco, CA, October 18, 2011), http://www.kpcb.com/insights/internet-trends-2011.

[3] Richard Bennett, "Live Different: Susan Crawford's Broadband Blinkers," *Innovation Files*, December 5, 2011, http://www.innovationfiles.org/live-different-susan-crawfords-broadband-blinkers/.

Another social picture sharing service, Pinterest, is the third largest social network only two years after its formation.[4]

“Mobile Augmented Reality” is a new application category that extracts information from massive databases in the Cloud relevant to a user’s location, activity, and preferences; it moves video streams between the user and the Cloud in both directions, sometimes from “Smart Spectacles” that combine a video camera and display screen such as Laster Technologies’ *IEEE Spectrum* 2011 Technology of the Year winner. All of these applications require spectrum – the more the better – and as they are truly mobile there are limited opportunities to offload their spectrum needs to short distance Wi-Fi networks. The spectrum needs of tablets are more in line with those of the laptops they’re replacing, however as tablets are “nomadic” devices that we use in stationary fashion from multiple locations. The spectrum needs of tablets can generally be met through Wi-Fi.

Figure 1 Laster Techologies "Smart Spectacles" wearable video camera and display system. Credit: Laster

The Spectrum Crunch

The National Broadband Plan famously forecasts a need for 300 MHz of licensed and 200 MHz of unlicensed spectrum, less than double the 475 MHz we currently have for licensed[5] and the 350 MHz we have for unlicensed Wi-Fi alone.[6]

This estimate is low because we’ve seen that network applications are generally able to make use of all available bandwidth: Residential broadband connections, for example, are roughly ten times faster than they were in the late 1990s, and many of these connections are unshared.

Commercial Spectrum Use

Mobile social networks are using infrastructure initially designed for low bandwidth telephone service. Video sharing applications will consume ten times as much capacity per minute as telephony with the best compression we can use. Cellular networks in major cities are running close to capacity during peak periods already. From 2006 to 2009, the first three years the iPhone was available on the AT&T network, traffic grew 5000%.[7] This figure probably represents users spending

Figure 2 Augmented Reality in a contact lens. Credit: Raygun Studio

[4] Bill Tancer, *The 2012 Digital Marketer Trend and Benchmark Report* (Experian Marketing Services, 2012), http://go.experian.com/forms/experian-digital-marketer-2012.
[5] Brad Reed, “LTE Spectrum: How Much Do the Big Carriers Have?,” *Network World*, January 23, 2012, http://www.networkworld.com/news/2012/012312-lte-spectrum-255122.html?page=1.
[6] Wikipedia, “List of WLAN Channels,” encyclopedia, n.d., http://en.wikipedia.org/wiki/List_of_WLAN_channels.
[7] Michelle Megna, “AT&T Faces 5,000 Percent Surge in Traffic,” *InternetNews*, October 8, 2009, http://www.internetnews.com/mobility/article.php/3843001/ATampT+Faces+5000+Percent+Surge+in+Traffic.htm

five times as many minutes on their iPhones as they spent on their dumb phones, and performing tasks that are ten times as data-intensive. AT&T forecasts a need for eight to 10 times as much data capacity over the next five years as it can carry today.[8] Some of this capacity can be met by improvements in spectrum efficiency (mainly in terms of coding advances,) some by increased tower deployment, some by small cells, but much of it depends on more spectrum.

The balance between these methods is largely economic. Increased spectrum is the least expensive option, building towers the most expensive, and the costs of more spectrum are ultimately born by users. Some analysts believe that advances in technology alone will meet the demand, but this projection ignores the fact that historical advances in spectrum efficiency follow Cooper's Law, doubling every 30 months, while increases in demand follow Moore's Law, doubling every 18 months.[9] Left to its own devices, technology will fail to meet consumer needs.

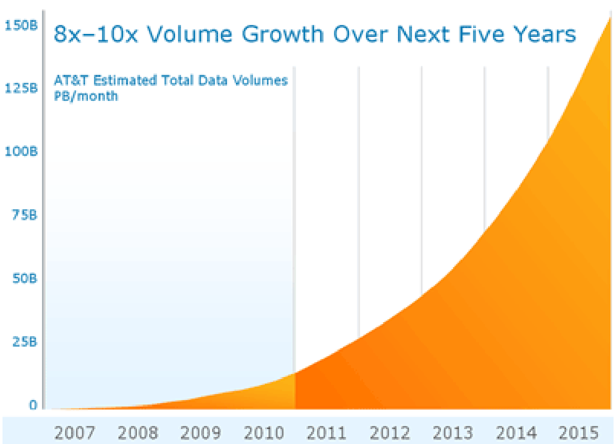

Figure 4 AT&T projects wireless data sent over its network to grow by a factor of 8 to 10 in the next five years. Credit: AT&T.

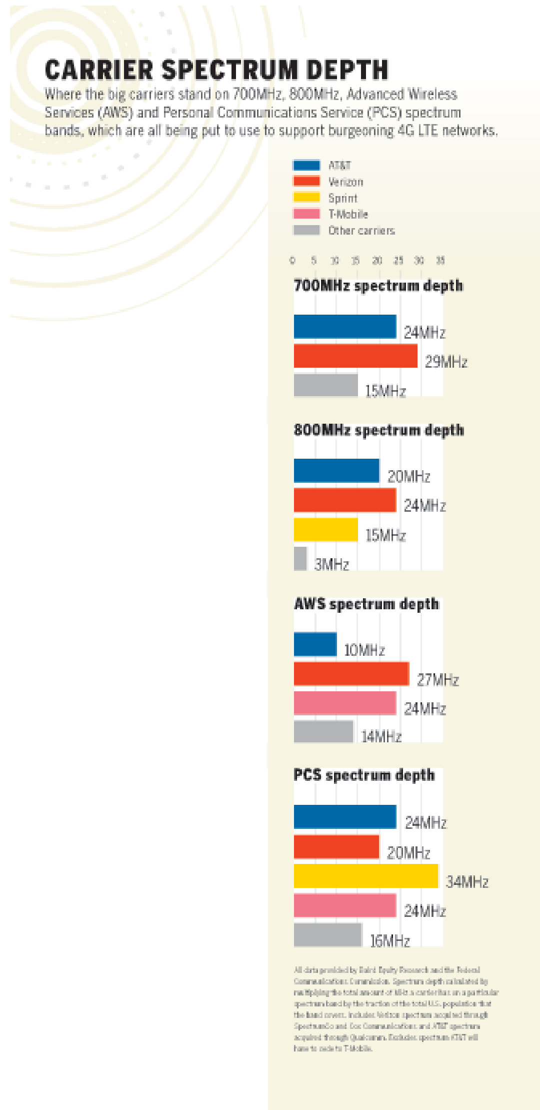

Figure 3 List does not include 150 MHz of Sprint/Clearwire spectrum. Credit: Network World.

[8] Kris Rinne, "Building the Nation's Most Advanced Mobile Broadband Experience" (presented at the AT&T CIO Executive Forum, Colorado Springs, CO, June 15, 2011), http://www.business.att.com/content/speeches/ATT_Mobility_Network_Evolution_KrisRinne.pdf.
[9] "Martin Cooper (inventor)," *Wikipedia*, n.d., http://en.wikipedia.org/wiki/Cooper%27s_Law.

The most efficient users of spectrum on a per-user basis over wide areas are the large networks. AT&T and Verizon get by with 0.86 and 0.93 MHz per million subscribers, while Sprint/Clearwire holds 3.72 MHz per million, according to Bernstein Research.[10]

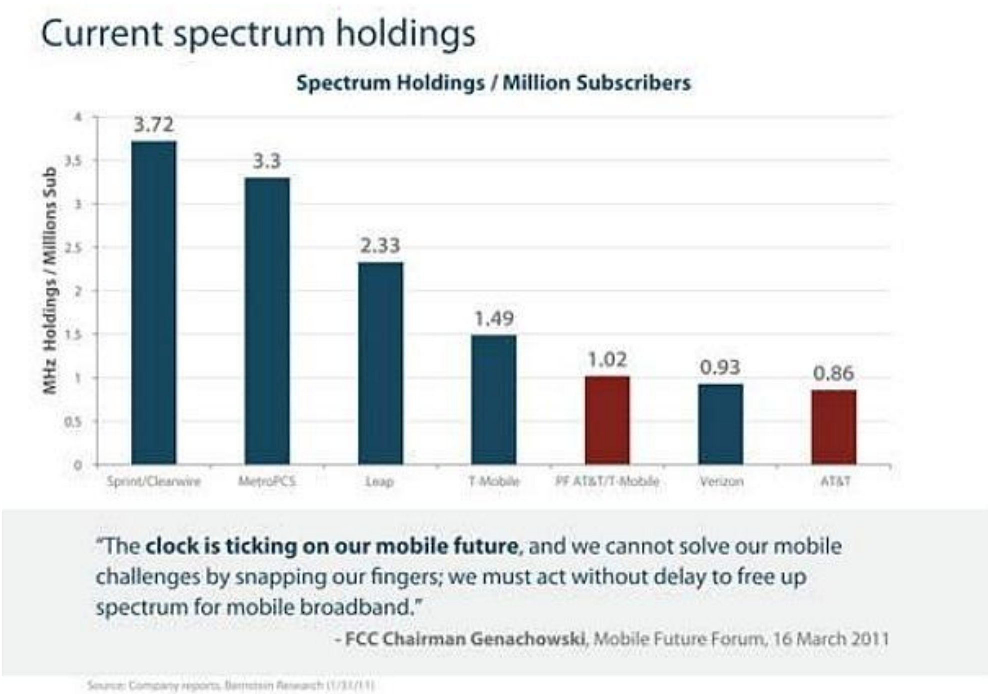

Figure 5 Credit: Bernstein Research, used by permission from Craig Moffett.

If we can't find spectrum to meet the needs of mobile users as they transition to smartphones, tablets, mobile social applications, augmented reality, and sensor networks, innovation will stall and economic growth will slow. The FCC forecasts that these effects will become visible as early as next year.[11]

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[10] Craig Moffett, *Company Reports* (Bernstein Research, January 11, 2011).
[11] Michael Kleeman, *Point of View: Wireless Point of Disconnect* (San Diego, CA: Global Information Industry Center, October 2011), http://giic.ucsd.edu/pdf/pow_wireless_point_of_disconnect_2011.pdf.

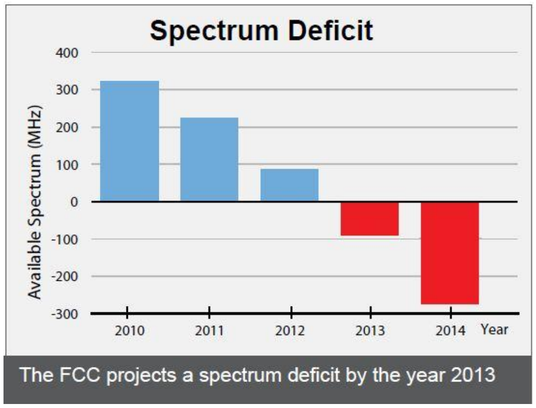

Figure 6 Credit: "Point of View: Wireless Point of Disconnect," Michael Kleeman, Global Information Industry Center

Government Spectrum Use

One source for additional commercial spectrum is the government. Most analysts say that the U. S. government has assigned 300 MHz more prime spectrum to itself than our European neighbors; this spectrum is managed by NTIA. While the U. S. leads the world in the deployment of fourth generation LTE networks, we lag the world in the allocation of spectrum to LTE networks.

The recent NTIA report, *An Assessment of the Viability of Accommodating Wireless Broadband in the 1755 – 1850 MHz Band*, is good news and bad news for the reassignment of government spectrum.[12] The good news is that some government agencies are playing ball, taking the exercise seriously and doing their best to increase the amount of spectrum available for general-purpose commercial networks. The NTIA says the entire band can be made available within ten years, and significant portions of it much earlier.

They caution that some sharing is going to be necessary for quite some time in a few areas, but they're hoping that the sharing is something both the commercial sector and the government can live with. The bad news is that DOD and the FBI still insist they have applications of such importance that they can't live without the allocations of spectrum they currently have. It's likely that the negotiations between the civilian agencies and the NTIA involved spectrum experts while those that took place with the DOD and DOJ involved non-technical administrators. That's what the report seems to indicate.

[12] John E. Bryson and Lawrence E. Strickling, *An Assessment of the Viability of Accommodating Wireless Broadband in the 1755 – 1850 MHz Band* (Washington, DC: U. S. Department of Commerce, March 2012), http://www.ntia.doc.gov/files/ntia/publications/ntia_1755_1850_mhz_report_march2012.pdf.

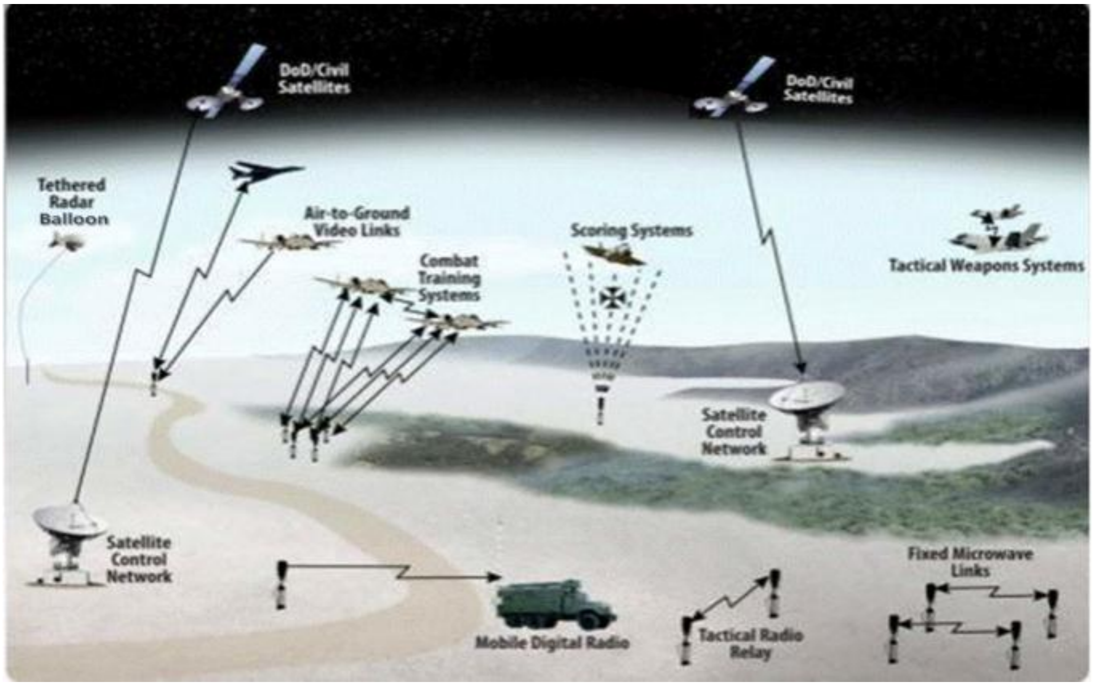

Figure 7 Credit: "An Assessment of the Viability of Accommodating Wireless Broadband in the 1755 – 1850 MHz Band," NTIA, March 2012, (NTIA Report) page 6.

The primary issue in reallocating spectrum from government use is whether the allocation makes sense, and the secondary issue is where in the spectrum map the government's assignments should be. The 1755-1850 spectrum band is important because it's been assigned internationally for mobile broadband, so there are tremendous benefits to U. S. firms and consumers if we can use it for that purpose. While the NTIA appears to have dragged DOD kicking and screaming into the discussion about relocating some of its vital systems to over bands, they don't seem to have made much progress toward getting them to consider alternate ways of performing their missions that don't require 200 to 300 MHz more bandwidth than our European allies have dedicated to their military establishments.[13] Maybe that's too much to ask just yet. And of course the estimated relocation costs provided by DOJ and DOD are outlandish, considering that all the equipment they've currently got should be replaced within five to ten years as a matter of course anyway, and this exercise has already been ongoing for ten years.

The executive summary declares: "In conducting the analysis, NTIA and the federal agencies endeavored to protect critical federal operations from disruption and to reach comparable capability via other spectrum, commercial services, or means that do not utilize spectrum, where appropriate" but this isn't totally reflected in the body of the report. What we see is a desire to preserve the current set of government applications with as little disruption as possible and very little attention to developing alternatives to the current application-based allocation scheme that was the 20th century's method of handling spectrum.

[13] Ginger Conton, "Free the Spectrum Now," *CRM Magazine*, May 2002, http://www.destinationcrm.com/Articles/Older-Articles/The-Edge/Free-the-Spectrum-Now-45519.aspx.

Here's a summary of the number of allocations to government users in the band. The total number is 3183 discrete allocations for particular purposes.

Table 2-1. Number of Federal Frequency Assignments in the 1755-1850 MHz Band

AGENCY	Fixed Point-to-Point Microwave	Military Tactical Radio Relay	Air Combat Training Systems	Precision Guided Munitions	Law Enforcement Mobile Video Surveillance Applications	High-Resolution Video Surveillance (fixed or transportable)	Telemetry, Tracking, and Commanding for Federal Space Systems	Air-to-Ground Telemetry	Land Mobile Robotic Video Functions (e.g. EOD & Hazardous Waste Disposal, etc)	UAS, UAV, RPV	TOTAL
Air Force	12		273	1		2	220	186	61	45	800
USAID						1					1
Army	45	408	4			36		19	4	378	894
DHS	152				25						177
DOC	8						1				9
DOE	91								2		93
DOI	26				1	1					28
DOJ					7	75			7	6	95
FAA	8										8
HHS						1					1
HUD						6					6
Marine Corps	4	169								21	194
Navy	14	2	430	20			48	303	6	14	837
OPM						1					1
NASA								6		11	17
Treasury						10					10
USCP						5					5
USPS						3					3
VA						4					4
TOTAL	360	579	707	21	33	145	269	514	80	475	3183

Figure 8 Source: NTIA Report, page 16.

A detailed examination of the assignments is illuminating.

Fixed Point-to-Point Microwave

The first application, fixed point-to-point microwave, should raise a red flag immediately because nearly all its 360 allocations can be probably be replaced by a wireline or commercial alternative. Point-to-point microwave is a virtual wire whose history pre-dates fiber optics and it's a laggard in terms of performance and quality.

The report excuses these allocations as being cheaper or higher quality than commercial or wireline alternatives, but that analysis only works if you value the spectrum at zero. Replacing 95% of these allocations with fiber backhaul could end up being a net positive for the government because they could over-provision and lease dark fiber to the commercial sector. The only rational application for fixed point-to-point microwave these days is connecting mountain tops in rural areas where there's no plausible case for fiber and I doubt that's the government's typical use case.

Military Tactical Radio Relay

Per the report, "Tactical Radio Relay is a generic term for a class of transportable fixed microwave systems that support Army, Navy, and Marine Corps training at a number of sites and on tactical operational missions." These systems probably have a stronger use case that fixed microwave, but probably not much of one. The purpose of these allocations should be to connect a training network to a fiber terminal, and it would be very surprising if DOD needs 579 separate allocations to do this for active training missions. Even if they had hundreds of training missions going on at the same time, they're not in the same place so there's no practical reason they need that many allocations. This is another category of microwave, and there are commercial systems and higher frequencies available to support it that aren't appealing to mobile networks. In fact many of these systems are indistinguishable from commercial mobile broadband systems in function and purpose. Most of these 579 allocations duplicate commercial systems.

Air Combat Training System

The report describe this application as one that "provides, via ground-based and airborne components, real-time monitoring of air combat training including gun-scoring; no-drop bombing; evasion and intercept tactics, techniques, procedures; and electronic warfare." It seems that the major problem with these allocations is systems that require specific frequencies on which to operate. Combat systems have to be capable of operating overseas, in countries that have not made specific allocations of spectrum to invading armed forces, so you'd want to have some flexibility in them. And in fact they are designed that way, with the ability to operate on a number of frequencies (just like a car radio.) See the following table for some options.

Table 3-1. Potential Comparable Spectrum Bands

Initial Categories of Systems	Potential Bands for Relocation		Factors Considered
Fixed Point-to-Point Microwave	4400-4950 MHz 7125-8500 MHz Wireline or Commercial	14.5-14.7145/ 15.1365-15.35 GHz Possibly higher (e.g., 25-27.5 GHz)	Equipment is available and there is adequate spectrum.
Military Tactical Radio Relay	1435-1525 MHz 2025-2110 MHz	2110-2165 MHz 2200-2310 MHz*	These bands minimize the need for modifications to equipment (e.g., existing equipment such as Mobile Subscriber Equipment and HCLOS tune up to 2690 MHz, so no equipment modifications are necessary).
Air Combat Training Systems	1350-1390 MHz 1435-1525 MHz 2025-2110 MHz	2200-2300 MHz* 2360-2395 MHz	Airborne operations can be accommodated or are already being performed in these bands; these bands have similar or better propagation characteristics; and coordination with aeronautical telemetry is possible.
Precision Guided Munitions	1350-1390 MHz 1435-1525 MHz 2025-2110 MHz	2200-2300 MHz* 2360-2395 MHz	Airborne operations can be accommodated or are already being performed in these bands; these bands have similar or better propagation characteristics; and coordination with aeronautical telemetry is possible.
Law Enforcement Mobile Video Surveillance Applications	225-328.6/ 335.4-380 MHz 420-450 MHz 902-928 MHz 1350-1390 MHz	1435-1525 MHz 1675-1695 MHz 2025-2110 MHz 2200-2300 MHz* 2360-2395 MHz	Equipment is available; and/or propagation characteristics are similar or better; and/or the incumbent radio services are similar to those in the 1755-1850 MHz band where successful sharing exists.
High-Resolution (fixed or transportable) Video Data Links for Surveillance	225-328.6/ 335.4-380 MHz 420-450 MHz 902-928 MHz 1350-1390 MHz	1435-1525 MHz 1675-1695 MHz 2025-2110 MHz 2200-2300 MHz* 2360-2395 MHz	Equipment is available; and/or propagation characteristics are similar or better; and/or the incumbent radio services are similar to those in the 1755-1850 MHz band where successful sharing exists.
Tracking, Telemetry, and Commanding for Federal Space Systems	2025-2110 MHz 7125-8500 MHz	20/30 GHz	Equipment is available and there is adequate spectrum.
Air-to-Ground Telemetry	1350-1390 MHz 1435-1525 MHz 2025-2110 MHz	2200-2300 MHz* 2360-2395 MHz	Airborne operations can be accommodated or are already being performed in these bands; these bands have similar or better propagation characteristics; and coordination with aeronautical telemetry is possible.
Land Mobile Robotic Video Functions	225-328.6/ 335.4-380 MHz 420-450 MHz 1350-1390 MHz 1435-1525 MHz	1675-1695 MHz 2025-2110 MHz 2200-2310 MHz* 2360-2395 MHz	Propagation characteristics are similar or better and the incumbent radio services are similar to those in the 1755-1850 MHz band where successful sharing exists.
UAS, UAV, RPV	225-328.6/ 335.4-380 MHz 2025-2110 MHz 2200-2300 MHz*	4400-4950 MHz 14.5-14.7145/ 15.1365-15.35 GHz	Although these bands are already used, they can also support the operations conducted in the 1755-1850 MHz band.

* The correct band for consideration is 2200-2290 MHz; however, because NTIA identified two different bands, 2200-2300 MHz and 2200-2310 MHz, in the initial list of candidate comparable bands, these bands are sometimes referenced throughout this report.

Figure 9 Source: NTIA report, page 16.

The DOD is the prime developer of “software-defined radios” that operate at a wide range of frequencies, and these should be used in all military and law enforcement systems within the next five years in the course of normal replacement of obsolete equipment. The instances in which a particular frequency is needed for testing are rare, but they do exist. They can be accommodated, however, by short term use of the test frequency in a specific area rather than permanent assignment. Test conditions should resemble real-world conditions, after all. 707 allocations are at stake here, as well as the flexibility and utility of real combat systems.

Precision Guided Munitions

These systems "provide critical tactical communications between launched weapons and controlling platforms, allowing for precise and effective targeting." Like other air combat training systems, they need to function in real-world settings that don't provide them with a dedicated band and the ability to share and adapt to such conditions. They can be re-assigned to the same bands as air combat training systems.

Tracking, Telemetry, and Commanding

Here's an application that makes some sense: "DOD satellites provide communications, navigation, surveillance, missile early warning, weather monitoring, and research and development support." This application needs some specific spectrum assignments because it's doing things that aren't generic and don't have to co-exist with generic systems. These systems have some general utility, and aren't going to be usurped by commercial systems. Unfortunately, DOD has not build spectrum flexibility into satellites in the past, so they're less functional than car radios in this respect. They propose to make a minimal change to allow the use of two bands in future satellites (the current "L" band and the future "S" band) but no more. This seems a bit uncooperative given that the "S" band at 2025-2110 MHz is pretty juicy for mobile broadband and there's a lot of spectrum available above 3 GHz that doesn't appeal to mobile.

We'd like to see a general principle in place to the effect that we don't launch billion dollar systems into space that are hard-wired to operate on only one or two frequencies.

Aeronautical Mobile Telemetry

The report says it all: "Aeronautical mobile telemetry systems operate from manned aircraft, unmanned vehicles, aerostats, missiles, or other platforms to provide real-time flight characteristics from the airborne vehicles to the ground, real-time video of cockpit or project information, real-time monitoring of flight research/test parameters, and real-time command and control of the vehicle.

"NASA determined that it can vacate its aeronautical mobile telemetry operations from the entire 1755-1850 MHz band in less than five years. Relocation to the 2025-2110 MHz and 5091-5150 MHz band requires a primary federal allocation for the aeronautical mobile service." But DOD takes longer and wants more spectrum in return.

Video Surveillance

Of all the applications in the NTIA report, this is the most puzzling. The report declares: "DHS, DOJ, and the Treasury state they need to retain up to 30 megahertz of contiguous spectrum for surveillance in the 1780-1850 MHz band pending the successful development of new technology and the availability of spectrum in the comparable bands." Granted, keeping the people safe from terrorists, criminals, and tax evaders is a noble work, but video bits are not so special that they need their own network. Commercial networks can easily accommodate the needs of law enforcement for transporting video bits just as they must do the very same job for consumers every day. There is no justification for putting 30 MHz of contiguous spectrum on hold just after allocating the D Block to the nation-wide public safety network that's about to be built. The NTIA needs to say "no" to this application, resoundingly.

Unmanned Aerial Systems

The report advises that "The use of unmanned aerial systems has grown significantly with deployment of more sophisticated payloads for expanded functions of electronic attack, communications relay, firefighting, science observation, and search and rescue" and asks for the 2025-2110 MHz band to support this app, gulp. That's twice as much spectrum as T-Mobile has today. This is a terrestrial application that seems to have most relevance for temporary uses within U. S. borders. Hence it's difficult to justify such a huge allocation for it.

Government Spectrum Conclusions

It seems that the ice is beginning to melt around federal spectrum allocations in the 1755-1850 MHz band. Civilian agencies are generally working in the right spirit toward the national goal, and military and law enforcement agencies are beginning to recognize that their extravagant historical claims on spectrum rights need to be scaled back, even if they're not entirely happy about it.

This exercise can be judged effective only if the total amount of government spectrum is sharply reduced; simply moving government agencies from one prime spot below 3 GHz to another is actually a failure. Agencies should also realize that they serve the public by performing their roles to the best of their abilities, and these roles do not generally include network operations. The DOD is strangely lacking in enthusiasm for the software-defined radio technology it pioneered. It's important that we understand why.

Meeting the Need for Spectrum

The same RF spectrum exists around the world, but our regulatory process has assigned too much to government use – roughly 300 MHz of the prime frequencies between 500 MHz and 3GHz. We have also assigned too much spectrum to satellite-based Mobile Telephone Services (MSS) with limited capacity and high latency.[14] When the Telstar satellites were launched in the 1960s, there were high hopes that satellites would enable a wide range of applications, but experience shows that satellite networks are a poor substitute for wireline and terrestrial wireless ones in practically all applications except one-way broadcasting. Satellite signals have high delay – on the order of a half-second round trip – and cover an area that's excessively large.

The more general problem around the world is the 100 year history of assigning spectrum to applications rather than to networks. The following diagram illustrates the complexity of the U. S.

[14] European Commission, "eCommunications: Radio Spectrum Policy: Mobile Satellite Services," *Europe's Information Society*, n.d., http://ec.europa.eu/information_society/policy/ecomm/radio_spectrum/topics/ecs/mss/index_en.htm.

spectrum allocation system. A more ideal system would many fewer allocations, each for a substantially larger amount of spectrum.[15]

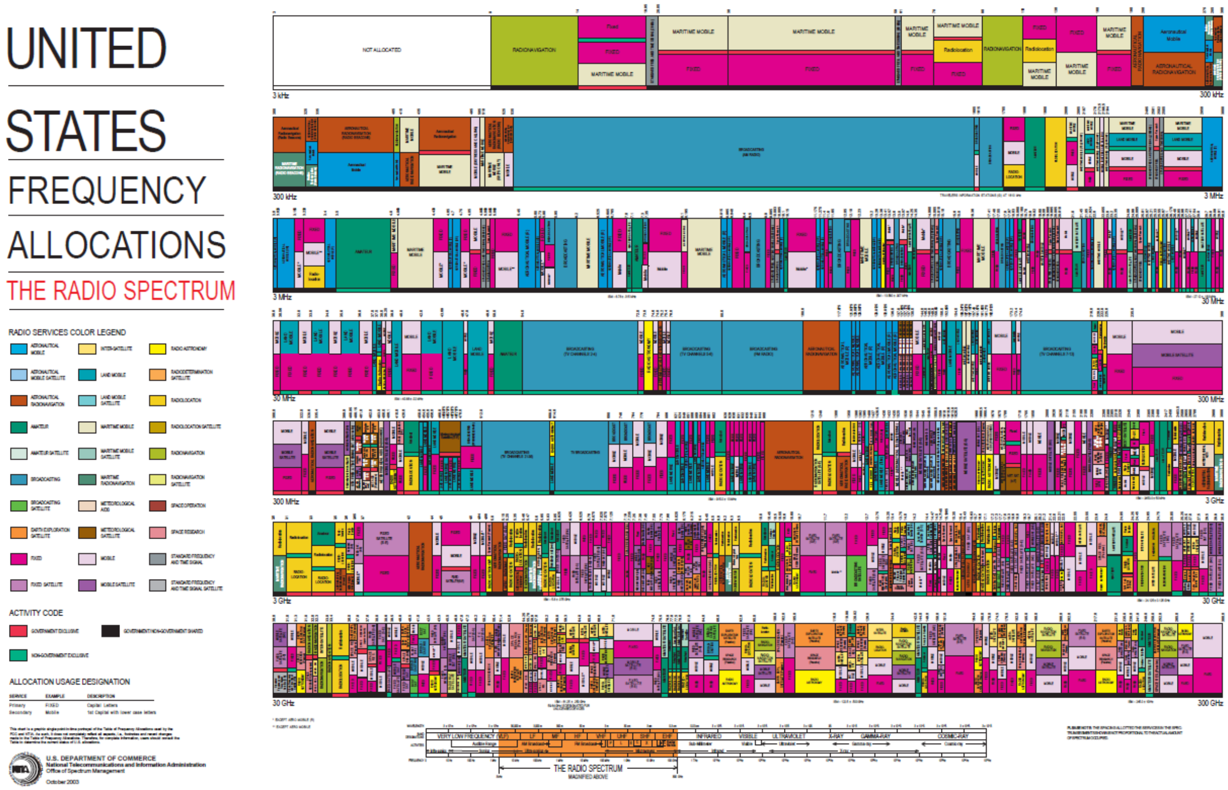

Figure 10 Source: NTIA

From the application perspective, spectrum sharing on commercial networks is a solved problem. We don't have one network for Instagram and another for Pinterest, we have one group of networks that handle a wide range of applications. What we're doing with such technologies as Dynamic Spectrum Access and Authorized Shared Access is reversing the effects of historical spectrum allocation policy. When successful, these approaches will create networks that resemble commercial networks in their application support. This is a way of putting Humpty-Dumpty back together again.

In order to meet the need for network capacity, carriers will supply more spectrum per user. The easiest way to do this is to offload the cellular network onto femto cells and Wi-Fi networks, but this is a limited strategy because it fails to meet the needs of mobility. Wi-Fi is a nomadic network, not a truly mobile one, and femto cells have similar characteristics. The small cells that will help relieve the crunch are deployed outdoors on frequencies that coordinate with the macro cells on which the cellular network is

[15] Richard Bennett, *Spectrum Policy for Innovation* (Washington, DC: Information Technology and Innovation Foundation, September 2011), http://www.itif.org/files/2011-spectrum-policy-innovation.pdf.

based. Building micro cells within the macro cellular fabric is a bricks-and-mortar exercise that requires massive investment and zoning approval.[16]

Facilitating R&D on Spectrum Sharing and Efficient Use

As Figure 10 indicates, the general problem of spectrum policy today is fragmentation: Regulators have assigned slices of spectrum to myriad applications and it's now all spoken for. The task before us is to reverse the effects of fragmentation, to essentially put Humpty-Dumpty back together again. The easy way to do this is to take spectrum away from low-value applications (such as the government's dedicated video surveillance frequencies, many lightly-used satellite services, and over-the-air TV) and assign it to high-value commercial networks by auction. Sharing is inherent in commercial networks; it's how they make money and they're very good at it.

Network Time Sharing: Dynamic Spectrum Access and Authorized Shared Access

Unlicensed radio systems are most effective over short distances: Bluetooth and Wi-Fi are their signature accomplishments. These systems manage spectrum access at the network edge using "contention" systems that become less efficient as network distances and data rates increase. Licensed commercial systems employ centrally-managed spectrum access controls that are effective at a broad range of speeds over longer distances, but at the cost of much greater planning and more complex infrastructure.[17] Each approach has distinct benefits and ideal deployment scenarios: We would not want to build nationwide networks with Wi-Fi, and we would not want to centrally manage Bluetooth connections between smartphones and headsets.

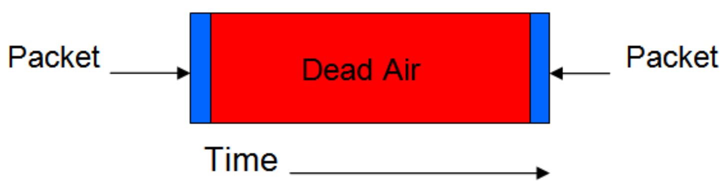

Figure 11 Actual overhead of IEEE 802.11n carrier sensing for single packets sent at high rate.[18]

In addition to the spectrum sharing that licensed commercial networks and unlicensed networks already do, research has developed (and will continue to develop) systems that coordinate spectrum use among networks themselves. The best known of such systems are Dynamic Spectrum Access (DSA) and Authorized Shared Access (ASA.) These systems simply coordinate spectrum access among and between network operators where idle spectrum exists and sharing agreements of some kind are in force.

In order for these systems to function, the pool of idle spectrum can be used by capable devices when certain conditions are met and an operator claims the spectrum, either with government permission (as is the case in the White Spaces systems,) or in accord with a commercial agreement between network

[16] Richard Bennett, *Going Mobile: Technology and Policy Issues in the Mobile Internet* (Washington, DC: Information Technology and Innovation Foundation, March 2010), http://itif.org/publications/going-mobile-technology-and-policy-issues-mobile-internet.
[17] Ibid.
[18] Ibid.

operators in other cases, or in terms of an informal agreement in yet other cases. The act of claiming the spectrum makes the network operational, and once this takes place, the process of network operator-mediated sharing among applications follows, with potentially as much efficiency as commercial licensed networks exhibit over a broad range of operating conditions.

These systems will prove beneficial in the short to medium term, until we reach the point where there is no longer any idle spectrum to claim and assign dynamically. At that point, advances in spectrum sharing will depend on more advanced and more beneficial technologies that that allow a single frequency to be shared among multiple *simultaneous* users. We don't do this today, and we won't do this with DSA and ASA.

In DSA and ASA systems, as with common commercial systems, users take turns accessing spectrum in round-robin fashion, typically for a few milliseconds at a time. In other words, conventional packet radio systems, whether licensed or unlicensed, fixed or dynamic, only permit the transmission of one packet of data at a time in a given place, time, and frequency.[19] DSA and ASA systems reduce to the effects of this fundamental limitation by marshaling more spectrum to each location. The next stage in spectrum engineering is systems that allow for multiple packet transmissions in each time and place on the same range of spectrum.

The most fertile test bed for DSA operations research is the vast pool of lightly-used and locally-used government spectrum. Many government systems that use spectrum only do so occasionally and in specific locations, so this spectrum is ripe for use by both commercial and non-commercial systems in other times and places. The IEEE 802.11y variant of Wi-Fi is a good example of the dynamic sharing of government spectrum.[20]

Simultaneous Network Sharing

Truly simultaneous spectrum use requires transmissions to be effectively focused or cloaked from each other so as not to create discernible interference; these systems can be called Simultaneous Shared Access (SSA.) One way of doing this is Space-Division Multiple Access (SDMA,) a system that effectively sends a radio beam to a receiver in such a focused way that other receivers don't see it. Another system for simultaneous sharing would be an advanced form of Code Division Multiple Access (CDMA,) a system that scrambles transmissions so that only the intended receiver can unscramble them, and other potential receivers automatically filter them out. Current CDMA systems reduce the data rates of simultaneous transmissions relative to theoretical capacity; advanced CDMA would be less limited in this respect.

Yet another method is Ultra-Wideband (UWB,) a system that uses very wide radio channels "underneath" conventional narrow channels. While conventional cellular channels are 5, 10, or 20 MHz wide, UWB channels are spread over 500 MHz each, so the UWB energy is very faint to cellular

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[19] There are some exceptions to this rule, but they apply to systems that reduce packet radio data rates, such as CDMA.

[20] Wikipedia, "IEEE 802.11y-2008," *Wikipedia*, n.d., http://en.wikipedia.org/wiki/IEEE_802.11y-2008.

receivers. UWB transmissions are also pulsed to as to appear more like sporadic noise to conventional receivers. Therefore, UWB transmissions blend into the background noise filtered by narrowband receivers by design. Of these three approaches, only CDMA has proved a commercial success so far, but its sharing efficiency is less than expected.

Research spending should focus on Simultaneous Sharing. It would be prudent to organize research funding for simultaneous sharing under a coherent National Science Foundation program. The best way to do this may be to create an NSF Engineering Research Center (ERC) for simultaneous sharing similar to the research centers that already exist in the Microelectronics, Sensing, and Information Technology area, such as the ERCs for Integrated Access Networks, Extreme Ultraviolet Science and Technology, Collaborative Adaptive Sensing of the Atmosphere, and Mid-Infrared Technologies for Health and the Environment.

A report released by the White House Council of Economic Advisors in February, *The Economic Benefits of New Spectrum for Wireless Broadband*, touts the benefits of "research on standards, technologies, and applications to advance wireless public safety communications." While such research is clearly necessary and beneficial, we should acknowledge that it is low-risk applied research with a known outcome. In addition to applied research, we need to support pure research that can potentially push the boundaries of mobile networking to the next stage.

The research agenda can be organized on a timeline between short-, medium-, and long-term initiatives, as follows:

Short-term	Authorized Shared Access
Medium-term	Dynamic Spectrum Access
Long-term	Simultaneous Shared Access

When SSA is fully developed and non-SSA receivers are replaced by SSA-capable ones, the problem of spectrum allocation and management will become much simpler than it is today.

Striking the Balance between Commercial and Government Use of Spectrum

Government and the private sector play different roles in the development of technology and the management of shared resources such as spectrum. We expect government to support pure research and to share support of applied research with the private sector. We expect government to set parameters and regulations for economic activities such as mobile networking, and for the private sector to provide actual services to the public. We also expect government to provide some general facilities such as GPS because there was no discernible business case for location-sensing systems when the GPS system was devised and government assumed the role of provider of last resort as is sometimes the case.

These "provider of last resort" situations can become a source of conflict when systems such as GPS or public safety networking become generally useful. In the case of public safety networking, we now have police and first responders around the country operating networks similar in function to commercial mobile networks. Public safety got into the network operations business when they had no choice but to operate their own networks or to do without. This is no longer the case, as Congress realized when the 9/11 Commission laid out the interoperability problems in New York on the day our country was attacked. A decade after 9/11, Congress assigned operational responsibility for public safety networking to NTIA. This was a step forward, but not the end of the game.

The basic problem with a government-owned and operated public safety network is the conflict of interest between the government as regulator of spectrum allocation and network operations and the government's interests as a user and operator of networks. If public safety networking were to be carried out by commercial networks under contract with public safety agencies (under the technical guidance of NTIA) there would be no conflict and no balance to be struck apart from budgeting for the amount of network capacity needed to perform services deemed necessary by Congress year after year.

Government can fund research, and it can make purchasing decisions to support the commercialization of leading-edge technologies. In so doing, it expands the pool of useable spectrum. Government does not need to compete with the private sector as a provider of network services generally.

Conclusion

Thank you for providing ITIF the opportunity to offer this testimony today. Despite the many challenges we face in converting our system of spectrum assignment from one of administrative fiat to a pragmatic and dynamic system of continual economic stimulus, the rewards are great. The nations that lead the way in the deployment of advanced technologies stand to reap the benefits that increased efficiency brings to economic growth.

While it has become routine for policy analysts to bemoan the U. S. for its position in traditional rankings of wired broadband adoption (where we lag because of low rates of household computer ownership) and speed, we're the clear leader in LTE adoption.[21] LTE is very significant step in the evolution of mobile networking not only for its radio technology but also because it's a system entirely based on Internet Protocol that stands to not only increase the capacity of mobile networks but to make the Internet itself a more reliable and robust system.

Continued leadership in LTE depends on the continued release of spectrum to the most successful commercial networks through reassignment of government applications and the transfer of licenses from declining systems such as MSS and OTA television broadcasting to high-value mobile broadband. Leadership in the systems that will take the place of LTE and LTE Advanced depends on increased investment in the technologies for simultaneous spectrum sharing that will ultimately relieve the spectrum crunch once and for all.

[21] *US Tops Global LTE Smartphone Market* (Pyramid Research, October 10, 2011), http://www.pyramidresearch.com/points/item/111010.htm.