Investigation into US Radio Spectrum Policy and Management

An Interactive Qualifying Project Report

Submitted to the Faculty of the
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements for the
Degree of Bachelor of Science
By

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4/26/2012

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Abstract

This project provides an examination of the FCC's policies towards spectrum reallocation. The project examines the National Broadband Plan and how the FCC has approached the goals described within it. The demand for broadband communications has increased dramatically in recent years and has resulted in a predicted spectrum deficit in the near future. In addition to a number of spectrum auctions and their winners the project examines how the redistribution of spectrum impacts the broadband community. The project also provides an examination of spectrum reallocation and policy in other countries, to provide a broader view of spectrum policy. Finally the project examines new spectrum technologies and spectrum usage policies to further examine how the US's spectrum policies should evolve.

1 Introduction

Julius Genachowski, Chairman of the Federal Communications Commission (FCC) stated at the CTIA (Wireless Industry Association) conference in San Diego in October 2009, "I believe the biggest threat to the future of mobile in America is the looming spectrum crisis." [CTIA 2012] Spectrum is a "natural resource" available to all however, it is not like mineral resources such as metal ore, crude oil or water. Land or real estate is a good comparison to spectrum bands, because they are not consumed but occupied. Radio communications services occupy the spectrum bands that provide the best technical performance for their individual needs. Figure 1 illustrates the frequency bands in common use today. Why should we care about Spectrum? We care because as a "national resource", it must be managed properly to provide the maximum benefit to the American people. Countries throughout the world especially the US are interconnected by radio-communication networks. The commercial success of any country now depends completely on the exchange of information through these networks. Spectrum is owned and administered by each country. Radio-service operators are permitted to use a particular frequency band by obtaining a government issued license. It is the job of the government regulating authority to ensure that the best use is made of each part of the spectrum.

Radio communication services are now vital to the health of the US economy and now directly influences how industry is conducted in the US. Commercial interests are very often at odds with the social needs of all Americans. The correct balance between promotion of radio communication industries and the availability of broadband services to everyone is the responsibility of the Federal Government. The spectrum management task provided by the FCC has become much more difficult over the last 10-15 years because some frequency bands have become very valuable. The value of these attractive bands has increased very significantly due the growth of mobile communication networks. In the past, the FCC could respond to radio service operator's spectrum needs without much scrutiny. People were not concerned about licenses bought by traditional radio service industries like the audio and TV broadcast companies because there were no other competing industries for the VHF and UHF frequency bands. The first 1G cellular network using the 800 MHz band was introduced into the US in 1983 by a company that is now part of AT&T. The establishment of this network was the starting point for increased competition for frequency blocks in the UHF band. The FCC has tried to satisfy this need. Public debate about spectrum policy has been increasing steadily as the American people have been purchasing wireless devices such as cell phones, smart-phones, tablets, and laptops. This has resulted in the FCC's spectrum band sales and assignments to the mobile communications industry to become more important. Mobile broadband coverage is now viewed as an essential part of modern life in the US. Many reports, articles, and comments written and posted on the Internet that have argued that spectrum is getting scarce.

Due to this scarcity of spectrum and the demand for mobile services, the mobile broadband industry is pursuing new sources of spectrum aggressively. The FCC is seeking ways to satisfy the demand from mobile services operators. [FCC 2012 A] This is no easy task because the most attractive spectrum bands are already being used by other radio-communication services. In order to provide the broadband industry with more spectrum blocks, the FCC has had to investigate the redistribution of frequency bands used by established radio services. Federal Government and Military radio services are being assigned to different frequency bands for this purpose.

One of the FCC's major functions is to provide oversight for all radio service industries in the US. The NBP defined recommendations, goals and objectives for expanding and improving broadband services in the US. Given the increased pressure applied to the FCC by the demand for more spectrum bands, have their actions been performed according to the plan? Has the agency changed its policies to comply with the plan? There has been a lot of criticism of its decisions expressed and published in the online media. The FCC has been criticized for ignoring international open standards, and allowing communications companies to use proprietary standards and implement anticompetitive practices. It has been accused of allowing mobile operators to create barriers to market entry by new entrants. Spectrum auctions have been conducted by the FCC since 1994. Frequency blocks have been purchased by the mobile communications industry in the following spectrum bands, 700 MHz, 1.9 GHz, 2.1 GHz, and 2.5GHz. This paper will analyze the sale of these blocks in a series of case studies. The FCC's Office of Engineering and technology (OET) advises the agency on the technical aspects of spectrum management. The OET publishes technical reports, studies and measurement models. Some of these documents will be used to determine how spectrum is being allocated and repurposed for different radio communications industries. Criticism of the FCC's actions accuses the agency of favoring the mobile communications industry. Analysis of the intentions documented in the FCC's reports is compared with agency's actions to determine if the social benefits of the radio communication services are being maintained and enhanced in the US.

The transition of analog to digital TV transmission has made a large portion of spectrum available for repurposing. The propagation characteristics of the TV bands in UHF ranges between 470 MHz and 698 MHz are well suited for wireless broadband applications. This spectrum is a valuable property for mobile broadband due to its excellent propagation characteristics. Technical staff at the FCC provided propagation loss estimations for both urban and rural areas using the "Hata-Okumura" model, to determine its suitability for the cellular network operations. [AWE 2012] The UHF and VHF TV broadcast bands are not all equally suited to broadband use. The FCC is not planning to end Over the Air (OTA) TV broadcast industry's use of the UHF band because multiple radio services operations must now coexist within this band. The TV broadcast industry is still recognized as providing a significant benefit to the United States population. One of the FCC's major goals is to create new market and investment opportunities in the broadband service industry. In order to fulfill these goals the FCC must find a way to transfer spectrum currently being used for OTA TV broadcast to mobile broadband use without interrupting the TV services.

The FCC considers the commercial, social, and technical issues of reallocating spectrum when frequency bands are targeted for reuse. The commercial interests for reallocating spectrum are important to the FCC because spectrum auctions provide the government with an important source of revenue. Some of these funds are used to reimburse any services that have been inconvenienced by the reallocation process. The technical characteristics of each frequency band targeted for reuse also have to be evaluated accurately so that the established users of these bands are not inconvenienced by interference issues. Each of these considerations are key to the FCC's decision to reallocate a band and only when they are all satisfied does the FCC proceed. Spectrum policy is complex and daunting because it tries to satisfy consumer preferences, commercial interests, technological advances and priority allocation changes all at the same time. The FCC is always aware of the needs of the American people, however despite this, the United States has fallen behind in the race for wireless innovation. The reallocation process has to be done in a manner that did not impede or stifle innovation while preserving the interests of the American people.

The goal of this IQP project is to provide an evaluation of the current state of radio spectrum policy and the development of spectrum resources in the US. Does the "winner takes all" model of spectrum auctions provide the best result for the American people? This paper examines the actions taken towards the goals set out in the National Broadband Plan (NBP) [FCC 2012 C]. The reallocation of spectrum bands from radio-communication services used by both Federal and Non-Federal organizations has resulted in some valuable spectrum resources being sold to the mobile communications industry. In order to understand where spectrum sharing and spectrum competition approaches fit within the broader range of possible policy options available to address issues of radio spectrum scarcity, this project examines evidence and examples from past and present, within and beyond the United States. Measurements of spectrum occupancy have shown that only a small proportion of it is in use at any one time. Technology innovations in the radio-communications industry are investigated to determine if intelligent spectrum sharing of the same frequency blocks by multiple radio communications industries is possible.

2 Background

Spectrum management is the process of regulating the use of radio frequencies to promote the most efficient usage and gain the best social benefit. The policies the FCC uses to manage the United States' spectrum have evolved from responding to commercial needs. Although the radio spectrum is very wide only 90 percent of its use is concentrated into 1% of frequencies that are below 3.1 GHz. [GAO 2004] The crowding in this region has occurred because these frequencies have properties that are well suited for many important wireless technologies, such as mobile phones, radio and television broadcasting, and numerous satellite communication systems. Spectrum allocation has been adopted in the United States as an effective means of apportioning frequencies among the various types of uses and users of wireless services thus preventing congestion and interference. This is done by segmenting the radio spectrum into frequency bands that are designated for use by particular types of radio services or classes of users. The spectrum bands used by the US have evolved over the last 100 years or so into what it is today. Radio sets use both Amplitude Modulation (AM) and Frequency Modulation (FM) bands. These receivers placed in people's homes provided news and entertainment broadcast by local radio transmission stations. This marked the start of spectrum management.

2.1 Radio Spectrum Establishment

In order to understand how the radio spectrum is assigned today it is important to know how the radio frequency bands came to be categorized. **Error! Reference source not found.** illustrates the frequency ranges between 3 KHz and Microwaves, and their corresponding applications. The electromagnetic spectrum extends beyond these frequency ranges however, they are used by over 90% of the radio services in the US. Government agencies have been established through Acts of Congress to manage and regulate all frequency bands used in the US. These include bands used for commercial, military, Federal Government, and scientific purposes. [NTIA 2012 C]

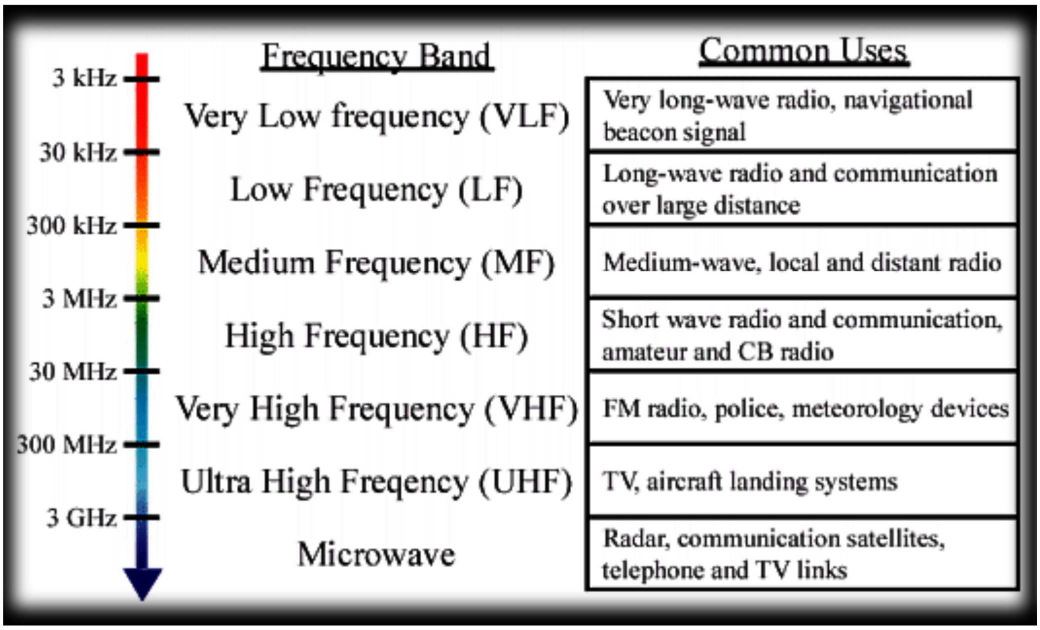


Figure 1 Radio Frequency Bands, Very Low Frequency through Microwave [Young, Kathleen 2003]

The following list provides a summary of each frequency range category and their applications:

- Very low frequency bands between 3kHz to 30 KHz, and wavelength range 100 km to 10km are used for submarine communication, and wireless heart rate monitors
- Low frequency bands between 30kHz to 300 KHz, and wavelength range 10 km to 1 kilometer are used for navigation, time signals, and AM Longwave broadcasting
- Medium frequency bands 300 KHz to 3000 kHz, and wavelengths 1 km to 100 m are used for AM medium-wave radio broadcasting.
- High frequency bands 3 MHz to 30 MHz, and wavelength range 100 meters to 10 meters are used for shortwave broadcasting and amateur radio.
- Very high Frequency bands (VHF) 30 MHz to 300 MHz, and wavelength range 10 meters to 1 meter are used for FM broadcasting and analog TV broadcasting.
- Ultra High Frequency bands (UHF) 300 MHz to 3000 MHz, wavelength range 1 meter – 100 millimeters are used for digital TV broadcasts, mobile phones, wireless local area networks (WLAN), and ground-to-air and air-to-air communications.
- Super High Frequency bands (SHF) 3 GHz to 30 GHz, and wavelength range 100 millimeters to 10 millimeters are used for microwave devices, mobile phones (W-CDMA), WLAN, and modern radar systems. Extremely High Frequency bands (EHF) 30 GHz to 300 GHz, and wavelength range 10 millimeters – 1 millimeter are used for Radio astronomy, and high-speed microwave radio relay.

Radio sets could receive broadcast transmissions using the AM and FM bands by the 1930s. Early television sets came to America in the 1950s. The telephone in people's homes was a device attached to a wire until the invention of mobile phones in the 1980s. The establishment and history of radio and television broadcasting radically changed people's lives throughout the world. Local and international news was made available to every American with a radio or TV set. Telephone service was characterized as local or long distance and restricted to the US and Canada. Under-sea cables were laid on the ocean floors to enable telephone services to be connected between continents. The introduction of mobile communication services in 1981 allowed people to carry a radiotelephone handset (cell phone) in their automobiles. Technological advances provided the transition from analog to digital cellphones, and they were reduced in size to fit into people's pockets. The switchover from Analog to Digital TV broadcasting occurred in 2009. Cable TV companies provided 100's of TV channels to homes via coaxial cables. Satellite TV companies were established to provide the same TV channels to antennas placed on people's homes. Modern society has been transformed by communications technologies. Radio communication and traditional wired communication services have been interconnected so that people can make telephone calls, get map directions, listen to news and entertainment, watch real-time news clips, and follow the financial markets from virtually anywhere in the world.

2.1.1 TV Broadcast Frequency Bands

The US TV broadcast frequencies are on designated television channels numbered two through 69, approximately between 54 and 806MHz. Television broadcasting uses the very high frequency (VHF) band that spans 30 to 300MHz and the ultra-high frequency (UHF) band that spans from 300MHz to 3GHz. The old TV Analog broadcast stations had to be separated by at least one unused channel to avoid interference. Only the non-adjacent channel pairs 4 and 5, 6 and 7, and 13 and 14 did not have a 6MHz separation. Analog TV was the original means of transmitting TV transmission to the public. When Analog TV was invented, there were major problems with interference, much like the problems that AM radio faced. In order to avoid these problems the FCC decided to separate the TV channels so that no interference could take place. Only a fraction of 49 (6 MHz) TV channels in the TV bands are allotted to full-power TV stations in each FCC defined designated market area (DMA). Throughout the US an average of 20 television stations are located in a single DMA. [FCC 2012 B] Figure 2 shows the 4 bands used by TV broadcast services in the US. Each band contains a number of 6 MHz channels. The VHF low band provides channels 2 through 6, 54 MHz to 88 MHz. The VHF high band provides channels 7 through 13, 174 MHz to 216 MHz. The UHF band used for TV broadcast services in the US has been modified by the Analog to Digital switchover. Channels 14 through 51 remain in use for Digital TV broadcast services. Channels 52 through 69 however have been cleared for use by the mobile communications industry, and are now known as the 700 MHz band.

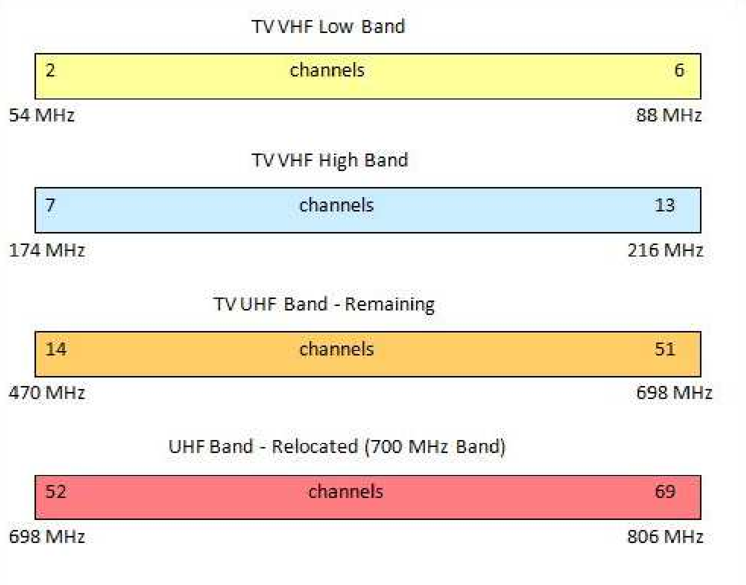


Figure 2 VHF low band and high band, and UHF Channels used for TV Broadcast Service

Analog TV broadcasts ended in June 2009 and replaced with digital transmissions. In most regions, new digital television stations are placed on UHF channels (14 to 51, and sometimes 14 to 20) or high-VHF channels (7-13), although other channels are used in some of the more crowded media markets. The US is divided into a number of TV broadcast DMAs based on the geography of the region, and the density of the population. The assignment of TV channels is unique to each DMA. The Analog to Digital switchover caused channels to be moved around to allow the 700 MHz band to be reassigned.

Figure 3 shows the locations within Massachusetts that had new channels assigned. The locations using channels previously in the 700 MHz band were reassigned channels in the remaining UHF band.

Massachusetts Location	Old Channel	New Channel	Population (thousands)
ADAMS	19	36	1724
BOSTON	7	7	7035
BOSTON	2	19	7320
BOSTON	5	20	7199
BOSTON	4	30	7274
BOSTON	25	31	6911
BOSTON	68	32	6343
BOSTON	38	39	6586
BOSTON	44	43	7091
CAMBRIDGE	56	41	6870
LAWRENCE	62	18	6962
MARLBOROUGH	66	27	6431
NEW BEDFORD	28	22	4604
NEW BEDFORD	6	49	5455
NORWELL	46	10	5297
PITTSFIELD	51	13	653
SPRINGFIELD	22	11	2449
SPRINGFIELD	57	22	2074
SPRINGFIELD	40	40	2286
VINEYARD HAVEN	58	40	973
WORCESTER	27	29	6977
WORCESTER	48	47	5984

Figure 3 Reassignment of TV broadcast channels from the Analog to Digital switchover [FCC 2010 C]

It was possible to reallocate the TV bands because the transition to digital transmission decreased the bandwidth needed to transmit the same amount of data. The reduced bandwidth requirements of lower-resolution images allow up to six standard-definition "sub-channels" to be broadcast on a single 6 MHz TV channel. High-resolution images allow 2 high-definition “sub-channels” to broadcast on a 6 MHz channel. This meant that the TV bands could be restructured without losing stations or causing interference. [FCC 2012 A]

ATSC standards are a set of standards developed by the Advanced Television Systems Committee for digital television transmission over the air (OTA), cable, and satellite networks. The ATSC standards were developed in the early 1990s by a consortium of electronics and telecommunications companies that assembled to develop a specification for what is now known as high definition television (HDTV). The high definition television standards defined by the ATSC produce wide screen 16:9 images up to 1920×1080 pixels in size; this is more than six times the display resolution of the earlier National TV Standards Committee (NTSC) standard. However, many different image sizes are also supported. ATSC replaced much of the analog NTSC television system in the US on June 12, 2009. Broadcasters who use ATSC and want to retain an analog signal must broadcast on two separate channels, as the ATSC system requires the use of an entire channel. Virtual channels allow channel numbers to be remapped from their physical RF channel to any other number 1 to 99, so that either ATSC stations can be associated with the related NTSC channel numbers, or all stations on a network can use the same number. [FCC 2012 A]

2.1.2 Mobile Communications Frequency Bands

The US mobile communications industry has established six major frequency bands for mobile voice and data services throughout the US. For historic reasons they have the following names: 800, Cellular, PCS, AWS, 700, and BRS/EBS. Wireless technology standards have developed rapidly over the last 20 years. There are four stages of technology advancement called first generation (1G), second generation (2G), third generation (3G), and forth generation (4G) respectively. The majority of services today are 2G, and 3G. Two main types of technology standards are used in 2G and 3G networks, Global System for Mobile Communications (GSM), and Code Division Multiple Access (CDMA). Two standards have become dominant for 4G networks, IEEE 802.16 WiMax, and Long Term Evolution (LTE).

Figure 4 shows the different frequency bands for wireless technology standards.

Wireless Technology Standard	Generation	Band Name	Frequency Band (MHz)
iDEN, CdmaOne	2G	800	806-824 and 851-869
D-AMPS	2G	Cellular	824-849 and 869-894
GSM,UMTS, HSDPA, HSUPA, HSPA, HSPA+	3G	Cellular	824-849 and 869-894
GPRS, EDGE	2.5G	Cellular	824-849 and 869-894
D-AMPS	2G	PCS	1850–1910 and 1930–1990
GSM, CDMA2000, 1xRTT, 1xAdvanced, UMTS, HSDPA, HSUPA, HSPA, HSPA+	3G	PCS	1850–1910 and 1930–1990
GPRS, EDGE	2.5G	PCS	1850–1910 and 1930–1990
CDMA2000, 1xRTT, 1xAdvanced, UMTS, HSDPA, HSUPA, HSPA, HSPA+	3G	AWS	1710–1755 and 2110–2155
LTE Advanced	4G	700 MHz	698-806
WiMax IEEE 802.16	4G	BRS/EBS	2496–2690

Figure 4 Wireless Technology Standards used in the US, 1G through 4G [FCC 2012 A]

Figure 5 shows the progression of the wireless standards from 2G through to 4G. Global System for Mobile Communications (GSM) and Interim Standard 95A (IS-95A) were the two most prevalent 2G mobile communication technologies in 2007. GSM used time-division multiple access (TDMA) modulation technique to time slicing the channel. The IS-95A standard used code-division multiple access (CDMA) which is a digital modulation technique called spread spectrum that spreads the voice data over a wide channel. GSM made the transition to 3G through General Packet Radio Services (GPRS) and Enhanced Data GSM Environment (EDGE) standards. IS-95A progressed to the CDMA2000 3G standard through an IS-95 enhancement, IS-95B. The 3G standard Universal Mobile Telecommunications System (UMTS) employs Wideband Code Division Multiple Access (W-CDMA) radio access technology for greater spectral efficiency. CDMA2000 1X (IS-2000), also known as 1x and 1xRTT, is the core CDMA2000 wireless air interface standard. CDMA2000 1xEV-DO (Evolution-Data Optimized), often abbreviated as EV-DO is standardized by the 3rd Generation Partnership Project 2 (3GPP2). Long Term Evolution (LTE) is based on the GSM, EDGE, UMTS, and High Speed Packet Access (HSPA) network technologies, increasing the capacity and speed using new modulation techniques. LTE is derived from 3rd Generation Partnership Project (3GGP) Long Term Evolution specification, and is also known as 4G. WiMax is another 4G standard and refers to interoperable implementations of the IEEE 802.16 family of wireless networks standards ratified, by the WiMAX Forum.

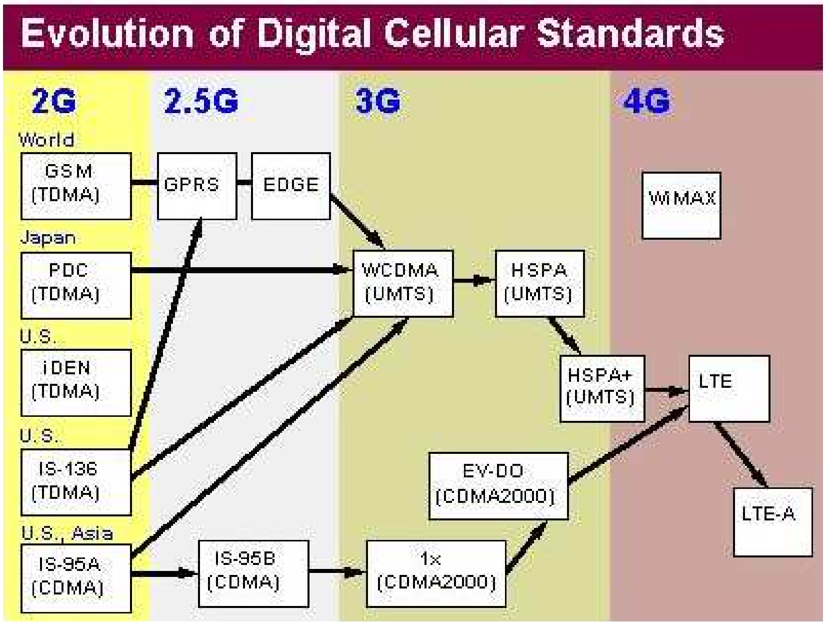


Figure 5 Evolution of Digital Cellular Standards 2G through 4G [Free Dictionary 2012]

Figure 6 shows the major US mobile communications operators and the technology standards deployed in their networks. The country has 322.9 million subscribers in total, or a 103% penetration rate.

Operator	Mobile Technology Standards in operation	Subscribers (millions)
Verizon Wireless	CdmaOne, CDMA2000 1xRTT, EV-DO; 700 MHz LTE	107.7
AT&T Mobility	850/ 1900 MHz GSM, GPRS, EDGE; 850/ 1900 MHz UMTS, HSDPA, HSUPA, HSPA, HSPA+, 700 MHz LTE	100.7
Sprint Nextel	iDEN, WiDEN, CdmaOne, CDMA2000 1xRTT 1xAdvanced, EV-DO, WiMAX, LTE	53.4
T-Mobile USA	1900 MHz GSM, GPRS, EDGE; 1700/ 2100 MHz UMTS, HSDPA, HSUPA, HSPA, HSPA+(42 Mbit/s), LTE	33.711
TracFone Wireless	CdmaOne, CDMA2000 1xRTT, GSM, GPRS	19.269
Clearwire	WiMAX, LTE	9.541
MetroPCS	CdmaOne, CDMA2000 1xRTT, EV-DO 1700 MHz LTE	9.3
Cricket	CdmaOne, CDMA2000 1xRTT, 1x Advanced, EV-DO, LTE	5.934
U.S. Cellular	CdmaOne, CDMA2000 1xRTT, EV-DO, LTE	5.891

Figure 6 Major US Mobile Communications Operators and Wireless Standards [CTIA 2012]

2.2 Governance and Regulation

In order to understand how the spectrum is regulated it is important to understand how the organizations that govern it came about. The history behind the formation of the FCC and NTIA, the two government bodies that regulate and control spectrum is complex. The laws and licensing regulations evolved as the radio communications technologies evolved. The history of spectrum regulation and the Federal Government management of frequency bands provide an insight into the operation of the FCC.

2.2.1 History of US Government Radio Regulation

The “commerce” clause of the U. S. Constitution assigned to Congress the task of regulating interstate and foreign commerce. Early radio stations served as basic communication systems, transmitters of messages that were meant to facilitate commerce and protect the health and well-being of the US people. This began with the Wireless Ship Act of 1910 that required ocean-going ships traveling to or from the US to have radio equipment if more than 60 passengers were onboard. A little over 100 years ago the Department of Commerce started by providing minimal oversight of the infant radio industry. Today government agencies created specifically for radio regulation provide the complex services required to support a variety of industries in the US. Acts of Congress have been created to define and enforce legislation for this purpose.

2.2.1.1 Radio Act of 1912

The Radio Act of 1912 was the first attempt to apply some comprehensive legislative oversight to the radio industry. The law established licensing for all transmitting apparatus for interstate or foreign commerce by the Secretary of Commerce. Each radio station operator had to be licensed. The Radio Act of 1912 did not mention radio broadcasting. This became a problem in the 1920s when a proliferation of new stations were seeking licenses and vying for airtime on an extremely limited allocation of frequencies. New frequencies were allocated and a self-regulation model was attempted. [Messere, Fritz 2001]

2.2.1.2 Radio Act of 1927

The Radio Act of 1927 (P.L 632, 69th Congress) was enacted on February 23, 1927. The legislation created the Federal Radio Commission (FRC) with authority to designate licensees, and regulate radio station operating times and power output. The act asserted a public interest in broadcasting and public ownership of the airwaves. The legislation designated the radio spectrum as part of the public domain, allowing the FRC the power to grant rights to users of the spectrum but forbidding private ownership over communication channels. [Messere, Fritz 2001]

2.2.1.3 Communications Act of 1934 establishing the FCC

The passage of the Communications Act of 1934 (P.L. 416, 73 Congress) established a permanent commission to oversee and regulate the broadcasting and telecommunications industries, the Federal Communication Commission (FCC). By 1934, broadcasting had evolved into a highly profitable business. The structural components of the network radio system, almost wholly outside the jurisdiction of the Federal Radio Commission, had developed into a series of highly successful operations. Different uses would require differing amounts of spectrum space; the FCC was required to decide which services and users could use the various parts of the spectrum. [Messere, Fritz 2001]

2.2.1.4 The National Telecommunications and Information Administration Creation 1978

The NITA was created in 1978 by combining various functions of the White House's Office of Telecommunications Policy (OTP) and the Commerce Department's Office of Telecommunications (OT). The NTIA Organization Act of 1992 codified NTIA's authority in detail and incorporated this organizational structure into statute. The NTIA’s job is to regulate and control all of the government owned spectrum. [NTIA 2012 B]

2.2.1.5 Omnibus Budget Reconciliation Act of 1993

This act authorized the FCC to use competitive bidding (auctions) to choose licensees, and ordered identification and transfer of 200 MHZ from government use to FCC jurisdiction. This decision was made for a number of reasons but chiefly the introduction of auctions made it possible for the FCC to generate funds that the government could use improve the public’s telecommunication services. [FCC 2012 A]

2.2.1.6 Telecommunications Act of 1996

This act set the stage for licensing of digital television channels to broadcasters and essentially precluded an open auction. It granted broadcasters the flexibility to use their spectrum for non-broadcast services making the spectrum truly owned by the broadcast company that bought it. This act has resulted in questions today of whether a specific company owning a band of frequencies is beneficial to the public. [FCC 2012 A]

2.2.1.7 Balanced Budget Act of 1997

This act required the transfer of additional 20 MHZ of spectrum below 3 GHz from the Federal Government to be used by the FCC for reallocation. It also set 2006 as the year broadcasters had to give up their analog channels however this not happen until 2009. [FCC 2012 A]

2.2.1.8 Commercial Spectrum Enhancement Act 2003-2004 108th Congress

This act created the Spectrum Relocation Fund to provide a centralized and streamlined funding mechanism through which federal agencies can recover the costs associated with relocating their radio communication systems from certain spectrum bands that were reallocated for commercial purposes. The legislation appropriated the necessary funds required for relocation costs, to be financed by auction proceeds [FCC 2012 A]

2.2.1.9 Digital Transition and Public Safety Act of 2005

This act set the date of Feb. 17, 2009 as the date that analog TV transmission would cease and digital TV transmission would start. It also allowed the TV Broadcast industry to provide High Definition (HD) TV channels. This transition made way for the reallocation of blocks of frequency bands previously used for analog TV channels. [FCC 2012 A]

2.2.2 Federal Communications Commission, FCC

On June 19, 1934, Congress enacted legislation establishing the Federal Communications Commission (FCC). This legislation supported the regulation of broadcasting, wired communications, and had three divisions: broadcast, telegraph, and telephone. The 1934 Act has been amended many times to include, television, satellite and microwave communications, cable television, cellular telephone and PCS (personal communications) services. The FCC can license operators of telecommunication services and uses auctions to sell access to parts of the radio spectrum. These auctions are the primary means of determining who would be awarded licenses for these services. It licenses all transmitters whose signal can travel various distances, although there are a few exceptions for very low power radio transmitters, such as those in CB radios and walkie-talkies. As more radio and television stations obtained licenses, restrictions that limited ownership to a few stations were determined to make less sense to the FCC. The ownership rules were relaxed in 1985. [FCC 2012 A]

2.2.3 National Telecommunication Initiative Administration, NTIA

The NTIA is the President's principal adviser on telecommunications and information policy issues and in addition, it manages the Federal use of the spectrum. It has the President's authority to assign frequencies to radio stations belonging to and operated by the United States and long-range spectrum planning in cooperation with the FCC. As the administrator of Federal spectrum, the NTIA serves as a reactionary entity, catering to the demands of Federal departments in need of spectrum for national defense or safety. As part of the Department of Commerce, it functions as an important link between the telecommunications private sector and the government. [NTIA 2012 B]

2.2.4 Licensing

Since 1994, new spectrum licenses are determined by competitive bidding auctions that are administered through the FCC's website. A band is allocated for a particular service in a particular geographic location. The auctions are held in a simultaneous multi-round approach consisting of thirty-minute time segments until the bidding stops. The winners of the auction receive an operating license of 5 years. Auctions are an important process in the FCC's spectrum policies; however, only 7% of all Radio Spectrum is available for auction, the remaining frequencies are either in use or not eligible for reassignment. [FCC 2012 A] A wireless connected device or service can be either licensed or unlicensed. In the US, licensed connections use a privately owned spectrum. The user has secured rights to that frequency range from the FCC and can use that frequency range is any way they desire within the rules of the acquired license. The user is not bound by any implementation rules such as the spectrum must be put into operation within a specific time-period. Licensed spectrum is very expensive and is generally owned by large companies who purchase licenses FCC spectrum auctions. An example is the purchase of spectrum blocks in the 700 MHz band by Verizon Wireless for $9,363,160,000 in 2008. Unlicensed or license-free spectrum is a frequency band that has pre-defined rules for both the hardware and deployment methods. This spectrum is designed to be used without a large amount of control over who is transmitting on what specific frequency. The radio interference is mitigated by the technical rules defined for the bands rather than it being restricted for use by only one entity through spectrum licensing. Typically, the power allowed for unlicensed devices is much lower than that enjoyed by licensed spectrum holders.

In order to build a TV or radio station a construction permit is required. The applicant must demonstrate it is qualified to construct and operate a TV station as specified by FCC regulations. The proposed facility must also be proved not to cause interference with any other station. Upon grant of that license application, the FCC issues the new license to operate the new station for up to eight years. The FCC will also impose conditions on the TV Broadcast operator, one of which is to provide a free program channel for local services. This type of condition is not imposed on wireless operators.

2.3 The National Broadband Plan

In early 2009, the US Congress directed the FCC to develop a National Broadband Plan (NBP) to ensure every American has "access to broadband capability." The FCC started the process of creating the NBP with a Notice of Inquiry in April 2009. Thirty-six public workshops were held by the agency and streamed online. Thirty-one public notices generated over 23,000 comments totaling about 74,000 pages from more than 700 parties. The document is titled "Connecting America: The National Broadband Plan" is 377 pages in length and was written as part of the FCC's "Omnibus Broadband Initiative" (OBI). The mandates, goals and objectives of the plan are examined in this paper.

The US Government defined four ways in which it can influence the broadband ecosystem. [FCC 2012 A]

- The first is to establish policies and recommendations that foster greater competition across the ecosystem. This objective indicates the desire to promote competition across the broadband industry to promote innovation and lower prices.
- The second is to ensure efficient allocation of government owned and government-influenced assets. This objective wants to distribute government owned and regulated spectrum blocks across commercial, military, federal agencies, and scientific users for optimum social benefit of the American people.
- The third is to create incentives for the universal availability and adoption of broadband for all Americans. This objective promotes the need to eliminate the "digital divide" by providing universal access of broadband services to everyone in the US regardless of physical location or income level.
- The forth is to update policies, set standards and align incentives to maximize the use of all broadband resources for national priorities. This objective indicates the need to provide the best technical and regulation oversight so that education, security, and public safety organizations in the US gain timely access, and optimal performance of broadband services.

The NBP recommends that the US adopt and track the six goals to serve as a compass over the next decade. [FCC 2012 A]

- Goal number 1 “At least 100 million U.S. homes should have affordable access to actual download speeds of at least 100 megabits per second and actual upload speeds of at least 50 megabits per second”.
- Goal number 2, “The United States should lead the world in mobile innovation, with the fastest and most extensive wireless networks of any nation”.
- Goal number 3, “Every American should have affordable access to robust broadband service, and the means and skills to subscribe if they so choose”.
- Goal number 4, “Every American community should have affordable access to at least 1 gigabit per second broadband service to anchor institutions such as schools, hospitals and government buildings”.
- Goal number 5, “To ensure the safety of the American people, every first responder should have access to a nationwide, wireless, interoperable broadband public safety network”.
- Goal number 6, “To ensure America leads the clean energy economy, and every American should be able to use broadband to track and manage their real-time energy consumption”.

The budget for the NBP was to be provided through the sale of spectrum bands to industry. The executive summary makes the following statements,

> *Given the plan’s goal of freeing 500 megahertz of spectrum, future wireless auctions mean the overall plan will be revenue neutral, if not revenue positive. The vast majority of recommendations do not require new government funding; rather, they seek to drive improvements in government efficiency, streamline processes and encourage private activity to promote consumer welfare and national priorities. The funding requests relate to public safety, deployment to unserved areas and adoption efforts. If the spectrum auction recommendations are implemented, the plan is likely to offset the potential costs.* [FCC 2012 C]

The primary goal of the plan is to ensure every American has access to broadband products and services. Radio communication and wired communication services are cheaper to install in urban densely populated areas than in rural areas. Incomes are higher in some States than in others. The NBP wishes to provide a minimum set of broadband services independent of geographic location or income level. This paper will examine the repurposing and the sale of spectrum bands for use by the broadband industry together with, the progress made toward expanding broadband services into rural America.

3 Methodology

The goal of my project was to analyze the US radio spectrum policy and management. I considered the structure of the current regulating and authorizing organizations within the US Government providing the support and licensing structure necessary for the radio communications industry. Analysis of the decision-making and responsibilities associated with these agencies gave me the information needed to evaluate the success or failure of their actions. I determined possible options for improving the abilities of the agencies to meet their stated objectives. I reviewed the National Broadband Plan to examine the goals and recommendations set out in the document for the enhancement of broadband services in the US. Spectrum demand was evaluated using quantative analyzes of the growth of mobile devices and of the growth of cellular networks. The increased visibility that spectrum availability has attained in the media required that I determine how the interplay between the needs of society with the actions taken by Government affected the management of this natural resource. The specific questions that I attempted to answer were the following:

- Has the US Spectrum policy been appropriately enhanced to keep pace with the rapid advances in radio communications technology?
- Has the US Spectrum policy and management done enough to allow all Americans access to all radio communication services available in the US?
- Was selling blocks of spectrum bands at auction the best approach for promoting the most universally accessible radio communication services throughout the US?
- Are the American people getting the "best bang for the buck", and does the richest country have the best penetration of radio communication services?
- Has the US established a competitive environment for the radio communications industry, since two large corporations still dominate?
- Have we embraced new technologies sufficiently well to make the most optimal use of all spectrum bands?

3.1 Has the US Spectrum Policy been appropriately enhanced?

To answer this question I needed to research the history of the establishment of the Government agencies responsible for establishing and maintaining spectrum policy in the US. The Federal Communication Commission (FCC), the National Telecommunications Information Administration (NTIA) and other agencies provided comprehensive information about their actions. A very large quantity of information is provided in the public domain by the FCC and NTIA to comply with their goal of being open and transparent. Condensing the appropriate reports of the actions, recommendations and goals of the various groups within the agencies allowed me to formulate my understanding of their structure and inner workings. I analyzed this information to determine the evolution of spectrum policy since the establishment of radio stations in the US starting in the early 1900s.

3.2 Has the US Spectrum Management provided all Americans access to Mobile Broadband?

The United States is the largest industrial country in the world as measured by its Gross Domestic Product (GDP). It has a free market economy and a robust mobile communications industry. I needed to determine whether all Americans had equal access to mobile broadband services. To determine how the cellular networks were established in the US, I analyzed information provided by the largest mobile providers in the US, namely AT&T, Verizon, Sprint, Clearwire and others. Collecting statistics of the types of mobile services and the coverage provided by these companies allowed me to determine if mobile broadband service was universally available throughout the US. Information about the mobile technologies they were employing and those that they plan to establish in the future gave me an understanding of their competitive positions within the industry.

3.3 Was selling blocks of spectrum bands at auction the best approach?

I investigated the initiatives established by the US Government towards providing mobile broadband access to all Americans. I researched the directives taken by the office of the President and the US Congress to reallocate spectrum bands for the use by the mobile communications industry. The ambitious plans for freeing up 300 MHz, and 500 MHz, in 5 and 10 year, timeframes were evaluated to determine if the best approaches for making spectrum blocks available were taken. The selling of spectrum blocks at auction has been controversial. The criticism of the actions taken by the FCC by academic institutions and industry knowledgeable groups was investigated to determine if the provision of new spectrum blocks had been done at the expense of incumbent radio services such as the TV broadcast industry. The US Government has generated significant revenue through spectrum auctions. I investigated whether this money was obtained without affecting the existing educational, scientific, and other institutions using radio services in the US. I analyzed the spectrum auctions and determined which companies won, which designated market area (DMA) licenses. I then, tabulated the resultant revenue generated at each auction and determined the value of each block of spectrum sold.

3.4 Are the American people getting the "best bang for the buck"?

As the richest country in world as measured by GDP per Capita, are the people of America getting value for money from the radio communication services in the country? I gathered statistics from various domestic and international organizations to answer this question. The difference between services available between urban and rural areas was appraised. The US has a large land mass and hence people living in remote and under-populated areas do not get the level of mobile broadband services that are available in US cities. I researched the policies the Government agencies have established to resolve this inequity. An evaluation was made of the agency's actions taken to promote the wider establishment of mobile broadband services to remote areas. The mobile communication service penetration in the US was compared with other countries to determine our ranking amongst the leading industrial nations.

3.5 Has the US established a Competitive Environment for US Radio Services?

The competitive environment within the radio communications industry was evaluated to determine if the two largest companies AT&T and Verizon exert too much influence on telecommunications services in the US. These companies have deep pockets and hence enjoy a significant advantage over smaller mobile operators. Research into the actions taken by the FCC to promote fair access to the acquisition of spectrum blocks provided an understanding of the criticism made of the agency about this issue. The FCC issued licenses to the TV broadcast industry allowing TV stations to be built in the US starting in the 1950s. I researched the structure and requirements of the licenses issued to TV broadcasters and compared them with those issued to the mobile communications industry. By studying the differences in these license approaches, I determined that the FCC has been significantly more lenient with mobile operators. I evaluated whether the leniency resulted from a change in spectrum policy or due to influence by the mobile operators. The initiatives made to free up large amounts of spectrum has been done to the advantage of the mobile operators and to the possible detriment to the TV broadcast industry. The lack of fairness of the FCC actions towards the different radio industry sectors was evaluated.

3.6 Have we embraced new technologies well for optimal spectrum use

I researched measurements of spectrum occupancy made by various organizations. I gained the understanding that large parts of the radio spectrum are underutilized. I investigated various technical approaches that attempt to correct this problem. I studied the spectrum policy changes being established by the FCC to promote secondary user markets for these underutilized frequency bands. Research into newly proposed technologies allowed to me to understand the future possibilities of sharing spectrum bands between multiple users. I determined that there are organizations that would like to see spectrum bands treated as a common resource. I investigated whether this promising trend will continue in the future, and if the current radio industry is willing to change its operational structure to accommodate these new ideas.

4 Findings and Discussion

There is very aggressive competition for new radio spectrum frequency bands when they become available in the US. Very high prices are being paid for bands with the most attractive technical characteristics. Governmental, Industrial and public interest considerations provide the primary focus, however new technologies and their effect on radio spectrum allocations need to be taken into consideration. Spectrum management has been the subject of criticism from many groups. There is considerable concern about spectrum efficiency and some people have called the current spectrum allocation regulations outdated and in need of restructuring.

4.1 Problems with the current Spectrum Management scheme

This paper is focused on the radio spectrum management situation in the US. Spectrum management is the process of regulating the use of radio frequencies to promote the most efficient usage and gain the best social benefit. Since the 1930s, spectrum was assigned through administrative licensing. Signal interference was once considered the major problem to spectrum use and hence exclusive licensing was established to protect licensees' signals. The rapid advance digital signal transmission has lessened the radio interference problem however it remains an important consideration when establishing new radio services. This former practice of discrete bands licensed to groups of similar services is giving way to a spectrum auction model that is intended to speed technological innovation and improve the efficiency of spectrum use. The sale of spectrum bands is providing the Federal Government with billions of dollars in revenue. Promotion of the social benefits of spectrum band allocation for radio communication services is being compromised for monetary gain.

The US considers the RF spectrum as an exclusive property of the state. Effective spectrum management is essential to maintain the integrity of RF spectrum. Within the United States, the Communications Act of 1934 grants authority for spectrum management to the President for all federal use (47 USC 305). The National Telecommunications and Information Administration (NTIA), manages the spectrum for the Federal Government. The Federal Communications Commission (FCC) manages and regulates all domestic non-federal spectrum use (47 USC 301). The regulators are the centralized authorities for spectrum allocation and usage decisions. The FCC determines the cases for specified use of portions of the spectrum, as well as the parties who will have access to them.

The allocation decisions are often static meaning that they are valid for extended periods usually decades and for large geographical regions countrywide. The usage is often set to be exclusive; each band is dedicated to a single provider, thus maintaining interference free communication. This model dates back to initial days of wireless communications, when the technologies employed required interference-free mediums for achieving acceptable quality. Thus, it is often argued that the exclusive nature of this approach is an artifact of outdated technologies. [Ryan, Patrick 2005] The Government Accounting Office GAO published a report criticizing the current spectrum management scheme. An excerpt from the report makes the following statement:

> *The current structure and management of spectrum use in the United States does not encourage the development and use of some spectrum efficient technologies. Because the spectrum allocation framework largely compartmentalizes spectrum by types of services (such as aeronautical radio navigation) and users (federal, non-federal, and shared), the capability of emerging technologies designed to use spectrum in different ways is often diminished.* [GAO 2004]

Spectrum scarcity is a major problem when trying to launch new wireless services. Billions of dollars are often needed to secure access to specified bands; however, spectrum utilization measurements have shown that the available spectrum is underutilized. Scarcity is often considered the result of static and rigid governing authority. [ITU 2007] The FCC and other government bodies are considering changes to spectrum allocation. Progress however is very slow because different stakeholders have to be consulted and the documents presented at public forums for discussion. A US TV broadcast license is a specific type of spectrum license that grants the licensee the privilege to use a portion of the radio frequency spectrum in a given geographical area for broadcasting purposes. If the frequency band is designated as being underutilized and suitable for reassignment, it is then put up for auction. The wireless operator then bids for the right to use the frequency band in various parts of the country. The FCC geographically divides the US into a number of Trading Areas. A wireless operator bids for a license to operate on a specific frequency band in each trading area. The spectrum repurposing process remains slow and expensive. [FCC 2012 A]

4.2 Recent Spectrum Management Initiatives

To promote economic growth and unleash the potential of wireless broadband, the federal government unveiled an initiative to reform spectrum policy and improve America's wireless infrastructure. In June 2010, the National Telecommunications and Information Administration (NTIA), in collaboration with the FCC, were given a directive to make 500 megahertz of spectrum available for fixed and mobile wireless broadband in the next ten years. The FCC has begun implementing recommendations in the National Broadband Plan (NBP) to make available, in five years, 300 megahertz of spectrum for mobile uses. The bands that NTIA and the FCC selected for initial evaluation fall within the range 225 MHz to 4400 MHz. Bands below 225 MHz generally in use for VHF TV broadcasts have insufficient usable bandwidth for wireless broadband services, and bands above 4400 MHz do not appear to be of current interest by industry for mobile use. The TV Broadcast Frequency Bands yield 120 MHz, and are candidates for mobile broadband. A detailed evaluation of an initial set of candidate bands is then presented to the current owners of the bands; these can be federal and non-federal owners. Negotiations then take place to determine whether frequency band candidates are either put up for auction or possibly swapped for other bands. The costs of the repurposing operations, which could include the construction of new TV broadcast stations, combining existing stations, purchasing new transmission equipment is then offset against any revenues, generated from auctions of frequency bands. [FCC 2012 D] The candidate bands are shown in Figure 7.

Frequency Band (MHz)	Amount (MHz)	Current Allocation/Usage (Federal, Non-Federal, Shared)
(Broadcast TV)** VHF/UHF Frequencies ****	120	Non-Federal
406.1-420****	13.9	Federal
(D-Block)**	10	Non-Federal
(MSS)** 758-763****,788-793****, 1300-1390****	90	Federal
(MSS)** 1525-1559, 1626.5-1660.5	40	Non-Federal
(MSS)** 1610-1626.5 2483.5-2500	10	Non-Federal
(MSS)** 1675-1710*	35	Federal/non-Federal Shared
(MSS)** 1755-1780*	25	Federal
(MSS)** 1780-1850	70	Federal
(AWS 2/3)** 1915-1920**** 1995-2000	10	Non-Federal
(MSS)** 2000-2020 2180-2200	40	Non-Federal
(AWS 2/3)** 2020-2025	5	Non-Federal
(AWS 2/3)** 2155-2180	25	Non-Federal
(AWS 2/3)** 2200-2290***	90	Federal
(WCS)** 2305-2320**** 2345-2360****	30	Non-Federal
(WCS)** 2700-2900****	200	Federal
(WCS)** 2900-3100	200	Federal/non-Federal Shared
(WCS)** 3100-3500	400	Federal/non-Federal Shared
(WCS)** 3500-3650*	150	Federal
(WCS)** 3700-4200	500	Non-Federal
(WCS)** 4200-4400**** ,[4200-4220 & 4380-4400]*	200	Federal/non-Federal Shared
Total	2263.9	
* Bands selected for Fast-Track evaluation		
** Identified in the National Broadband Plan, Recommendation 5.8, page 86 (using nomenclature contained in Exhibit 5-E)		
*** NTIA notes the ITU-R SA.1154 Recommendation		
**** Band obligated by a U.S.-Canada or U.S.-Mexico bilateral agreement(s)		

D-Block – Public Safety Spectrum, MSS – Mobile Satellite Service Spectrum, AWS – Advanced Wireless Services Spectrum, WCS – Wireless Communications Service Spectrum

Figure 7 Repurposed Frequency Bands from Federal and Non-Federal Sources [Locke, Gary 2010]

4.2.1 Frequency Band Repurposing Initiatives from the Federal Government

The process for reallocating spectrum varies depending on whether the spectrum is currently allocated for Federal, non-Federal or shared use. The NTIA evaluates each band for its suitability to support for wireless broadband use and whether it is contiguous. It takes account of industry’s interest in the band and its expected auction revenue. The availability of comparable spectrum bands if the relocation of incumbent users is necessary is evaluated. The estimated costs of relocating Federal incumbents to another band are calculated.

Spectrum blocks in the 1710 MHz to 1755 MHz band used by 12 Federal agencies were repurposed. There were 1,990 NTIA-issued Federal frequency assignments in this spectrum. Federal communications systems utilized these frequency assignments to transmit voice, data, and video information to facilitate agency operations. On September 18, 2006, the FCC concluded an auction of licenses for Advanced Wireless Services (AWS), on radio spectrum in the 1710 megahertz (MHz) to 1755 MHz band. The relocation cost was over $1B, which is $22/Hz. An FM radio channel uses 200 KHz, and hence the cost would be $4.4M. The majority of the affected systems were fixed microwave systems, which transmit voice and data signals from site to site to enable a variety of agency activities. They utilized commercially available technology to make the changeover. More specialized systems such as those used for surveillance and law enforcement purposes were not able to utilize commercial technology and hence commissioned new equipment for their particular needs. The repurposing of the frequency bands was completed over 6-year period with the majority completed within 3 years. [OMB 2007]

4.3 Benefits of Additional Spectrum to Broadband

Spectrum demand by new and existing users indicates that the current spectrum allocation is insufficient for the rapidly expanding mobile communications industry. New spectrum demand for voice services is relatively flat. The demand for new spectrum bands for data services is very high.

4.3.1 Mobile Broadband Demand

Mobile broadband growth is even faster than in wireline (wired transmission) networks. This is because not only are individual users consuming ever more data, the percentage of users using mobile broadband is increasing. The result is a huge projected increase in data consumption as shown in Figure 8, a Cisco projection of global mobile broadband traffic measured in petabytes (million gigabytes) per month. This growth is at a 108% compound annual rate over five years. [Cisco Systems 2011]

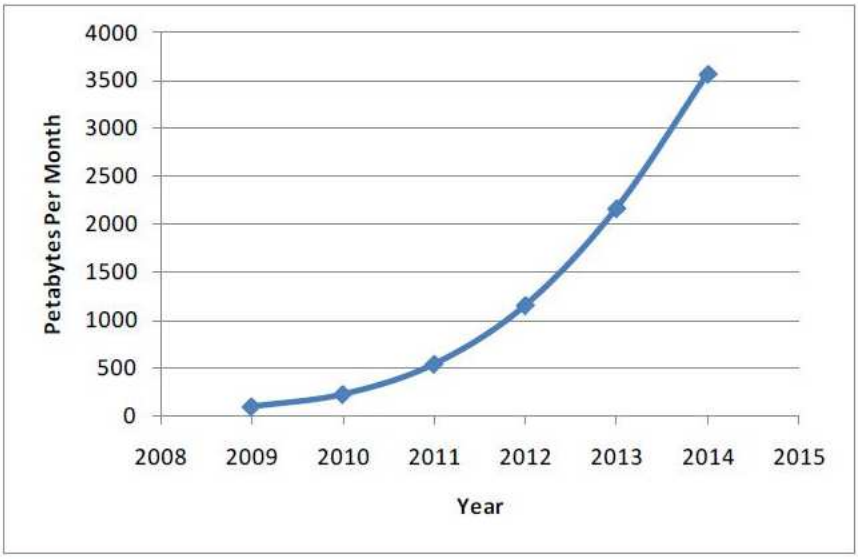


Figure 8 Global Mobile Broadband Data Rate in Petabytes per Month 2009-2014 [Cisco Systems 2011]

These forecasts indicate that the need for mobile devices and mobile broadband will continue to grow very rapidly in the next few years and hence the spectrum it occupies needs to grow to support that demand. Statistics from a recent industry report show the alarming growth rate of mobile broadband data consumption in 2010 and 2011. Global mobile data traffic grew 133 percent in 2011. Global mobile data traffic in 2011 at 597 petabytes per month was over eight times greater than the total global Internet traffic in 2000 at 75 petabytes per month. Mobile video traffic was 52 percent of traffic by the end of 2011. Globally, the average mobile network connection speed for smartphones in 2011 was 1344 kbps, up from 968 kbps in 2010. Although 4G connections represent only 0.2 percent of mobile connections today, they already account for 6 percent of mobile data traffic. The average amount of traffic per smartphone in 2011 was 150 MB per month, up from 55 MB per month in 2010. In 2011, the typical smartphone generated 35 times more mobile data traffic at 150 MB per month, than the typical cell phone that generated only 4.3 MB per month of mobile data traffic. In 2011, mobile data traffic per tablet was 517 MB per month, compared to 150 MB per month per smartphone. Mobile data traffic per laptop was 2.1 GB per month, up 46 percent from 1.5 GB per month in 2010. Non-smartphone usage increased 2.3-fold to 4.3 MB per month in 2011, compared to 1.9 MB per month in 2010. The average iPhone user consumed 400 Mbytes per month in 2010. [Cisco Systems 2011]

The Wireless Industry Association (CTIA) publishes a wireless industry overview document every 6 months. This document tracks the growth and economic impact over the wireless industry on the world. One of its projections is that Fourth Generation (4G) wireless services build out could mean $25-$53B in U.S. infrastructure investment, and $73-$151B US Gross Domestic Product (GDP) growth through 2016. [CTIA 2012] Projected US wireless data usage is growing very rapidly, from December 2009 to December 2010, it grew from 107.8 billion MB in the last half of 2009 to more 226.5 billion MB in the last half of 2010.

Rapidly increasing Smartphone penetration is currently driving network usage. There has been a 25% increase in 2010, and is ready to hit 50% with two years. [Cisco Systems 2011] Today's cellphones and Smartphones are used to support an astounding and rapidly proliferating array of tasks that were not traditionally associated with the telephone. For example, users of these devices browse the Web at large, e-mail with attachment viewing, navigate with maps, watch video, do social networking, perform banking operations, access business information, and provide entertainment. People love their Smartphones because a small handheld device gives them access to the same tools and information that previously required a laptop computer. The rapidly diversifying uses of these technologies do however entail some risks. A small number of mobile users with bandwidth-intensive applications can easily consume the available wireless network capacity.

We are not quite at the stage of capacity exhaustion, but we are seeing early instances of it, and analysis shows that the available capacity can be consumed by a relatively small percentage of high-bandwidth subscribers. To combat heavy users monopolizing data networks service providers such as ATT are limiting the amount of data users can transfer on a monthly basis to 250G bytes. Additional fees are imposed if the limits are exceeded. [ATT 2012]

Data capabilities of cell phones and smartphone have improved at a rapid rate with Enhanced Data Rates for GSM Evolution (EDGE), then 3G technologies like High Speed Packet Access (HSPA), Evolved Data Optimized (EV-DO), WiMAX, and 3GPP Long Term Evolution (LTE). [Rysavy Research 2010] Each wireless networking technology has enabled greater data consumption by mobile phones. Coping with this rate of change, especially with data now outstripping voice in traffic volume, is extremely challenging for mobile operators.

Bytemobile issued a report on the impact of smartphones on mobile networks showing how smartphone usage is beginning to approach laptop usage. This includes touch smartphone browsing sessions of 38 minutes being approximately 63% of laptop sessions. The report also shows that one video user consumes fifteen times more network bandwidth than a Web user. In 2010, there were still ten to fifteen times more Web users than video users, but video usage is growing quickly as Web sites offer more and more video. [Byte Mobile 2009]

Figure 9 lists recommended bandwidths for different applications a typical voice call uses 8 Kbps while a streaming video can use 2Mbps. The streaming video application is therefore demanding 25 times the bandwidth of a voice call.

Application	Recommended Bandwidth
Mobile voice call	6 kbps to 12 kbps
Text-based e-mail	10 to 20 kbps
Low-quality music stream	28 kbps
Medium-quality music stream	128 kbps
High-quality music stream	300 kbps
Video conferencing	384 kbps to 3 Mbps
Entry-level, high-speed Internet	1 Mbps
Minimum speed for responsive Web browsing	1 Mbps
Internet streaming video	1 to 2 Mbps
Telecommuting	1 to 5 Mbps
Gaming	1 to 10 Mbps
Enterprise applications	1 to 10 Mbps
Standard definition TV	2 Mbps
Distance learning	3 Mbps
Basic, high-speed Internet	5 Mbps
High-Definition TV	7.5 to 9 Mbps
Multimedia Web interaction	10 Mbps
Enhanced, high-speed Internet	10 to 50 Mbps, 100 Mbps emerging

Figure 9 Bandwidth Requirements per Application used on Mobile Devices [Rysavy Research 2010]

Mobile voice and text-based e-mail communications require relatively little bandwidth, whereas high-definition video consumes more bandwidth than any other application. A high-definition YouTube video at 2 Mbps consumes as much bandwidth as 200 voice calls. [Rysavy Research 2010]

4.3.2 Broadband Capacity and Cell-Site Spectral Efficiency

Calculation of broadband capacity requires that wireless network performance has to be determined. One important metric is spectral efficiency measured in bits per second per Hertz. Spectral efficiency is an indicator of the capacity of average downlink data for a cell-site. This metric indicates the amount of data a sector can transmit over a fixed time-period, and hence provides a measure of the average-downlink-data-capacity of a cell-site. Figure 10 shows the evolution of the capacities of downlink data traffic for a single sector in a 3-sector GSM cell-site. Cell sites are typically divided into three sectors, with each sector operating as a separate radio-coverage area. Figure 10 also shows the spectral efficiency of air interface standards as they have evolved from 2G (GPRS) to 3G (HSDPA) to 4G (LTE). Spectral efficiency is measured using the following formula.

$$(R/B)/K \ per \ site$$

R is the net bit-rate per carrier, B is the bandwidth per carrier, and (1/K) is the reuse factor. Technology advances have allowed the bit-rate per carrier and bandwidth per carrier to increase. This has allowed spectral efficiency to increase with every advance in communications technology.

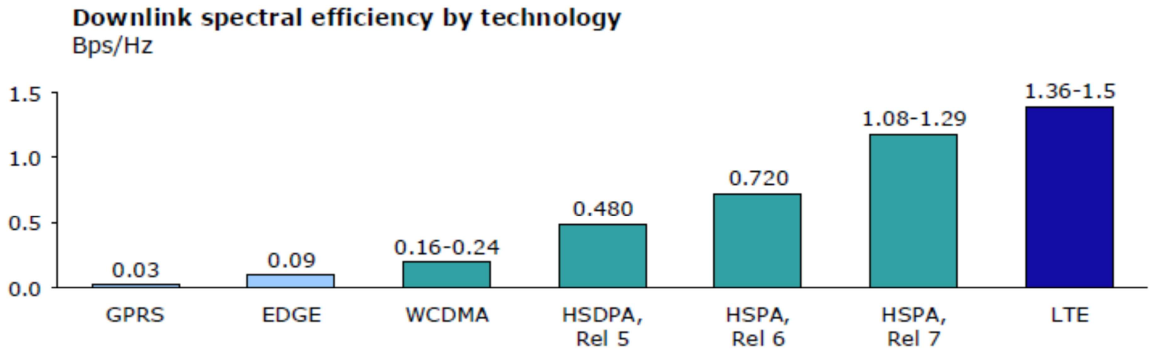


Figure 10 Wireless Spectral Efficiency by Technology [FCC 2010 A]

Figure 10 is being used to compare the relative spectral efficiency of old versus new communication technologies. The average spectral efficiency of wireless networks is projected to double, from about 0.625bps/Hz in 2009, to 1.25bps/Hz in 2014. This improvement in spectral efficiency of approximately 20% per year will however, not be enough to match the increase in mobile data traffic demand hence more spectrum is still required. [FCC 2010 A]

4.3.3 Spectrum Utilization Projection Model using Broadband Data Growth Rate

Rysavy Research is consulting company that advises clients such as large service providers on wireless network performance. They developed a spectrum demand model that considers both smartphone platforms and other devices such as netbooks and notebooks. Cisco reports that 25% of the day's Internet traffic is consumed in the busiest four hours, which are generally 2 hours in early morning and 2 hours in the early evening. [Cisco Systems 2011] The model calculates the bit-per-second load per broadband subscriber per device type during the busiest times of the day. The model then multiplies the per-user traffic amount by the number of mobile broadband users in a typical cell sector to obtain a total data load in that sector. The model takes into consideration an increase in data usage per month, an increase in mobile user penetration rate, and an increase in spectral efficiency as new technologies are introduced. Figure 11 shows two graphs showing projections of the data consumption in Gbytes per month for Smartphones and other devices. According to Cisco, iPhones consumed approximately 400 Mbytes per month, and small laptop devices are consumed approximately 1.5 Gbytes per month via mobile broadband in 2010. The increase rate of Smartphone data consumption per year from 2010 to 2016 was projected to be an average of 60% per year. The increase rate of Netbook and Laptop device data consumption from 2010 to 2016 was projected to be an average of 40% per year. In 2016, smartphones would be consuming 6.7Gbytes per month. Other devices such netbooks and laptops would be consuming 17.2Gbytes per month.

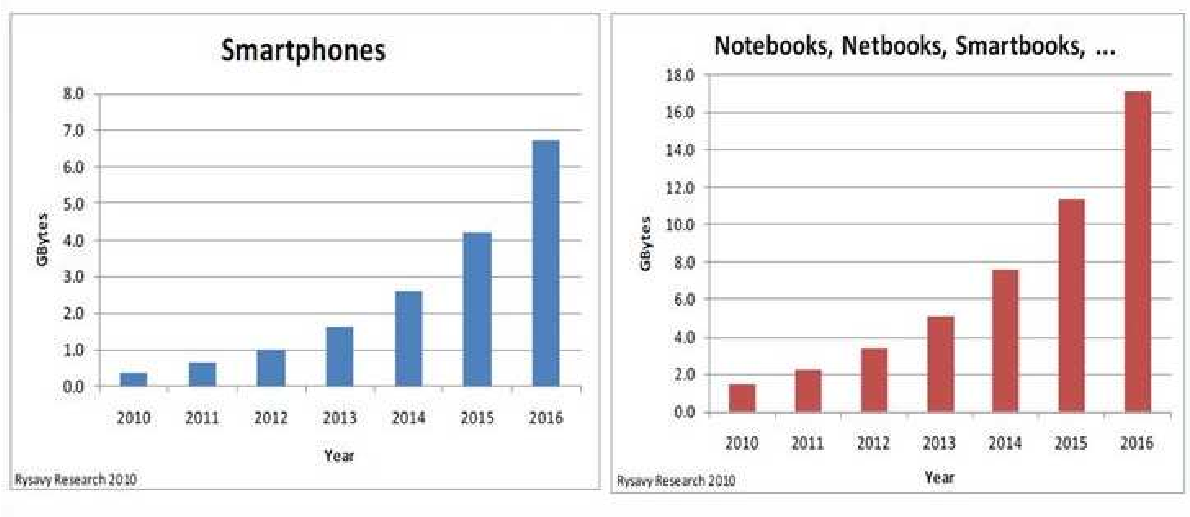


Figure 11 Smartphone, and Other Device Projected Data Throughput 2010 – 2016 [Rysavy Research 2010]

Figure 12 illustrates the mobile broadband penetration rates of Smartphones and Other devices such as netbooks. According to Cisco the penetration rate of Smartphones, using mobile broadband was 25% in 2010, and the penetration rate of other devices using mobile broadband was 5%. Figure 12 shows that smartphone penetration will reach 90% by 2016, and that Netbook and Laptop devices will reach a penetration rate of over 40% by 2016.

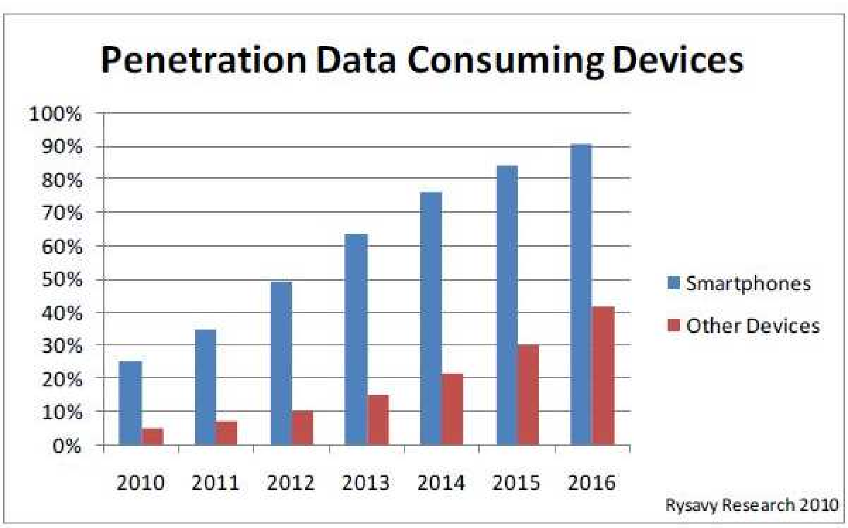


Figure 12 Penetration Rate of Smartphones and Other Devices 2010-2016 [Rysavy Research 2010]

Based on these projections, the model calculates the amount of spectrum that a large operator would need to support this level of demand. The model assumes all services are supported in either 3G or enhanced 3G mode. The model further assumes that the spectral efficiencies of the technology will improve as operators deploy technologies such as HSPA+, WiMAX and LTE. The formula for projecting the new spectrum required for next year (NS) is as follows,

$$NS = \frac{OS\big(Ds(1 + Ps * Rs) + Dl(1 + Pl * Rl)\big)}{(Ds + Dl) * (1 + Si)}$$

NS - new spectrum amount for next year, OS – old spectrum amount, Ds – data consumption of smartphones, Dl – data consumption of laptops, Ps – penetration rate of smartphones, Pl – penetration rate of laptops, Rs – smartphone consumption rate of increase, Rl – laptop consumption rate of increase, Si – Spectral Efficiency increase. Figure 13 shows the amount of spectrum an operator would require in their busiest markets to meet the demand shown in the prior figures.

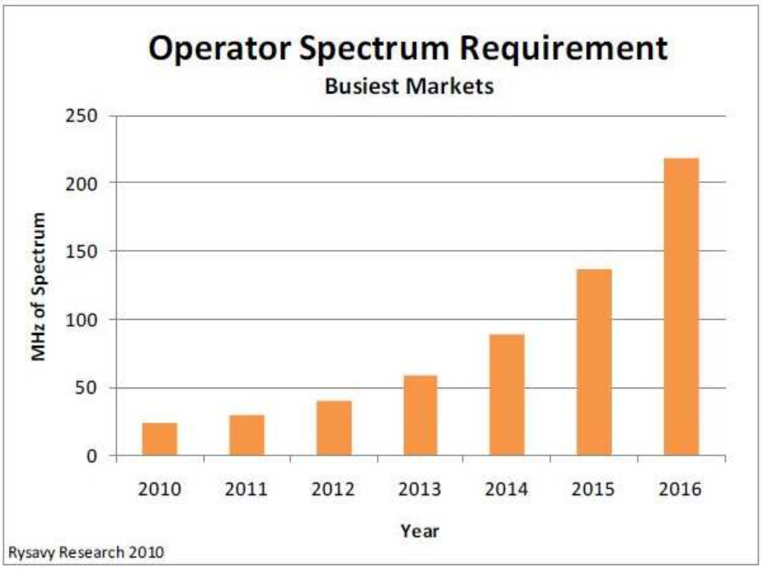


Figure 13 Projected Increase in Spectrum for a Large Operator given Projected Mobile Data Growth [Rysavy Research 2010]

Using the projected mobile broadband data growth rates expected from 2010 through 2016, the RySavy model projects that a large mobile operator would need approximately 9 times more spectrum in 2016 as they used in 2010.

4.3.4 Spectrum Utilization Projection Model using Cell-Site Growth Rate

Wireless operators continue to invest capital in building new cell-sites. Cell sites can be engineered for different purposes, including increasing capacity, to improve signal quality, and to expand coverage. According to data published by the International Association of the Wireless Telecommunications Industry (CTIA), the wireless trade association, the number of cell sites in the US has been growing at about a 7% compound annual growth rate (CAGR) over the past five years. [FCC 2010 A] This trend is partly a function of saturation of wireless availability; an estimated 99.6% of the population now has wireless access, therefore new cell-site growth will be due to increased capacity. Voice services are projected to be flat and hence all the cell-site growth is due to increased data traffic capacity.

The National Broadband Plan indicates that 547 MHz is currently licensed by the wireless operators for mobile broadband data services and voice services. Only 170 MHz of that spectrum is heavily used. The remaining 377 MHz of spectrum has been purchased over the last 6 years and it is only now coming into use. Data demand growth relative to 2009 was forecasted by three companies, Cisco Systems, Yankee Group, and Coda Research. [FCC 2010 A] Figure 14 provides the average of three company's mobile data growth forecasts.

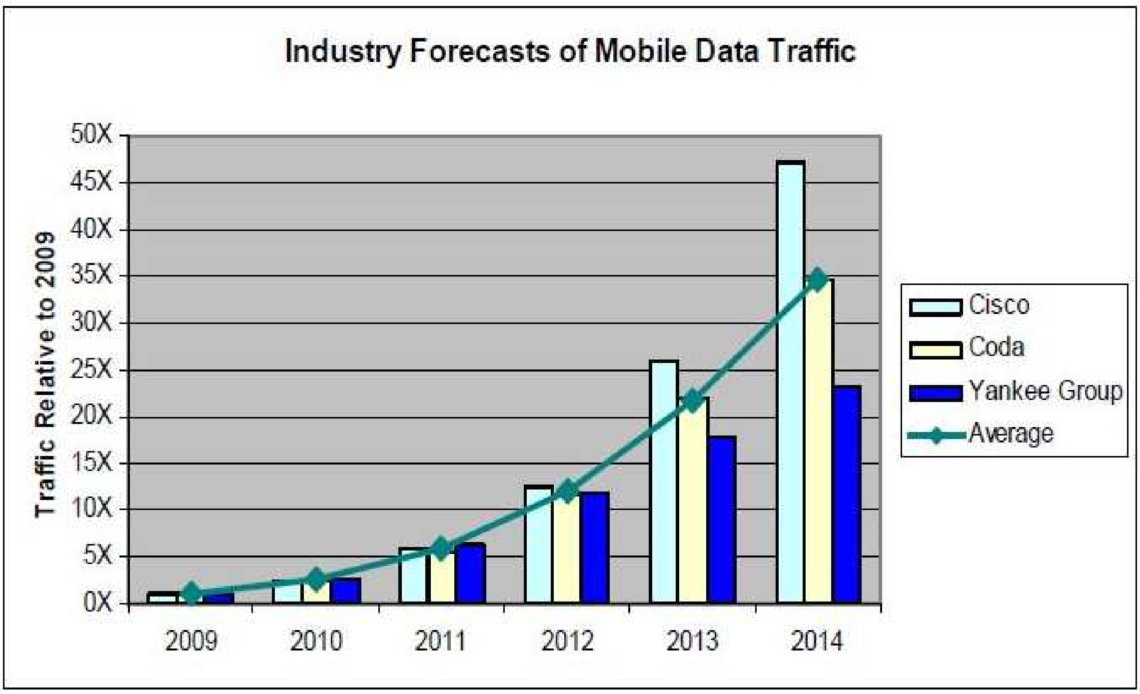


Figure 14 2009 - 2014 Mobile Data Growth Forecasts by Cisco, Coda and Yankee Group [FCC 2010 A]

Figure 15 provides calculations for projected spectrum usage from 2009 through 2014. The assumptions made for the calculation were that cell site growth was 7% per year, spectral efficiency increased by an average of 20% per year, and that the initial ratio of voice to data traffic was 2:1 in year 2009. The following equation calculates the requirement for data traffic spectrum for each year.

$$NSd = OSd * \frac{1 + Rd}{(1 + Cg) * (1 + Si)}$$

NSd –Data traffic spectrum required for next year adjusted for cell site growth and spectral efficiency growth, OSd – Data traffic spectrum for year 2009, Rd – Data traffic consumption increase relative to 2009 taken from Figure 14, Cg – Cell site increase relative to 2009, Si – spectral efficiency increase relative to year 2009. The next equation calculates the deficit or surplus spectrum for each year.

$$Sds = Sav - (NSd + Sv)$$

Sds – Spectrum deficit or surplus for combined voice and data traffic per year, Sav – Spectrum available as per NBP (547 MHz), Sv – Spectrum needed for voice for each year (113 MHz)

Figure 15 shows the values calculated from the equations for years 2009 through 2014. An example for Nsd for year 2010 is ((1 +1.53)/(1 +0.7)*(1 + 0.2))*57 MHz resulting in 112 MHz. Sds for year 2010 is 547 – (112 + 113) MHz resulting in 377 MHz surplus. In year 2014, Nds is calculated as 712 MHz, which means that Sds is calculated as an deficit of 278 MHz.

Description	Year 2009	Year 2010	Year 2011	Year 2012	Year 2013	Year 2014
Rd – Data traffic consumption increase relative to 2009	0	1.53	4.89	10.99	20.82	34.06
Cg – Cell site increase relative to 2009	0	0.7	0.14	0.23	0.31	0.4
Si – spectral efficiency increase relative to year 2009	0	0.2	0.4	0.6	0.8	1.0
NSd –Data traffic spectrum per year adjusted for data rate increase, cell site growth and spectral efficiency growth (MHz)	57	112	210	346	527	712
Sv – Spectrum needed for voice for each year (MHz)	113	113	113	113	113	113
Sav – Spectrum available as per NBP (MHz)	547	547	547	547	547	547
Sds – Spectrum deficit or surplus for combined voice and data traffic per year (MHz)	377	322	223	85	-93	-278

Figure 15 Spectrum Utilization and Future Requirement Projections [FCC 2010 A]

The spectrum utilization projections described in Figure 16 support the National Broadband Plan's recommendation to make available an additional 300 MHz of spectrum in the next 5 years. The shortfall of spectrum is 278 MHz in 2014. The pink line shows the spectrum required for voice traffic; it is projected to be flat. The blue line shows the spectrum required for data traffic; this rises dramatically since all the new cell sites are to be deployed due to the increase in data traffic. The yellow line shows the 377 MHz spectrum surplus dropping into a deficit as data traffic demand increases.

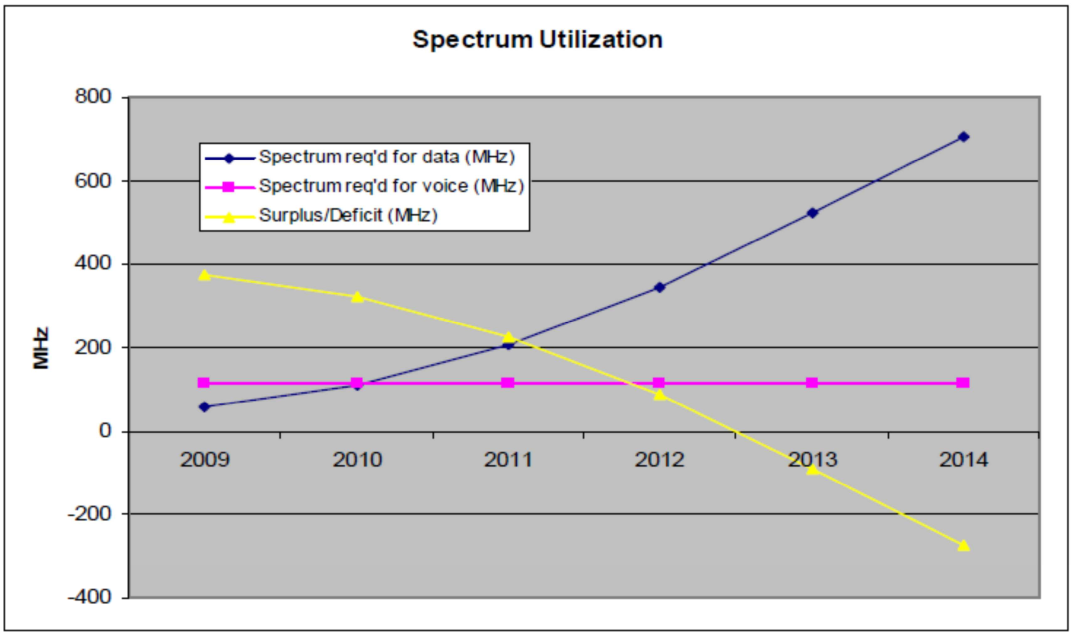


Figure 16 Graph of Projected Spectrum Utilization 2009 through 2014 [FCC 2010 A]

The CTIA stated in its recent comments to the FCC on new spectrum allocation that another 800 MHz are needed in the next six years. AT&T indicated in its comments to the FCC that an additional 800 MHz to 1 GHz are required. The two spectrum utilization models show the same rapid upward trend where the first is using the cell site growth and the second is using data demand growth.

4.4 Spectrum Analysis: Options for TV Broadcast Spectrum

The options for TV broadcast spectrum are examined. The TV broadcast spectrum is in the UHF band and shares it with some mobile communications services. OTA TV broadcast has declined in interest in favor of cable in recent years. This means that transferring from Analog broadcast to digital has become simpler as the changeover will affect fewer viewers. This also means that the spectrum can be reorganized so that parts of the TV spectrum can be auctioned for mobile broadband services. The frequency bands designated for repurposing are examined.

4.4.1 Characteristics of TV Broadcast Bands

The spectrum occupied by broadcast television stations has excellent propagation characteristics that make it well suited for broadband in both urban and rural areas. It is well suited for rural areas because the path loss is lower. The path loss of LTE at 728 MHz and 1805 MHz in a free space line of sight channel can be calculated using a very simplistic model that indicates that ratio of the received signal strengths at these frequencies can be simply found as:

$$(f1/f2)^2 = (1805/728)^2 = 6.15$$

The received signal strength at 728 MHz is 6.15 times higher than the received signal strength at 1805 MHz. [RAY Maps 2012] A more realistic channel model is known as the COST-231 model, and this model shows even higher signal strength for the lower frequency. It well suited for use in urban areas because the penetration loss is lower. Using the properties of concrete and a concrete wall thickness of 10cm the penetration loss at 728 MHz and at 1805 MHz is calculated to be 4.16 dB and 10.38 dB i.e. there is a gain of 6.22 dB when using the lower frequency. [RAY Maps 2012] The broadcast TV bands are wide enough to re-configure into larger, contiguous blocks. Today, 3G technologies utilize channel bandwidths of 1.25 MHz and 5 MHz, and next generation wireless broadband technologies (WiMax and LTE) will take advantage of even larger channel sizes. Wider channels offer faster data rates.

The mobile communications industry has the challenge of minimizing the cost of migration of 2G services to 3G. Since 2G networks still carry large amounts of voice and data traffic, releasing 2G spectrum for 3G services cannot be done overnight. The remaining 2G traffic needs to be supported until 2G networks are fully decommissioned. Migration of the 2G traffic onto 3G networks takes time and additional equipment, and hence implementing new technology such as LTE without interrupting the existing mobile users is usually done by using new spectrum bands in order to maintain the integrity of the existing services.

4.4.2 Value of TV Broadcast Bands to the Mobile Broadband Industry

The market value difference between the spectrum used for Over-The-Air (OTA) TV broadcast and that of broadband spectrum is widening as TV broadcast usage goes down, broadband usage goes up. The economic value of spectrum is estimated by industry convention in terms of dollars per megahertz of spectrum, per person reached (dollars per megahertz-pop). In 2008, the FCC held an auction of 52 megahertz of broadcast TV spectrum in the 700 MHz band that was recovered as part of the DTV transition. It raised $19 billion, with an average spectrum valuation, primarily for mobile broadband use, of $1.28/megahertz-pop. The remaining UHF TV bands adjacent to the 700 MHz band had lower estimated values even though they had similar propagation characteristics. These bands had values only ranges from $0.11 to $0.15 per megahertz-pop. [FCC 2010 C] There are several reasons for this, projected higher growth in mobile broadband than in OTA broadcasting, OTA broadcast requires interference bands, and OTA TV is required to provide channels for public interest obligations.

Figure 17 shows the calculation of the value of the TV spectrum.

Parameters for Valuation of Spectrum	Valuation of Spectrum Occupied by OTA TV
Total Broadcast TV Industry Enterprise Value	$63.7B
OTA audience as a % of total	14-19%
Value of OTA Broadcast TV	$8.9 – 12.2B
Total Amount of available TV Spectrum according to the FCC	294 MHz
US Population	281.4 Million
$/megahertz–pop	$0.11 – 0.15

Figure 17 Dollar per MHz – Population [FCC 2010 C]

The percentage of households viewing television solely through OTA broadcasts has steadily declined over the past decade, from 24% in 1999 to 10% in 2010. Cable networks and on-demand TV content has increased to the cost of OTA TV viewing, Figure 18 shows a 25-30% decline in the average prime time ratings of all broadcast TV networks over the past decade. This is primarily caused by the proliferation of cable networks.

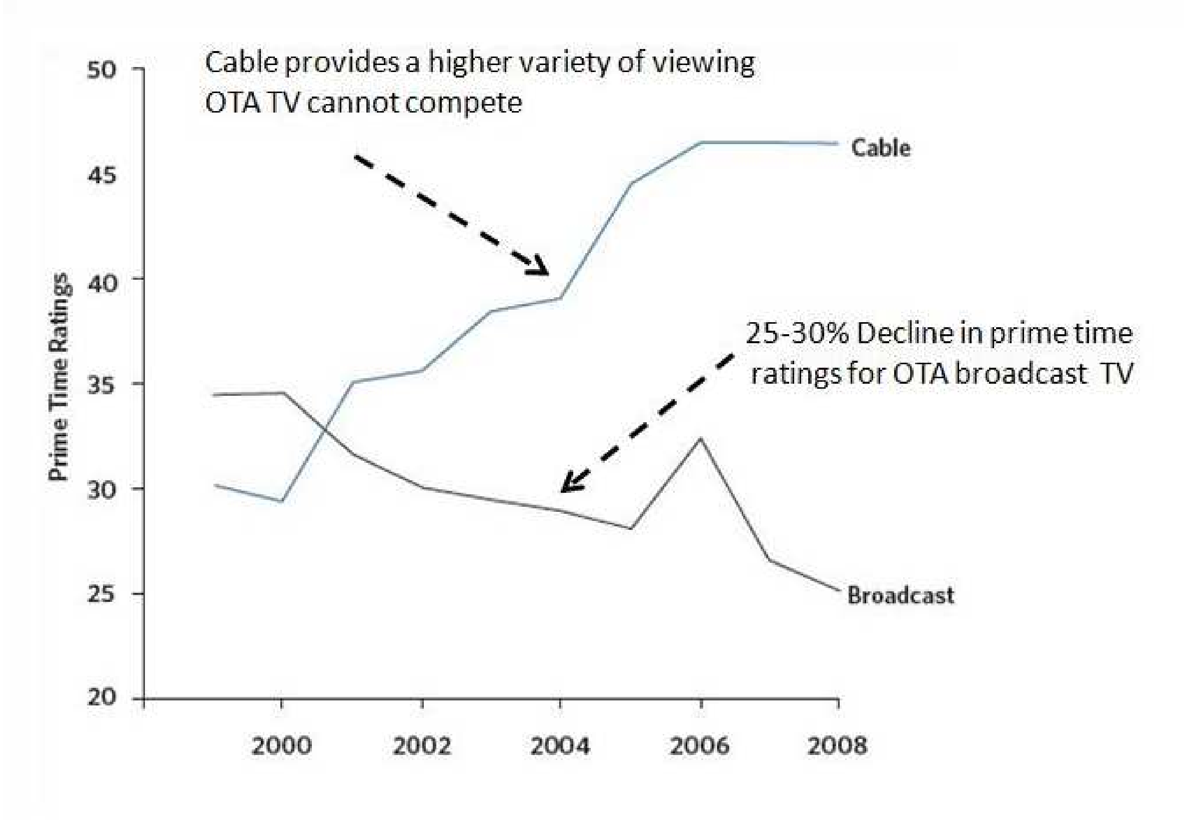


Figure 18 Over-the-air TV versus Cable TV Prime-Time Ratings [FCC 2010 C]

Although overall television viewership continues to increase, the proliferation of programming options such as cable networks and on-demand content has caused broadcast TV viewership to decline.

4.4.3 Elimination of TV Broadcast Interference Protection bands

Radio and TV signal transmission is susceptible to electromagnetic interference (EMI). Two types of interference need to be avoided when building Analog TV stations; these are co-channel interference and adjacent channel interference. Co-channel interference (CCI) is crosstalk from two different radio transmitters using the same frequency. A typical cause of CCI can be found in highly crowded populated areas where FM transmitters are not adequately spaced apart. Adjacent-channel interference (ACI) is interference caused by extraneous power, or unwanted emission from a signal leaking into an adjacent channel. [Radioing 2011]

In order to ensure transmitters do not interfere with each other, the FCC sets interference-protection standards for stations that broadcast on the same channels “co-channel stations” and those that broadcast one or more channels apart “adjacent channel stations”. The installation of interference protection meant that only a fraction of 49 separate 6MHz channels in the TV bands are allotted to full-power stations in each market. In the 10 largest markets in the U.S., a median of 20 channels are allotted to full-power stations. [FCC 2010 C]

These channel allotments in each market are scattered across the 49-channel section of broadcast spectrum. Less than half of the Over-The-Air (OTA) TV channels are actually being used for transmission. Figure 19 shows the spectrum allotted to full power TV broadcast transmission stations and the spectrum allotted for interference protection in designated market areas (DMAs). Out of 294 MHz designated spectrum, 174 MHz is used for interference protection. Since the transition from analog to digital, these interference bands are no longer necessary. The transmission format of TV broadcasts provides better reception because the audio and video components of the signal are synchronized digitally. Reception of the digital signal by the TV must be complete and hence the ghosting (a double image appears) and snow effect (blurred white dots appear) caused by weak analog TV signals is not seen. Digital TV interference is usually seen as small blocks appearing on the screen. The entire 294 MHz is potentially available for repurposing. Figure 19 shows the percent of unused spectrum for different Designated Market Areas (DMAs).

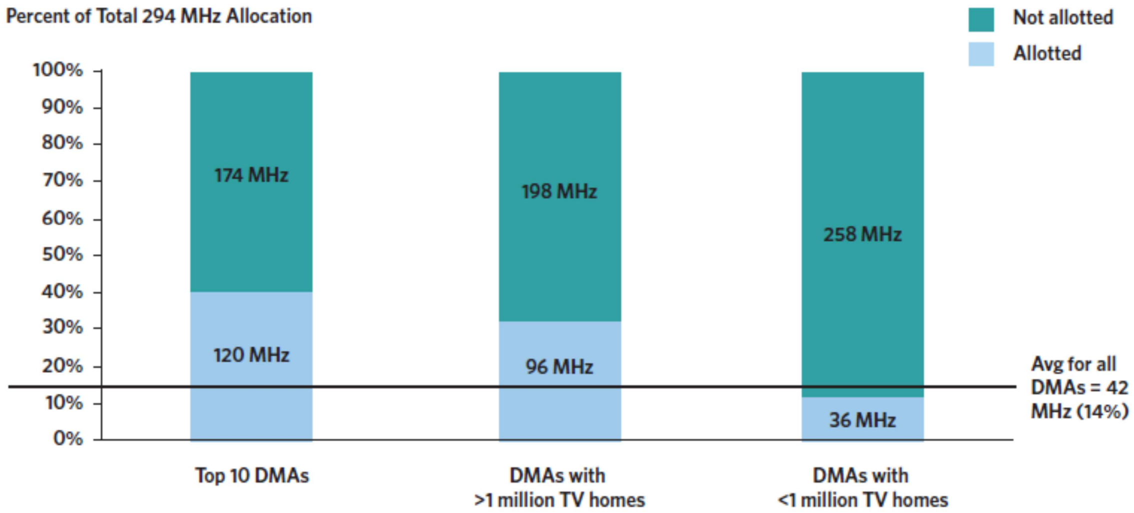


Figure 19 Spectrum Allocation to TV Broadcast Stations and Interference Protection [FCC 2010 C]

Figure 19 shows that a large portion of the broadcast TV spectrum is inactive. The broadcast TV spectrum that is allocated to interference bands does not contain any signals at any time. If much of this bandwidth was repurposed for broadband rather than OTA TV there would be little or no loss to the viewers or the TV channel owners provided the process of unlocking unused spectrum capacity is done carefully and on a band-by-band basis. These interference guard bands are sometimes referred to as "white space". On March 19 2009, Senators John Kerry (Democrat-Massachusetts) and Olympia Snowe (Republican-Maine) introduced the Radio Spectrum Inventory Act, which directs NTIA and the FCC:

> *to report on the use of all spectrum bands between 300 Megahertz and 3.5 Gigahertz, including information on the licenses or government user operating in each band, the total spectrum allocation of each licensee or government user, the number and types of radiators that have been deployed in each band, and contour maps illustrating signal coverage and strength* [GPO 2009]

The TV band "white space" database has built on the TV Bands Database, which the FCC's Office of Engineering and Technology has defined as the means of identifying and accessing available "white space" channels not in use in discrete geographic locations across the nation's 210 local TV markets. [Calabrese, Michael 2009]

4.4.4 Elimination of some TV Broadcast Licensing Restrictions

TV broadcast licenses dictate a restricted usage mandate that results in less business models and fewer revenue streams, for example one restriction states “broadcasters must transmit at least one OTA video program signal at no direct charge to viewers”. [FCC 2010 C] The standards used by transmission facilities to provide the services are required to be strictly enforced, and subject to public interest obligations. Licensees in the broadcast TV spectrum cannot migrate to alternative uses of their spectrum, such as mobile broadband services. They cannot transfer their licenses to another party. Under the current technical standards, ownership restrictions and public interest obligations tied to their licenses, licensees have limited flexibility to evolve their business model in response to changing consumer preferences and habits. The FCC deliberately constructed these constraints to promote the public interests of the time; however, they are now prohibiting any new innovative approaches towards better use of the frequency bands used by the TV broadcast industry. If the FCC were to remove some of these restrictions then much of the TV spectrum that is unoccupied could be repurposed. Many of the TV channels themselves are unused apart from the interference channels. These channels could also be repurposed to advance technologies in the broadband area.

4.4.5 Public Interest Trade-Off: Free Broadcast TV versus Broadband

Free, OTA television provides significant public benefits, and the only alternative to subscription- based cable or satellite television. OTA-only households include segments of the population that either cannot afford or do not desire paid television services, or cannot receive those services at their homes. The FCC is determined to continue to provide these Americans with OTA TV broadcast. The Analog to Digital transition means that these members of the population will still be able to receive OTA television while opening up a significant portion of spectrum for repurposing. [FCC 2010 C] The US is divided up into 210 broadcast TV market areas. The US map in Figure 20 shows white dots for each market area in each state,

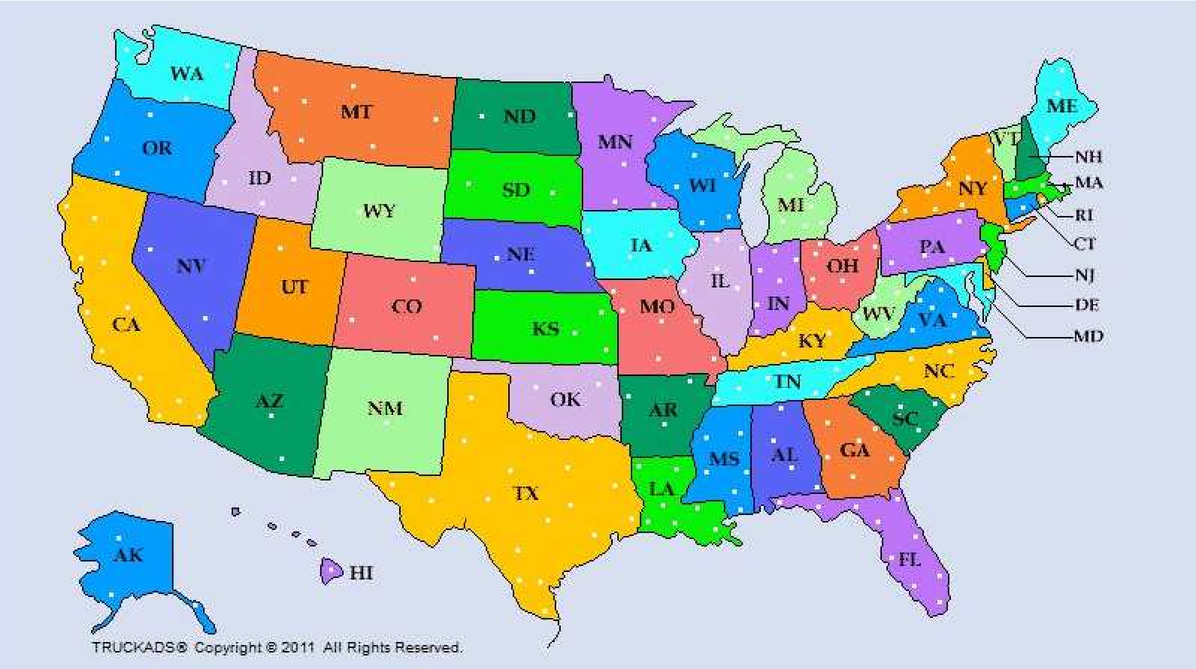


Figure 20 Broadcast TV Market Areas for each State [Media Maps 2012]

Figure 21 illustrates the number of TV Broadcast stations in each state. The states with the largest populations have the most market areas, and hence the most TV Broadcast stations,

State	Number of TV Broadcast Stations	State	Number of TV Broadcast Stations
Alabama	43	Montana	23
Alaska	16	Nebraska	15
Arizona	31	Nevada	22
Arkansas	26	New Hampshire	7
California	108	New Jersey	16
Colorado	39	New Mexico	28
Connecticut	13	New York	54
Delaware	4	North Carolina	50
Florida	94	North Dakota	8
Georgia	42	Ohio	52
Hawaii	14	Oklahoma	29
Idaho	21	Oregon	30
Illinois	42	Pennsylvania	46
Indiana	41	Rhode Island	5
Iowa	29	South Carolina	32
Kansas	15	South Dakota	9
Kentucky	26	Tennessee	43
Louisiana	39	Texas	134
Maine	15	Utah	18
Maryland	16	Vermont	8
Massachusetts	22	Virginia	38
Michigan	51	Washington	36
Minnesota	21	West Virginia	12
Mississippi	27	Wisconsin	44
Missouri	35	Wyoming	11

Figure 21 TV Broadcast Stations in each State [Station Index 2012]

Providing those Americans with access to free television constitutes a core principle of American mass communications policy. Internet access though mobile broadband is not subject to the public-interest requirements of broadcast TV, however many of the innovations and transformations enabled by mobile broadband are considered a necessity for modern life in the US. Protecting longstanding public interest policy goals served by OTA television and supporting those for extended broadband use should be the new set of objectives for the US.

4.4.6 Computational Analysis Methods

The FCC uses statistical models to determine the cost and difficulty of moving TV broadcast stations from spectrum channels or consolidating them with existing channels. They also use models created from analysis of the propagation characteristics of radio signals to understand the effectiveness of a proposed TV station relocation or consolidation. The topographic nature of the land and the height and size of buildings alter the behavior of radio signals as they are transmitted through the air. If radio signals are dampened, reflected, or refracted because of a hill or a high concrete building then the lack of adequate propagation may make the repositioning of a TV station impractical.

The allotment optimization model created by the FCC seeks to clear a contiguous block of channels, starting at the top of the UHF band (Channel 51). The model required that the maximum number of channels be cleared at the top of the UHF band and the bottom of the VHF bands. It also required the number of stations moved to a different tower and the number of stations sharing channel to be minimized. Minimizing the total number of station channel reassignments and relocations was also necessary. The allotment optimization tool allows operators to discover the affects of manipulating minimum distance spacing, border restrictions, mobile channels, and the number of stations that can be moved or consolidated on channels through channel sharing. [FCC 2010 C] The number of stations together with their associated markets that could participate in an incentive auction towards freeing 120 MHz of TV broadcast spectrum could be determined. The tool could also show that channel sharing and repacking is not practical for a particular scenario.

When TV broadcast stations change transmission location or change the radio frequency channel from which they transmit, the change may affect viewer reception of their signals. To model propagation of broadcast television signals, the FCC uses the Longley-Rice model. [FCC-OET 2002] Coupled with data on population and terrain, FCC models can predict which population pockets will receive which TV broadcast signals. To model interference, a separate analytical program predicts how, and where, Longley-Rice modeled signals interfere with each other. They can also predict where this interference translates into loss of service. The FCC can predict how many households should receive a given station's signals by considering coverage areas and interference on a station-by-station basis. These models cannot replicate all the conditions of the real world but they are a good means of determining the results of reallocation. The FCC has put these methods into action to determine the ramifications of reallocating parts of the TV spectrum.

4.4.7 Results from Scenario Evaluation and Model Creation

The FCC may be able to repack channel assignments more efficiently to fit current stations with existing 6 MHz licenses into fewer total channels, thus freeing spectrum for reallocation to broadband use. Broadcasters could combine multiple TV stations onto a single 6 MHz channel; specifically, two stations would generally broadcast one primary high definition (HD) video stream each over a shared 6 MHz channel. The current broadcast TV rules provide each licensee a 6 MHz channel that is capable of transmitting data at a rate of 19.4 Mbps. Television stations broadcast their primary video signal either in HD or in standard definition (SD). HD requires 6-17 Mbps and SD requires 1.5-6 Mbps of data throughput. Two-to-one (2:1) Channel sharing is defined as 2 or more stations combining transmissions to share a single 6 MHz channel. [FCC 2010 C] An estimate was made using the Allotment Optimization Model (AOM) of the impact on spectrum reclamation for consumers and broadcasters if pairs of stations were to share 6 MHz channels in select markets.

In order to clear 60‑120 megahertz of contiguous spectrum, 2‑12% of stations would need to share channels voluntarily, 18‑41% of stations would receive channel reassignments, and stations on average would experience a net gain in service area of 0.0-0.4%. Channel repacking, is defined as the repacking of channel assignments to fit current TV Broadcast stations. An estimate was made using AOM showing a more efficient channel repacking scenario in which stations would occupy 42-48 channels in total, recovering 1-7 channels (6-42 megahertz) for reallocation, depending on the inclusion or exclusion of border restrictions. [FCC 2010 C] The FCC will use channel sharing and repacking estimates from running AOM scenarios to identify the best geographical areas and markets for future spectrum auctions.

4.5 US Spectrum Auctions

The FCC divides the country into market areas. Market areas are organized around population densities. They do not have to follow state boundaries, however the larger areas tend to contain one of more US States, and the smaller areas tend to sub-divide the US States. The types and sizes of market areas licenses are shown in Figure 22.

Market Area Name	Symbol	Number
Major Trading Areas	MTA	51
Basic Trading Areas	BTA	493
Economic Areas	EA	176
Cellular Market Areas	CMA	734
Major Economic Areas	MEA	52
Metropolitan Statistical Area	MSA	734
Rural Service Area	RSA	734
Economic Area Groupings	EAG	6
Regional Area Groupings	REAG	12

Figure 22 Types of Market Areas used at Spectrum Auctions [FCC 2012 F]

The FCC has been conducting spectrum auctions from 1994 through the present day. There have been 92 auctions. A set of case studies examines how the spectrum auctions attended by mobile communications operators were held, who purchased the licenses and the total revenue obtained.

4.5.1 Case Study: 1900 MHz Band Auctions

In the US, the Broadband Personal Communications Service PCS services are provided in the 1850-1990 MHz frequency band (commonly referred to as the "1900 MHz band"). This frequency band was designated by the FCC to be used for new wireless services to alleviate capacity caps inherent in the original AMPS and D-AMPS cellular networks in the 800-894 MHz frequency band (commonly referred to as the "850 MHz band"). Sprint PCS was the first company to build and operate a PCS network. Sprint originally built out the network using GSM radio interface equipment. Sprint PCS later selected CDMA as the radio interface for its nationwide network. T-Mobile later took over the original Sprint Baltimore-Washington GSM network. [Veeneman, Dan 2005] Originally, Broadband PCS included 120 MHz of licensed spectrum and 20 MHz of unlicensed spectrum. Later, 10 MHz of the unlicensed spectrum in the 1910 – 1915 and 1990 – 1995 MHz range (this is sometimes referred to as the G Block) became available. The FCC assigned G Block to Nextel, now Sprint-Nextel to solve interference issues. Deployment of 2G wireless networks appeared in the early 1990s with the opening of the 1.9 GHz Personal Communications Service (PCS) bands. There were 9 auctions used to sell blocks of the “1900 MHz band” to mobile communications operators wishing to build 2G wireless networks. [FCC 2012 F] Figure 23 shows the position of the A, B, C, D, E, and F paired blocks in the “1900 MHz band”. It also illustrates the sub-division of the C blocks and the 20 MHz unlicensed block. The colors in Figure 23 are used to illustrate the pairs of spectrum blocks within the 1900 MHz band.

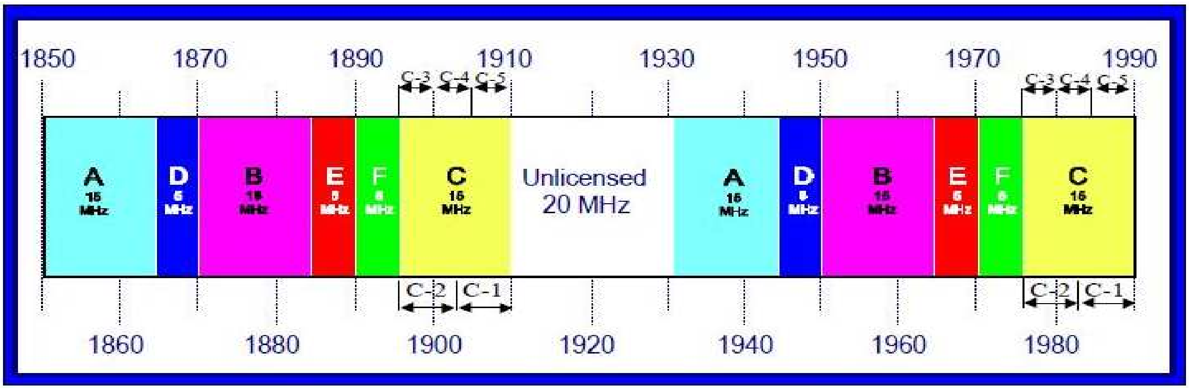


Figure 23 Personal Communications Service PCS 1900 MHz Band [FCC 2012 F]

Figure 24 shows the bandwidth of the paired bands A, B, C, D, E and F. It also provides the frequency ranges for each block and the type of license for which they were assigned.

Channel Block	Bandwidth of Paired Bands	Frequencies	Licenses
A	15 MHz	1850-1865, 1930-1945	issued by MTAs
B	15 MHz	1870-1885, 1950-1965	issued by MTAs
C	15 MHz	1895-1910, 1975-1990	issued by BTAs
C1	7.5 MHz	1902.5-1910, 1982.5-1990	issued by BTAs
C2	7.5 MHz	1895-1902.5, 1975-1982.5	issued by BTAs
C3	5 MHz	1895-1900, 1975-1980	issued by BTAs
C4	5 MHz	1900-1905, 1980-1985	issued by BTAs
C5	5 MHz	1905-1910, 1985-1990	issued by BTAs
D	5 MHz	1865-1870, 1945-1950	issued by BTAs
E	5 MHz	1885-1890, 1965-1970	issued by BTAs
F	5 MHz	1890-1895, 1970-1975	issued by BTAs
G	10 MHz	1910 – 1915,1990 - 1995	Issued by EAs
Unlicensed	20MHz (not paired)	1910-1930	N/A

Figure 24 PCS Blocks and associated paired bandwidth [FCC 2012 F]

Nine auctions were held between March 1995 and August 2008 for a grand total of $39.9 Billion. FCC auctions 4, 5, 10, 11, 22, 35, 58, 71, and 78 were held to sell blocks for PCS applications. In some of the auctions, a few licenses were not awarded.

Figure 25 show the results from Auctions 4 through 78 for the 1900 MHz band. In Auction 4 the FCC awarded 3 licenses by pioneer’s preference. The FCC pioneer’s preference program provides inventors with spectrum bands for new state-of-the-art communications services.

Auction & Date	Spectrum For Sale	Licenses Available	Bidding Results	Revenue Received
No.4 12/5/1994 – 3/13/1995.	PCS A and B Blocks	2 Licenses for each of 51 MTAs	18 bidders won 99 licenses. 3 awarded by pioneer's preference	$7,019,403,797
No. 5 12/18/1995 – 5/6/1996.	PCS C Block	493 BTA licenses	89 bidders won 475 licenses	$10,071,708,842
No. 10 7/3/1996 – 7/16/1996.	Resale of PCS C Blocks	18 BTA licenses	7 bidders won 18 licenses BTA licenses defaulted from auction 5	$904,607,467
No. 11 8/26/1996 – 1/14/1997.	PCS D, E, and F Blocks	3 licenses in each of 493 BTAs	125 winners won 1472 licenses, 93 bidders won 598, 32 bidders won 874, and7 licenses held back by FCC	$2,517,439,565
No. 22 3/23/1999 – 4/15/1999.	PCS C, D, E, and F Blocks	347 licenses, 133 15 MHz C block, 206 30 MHz C block, 6 10 MHz E Block, and 2 10 MHz F block licenses	57 bidders won 302 (8 10 MHz, 115 15 MHz, and 179 30 MHz licenses), 48 bidders won 277, and 9 bidders won 25 licenses	$412,840,945
No. 35 12/12/2000 – 1/26/2001.	PCS C and F Blocks	312 10 MHz C block, 43 15 MHz C block, and 67 10 MHz F block licenses	35 bidders won 422 licenses.	$16,857,046,150
No. 58 1/26/2005 – 2/15/2005.	All PCS Blocks	242 licenses, 2 A block, 188 C block,11 D block, 20 E block, and 21 F block licenses	24 bidders won 217 licenses.	$2,043,230,450
No. 71 5/16/2007 – 5/21/2007.	PCS C, D, E, and F Blocks.	38 licenses, 3 A block MTA, 26 C block BTA, 1 D block BTA, 2 E block BTA, and 6 F block BTA licenses	12 winners won 38 licenses.	$13,932,150
No. 78 8/13/2008 – 8/20/2008.	AWS-1 and PCS blocks	55 licenses, 35 AWS-1, and 20 PCS Licenses	16 winners won 55 licenses.	$21,276,850

Figure 25 Results from the 1900 MHz Auctions [FCC 2012 F]

Figure 26 shows the current state of PCS spectrum block acquisitions and their owners as of 1997. The industry has seen considerable consolidation since 1997, and many of the companies in the table are now part of larger corporations. The distinction between Cellular and PCS networks is also now very blurred. Today, AT&T, Verizon, T-Mobile and Sprint use these bands.

Company	Market Licenses	Market Population (million)	Major Market Areas
Sprint PCS*	29	145	New York, Los Angeles
AT&T Wireless PCS	21	107	Detroit, Washington, D.C.
PCS PrimeCo**	11	57	Chicago, Dallas
Pacific Telesis Mobile Service (PacTel)	2	31	San Francisco, Los Angeles
GTE Macro Communications Corporation	4	19	Atlanta, Denver
American Portable Telecommunications, Inc.	8	26	Minneapolis, Orlando
Ameritech Wireless Communications, Inc.	2	8	Cleveland, Indianapolis
Western PCS Corporation	6	14	Honolulu
Powertel PCS Partners, L.P.	3	9	Memphis
PhillieCo, L.P.	1	9	Philadelphia

Figure 26 Top 10 PCS license holders and their Major Market Areas of 1997 [Veeneman, Dan 2005]

4.5.2 Case Study: 2.5 GHz Band Auctions

The Broadband Radio Service (BRS), formerly known as the Multipoint Distribution Service (MDS)/Multichannel Multipoint Distribution Service (MMDS), is a commercial service. In the past, it was used for the transmission of data and video programming, also known as wireless cable. The Educational Broadband Service (EBS), formerly known as the Instructional Television Fixed Service (ITFS), is an educational service that has been used for the transmission of instructional material to educational institutions. [FCC 2012 F]

The BRS and EBS bands combine to form the 2496-2690 MHz band. The BRS and EBS bands were moved to new frequency assignments thus enabling the 2496- 2690 MHz band to be reassigned for new services. This transition was started in 2005 and completed in 2008. The MDS and MMDS bands previously occupied by BRS services were made available for sale in Auction 6 that was completed in 1996. Auction 6 offered 493 BTAs licenses to provide access to all BRS spectrum nationwide that was not assigned to pre-existing MDS or MMDS site-based licenses. The licenses offered in Auction 86 consisted of the available spectrum in 78 BRS BTAs. Overlay licenses for 75 of the BTAs originally offered in Auction 6 were made available at this time due to default, cancellation, or termination. The spectrum purchased in Auction 6 was not usable until the completion of Auction 86. Figure 27 shows the MDS, and MMDS frequency bands made available in Auction 6. The Instructional Television Fixed Service (ITFS) used the MDS/MMDS band together with BRS prior to the transition started in 2005.

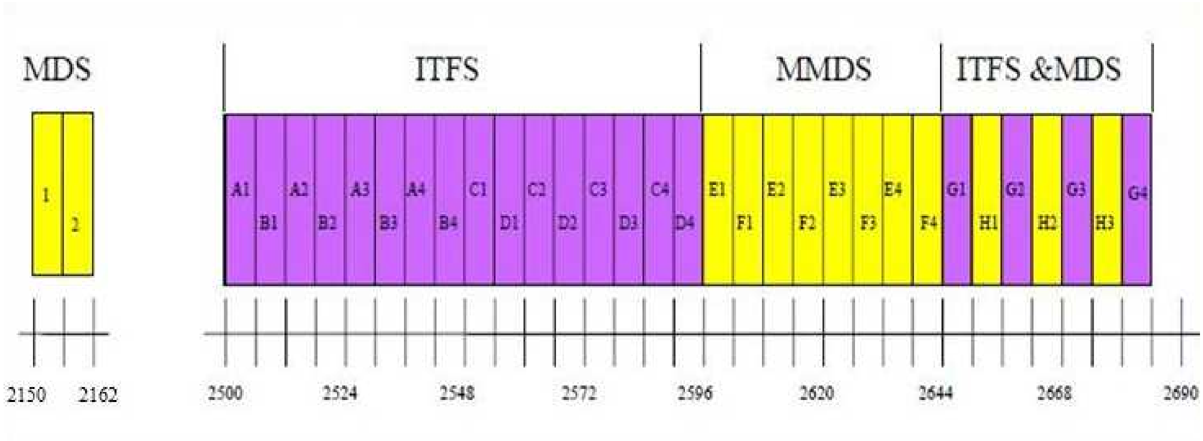


Figure 27 MDS and MMDS, and ITFS Frequency Blocks in the 2.5 GHz Band [FCC 2012 F]

Figure 28 shows the frequency blocks made available in Auction 6.

Channel	Frequency Range	Bandwidth
MDS 1	2150-2156	6 MHz
MDS 2	2156-2162	6 MHz
MMDS E1	2596-2602	6 MHz
MMDS F1	2602-2608	6 MHz
MMDS E2	2608-2614	6 MHz
MMDS F2	2614-2620	6 MHz
MMDS E3	2620-2626	6 MHz
MMDS F3	2626-2632	6 MHz
MMDS E4	2632-2638	6 MHz
MMDS F4	2638-2644	6 MHz
MDS H1	2650-2656	6 MHz
MDS H2	2662-2668	6 MHz
MDS H3	2674-2680	6 MHz

Figure 28 MDS and MMDS Frequency Blocks in the 2.5 GHz Band [FCC 2012 F]

After the 2005-2008 transition, the “2500 Band” was realigned into paired spectrum bands of 76 MHz. The first paired spectrum band is 2496 – 2572 MHz, and the second paired band is 2614 – 2690 MHz. Figure 29 illustrates the realignment that resulted into the 76 MHz paired bands, and a 42 MHz middle band.

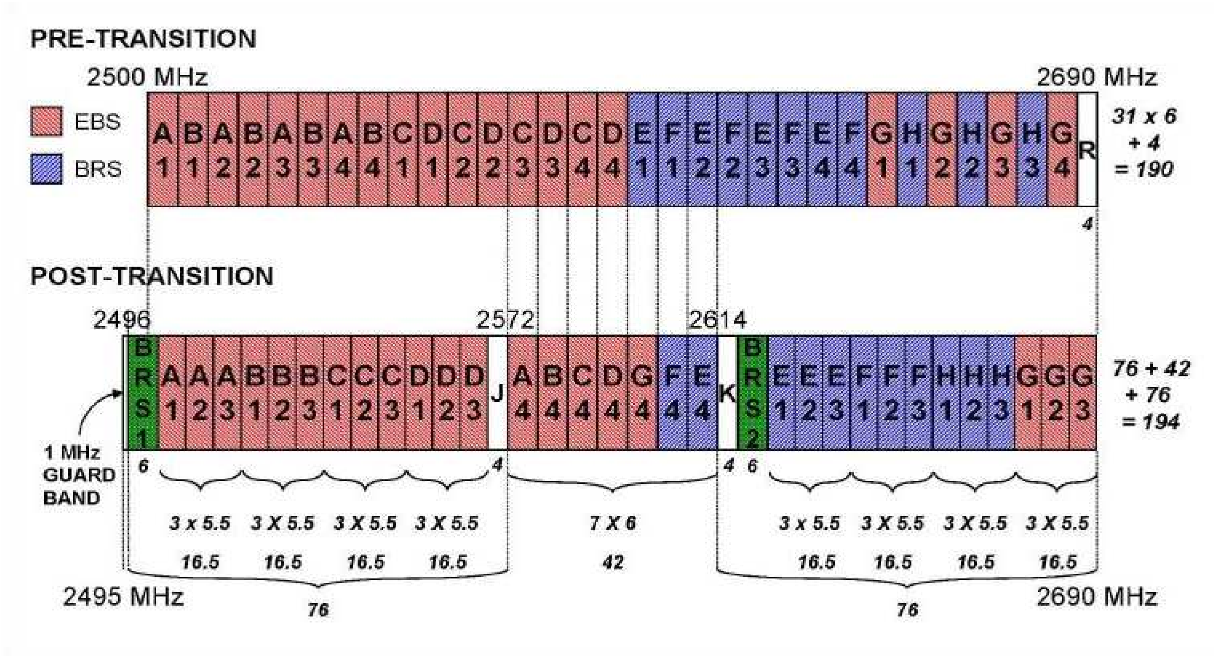


Figure 29 BRS and EBS Frequency before and after the 2005-2008 Transition [FCC 2012 F]

WiMax 4G is being deployed by Sprint and business partner, Clearwire Communications, a company backed by investors such as Time Warner, Cox, Bright House, Google and Intel. In 2008, Sprint and Clearwire Communications combined their 2.5 GHz Broadband Radio Service (BRS) frequency holdings under Clearwire, which is 54% owned by Sprint. [Sprint Co. 2012] Clearwire is in debt and heavily dependent on Sprint. The BRS spectrum holdings owned by Clearwire are said to be worth $31 Billion. [Reinstadtler, Steve 2012] In 2009, the Company showed a $1.1 billion dollar loss of which $260 million was attributed to "spectrum lease expense". Clearwire pays lease payments to the original educational institutions that once used the EBS/ITFS part of the spectrum. [Bowman, Brad 2010]

Figure 30 shows the results from auctions 6, and 86 for the 2.5 GHz band.

Auction & Date	Spectrum For Sale	Licenses Available	Bidding Results	Revenue Received
No. 6 11/13/1995-3/28/1996	2150-2680 MHz block	493 licenses one in each of 493 BTAs. 13 channels per license with 6.0 MHz per channel for a total of 78 MHz in 493 BTAs	67 bidders won 493 licenses	$216,239,603
No. 86 10/27/2009-10/30/2009	Blocks 2496-2502 MHz, 2602-2615 MHz, and 2616-2673.5 MHz, for a total of 76.5 MHz.	78 licenses, (75 BTAs, and 3 covering BRS service areas in the Gulf of Mexico)	10 bidders won 61 licenses	$19,426,600

Figure 30 Results from the Auctions held for the 2.5 GHz Band [FCC 2012 F]

Figure 31 shows the distribution of market area licenses acquired at Auction 86. Clearwire was by far the most successful bidder by purchasing 42 licenses.

Bidder	Sale Price from Auction 86	Market Area Licenses
Clearwire Spectrum Holdings III,LLC	$11,177,000	42
Utopian Wireless Corporation	$375,700	4
McCotter, James E	$267,000	3
Vermont Telephone Company, Inc.	$2,829,650	3
DigitalBridge Spectrum II, LLC	$794,000	2
Stratos Offshore Services Company	$1,961,000	2
Ztark Communications LLC	$768,300	2
Cellular South Licenses, Inc.	$202,000	1
Trident Global Communications, LLC	$655,000	1
Twin Lakes Telephone Cooperative	$396,950	1
Total	$19,426,600	61

Figure 31 Auction 86 Successful Bidder Market Area Licenses and Revenue [FCC 2012 F]

4.5.3 Case Study: 1.7 GHz and 2.1 GHz Auctions

AWS is the term coined by the FCC for new and innovative fixed and mobile terrestrial wireless applications using bandwidth sufficient for a wide range of voice, data and broadband services over a variety of mobile and fixed networks. Current 3G technologies such as EVDO revision A, WCDMA, and HSDPA are being deployed in AWS spectrum. T-Mobile acquired AWS bands solely for the ability to launch 3G services, and hence built a WCDMA and HSDPA network for that purpose. Verizon and Cingular (now AT&T) bought the spectrum bands to continue expanding their 3G services. Verizon could afford to spend $2.8 billion on spectrum and sit on it for a few years until it was later needed. Verizon's AWS spectrum overlaps with their existing spectrum, so they could use it exclusively for data. MetroPCS, Cricket, and US Cellular, bought the spectrum in an attempt to expand their coverage to new areas. SpectrumCo one of the other purchasers at Auction 66, now wishes to sell their AWS spectrum bands to Verizon. The sale of the AWS spectrum bands did not represent any kind of paradigm shift for the industry, but it did enable it to continue growing. AWS Auction 66 (AWS-1) represented the largest amount of spectrum suitable for deploying wireless broadband ever made available in a single auction, 2 x 45 MHz of spectrum. Figure 32 shows the AWS upper and lower bands associated with the PCS bands. The PCS bands were partitioned in 1994 and provided for auction in 1995. The 1755-1850 MHz band, and the 2025-2110 MHz band are still being used for military and federal government purposes. The FCC partitioned the AWS bands in consideration of these needs.

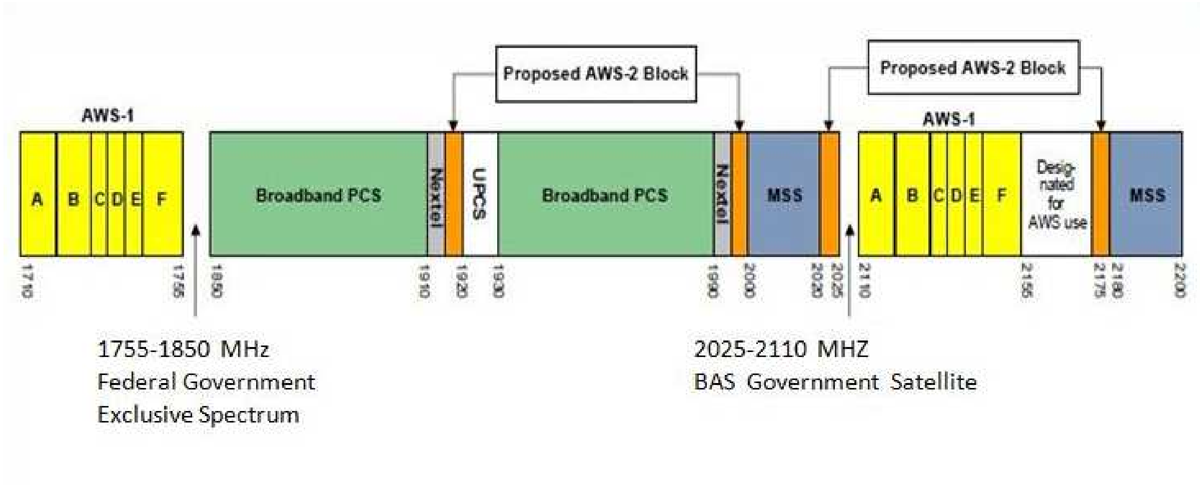


Figure 32 AWS Spectrum Bands Adjacent to PCS Bands [FCC 2012 F]

Figure 33 shows the upper AWS band used for Mobile to Base transmission. The 1710-1755 MHz portion of the AWS-1 band is used for uplink service from the mobile handset to the cell tower. Market areas were defined to use separate spectrum blocks. Each uplink block is paired with the downlink service block in the 2110-2155 MHz band.

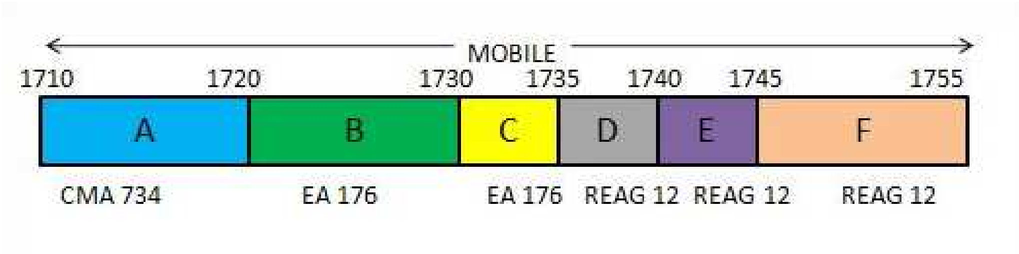


Figure 33 Upper 45 MHz AWS Spectrum Band Used for Uplink Transmission [FCC 2012 F]

Figure 34 shows the lower AWS band used for Base to Mobile transmission. The 2110-2155 MHz portion of the AWS-1 band is used for downlink service from the cell tower to the mobile handset. Market areas were defined to use separate spectrum blocks. Each downlink block is paired with the uplink service block in the 1710-1755 MHz band.

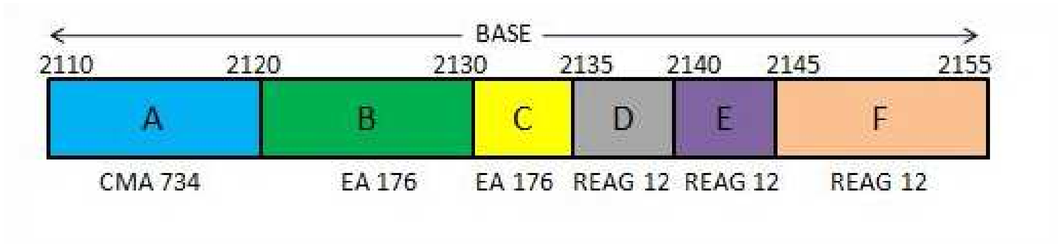


Figure 34 Upper 45 MHz AWS Spectrum Band Used for Downlink Transmission [FCC 2012 F]

Figure 35 shows the 1122 licenses that were offered at the auction together with the frequency ranges of each spectrum block.

Block	Frequencies	Pairing	Bandwidth	Licenses	Area Type
A	1710-1720 MHz/2110-2120 MHz	2 X 10MHz	20 MHz	734	CMA
B	1720-1730 MHz/2120-2130 MHz	2 X 10MHz	20 MHz	176	EA
C	1730-1735 MHz/2130-2135 MHz	2 X 5MHz	10 MHz	176	EA
D	1735-1740 MHz/2135-2140 MHz	2 X 5MHz	10 MHz	12	REAG
E	1740-1745 MHz/2140-2145 MHz	2 X 5MHz	10 MHz	12	REAG
F	1745-1755 MHz/2145-2155 MHz	2 X 10MHz	20 MHz	12	REAG

Figure 35 AWS Spectrum Blocks and Associated Licenses [FCC 2012 F]

Figure 36 shows the results from auctions 66, and 78.

Auction & Date	Spectrum For Sale	Licenses Available	Bidding Results	Revenue Received
No. 66 8/9/2006- 9/18/2006	All AWS-1 blocks	734 CMA, 352 EA, and 36 REAG licenses	104 winning bids for 1087 licenses with 35 held back by the FCC.	$13,700,267,150
No. 78 8/13/2008 – 8/20/2008.	AWS-1 and PCS blocks	55 licenses, 35 AWS-1 licenses held back at Auction No. 66, and 20 PCS Licenses	16 winners won 55 licenses.	$21,276,850

Figure 36 Results from Auctions 66 and 78 [FCC 2012 F]

Figure 37 shows the top 14 winning bidders and the number of licenses they bought at Auction 66.

Company	Market Area Licenses
AWS Wireless Inc.	154
Spectrum Co LLC	137
T-Mobile License LLC	120
Cricket Licensee 99	99
American Cellular Corp.	85
Cingular AWS LLC	48
Cable One (Washington Post)	30
Cavalier Wireless	30
Barat License L.P. (US Cellular)	17
Atlantic Wireless L.P.	15
Cellco Partnership (Verizon Wireless)	13
Cellular South Licenses	10
Cincinnati Bell Wireless	9
Denali Spectrum License LLC (Cricket)	1

Figure 37 Winning Bidders and Number of Licenses obtained at the AWS Auction [FCC 2012 F]

The top 14 bidders represented 99% of total dollars spent at the auction; each one spent more than $20 million on licenses.

4.5.4 Case Study: 700MHz Band Auctions

In the US, in 2001 and 2002, the FCC auctioned off four small slices of spectrum each totaling 6 MHz in the 746- to 806-MHz range, the upper 700-MHz band that had been allocated as "guard bands." Along with the right-to-use, the spectrum came with tight rules to minimize interference with public-safety services. The FCC packaged the spectrum in two pieces for 52 market areas, creating 104 licenses, which were auctioned for $540 million. The top three buyers were Access Spectrum, Nextel, and Pegasus Communications. In 2002 and 2003, the FCC auctioned off 18 MHz between 698 and 746 MHz, which covered 3 UHF channels, 54, 55, and 59. The spectrum was again packaged into geographical pieces, both to be attractive to buyers and to maximize returns. Channel 55 was sold in six regional spectrum blocks, while 54 and 59 were sold as a pair in 734 markets. The total sales brought the U.S. government $145 million. Qualcomm Inc., of San Diego, won the auction for the spectrum previously occupied by channel 55 in five of the six auctions. It then bought the rights for the sixth region from Aloha Partners LP, of Providence, R.I. [Rast, Robert 2005]

Qualcomm intended to use its spectrum to send video and audio programming to cell phones, PDAs, and other portable devices nationwide. The company calls its service MediaFLO ("Media" plus "Forward Link Only"). Aloha, which resold its channel 55 spectrum to Qualcomm, was the most successful bidder in the 54/59 channel-pair auctions numbers 44, and 49. Aloha won 125 out of the 734 regional auctions and claimed it now had spectrum in 244 of the 734 licensed markets, covering 175 million potential customers, including 100 percent coverage in the nation's 10 largest markets and 84 percent coverage in the top 40 markets. These two auctions accounted for just 24 MHz of the 108 MHz. Of the 84 MHz remaining, in 1997, the FCC reserved 24 MHz for public-safety communications, such as police and fire services; those previously designated for use by UHF TV channels, 63, 64, 68, and 69. The channels 52, 53, 56 to 58, 60 to 62, and 65 to 67, are divided into five blocks. Four of the five will be channel pairs: 52 and 57, 53 and 58, a pair of 5-MHz channels in 60 and 65, and a pair of 10-MHz channels in 61 to 62 and 66 to 67. Channel pairs are used in cell phone services to separate uplink and downlink bands for interference prevention. [Rast, Robert 2005] The revised 700 MHz band plan is illustrated in Figure 38. AT&T now has B, and C blocks in the lower 700 MHz band. This gives them paired spectrum 2 X 12 MHz that was previously used occupied by channels 53, 54, 58, and 59. Verizon now has the C block in the upper 700 MHz band. This gives them paired spectrum 2 X 11 MHz that was previously occupied by channels 60, 61, 65, and 66. The other 2 X 1 MHz of paired spectrum is block A that used to be occupied by channels 61, and 65.

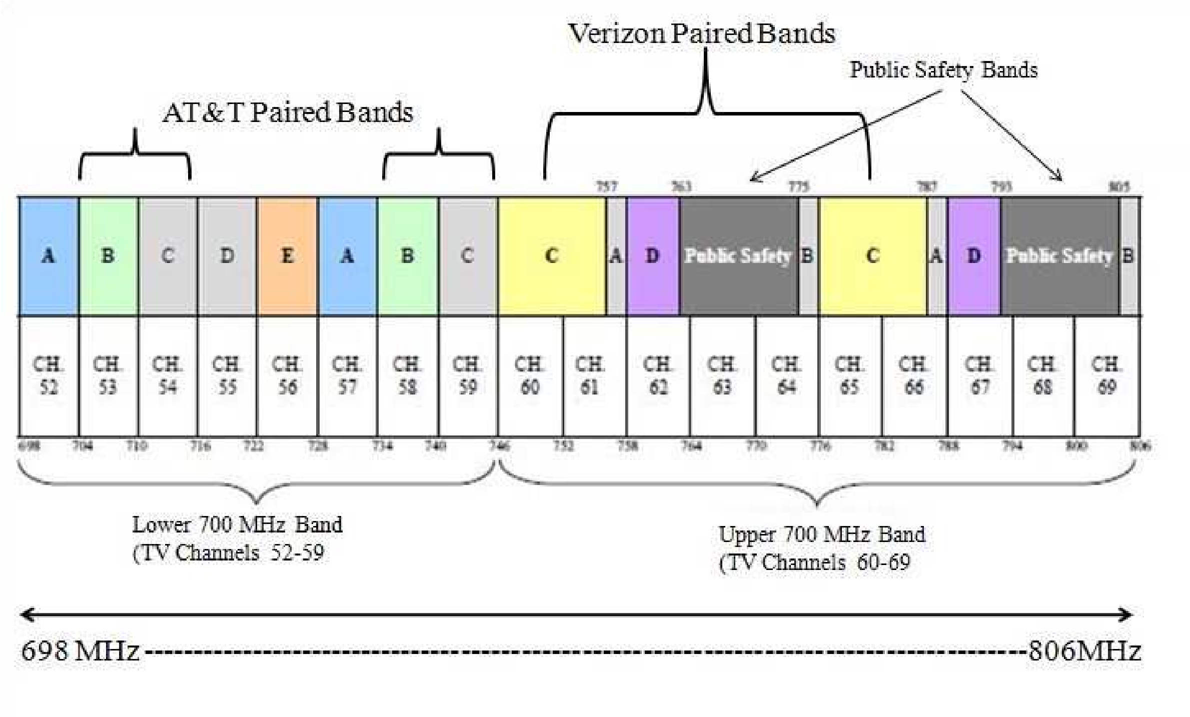


Figure 38 Revised 700 MHz Band for Commercial and Public Safety Services [FCC 2007]

Figure 39 shows the blocks, frequency ranges, pairing designation, type of market area, and the number of licenses obtained by successful bidders for pieces of the lower 700 MHz band. Blocks C and D were sold during auction 44 and 49. Blocks A, B, and E were sold during auction 73.

Block	Frequencies (MHz)	Bandwidth	Pairing	Area Type	Licenses
A	698-704, 728-734	12 MHz	2 x 6 MHz	EA	176
B	704-710, 734-740	12 MHz	2 x 6 MHz	CMA	734
C	710-716, 740-746	12 MHz	2 x 6 MHz	CMA	734
D	716-722	6 MHz	unpaired	EAG	6
E	722-728	6 MHz		EA	176

Figure 39 Lower 700 MHz Band [FCC 2007]

Figure 40 shows the blocks, frequency ranges, pairing designation, type of market area, and the number of licenses obtained by successful bidders for pieces of the upper 700 MHz band. Spectrum Blocks A, and B were sold during auction 44 and 49. Spectrum Blocks C, and D were sold during auction 73.

Block	Frequencies (MHz)	Bandwidth	Pairing	Area Type	Licenses
C	746-757, 776-787	22 MHz	2 x11 MHz	REAG	12
A	757-758, 787-788	2 MHz	2 x 1 MHz	MEA	52
D	758-763, 788-793	10 MHz	2 x 5 MHz	Nationwide	1
B	775-776, 805-806	2 MHz	2 x 1 MHz	MEA	52

Figure 40 Upper 700 MHz Band [FCC 2007]

There have been 5 auctions held for the 700 MHz bands by the FCC; Auctions 44, 49, 60, 73, and 92. Auction 73 was by far the largest with $19 billion raised. Over 1000 licenses were sold and the largest quantity of spectrum was offered. Figure 41 shows the results from auctions 44 through 93 for the 700 MHz band.

Auction & Date	Spectrum For Sale	Licenses Available	Bidding Results	Revenue Received
No. 44 8/27/2002-9/18/2002	Blocks C and D	740 licenses, 734 CMA, and 6 EAG licenses, CMA Block C: (710-716, 740-746 MHz) and EAG Block D: (716-722 MHz). Block C was 12 MHz (2 x 6 MHz paired) in each CMA and Block D was 6 MHz (unpaired) in each EAG.	102 bidders won 484 licenses with 256 licenses held back by the FCC.	$88,651,630
No. 49 5/28/2003-6/13/2003	Blocks C and D	256 licenses held back from Auction 44, 251 CMA and 5 EAG licenses, CMA Block C: (710-716, 740-746 MHz) and EAG Block D: (716-722 MHz). Block C was 12 MHz (2 x 6 MHz paired) and Block D was 6 MHz (unpaired).	35 bidders won 251 licenses (5 EAG & 246 CMAs) with 5 CMA licenses held back by the FCC.	$56,815,960
No. 60 7/20/2005-7/26/2005	Block C	5 CMA licenses offered for Puerto Rico only, Block C: (710-716, 740-746 MHz), and 12 MHz (2 x 6 MHz paired).	There were 3 winners for 5 licenses.	$305,155
No. 73 1/24/2008-3/18/2008	Blocks A, B, C, D, and E totaling 62 MHz in 1,099 licenses.	Block A 176 EA licenses, 12 MHz (698-704 / 728-734 MHz) and 2 X 6 MHz paired. Block B 734 CMA licenses, 12 MHz (704-710 / 734-740 MHz) and 2 X 6 MHz paired. Block E had 176 EA licenses, 6 MHz (722-728 MHz) unpaired. Block C 12 REAG licenses, 22 MHz (746-757 / 776-787 MHz) and 2 X 11 MHz paired. Block D had 1 nationwide license 10 MHz (758-763 / 788-793 MHz), 2 X 5 MHz paired.	There were 101 winners won 1090 licenses with 9 held back by the FCC.	$18,957,582,150
No. 92 7/19/2011-7/25/2011	Blocks A and B	Block A 2 EA licenses, 12 MHz (698-704 / 728-734 MHz) and 2 X 6MHz paired Block B 14 CMA licenses, 12 MHz (704-710 / 734-740 MHz) and 2 x 6 MHz paired.	7 winners for 16 licenses	$19,770,250

Figure 41 Results from the 700 MHz Band Auctions [FCC 2012 F]

The results of Auction 73 are shown in Figure 42. This shows the dominance of AT&T and Verizon Wireless at this auction. Qualcomm and Aloha Partners purchased a large part of the spectrum offered in Auctions 44, and 49. Auctions 60 and 92 sold small numbers of licenses for Puerto Rico, and US rural areas.

Bidder	Number of PWBs	Total Net PWB Amount	Breakdown of winnings
Verizon Wireless	109	$9,363,160,000	7 C block covering 98% of pops 25 A block covering 52% of pops 77 B block covering 16% of pops
AT&T	227	$6,636,658,000	227 B block covering 62% of pops
Echostar (Frontier Wireless)	168	$711,871,000	168 E block covering 76% of pops
Qualcomm (now AT&T owned)	8	$558,142,000	5 E block covering 24% of pops 3 B block covering 0.1% of pops
MetroPCS	1	$313,267,000	1 A block license covering 2.8% of pops
Cox Wireless	22	$304,633,000	14 A block covering 6.6% of pops 8 B block covering 0.6% of pops
US Cellular (King Street Wireless)	152	$300,478,500	25 A block covering 7.6% of pops 127 B block covering 6.6% of pops
Cellular South	24	$191,533,000	14 A block covering 4.7% of pops 10 B block covering 0.5% of pops
CenturyTel	69	$148,964,000	21 A block covering 3.8% of pops 48 B block covering 2.4% of pops
Vulcan Spectrum	2	$112,793,000	2 A block licenses covering 2.5% of pops

(PWB – provisionally winning bids, pops – population in market areas)

Figure 42 Results from FCC Spectrum Auction 73 [FCC 2012 F]

Figure 42 indicates that AT&T obtained 12 MHz (2*6) of paired frequency bands in the lower 700 MHz spectrum, labeled band block B in Figure 38 above. Verizon Wireless obtained 22 MHz (2*11) of paired frequency bands in the upper 700 MHz spectrum, labeled band block C. AT&T and Verizon Wireless emerged from Auction 73 with the largest holdings of 700 MHz spectrum and contributed nearly 82% of the total auction revenue. Verizon Wireless owns the upper C Block within the continental United States, along with significant holdings in the lower A Block (147.9 million POPs) and B Block (46.3 million POPs). Prior to the auction, AT&T had purchased much of the lower C Block from other license holders, and emerged from the auction with the winning bid for most of the lower B block licenses (175.8 million POPs). [FCC 2007]

There are inevitably winners and losers, companies successfully bidding at the auctions appear initially to be winners; this however does not mean that their ventures have achieved their original expectations. Aloha Partners LP was the largest buyer of spectrum in the FCC auctions of radio frequencies in the 700MHz band in 2001 and 2003. On February 4, 2008, the FCC approved the $2.5

billion buyout of Aloha Partners by AT&T Mobility. This gives AT&T control of former television channel 54 and 59 in a coverage area that includes 72 of the top 100 metropolitan areas and 196 million people in 281 markets. MediaFLO was a technology developed by Qualcomm for transmitting audio, video and data to portable devices such as mobile phones and tablets. In December 2010, AT&T announced that it would purchase Qualcomm's FCC licenses in the 700 MHz band. It has been difficult for Aloha and Qualcomm to realize their original plans for the spectrum in channels 54, 55, and 59. They have subsequently both sold out to AT&T. [Rast, Robert 2005]

4.6 The 700 MHz Band Spectrum Dividend

The unused TV spectrum that was auctioned between 2002 and 2011 raised over $19 billion. The repurposing of these frequency bands from the TV broadcast industry to the mobile communications industry is examined. In 2006, 108 MHz of spectrum--the upper end of the UHF band, or TV channels 52 to 69 was selected for other uses. [Rast, Robert 2005] The TV channels 52, to 69 occupy frequencies 698 MHz through 806 MHz, and they are known as the 700 MHz band. The reallocation of this much spectrum, was sufficiently large to attract mobile operators looking for frequency bands for new wireless broadband services. The entire AM radio spectrum is less than 1.2 MHz. All local area networks using IEEE 802.11b and 802.11g, the most common forms of Wi-Fi, occupy just 83.5 MHz. [Rast, Robert 2005] Members of the mobile broadband industry wanted a piece of this spectrum for their planned next generation communications networks.

In the recent past, the auctions arranged by the FCC that sold spectrum bands have provided the US government with a significant amount of revenue. This has helped to balance the federal budget. This is the claim made by the FCC, although there are many critics of the way in which the agency has organized the spectrum auctions. At the FCC web site “Incentive Auctions”, it makes this statement:

> *The FCC has successfully auctioned commercial licenses to use spectrum since the mid-1990s, raising over $50 billion for the U.S. Treasury and driving growth of the wireless industry to over $150 billion in annual revenue, with mobile phone penetration now at over 90% of the population*. [FCC 2012 E]

The FCC believes that the auctions were conducted in everyone’s interest as it provided the US with significant revenue to spend on telecommunications in underdeveloped regions of the country. The spectrum that was being repurposed was the result of the analog to digital TV transition and the mobile broadband industry was eager to acquire new spectrum for planned new services. The newly available spectrum was coined "Beachfront Spectrum" because of its desirability to the broadband community. [Klein, Ezra 2011]

4.6.1 Attractive Characteristics of the 700 MHz Band

Signals in the 700 MHz frequency band propagate farther and penetrate buildings better than signals in today's cellular bands, which go up to 1.9 gigahertz. This is because signals at these frequencies are less likely to be impeded by materials such as brick and cement. The loss in signal strength of a radio wave that would result from a line-of-sight path through free space with no obstacles nearby to cause reflection or diffraction is known as free-space path loss (FSPL). FSPL is proportional to the square of the distance between the transmitter and receiver, and proportional to the square of the frequency of the radio signal. Reflection, diffraction, and scattering propagation mechanisms affect the path of a radio wave. Reflection occurs when the wave impinges on a large object such as the surface of the earth or the sides of buildings. Diffraction occurs when the wave path is obstructed by an object that has sharp edges; this gives rise to secondary waves that result from a bending of the waves around the object.

Scattering waves are produced by small objects such as foliage, street signs and objects with rough surfaces. Penetration loss is the signal attenuation suffered by signals passing through buildings. The propagation formula depends upon the frequency, relative permittivity, relative permeability and conductivity of the material. [RAY Maps 2012] Using the properties of concrete and a concrete wall thickness of 10 cm, the penetration loss at 728 MHz and at 1805 MHz is calculated to be 4.16 dB and 10.38 dB respectively. There is therefore a gain of 6.22 dB when using the lower frequency. In simpler terms, the signal at the lower frequency would be more than 4 times stronger. [RAY Maps 2012] The reflection that occurs at the interface was ignored because its effect is comparably quite small.

Mobile broadband providers are expecting to decrease the cost of cellular infrastructure by 90 percent with the addition of these new bands. The recently available frequencies would require less cell towers to broadcast, as the signals propagate over a greater distance due to better frequency propagation characteristics. [Rast, Robert 2005]

4.6.2 Anti-competitive practices and the 700 MHz band

AT&T and Verizon are the two largest and hence dominant mobile operators. There are public interest groups such as the rural cellular association (RCA) that are lobbying congress and the FCC to restrict this dominance and promote more interoperability between wireless service providers and the devices using their networks. Currently, three different technologies, CDMA, GSM, and iDEN are the most widely used in wireless cellular networks. Mobile phones are built for specific technologies and spectrum bands, although it is common for a particular phone to support many different bands and multiple technologies. Today, interoperability exists within the entire band. This means that if the device works on any frequency block within a particular band, it works throughout the band. This interoperability allows seamless roaming across networks supporting the particular technology. If the phone supports multiple wireless technologies, then roaming is supported across these networks. [FCC 2007]

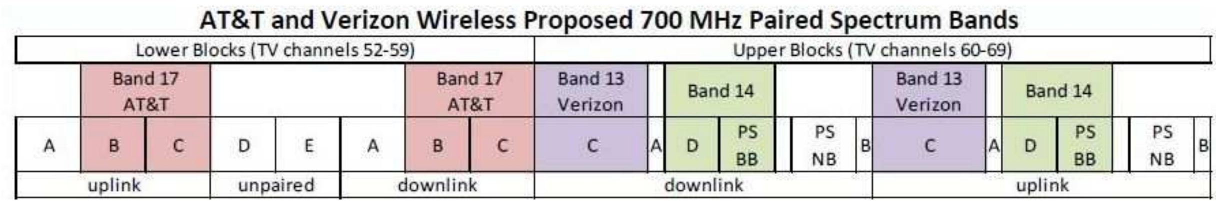
The industry is moving toward a common technology standard called Long Term Evolution (LTE) for 4G networks. The convergence to a common technology should facilitate interoperability, roaming, and competition. However, these benefits will be lost if the dominant incumbents, AT&T and Verizon Wireless, are not prevented from adopting carrier-specific band plans and restrictive devices. Industry consolidation has resulted in four nationwide or near-nationwide operators (AT&T, Verizon Wireless, Sprint, and T-Mobile) as well as a competitive fringe of regional and rural operators. The competitive landscape has however been severely deteriorated in recent years, and this has allowed AT&T and Verizon to dominate the mobile market. AT&T has also tried to further consolidate its dominate position by attempting to acquire T-Mobile. The US Department of Justice and other Government agencies have ruled that the proposed merger would contravene US antitrust laws. [Cramton, Peter 2010]

An important competitive advantage of the two largest operators is their network coverage due to their holdings of low frequency spectrum (below 1 GHz). Currently, they have a near-duopoly in the original 800 MHz cellular spectrum. This low-frequency spectrum is referred to as “beachfront spectrum” because of its desirable propagation characteristics. Many fewer cell towers are required than networks built for PCS and AWS spectrum. Because of the aggressive bidding of AT&T and Verizon Wireless in the 700 MHz auction, the Big Two won an overwhelming majority of the paired spectrum in the major cellular market areas (CMAs). The smaller competitors were only able to win the leftovers; primarily small regions such as those in the less expensive lower A Block. Small operators are more agile than the Big Two and are able to set up mobile service in smaller rural communities relatively quickly. They can only do this if low cost phones are also available to use with the spectrum. [Cramton, Peter 2010]

Equipment manufacturing depends on economies of scale, and the Big Two are sufficiently large to achieve these economies alone. In contrast, lower A Block spectrum winners have insufficient scale to develop affordable end user devices that would work on the A Block. Customers wishing to roam between rural networks traversing AT&T and Verizon networks will be prevented from doing so. As a result, the A Block spectrum is likely to be orphaned for multiple years. Similarly, the value of the upper D Block and the public safety block in the upper band will be compromised. The importance of interoperability for public safety is especially great in rural markets where first responders are volunteers and more apt to rely on interoperability with commercial operators. [Cramton, Peter 2010]

Both AT&T and Verizon have announced plans to deploy 3GPP Long Term Evolution (LTE) technology in their respective blocks, with the first markets planned for launch in 2010 and 2011. As the LTE standard evolved within 3GPP, four band plans for 700 MHz were introduced. Verizon Wireless has selected 3GPP Band 13, which covers the upper C block. AT&T is targeting Band 17 for LTE devices, which covers the lower B and C blocks. Devices built for AT&T may only work on the lower B and C Blocks (3GPP LTE Band 17), predominantly held by AT&T, and devices built for Verizon Wireless may only work on Verizon Wireless' upper C Block (3GPP LTE Band 13). [FCC 2007] Figure 43 illustrates the AT&T and Verizon paired blocks they intend to use for LTE.

The strategy adopted by the Big Two strengthens their competitive advantage by protecting their markets from erosion from smaller operators; however, this is in direct opposition to the goals of the FCC directives to extend broadband access to rural areas. Without intervention from the FCC, devices built for AT&T and Verizon Wireless will only support their individual spectrum holdings in 700 MHz spectrum sector. [Cramton, Peter 2010]



Note: Band 13, 14, and 17 are defined in the 3GGP LTE technical documentation. They do not signify frequencies, i.e. band 13 is NOT 13 MHz.

Figure 43 AT&T and Verizon Proposed 700 MHz Bands [Cramton, Peter 2010]

4.6.3 Proposed Remedy to Anti-competitive practices in the Wireless Industry

Fragmentation of the 700 MHz spectrum is not necessary. The Coalition for 4G in America has proposed an alternative for the 700 MHz paired spectrum, the current 3GGP Band 12 (lower blocks A, B, and C) and a new upper band (blocks C, A, D, and Public Safety broadband) as shown in Figure 44. The upper A Block would be returned to the FCC and combined with the D Block. The 3GGP Band 12 and the new upper band greatly reduce the market fragmentation problem. If devices now support both the 3GGP Band 12 and the new upper band, the market fragmentation problem is eliminated. In contrast, if AT&T and Verizon Wireless are successful in fragmenting the market, the build out of 4G to rural regions and for public safety will be substantially delayed and be more costly when built. [Cramton, Peter 2010]

The 700 MHz spectrum has been targeted by the US federal government to enhance rural and public safety coverage. Other countries have taken a more aggressive approach; for example, in the German

4G auction ending May 2010, winners of the 800 MHz blocks must build out the rural areas before the spectrum can be used in urban areas. In contrast, AT&T and Verizon Wireless instead intend to build out the urban areas and have no specific plans for the rural areas. Large companies cannot be singled out because they are likely to bring lawsuits against the FCC protesting unfair practices, however if the spectrum usage rules were structured properly prior to an auction then all parties will be treated equally. [Cramton, Peter 2010]

Figure 44 Coalition for 4G in America 700 MHz Proposal [Cramton, Peter 2010]

4.7 Global Spectrum Policy and Development

Spectrum policy and development decisions are made by individual countries in conjunction with international standards bodies. Each country is responsible for defining and managing their individual frequency allocation maps, which typically contain a brief description of the radio application, and the frequency ranges they use. Market forces drive radio service deployments with licenses authorizing their implementation provided by government regulators. Smaller nations tend to rely more heavily on standards bodies for guidance. Large industrial nations like the US view standards bodies as complements to their regulatory authority.

4.7.1 International Standards Bodies

A number of international forums and standards bodies work on standards for frequency allocation. The four most prominent bodies are the International Telecommunication Union (ITU), the European Conference of Postal and Telecommunications Administrations (CEPT), the European Telecommunications Standards Institute (ETSI), and International Special Committee on Radio Interference (CISPR).

ITU is a specialized agency of the United Nations that is responsible for information and communication technologies. ITU coordinates the shared global use of the radio spectrum, recommends improvements for telecommunication infrastructure, and establishes worldwide standards. [ITU 2012 B] The ITU comprises three sectors, each managing a different aspect of the matters handled by the Union, as well as ITU Telecom. The Radiocommunication group (ITU-R) manages the international radio-frequency spectrum and satellite orbit resources. The Standardization group (ITU-T) organizes the ITU's standards functions. The Development (ITU-D) publishes technical papers concerning information and communication technologies. (ITU 2012 B] The ITU divides the world into five administrative regions, the Americas, Western Europe, Eastern Europe and Northern Asia, Africa, and Asia and Australasia. The ITU divides the world in regions. Region no. 1 is for Europe, Middle East, Africa, the former Soviet Union, including Siberia and Mongolia. Region no. 2 is for North and South America and Pacific countries east of the International Date Line. Region no. 3 is for Asia, Australia and the Pacific Rim countries west of the International Date Line. For the last 20 years, ITU has been coordinating efforts of government and industry and private sector in the development of a global broadband multimedia international mobile telecommunication system, known as International Mobile Telecommunications (IMT). [ITU 2008]

The European Conference of Postal and Telecommunications Administrations body (CEPT) was established in 1959, as a coordinating function for European state telecommunications and postal organizations. [CEPT 2012] The work of CEPT is conducted by three autonomous business Committees, the Electronic Communications Committee (ECC), the European Committee for Postal Regulation (CERP), and the Committee for ITU Policy (Com-ITU). CEPT created the European Telecommunications Standards Institute (ETSI) in 1988.

The European Telecommunications Standards Institute (ETSI) is a standardization organization in the telecommunications industry for Low Power Radio, Short Range Device, GSM cell phone systems. It has 740 members from 62 countries/provinces inside and outside Europe. Significant ETSI standardization bodies include TISPAN (for fixed networks and Internet convergence) and M2M (for machine-to-machine communications). The ETSI organization inspired the creation of the 3GPP. [ETSI 2012]

The Comité International Spécial des Perturbations Radioélectriques (CISPR) was founded in 1934 to set standards for controlling electromagnetic interference in electrical and electronic devices. It is part of the International Electrotechnical Commission (IEC). [CISPR 2012] Standards cover the measurement of radiated and conducted interference. CISPR' work involves measuring interference, establishing limits and immunity requirements, and prescribing (in liaison with other IEC technical committees) methods of measuring immunity. The CISPR publishes EMC standards and standardization policies through six committees known as CIS/A through CIS/I.

4.7.2 International Spectrum Decisions

International co-operation concerning spectrum policy and development has taken place through standards bodies such as the ITU, technical working groups, and international conferences. Neighboring countries have traditionally made agreements and signed treaties regarding radio spectrum issues because of their close proximity to each other. The US has many agreements with Canada and Mexico concerning broadcast, mobile and special purpose frequency bands. [FCC 2011]

The ITU holds World Radiocommunication Conferences (WRC) every three to four years. It is the job of WRC to review and if necessary, revise the ITU Radio Regulations and the international treaty governing the use of the radio-frequency spectrum. [ITU 2008] The European Union (EU) has instigated many policy initiatives regarding radio services, and the latest is the Radio Spectrum Policy Program that will begin in early 2012 and run through to the end of 2015. [EU 2012] Two of its objectives are to create a European radio spectrum inventory, and to make at least 1200 MHz of spectrum available for wireless broadband services in the Union by 2015. European Member States will be required to authorize the use of the "digital dividend" 800 MHz band for wireless broadband by January 2013.

The Asia Pacific Telecommunity (APT) was founded on the joint initiatives of the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) and the ITU. The APT is an Intergovernmental Organization founded in 1979 that operates in conjunction with telecom service providers, and communications equipment manufacturers. [APT 2012] It has assisted members in the preparation of Global conferences such as ITU Plenipotentiary Conference (PP), World Telecommunication Development Conference (WTDC), World Radiocommunication Conference (WRC), World Summit on the Information Society (WSIS), World Telecommunication Standardization Assembly (WTSA) and the ITU meetings.

4.7.3 Mobile Communication Standards

A new generation of cellular standards has appeared approximately every tenth year since first generation (1G) systems were introduced in 1981/1982. Each generation is characterized by new frequency bands, higher data rates and non-backwards compatible transmission technology. Original 1G cell phones used 800 MHz and 900 MHz frequency bands. Second generation (2G) technologies can be divided into GSM and CDMA-based standards. Third generation (3G) is a set of standards defined by International Mobile Telecommunications-2000 (IMT-2000) specifications. The ITU-R approved in June 2003 the following bands for the IMT-2000; 806-960 MHz, 1710-2025 MHz, 2110-2200 MHz and 2500-2690 MHz. The LTE Advanced standard was submitted and approved for Fourth Generation (4G) systems by the ITU-T in late 2009. AT&T and Verizon plan to use part of the 700 MHz band released by the digital TV switchover for 4G service. International Mobile Telecommunications-Advanced (IMT-Advanced) are requirements issued by the ITU-R in 2008 for 4G mobile phone and Internet access service. [ITU 2012 A]

4.7.4 Spectrum Decisions made at WRC conferences

The WRC-2000 conference was held in the year 2000. Spectrum was identified for the ITU's IMT-2000 standard. Frequency bands (806-960 MHz), (1710-1885 MHz), and (2500-2690 MHz) were chosen. [ITU 2000] In the official WRC preparatory process for the WRC-2007, the future spectrum requirements for IMT were determined up to the year 2020. The spectrum required was in addition to that already assigned for IMT-2000. This assessment is contained in document "CPM Report on technical, operational and regulatory/procedural matters to be considered by the 2007 World Radiocommunication Conference, Geneva 2007". [ITU 2007]

Figure 45 is taken from the CPM document, low and high estimates for each of the 3 regions are shown.

All ITU Regions		Region 1		Region 2		Region 3	
Threshold	Predicted Total Spectrum (MHz)	Identified Available Spectrum (MHz)	Additional Spectrum Required (MHz)	Identified Available Spectrum (MHz)	Additional Spectrum Required (MHz)	Identified Available Spectrum (MHz)	Additional Spectrum Required (MHz)
Low	1280	693	587	723	557	749	531
High	1720	693	1037	723	997	749	971

Figure 45 Predicted Total Spectrum Required for IMT by 2020 [NGMN 2012]

The deliberations in the ITU World Radiocommunications Conference (WRC-07) resulted in approximately 400 MHz of additional spectrum earmarked for IMT-2000 and IMT-Advanced.

Figure 46 shows the frequency bands targeted by WRC-07.

Spectrum	Geographic Location	Frequency Bands
20 MHz	Globally	450 – 470 MHz
72 MHz	Region 1 (Europe) and parts of Region 3 (Asia)	790 – 862 MHz
108 MHz	Region 2 (Americas) and some countries of Region 3 (Asia)	698 – 806 MHz
100 MHz	Globally	2.3 – 2.4 GHz
200 MHz	No global allocation, but identified in 82 countries	3.4 – 3.6 GHz

Figure 46 Targeted Frequency Bands at the WRC-2007 Conference [NGMN 2012]

The maximum available spectrum is 392 MHz for Europe, 428MHz for North and South America, and 428 MHz for the Asia-Pacific region. WRC-07 identified 108 MHz of UHF spectrum for ITU-R Region 2 and nine countries in Region 3, including China, India, Japan and South Korea. This band is the most attractive because it allows mobile operators the means to provide a cost-effective, continuous, broadband capability. The US has already started the deployment of 4G LTE in the 2010-2011 timeframe, and it forms the basis of a regional 700 MHz band plan. AT&T and Verizon have slightly different band plans and pressure is being applied by interested groups to conform to a common frequency plan. Figure 47 shows the FDD 2x18 MHz uplink and downlink paired bands and the FDD 2x11 MHz uplink and downlink paired bands. [NGMN 2012]

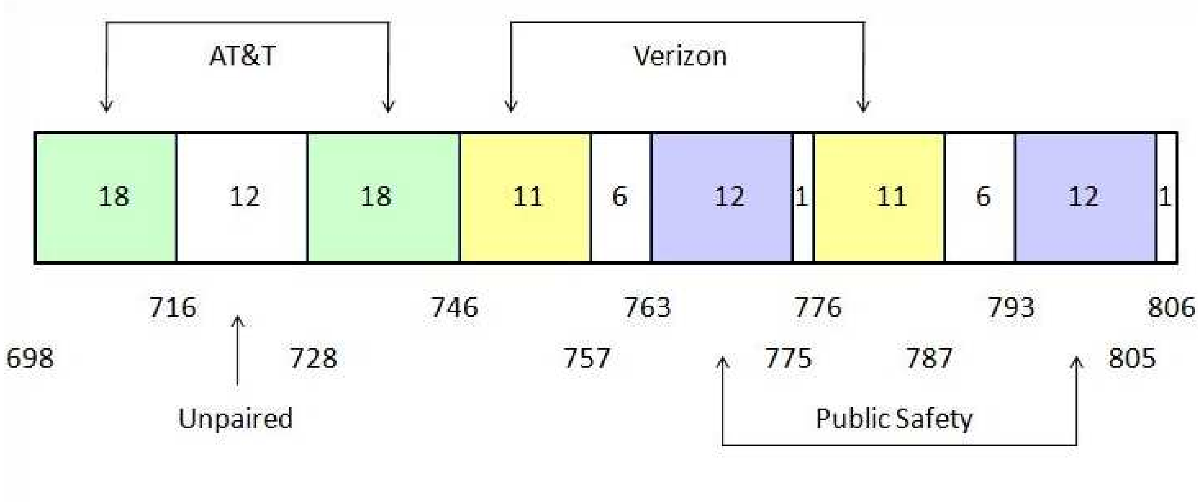


Figure 47 US Plan 698 - 806 MHz (700 MHz Band) with AT&T, Verizon, Public Safety Blocks

(PPDR - Public Protection and Disaster Relief (called Public Safety Band in the US))

The CEPT has developed a preferred harmonized frequency arrangement for the 791 – 862 MHz band, adopted in October 2009, and it is known as the 800 MHz band. The CEPT preferred harmonized frequency arrangement is 2 x 30 MHz with a duplex gap of 11 MHz, based on a block size of 5 MHz, paired and with reverse duplex direction. The FDD downlink starts at 791 MHz and the FDD uplink starts at 832 MHz. Figure 48 shows the 30 MHz paired bands.

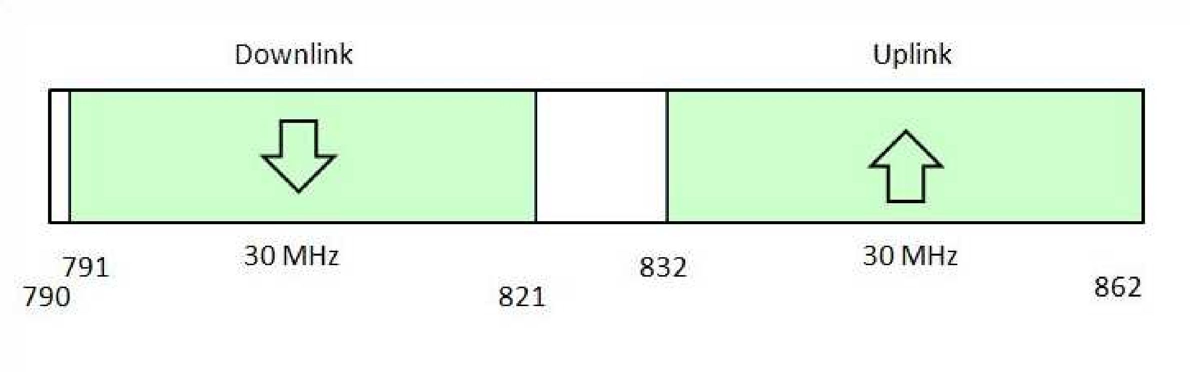


Figure 48 European Union Plan 791 - 862 MHz (800 MHz Band)

Following WRC-07, AWF, the Wireless Forum of Asia-Pacific Telecommunity (APT) organization, established a group to develop recommended harmonized approaches for the introduction of new wireless technologies, services and applications in the released spectrum. Recognizing the need to provide sufficient protection for the services in adjacent bands and based on studies of the various interference issues it was decided that spectrum should be allocated with a lower guard-band of 5 MHz between 698-703 MHz, and an upper guard-band of 3 MHz that should be allocated between 803-806 MHz. To maximize the amount of FDD spectrum, a 2 x 45 MHz FDD structure with a 10 MHz center-band gap was decided. Figure 49 shows the 45 MHz paired bands.

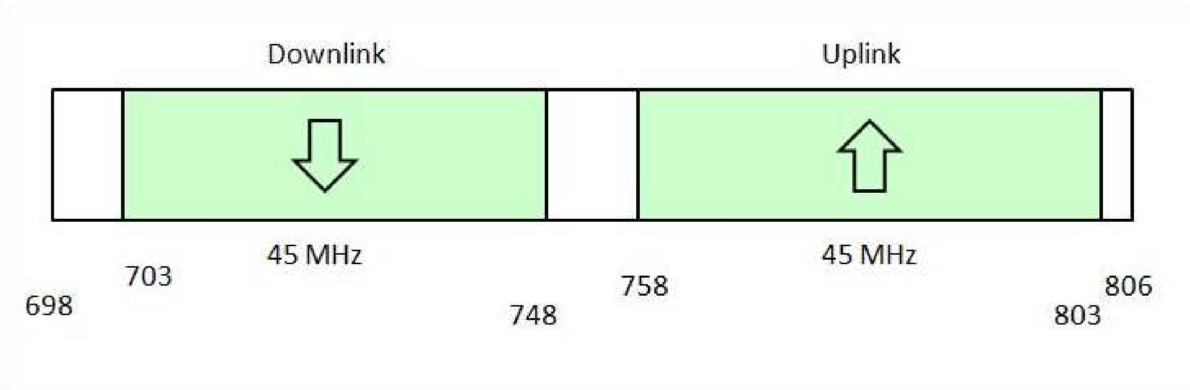


Figure 49 Asia-Pacific Telecommunity Plan 698 - 806 MHz (700 MHz Band)

4.7.5 International Digital TV Switchover

Digital terrestrial television (DTTV) is transmitted on radio frequencies through terrestrial space in the same way as standard analog television, with the primary difference being the use of multiplex transmitters to allow reception of multiple channels on a single frequency range (such as a UHF or VHF channel) known as sub-channels. [DTV 2012]

"The Digital Video Broadcasting (DVB) standards are used in European countries, the Advanced Television Systems Committee (ATSC) standards are used by the US, Canada, and Korea, the Integrated Services Digital Broadcasting (ISDB) standards are used in Japan and Latin America countries, and the Digital Terrestrial Multimedia Broadcast DTMB standards are used in China." [MED 2011] The distribution of the DTTV standards is illustrated in the world is shown in Figure 50.

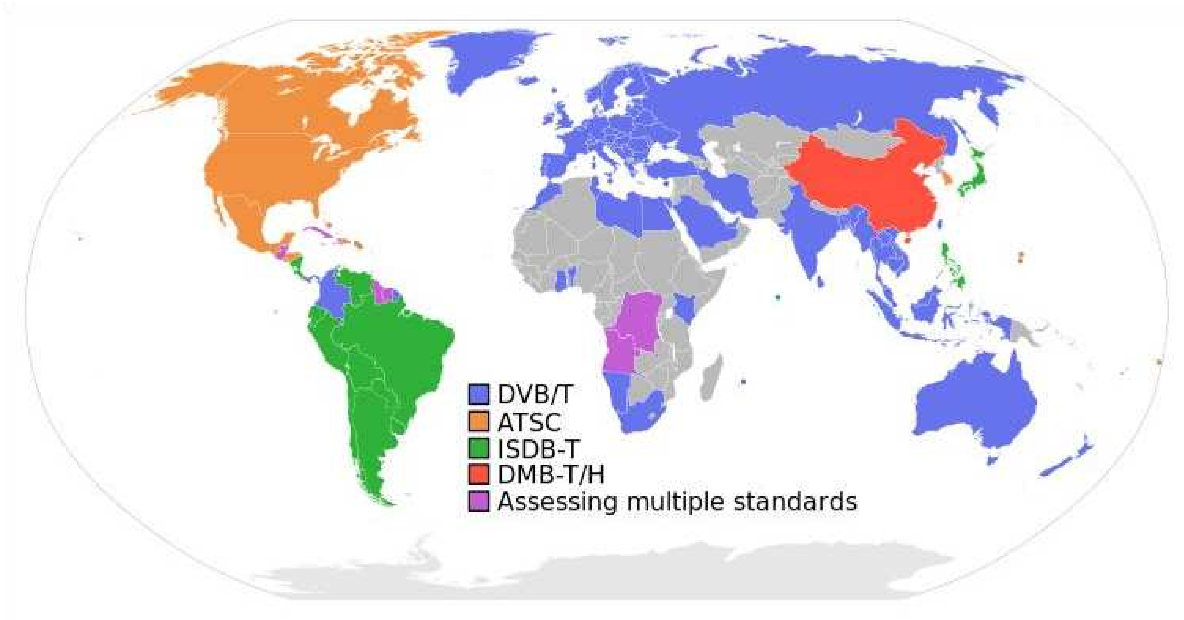


Figure 50 Digital Television Standards used across the World [DTV 2012]

The digital TV switchover has released frequency bands for new uses in both the 700MHz and 800 MHz frequency blocks. These frequency blocks are known as the "digital dividend". The United States held an auction in 2007, which resulted in two national mobile network operators acquiring spectrum, along with many regional operators. "Germany and Sweden held auctions in June 2010 and February 2011 respectively. In both countries, three mobile network providers won 2x10 MHz each. France and the United Kingdom are planning to hold auctions to allocate the digital dividend bands later in 2012. Australia expects to hold an auction in 2012 to allocate the digital dividend bands. India has begun considering the use of the 700 MHz band for new 4G wireless broadband uses. To date, Finland, Sweden, France, Switzerland, Germany, Spain and Denmark have decided to release the whole of the 800 MHz band. Canada, Mexico, and many South American countries have yet to determine a band plan. It is likely that Canada and Mexico will implement the US band plan due to their proximity to the USA. Several countries in South America, however, have indicated an interest in implementing an alternative plan, such as the plan developed by the APT."[MED 2011]

4.7.6 UK Spectrum

The UK is located off the northwestern coast of continental Europe. Government is centralized in London in the south east of England. The UK Radio history is over 100 years old and originated from the early experiments made by Marconi in 1890s. Commercial radio and TV broadcasting was banned until the 1950s and controlled by the UK Government owned British Broadcasting Company (BBC). Radio stations on ships in the North Sea located to the east of England illegally transmitted radio services to the mainland. They called pirate radio stations and were frequently harassed by the British Government. Commercial TV broadcasting started in the 1955, however commercial radio stations were not allowed until the 1980s. The BBC and the UK Ministry of Defense (MOD) controlled the allocation of spectrum bands until the 1990s.

4.7.6.1 Radio Spectrum Policy and Regulation in the UK

Before the British Government passed Wireless Telegraphy (WT) Act of 1998, licenses were awarded for a specific technology and use. Fees were set to cover administrative costs only. Prospective businesses would submit proposals to the regulator, who would pick the proposal it deemed economically and socially beneficial. This was changed in 2003 and now a super-regulator, Ofcom manages civil radio spectrum in the UK and grants spectrum licenses, giving users the right to operate over a set locality at a selected range of frequencies. [OfCom 2012]

Ofcom is the UK Communications Systems regulator. It regulates the TV and radio sectors, fixed line telecoms, mobiles, and the airwaves over which wireless devices operate. Ofcom operates under the UK Communications Act 2003. Accountable to the British Parliament, it is responsible for all technical aspects of communication systems regulation, as well as implementing and enforcing the law. Ofcom is funded by fees collected from industry for regulating broadcasting and communications networks, and money from the British Government. The fees are made up of licensing payments and the sale of the access to spectrum frequency bands. [OfCom 2012] The Radiocommunications Agency (RA) was an Executive Agency of the UK Department of Trade and Industry . It was responsible for the management of the non-military radio spectrum in the UK, which involves international representation, commissioning research, allocating spectrum and licensing its use, and keeping the radio spectrum free from interference. Five UK regulatory bodies amalgamated to form the Ofcom in December 2003. The UK signs treaties with the ITU that eventually become UK law. The European Union (EU) also legislates on spectrum use and decisions are binding for the UK.

4.7.6.2 Radio Spectrum Development in the UK

The UK Government commissioned an audit of spectrum holdings in 2005. It looked at several radio services and published the following results. Cellular networks will require an additional 800 MHz of spectrum by 2025. For Broadband wireless access networks, there is an expected demand for an additional 200 MHz of spectrum mainly for expansion into rural areas. Terrestrial television requires 400 MHz of additional spectrum over and above the 2012 post- Digital TV switchover allocation of 112 MHz. [Cave, Martin 2005]

The demand for broadband data services and mobile phone services is high in the UK. It has one of the highest population densities of any European nation. The UK is served by primary mobile providers, Everything Everywhere, O2, Vodafone and 3. Virtual providers Virgin Mobile, Tesco, and others also supply mobile service. The mobile operators provide 2G, and 3G services in frequency ranges 800 MHz through 2G Hz. The coverage throughout the British Isles is generally very good principally because of its density of population on a small group of islands. The UK has 80.375 million subscribers in total, or a 130.55% penetration rate. The number of subscribers for each primary mobile operator is illustrated in

Figure 51.

Operator	Technology	Subscribers (millions)
Everything Everywhere Formerly Orange and T-Mobile	1800 MHz GSM, GPRS, EDGE; 2100 MHz UMTS, HSDPA, HSPA+ Wi-Fi UMA; 1800 MHz LTE	27.5
O_2	900/ 1800MHz GSM, GPRS, EDGE; 900/ 2100 MHz UMTS, HSDPA, HSPA+	22.2
Vodafone	900/ 1800 MHz GSM, GPRS, EDGE; 2100 MHz UMTS, HSDPA, HSPA+	19.0
Three	2100 MHz UMTS, HSDPA, HSPA+, 2G roaming on Orange in rural areas	7.5

Figure 51 UK Mobile Communications Operators [OfCom 2012]

The spectrum dividend that will result from the analog to digital TV switchover due for 2012 is very attractive to a number of service operators. This is being termed the “digital dividend”.

Digital TV Dividend

The ongoing debate about spectrum availability in the UK is focusing on a “sweet-spot” where most modern communication technologies such as DAB Digital Radio, digital television, 3G mobile phones and Wi-Fi wireless Internet access services operate. The sweet-spot, in fact, is the upper part of the Very High Frequency (VHF) band and the whole of the Ultra High Frequency (UHF) band, incorporating frequencies from around 200 MHz to 3 GHz as illustrated in Figure 52.

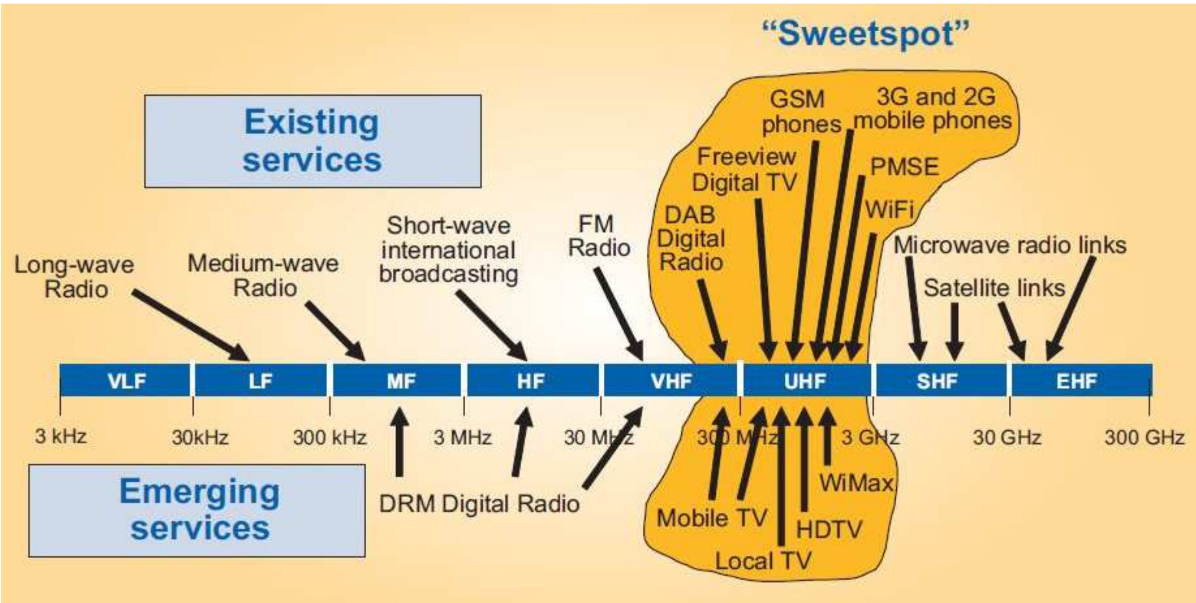


Figure 52 Frequency Sweet-spot for New Radio Services in the UK [Laflin, Nigel 2007]

The most valuable spectrum in the UK has been defined as between 200MHz and 1GHz – which offers the best combination of range and capacity. At present, nearly half of this spectrum is used to broadcast analog television – 368MHz, or 46%, of the 800MHz. The UK's analog TV broadcast services will be ended between 2008 and 2012, which means that all 368MHz might be available for new uses. The British Government has determined that 256MHz of the 368MHz should be used for digital TV broadcasting at the switchover. Digital broadcasting will be provided by six multiplexes, each of which will carry a number of television channels and other services. In the UK, a multiplex is a band of fixed width containing a number of channels. In the US, the same arrangement is often described as a channel with virtual sub-channels.

The British Government has given Ofcom and "Digital UK" joint responsibility for discontinuing analog TV broadcasting. Each multiplex is an error-protected bitstream of 18 or 24 megabits per second, which can be used for almost any combination of digitally encoded video, audio and data. The DVB-T standard provides a multiplex service that can make trade-offs between the number of services and the picture and audio quality. [OfCom 2007]Three multiplexes will be for public service broadcasting and contain around 25 TV channels, including all the television channels from the BBC, ITV, Channel 4 , 4C and Channel 5, together with radio stations and text/interactive services. The other three multiplexes (A, C and D) will continue to be operated by their respective commercial license-holders.

The remaining spectrum 112MHz to be released for new uses forms the core of the 'digital dividend'. The 112MHz mentioned above that comprises 14 channels of 8MHz, which is presently used for analog TV, and on a secondary basis for uses such as wireless microphones. Both primary and secondary uses will cease at switchover. Two other blocks of spectrum, channel 36 and channel 69 will be cleared. Interleaved spectrum, this is often referred to, as the 'white space' that exists between the transmitters will be used for the digital TV multiplexes. When digital switchover is complete, two new sub-bands of the UHF spectrum will be cleared (frequencies corresponding to channel ranges 31-40 and 62 to 69), leaving only channels 21-30 and 41-62 for digital television multiplexes. [OfCom 2007] The reallocated frequency bands will be re-used for, mobile TV services, mobile broadband services, wider coverage for remote and rural areas, an increased number of multiplexes carrying more channels, HDTV services, and Digital Audio Broadcast (DAB) services.

Figure 53 shows the frequency bands between 430 MHz and 950 MHz. Above 862MHz is occupied by GSM mobile telecommunications, license exempt applications and military applications for the UK Ministry of Defense (MOD). Below 470MHz, the principal user is MOD, for a variety of applications including radar. There is also some civil use, including extensive private mobile radio (PMR) use in the 450- 470MHz band. [OfCom 2007]

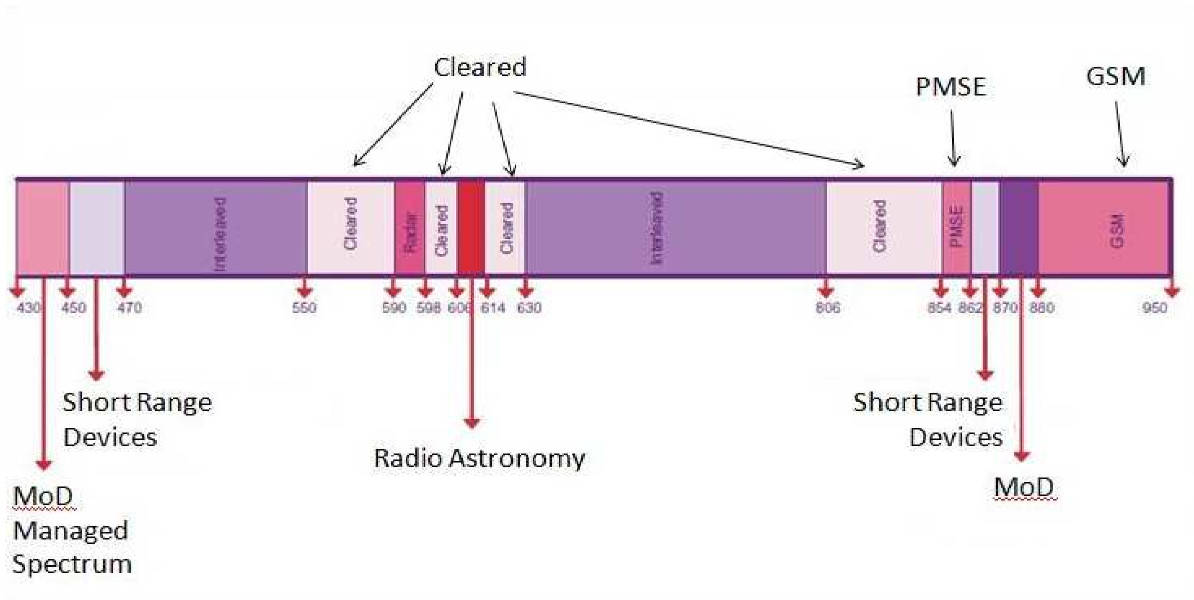


Figure 53 430M Hz - 950 MHz Frequency Band showing Cleared Blocks in the UK [OfCom 2007]

OfCom's latest timeframe is that the rights awarded to the spectrum cleared due to the Digital TV switchover would begin after the London 2012 Olympic Games have been concluded. [OfCom 2008] OfCom also intends to clear the 800 MHz band – 790-862 MHz, channels 61 to 69 in UHF Bands IV and V– of existing and previously planned users and align the upper band of the UK's digital dividend with the spectrum being identified for release by other European countries. The CEPT has issued a plan identifying a larger (upper) band of spectrum than originally planned in the UK, comprising 72 MHz at 790-862 MHz (channels 61-69), also known as the 800 MHz band. Clearing the 800 MHz band in the UK would increase by 24 MHz the valuable spectrum that is made available in the upper band of the digital dividend for new uses. Digital Terrestrial Television (DTT) in channels 61 and 62 will be moved into channels 39 and 40, and Program-Making and Special Events (PMSE) in channel 69 will be moved into channel 38. This means the cleared spectrum in the digital dividend will comprise 550-606 MHz (channels 31-37, the 600 MHz band) and 790-862 MHz (channels 61-69, the 800 MHz band). [OfCom 2009] Figure 54 illustrates the proposed changes,

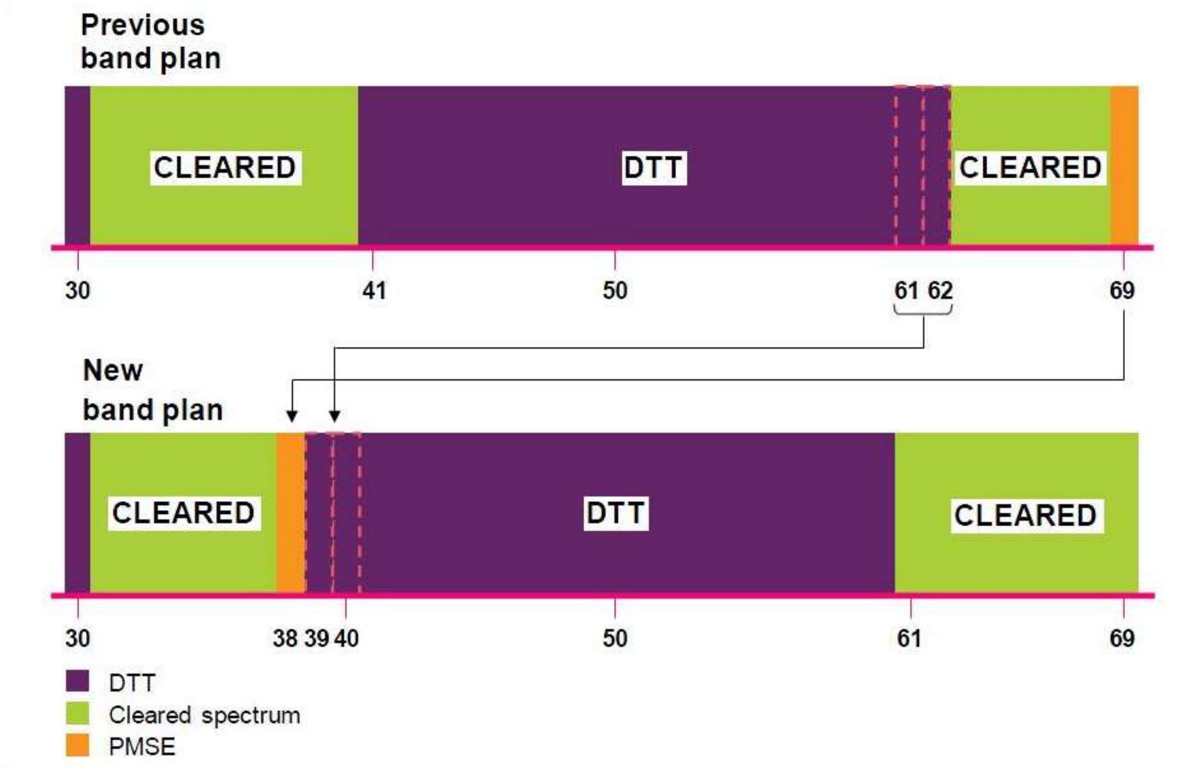


Figure 54 800 MHz Upper Band Organized in Conformance with EU Requirements [OfCom 2009]

The ITU Geneva 2006 Radio Regulations Broadcasting agreement is referred to as GE06. Under GE06, the UK has spectrum rights to operate eight national DTT multiplexes in channels 21-68 of UHF Bands IV and V (excluding channels 36 and 38). The existing six DTT multiplexes are therefore located within the spectrum retained for broadcast use (i.e. channels 21-30 and 41-62).The remaining two layers were secured to provide the upper (channels 63-68) and lower (channels 31-40) bands of cleared spectrum. There are no UK international rights in place for channel 69, and hence they will have to be separately negotiated. [OfCom 2009]

Spectrum Sales and Trading

The OfCom agency has targeted various frequency bands for reallocation. Most of these bands are tradable. This is a result of the recent introduction of a liberalization approach to spectrum management. The spectrum bands identified for reuse as follows,

The use of the radio spectrum has historically been highly controlled by regulators in the UK and has been conducted in the “command and control” style. Studies done by European countries have shown how excessive regulation of spectrum has led to scarcity and reduced flexibility thus affecting competition and innovation. New operators and new technologies have both struggled to gain access to markets due in part to this rigid method of regulation. OfCom now wishes to promote a more liberal attitude towards spectrum reallocation. Despite the reduction in regulation OfCom, is maintaining both its spectrum acquisition limits and its spectrum acquisition floors. The spectrum limits are specific to all sub-1 GHz spectrum bands. The design of the auction and the spectrum caps is intended to ensure a minimum of four Mobile Network Operators (MNOs) holding spectrum packages. This has been deemed by Ofcom, as sufficient to provide an effective and competitive mobile service.

OfCom has conducted technical research in a similar manner to the FCC using modeling techniques to help determine the best uses for newly available spectrum. The licensing rules set out in the OfCom DDR document for the spectrum auctions of the digital dividend frequency bands define a term of 18 years, some technical restrictions will be applied, the spectrum will be tradable, and competition will be promoted. The spectrum blocks will either be 5 MHz or 8 MHz in size, a spectrum cap of 50 MHz will be applied, and provision will be made for PMSE services. [OfCom 2008] The liberalization approach to spectrum sales will make it harder to predict what devices will be operating, where, and at what frequencies. This could make interference harder to manage, and hence Ofcom has introduced Spectrum Usage Rights. These would impose generic restrictions on the power of transmissions that a licensee may transmit in adjacent frequency bands or locations regardless of the type of radio transmitter operated. Legal responsibility for limiting interference and meeting any associated costs if it occurs has to be established before spectrum is licensed. [OfCom 2007]

4.7.6.3 Comparison with the US

The UK has a comparatively small land mass to the US. The rural population is much accessible in the UK compared with the US. OfCom and the FCC are both moving towards a more liberal approach to spectrum management. OfCom has developed an Administered Incentive Pricing (AIP) policy to encourage more efficient spectrum use. The UK has a large number of competing business sectors for the digital dividend spectrum whereas the US has settled on 4G LTE use. The UK is partitioning some of the digital dividend spectrum for special uses, namely PMSE licenses. This is initially targeted for use in the 2012 Olympics. Spectrum auctions are still viewed by the British as the fairest way of providing frequency bands to the radio communications industry in the UK. European harmonization is challenging because the EU is promoting unrestricted roaming between countries. Compliance with mandates from the ITU is sometimes difficult to satisfy. For example, the ITU has identified the 2.6 GHz band for 3G uses however; some UK operators want to use it for WiMax service. The British Ministry of Defense (MOD) still controls 30% of the UK spectrum. An audit of the MOD spectrum holdings is being conducted so that more frequency bands can be released.

4.7.7 New Zealand Spectrum

New Zealand is an island country located in the southwestern Pacific Ocean. Telecom New Zealand Telecom still owns the majority of the telecommunications infrastructure in the country. It is user of radio technology and as such tends to follow the surrounding Asia-Pacific countries when making telecommunications decisions.

4.7.7.1 Radio Spectrum Policy and Regulation in New Zealand

Spectrum regulation and governance in New Zealand (NZ) is complex. Including the Ministry in charge of spectrum management, there are two agencies responsible for spectrum management and spectrum policy development in New Zealand, the Ministry of Economic Development (MED), and the Spectrum Management Authority (SMA). The groups within MED related to spectrum policy are, the IT and Telecommunications Policy Group, the Radio Spectrum Policy and Planning Group, and the Radio Spectrum Management Group. [MED 2012] The SMA's tasks are to provide advice on policy, spectrum planning and allocation. It also administers radio apparatus licenses. It advises the NZ Government on spectrum allocation under the spectrum rights regime (SRR). The MED administers the Radiocommunications Act (1989). The MED and SMA jointly approve spectrum allocations for social, cultural and defense needs. The Commerce Commission is jointly the Competition law authority and the regulator of the telecom sector. Merger rules and rules governing anti-competitive practices by dominant firms are administered by the Commerce Commission. Such rules apply to primary and secondary sales of spectrum. [MED 2012] Three licensing systems apply to spectrum in New Zealand. The Management Rights Regime (MRR) applies to spectrum used for commercial purposes. The Radio License Regime (RLR) applies to spectrum used for applications in the public interest. General User Licenses (GULs) apply to low-powered devices such as Wi-Fi.

The Radiocommunications Act 1989 was pioneering because New Zealand was the first country to redefine spectrum in terms of property rights and designate it as tradable. New Zealand's first spectrum auction was held in 1989. In 2005, the MED published a review of radio spectrum policy and deemed that spectrum trading had not realized its projected efficiencies. The small size of the market in New Zealand, entry barriers to sectors using radio spectrum, and the availability of alternative spectrum in the RLR licensing framework were identified as the cause. [MED 2012]

4.7.7.2 Radio Spectrum Development in New Zealand

New Zealand uses Local Multipoint Distribution System (LMDS) microwave technology as an alternative to installing optical fiber all the way to the user. An auction was held in 2001 for LMDS bands and 800-900 MHz bands for GSM and CDMA cellular services. This was the first auction where management rights were provided with the spectrum bands. New Zealand does not have the type of fierce competition for establishment of mobile communications services as some of its neighboring Pacific Rim countries like China and Japan. It has been able to introduce telecommunications services in a careful and organized manner. [MED 2001 B]

The Cellular spectrum in NZ was allocated under the management rights regime for terms of twenty years. Currently, several bands are available to provide mobile cellular services in NZ, including the 850/900 MHz, and 1.8 GHz, 2.1 GHz, 2.3 GHz, and 2.6 GHz bands. Rights in the 850 and 900 MHz bands were originally allocated in 1990. The renewal policy for these rights was confirmed in 2007, included aligning expiry of all cellular rights in 2031. [MED 2001 A] As of March 2011, the penetration rate in New Zealand was 124.326% over a population of around 4.3 million. The NZ mobile operators and number of subscribers is shown in

Figure 55.

Operator	Technology	Subscribers (in millions)
Vodafone	GSM, GPRS UMTS, WCDMA, HSDPA, HSPA+	2.47
Telecom Corp New Zealand (TCNZ), Telecom XT	CdmaOne UMTS, WCDMA, HSDPA, HSPA+	2.19
2degrees	GSM, GPRS,EDGE UMTS, WCDMA, HSDPA, HSPA+	0.58
TelstraClear (using Vodafone)	GSM, GPRS UMTS, WCDMA, HSDPA, HSPA+	0.03

Figure 55 New Zealand Mobile Communications Providers [MED 2001 A]

The major allocations of spectrum for cellular mobile services were made between 2001 and 2007 and the mobile market has developed substantially. A third mobile network provider, Two Degrees Mobile (2degrees) has recently entered the market. The market share of the three operators, by number of subscribers is, Vodafone (51.5%), Telecom NZ (39%) and 2degrees (9.5%).

Digital TV Dividend

The New Zealand UHF television band is 518 to 806 MHz and the analogue and digital services are mixed throughout the band. The digital dividend is the spectrum in the frequency range 694-806 MHz. This spectrum will be freed up by the switchover to digital television, scheduled to be complete by December 2013. Two mobile broadband technologies likely to be implemented in New Zealand are, Long Term Evolution (LTE) and WiMAX for 4G services. Both technologies are available in frequency-division duplexing (FDD) or time-division duplexing (TDD) modes. The 700 MHz band plan options under consideration for used in New Zealand are from the European Union band plan, the US band plan and the APT band plan. “The European Union has recommended a band plan that consists of 30 MHz paired with an 11 MHz centre gap, spanning 790-862 MHz. This is not compatible with New Zealand’s digital dividend (694-806 MHz). Some countries in Africa are expected to use the European band plan. A number of countries are also interested in a band plan that has been developed by the Asia-Pacific Telecommunity (APT), as it aligns better with their potential digital dividend.” [MED 2011]

“The United States has implemented a band plan for 698-806 MHz and has begun deploying services. While it aligns with New Zealand’s digital dividend, the United States’ band plan is considered inefficient for use in New Zealand. It provides two paired spectrum holdings totaling 2x29 MHz for use nationwide, with many fragmented regional allocations, and unpaired allotments.”[MED 2011] The nationwide uplink and downlink spectrum blocks have been designed in a manner that only allows for two nationwide mobile network operators, and prevents handsets from being able to operate in both nationwide networks. The plan is also designed around 6 MHz blocks of spectrum originally used for broadcasting. These do not align particularly well with the expected carrier sizes for LTE. [MED 2011] The APT has recommended to the ITU a band plan that consists of 45 MHz paired, with a 10 MHz centre gap. New Zealand has been involved in the development of this band plan. Figure 56 shows the APT band.

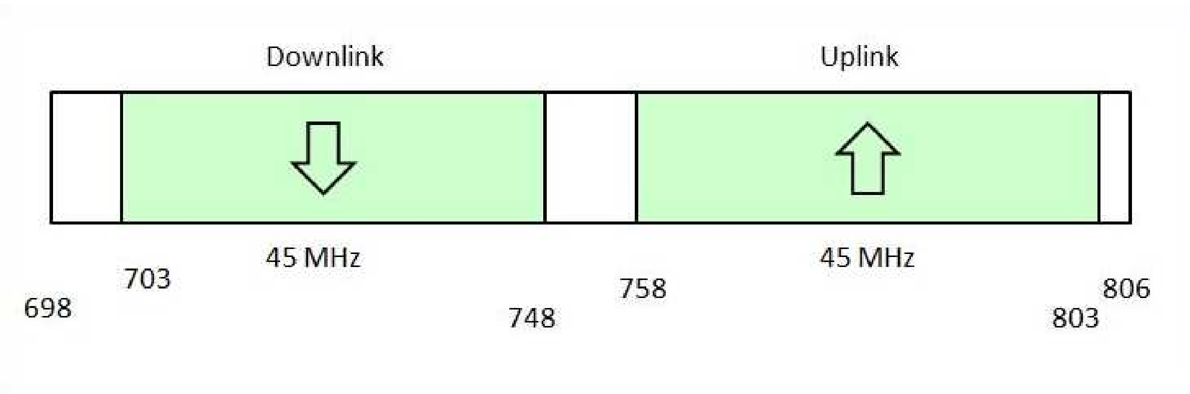


Figure 56 Asia-Pacific Telecommunity 700 MHz Freq Band adopted by New Zealand

Of the three options, this band plan offers the largest amount of useable spectrum. Due to the potential for large-scale regional or worldwide adoption, it is hoped that this plan will help drive significant economic growth in the region. However, despite strong technical support for the plan internationally, few countries have formally confirmed their support for the band plan at this stage. “There is also some initial work underway to develop an APT ‘TDD’ band plan; however, the detailed engineering work for this plan is not yet particularly advanced. It is likely to span 100 MHz from 703-803 MHz, with no centre gap. Interference between TDD operators would need to be managed, either through coordination between operators on uplink and downlink operation, or the imposition of individual guard bands between operators.” [MED 2011]

The NZ Government is interested in using the 700 MHz for public safety communications operated by agencies such as the Police, and Fire and Ambulance services (known generically as Public Protection and Disaster Relief (PPDR) services). The US has set aside freq bands in the 700 MHz block for PPDR however; Australia does not plan to make provisions for public safety organizations in their 700 MHz band plans. New Zealand does have opportunities for broadband PPDR use in other parts of the spectrum and hence harmony of the PPDR provisions with that of Australia is preferred.

The NZ Government proposes allocating the 700 MHz band as management rights for a term of slightly less than 20 years, to align with the expiry of the 850/900 MHz rights. This will allow renewal policies for all mobile cellular spectrum holdings below 1 GHz to be developed at the same time. It has decided to adopt the Asia Pacific Telecommunity (APT) 700 MHz FDD band plan, comprised of 45 MHz paired separated by the 10 MHz centre gap. [MED 2011]

Spectrum Sales and Trading

New Zealand implemented a market-based system of spectrum allocation and secondary trading in 1989. The NZ Government encourages competition consideration for new entrants into the market by the application of license provisions. A certain amount of spectrum is set aside for allocation solely to a new entrant. If allocation is not successful in the initial process, this spectrum may be reserved for reallocation to a new entrant later. Spectrum acquisition caps are tailored to ensure a minimum number of parties acquire spectrum in the allocation process. Spectrum is allocated with a provision that some rights requiring an incumbent operator to sell part of its spectrum holdings to a new entrant. In New Zealand, implementation requirements were placed on operators using the 850/900 MHz band. The implementation requirement was that the spectrum be used to provide services to at least 65 percent of the population within five years. A ‘buy-out’ option was also provided, which allows spectrum holders to pay an additional 15 percent of the original purchase price to gain an additional two years to meet the implementation requirement. These constraints were aimed at increasing competition so that a larger number of operators would still be required to invest in network expansion and improvement. [MED 2012]

NZ has defined the following spectrum auction criteria for the 700 MHz band plan. Allocation will be 2x5 MHz blocks with management rights, for the period December 2013 to December 2031 for alignment with expiry of the existing 850/900 MHz cellular band rights. A spectrum cap of 2x15 MHz will be applied, allowance for one party to achieve a 2x20 MHz block size is provided. An imposition of a 2x30 MHz cap on all holdings below 1 GHz, or a ‘sell-down’ requirement of at least 2x5 MHz below 1 GHz. [MED 2011] An imposition of an implementation requirement to provide 4G mobile broadband services to at least 50 percent of the population of market area within five years.

4.7.7.3 Comparison with the US

New Zealand is an island nation in the Pacific. It has a strong commitment to enhancing the lives of its native Maori people. Maori community elders are consulted when new technologies are introduced or enhanced in the country. Unlike the US, New Zealand is not a developer of radio service technology. It relies on its Asia-Pacific neighbors for technology leadership and follows the mandates of standards bodies like the ITU. It is new to spectrum management however; it has created a spectrum auction model for satisfying its incumbent telecommunications providers together with a means to encourage smaller competitors to enter their market.

4.7.8 Canada Spectrum

Canada is located directly north of the US, it extends from the Atlantic Ocean in the east to the Pacific Ocean in the west, and northward into the Arctic Ocean. It has a very long border with the US that influences telecommunication infrastructure decisions. It has a long tradition in radio technology going back to Reginald Fessenden who some believe was the true inventor of voice transmission over radio waves.

4.7.8.1 Radio Spectrum Policy and Regulation in Canada

The two agencies responsible for the regulation of radio in Canada are the Canadian Radio-Television and Telecommunications Commission (CRTC), and Industry Canada, Canada's Department of Industry. Spectrum policies are handled by the Office of Spectrum Management and Telecommunications with the Industry Canada organization. The division of responsibilities is largely due to history reasons. The CRTC regulates all Canadian broadcasting and telecommunications activities and enforces rules to carry out its assigned policies as set out in the Broadcasting Act. The CRTC is similar to the US FCC agency however, the Department of Industry known as "Industry Canada" is responsible for allocating frequencies and call signs, managing the broadcast spectrum, and regulating other technical issues. [CRTC 2012] The licensing method used by Industry-Canada has been to deal with applications for fixed and mobile radio facilities and assignment of frequencies on a first-come, first served basis. Spectrum auctions are held in the same way as they are in the US. Industry Canada will generally provide licensees with the maximum possible flexibility. This is in line with the FCC's definition of "exclusive rights" to the spectrum purchased. Only those limitations required for interference management purposes are be imposed; Canada does however, wish to promote competition amongst its wireless providers.

4.7.8.2 Radio Spectrum Development in the Canada

Canada's spectrum licensing process administered by Industry Canada has dealt with cases of high demand for frequencies in spectrum-congested situations, such as mobile service in the 450 MHz and 800/900 MHz frequency ranges. The 800 MHz cellular band was auctioned off with 40MHz in 1986, and 10MHz in 1991. Canada has 25.54 million mobile phone subscribers, and a 71.78% penetration rate as of September 2010. The technology provided and the number of subscribers per mobile operator is illustrated in the

Figure 57.

Operator	Technology	Subscribers (millions)
Rogers Wireless	850/ 1900 MHz GSM, GPRS, EDGE 850/ 1900 MHz UMTS, HSPA,HSPA+ (21 Mbit/s), 1700 MHz LTE	9.29
Bell Mobility	CdmaOne, CDMA2000 1xRTT, EV-DO 850/ 1900 MHz UMTS, HSPA,HSPA+ (42 Mbit/s), 1700 MHz LTE	7.37
Telus Mobility	iDEN, WiDEN, CdmaOne, CDMA2000 1xRTT, EV-DO; 850/ 1900 MHz UMTS, HSPA,HSPA+ (42 Mbit/s), LTE	7.21
6 others, SaskTel Mobility, MTS Mobility, Wind Mobile, Videotron Cellulaire, Mobilicity, Public Mobile	CdmaOne CDMA2000 1xRTT, UMTS, HSPA HSPA+	1.72

Figure 57 Mobile Communications Operators in Canada [CRTC 2012]

The wireless network covers approximately 20% of Canada's geographic area and 99% of Canadians. Wireless market sector revenues are the largest component (41%) of total telecommunications revenues. The growth rate of additional subscribers from 2008 to 2009 was 7.8%. The compounded annual growth rate (CAGR) for 2005 – 2009 was 8.8%. [CRTC 2010]

Canada has the following spectrum holdings for mobile network services as shown in

Figure 58.

Type of Spectrum	Quantity
Cellular: 824-849 MHz/869-894 MHz	50 MHz
Cellular 1670-1675 MHz	5 MHz
Advanced Wireless Services (AWS): 1710-1755 MHz/2110-2155 MHz	90 MHz
Personal Communication Systems (PCS): 1850-1915 MHz/1930-1995 MHz	130 MHz
Broadband Radio Services (BRS): 2500-2690 MHz	190 MHz

Figure 58 Spectrum holdings for Mobile Networks in Canada [CRTC 2012]

The percentage of total holdings represents spectrum assigned to each operator in Canada and is regionally weighted by population of the assigned service areas, where applicable. In 1995, Industry Canada awarded four PCS spectrum licenses using a comparative licensing process for a total of 80 MHz in the 2 GHz band (1850-1990 MHz). A simultaneous multiple-round auction was held in January 2001 and, of the 62 PCS licenses for auction, 52 were assigned. The Advanced Wireless Service (AWS) auction in 2008 made available an additional 105 MHz to the commercial mobile industry in three different bands: AWS, PCS and 1670-1675 MHz. [Industry-Canada 2001]

As part of their input to the ITU for the World Radiocommunication Conference (WRC-2000), the mobile operators identified a need for 160 MHz of additional spectrum by the year 2010 for the provision of advanced mobile services, including 3G. Canada, together with 11 other countries of the Americas, submitted a proposal that identified the 1710-1850 MHz band as the preferred band for additional spectrum for International Mobile Telecommunications-2000 known as IMT-2000, the global term for 3G.

In June 2000, WRC-2000 identified a number of bands in the International Table of Frequency Allocations as spectrum for use by administrations wishing to implement IMT-2000. The prime bands identified were (806-960) MHz, (1710-1885) MHz and (2500-2690) MHz in addition to previously identified bands (1885-2025) MHz and (2110-2200) MHz. Figure 59 shows the spectrum that has already been licensed for the wireless industry together with spectrum that has been designated for future allocation as of 2001.

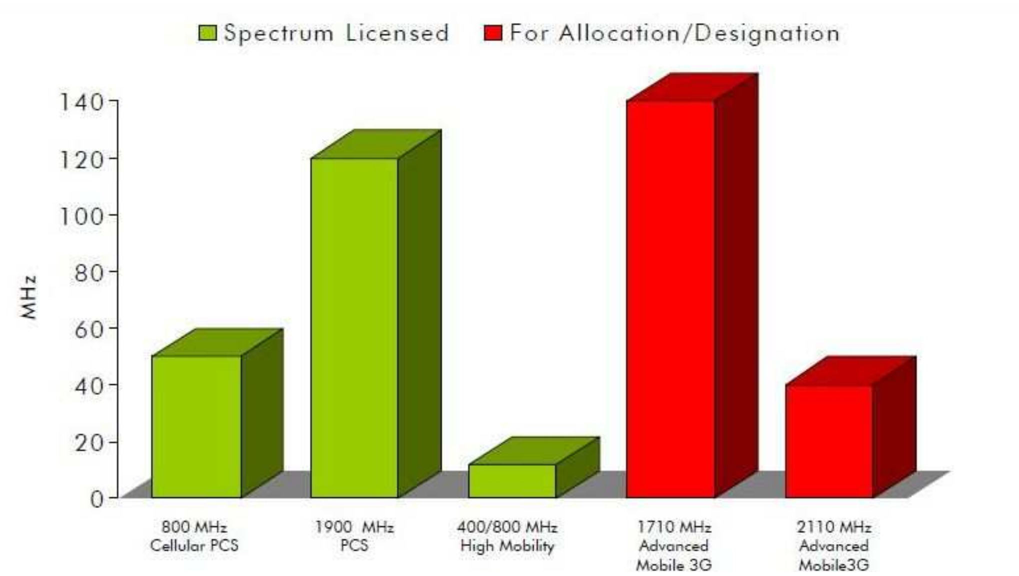


Figure 59 Canadian Spectrum Licensed Bands, and those Designated for Allocation in 2001 [Industry-Canada 2001]

The Canadian wireless industry has highlighted the importance of harmonization of mobile spectrum worldwide and especially with the US. Industry Canada tends to proceed in step with the U.S. agencies FCC and NTIA. Frequency bands designated, as spectrum for license-exempt (LE) uses are, (902-928) MHz, (1910-1930 MHz) for LE PCS services, and (2400-2483.5) MHz. The (5150-5250) MHz, (5250-5350) MHz and (5725-5825 MHz) are used by Wireless LANs. The (59-64) GHz, (46.7-46.9) GHz and (76-77) GHz are used for radar. [CRTC 2010]

Digital TV Dividend

Canada uses the following bands for analog and digital TV broadcasting, VHF Bands – (54-72 MHz, 76-88 MHz, (174-216 MHz) and UHF Bands – (470-608 MHz, 614-806 MHz). In 1997, Canada adopted the ATSC Digital Television standard for broadcast transmission to replace the NTSC standard used for analog TV broadcasting in the UHF and VHF bands. In anticipation of the digital TV (DTV) transition in Canada, Industry Canada published the first DTV Transition Allotment Plan in 1998. The DTV allotment plan relocated all UHF high power broadcasting undertakings into the frequency range 470-698 MHz. As a result, the frequency range 698-806 MHz, is available for other services and applications. All OTA analog TV broadcasting ended in August 2011 in the 31 identified mandatory markets and for those operating on channels 52-69 outside of the mandatory markets. [Industry-Canada 2010]

In June 2004, the Department issued the Spectrum Utilization Policy document, “Mobile Service Allocation Decision and Designation of Spectrum for Public Safety in the Frequency Band 746-806 MHz”, SP-746. This document established the mobile service as a co-primary service with the broadcasting service in the 746-806 MHz band. SP-746 also designated the bands 764-770 MHz (TV channel 63) and 794-800 MHz (TV channel 68) for public safety.

In June 2009, the document, “Narrowband and Wideband Public Safety Radiocommunication Systems in the Bands 768-776 MHz and 798-806 MHz”, was released, designating the bands 770-776 MHz (TV channel 64) and 800-806 MHz (TV channel 69) for public safety. A new band plan specifying the bands 768-776 MHz and 798-806 MHz for narrowband and wideband public safety communications was also included. This aligned the 700 MHz band with the United States. The use of the spectrum designated for public safety in the bands 764-768 MHz and 794-798 MHz was designated to be subject to future consultation. [Industry-Canada 2010] Industry Canada is proposing a number of options in their band plan architecture. Figure 60 shows a plan with 8 and 10 MHz channel blocks in the Lower 700 MHz band.

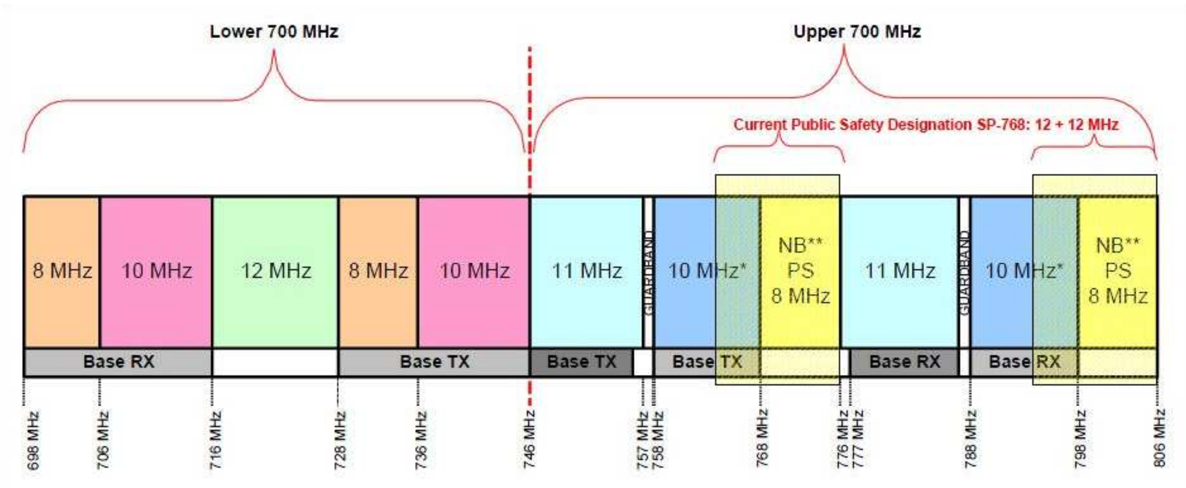


Figure 60 Adjusted US 700 MHz Plan with Larger Block Allocations [Industry-Canada 2010]

Figure 61 shows a plan with a mix of 3 and 5 MHz channel blocks in the Lower 700 MHz band.

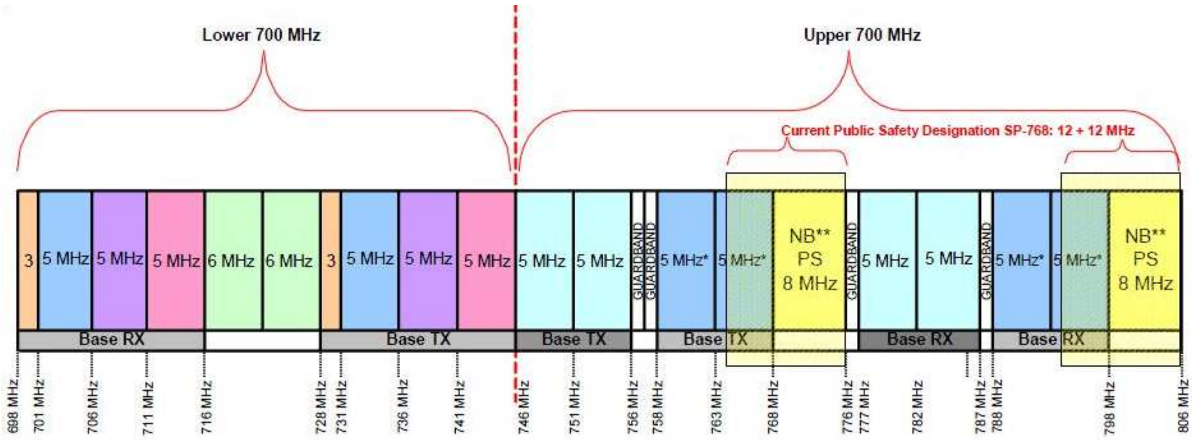


Figure 61 Adjusted US 700 MHz Plan with Smaller Block Allocations [Industry-Canada 2010]

Spectrum Sales and Trading

Spectrum licenses are transferable and can be divided and aggregated. They are issued for periods of up to 10 years. Licensees have to operate in a competitive marketplace after an auction has been completed. The Canadian government promotes a competitive post-auction marketplace by restricting the participation of certain entities in an auction or by placing spectrum caps. To date a total of 170 MHz of spectrum has been licensed to support the evolving cellular and PCS infrastructure. The current spectrum cap limit of 55 MHz is under review and may need to be increased to permit wireless carriers to acquire new spectrum resources to expand their networks. One license in the recent 700 MHz band was pre-assigned to a new entrant on favorable terms, in order to promote a new entry in a tight three-operator dominated market. [CRTC 2010] In Canada, the government in 2008 implemented rules designed to prevent new market entrants from selling their spectrum licenses to the 3 largest incumbent wireless telecoms providers (Rogers, Bell Canada, and Telus). The 10-year licenses awarded to firms that won spectrum at a government auction cannot be resold to any company that does not meet the criteria of a new entrant in the wireless industry for five years. The Canadian government has also stated that it expects the spectrum to be put into its highest productive use immediately.

4.7.8.3 Comparison with the US

Canada has adopted spectrum auctions and has a "market driven" spectrum policy model. It has a very long border with the US and hence cross-border roaming for mobile communications services is very important. Canada also wants to maintain public safety services, and radio and TV broadcast services across the border. The population density is very low at 3.4 people per sq km., this compares with US at 31.3 people per square kilometer. It has been estimated that the cost of providing broadband service to everyone in Canada is $7b (Canadian dollars) over a 10 year period. Next generation satellites and WiMax systems are seen as the best technologies available for serving the very remote communities in the North of Canada. The CRTC has set targets of providing 1 Megabit upload and 5 Megabit download broadband service for all Canadians by 2015.The 700 MHz digital dividend auction is targeted for late 2012. Bell Canada, and Rogers want an open auction for the 700 MHz band, however the smaller players such Videotron, Wind, and Mobilicity want the CRTC to impose set asides to prevent the larger operators from acquiring the most desirable frequency bands.

4.7.9 Japan Spectrum

Japan is an island nation in East Asia. It is located in the Pacific Ocean, and it lies to the east of the Sea of Japan, China, North Korea, South Korea and Russia. The Japanese people embrace new technology with fantastic enthusiasm. Japan leads the world in many areas of high technology and as such is extremely knowledgeable in the telecommunications sector.

4.7.9.1 Radio Spectrum Policy and Regulation in Japan

The Ministry of Public Management, Home Affairs, Posts and Telecommunications (MPHPT) is responsible for policy regarding frequency management in accordance with the Radio Law of 1950. The Radio Law requires equitable and efficient use of radio spectrum. The Telecommunications Council within the MPHPT sets out the vision for radio spectrum policy. The Telecommunications Bureau in the MPHPT acts as the spectrum management agency. [MPHPT 2004]

In August 2002, the Telecommunications Council launched a consultation process that led to new guidelines being published in October 2003 on spectrum re-farming. Japanese policy has focused largely on re-farming and compensation schemes. Compensation would take account of the economic costs to incumbent licensees (such as removal costs and salvage values) and use revenue from additional spectrum user fees from the new spectrum users. Spectrum user fees were introduced in 1993 based on the recovery of administrative costs. The MPHPT does not use auctions to assign licenses and prefers to use comparative selection methods. Trading of spectrum appears not to be possible in Japan. [MPHPT 2004]

4.7.9.2 Radio Spectrum Development in Japan

Japan is densely populated island nation and as such has two advantages for spectrum management. It has no land borders with other countries and hence the interference issues are all internal. Radio service coverage is excellent because the small size of the country. As of January 2012, Japan has 126,610,300 subscribers in total, a 100.68% penetration rate.

Figure 62 provides a list of the mobile operators in Japan.

Operator	Technology	Subscribers (in millions)
NTT DoCoMo	PDC, UMTS, HSDPA, LTE	59.195
au	CdmaOne, CDMA2000 1x, EV-DO	34.004
SoftBank Mobile	UMTS, HSDPA, DC- HSDPA	27.458
Willcom	PHS	4.264
EMOBILE	UMTS, HSPA+, DC-HSDPA	3.707

Figure 62 Japan Mobile Communications Operators [MPHPT 2004]

About 84% of all mobile phone subscribers in Japan have upgraded from slower 2G mobile services to 3G, and four mobile operators offer nationwide 3G services, these are, DoCoMo, KDDI, SoftBank and eMobile. The fifth mobile operator Willcom will also upgrade PHS services to a much faster next generation service to compete with 3G services in the near future. An upgrade of DoCoMo and SoftBank's services to faster HSDPA services is in progress, while eMobile from its start offered HSDPA services. Currently HSDPA services in Japan offer data speeds of up to 3.6 Mbps, and upgrades to 10 Mbps are technical possible. Starting in 2010, Japanese mobile operators have started to upgrade to LTE services. KDDI has announced to switch from the current CDMA2000-1x EVDO technology track to the LTE. [Euro Technology 2011]

Both Spectrum Management and Broadcasting in Japan is the responsibility of the MPHPT. Broadcast services are provided by the license-fee funded national broadcaster, Nippon Hoso Kyokai (NHK) and a number of commercial, advertising-funded broadcasters. NHK operates two national analog terrestrial channels and three satellite channels, which are simulcast in analog and digital format. At least four commercial terrestrial channels are available for 89% of the population. Japan has pioneered the delivery of HDTV, with commercial analog HDTV services available over satellite. The Ministry of Internal Affairs and Communications (MIC) has been reallocating the frequency bands according to the “Guidelines for Radio Spectrum Reallocation” published in October 2003 due significant congestion and previous poor spectrum management. The MIC has been very actively seeking ways of reallocating spectrum for new uses throughout Japan from the year 2000 to the present. The following examples demonstrate what has been achieved. [Mori, Takashi 2007]

70 MHz of spectrum was freed in 1.7 GHz band, 15 MHz x 22 for the whole nation and 20 MHz x 2 for the Tokyo, Nagoya, and Osaka regions. A further 15 MHz was reallocated from the 2 GHz band to TDD type 3 cellular services in 2005. Commercial dispatch radio systems use two frequency bands, 800 MHz and 1.5 MHz bands. The 66 MHz currently in use has been reduced by 22 MHz. Airport dispatch radio systems with 4 MHz-width frequency allocation in the 800 MHz band, the been moved to a 400 MHz band. Radio services used for regional disaster prevention with 6 MHz frequency block in the 800 MHz band have been moved to the 260 MHz band. [Mori, Takashi 2007] The 800 MHz/900 MHz bands have been allocated fragmentally not only to cellular systems but also to various other mobile communication systems. These frequencies have been reallocated for use of cellular systems by rectifying fragmented allocations. 2G user bands currently used by more than 60 million subscribers will be reallocated to 3G systems by the year 2012. This reallocation will change transmitting/receiving frequency intervals within the same band and switch the current high-frequency bands for terminal transmission to low-frequency bands as in other foreign countries.

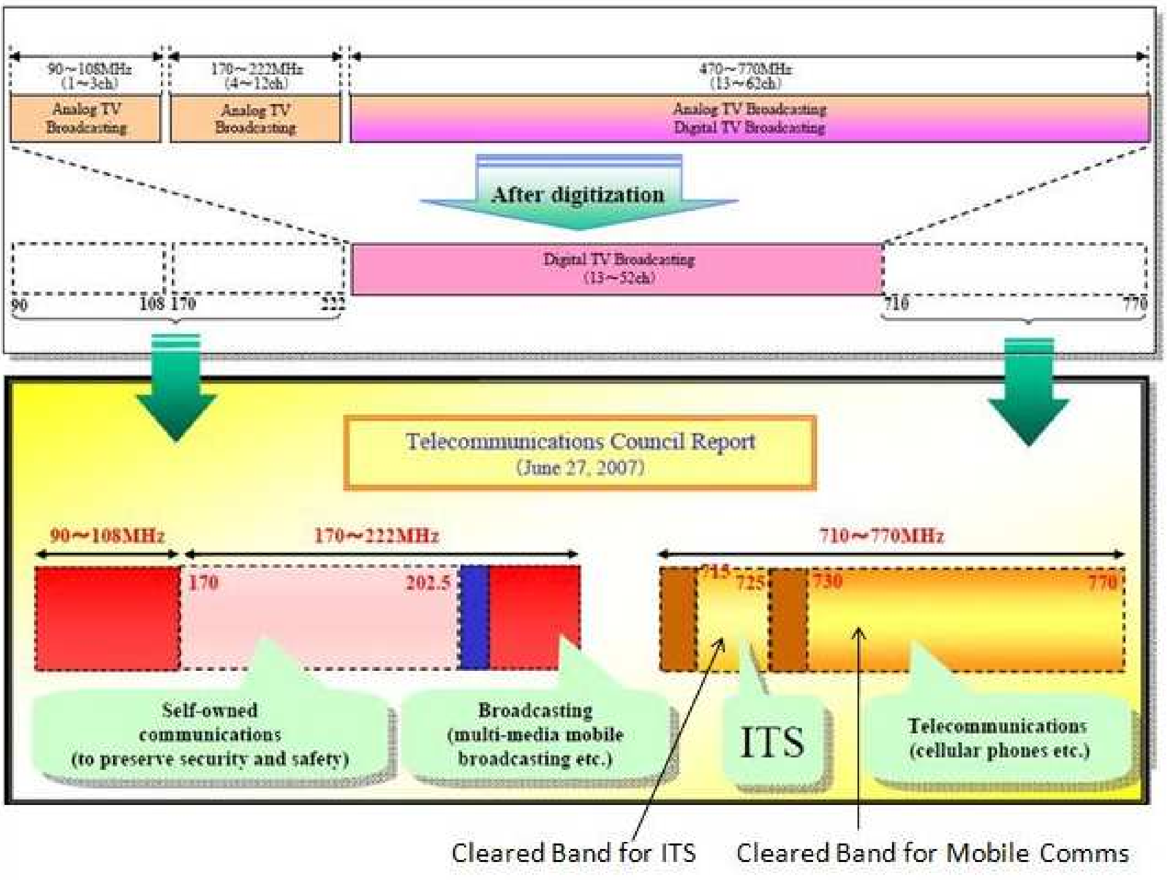
With the digitalization of TV broadcasting, the VHF and UHF bands used for analog TV broadcasting are have been reallocated. Consequently, the VHF bands (90 to 108 MHz and 170 to 222 MHz) were freed in July 2011. The 170 to 222 MHz band will be available for mobile communication services or sound broadcasting services. The UHF band (722 to 770 MHz) is expected to be free by July 2012 and will be used for land mobile communication systems. The frequency band of 710 to 722 MHz for TV broadcasting services will be reallocated for use for land mobile communication systems. The Telecommunication Council recommended that the frequencies of 715 to 768 MHz freed through TV digitalization should be used for cellular services as paired spectrum bands. The 905 to 958 MHz frequency band will be used by existing cellular services that presently use the 800/900 MHz bands. [Mori, Takashi 2007] The fixed microwave links for telecommunications businesses in the 4 and 5 GHz frequency bands (3.6 to 4.2 GHz and 4.4 to 4.9 GHz) are planned for clearance by November 2012, and the bands will be allocated to mobile communication systems. In Japan, a more flexible framework for a use of assigned frequency bands is being instigated. For example, in the 800/900 MHz bands, cellular operators are now allowed to transfer from 2G to 3G systems. Its spectrum policy relies on large-scale reallocation when new spectrum is required for new services.

Mobile Communication Systems in Japan below 5GHz have seen a large increase in spectrum demand. An additional 270 MHz of bandwidth was the shortfall in 2003. A further 340 MHz was required by 2008. A forecast of an additional 1380 MHz of bandwidth has been calculated for 2013. Major candidates for additional frequency bands for mobile communication systems are the 800MHz band, and the 1.5 GHz band currently used by Multi-Channel Access trunked radio systems. The 1.7 GHz band and 4 GHz / 5 GHz bands currently used for fixed communications systems are also candidates. Wireless LANs (mainly in 5GHz band) have seen a large increase in spectrum demand, 200 MHz bandwidth was the shortfall in 2003, 480 MHz bandwidth was the shortfall in 2008, and 740 MHz bandwidth is the forecasted shortfall by 2013. Major candidates for additional frequency bands for Wireless LANs are the 4.9-5.0 GHz band currently in use by fixed communications systems, and the 5.25-5.35 GHz band and the 5.47-5.725 GHz band currently used by radar applications. [Mori, Takashi 2007]

Frequency band reallocation for use by mobile communications operators took place in 2007. Approximately 340 MHz of bandwidth was reallocated from the 1.7GHz band for use by 3G cellular networks by moving government owned radio equipment to new frequency bands, and from the 2GHz and 2.5 GHz bands used by fixed stations. The 2.5 GHz band is being targeted for future WiMax services. The additional 1.38 G Hz will come from the following sources; UHF bands after the completion of digitalization of terrestrial TV broadcasting, the 1.5GHz band after the reallocation of the band currently used for 2G, the 3.5GHz band currently used for STL/TTL/TSL microwave applications, and the 4G/5GHz band currently used by fixed stations. The bandwidth released from the 1.5 GHz band and the 3.5 GHz band is targeted for 3G networks, and the bandwidth released from the 4G/5G Hz band is targeted for reallocation for IMT-Advanced applications.

Digital TV Dividend

The Ministry of Internal Affairs and Communications (MIC) is responsible for the Analog to Digital TV switchover in Japan. The Japanese government plans to spend 180bn Yen to fund analog to digital migration. The Government's objective is to achieve a total migration to digital by 2012, with simulcast continuing in the meantime. Frequency assignments will be changed to facilitate the rollout of digital. Japan has six nationwide analog channels and DTT was launched in three metropolitan areas in December 2003 and extended nationwide in the following three years. Analog TV broadcasting switch-off is scheduled for July 2011. All broadcasters must simulcast until then. Each DTT channel in Japan is divided into 13 segments. HDTV occupies 12 segments, while the 13th will be used for mobile devices. The UHF bands vacated by the switchover to DTT will be used for mobile communications after 2012. 130 MHz of spectrum will be made available. The MIC Telecommunications Council collected 149 proposals for new uses of frequency bands and determined it needed 810 MHz, which is over 6 times the 130 MHz that will be available. [MIC 2007] Figure 63 illustrates the partitioning of the 710 – 770 MHz band for new services as detailed in the MPHPT Telecommunications Council Report of 2007. Intelligent Transport Systems (ITS) will be allocated 10 MHz, and mobile communications will be allocated 40 MHz.



(ITS – Intelligent Transport Systems)

Figure 63 Prospective Cleared Spectrum Bands for ITS and Mobile Communications in Japan [MIC 2007]

Spectrum Sales and Trading

Spectrum allocation is currently controlled exclusively by the MIC. The MIC does not currently use spectrum auctions. As of January 2012 Japan's official statements about spectrum auction demonstrate a delay tactic. The US Department of State's IIP web site states the following "Introducing spectrum auctions: Japan will introduce a system within three years enabling commercial spectrum to be assigned by auction. Spectrum auctions will increase competitive opportunities for new entrants and new wireless technologies by improving objectivity, transparency and accountability in the spectrum-assignment process". Recently the MIC divided 45 MHz to four bands, 10MHz*3 + 15MHz for use by 3.9G cellular LTE networks because there are four incumbents in Japan, NTT DoCoMo, KDDI, SoftBank, and e-Mobile. [IIP 2012]

4.7.9.3 Comparison with the US

The Japanese are very aggressive adopters of new technology. The mobile phone subscriber penetration is greater than 100%. The Japanese government still maintains a "command and control" policy of spectrum allocation. They are very heavy consumers of radio spectrum and the rate of consumption is projected to increase from 68 MHz per year in 2008 to 138 MHz per year by 2013. The Japanese Government uses a comparative selection method to reassign frequency bands to more demanding applications. This has a disruptive affect on some telecommunications sectors however this seems to be accepted by those businesses that are affected. Currently no spectrum trading takes place in Japan, and they no use auctions. The ITU recommendations are observed and the Japanese participate in the conferences however, they set their own policies for spectrum allocation. The digital dividend from the UHF band will be used for Intelligent Traffic Systems (ITS) as well as telecommunications applications.

4.7.10 India Spectrum

India is a country in South Asia. It is the seventh-largest country by geographical area, the second-most populous country with over 1.2 billion people, and the most populous democracy in the world. It has the fastest growing telecommunications industry is the world.

4.7.10.1 Radio Spectrum Policy and Regulation in India

The Wireless Planning & Coordination (WPC) group of the Ministry of Communications in India is responsible for frequency spectrum management for both government and commercial users. WPC is divided into 3 functions, Licensing and Regulation (LR), New Technology Group (NTG) and the Standing Advisory Committee on Radio Frequency Allocation (SACFA). SACFA makes the recommendations on major frequency allocation issues, and formulation of the frequency allocation plan. [MIT-India 2012] The Telecommunication Regulatory Authority of India (TRAI) acts as an independent regulator of the business of telecommunications in the country. The main objective of TRAI is to manage the introduction of new service providers, and ensure technical compatibility between all providers.

4.7.10.2 Radio Spectrum Development in India

There were only six radio stations in India at the time of independence in 1947. India now supports fixed, mobile, and broadcast radio services. TV broadcasting which is exclusively run by the Indian government provides television coverage to over 90% of India's 900 million people. As of November 2011, India has 884.37 million mobile phone subscribers in total or a 73.44% penetration rate. [MIT-India 2012]

Figure 64 illustrates the frequency bands used by radio services in India.

Radio Service	Frequency Band
Radio Navigation	9 – 14 kHz
Mobile (Distress & Calling)	495 – 505 kHz
Broadcasting	535 – 1605.5 kHz
Maritime Mobile	2065 – 2107 kHz 2170–2178.5 kHz 2190.5 – 2194 kHz
Fixed, Mobile, Broadcasting Radio Astronomy	610 – 806 MHz
Mobile, Fixed, Broadcasting	890 960 MHz
Mobile satellite	942 – 960 MHz
Radio Location	1350 – 1400 MHz
Mobile, Fixed, Space operation, space research	1710 – 1930 MHz

Figure 64 India Radio Services and associated Frequency Bands [IDS 2009]

Mobile telephone service providers in India use GSM and CDMA technologies. The 800, 900 and 1800 MHz bands were earlier allotted to the India Military Services for their mobile communication usage. They have since been reallocated for use by commercial mobile communications providers. The top seven mobile communication providers are listed in

Figure 65.

Operator	Technology	Subscribers (in millions)
Bharti Airtel	GSM, EDGE, HSPA	174.69
Reliance Communications	CdmaOne, EVDO, GSM, HSPA+, WiMAX	149.13
Vodafone India	GSM, EDGE, HSPA+, EVDO using MTS India	146.84
Idea Cellular	GSM, EDGE, HSPA	103.99
BSNL	GSM, EDGE, UMTS, HSDPA, CdmaOne, EVDO, WiMAX Wi-Fi	96.01
Tata Teleservices	GSM HSPA+, CDMA,, EVDO, WiMAX	83.39
Aircel	GSM, EDGE, HSPA	60.95
8 Others – Uninor, MTS India, Videocon, MTNL, S Tel, Loop Mobile India, Etisalat DB Telecom, Ping Mobile	GSM, EDGE, HSPA, CDMA EVDO	69.32 for 8

Figure 65 India Mobile Communications Providers [MIT-India 2012]

GSM has 25 MHz allocated in the 900 MHz band (890 – 915 / 935 – 960 MHz) and 75 MHz in the 1800 MHz band (1710 – 1785 / 1805 – 1880 MHz). Only 15 MHz in GSM 1800 band is available because 60 MHz is still to be vacated by the Indian Defense department. CDMA has 20 MHz allocated in the 800 MHz band (824 – 844 / 869 – 889 MHz). In this 20 + 20 MHz spectrum, 14 CDMA carriers of nominal 1.25 MHz each are possible for assignment to service providers. 3G mobile services has only a total 2×5 MHz in the 2.1 GHz band which is the minimum carrier requirement for providing 3G services using wideband code division multiple access (WCDMA) technology in the 2.1 GHz band. The ITU has identified 2x60 MHz of spectrum at 2.1 GHz to 3G services using W-CDMA. Other countries provide 2x10 MHz or 2x15 MHz assignments per operator to ensure effective deployment of 3G services. [Aegis Systems 2008]

The Indian policy has been criticized for its single-minded agenda on maximizing the number of subscribers per unit of spectrum ignores the importance of spectral efficiency. To date spectrum assignment policy in India has been focused on ensuring that there is sufficient spectrum available for new entrant mobile operators and on ensuring that the existing operators maximize spectrum use. There are three times more mobile communications operators with spectrum assigned in a typical service area in India than in other countries. The average Indian operator can use only about one quarter of the spectrum available to mobile operators elsewhere in the world. Evidence suggests that, in most countries, the benefits of additional competition diminish rapidly once the number of operators exceeds four. Studies show that the Indian policy of rationing spectrum to mobile operators is restricting growth of mobile services in India. The Indian Defense organization seems to be reluctant to give up the required spectrum to improve future mobile service expansion. [Aegis Systems 2008]

Digital TV Dividend

The TRAI has set a date of December 2013 for the Analog TV switch off. It also expects that India will have fully digitized TV service by March 2015. DD, an India broadcast company is in the process of planning for up gradation of its 14 analog TV Channels transmission to digital TV transmission in the UHF Band-IV (470 -582 MHz) with 8 MHz channel bandwidth. The digital dividend resulting from analog to digital switchover is still being evaluated. [TRAI 2012]

Spectrum Sales and Trading

India has one of the most competitive mobile communications markets in the world. To illustrate the sale of spectrum frequency bands it is useful to examine the results of a recent auction. The 3G license auction in India started on 9th April 2010 and concluded on 20th May 2010, and after 183 rounds of bidding 9 mobile providers had spent $14.108 billion. This was 5 times the expectation of the Indian Government. India is divided into 23 telecom circles. A telecom circle is a cellular mobile service area in India classified by subscriber base and revenue potential. The Indian government decided to auction 3G frequency blocks in the 2.1 GHz band in 2 x 5 MHz configurations with a maximum of 5 blocks per circle. [Sinha, Pankaj 2011]

The auction was for 3G services in the 2.1 GHz band. Eligibility was defined as any entity holding a Unified Access Service (UAS)/Cellular Mobile Telephone Services (CMTS) License; or any entity having previous 3G experience whether directly or through a majority-owned subsidiary and undertaking to obtain a UAS license prior to commencement of operations. The frequency bands were 2 x 5 MHz blocks in the 2.1 GHz band with a maximum of 5 blocks per circle. At the end of 5 years from the date of spectrum allocation or grant of UAS license, the service provider needs to cover 90% of the Metro areas and 50% of the District Headquarters (DHQs) or cities in the service areas, out of which 15% of the DHQs must be rural Short Distance Charging Areas. A district is similar to a county, and a territory is similar to a state. Many Indian districts make up an Indian territory. Standalone 3G carriers will be charged 3% of Adjusted Gross Revenue (AGR) after the first year of allocation of spectrum, which is the same as the license fees paid by a 2G carrier with base spectrum of 4.4 MHz of GSM spectrum. [Sinha, Pankaj 2011] Aircel, Bharti & Reliance won 13 blocks of 2x5 MHz spectrum in 13 circles, Idea won 11, Vodafone won 9, TTSL won 9 and STel won 3 licenses. The 3G spectrum bandwidth offered in India was 2X5 MHz frequency blocks, which is much lower than offered in other countries. This has resulted in problems for the introduction of data intensive applications like video streaming and mobile television.

4.7.10.3 Comparison with the US

India is the 2nd most densely populated country in the world. Its people are technically very knowledgeable. It has created a comprehensive infrastructure of radio services that now rivals some European countries. This rapid development has made the Indian Government very aware of the need for good spectrum management. Spectrum auctions have been very successful, and have generated considerable income for the Indian Government. It has an extremely competitive mobile communications market. The India Military have traditionally believed that the radio spectrum should be controlled by them, and this has caused friction with the India Government Ministries responsible for spectrum allocation for commercial purposes. Frequency band blocks have been allocated in small quantities leading accusations of rationing. India has the opposite problem to the US; it has too many mobile operators whereas the US is dominated by two companies, namely AT&T and Verizon. Indian operators have only 25% of the spectrum available as operators in the rest of the world. There are 3X more operators to a typical market area than in the rest of the world. Eight times more capacity by "busy hour traffic/ sq km per MHz" has been measured in India's densely populated urban areas than in the rest of the world. Consolidation of the industry and more spectrum allocation would increase operating efficiency and eventually reduce prices.

4.7.11 China Spectrum

China is located in East Asia. The People's Republic of China (PRC) is a single-party state governed by the Communist Party of China. China currently has the most cell-phone users of any country in the world, and has the world's largest number of internet and broadband users. It is a totalitarian state and hence all telecommunications decisions are made by committees controlled by the PRC government.

4.7.11.1 Radio Spectrum Policy and Regulation in China

China Mobile Limited is a Chinese state-owned telecommunication company that provides mobile voice and multimedia services through its nationwide mobile telecommunications network, and is the largest of its kind, worldwide. Government control is maintained through a government-owned holding company, China Mobile Communications Corporation (CMCC). China Mobile operates a GSM network, which encompasses all 31 provinces, autonomous regions and directly administered municipalities in Mainland China and includes Hong Kong.

Ministry of Industry and Information Technology (MIIT) established in March 2008, is the state agency of the PRC responsible for regulation and development of the postal service, Internet, wireless, broadcasting, communications, production of electronic and information goods, software industry and the promotion of the national knowledge economy. [MIIT 2012] The transition to digital TV is not as advanced as it is the US and European countries. According to the Chinese government's plans, by 2010 the existing cable television in cities in eastern and middle parts of China as well as in most of cities in western parts of the country will be digitalized. By 2015, the analog TV signals within the country will be stopped.

4.7.11.2 Radio Spectrum Development in China

The MIIT has Bureau of Radio Regulation that administers the Radio Regulatory Provision of the People's Republic of China (PRC), the Provisions for Radio Frequency Allocation of the PRC, and the Provisions for Regulation of Imported Radio transmitting equipment of the PRC. The Bureau is responsible for the allotment and assignment of frequencies according to the plan. As of July 2011, Mainland China has 916.53 million mobile phone subscribers in total with a penetration rate of 65.506% over a population estimated over 1.3 billion. [MIIT 2012]

Figure 66 shows China's three mobile communications operators.

Operator	Technology	Subscribers (in millions)
China Mobile	GSM, GPRS, EDGE TD-SCDMA, TD-HSDPA TD-LTE	621.85
China Unicom	GSM, GPRS, EDGE, PHS, W-CDM (UMTS) , HSDPA, HSPA+	183.74
China Telecom	PHS, CDMA, CDMA2000, EVDO	110.94

Figure 66 China Mobile Communications Operators [MIIT 2012]

Significant growth in mobile Internet is taking place as 3G usage increases. At the start of 2010, the number of mobile Internet users reached 233 million, accounting for 60.8% of the total number of internet users. China Unicom testing its HSPA+ networks in Guangzhou, Shenzhen, and Zhuhai, which were completed in October 2009. The total number of broadband subscribers continues to grow reaching over 120 million by mid-2010. This represents the largest number of broadband subscribers worldwide and accounts for 45% net increase of the worldwide users in Q1 2010.The Internet population had reached over 400 million users by May 2010. The Chinese government wants to make it available to 50% of its 1.3 billion people population by 2015. This would be a total of over 650 million by 2015 and reaching almost 40% of the vast rural population.

China's three telecom operators continue to accelerate plans to roll out mobile TV services in order to gain market share for 3G services. All three operators are relying on the China-developed China Multimedia Mobile Broadcasting (CMMB) mobile TV standard to deliver their mobile TV services to both their 2G and 3G customers.

Figure 67 illustrates the current radio services deployed in China for dense urban areas, residential areas, and rural areas,

Wireless Application	Frequency bands (MHz)	Technology
Urban area (last 1Km connection)	1785-1805 3300-3400 3400-3430/3500-3530 5725-5850 24507-25515 / 25757-26765	TDD TDD (in trial stage) FDD FWA channel spacing is 1.75, 3.5, 7MHz FDD FWA (share WLAN frequencies) FDD FWA channel spacing is 3.5, 7, 14, 28MHz
Residential area (last 100m or 500m connection)	1800-1805 MHz and 1900-1920 2400-2483.5 5725-5850	TDD PHS or DECT (90m subscribers) WLAN, Bluetooth etc. WLAN
Rural area	406.5-409.5 460.5-462.0 / 450.5-452.0 MHz 464.1-467.075 / 454.1-457.075	TDD SCDMA FDD (25kHz channel spacing)

Figure 67 China Radio Service Frequency Table [Chang, Ruoting 2006]

China has recognized that harmonized worldwide bands for IMT are desirable for global roaming and benefits of economies of scale and have therefore decided to adopt IMT both IMT-2000 and IMT Advanced systems for their mobile communications networks. The frequency bands that China has selected from the list created at the WRC-07 conference are 450-470MHz, 1710-2025MHz, 2110-2200MHz, 2300-2400MHz, 2500-2690MHz, and 3400-3600MHz for IMT applications. It is China's intention to migrate their mobile communications networks towards full compliance with the ITU standards for both terrestrial and satellite applications. [MIIT 2012] The frequency bands in use or designated for future use for 2G and 3G cellular networks in China are listed in

Figure 68. The frequency bands for microwave point to point, and point to multi-point applications are also listed in the

Figure 68.

Communication Service	Frequency Bands
2G Digital Cellular Networks	GSM bands, 885 - 915 / 930 - 960 MHz, 1710 - 1755 / 1805 – 1850 MHz; CDMA bands, 825 - 835 / 870 - 880 MHz
3G Digital Cellular Networks	825 - 835 / 870 - 880 MHz, 885 - 915 / 930 - 960 MHz, 1710 - 1785 / 1805 - 1880 MHz, 1785 - 1805 MHz, 1880 - 2025 MHz, 2110 - 2200 MHz, 2300 - 2400 MHz
Microwave relay communications, Point to multi-point communication systems:	1427 – 1525 MHz
Microwave relay communications, Point to point relay communication systems:	3600– 4200MHz；4400– 5000MHz；5925– 7110MHz；7125– 8500MHz；10700– 11700MHz；12750– 13250MHz；14249– 14501MHz；14500– 15350MHz；17700– 19700MHz; 21200-23600MHz；

Figure 68 China Mobile Communication Service Frequencies [Lihua, Liu 2002]

Digital TV Dividend

China uses the 470-566MHz and 606-798MHz frequency bands for Analog television services. According to the provisions of State Administration of Radio, Film, and Television (SARFT), China will started digital TV broadcasting in 2010, and will halt Analog TV programs in 2015. With the approaching deadline, the pace of conversion to DTV speeds up in China. In 2009, China boasted of 174 million cable TV subscribers, including 65 million cable DTV subscribers. The allocation of UHF frequency bands freed up by the Digital TV switchover have not been publicly announced however it is likely that China will following the APT band plan.

Spectrum Sales and Trades

All allotment of spectrum frequency bands is done by the MIIT. The mobile communications providers are all state owned and hence spectrum auctions are not required and any subsequent trading does not take place.

4.7.11.3 Comparison with the US

China has the largest telecommunications and mobile communications markets in the world. China is a totalitarian state and hence does not have a free market economy however, the Government is very aggressively promoting growth in fixed, mobile and broadcast radio services especially its cellular networking sector. China still suffers from a significant “digital divide” and some of the rural population does not have radio broadcasting or telephone services. China’s big cities have mobile communications services and internet access that rival western cities. China attends ITU conferences and uses ITU spectrum management recommendations to design its radio services infrastructure. Hong Kong holds spectrum auctions and acts as if it were part of a free market economy. The Hong Kong telecommunications systems were acquired at the time of the integration in 1997. China has left the Hong Kong’s technology in place and the administration built to maintain it. Spectrum allocation is a command and control system in Mainland China while Hong Kong has a market driven system.

4.7.12 Trinidad and Tobago Spectrum

The Islands of Trinidad and Tobago gained their independence from Great Britain in 1962. It is the second richest country in the Caribbean, positioned only behind the Bahamas in income per capita. Oil and gas account for about 40% of GDP and 80% of exports. This wealth has stimulated the growth of telecommunications and cellular networks on the islands. The population of Trinidad and Tobago combined is 1,227,505 people as July 2011. The islands are 1,981 square miles in size. Trinidad and Tobago is a republic with a two-party system based on the British parliamentary system. Trinidad is split into 14 regional corporations and municipalities, consisting of 9 regions and 5 municipalities and administered by the Municipal Corporations Act 21 of 1990 and its amendments.

4.7.12.1 Radio Spectrum Policy in Trinidad and Tobago

Telecommunications Services of Trinidad and Tobago Limited (TSTT) is the largest telephone and Internet service provider in Trinidad and Tobago, and is owned by the Government and Cable & Wireless, a British telecommunications company. The Telecommunications Authority of Trinidad and Tobago (TATT) is the regulatory organization for all wired and mobile telephone services, radio and TV services, spectrum management and Internet services available on the two Caribbean islands. It provides all the licensing and registration of radio frequencies for all terrestrial stations as well as ships, aircraft and satellites. It collects all fees, investigates harmful interference issues, and test and certifies all telecommunications and broadcast equipment for use on the islands. [TATT 2012 A] It is solely responsible for the allocation, assignment or reassignment of radio frequencies. It uses spectrum auctions to distribute spectrum rights to commercial operators.

4.7.12.2 Radio Spectrum Development in Trinidad and Tobago

The country has 1.2 million subscribers in total, or a 95% penetration rate. The two mobile communications operators are bMobile owned jointly by TSTT and Cable & Wireless, and Digicel. The both provide 2G and 3G service.

Figure 69 shows the number of subscribers supported by both companies.

Operator	Technology	Subscribers(millions)
bMobile	GSM, EDGE	1.005
Digicel	GSM, EDGE	0.25

Figure 69 Cellular Operators in Trinidad and Tobago [TATT 2012 A]

A Frequency Allocation Table (FAT) is maintained for Trinidad and Tobago; it currently covers the frequency bands from 88 MHz to 5850 MHz. Allocation of spectrum for national security, commercial, private, aeronautical, maritime, public health and safety services is done as required and the FAT maintains a record of frequency bands in use. [TATT 2005] Spectrum efficiency is ensured by using a market pricing approach, employing optimization techniques, monitoring the use of frequencies assigned, and the reservation of bands to cater for expansion and new technologies. Spectrum was granted to users on an "exclusive use" basis in the past however, that did not always result in the most efficient use of the frequency bands. A condition for the trading of spectrum is that frequency band licenses have intrinsic "property rights" so that licensees may be resold, traded or parts of the spectrum could be sub-let under certain specific conditions. Spectrum re-allocation or re-assignment could result in the displacement of incumbents from particular frequency band(s) if they are required more urgently. In this case, the use of "overlay auctions", where spectrum is auctioned with incumbents present and the incumbents are given a deadline to vacate the spectrum (typically several years). TATT retains the governing right to modify or amend the FAT as deemed necessary. No compensation is provided if spectrum reassignment is deemed necessary by the government.

Spectrum pricing has two parts, the auction award price, and an annual license fee. The license fee is sufficient to cover recovery of administrative cost, the size of the frequency block, the market area, and the opportunity cost resulting from the denial of the spectrum to other users or services. TATT has instigated a flexible licensing model, and has defined three types of license, a station license, a spectrum license and a class license. [TATT 2005] A spectrum license is required for the provision of mobile, fixed wireless access, and Point-to-Point/Point-to-Multipoint systems. A station license is provided where technical parameters of the equipment/systems to be deployed i.e. antenna characteristics (gain, directivity, front to back ratios, etc), transmitter output levels, polarization, frequency, and modulation techniques, need to be maintained to predefined standards by the licensee. A class license is applied to a variety of low power, short range, mass consumer market devices that utilize specific bands of spectrum on a shared basis.

In 2008, TTAT wanted to introduce broadband wireless access (BWA) services to Trinidad and Tobago. A spectrum occupancy investigation was undertaken. BWA technologies are currently deployed today to provide broadband Internet access and voice telephony as well as subscription broadcasting services.

Figure 70 illustrates the licensing decisions made.

BWA Technology	Frequency Range of Operation	Licensing Approach
(CDMA) 450	410 – 430 MHz, 450 – 470 MHz	Insufficient spectrum required moratorium on licensing for 400 MHz band
Multichannel Video Distribution and IP Services	698 – 746 MHz	3 spectrum blocks assigned by auctions 2007 and 2009
WiMAX	2300 - 2360 MHz	Cleared for public telecommunications and broadcasting services.
Wireless Fidelity (Wi-Fi)	2400 – 2483.5 MHz	Class licenses only in this band
WiMAX	2495 – 2690 MHz	2 new users via reallocation exercise in 2008
WiMAX Fixed Wireless TDD and FDD	3400 – 3600 MHz 3600 – 3800 MHz	Insufficient spectrum for new users, incumbent users have 1 year to give up spectrum in excess of the spectrum cap.
Wi-Fi WiMAX	5150 – 5250 MHz 5470 – 5725 MHz, 5725 – 5850 MHz	Class licenses only in this band Cleared for public telecommunications and broadcasting services.
Multichannel Video Distribution and Data Services (MVDDS)	12.2 – 12.7 GHz	12 spectrum blocks allocated in 2007, no spectrum available for new users
Local Multipoint Distribution Service (LMDS)	25.35 – 28.35 GHz	No assignment of spectrum blocks provided

Figure 70 Spectrum Provisioning for Broadband Wireless Access Service [TATT 2012 B]

The frequency band 698 – 746 MHz is identified as a sub-allocation in the FAT's 614 – 806 MHz band. The radio communication services allocated to this band are broadcast services on a primary basis, fixed, and mobile services on a secondary basis. This follows the ITU Region 2 Table of Frequency Allocations recommendations. TATT made provision for Multichannel Video Distribution services in the 698 – 746 MHz band in accordance with ITU recommendations. The ranges 704 – 716 MHz and 740 – 746 MHz were assigned for use by BWA users via an auction held in October 2007.

Digital TV Dividend

The Television Broadcasting Sector of Trinidad and Tobago is following its ITU Region 2 neighbors in North America. The band plans and standards previously adopted in Trinidad and Tobago originated from North America, as well as the equipment used in deploying broadcasting stations. The digital TV switchover in the US and Canada enabled the reallocation of television channels 52 – 69, i.e. 698 – 806 MHz to Fixed and Mobile services in addition to the current Broadcasting Services allocation. In the USA, channels 52 – 59, i.e. 698 – 746 MHz known as the Lower 700 MHz band have been reallocated to commercial Fixed and Mobile Services. The remaining channels 60 – 69, i.e. 746 – 806 MHz known as the Upper 700 MHz band have been allocated to public health and safety services, as well as Fixed and Mobile Services. [TATT 2008) TATT has not completed its assessment of the quantum of spectrum in the Upper 700 MHz Band that should be allocated towards public health and safety services in Trinidad and Tobago. The Lower 700 MHz band has been considered for assignment to new spectrum users. The Spectrum Cap for the Lower 700 MHz band was set at 24 MHz, equivalent to four (4) spectrum blocks of 6 MHz each. [TATT 2008)

A Digital TV service using the DVB-T standard has been launched by Green Dot Ltd. in Trinidad and Tobago. Green Dot has deployed the Harmonic IP-based headend system at St. James, Trinidad. A headend is a cable television signal reception facility. The Green Dot TV service is then sent from the headend to a mountaintop tower via IP microwave link and then transmitted over the Islands. The service has been tailored to be usable with the Islands NTSC receivers. Set top boxes for DVB-T in 6MHz channels using MPEG-4, H.264 AVC decoding and outputting NTSC video has been provided to all Green Dot subscribers. Currently 50 services are being broadcast using four 6MHz multiplexes. Trinidad has a population of 1.3 million people and 350,000 TV households. It is currently covered by cable with 120,000 subscribers and satellite by Direct TV with 12,000 subscribers. The DVB-T DTT service covers 80% of the country. [DVB 2009] The digital TV switchover from OTA analog TV broadcast service to a DTV standard like DVB-T is still in the planning stage.

Spectrum Sales and Trading

In 2005, an auction of spectrum blocks for the introduction of additional public domestic mobile telecommunications was conducted**.** Bidding took place for spectrum blocks in the 850 MHz band (824 – 894 MHz) and 1900 MHz (1880 – 1990 MHz) bands. Two concessions were awarded; Digicel Trinidad and Tobago Limited's winning bid amounted to US$15,756,003 and LaqTel Limited's was US$9,300,007. [TATT 2012 B] On October 5 2007, an auction of spectrum blocks for the provision of Broadband Wireless Access (BWA) services was held. Bidding took place for spectrum block in the Lower 700 MHz (698 – 746 MHz), 12 GHz (12.2 – 12.7 GHz) and 28 GHz (25.35 – 28.35 GHz) bands. In the 12 GHz band, the winning bidder was Telstar Cable System Limited, who won all twelve (12) blocks in this band at TT$ 650,000.00 (US$101,500) per block per annum. The annual license fee was TT$ 7.8 million (US1.22m) per annum. In the Lower 700 MHz band, the winning bidder was Green Dot Limited, who won three (3) blocks in this band at TT$ 177,000.00 (US$27,700) per block per annum. The annual license fee was TT$ 531,000.00 (US$83,000) per annum. In the auction of spectrum blocks in the 28 GHz band, there was no winning bidder and no award was made. [TATT 2012 B] On April 3, 2009, a second BWA auction was conducted for spectrum blocks in the 2.3 GHz (2.3 – 2.36 GHz) and 2.5 GHz (2.5 – 2.69 GHz) bands, along with the spectrum remaining in the Lower 700 MHz band from the first BWA auction. Similar license fee prices to the October 2007 auction were collected at this auction, and it is presumed that an additional 6 MHz block was made available in the Lower 700 MHz band.

4.7.12.3 Comparison with the US

The island community of Trinidad and Tobago is a member of the Caribbean Telecommunications Union (CTU). In September 2004 the CTU Secretariat to established a Caribbean Spectrum Management Task Force to review the spectrum management policies and make recommendations for spectrum use in the region. The findings of the task force were published in a document, called the "Caribbean Spectrum Management Policy Framework" in October 2007. [CTU 2007] This diversity of the nations in the Caribbean gives rise to a number of constraints. Some of the challenges include, lack of trained personnel, varied legal and regulatory frameworks, lack of central coordination, and insufficient financial resources. The document defines a set of policy framework objectives to ensure that Caribbean telecommunications markets operate effectively to offer Caribbean citizens affordable access to the full range of telecommunications services available from wireless technologies. The US and Canada have a strong requirement for harmonization of services across its very long border, however the Caribbean communities have an even greater challenge coordinating radio spectrum dependent services across islands stretching across 2000 miles. They are organized as approximately 30 territories however; they suffer from a lack of political stability. Trinidad and Tobago however have one of the most sophisticated regulatory structures in the region.

4.8 Real-time Spectrum Measurement

The U.S. Government is investing in research and development to develop spectrum-sharing technology. Programs such as the National Science Foundation NSF NeTS-Pro-WIN Program and the DARPA XG Program are prime examples. Spectrum occupancy analysis is required so that the utilization of frequency bands can be fully evaluated. The type of information required is:

- Which bands have low utilization and which bands have high utilization?
- How the spectrum is being used (what types of modulation schemes, data rates, equipment characteristics, where, when, mobile or fixed …)?
- What are the existing user's aggregate equipment parameters (signal bandwidth, modulation, power levels, etc)?
- The spectrum occupancy gap width and duration statistics
- The number and location of transmitters in each band
- The background noise level

These parameters are critical to developing cognitive radio (CR) algorithms for dynamic spectrum sharing. Some of the parameters come directly from inspection of spectrum data, and others need to be interpreted using models, hypothesis, observations and investigations. Spectrum occupancy studies have been sponsored and organized by scientific groups such as Crowncom in Sweden, IEEE Vehicular Networking Conference (VNC), as well as NSF, and DARPA sponsored by the US Government. Programs are also conducted by academic institutions, WPI, Illinois Institute of Technology (IIT), Stevens College of Technology and many more. Research conducted by WPI is done at the Wireless Innovation Lab that was founded and organized by Professor Wyglinksi. The following four studies provide a sample of spectrum occupancy measurement work undertaken:

- Spectrum Occupancy Measurements Chicago, Illinois November 2005 for the NeTS-ProWIN project called "Wireless Interference: Characterization and Impact on Network Performance" and conducted by SharedSpectrum Co. of Vienna Virginia.
- A Quantitative Assessment of Wireless Spectrum Measurements for Dynamic Spectrum Access, by Srikanth Pagadarai and Alexander M. Wyglinski from WPI was presented at the 4th International Conference called Crowncom 2009.
- Wireless Spectrum Characterization and Dynamic Utilization in Vehicular Communication Networks by Srikanth Pagadarai and Alexander M. Wyglinski from WPI for the Toyota InfoTechnology Center Co., Ltd.
- Feasibility Analysis of Vehicular Dynamic Spectrum Access via Queuing Theory Model, by Si Chen, and Alexander M. Wyglinski from WPI together with Rama Vuyyuru and Onur Altintas from the Toyota InfoTechnology Center Co. presented at VNC 2010.

4.8.1 Spectrum Occupancy Measurements by SharedSpectrum Co.

Spectrum occupancy measurements were performed by Shared Spectrum Company in conjunction with the Wireless Interference Lab of the Illinois Institute of Technology in Chicago, Illinois on November 16 to 18, 2005. This site was intentionally selected as an urban setting with a presumed high level of wireless activity. The goal for the Chicago measurements was to gain a better understanding of the actual utilization of spectrum in this dense urban environment with the potential to identify spectrum bands with low occupancy. The research was funded by the National Science Foundation (NSF) under its Computer and Information Sciences & Engineering organization and specifically its NeTS-ProWIN program. [McCloskey, McHenry 2005] Figure 71 shows a summary of the Spectrum Occupancy in each band in New York City and Chicago.

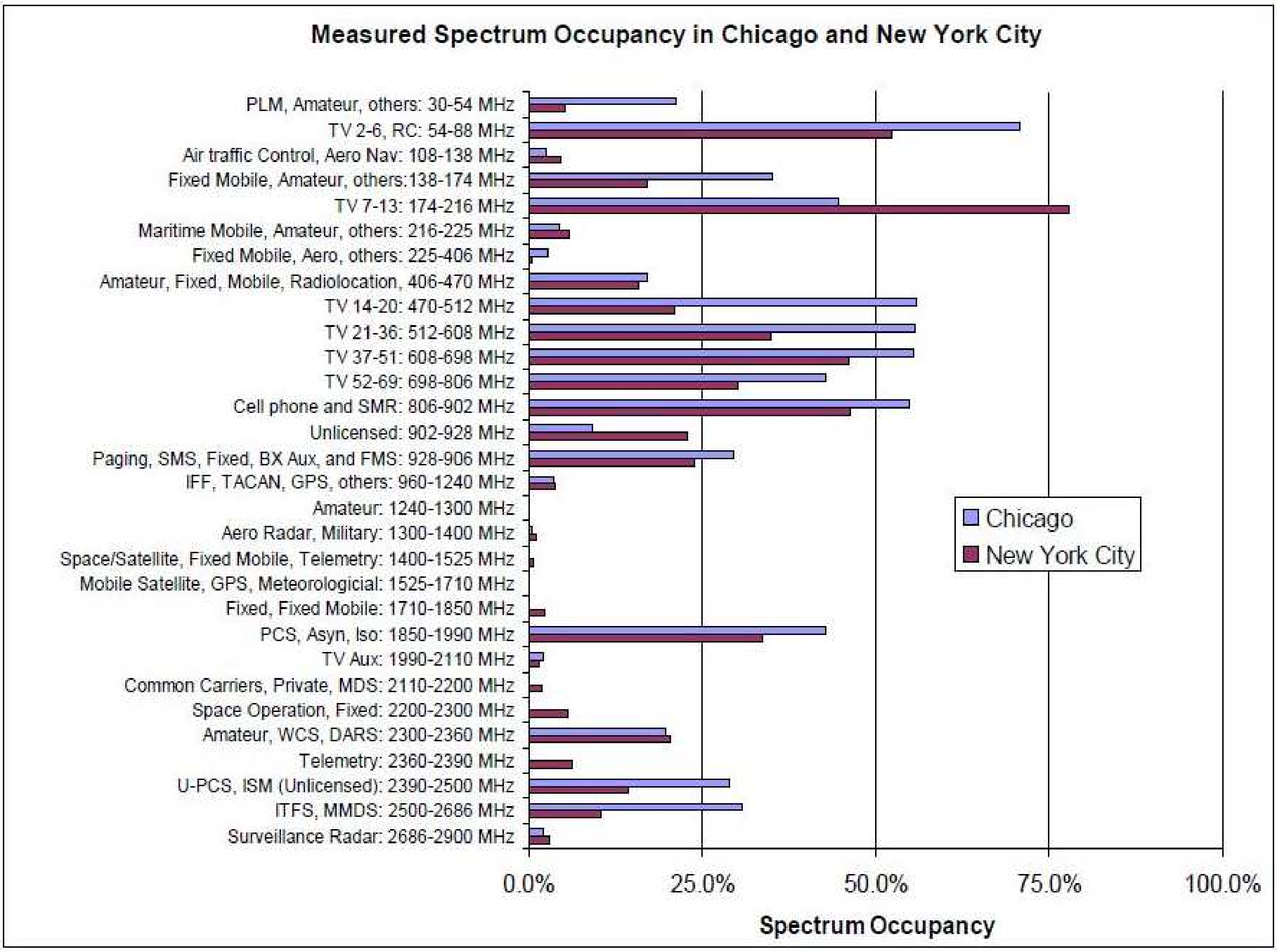


Figure 71 Spectrum Occupancy Chicago and New York [McCloskey, McHenry 2005]

Tables showing the results of spectrum occupancy measurement for the cities of Chicago and New York are found in the Appendix. Figure 72 shows “white space” in the 700 MHz band due to the TV Broadcast Interference Guard bands.

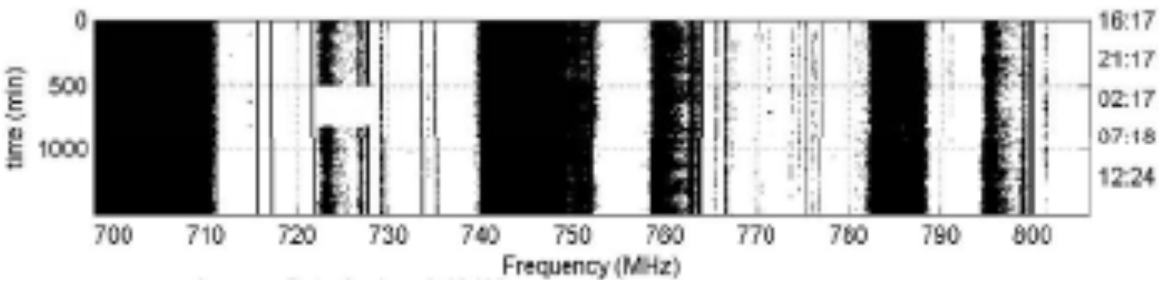


Figure 72 Spectrum Occupancy in 700MHz Band showing White Spaces [McCloskey, McHenry 2005]

Chicago has a higher spectrum occupancy rate at 17.4% than New York City, at 13.1%. In general, the band occupancy in each location is similar. Chicago had a higher occupancy than New York due to differences in TV band use and in the 1850-1990 MHz Personal Communications Service (PCS) band. These measurements show clearly that large portions of the spectrum between 30 MHz and 3 GHz are underutilized. The analog TV bands indicate the highest occupation at about 40%. This reflects peak evening TV viewing. Figure 72 illustrates white space in the 700 MHz band indicating the analog TV interference bands that are not used.

4.8.2 Quantitative Assessment of Wireless Spectrum Measurements for CrownCom 2009

This study provided a qualitative assessment of the spectrum usage across five geographically separated sites in four mid-size metropolitan centers located in the United States. Specifically, the variations in spectrum occupancy across space, time and frequency were investigated and compared between different sites within the city as well as with other cities. Large variations of spectrum occupancy at different locations within the same city were demonstrated. Measurements were made at 5 sites for each of the four cities, Rochester NY, Buffalo NY, Pittsburgh, PA and Worcester Ma. Figure 73 shows the percentage occupancy for the city of Rochester in the PCS band. From the figure, it is clear that at Site 4, the spectrum occupancy is considerably higher when compared with the other sites in the frequency ranging from approximately 1940 MHz to 1990 MHz. [Pagadarai, Wyglinski 2009 A]

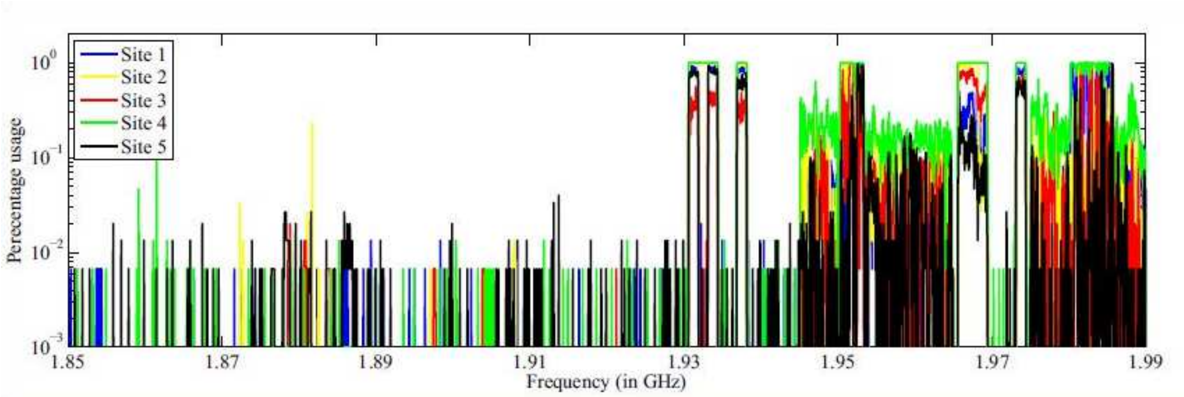


Figure 73 Percentage usage of 40 kHz channels across 5 different locations in the PCS band [Pagadarai, Wyglinski 2009]

4.8.3 Wireless Spectrum Characterization for Toyota 2009

The goal of the project was to characterize DTV spectrum over several locations on Interstate I-90 highway in the state of Massachusetts. Given the mobility aspect of a vehicular communication network, the spectrum occupancy across a range of frequencies starts becoming a time-varying phenomenon due to vehicles either moving into or out of range of a TV broadcasting site. Consequently, it is necessary to devise a quantitative model that accurately characterizes the spectrum occupancy behavior of a DSA-based vehicular communication network. It was observed that the number of available channels for secondary usage decrease as a mobile White-space device (WSD) goes from western MA towards Boston due to the increasing number of TV channels allocated to TV stations. Clearly, since the vehicular traffic is going to be high in a metropolitan area like Boston, a conflicting scenario arises. A larger bandwidth is available for vehicular communications in areas with fewer vehicles, and less bandwidth is available for vehicular communications in areas with more vehicles per mile. The total available bandwidth for secondary usage measured at different locations along I-90 in the state of Massachusetts is shown in Figure 74 below. The contiguous bandwidth available to white-space devices decreases from the western part of the state to the eastern and part of the state with a higher density of population. [Pagadarai, Wyglinski 2009 B]

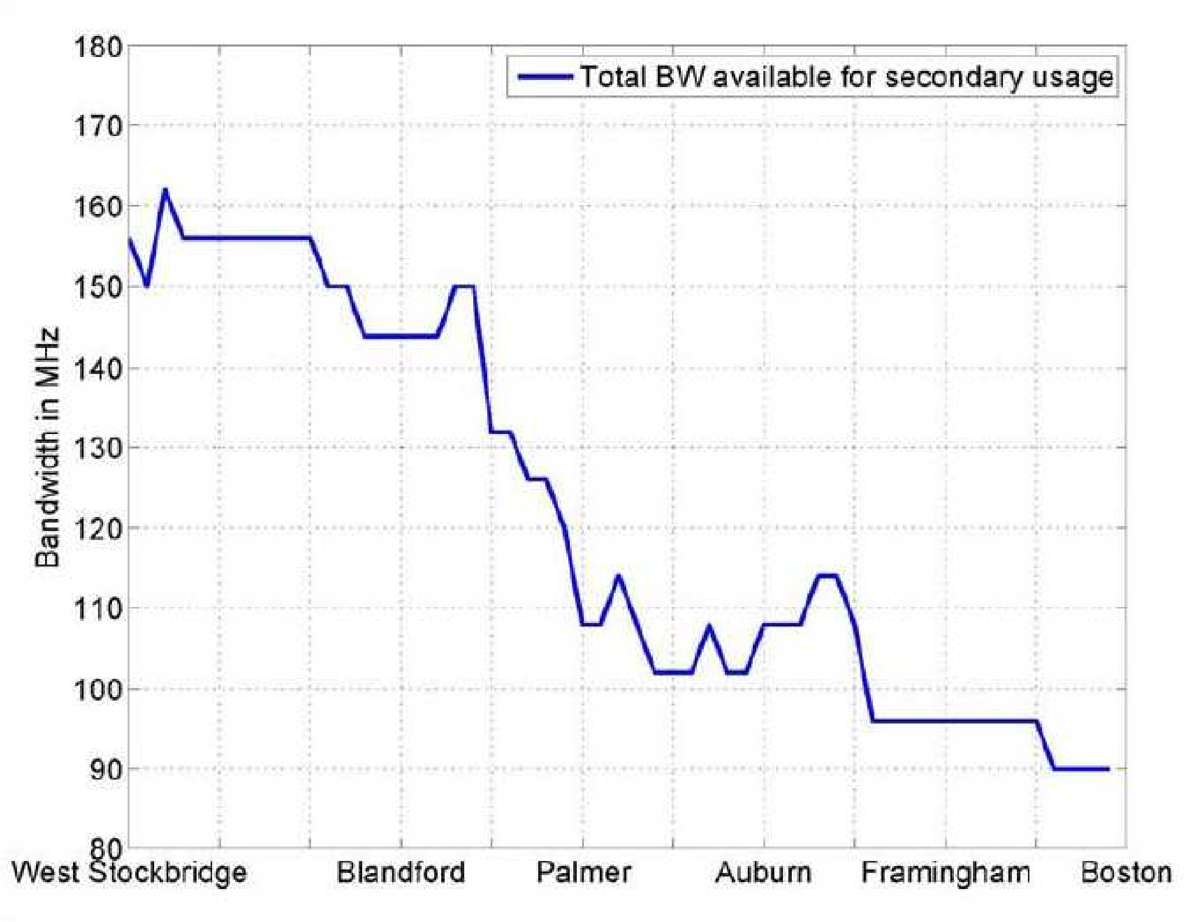


Figure 74 Total Available Bandwidth for Secondary Usage at Different Locations along I-90 [Pagadarai, Wyglinski 2009]

4.8.4 Feasibility Analysis of Vehicular Dynamic Spectrum Access for VNC 2010

This study provided a feasibility analysis for performing vehicular dynamic spectrum access across vacant television spectral channels via a queuing theory approach. Vacant TV channels were modeled as a multi-server queuing system in which available servers represent vacant channels. The servers become unavailable in a time/location-varying fashion such that they represent spatially occupied TV channels. The FCC allocated 75 MHz of spectrum in the 5.9 GHz band for dedicated short-range communications

(DSRC) to be used by Intelligent Transportation Systems (ITS). It is expected that vehicular communications will become more popular in the future, resulting in a significant increase in the spectral bandwidth required by these applications. In order to utilize vacant UHF TV channels for vehicular communications, all vehicles must follow the rules defining TV band devices (TVBDs). The study used information gathered in the VNC 2009 exercise where a geo-location database approach was used to create a spectral map of available channels. The results of applying a queuing model to the vehicles traveling along I-90 in the state of Massachusetts were presented, showing that in most rural and suburban areas, vacant TV bands are a feasible resource for vehicle communications similar to that defined for DSRC systems. [Chen et al 2010]

4.9 Expanding Wireless Broadband in Rural America

Rural America comprises the largest portion of the population with no broadband, and those with poor broadband access, which is defined by the FCC as < 4 Mbps. The Census Bureau identified 7,035,613 US homes as having either no, or poor broadband access. [NTIA 2012 A] This is no surprise since national carriers have determined that broadband capital investment is not economic in regions with low-density populations that are socio-economically depressed. The FCC in its National Broadband Plan defined objectives to stimulate deployment of broadband facilities in communities with no, or poor broadband access. Studies have been conducted that show significant economic benefits of broadband access to rural communities. Wireless operators are reluctant to provide coverage in rural areas and hence incentives have been identified by the FCC to persuade them to provide the necessary broadband services to these communities. The FCC conducted spectrum auctions in the 700 MHz band. The two largest carriers AT&T and Verizon have since acquired parts of the 700 MHz band, however their proposed usage of the band subsets will not interoperate with each other. The rural cellular association (RCA) is lobbying congress to restrict the power and influence of the big two providers AT&T and Verizon so that smaller providers can maintain their competitive edge and rural communities can have more broadband service options. [RCA-USA 2012]

One of the basic objectives of the Broadband Technology Opportunity Program (BTOP) and of the Broadband Initiatives Program (BIP) is to stimulate deployment of broadband facilities in rural communities. BTOP is administered by the NTIA, and BIP is administered by the USDA. It is assumed that the desired coverage goals will come from a combination of the investment of the private sector, primarily rural carriers, and government stimulus, such as the BTOP and the USDA Broadband Loan programs. Carriers have acquired 700 MHz spectrum to deliver broadband services in their footprint, however interoperability with service providers operating in other bands exist. This has caused considerable delays in the deployment of wireless infrastructure in rural areas. The FCC has yet to resolve these issues because they involve the political lobbying power of the two most powerful carriers namely AT&T and Verizon. [RCA-USA 2012]

The FCC’s policy of auctioning off spectrum to the highest bidder does not fully realize the FCC’s goal. By making spectrum the exclusive property of a company, the FCC cannot control how that spectrum is used. The new spectrum’s owner is fully capable of rolling out a new mobile communication service that is not necessarily aligned with the American public interest. Companies that own spectrum are not driven by a desire to improve the public’s telecommunications. This means that by auctioning off spectrum in this manner, the FCC is not aiding the evolution of mobile technology and it is not improving mobile broadband access coverage across the nation. [RCA-USA 2012] Others argue that the revenue generated by the spectrum auctions can be used to reduce the “digital divide” in the US and build new broadband services in rural and under-populated areas.

4.9.1 Broadband Initiatives Program

The Broadband Initiatives Program (BIP) was established in response to the American Recovery and Reinvestment Act of 2009 (Recovery Act). The primary goal of the Recovery Act was to provide a fiscal boost to the nation during the economic crisis. BIP funding for loans, grants, and loan/grant combinations has assisted the expansion of broadband services across rural America. By September 30, 2010 there were 320 awards made for a total of $3.529 billion. There were 285 last-mile projects for a total of over $3 billion, 12 middle-mile awards totaling $172.6 million, four satellite awards for $100 million, and 19 technical assistance awards for over $3.4 million. [USDA 2012] Awards were made in 45 states and 1 Indian Territory.

The awards have provided broadband access to 2.8 million households, 364,000 businesses, and 32,000 anchor institutions across more than 300,000 square miles. The projects created more than 25,000 jobs and contributed to the long-term economic development of rural community where a broadband project was launched. [USDA 2012] Most of the projects have used fiber optic cabling rather than wireless networks due to the FCC not wishing to apply socially beneficial conditions at spectrum auctions. Germany's recent auction of 800 MHz spectrum as well as other bands limited the holders of 900 MHz spectrum to bid for only two 10-MHz blocks, while other incumbents could bid for three and new entrants could bid for four. [Cramton, Peter 2010] The FCC has indicated that increased competition is one of its goals in the National Broadband Plan however; they seem reluctant to enforce it.

4.10 Sharing Spectrum Usage Rights

Government regulators cannot assess the merits of competing firms' business plans properly, and hence an auction forces executives ''to put their money on the table," when they make their bids. The difficulty of specifying and evaluating criteria for an auction makes it a time-consuming, and a hidden process that leads to political and legal controversy. It can also lead to the perception of favoritism. An auction held in April 2000 held in the UK raised a staggering 22.5 billion pounds, or $34b to support the public finances. It yielded about 2.5 percent of the UK GNP, or enough money to build 400 new hospitals. [Klemperer, Paul 2002] Spectrum auctions do not encourage competition and hence are not entirely in the public interest. Smaller companies cannot compete with mobile giants like AT&T and Verizon, and have to be content with picking up the less desirable spectrum bands. The FCC is considering changes to the way spectrum is auctioned such as modifying the usage rights of winning bidders to encourage competition.

4.10.1 Spectrum Usage Regimes, Exclusive and Shared

Large telecommunications companies are taking advantage of the system in order to maintain their market dominance. The way spectrum is viewed needs to change in order to encourage market-based allocation and innovation. Spectrum owners have exclusive property rights to their spectrum in a similar way to real estate. Like real estate, spectrum can be divided, aggregated, resold, and reallocated in any form the owner wishes. [Ryan, Patrick 2005] Strict requirements on services and communications technologies were typically inherent in earlier FCC licensing regimes. The TV broadcast industry is a good example. TV broadcasters are required to provide services directed towards the public interest of the community such as free TV channels as well as conforming to extremely detailed transmission regulations. The FCC does not impose similar requirements on the successful bidders in the spectrum auctions. Many people are calling for better market oversight in the spectrum allocation procedures but there is another option to spectrum auctioning. Advocates of the "Open Spectrum" philosophy believe that the current technology has outgrown the need for government licensing of frequencies and spectrum property rights. They believe that spectrum should be a common resource available for everyone to use but not owned by any one company. [Ryan, Patrick 2005] The Internet is "net-neutral", there are no restrictions imposed by Internet service providers (ISPs) or the United States government on consumers' access to networks that participate in it. Many people believe that the next step in spectrum evolution is to introduce "net-neutrality" to spectrum. There are numerous advocates of an "open spectrum" where the present exclusive spectrum ownership rights held by companies such as AT&T and Verizon are removed. This approach has been called "spectrum commons" [GAO 2004]. The concept regards the radio spectrum as a common resource rather than a piece of real estate.

The spectrum exclusive rights model is often criticized for potentially leading to artificial scarcity of available spectrum because of the high prices demanded. The spectrum auctions tend to attract large corporations with deep pockets. The same corporations may even purchase the spectrum blocks to keep them out of the hands of their competitors. This creates a spectrum warehousing effect that delays the deployment of it in new networks and slows the evolution of new technologies. Large companies often adopt these tactics when a new potentially disruptive technology is being proposed by the industry. [Ryan, Patrick 2005] The disruptive technology is viewed as a threat to existing networks solutions because its deployment would drive down the price of the older network services already in place. Under US law, the spectrum is not considered as the property of the private sector nor of the government. It is the property of the American people. The FCC has been trying to satisfy advocates of an open spectrum by creating a task force to examine the advantages and disadvantages of a commons model for radio spectrum. [Werbach, Kevin 2002]

4.10.2 FCC Spectrum Policy Task Force

The FCC has set up a Spectrum Policy Task Force and a Spectrum Rights and Responsibilities Working Group from members of its own staff. The Working Group examined the comments filed in response to the Public Notice issued by the Task Force on June 6, 2002. The Spectrum Policy Task Force held a Public Workshop on Spectrum Rights and Responsibilities on August 9, 2002, in which law professionals, economists, engineers, and other experts drawn from various segments of the telecommunications industry and the academic community participated. The working group's objective is to create theoretical spectrum rights models and document the advantages and disadvantages of various licensed and unlicensed approaches. They have evaluated the technical needs of commercial as well as government organizations. It categorized the FCC's policy as three usage models, these are Command-and-control, Exclusive use and Commons or Open Access. [FCC 2002]

The "Command-and-control model" is described as the traditional process of spectrum management in the United States. This model governs most of the radio spectrum within the Commission's jurisdiction for instance the public Safety spectrum. This model allocates and assigns frequencies to limited categories of spectrum users for specific government-defined uses. The users of the spectrum do not have extended rights to the spectrum. The spectrum is owned by the government.

The "Exclusive use model" is a licensing model in which a licensee has exclusive and transferable rights to the use of specified spectrum within a defined geographic area. Spectrum that is governed by this model has flexible use rights that are governed primarily by technical rules to protect spectrum users against interference. Under this model, exclusive rights resemble property rights.

The "Commons model" also known as the Open Access model allows unlimited numbers of unlicensed users to share a certain bandwidth of spectrum. Transmissions are governed by technical standards or etiquettes, but no operator has right to protection from interference from another operator. Spectrum is available to all users that comply with established technical "etiquettes" or standards that set power limits and other criteria. The main goal of these standards is to avoid potential interference between users. [Ryan, Patrick 2005]

4.10.3 Current FCC Spectrum Policy Models

In most bands, the FCC has historically used variations of the traditional command-and-control approach to define spectrum rules and allocation. These rights often specify very narrow uses and limitations on the spectrum. The FCC has developed rules for an "exclusive rights model" spectrum, as well as rules for a "commons model" spectrum. The mobile communications industry has enjoyed the advantages of the exclusive rights model however; there still exists a confusing set of rules, regulations and limitations. This is the result of historical petitions, and actions taken by government regulators made over the last 100 years. [FCC 2002] The 902-928 MHz band is a block of spectrum in which a number of licensed services as well as unlicensed users operate. A series of specific regulatory decisions made over time has resulted in a complex hierarchy of users subject to significant restrictions. The band contains a number of different users. One such type of user is the Location and Monitoring Service (LMS) systems user. The LMS systems are permitted to use these bands provided they do not interfere with the operation of the Government stations and the industrial, scientific, and medical (ISM) devices that are authorized in these bands. In addition to the LMS systems, the ISM devices and the Government stations on the spectrum there are also amateur users in these bands. Stations in the Amateur service must tolerate any interference from the operations of ISM devices, LMS systems, and the operations of Government stations authorized in this band.

The most successful application of the "exclusive use" approach is the broadband Personal Communications service (PCS). This service operates in the 1850-1910 MHz and 1930- 1990 MHz bands. The PCS rules follow the "exclusive use" model quite closely. The FCC granted the PCS licensees rights to large blocks of spectrum and allowed substantial flexibility in terms of technology and usage rights. These rights are only subject to interference parameters to protect neighboring geographic areas and adjacent spectrum blocks. Unlike the "pure" exclusive use model, the PCS rules do not allow total flexibility of use.

The FCC has also applied rules to several spectrum bands that resemble the commons model. For example, the 2.4 GHz band (2402-2450 MHz) is used on an open access, unlicensed basis. Thousands of unlicensed consumer and industrial devices, including cordless phones, microwave ovens, and wireless LANs such as those using 802.11b and Bluetooth technology use these bands without owning the spectrum. The FCC did not anticipate the proliferation of Wi-Fi when it developed rules for this spectrum, but the open access and technical flexibility defined by these rules has not stifled innovation. The primary constraints on transmitters on the 2.4GHz band are the limitation of "Part 15" devices to very low power. "Part 15" refers to those devices that are regulated by the FCC Code of Federal Regulations, Title 47, Part 15 (47 CFR 15) for unlicensed transmissions. [FCC 2002] The popularity of the unlicensed 2.4 GHz band shows that a commons-type usage model for some spectrum does work well for many types of devices. The types of equipment used in this model must be registered and operate under certain rules such as those regarding primary use rights and equipment standards.

An examination of the flexible exclusive use and commons models as they have been applied to date suggests that each model has led to different types of technical and economic efficiencies. In broadband PCS, for example, licensees have developed centrally managed wireless networks that cover large geographic areas and accommodate large numbers of mobile customers. The licensing of multiple operators should have led to significant competitive benefits in the wireless service provider market however; the "Big Two" still dominate. The commons model applies well for low power devices such as cordless phones, and garage door openers because they do not cause major interference problems. The model does not offer sufficient interference protection certainty or reliability for mobile broadband service providers. Their argument is that services requiring large upfront capital investments or promising a certain standard of service to paid subscribers cannot be put at risk from not knowing exactly where, when, and with whom they have to co-operate.

4.10.4 Proposed Changes from the Spectrum Rights and Responsibilities WG

It is universally agreed that Spectrum Policy has to be revised to allow more sharing of spectrum bands. The historical precedent makes this objective very difficult to achieve because the exclusive use model and the commons model cannot both be satisfied at the same time.

A quote from the Spectrum Policy WG:

> *The Working Group agrees with the consensus view expressed by participants in this process that "one size does not fit all" in spectrum policy. We also believe that there is considerable room to move from the largely ad hoc approach to spectrum rights that has evolved historically to a much smaller set of basic spectrum rights models that can be applied more consistently and comprehensively across the radio spectrum as a whole.* [FCC 2002]

Spectrum management is difficult to regulate for the satisfaction of all spectrum users. Recent technological advances have reduced the potential of interference in a commons model system. Software-defined radio (SDR) and cognitive radio (CR) are technologies that avoid interference by dynamically selecting frequencies before transmission. A cognitive radio has been defined as, "A radio frequency transceiver designed to intelligently detect whether a particular segment of the radio spectrum is in use, and to jump into (and out of) the temporarily unused spectrum very rapidly, without interfering with the transmission of other authorized users." [Mitola, Joseph 2000]The FCC is considering imposing regulatory limitations on spectrum use. These limitations would be analogous to zoning restrictions that local governments place on property owners. One option is a limited exclusive use model. This model would be structured so that the primary licensee has exclusive rights to provide any service on their assigned frequencies however; secondary users would be allowed to use those frequencies as long as they did cause interference.

The FCC has proposed two alternative approaches to facilitate access for secondary users. The first alternative allows the licensee of the spectrum to lease spectrum usage rights to secondary users. They would hold the rights associated with determining which potential users could have access to the spectrum and under what conditions. The second approach follows an "Open Access" model that allows the FCC to grant secondary users access to the spectrum bypassing the licensees. [FCC 2002] Proponents of secondary user schemes assert that the market can solve access problems by conducting privately negotiated agreements between the primary licensee and the secondary users. This approach is not liked by many broadband companies because the FCC does not have any means of enforcing these arrangements. The FCC could also allow "opportunistic" devices to search across licensed spectrum and operate in licensed but unused spectrum without permission of the licensee. This scheme necessitates strict rules on interference regulation. The devices must not cause interference to incumbent licensees and must instantly ceased transmitting whenever a licensee wished to use the spectrum. Easement proponents contend that exclusive rights holders will look for ways to block access by such devices to protect their investments. This approach assumes that devices using "software defined radio" (SDR) techniques are already being deployed. The mobile broadband industry is using SDR as an enabling technology and is integrating SDR features into chipsets and new base stations. It is not envisioned that there will not be a switchover from non-SDR networks to SDR-enabled networks however; a gradual introduction of SDR features is highly desirable. [Winn Forum 2012]

Another shared spectrum concept has recently been proposed, it is called “interruptible spectrum leasing”. Cognitive radios could enable secondary markets in licensed spectrum by allowing a lessee to gain access to spectrum on a secondary basis and allow it to revert to the primary licensee on demand. The lessee’s transmitter must have the ability to receive a beacon signal sent continuously by the licensee at times when transmissions by the lessee are permitted. The lessee may not commence transmissions if the beacon signal is not received, and if the beacon signal is present but then stops while the lessee is transmitting, transmissions must cease within a specified time interval. Other schemes include a central server for lease negotiation and a token exchange mechanism to manage the shared spectrum transactions between a licensee and a secondary market user. [FCC 2005]

4.11 New Technologies for Spectrum Use

Traditional radio communications assume the receiving equipment is “dumb”. The only way to ensure that the radio understands the communication is to have a high signal-to-noise ratio. If the signal being sent from the transmitter is not strong enough, the simple radio has no way of differentiating between the true signal and noise. SDR is an intelligent radio in which the transmitter modulation is generated by software resident in an onboard processor. [Mitola, Joseph 2000] Network architectures are now being developed that couple satellite and cellular network base stations to support very large mobile communication systems. These innovative techniques are examined.

4.11.1 Software Defined Radios and Cognitive Radios

The FCC issued Docket 05-57 titled “Facilitating Opportunities for Flexible, Efficient, and Reliable Spectrum Use Employing Cognitive Radio Technologies” to regulate the use of Cognitive Radio based technologies. Radio equipment manufacturers expect that full development of cognitive radio capabilities will lead to a vastly different model for spectrum use. They envision “smart radios” operating on an opportunistic basis, finding idle spectrum, using it and vacating it automatically. [FCC 2005] The concept is similar to our interconnected highway systems. A vehicle can drive on and off them at the whim of the driver, never having to drive in the same “lane” or in this case frequency. Radios were traditionally built with unalterable hardware devices that performed specific functions or operations, such as filters, mixers, amplifiers, and detectors. SDR features provide a degree of intelligence that provides a programmable means to alter these same radio functions and operations in any way to best receive or transmit data. Figure 75 provides an overview of the functions within a software communications system from the initial software defined operations through the radio functions and onto the channel set.

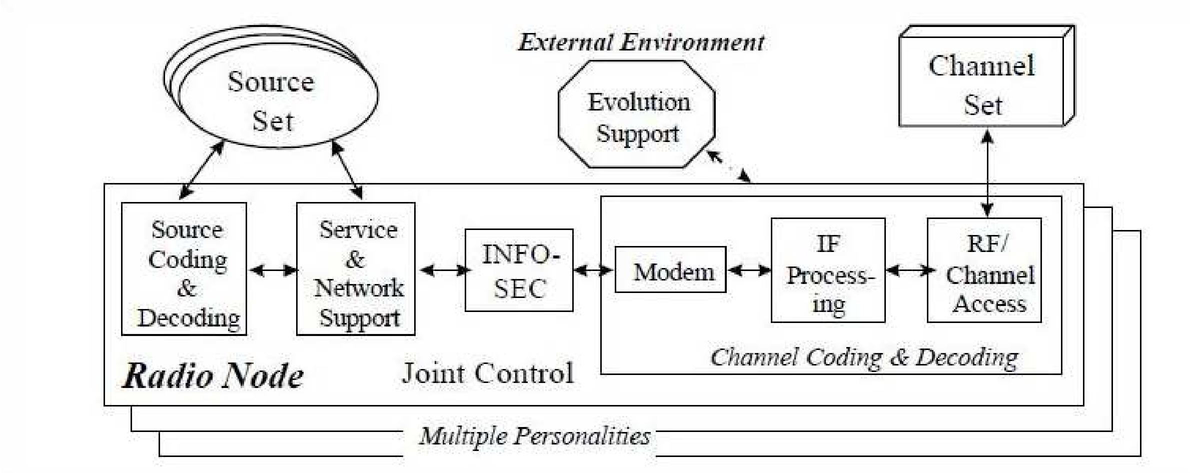


Figure 75 Functional Model of a Software Radio Communications System [Mitola, Joseph 2000]

The FCC has loosely defined "software defined radios" as devices that include a transmitter in which the operating parameters of frequency range, modulation type or maximum output power can be altered dynamically. The radio can be programmed to transmit and receive on a variety of frequencies and use one or more, different transmission formats supportable by its hardware design. Radio systems have been gaining computational features allowing them to be "cognitive"; to adapt their behavior based on external factors. This "ability to adapt" is opening up dynamic access methods providing significantly improving spectrum use efficiency. [FCC 2005] A "cognitive radio" (CR) uses SDR features to alter its transmitter parameters based on interaction with the environment in which it operates. This interaction may involve active communications with other spectrum users and/or passive sensing and decision making within the radio. Figure 76 illustrates the cognitive cycle between the transmitter, receiver, and the RF environment.

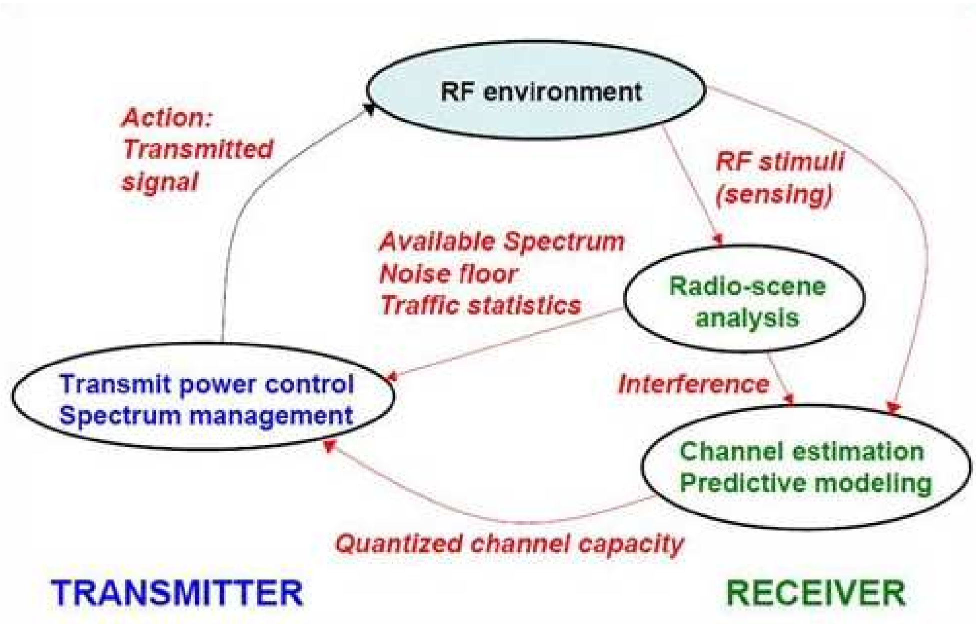


Figure 76 Cognitive Radio Cycle showing Operational State Transitions [Mitola, Joseph 2000]

If a mobile broadband operator wanted to install a cellular base station to serve a large number of modulation formats without using SDR methods, each format would have to have a to pre-allocate each format so that every one of them had enough capacity. A base station using cognitive radio capabilities could dynamically allocate the required capacity among the different modulation formats on a real-time basis. Cognitive radios are now being built that can recognize factors in their environment and modify their performance characteristics through SDR features built inside the radio. Figure 77 illustrates the major functional blocks within the software radio. Wideband analog to digital and digital to analog converters (ADCs and DACs) transform each RF service band among digital and analog forms at the Intermediate Frequency (IF) processing module. The single resulting digitized stream of bandwidth accommodates all subscriber channels, each of which has a channel bandwidth as shown in Figure 77.

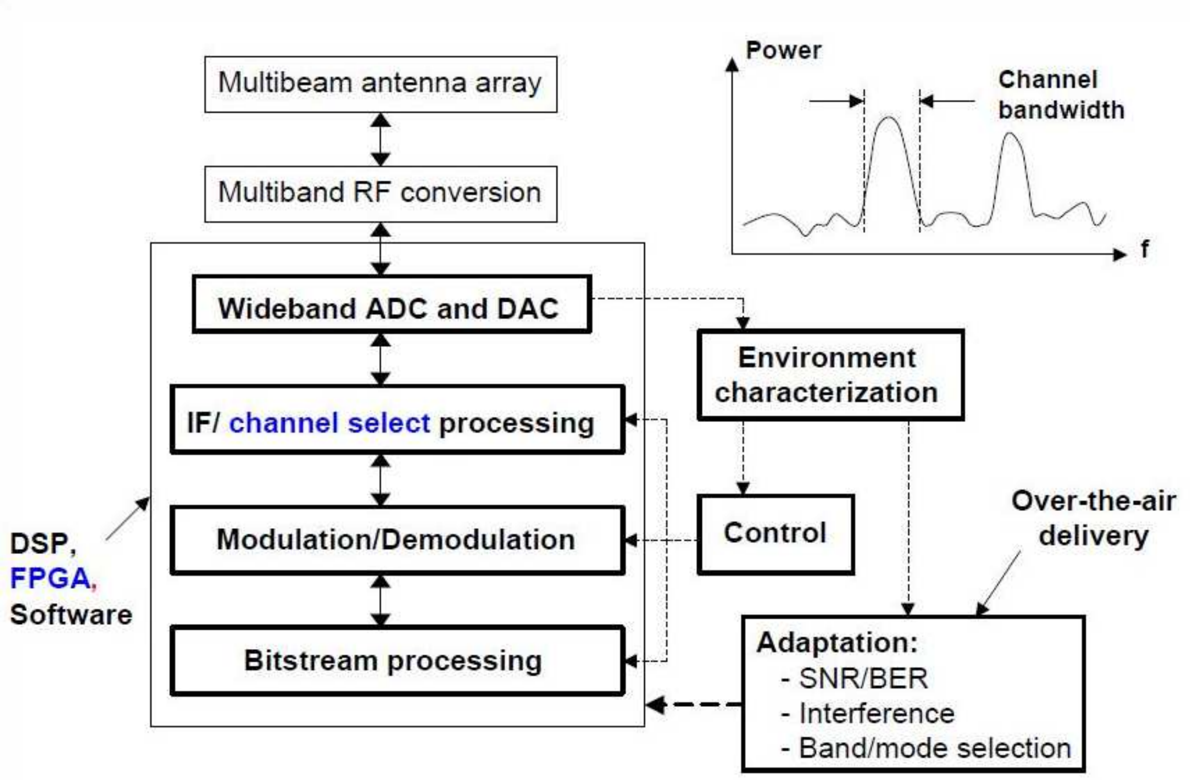


Figure 77 Software Radio Functions and Components [Mitola, Joseph 2000]

The FCC has defined a suite of CR features to define the different attributes and abilities of Software Defined Radios. [FCC 2005]

Figure 78 provides a list of the CR features and their descriptions.

Cognitive Radio Feature	Feature Description
Frequency Agility	Ability of a radio to change its operating frequency for optimal use
Dynamic Frequency Selection (DFS)	ability to sense signals from other nearby transmitters in an effort to choose an optimum operating environment
Adaptive Modulation	Ability to modify transmission characteristics and waveforms
Transmit Power Control (TPC)	Permits transmission at full power limits when necessary, and constrains transmitter power if necessary
Location Awareness	Allows detection of other surrounding transmitter locations and the subsequent selection of the appropriate operating parameters such as the power and frequency allowed at its location
Negotiated Use	Enables sharing of spectrum under the terms of a prearranged agreement between a licensee and a third party, or the negotiation of spectrum band use on an ad hoc or real-time basis

Figure 78 Cognitive Radio Feature List and Feature Description [FCC 2005]

Although Cognitive Radio technology is in its infancy, there are already a number of devices using CR capabilities. Unlicensed Personal Communication Service (PCS) devices are required to monitor the spectrum prior to transmission to avoid interference with other unlicensed PCS devices. In addition, Unlicensed National Information Infrastructure (U-NII) devices operating in the 5.25-5.35 GHz and 5.47-5.725 GHz bands are required to incorporate DFS and TPC to avoid interference with Federal Government operations.

4.11.2 IEEE 802.22 Wireless Regional Area Networks using Cognitive Radios

The IEEE 802.22 draft Wireless Regional Area Network (WRAN) standard uses cognitive radio techniques to allow sharing of spectrum with TV broadcasting services to bring broadband access to hard-to-reach low-population-density areas typical of rural environments. A cognitive radio observes its environment and modifies its transmission characteristics accordingly. These cognitive radio networks operate in a cycle that includes radio scene analysis, channel state estimation and predictive modeling, and transmit power control and spectrum management commands. A cognitive radio uses the concept of dynamic spectrum access that dynamically identifies and uses portions of the spectrum that are not being used by other systems also known as white space. Spectral awareness is achieved in two methods. The first is using a database of licensed transmitters to determine which channels are locally available, and the second is using a spectrum sensing mechanism to detect transmitting channels. The IEEE 802.22 draft standard declares that an installation will provide wireless broadband access to a rural area of typically 17–30 km or more in radius with a maximum of 100 km. [IEEE 2009]

It will serve up to 255 fixed units of customer premises equipment (CPE) with outdoor directional antennas located at nominally 10 m above ground level, similar to a typical VHF/UHF TV receiving installation. The spectrum manager is the cognitive function at the BS that will use the inputs from the spectrum sensing function (SSF), global position, and the incumbent database to choose which TV channel to use as well as the effective isotropic radiated power (EIRP) limits imposed on the specific

WRAN devices. The IEEE 802.22 draft standard requires all devices in the network to be installed in a fixed location and the base station (BS) is required to know its location and the location of all of its associated CPEs. The location of the BS must be known to within a 15 m radius while the location of CPE must be known to within a 100 m radius. The global position of the CPE in latitude and longitude is passed to the BS together with antenna pattern, height, and EIRP, so that the incumbent database service can determine the expected area over which the CPE could potentially interfere. All nodes in the 802.22 network will sense licensed transmissions using an antenna with a gain of at least 0 dBi (forward gain of the antenna) in all directions. [IEEE 2009] The sensing antenna must be outdoors, clear of obstructions as much as possible, and at a minimum height of 10 m above ground level. Sensing is performed in both the BS and the CPE, but the final decision on whether a given channel is available for use by the WRAN is made at the BS.

4.11.3 Lightsquared

The private company, LightSquared was formed in 2010 to build a new nationwide wireless broadband network using the 4G wireless technology. Instead of competing directly against AT&T and Verizon Wireless, the company decided to sell its service on a wholesale basis only. LightSquared has a nationwide license for about 59MHz of spectrum mostly in the 1.6GHz band. [Lightsquared Co. 2012] In January 2011, the company received a waiver from the FCC that allowed the spectrum to be used for land-based-only LTE communication. LightSquared was anticipating coverage of roughly 92 percent of the U.S. population with its service by 2015. The project was however blocked from proceeding in April 2012. The company has already testing its service in Baltimore, Denver, Las Vegas, and Phoenix. As the wireless industry consolidates with big players gobbling up smaller providers, LightSquared was trying to offer smaller wireless operators a chance to compete. The deal between Sprint and LightSquared would have given it access to Sprint's 3G infrastructure. The use of the spectrum in rural areas where Sprint does not have a network could have helped Sprint cut back on roaming deals with competitor Verizon. LightSquared's network could have offered device makers the option of bypassing the big phone companies altogether. [CNET 2011]

The company SkyTerra was formally called Mobile Satellite Ventures (MSV); it developed a system that integrated satellite and terrestrial radio communication technologies into one functional entity. In March 2010, the company became part of LightSquared. MSV developed a new technology called the Ancillary Terrestrial Component (ATC) device. In an application to FCC in 2001, MSV unveiled a new architecture for a mobile satellite system (MSS) with an ATC. Users of the system could transmit and receive information from virtually anywhere using handheld mobile devices that could communicate through satellite and ground facilities using the same frequencies. The FCC approved the new ATC enabled broadband wireless networks for deployment. [Parsons, Gary 2005] The ATC allows reuse of the same spectrum operating over the satellite across a very large number of ground stations. A hybrid satellite-terrestrial wireless network (“MSS/ATC hybrid network”) comprises one or more multi-spot beam satellites and a very large number of terrestrial cell sites using a common set of frequencies. A communications service, such as voice or packet-switched data, can be supported by the same user device in both terrestrial and satellite modes. Spectral efficiency is significantly improved due to the scale provided by the satellite systems. Terrestrial cells are nested inside satellite cells (“satellite spot beams”); the satellite cells are much larger at more than one hundred kilometers in diameter. ATC enhanced terrestrial cell diameters can range from about one kilometer in dense urban environments, to about five kilometers in suburban areas, depending on subscriber density and network utilization. [Parsons, Gary 2005] Figure 79 illustrates a MSS/ATC hybrid network configuration,

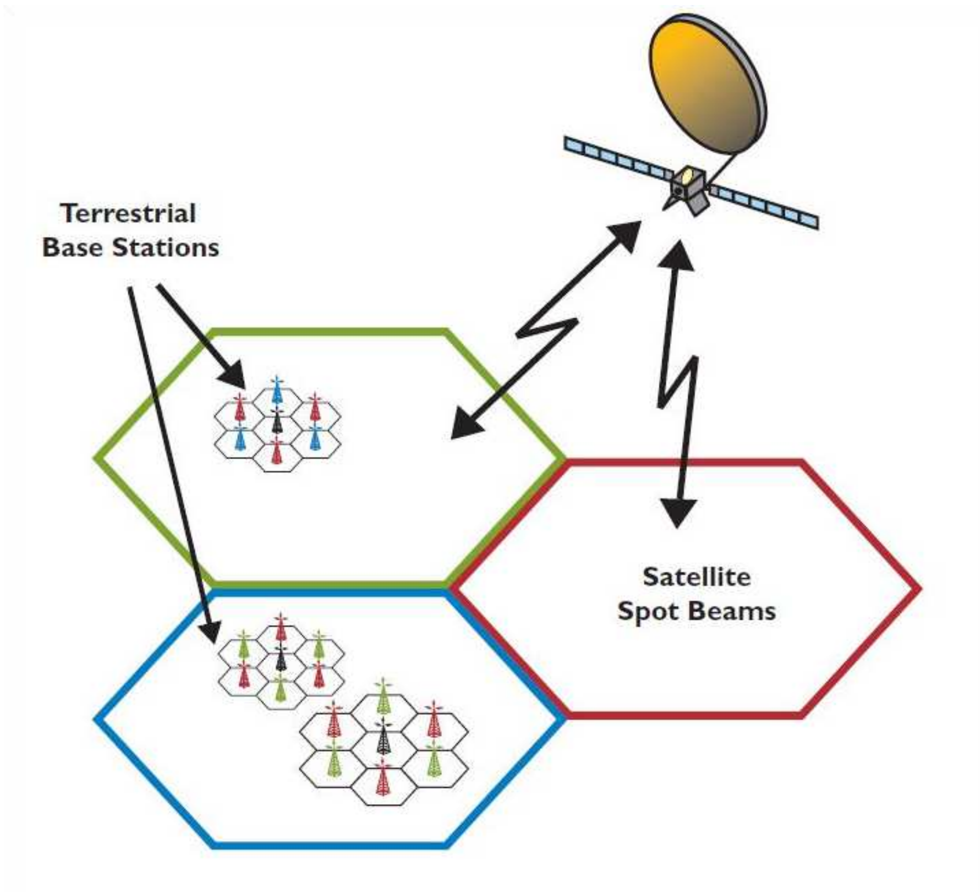


Figure 79 Terrestrial cells nested in Satellite Spot Beam Cells [Lightsquared Co. 2012]

The terrestrial cells inside a satellite cell use different frequencies from the satellite cell, thus avoiding interference. All the available frequencies are spatially reused many times over, greatly enhancing system capacity and efficient spectrum utilization. This nesting delivers system capacity, as needed, in high traffic regions (e.g., urban areas). Users within the high traffic areas are serviced by the ATC while users in lower traffic density regions (in unpopulated areas) are serviced by the satellites. [Parsons, Gary 2005] The powerful satellites are designed to transmit signals to, and receive signals from standard wireless devices that contain proprietary enhancements. In order to maximize communications robustness, signals from each transmitting user device are received by each of the two satellites. These signals are transported to the ground via the satellite feeder links and are combined at the satellite gateway where the user's signal is amplified. [Parsons, Gary 2005] The MSS/ATC hybrid network architecture is illustrated in Figure 80,

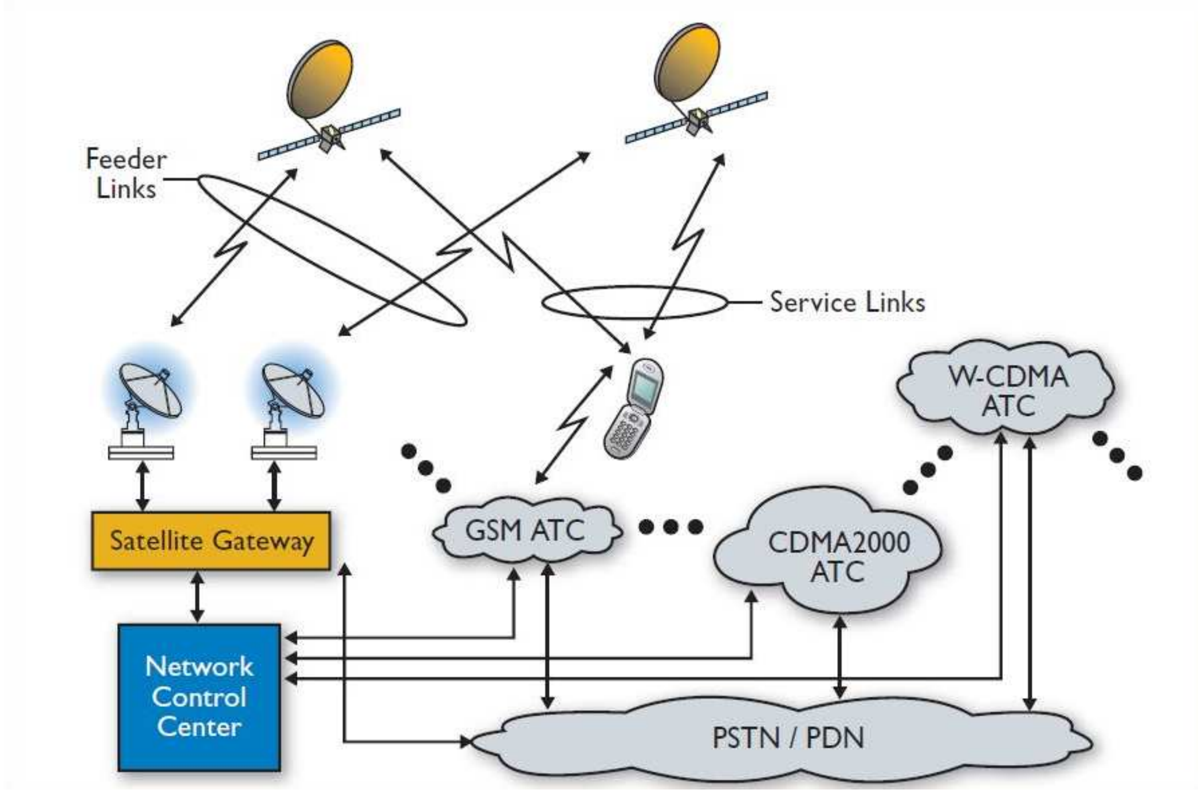


Figure 80 MSS/ATC Hybrid Architecture [Lightsquared Co. 2012]

The satellite service links use the frequency band 1525-1559 MHz for uplinks, and the 1626.5-1660.5 MHz frequency band for downlinks. The satellite feeder links use the frequency band 12.75 – 13.25 GHz for uplinks, and the 10.75 – 10.95 GHz and 11.20 – 11.45 GHz frequency bands for downlinks. LIghtsquared owns the MSS/ATC hybrid architecture Patents inherited from MSV. [Parsons, Gary 2005]

4.11.3.1 Interference Issues

Manufacturers of GPS equipment warn that signals from the LightSquared network could drown out signals for existing navigation systems. GPS makers say the issue is that satellite receivers, which are designed to detect weak signals from space, could be overwhelmed by higher-power signals coming from LightSquared's 40,000 cellular base stations that will be transmitting in a frequency band that is close the GPS bands. [Charette, Robert 2011] Figure 81 shows the GPS receiver response and the high potential for interference from Lightsquared base station emissions. Although LightSquared would operate in its own authorized band, the band is so close to the GPS signals that many GPS devices could pick up the stronger LightSquared signals and become overloaded or saturated.

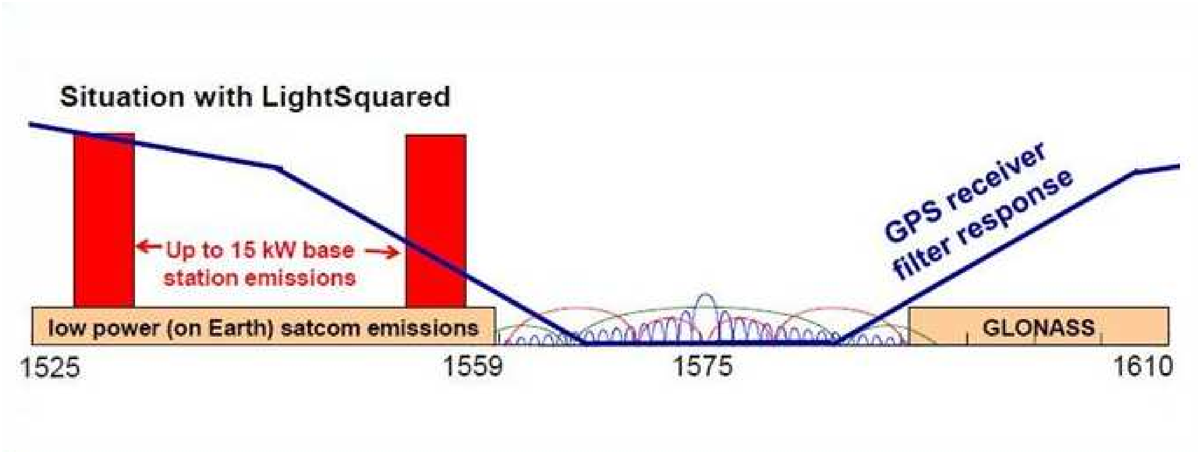


Figure 81 Interference caused by the Lightsquared project to the GPS system [GPS 2012]

Global Navigation Satellite System (GLONASS) is a radio-based satellite navigation system operated for the Russian government by the Russian Aerospace Defense Forces. It complements the US GPS system. LightSquared and a number of federal agencies spent a large part of 2011 testing GPS receivers in an effort to identify and mitigate the interference concerns. After the initial round of tests in early 2011 demonstrated the potential for widespread GPS disruption, LightSquared modified its signal plans, and the FCC and NTIA requested a second round of tests. These took place in late 2011, with the results raising continued interference concerns.

5 Conclusion

The current spectrum management scheme in the US has evolved on an "as needed basis". Every time a new radio-communication service was introduced, spectrum bands were awarded as required without regard to efficiency or long range planning. Interference avoidance was the primary concern, hence the implementation of guard bands. When spectrum was plentiful, this was not regarded as a problem. A survey created by Cisco indicates that global mobile broadband traffic demand has a projected annual growth rate of 108% rate over next five years. An FCC document titled "Mobile Broadband Benefits of Additional Spectrum" calculated the shortfall of spectrum for US mobile broadband consumption as 278 MHz in 2014. Other estimates put the number as high as 800 MHz in the next 6 years.

The FCC published the National Broadband Plan in 2009. The document indicated four ways the US Government could influence the US broadband ecosystem. Foster competition, ensure efficient allocation of government owned and government influenced assets, provide universal availability and adoption of broadband for all Americans, and maximize the use of all broadband resources for national priorities.

The plan also created 6 goals for the next decade. 100 million U.S. homes should have 100 Mbps download, and 50 Mbps upload speeds. The US should have the fastest and most extensive wireless networks of any nation. Every American should have affordable access to robust broadband service. Every American community should have 1 Gbps broadband service for schools, hospitals and government. Every first responder should have access to a wireless broadband public safety network. Every American should be able to use broadband to track and manage their real-time energy consumption. The document also indicated that given the goal of freeing 500 megahertz of spectrum, future wireless auctions would ensure the budget for the NBP would be revenue neutral, if not revenue positive. This paper has examined the actions taken by the FCC towards the goals, and objectives stated in the NBP. The FCC has been very successful with its spectrum auction program and the revenue generated is over $50 Billion since 1994 since the auctions began. The US Federal Government has taken advantage of the demand for spectrum bands. The success of these auctions has led some concerned organizations to ask the question; does the "winner takes all" model in recent US Spectrum auctions lead to the best result for the American people?

The FCC has had mixed results from its 6 goals so far. The first goal has not been met yet because the U.S. ranked twelfth in terms of average country speed at 5.8 Mbps [Bode, Karl 2011]. It seems highly unlikely that a third of all Americans would be enjoying 100 Mbps soon, given today's average speed of less than 6 Mbps. The second goal has definitely not yet been achieved because despite the highest Gross Domestic Product (GDP) per Capita, the US ranks lower than other countries. The Organization of Economic Cooperation and Development (OECD) provides global broadband usage statistics on its broadband portal. [OECD 2011] The US ranked 7 out of 34 countries for mobile broadband subscribers, as shown in

Figure 82. Internet penetration in 2011, which includes both wired and wireless access for the US was 78.3% compared with the world average of 30.7%. [Interworld Stats 2011]

Ranking	Country	No. of subscribers per 100 inhabitants	Gross Domestic Product (GDP) per Capita
1	South Korea	99.3	$29,004
3	Japan	80	$33,771
7	United States	65.5	$46,558
12	New Zealand	54.3	$29,865
17	United Kingdom	44.4	$35,917
26	Canada	31.8	$38,989
34	Mexico	0.5	$15,186

Figure 82 Mobile Wireless Broadband Penetration versus GDP per Capita [OECD 2011]

The third goal has not yet been achieved. The US still has rural areas without broadband access. A statistic that is useful to judge the "digital divide" within the US is the "Digital Access Index" (DAI). The DAI is a measure of the population's access to Information and Communications Technology (ICT). The DAI is measured on a scale from 0 to 1.

Figure 83 shows that the countries with the largest number of very low-income populations namely India and China have the lowest DAI values. As indicated in

Figure 83, the US is among the highest but is still overtaken by Sweden, Denmark, Iceland, South Korea, Netherlands, Finland, and Taiwan.

Country	DAI	Country	DAI	Country	DAI	Country	DAI
Sweden	0.85	Netherlands	0.79	Canada	0.78	Trinidad	0.53
Denmark	0.83	Finland	0.79	UK	0.77	Mexico	0.5
Iceland	0.82	Taiwan	0.79	Japan	0.75	China	0.43
South Korea	0.82	US	0.78	New Zealand	0.72	India	0.32

Figure 83 Digital Access Index - Countries throughout the World [Interworld Stats 2011]

The fourth goal has a very challenging objective. Fiber optic networks such as Verizon FIOS currently support 50 Mbps with peak of 150 Mbps. Google made a statement in 2010 that it would create a network with speeds up to 1 Gbps. The cost of providing 1 Gbps for every hospital, school, and government facility is very high and probably beyond the revenue created by spectrum auctions. The fifth goal of providing a wireless broadband public safety network for all US first responders is much more achievable. The FCC has allocated a pair of 12 MHz blocks in the 700 MHz band for public safety organizations. Public Safety organizations have been using radio communications for many years. The final goal is difficult to assess. Electricity use is measured by meters and networked smart meters are being installed throughout the country. Several companies have announced wireless products using cellular standards for the new smart grid industry. This adds to the mobile broadband data demand problem that requires more spectrum.

The NBP listed four ways the US Government wishes to influence the broadband ecosystem. The first objective was to foster competition. The FCC has definitely failed since it has consistently pursued a free market approach to their spectrum auction policy. AT&T and Verizon have acquired the majority of the 700 MHz Frequency bands that were recently auctioned. They plan to use it for new 4G LTE mobile communication services, however there is nothing to stop them from using different 3GGP LTE sub-bands for FDD operation. This has the unfortunate effect of allowing them to exclude other non-compatible users from their part of the spectrum. The FCC should have prevented this by imposing conditions and constraints on the sale of the spectrum bands in order to promote competition among the mobile operators serving these market areas. The second objective was to ensure efficient allocation of government owned and government influenced assets. The FCC has pursued revenue from spectrum auctions rather than meet this objective. When frequency bands are subject to repurposing, re-farming or reallocation, there are industry sector winners and losers. How do you make the best tradeoffs between different industries competing for the same spectrum frequency bands? In the case of the 700 MHz band in the US, the TV Broadcast industry is giving up spectrum to the mobile communications industry. It seems that mobile operators have more money to influence the FCC and they have more money to buy “beachfront spectrum” at auction. The same question is again raised “Is this in the public interest?” The TV broadcast industry is being overshadowed by the powerful mobile telecommunications companies. TV broadcast licenses require that free channels be made available to the local community; the FCC does not require mobile operators to provide similar free services. The NBP adds a recommendation as part of the second objective. Make 500 megahertz of spectrum newly available for broadband within 10 years, of which 300 megahertz should be made available for mobile use within five years. The FCC has been successful with its spectrum-repurposing program. This has been achieved by moving US Government agencies from spectrum bands in the 400MHz to 4G Hz range to other bands as shown in Figure 7.

The third objective was to provide universal availability and adoption of broadband for all Americans.

Figure 83 shows that despite the highest GDP per capita, the US does not have the highest DAI. Other countries such as New Zealand, UK, Trinidad, and Japan consider the social benefits of allocating spectrum when forming their spectrum policy. The UK regulator OfCom is promoting a more diverse set of services, such as digital audio, mobile TV, and expansion of rural areas, to be allocated frequency blocks in the 700 MHz band. Japan has allocated a frequency block in their 700 MHz band for Intelligent Traffic Services (ITS). New Zealand and Trinidad apply restrictions to the sale of frequency bands in their spectrum auctions to promote competition. Competition between mobile operators should provide cheaper wireless services. The fourth objective is to maximize the use of all broadband resources for national priorities. This is partially met by the allocation of frequency bands for public safety organizations. The FCC has however, encouraged educational organizations to sell and lease their spectrum holdings to the mobile communications industry. The BRS/EBS 2.5 GHz band was auctioned between 1995 and 2009. The revenue generation from the sale seems to have been more important than the social benefit of the spectrum.

In 2004, and 2005 measurements of spectrum occupancy were made in densely populated areas of downtown Chicago and New York for frequency bands between 30 MHz, and 3 GHz. The occupancy level in Chicago was measured at 17.4%, and the level in New York was measured at 13.1%. This indicates very poor spectrum occupancy. One approach is the development of a secondary user market that could take advantage of the free “white space”. The FCC has created task forces and working groups to investigate whether, sharing spectrum between primary and secondary users would lead to more efficiently used frequency bands. Intelligent radio equipment using SDR and CR technologies could play a significant role in establishing a secondary user market.

The FCC Spectrum Policy task force has been investigating ways in which the legal rights and responsibilities, attached to spectrum licenses can be improved to promote more efficient and productive use of the frequency bands. The trend towards spectrum policy modification is as follows,

Command & Control -> Market driven -> Commons (open spectrum)

The FCC has abandoned the Command & Control model in favor of a Market-driven model. There are organizations who would like to adopt a Commons model promoting the idea of an open spectrum. The "Open Spectrum" concept for all spectrum bands is not practical because of national security and public safety concerns, however if the non- military and non-public-safety bands have a strong secondary market, then it may be possible in the future. There exist today, non-licensed parts of the spectrum in use for low power devices such as Wi-Fi and products using the Information Scientific and Medical bands (ISM). This paper has explored spectrum-sharing proposals for co-existence of primary licensees and secondary users. It has also explored the way in which intelligent radio devices using SDR and CR features has made better productive use of the spectrum possible. This trend is being resisted by the powerful mobile communications operators whenever the concept of a Commons model for spectrum policy is discussed. It seems that political influence by major corporations is holding back innovation; however, the promising trend towards "open spectrum" is slowly evolving.

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7 Glossary of Terms and Acronyms

Acronym or Name	Definition
1G	First Generation wireless standard
1xAdvanced	Quadruples 1xRTT speed
1xRTT	Single-Carrier Radio Transmission Technology
2G	Second Generation wireless standard
3G	Third Generation wireless standard
3GPP	3rd Generation Partnership Project standard for 3G networks
3GPP2	3rd Generation Partnership Project 2 standard for CDMA networks
4G	Fourth Generation wireless standard
ACI	Adjacent-channel interference
AM	Amplitude Modulation
AMPS	Advanced Mobile Phone Service
ATSC	Advanced Television Systems Committee
AWS	Advanced Wireless Service
BIP	Broadband Initiatives Program
bluetooth	Wireless standard using the ISM band from 2400-2480 MHz
BRS	Broadband Radio Service formerly MMTS
BTA	Basic Trading Areas
BTOP	Broadband Technology Opportunity Program
CAGR	Compound Annual Growth Rate
CCI	Co-channel interference
CDMA	Code Division Multiple Access
CDMA2000	CDMA version of the IMT-2000 standard
CDMAOne	Code Division Multiple Access One
CEPT	European Conference of Postal and Telecommunications Administrations
CISPR	International Special Committee on Radio Interference
CMA	Cellular Market Areas - mobile service market area
CR	Cognitive Radio
CTIA	International Association of the Wireless Telecommunications Industry
D-AMPS	Digital-Advanced Mobile Phone Service, The second generation of TDMA
DFS	Dynamic Frequency Selection
DMA	Designated Market Areas
DTV	Digital Television
EA	Economic Areas
EAG	Economic Area Groupings
EBS	Educational Broadband Service
EDGE	Enhanced Data GSM Environment
EMI	Electromagnetic Interference
ESMR	Enhanced Specialized Mobile Radio- analog wireless standard
ETSI	European Telecommunications Standards Institute
EV-DO	1x Evolution-Data Optimized

FCC	Federal Communications Commission
FDD	Frequency Division Duplex
FM	Frequency Modulation
FRC	Federal Radio Commission
FSPL	Free-Space Path Loss
GAO	Government Accounting Office
GNP	Gross National Product
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communications
HDTV	High Definition TV
HDTV	high definition television
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
HSPA+	Evolved High-Speed Packet Access
HSUPA	High Speed Uplink Packet Access
iDEN	Integrated Enhanced Network – digital wireless standard
IMT-2000	International Mobile Telecommunications-2000
Industry Canada	Canadian Ministry of Industry
IS-136	Enhancements to TDMA
IS-95	2G wireless standard
ISM Band	Industrial, Scientific, and Medical Band
ISP	Internet service provider
ITFS	Instructional Television Fixed Service
ITU	International Telecommunication Union
ITU-D	ITU development section
ITU-R	ITU regulations section
ITU-T	ITU standardization section
LMS	Location and Monitoring Service
Long wave	Radio band below 535 kHz
LTE	Long Term Evolution 4G wireless standard
MDS	Multipoint Distribution Service – wireless cable standard
MEA	Major Economic Areas
Medium wave	Medium frequency (MF) Radio band
MMDS	Multichannel Multipoint Distribution Service – wireless cable standard
MSA	Metropolitan Statistical Area
MSA	Metropolitan Service Areas – mobile service market area
MTA	Major Trading Areas
NAB	National Association of Broadcasters
NBP	National Broadband Plan
NTIA	National Telecommunications and Information Administration
NTSC	National Television System Committee name for Analog TV standard
NZ	New Zealand
OBI	Omnibus Broadband Initiative
OTA TV	Over the Air Television

Part 15	Title 47, Part 15 (47 CFR 15) for unlicensed transmissions
PCS	Personal Communications Service wireless phone service
PDN	Packet Data Network
PSTN	Packet Switched Telephone Network
RCA	Rural Cellular Association
REAG	Regional Area Groupings
RSA	Rural Service Area
SDR	Software Defined Radio
SDTV	Standard Definition TV
Short wave	Radio Band wavelengths shorter than 200 m
SMR	Specialized Mobile Radio- analog wireless standard
TDD	Time Division Duplex
TDMA	Time Division Multiple Access- A satellite and cellular phone air interface
TPC	Transmit Power Control
UHF	Ultra High Frequency
UMTS	Universal Mobile Telecommunications System
U-NII	Unlicensed National Information Infrastructure
USDA	US Department of Agriculture
VHF	Very High Frequency
W-CDMA	Wideband Code-Division Multiple Access
WiDEN	Wideband Integrated Digital Enhanced Network
Wi-Fi	brand name for products using the IEEE 802.11 family of standards
WiMAX	IEEE 802.16 wireless standard – 4G
WLAN	wireless local area networks

8 Appendices

8.1 APPENDIX A

Spectrum Occupancy Measuremen Table for Chicago. Frequency samples were taken of a 30 MHz to 3 GHz range.

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	Chicago Day 1 Spectrum Fraction Used	Chicago Day 2 Spectrum Fraction Used	Chicago Avg Spectrum Fraction Used	Chicago Occupied Spectrum (MHz)	Average Percent Occupied
30	54	24	PLM, Amateur, others	0.23070	0.19371	0.21221	5.09	21.2%
54	88	34	TV 2 -6, RC	0.70872	0.70931	0.70902	24.11	70.9%
108	138	30	Air traffic Control, Aero Nav	0.02814	0.02442	0.02628	0.79	2.6%
138	174	36	Fixed Mobile, amateur, others	0.35443	0.34908	0.35175	12.66	35.2%
174	216	42	TV 7-13	0.44794	0.44730	0.44762	18.80	44.8%
216	225	9	Maritime Mobile, Amateur, others	0.04274	0.04511	0.04392	0.40	4.4%
225	406	181	Fixed Mobile, Aero, others	0.02791	0.02665	0.02728	4.94	2.7%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.17462	0.16853	0.17158	10.98	17.2%
470	512	42	TV 14-20	0.55919	0.55775	0.55847	23.46	55.8%
512	608	96	TV 21-36	0.56269	0.55182	0.55726	53.50	55.7%
608	698	90	TV 37-51	0.55387	0.55567	0.55477	49.93	55.5%
698	806	108	TV 52-69	0.42423	0.42958	0.42691	46.11	42.7%
806	902	96	Cell phone and SMR	0.55005	0.54676	0.54841	52.65	54.8%
902	928	26	Unlicensed	0.09584	0.09082	0.09333	2.43	9.3%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.29600	0.29668	0.29634	9.48	29.6%
960	1240	280	IFF, TACAN, GPS, others	0.03969	0.03235	0.03602	10.09	3.6%
1240	1300	60	Amateur	0.00016	0.00059	0.00037	0.02	0.0%
1300	1400	100	Aero Radar, military	0.00437	0.00428	0.00432	0.43	0.4%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.00013	0.00021	0.00017	0.02	0.0%
1525	1710	185	Mobile Satellite, GPS, Meteorologicial	0.00025	0.00026	0.00026	0.05	0.0%
1710	1850	140	Fixed, Fixed Mobile	0.00000	0.00002	0.00001	0.00	0.0%
1850	1990	140	PCS, Asyn, Iso	0.42920	0.42824	0.42872	60.02	42.9%
1990	2110	120	TV Aux	0.00654	0.03712	0.02183	2.62	2.2%
2110	2200	90	Common Carriers, Private Companies, MDS	0.00155	0.00224	0.00189	0.17	0.2%
2200	2300	100	Space Operation, Fixed	0.00183	0.00186	0.00185	0.18	0.2%
2300	2360	60	Amateur, WCS, DARS	0.19919	0.19883	0.19901	11.94	19.9%
2360	2390	30	Telemetry	0.00010	0.00015	0.00012	0.00	0.0%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.30898	0.27225	0.29061	31.97	29.1%
2500	2686	186	ITFS, MMDS	0.30350	0.31315	0.30833	57.35	30.8%
2686	2900	214	Surveillance Radar	0.02111	0.02301	0.02206	4.72	2.2%
Total		2850		0.0000	0.0000	0.0000	494.90	
							0.00	
Total Available Spectrum							2850.00	
Average Spectrum Use (%)							17.4%	

Figure 84 Spectrum Occupancy Chicago Nov 2005 [McCloskey, McHenry 2005]

Spectrum Occupancy Measuremen Table for New York. Frequency samples were taken of a 30 MHz to 3 GHz range.

Start Freq (MHz)	Stop Freq (MHz)	Bandwidth (MHz)	Spectrum Band Allocation	NYC Day 1	NYC Day 2	NYC Average	NYC Occupied Spectrum (MHz)	Percent Occupied
30	54	24	PLM, Amateur, others	0.04300	0.06250	0.05275	1.27	5.3%
54	88	34	TV 2 -6, RC	0.52830	0.52080	0.52455	17.83	52.5%
108	138	30	Air traffic Control, Aero Nav	0.05270	0.04030	0.04650	1.40	4.7%
138	174	36	Fixed Mobile, amateur, others	0.17080	0.16980	0.17030	6.13	17.0%
174	216	42	TV 7-13	0.77730	0.77950	0.77840	32.69	77.8%
216	225	9	Maritime Mobile, Amateur, others	0.05860	0.05950	0.05905	0.53	5.9%
225	406	181	Fixed Mobile, Aero, others	0.00530	0.00370	0.00450	0.81	0.5%
406	470	64	Amateur, Radio Geolocation, Fixed, Mobile, Radiolocation	0.16610	0.14750	0.15680	10.04	15.7%
470	512	42	TV 14-20	0.21140	0.21000	0.21070	8.85	21.1%
512	608	96	TV 21-36	0.35520	0.34270	0.34895	33.50	34.9%
608	698	90	TV 37-51	0.46160	0.46090	0.46125	41.51	46.1%
698	806	108	TV 52-69	0.29580	0.30790	0.30185	32.60	30.2%
806	902	96	Cell phone and SMR	0.46190	0.46450	0.46320	44.47	46.3%
902	928	26	Unlicensed	0.22270	0.23460	0.22865	5.94	22.9%
928	960	32	Paging, SMS, Fixed, BX Aux, and FMS	0.23640	0.24370	0.24005	7.68	24.0%
960	1240	280	IFF, TACAN, GPS, others	0.03560	0.04080	0.03820	10.70	3.8%
1240	1300	60	Amateur	0.00030	0.00010	0.00020	0.01	0.0%
1300	1400	100	Aero Radar, military	0.02160	0.00130	0.01145	1.15	1.1%
1400	1525	125	Space/Satellite, Fixed Mobile, Telemetry	0.01520	0.00050	0.00785	0.98	0.8%
1525	1710	185	Mobile Satellite, GPS L1, Mobile Satellite, Meteorologicial	0.00240	0.00130	0.00185	0.34	0.2%
1710	1850	140	Fixed, Fixed Mobile	0.02350	0.02540	0.02445	3.42	2.4%
1850	1990	140	PCS, Asyn, Iso	0.33090	0.34430	0.33760	47.26	33.8%
1990	2110	120	TV Aux	0.01910	0.00820	0.01365	1.64	1.4%
2110	2200	90	Common Carriers, Private Companies, MDS	0.01820	0.01900	0.01860	1.67	1.9%
2200	2300	100	Space Operation, Fixed	0.05270	0.06180	0.05725	5.73	5.7%
2300	2360	60	Amateur, WCS, DARS	0.20220	0.20530	0.20375	12.23	20.4%
2360	2390	30	Telemetry	0.06200	0.06420	0.06310	1.89	6.3%
2390	2500	110	U-PCS, ISM (Unlicensed)	0.13470	0.15510	0.14490	15.94	14.5%
2500	2686	186	ITFS, MMDS	0.10430	0.10420	0.10425	19.39	10.4%
2686	2900	214	Surveillance Radar	0.02860	0.03090	0.02975	6.37	3.0%
Total		2850		0.0000	0.0000	0.0000	373.97	
Total Available Spectrum							2850	
Average Spectrum Use (%)							13.1%	

Figure 85 Spectrum Occupancy Results New York September 2004 [McCloskey, McHenry 2004]