RYSAVY RESEARCH

Mobile Network Design and Deployment:

How Incumbent Operators Plan for Technology Upgrades and Related Spectrum Needs

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Table of Contents

Notice

Executive Summary

The wireless industry is an unparalleled success story resulting from synergistic innovation in both wireless networking and computing. Mobile broadband networks are transforming society, enhancing personal lives, making businesses more competitive, and redefining how human beings interact with each other. The success of mobile broadband, however, is coupled with dramatic increases in the consumption of data bandwidth, which depends on radio spectrum, a resource that is extremely finite and in danger of being exhausted.

The planning process for network upgrades and deployment of next-generation technology is typically a complex, lengthy, and extremely detailed process for network operators with existing infrastructure and mobile operations. Incumbent commercial mobile radio service (CMRS) operators face huge challenges in managing radio spectrum. First, operators can only occasionally obtain additional spectrum. In the last 30 years since analog cellular networks first were deployed, there have only been four times that significant new blocks of spectrum were made available, each involving a five-to-ten-year process between identifying the spectrum and the spectrum actually being available for use. Any operator that anticipates an eventual need for spectrum must obtain spectrum when it becomes available, even if the operator does not need it at that moment in time. This is analogous to oil companies that constantly explore and acquire oil reserves. These companies don't wait until they have run out of oil before looking for more.

Second, many operators must support multiple generations of technology, each requiring a certain dedicated amount of spectrum. Even though newer, more efficient technologies may be available (e.g., LTE), operators have to also support subscribers with older-technology devices, as well as users roaming into the network from other parts of the world and machine-to-machine applications that have long life cycles.

Once spectrum is available, there are many items that delay its deployment, including clearing incumbent users, developing and ratifying standards specifications to define use of the new bands, designing and producing infrastructure equipment, installing new equipment at cell sites, dealing with interference that may arise with neighboring bands, and waiting for chipsets and devices to become available in commercial volumes.

Finally, there are huge costs for deploying the infrastructure to put spectrum into use, costs that scale based on the amount of spectrum deployed. Given that demand grows over time, operators need to build to expected short-term demand, and then augment capacity as demand grows. Overbuilding would result in higher-than-necessary service pricing.

Such incremental deployment, combined with only being able to obtain additional spectrum occasionally and at times of others' choosing, inevitably results in periods of time when some of the spectrum an operator has licensed is not in use. This absolutely does not mean that the spectrum will not be used; only that it is in everybody's best interest to use it at the most appropriate time.

Introduction

Managing wireless networks is a complex process that must balance infrastructure investment with service revenues, capacity with demand, and that must optimally time the deployment of new technologies. Part of this balancing act is acquiring and deploying radio spectrum. Spectrum can neither be immediately acquired, nor can it be immediately deployed. Instead, operators have to phase it into their networks in conjunction with the right technology at the right time over periods that span many years. The fact that operators may have idle spectrum at specific points in time does not mean that they don't need it, and it does not mean that they don't intend to use it. The purpose of this paper is to illustrate the process by which cellular operators acquire and deploy spectrum and how they apply it to different generations of wireless technology.

Technology Time Cycles

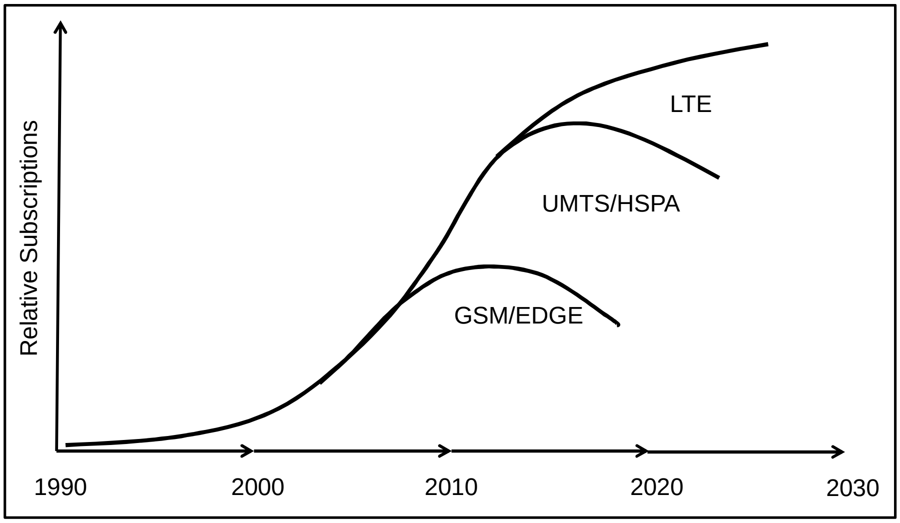
The regular release of new smartphones and tablet computers conveys the sense that new generations of technologies occur on a rapid basis such as every year. This actually is *not* the case – the time cycles for technology adoption are in fact much longer. Qualcomm has studied technology deployment and adoption and reports that in the wireless industry, there is typically eight-to-ten years between mobile-technology generations, with each generation essentially an entirely new platform.[1]

More significantly, there is an even longer period of time between initial launch of the technology platform and its peak adoption: 18 to 20 years. One can observe this in the history of the Third Generation Partnership (3GPP) family of technologies. Global System for Mobile Communications (GSM), a 2G technology, was initially deployed around 1990 and only recently saw its peak usage, as shown in Figure 1. Universal Mobile Telecommunications System (UMTS),[2] a 3G technology, became available in the 2000s, but is not expected to see its peak adoption until late this decade. Continuing the same cycle, Long Term Evolution (LTE) was launched in 2010, yet won't see its peak adoption until next decade. These long and overlapping cycles significantly complicate how operators manage their spectrum and require them to support legacy technologies for many years.

[1] Source: Qualcomm/4G Americas, "Building the Ecosystem: Chipsets and Devices," page 12, http://www.4gamericas.org/UserFiles/file/4G%20Americas%20at%204G%20World/Peter%20Carson,%20Qualcomm,%20Building%20the%20Ecosystem-Chipsets%20and%20Devices.pdf

[2] High Speed Packet Access (HSPA) is the data service that is part of UMTS.

Figure 1: Technology Adoption Cycle[3]



One can see similar platform shifts in the computing industry in which platforms went from mainframes to minicomputers to desktop computers to Internet computing to mobile computing. Within each platform, whether wireless networking or computing, there is constant innovation. For example, with 2G technology, Enhanced Data Rates for GSM Evolution (EDGE) significantly improved data performance compared to initial General Packet Radio Service (GPRS) capabilities. Similarly, High Speed Downlink Packet Access (HSDPA) hugely increased data speeds over initial 3G capabilities. LTE and LTE-Advanced also will acquire continual improvements that include both faster speeds and greater efficiency.

Each successive generation of wireless technology offers more features, and most importantly, greater spectral efficiency. Spectral efficiency refers to how much data throughput and how many voice users a specific amount of spectrum can support. LTE, for example, is about 50% more efficient than UMTS/HSPA. Similarly, UMTS/HSPA is significantly more efficient than GSM for both voice and data.

> "Until 2020 or later, GSM operators will have to have separate spectrum allocated for 2G, 3G, and 4G, a strain on their spectrum holdings beyond those from escalating mobile broadband demand."

[3] Source: Rysavy Research, "Mobile Broadband Explosion," 2011, page 17. http://www.rysavy.com/Articles/2011_09_08_Mobile_Broadband_Explosion.pdf.

Incumbent operators, however, cannot just turn off previous-generation technologies. They not only have to support subscribers with older handsets, they also have to support incoming roamers and machine-to-machine (M2M) applications that have much longer life cycles than consumer devices. For all of these reasons, Rysavy Research anticipates operators will need to support GSM all around the world until at least 2020. Until then, and probably later, GSM operators will have to allocate separate spectrum for 2G, 3G, and 4G, a strain on their spectrum holdings beyond the pressure from escalating mobile broadband demand.[4]

United States Spectrum

Spectrum is an extremely finite resource. Table 1 summarizes the main bands for commercial mobile radio service in the U.S. According to the FCC, there is currently 547 MHz of spectrum available. The history of this spectrum begins with 50 MHz awarded for analog cellular in 1981. The Personal Cellular Communications (PCS) band added 120 MHz in 1995, bringing many new operators into existence. The Educational Broadband Service (EBS)/Broadband Radio Service (BRS) band became available in 1996 and today is mostly controlled by Clearwire, which has rights to about 120 MHz. Advanced Wireless Service (AWS) added 90 MHz in 2006, followed by 70 MHz of television ultra-high frequency (UHF) spectrum in 2009.

[4] Similarly, analog cellular in the U.S. was only sunset in 2008 following FCC requirements for a five-year sunset period.

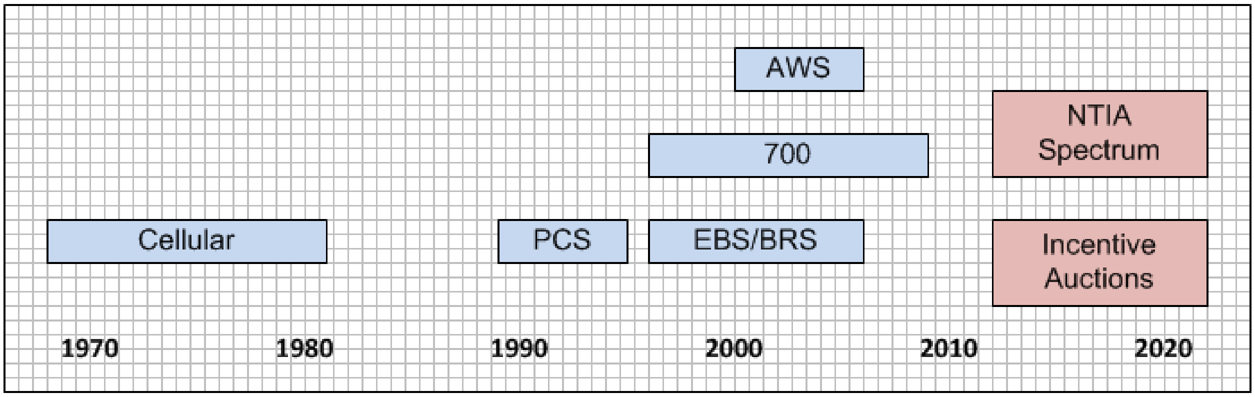
Table 1: U.S. Spectrum Allocations[5]

Band	Amount	Location	Year Available
Cellular	50 MHz	850 MHz	1981
Personal Communications Service (PCS)	120 MHz	1.9 GHz	1995
Educational Broadband Service (EBS)/Broadband Radio Service (BRS) – only partially used for mobile service	194 MHz	2.5 GHz	2006
Advanced Wireless Service (AWS)	90 MHz	1.7GHz/2.1GHz	2006
700 MHz	70 MHz	700 MHz	2009
Miscellaneous Including Enhanced Specialized Mobile Radio Service (ESMR)	23 MHz		
TOTAL	**547 MHz**		

How spectrum becomes available is both unpredictable and a drawn-out process, as shown in Figure 2. The bars depict the time from when government first repurposed that spectrum to when it became available for use.

[5] For additional details, refer to http://www.broadband.gov/plan/5-spectrum/.

Figure 2: Spectrum Acquisition Time[6]



The FCC is pursuing multiple avenues for making more spectrum available in the future. In the near term, there is potentially 90 MHz of Mobile Satellite Services (MSS) spectrum and 20 MHz of Wireless Communications Service (WCS) spectrum that could be available for use. Fifty MHz of the MSS spectrum, however, is owned by LightSquared, and is currently off the table due to concerns about interference with Global Positioning Systems (GPS).

The two biggest opportunity areas for new spectrum beyond MSS and WCS are NTIA-identified government spectrum from 1755 to 1850 MHz and incentive auctions of TV-broadcasting spectrum (up to 120 MHz). The NTIA spectrum involves a large number of government systems either migrating to other spectrum or co-existing with commercial systems by using shared approaches that are not yet identified. One portion, 1755 to 1780 MHz, could potentially be paired with 2155 to 2180 MHz and could come to auction in the next five years. With incentive auctions, the outcome depends on how many broadcasters choose to participate and under what compensation requirements.

Given these circumstances, it is almost impossible for operators to predict when they might acquire new spectrum. A huge industry concern is that current government spectrum plans do not adequately address the FCC's own projected need of 300 MHz of additional spectrum by mid-decade and 500 MHz of additional spectrum by the end of the decade. This is the challenging environment in which cellular operators must manage their networks.

Spectrum Deployment

Deploying spectrum is not a simple matter of an operator entering a command at a central console to increase the amount of spectrum used at specific cell sites from X to Y MHz. There are multiple

[6] Source for historical data, http://www.broadband.gov/plan/5-spectrum/; future expectations based on Rysavy Research analysis.

considerations that an operator must analyze in developing an optimal technology and business strategy, as described in Table 2.

Table 2: Spectrum Deployment Considerations

Item	Explanation
Escalating Demand	Demand keeps growing, especially mobile broadband, requiring networks to provide ever-increasing capacity.[7]
Infrastructure Investment	Capacity can be increased either by adding radio channels (moderate investment) or by deploying new technologies (high investment). Operators must carefully weigh how much spectrum to apply to legacy technologies versus new technologies. Deploying infrastructure is time consuming and uncertain, especially as new facilities need to be approved by localities.
Effective Business Model	Users may want additional capacity, however, operators must balance investment to increase capacity with the revenue they can obtain from services. For example, a newer technology such as LTE can deliver data at lower cost than earlier technologies, but involves a significant up-front investment.
Technology Maturity	Operators must deploy technologies at the right time. A newer technology may be spectrally more efficient and need less spectrum for the same amount of data capacity, but if it is not sufficiently mature, deployment may result in unreliable operation, and/or devices may be scarce. Waiting too long, however, may mean an operator is not competitive with other operators who can offer more robust features such as faster speeds.
Multiple Concurrent Versions of Technology	Due to large installed bases of users with handsets that only support older technologies and machine-to-machine applications that have long life cycles, operators have to support technologies for many years. The result is that operators have to devote spectrum to multiple generations of technology at the same time. For example, many Code Division Multiple Access (CDMA) operators are now

[7] For example, Cisco in its most recent report on mobile broadband demand predicts 78% compound annual growth of data from 2011 to 2016. See "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2011–2016," February 14, 2012.

Item	Explanation
	supporting 1xRTT, EV-DO, and LTE. GSM operators are supporting GSM, UMTS/HSPA, and LTE. Each technology constitutes a spectrum commitment.
Characteristics of Different Frequencies	Operators must decide what bands to use at what stage of deployment. Lower frequency bands may be better suited initially for coverage since fewer cells are required due to longer propagation, but later capacity requirements may mandate smaller cells that use higher frequencies.

Even if an operator wanted to deploy spectrum immediately, there are multiple sources of delay before spectrum can be put into service. First, there may be incumbent users (e.g., government, microwave) that have to vacate the spectrum, a process that, in itself, can take years.

Next, if the spectrum is new, the bands have to be added to standards specifications. Then, it takes time to actually get infrastructure equipment designed, developed, ordered, and finally deployed. For new bands and new radio technologies, it is possible that every single tower may need new antennas, filters, and other equipment. Engineering studies may be needed for loading on structures. In addition, adding new backhaul with more bandwidth consumes additional time.

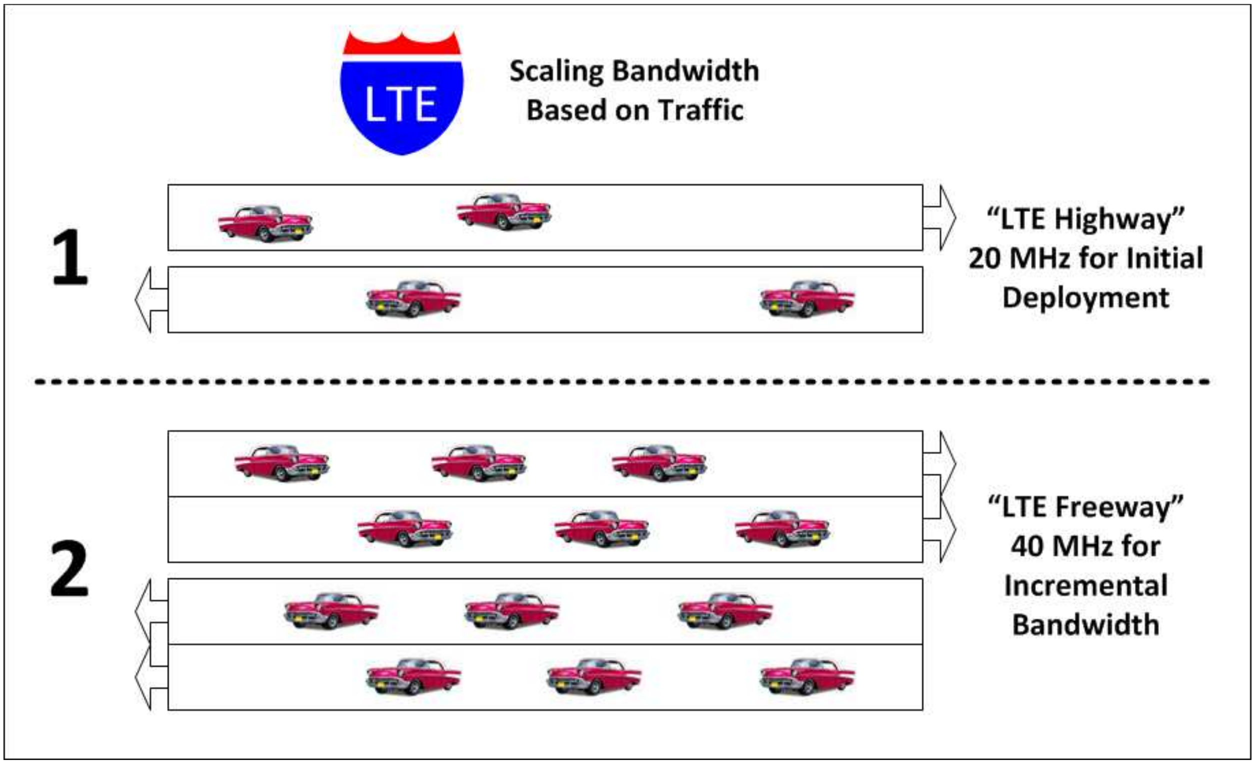
Once new spectrum is ready for deployment, tests may identify problems such as interference to systems that use adjacent bands, requiring operators to work with other entities to install filters. Even once networks are deployable, chipsets and devices may not be ready in production volume, further contributing to delays.

Beyond all these delays, to keep service prices as competitive as possible operators must deploy just the amount of spectrum needed to satisfy demand. This is because each wireless technology uses radio channels of a particular size. For example, HSPA uses 5 MHz radio channels for both the downlink and uplink while LTE, in most current deployments, uses 5 MHz or 10 MHz radio channels. There is an incremental investment at every cell site for using additional radio channels. With tens of thousands of cell sites in a national network, operators simply cannot simultaneously deploy every single MHz in their inventory across every site and market in the country. Rather, carriers must deploy based on what the demand portfolio is in a given market, the availability of infrastructure into which the spectrum can be added, and the utility of the spectrum in question to current versus future network technology deployments, among other items.

One can draw an analogy with highways. Tying up capital expenditures (CAPEX) to build a multi-lane super-fast highway to support the traffic of a small number of cars in an area means the money used to build that freeway can’t be applied to another area that needs a freeway to support many more cars.

Balancing the flow of traffic with the pace of spectrum deployment is key if carriers want to avoid artificially inflating service prices to recoup investment made to support little traffic. Figure 3 shows this process. Initial LTE deployment might occur with 20 MHz of spectrum commitment at 700 MHz while expanded-capacity deployment might occur with an additional 20 MHz of spectrum deployed in the AWS band.

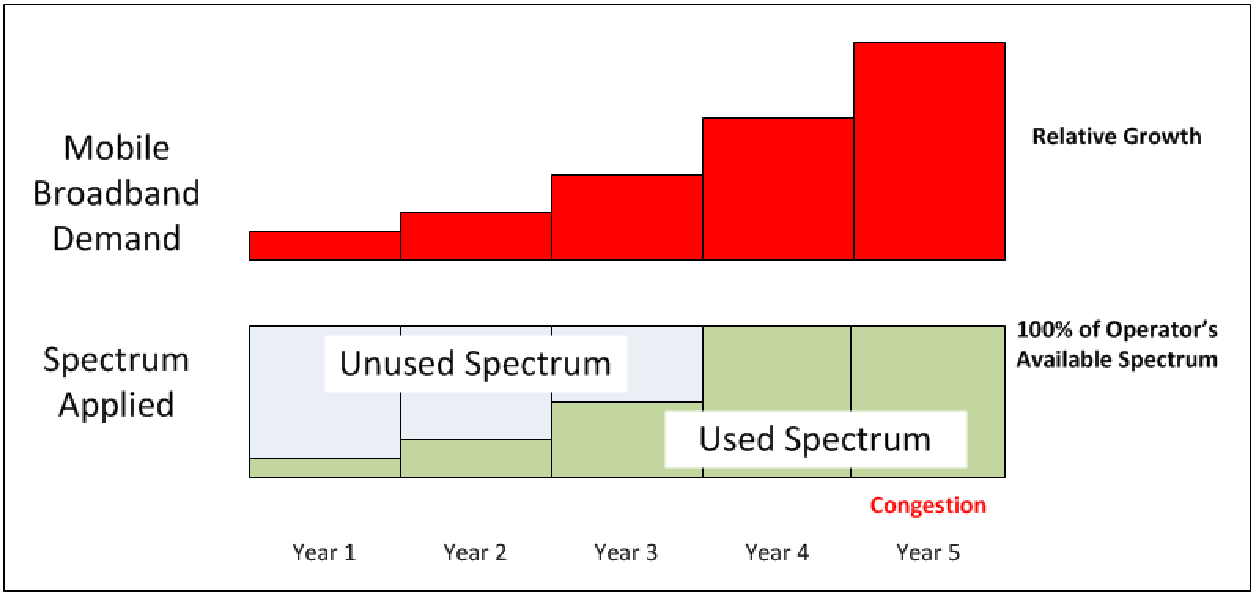
Figure 3: Scaling Highways Is Similar to Scaling Networks



Consequently, an operator's deployment and usage of spectrum varies over the life of the deployment. Figure 4 illustrates how this occurs. The red bars show growing annual demand for bandwidth, and the green bars show how much spectrum the operator needs to address that demand. In this example, during the first three years, the operator has more spectrum than needed for the level of demand, so it deploys the portion of its spectrum needed for that demand. By year four, however, the demand for services on the spectrum has exploded and the operator applies its entire spectrum portfolio and in year five, the operator starts experiencing network congestion as it is left with no more spectrum left to deploy to support continually increasing demand.

Some argue that if the operator is not using every MHz in its entire spectrum portfolio at every minute of every day in every market immediately upon acquiring it, the operator is "hoarding" spectrum. Deploying successive network technology upgrades and trying to stay ahead of evolving demand scenarios make it impossible – and foolish – to deploy every MHz at every location in every instance. The Appendix illustrates this process in a hypothetical operator scenario.

Figure 4: Application of Spectrum to Growing Demand



Capacity Augmentation Beyond Spectrum

Operators can augment capacity most quickly by using more spectrum. There are other ways that operators can augment capacity as summarized in Table 3, but they tend to take longer to implement.

Table 3: Capacity Augmentation

Method	Comment
Macro (large area) sites	Operators continue to add macro sites, however, given zoning approval and other logistical challenges, these can only be added at a relatively slow rate.
Small cells	The industry is vigorously pursuing small-cell architectures including picocells and femtocells. There are many technical issues to overcome including backhaul connections, management, and self-optimization, so small cells as a partial solution to the capacity crunch will be a "work in process" for the rest of the decade.
Distributed antenna systems	These primarily improve coverage indoors but can also boost capacity.
Ongoing advances in	LTE through LTE-Advanced has a rich roadmap of new features that will

Method	Comment
wireless technology	contribute to capacity enhancements including smart antennas and heterogeneous networks.
Wi-Fi offload	Increasingly, users can perform bandwidth-intensive tasks such as watching video over Wi-Fi connections.

It will take a combination of all of these approaches *plus* more spectrum to address mobile-broadband demand. Of all of these, more spectrum is the most efficient way of adding capacity quickly.

Conclusion

Opportunities for incumbent operators to obtain spectrum are few and far between. Given the chance to acquire additional spectrum, most operators will choose to do so any time spectrum is made available by governments or private entities, regardless of the stage of build-out of their networks. The spectrum they obtain may be used to augment their networks using current technology, or may be held for the deployment of new technologies such as what occurred with 700 MHz spectrum and LTE.

Acquiring spectrum is expensive, as is deploying it. Deciding what technology to deploy, using what spectrum and how much of it is a complex process, one that operators must manage carefully. This process is time consuming and inevitably results in periods of time when operators are not using every MHz of spectrum they might hold in various markets around the country. Over time, as operators continually augment their network capacity to address evolving consumer demand, all spectrum held by an operator will be used. Moreover, the FCC has build-out requirements for spectrum. Companies that have an embedded customer base, established brands and a need to take in revenue to cover CAPEX costs are typically in favor of meeting FCC construction obligations and avoiding their spectrum licenses being taken away for failure to put it into service.

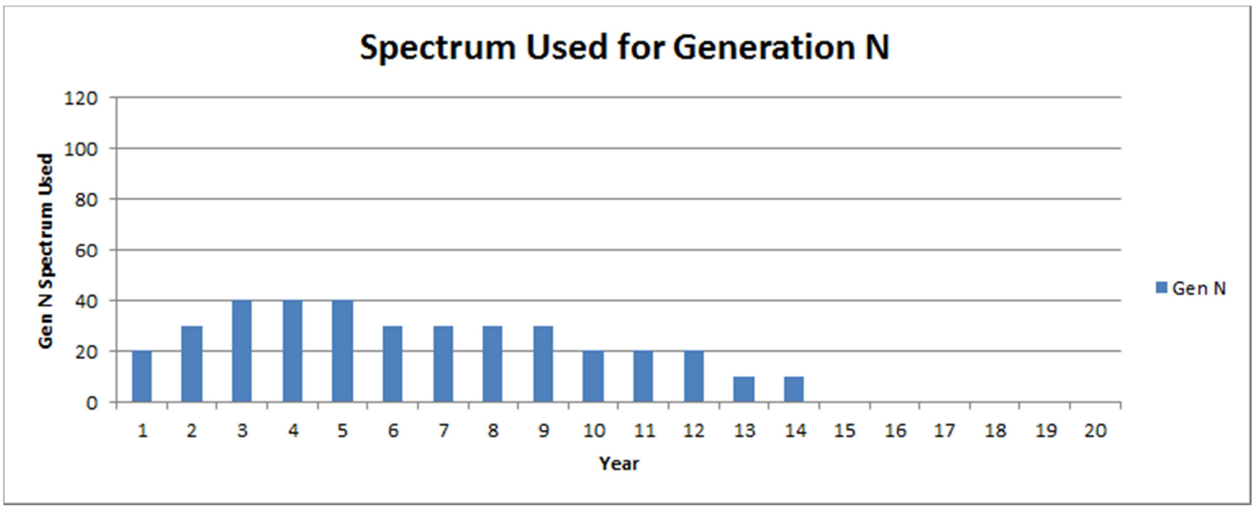
Demand for mobile-broadband capacity is so high and is growing so quickly that it will take far more than the spectrum that has already been allocated to address the wireless market's full potential.

Appendix: Hypothetical Spectrum-Deployment Scenario

One can examine the application of spectrum from a longer-term perspective, while also considering the effect of successive generations of technology. The following shows a hypothetical scenario over a 20-year period in which an operator begins with 50 MHz of spectrum in year one, and then acquires an additional 20 MHz every five years, resulting in a total of 70 MHz of spectrum in year six, 90 MHz in year 11 and 110 MHz in year 16.

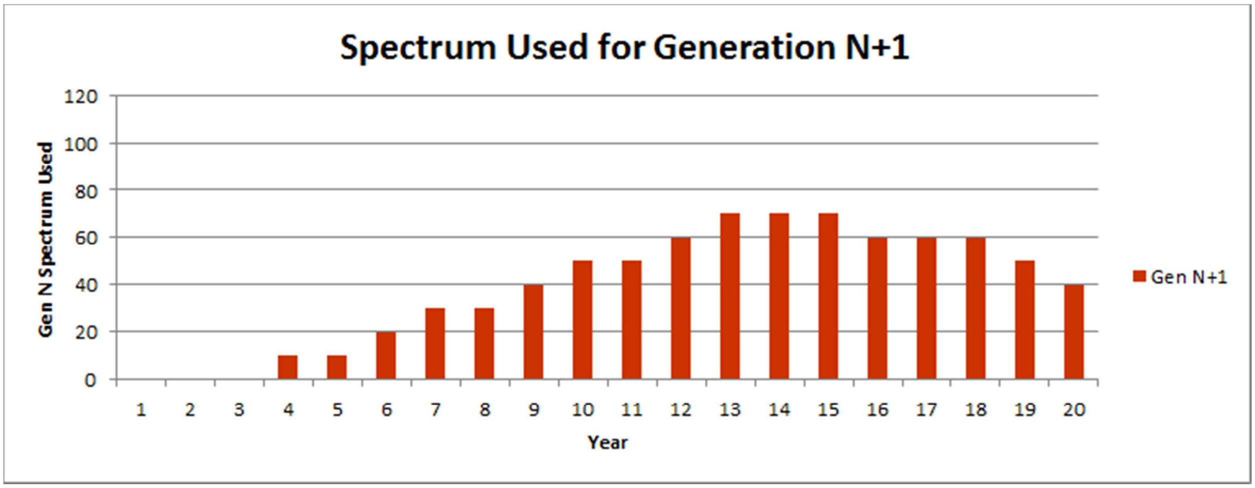
Figure 5 shows the operator scenario beginning with Generation N of technology (for example 2G) and 20 MHz of spectrum (out of 50 MHz available) deployed in year one. The operator increases capacity of this network until, in year three, the operator has 40 MHz applied.

Figure 5: Typical Operator Spectrum Deployment – Generation N



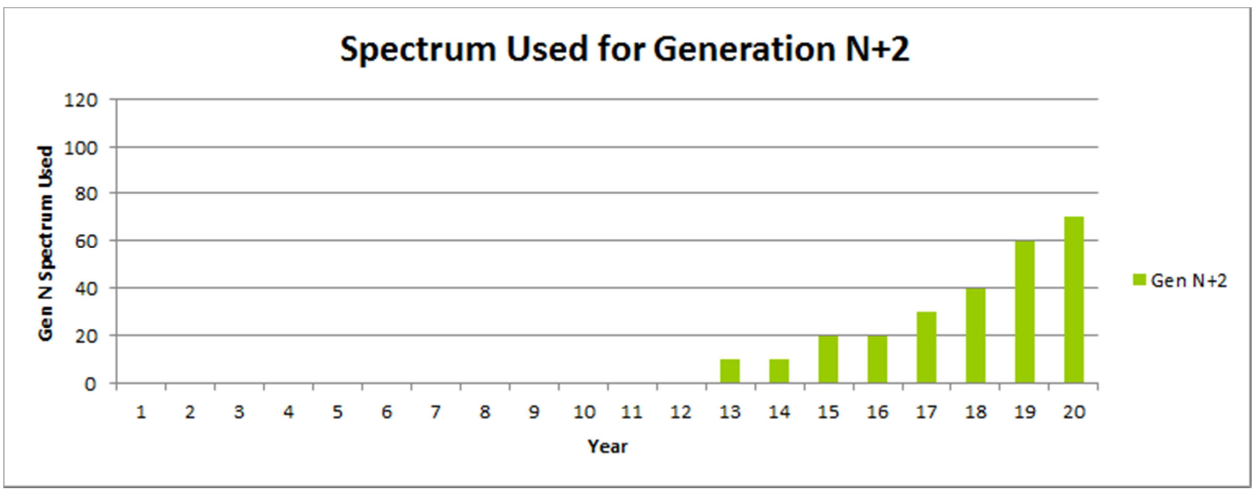
In year four, the operator introduces a new technology, Gen N+1 (for example, 3G), shown in red in Figure 6. The operator keeps adding spectrum to Gen N+1, reaching a peak of 70 MHz of spectrum used for Gen N+1 in year 13. Meanwhile, the amount of technology applied to the previous generation (Gen N) decreases beginning in year six (see previous figure) until the operator has phased the technology out entirely in year 15.

Figure 6: Typical Operator Spectrum Deployment – Generation N+1



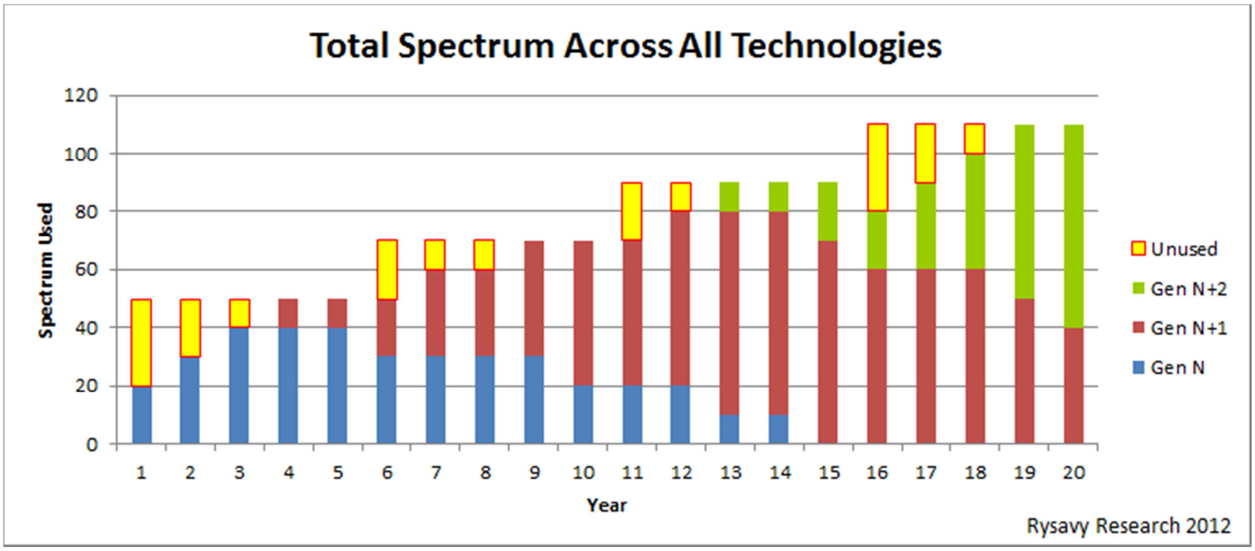
A similar cycle occurs with Gen N+2 (for example, 4G) technology that the operator starts deploying in year 13, as shown in green in Figure 7. By year 20, Gen N is no longer available, Gen N+1 is waning and Gen N+2 is reaching its peak deployment.

Figure 7: Typical Operator Spectrum Deployment – Generation N+2



Superimposing the spectrum used for the individual technologies, one gets the following complete picture of spectrum deployment, as shown in Figure 8.

Figure 8: Typical Operator Spectrum Deployment – All Generations



The yellow highlighted area shows years when spectrum is unused. As discussed previously, this is an inevitable consequence of operators only being able to obtain spectrum at discrete points in time, and minimizing service prices by deploying only the spectrum needed to address capacity needs. As one can see in this typical scenario, over time, the spectrum does become fully used.

About Rysavy Research

Peter Rysavy is the president of Rysavy Research, LLC, a consulting firm that has specialized in wireless technology since 1993. Projects have included reports on the evolution of wireless technology, spectrum analysis for broadband services, evaluation of wireless technology capabilities, strategic consultations, system design, articles, courses and webcasts, network performance measurement, and test reports. Clients include more than seventy-five organizations.

Peter Rysavy is a leading international authority on the capabilities and evolution of wireless technology. He has written more than a hundred and twenty articles, reports, and white papers, and has taught forty public wireless courses and webcasts. He has also performed technical evaluations of many wireless technologies including municipal/mesh Wi-Fi networks, Wi-Fi hotspot networks, mobile browser technologies, cellular-data services and wireless e-mail systems.

From 1988 to 1993, Peter Rysavy was vice-president of engineering and technology at LapLink where projects included LapLink, LapLink Wireless, and connectivity solutions for a wide variety of mobile platforms. Prior to that, he spent seven years at Fluke Corporation where he worked on touch screen and data acquisition products.

Peter Rysavy is also the executive director of the Portable Computer and Communications Association (PCCA, http://www.pcca.org), a group that evaluates wireless technologies, investigates mobile communications architectures, and promotes wireless-data interoperability. Peter Rysavy graduated with BSEE and MSEE degrees from Stanford University in 1979. More information is available at http://www.rysavy.com.