The Benefits of Using LTE in Digital Dividend Spectrum

November 2011

TABLE OF CONTENTS

EXECUTIVE SUMMARY

We are on the path to an explosion in mobile broadband usage that will put an unprecedented level of pressure on the capacity of wireless networks. This traffic explosion is fueled by continual enhancements in devices, expansions of applications, improvements in network performance, and evolution toward cloud based computing. This growth in mobile broadband usage is also very strategic for countries and regions. Mobile broadband is being seen as a platform for opportunity that can spur economic growth, job creation and solutions to address national concerns. Though LTE and LTE-Advanced are poised to be the dominant mobile broadband and broadcast technologies to support this project traffic growth, technology improvements alone will not be able to keep up with the ballooning network capacity demand. In short, the mobile industry needs the Digital Dividend spectrum. The allocation of the Digital Dividend spectrum for mobile networks will reduce deployment costs and bring broadband to remote regions of the world—bridging the digital divide and making broadband services more affordable to the masses.

The intent of this paper is to provide information on the benefits of using the Digital Dividend spectrum for mobile broadband, particularly with LTE technology, and to encourage regulators to move quickly toward allocating this spectrum for mobile broadband given its potential for providing social and economic benefits.

THE MOBILE BROADBAND TRAFFIC EXPLOSION DRIVING THE NEED FOR MORE SPECTRUM

Ever since the wireless industry began to focus on initial 3G technologies like UMTS about a decade ago, there have been predictions of a wireless data explosion. However, it is only within the last several years that such predictions have finally come true and these are now putting tremendous stress on wireless networks. Trends show that wireless data demands continue to increase at phenomenal rates. In fact, the ITU highlighted that mobile broadband subscriptions now materially surpass fixed broadband subscriptions, as shown in Figure 0-1, which punctuates this inflection point. Wireless networks are now expected to provide capacity for mass multimedia connectivity just like fixed networks, with some projections showing a 30-fold increase in wireless data capacity requirements over the next five years.

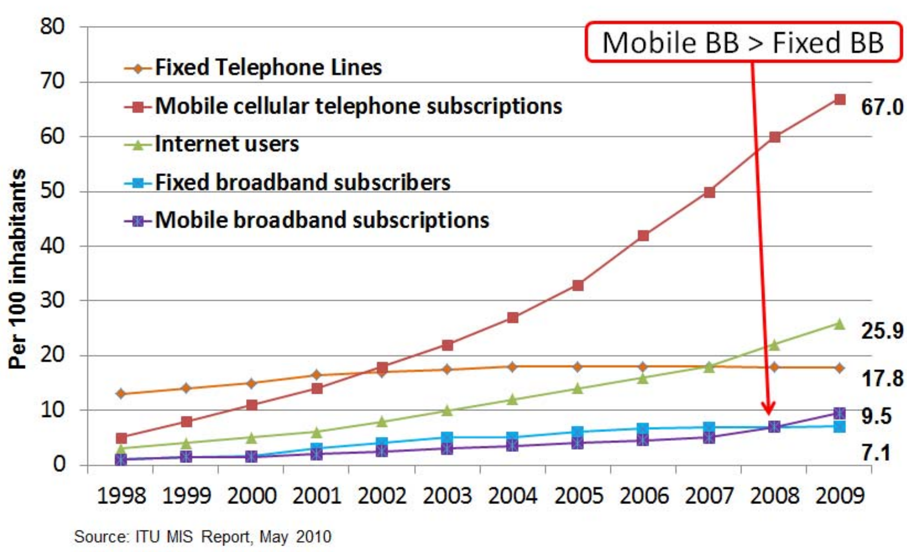


Figure 0-1: Yearly growth in broadband subscriptions

Many elements are at play when reviewing the fast rise of mobile broadband consumption. These include devices, networks and the technology standards they support, available applications and end-user needs or desires. These elements work together synergistically to improve the quality of experience for the end users. As illustrated in Figure 0-2, advancements in devices enabling more and better applications to be used over more advanced wireless networks will result in a superior wireless user experience, which, in turn, leads to increased satisfaction and usage. This trend is expected to continue in the next several years. As a result, wireless data capacity demands are projected to continue to increase at exponential rates over the next several years driving the critical need for increased spectrum to support mobile broadband services. One of the most prized spectrums under considerations around the globe is the Digital Dividend spectrum.

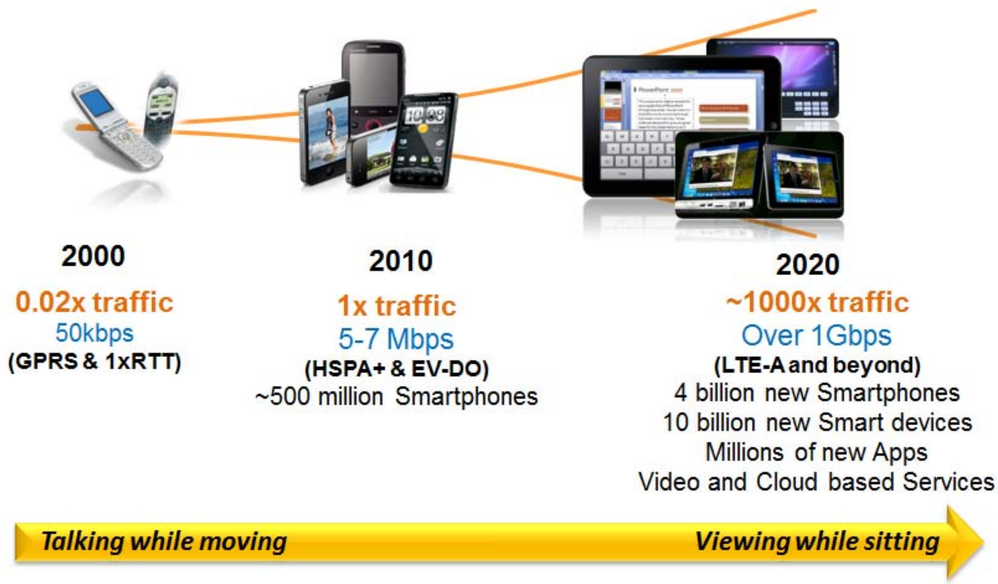


Figure 0-2: Evolutions of device, technology and applications driving MBB explosion

THE STATUS OF THE DIGITAL DIVIDEND SPECTRUM AROUND THE GLOBE

The Digital Dividend refers to spectrum in the 200 MHz to 1 GHz frequency range that is freed up by the replacement of legacy analog terrestrial TV transmitters with newer digital terrestrial TV technology. For years broadcast TV has been supported by analog transmission, but digital broadcast TV has proven to be significantly more spectrally efficient. There are two main technological improvements that make digital broadcast more spectrally efficient than analog and allow for the freeing up of spectrum. First, digital broadcast technology enables more channels to be packed into the same RF channel bandwidth used with analog broadcast technology. Second, digital broadcast enables greater frequency reuse, with much more lenient taboos on rules for channel spacing, even permitting adjacent channel allocations within shorter distances.

Given the benefits of digital broadcast technologies, the transition from analog broadcast to digital broadcast across the world is freeing up spectrum in the Digital Dividend frequency bands (i.e., ~700–900 MHz). However, the amount of spectrum being cleared, the exact part of the Digital Dividend bands where it is cleared as well as the timing for transitioning the broadcasters from analog to digital differs from region to region. This was to be expected since different analog and digital broadcast technologies are deployed in different regions. While harmonization is always a goal with new spectrum definitions for cellular use, the legacy broadcast spectrum situations in the various regions of the world make this difficult. Thus, different Digital Dividend band plans are expected in the different regions of the world. Figure 0-3 shows the projected analog to digital switchover time for broadcast TV around the globe according to Global System Mobile Associations (GSMA).

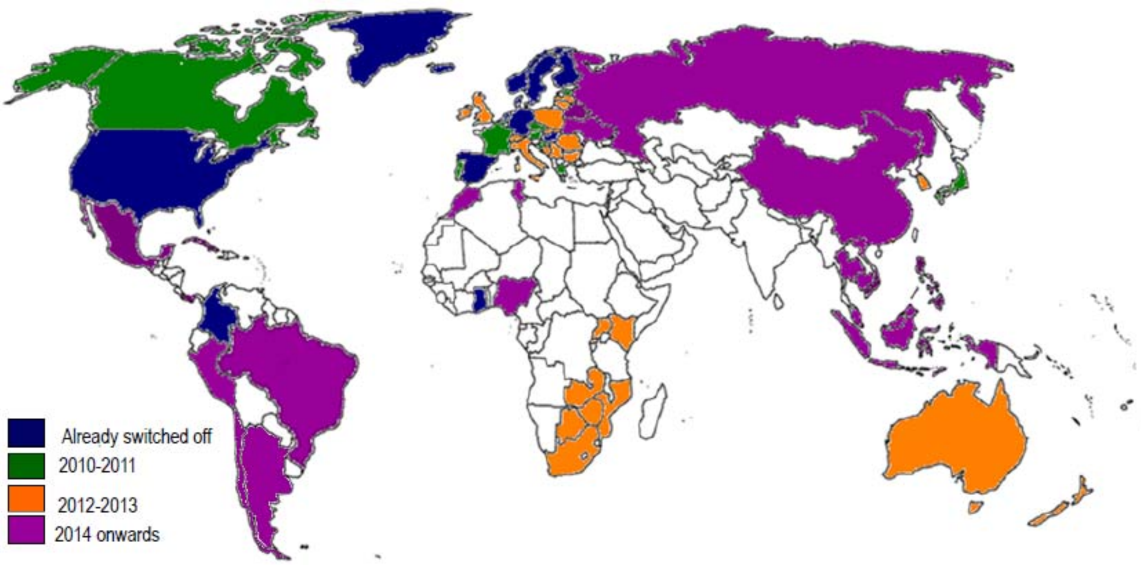


Figure 0-3: Projected analog to digital TV switchover time around the world

Figure 0-4 illustrates the definition of 3 regions around the globe. Region 1 is made up of Europe, Middle East and African countries. Region 2 consists of the countries in the Americas, and Region 3 contains all the Asian countries. According to the GSMA, the designations of the Digital Dividend spectrum for mobile services in each region are as follows:

- Region 1 (Europe, Middle East and Africa) identified 790–862 MHz for mobile services
- Region 2 (Americas) identified 698–806 MHz
- Region 3 (Asia) mobile allocations are 470–960 MHz, with a number of Asian Pacific nations identifying 698–806 MHz for IMT systems

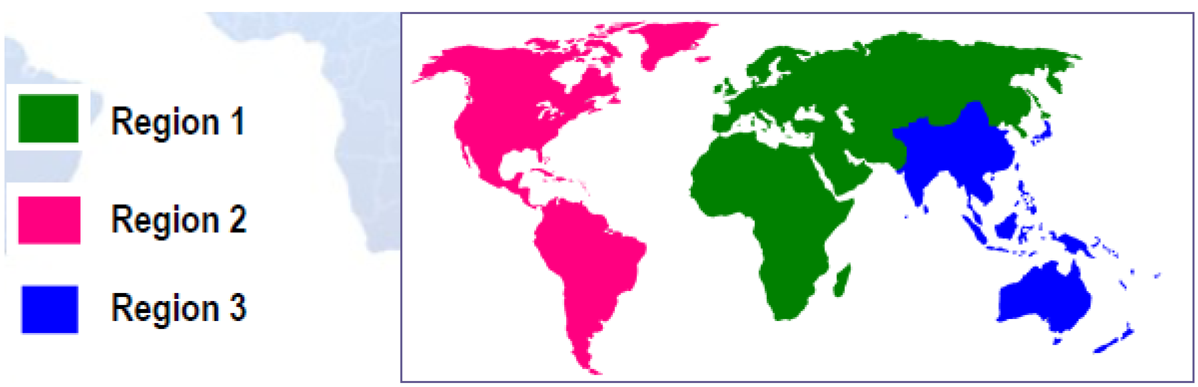


Figure 0-4: Region definition

THE SOCIAL AND ECONOMIC BENEFITS OF THE DIGITAL DIVIDEND SPECTRUM AND MOBILE BROADBAND AND BROADCAST

The Digital Dividend spectrum can bring game-changing benefits to all parties involved. It can serve society's greater needs in various vertical industries, such as healthcare, education and energy. It can ignite innovations in mobile broadcast, devices, applications and mobile cloud-based services. It can energize the economy with new investments, adding jobs and growing the GDP. The spectrum has ideal propagation characteristics, particularly for rural coverage, and can help bridge the digital divide and bring broadband services to the underserved and the unserved remote areas of the world. It offers the broadcast industry stakeholders a way to compete with the cable-, satellite-, and internet-based TV service providers, with services for both IP-based interactive broadcast television and on-demand videos, by leveraging LTE's (Long Term Evolution) unique capability to support both broadband and broadcast services on a single air interface. It is the one significantly important spectrum band left that also has the biggest potential for spectrum harmonization globally, which will benefit the consumers with a large scale device ecosystem. These benefits are discussed point by point below:

1. Wireless services cannot be offered without wireless spectrum. Viable internationally harmonized spectrum is in extremely short supply for existing and new wireless entrants. According to the FCC, "Spectrum bandwidth is a necessary input to the supply of mobile wireless services. If a potential entrant were to attempt to enter the mobile wireless services market, obtaining access to spectrum is crucial." The Digital Dividend spectrum, in particular, will be a critical spectrum source for the wireless industry in many countries. This spectrum has the potential to bring new service providers into rural markets or enhance existing carriers spectrum assets, both of which could ignite innovations and create lifestyle-changing experiences, especially to the millions of underserved in those markets today.
2. Around the globe, there is little dispute that mobile broadband delivered at the 700 MHz Digital Dividend spectrum provides great economic and social benefits. A sample of a few studies and papers on this subject shows the following results:
    - In Asia-Pacific, this benefit is estimated at an addition of approximately three-quarters of a trillion dollars to the GDP of the Asia-Pacific nations by 2020.
    - In Australia, this benefit is estimated at between $7 billion and $10 billion, depending on which mobile broadband market scenario is realized.
    - For developing countries of the world, it is estimated that bringing mobile broadband penetration to the level of that in today's Western Europe would result in $300 billion to $420 billion in contributions to these countries combined GDP and create an additional 10 to 14 million more jobs.
    - GSMA points to studies showing that there would be a 1.2 percent increase in GDP for every 10 percent increase in mobile penetration in many emerging markets.
    - For the Latin America region, a jointly commissioned study by GSMA and AHCIET and conducted by Telecom Advisory Services LLC (TAS) claimed a $15 billion total economic value to the region and expansion of wireless coverage to 93 percent of the population. The same study indicated that close to 11,000 new jobs would be created.
    - Another earlier study by McKinsey & Company on Latin American countries stated the combined GDP could increase by up to $70 billion, and add up to 1.7 million more jobs.
    - In EU countries, it is estimated that by 2020 the use of the Digital Dividend for mobile broadband will increase GDP by 0.6 percent annually.
3. From the early days of narrow-band packet-switched data services, we have enjoyed steady blasts of work and lifestyle enhancements as the result of device innovations, such as the QWERTY-equipped

devices for corporate email, and the feature phones for access to basic news, weather, traffic and gaming download services. This was followed by touch-screen smartphones, coming along just as the mobile broadband data services adoption rate was picking up, and once again revolutionized the mobile device concept and affected how we consume mobile broadband, particularly for the non-enterprise segments. We are now at the cusp of another major computer revolution with cloud computing, and one of the major drivers for this is the ubiquitous availability of mobile broadband. Tablets, with capabilities to access online stored contents wirelessly, are picking up market share from PC and laptop usage. Future innovations have no limits and could include a category of mass market mobile devices that are as powerful as PCs are today. These new devices will be leveraging processor, display, and battery innovations, to deliver the power and usability of a PC with the convenience of mobility that fits in the palm of your hand. The frenzied competitions among innovators to produce such a device are the buzz in the industry today. Machine-to-Machine (M2M) devices and applications are another area of innovation with game-changing promises. For example, imagine an intelligent electric car charger in communication with a centralized server that knows when the price of electricity is at its cheapest throughout the day to charge the car battery. Such potential for improved efficiency and lower costs for the consumers are boundless. Innovations in devices for vertical markets such as health care, enterprise, and education can raise the standards of living and increase economic productivity in a country.

4. The Digital Dividend spectrum is very unique with its ideal propagation characteristics for mobile broadband use. It is much more economical to deploy a wireless network using the Digital Dividend spectrum than spectrum in higher frequency bands. The GSMA stated that “it is approximately 70 percent cheaper to provide mobile broadband coverage over a given geographic area using UHF spectrum than with the 2100 MHz spectrum widely used for mobile broadband today.” The cost benefits come from the ability to use fewer cell sites to provide blanket coverage geographically as illustrated in Figure 0-5. Fewer cell sites means lower equipment capital expense, lower deployment costs requiring fewer towers and facilities, and lower operational costs in terms of maintenance costs, power consumptions, site leasing and backhaul leasing. Only with such economics can one have hopes of bringing broadband to every human being on the planet.

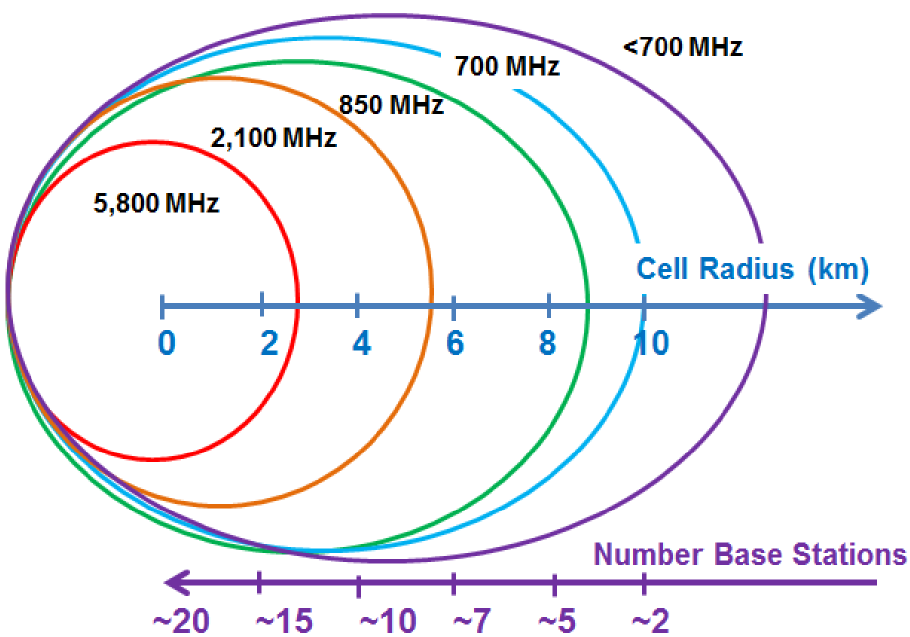


Figure 0-5: Cell site coverage radius at different frequency bands

5. The solution for broadcast TV operators to keep atop the interactive TV and Video On Demand (VOD) services trend and remain competitive in the TV services industry is LTE, or Long Term Evolution. LTE is a next-generation all-IP Mobile Broadband network technology that includes not only a mobile broadband component, which will be well-suited for VOD services, but also a mobile broadcast component with its enhanced Multimedia Broadcast and Multicast Systems (eMBMS) for broadcast services. In combining the mobile broadband and broadcast service delivery capability of LTE, operators can also offer mobile and interactive TV. Integrated Mobile Broadcast (IMB) is another broadcast technology option for 3G mobile broadband networks. Similar to eMBMS, IMB is an enhancement to the 3G MBMS technology designed to work with time division duplex (TDD) spectrum.

   There are various possible options for broadcasters looking to enter the mobile broadband and broadcast markets, which include building out a mobile TV network, sharing a network with existing operators, or becoming a virtual network operator (MVNO). With any options under consideration for broadcasters, there should be a net positive value for the broadcasters when compared to doing nothing.

ALTERNATIVES FOR MOBILE BROADCAST

The number of existing digital terrestrial broadcasting standards is quite high. From traditional terrestrial broadcasting to fixed receivers, the major standards in use around the globe are ATSC, ISDB-T, DVB-T and DTMB (formerly DMB-T/H), as shown in Figure 0-6. Each of these standards has in recent years obtained at least one dependent standard designed for mobile reception by handheld receivers, where antennas are typically telescopic and fixed to the device. Examples are ATSC-M/H, DVB-H, ISDB-T 1SEG, and CMMB. Additionally, several cellular standards have also added support for a true broadcast transmission mode (e.g., eMBMS for WCDMA and LTE, BCMCS for CDMA2000, and MBS for WiMAX).

Figure 0-6: Adoption of individual digital broadcasting standards around the world

One can argue that the latest traditional broadcast technologies, as described above, have solutions optimized for handheld devices, such as ATSC-M/H and DVB-H, and thus should be considered for mobile broadcast services. However, the key difference between those technologies and LTE with eMBMS is the lack of support for high-capacity, high-bandwidth IP-based mobile broadband unicast services in combination with mobile broadcast services. In addition, the eMBMS solution is based on the LTE radio specifications and would only require a software upgrade for support on the existing LTE chipset and devices. The number of LTE devices is projected to be in the billions within the next 10–15 years. Therefore, it would offer much greater economies of scale for LTE/eMBMS-capable devices than any scales that ATSC-M/H or DVB-H technology could offer. Table 0-1 highlights the key advantages and disadvantages between the different broadcast technologies for mobile broadcast services. eMBMS (and IMB) are designed to be deployed alongside a dense mobile broadband network, which allows it to meet the small delay spread requirement and delivers high performance even for very high mobility users. Traditional broadcast technology, on the other hand, imposes significant speed limitations on users, or does not efficiently support mobile broadband.

Metric technology	Delay spread tolerance	Deployment density	SFN performance	Mobility
ATSC M/H	Medium	Sparse	Low	High
DVB-T/DVB-H	Medium–High	Sparse	Low–Medium	Low–Medium
DVB-T2 (Lite)	Medium–Very high	Sparse	Low–High	Low–Medium
eMBMS & IMB	Low	Very dense	High	Very high

Table 0-1: Comparison of key metrics of digital broadcasting technologies

LTE IS THE FUTURE FOR MOBILE BROADBAND

LTE is the global standard developed by the 3rd Generation Partnership Project (3GPP) for next-generation mobile broadband networks supported by all major players in the industry. LTE offers the capacity and speed to handle a rapid increase in data traffic with close to 5 billion mobile broadband subscriptions expected by 2016.

- Performance and capacity – One of the requirements of LTE is to provide downlink peak rates of at least 100 Mbps. The technology allows for speeds of more than 300 Mbps, and the industry has already demonstrated the next step of LTE, i.e., LTE-Advanced, with theoretical peak rates up to 1.2 Gbps.
- Simplicity – LTE supports flexible carrier bandwidths, from 1.4 MHz to up to 20 MHz. LTE-Advanced allows for aggregation of carriers to support non-contiguous and multiband bandwidths of up to 100 MHz. LTE also supports frequency division duplexing (FDD) and time division duplexing (TDD).
- Latency – The user-plane latency achieved in LTE is less than in existing 3G technologies, providing a direct service advantage for highly immersive and interactive application environments such as multiplayer gaming and rich multimedia communications.
- Telephony services – In addition to the support of high-speed data, the LTE standard was also developed to include the features needed to effectively support voice-over-IP (VoIP) service. Telephony services in LTE specified by 3GPP are either realized by IP Multimedia Subsystem (IMS) and Multimedia Telephony (MMTel), aka Voice-over-LTE (VoLTE), or by circuit-switched fallback (CSFB) in the scenario where IMS is not deployed.

LTE will be a main driver for innovation in the years to come, possibly enabling the next Google, Facebook or iPhone, and opening doors to possibilities in a number of new areas like utility transport, health, and media, to name a few. There were 33 commercial LTE deployments around the world (October 2011), and at least 75 LTE networks are anticipated to be in commercial service by the end of 2012. In total, over 250 operators from around the world have committed to deploying LTE technology. Consequently, the LTE ecosystem is developing rapidly. According to the GSA, as of August 2011, there were 161 LTE devices by 45 manufacturers launched worldwide. In addition to LTE dongles and mobile phones, many computer and consumer electronic devices, such as notebooks, ultra-portables, gaming devices and cameras, will incorporate embedded LTE modules.[xxxiii]

Today over 200 million people have access to commercial LTE networks. Figure 0-7 illustrates the size of operators deploying commercial LTE networks in terms of number of current subscribers.

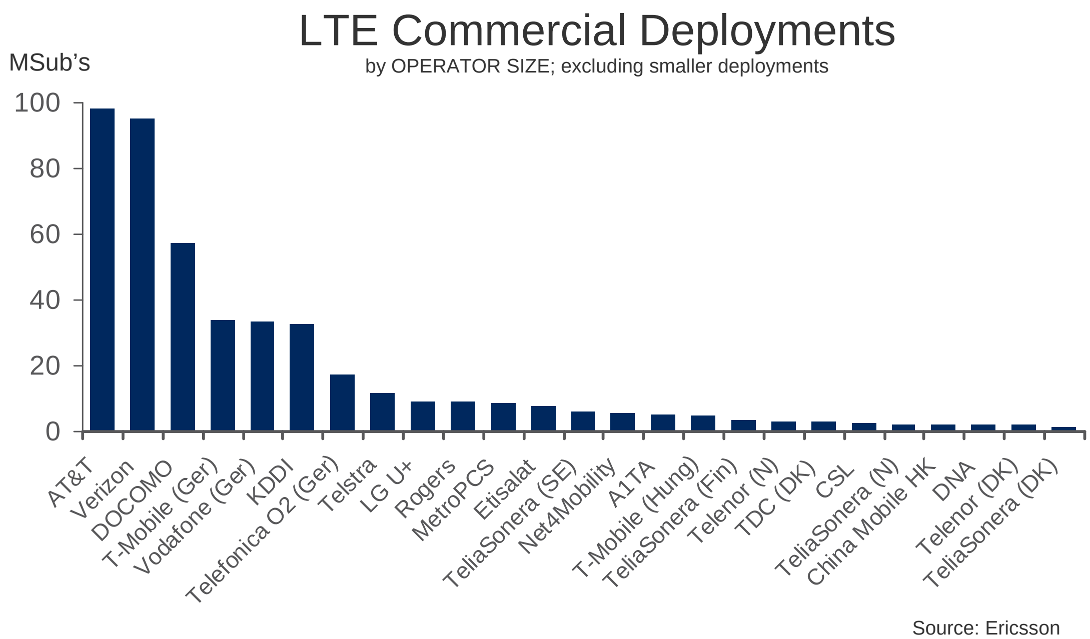


Figure 0-7: Million subscribers per operator deploying commercial LTE

SPECTRUM PLANNING CONSIDERATIONS

Based on industry experience, 4G Americas offers the following principles for spectrum allocation and assignment. Although this set of principles is generic, it should generate the development of strategies that ensure the continued vitality of mobile broadband services in the Americas by using LTE in the Digital Dividend band.

1. CONFIGURE LICENSES WITH WIDER BANDWIDTHS

   Upcoming technologies, such as LTE, will require wider bandwidths than current technologies, to take advantage of spectral efficiency and therefore support ever more supple mobile broadband capability. This is required to meet consumer demand for bandwidth-intensive and content-rich services. Spectrum allocations should therefore be in sufficiently large contiguous blocks to accommodate the future development of mobile broadband networks, particularly in urban and suburban areas where allocations should focus, at a minimum, on 2X10 MHz blocks.

2. GROUP LIKE SERVICES TOGETHER

   Current spectrum allocation frameworks largely tend to compartmentalize spectrum by types of services. The grouping of like services can reduce complexity and cost, and allows more flexibility in the form factor of the subscriber equipment. For example, by allocating the entire 700 MHz band for similar services, such as the Asia-Pacific band plan for LTE, the number of bands that a device must support is reduced. This would facilitate development of user equipment, accelerating availability at a low cost due to the economy of scale associated with using standard band plans. Mixing LTE services with high power downlink-only service is not recommended. This would create spectrum band usage inefficiency and increase complexity of both the network infrastructure, and especially of the end user device.

3. BE MINDFUL OF GLOBAL STANDARDS

Technical standards are the foundation service providers and manufacturers use to develop competitive products and services and to take advantage of worldwide economies of scale that lower costs for infrastructure equipment as well as devices. Furthermore, global standards contribute to faster and broader technology deployment. Without global standards, device diversity would be reduced, which has been seen to impede customers' interest to consume services. From an operator's perspective, a deployment that is not based on globally accepted standards introduces a risk factor. If customers are not interested in an operator's service offerings, it would mean a lesser return on investment, which, in turn, would slow down the network operator's capacity and coverage investments. This would diminish overall GDP growth. In addition, standards promote growth and maximize opportunities for innovation. In many instances, globally accepted standards take into consideration coexistence with adjacent services to optimize usage. In the case of the Digital Dividend, this means it would minimize the impact of adjacent broadcasting services below the 700 MHz band. Therefore, whether certain spectrum bands have been harmonized, and whether a standard exists, should be factored into spectrum allocation decision making.

4. PURSUE HARMONIZED/CONTIGUOUS SPECTRUM ALLOCATIONS

Ensuring that spectrum allocations are, to the greatest extent possible, in accord with international allocations promotes innovation and investment by creating critical economies of scale. Similarly, harmonization facilitates global roaming and helps countries that share borders to manage cross border interference. Without harmonization, a technology is not widely used. This prevents the sharing of development costs globally. This increases overall product and service costs, limiting technology proliferation and delaying the ability to get to the marketplace.

5. EXHAUST EXCLUSIVE USE OPTIONS BEFORE PURSUING SHARED USE

"Exclusive-use" option should be the recommended and preferred model for cost effective and rapid deployment of services, benefiting all parties involved: infrastructure vendors, device makers, service providers and most importantly customers. The "exclusive use" model refers to a framework in which a licensee has rights that are exclusive, flexible, and transferable, while at the same time inheriting specific responsibilities that come with these rights that would benefit a country's economy. Licensees are also afforded protection from interference and may use the spectrum in a flexible manner consistent with the terms of the license. Moreover, the certainty provided by the exclusive use licensing approach encourages investment (both in the network and the services) by promoting an environment in which interference and system capacity can be predicted.

In a spectrum-sharing environment, spectrum resources are made available based on established technical "etiquettes" or regulations that set power limits, and other criteria for operation of devices, to mitigate potential interference (such as geographic "protection" zones and temporal restrictions). Successful sharing arrangements must be tailored to the specific conditions in the band—on a band-by-band basis. These conditions must be known at the inception of the design to avoid inappropriate and costly technology development. Because each sharing environment is unique, technology research and development suitable for the services sharing frequency bands and knowledge of the specific sharing constraints are required, otherwise, investment and innovation will be impeded by such operational uncertainties.

Therefore, if spectrum sharing is to be considered over exclusive use of the 700 MHz band (in fact, for any other band), such a proposal needs to be closely examined. Each envisioned spectrum sharing opportunity should weigh the foreseen benefits and opportunities provided by a variety of factors including service viability, technology support, and adequate knowledge of the operating environment before being implemented. Any uncertainty about its positive outcome should be a signal to carefully consider an exclusive use and maximize benefit to all parties: services providers, customers and country's economy.

6. NOT ALL SPECTRUM IS FUNGIBLE – ALIGN ALLOCATION WITH DEMAND.

   Suitable lower-band frequencies, such as 700 MHz, have the ability to provide services more efficiently—they have the appropriate propagation characteristics to penetrate walls of buildings—and have a significant coverage range across a broadly defined geographic area without requiring the mobile handset to support an unwieldy antenna. Therefore, 700 MHz spectrum is essential to serve rural and isolated areas, where the population density is low.

CONCLUSION

In the "Announcing the National Broadband Plan" speech, FCC Chairman Julius Genachowski stated that broadband is an indispensable infrastructure of the 21st century—a foundation for the economy and democracy in the digital age. The Chairman highlighted that broadband is a platform for opportunity that can spur economic growth and job creation; a platform for innovations; a platform for solutions to national concerns in education, healthcare, energy dependence and public safety and a platform for global competitiveness. He stressed the need to make very high speed broadband connections affordable so all Americans would be connected. The FCC plan is aimed at maximizing investment by unleashing new spectrum, promoting competition, removing barriers to entry and lowering the cost of investment in infrastructure. In fact, in the U.S., the FCC is asking Congress for authority to move forward with rule making and incentive auctions for the underutilized TV broadcast spectrum.

This recognition in the importance of broadband to the economic and social infrastructures is not uniquely American. The European Commission also shares similar optimism concerning the opportunity for broadband to contribute to economic recovery. As the world is transforming to a global economy, driven largely by the ability on both the supply and demand sides to have access to broadband connections for digital information sharing and execution of electronic commerce, the value of universal broadband access should be recognized and sought after by all nations in order to remain competitive on the global stage.

At this juncture in our human technological understanding, and with the leading edge technologies that we have achieved, the Digital Dividend spectrum and LTE mobile broadband technology provides the most ideal solution for delivering universal mobile broadband access. The Digital Dividend radio frequency bands allow for the most efficient deployment of broadband, particularly to the far reaching regions where wireless connectivity is the only option. The added capacity that would result from the release of needed spectrum, and the deployment efficiencies unique to the Digital Dividend spectrum, could help make broadband affordable to all. With additional spectrum, there would be more mobile broadband networks serving societies, leading to new innovations. LTE is also unique as it is the only mobile communications technology standard that not only can deliver very fast 300 Mbps (20 MHz 4X4 MIMO) mobile broadband speeds on today's networks, but also has all the specifications in place to deliver extremely fast 1.2 Gbps mobile broadband speeds in the near future. It is the technology of choice for all operators, including those that are using 3GPP, 3GPP2 and the IEEE. It is forecast to reach global economies of scale with billions of users within the next 10 to 15 years.

The Digital Dividend spectrum and LTE have all the components to provide affordable high-speed broadband to all, to bridge the digital divide, bring education to remote regions, provide information access to the poor and enable innovations as part of the solution for education, health care, energy dependency and stagnated economic growth. Given the consensus on the economic benefits in using the Digital Dividend spectrum for mobile broadband, there is an associated opportunity cost for delay. One study by Spectrum Value Partners on the European markets shows a loss of around 9 percent in economic benefits associated with a one year delay in releasing the Digital Dividend spectrum. In addition, these economic benefits can only be maximized with the use of the Digital Dividend spectrum for mobile broadband, and would be decreased factors such as higher spectrum bands and time delay. Therefore, it is financially critical for nations and regions to move forward as quickly as possible and remove all barriers—through whatever means necessary.

1 INTRODUCTION

The mobile broadband industry is on the path to an explosion in usage that will put an unprecedented level of pressure on the capacity of networks. Some projections predict a 30-fold increase in traffic within 5 years, and a 500- to 1000-fold increase by 2020 compared to 2010 levels. This traffic explosion is fueled by continual enhancements in devices, such as smart phones and tablets, growth in numbers of applications, orders of magnitude improvements in network performance from generation to generation, and IT evolution toward cloud-based computing. This growth in mobile broadband usage is also very strategic for countries and regions. Mobile broadband is being seen as a platform for opportunity that can spur economic growth and job creation. It is a platform for innovation, for solutions to national concerns in education, healthcare, energy dependence and public safety, and for global competitiveness.

Though LTE and LTE-Advanced are poised to be the dominant mobile broadband and broadcast technologies to support this projected traffic growth, technology improvements alone will not be able to keep up with the ballooning network capacity demand. In short, the mobile industry needs more spectrum.

Viable internationally harmonized spectrum is very hard to identify. However, one promising possibility is the Digital Dividend spectrum. This is the spectrum that would be freed up after the TV broadcast industry switches from analog transmission technology to digital transmission technology. It is, in general, consistently defined across all the ITU regions around the world. It has very ideal propagation characteristics most suitable for mobile broadband networks today. The allocation of the Digital Dividend spectrum for mobile networks will reduce deployment costs and bring broadband to remote regions of the world—bridging the digital divide and making broadband services more affordable to the masses.

The intent of this paper is to provide information on the benefits of using the Digital Dividend spectrum for mobile broadband, particularly with LTE technology, to encourage regulators to move quickly toward allocating this spectrum for mobile broadband given its potential for providing social and economic benefits.

Section 2 discusses the mobile broadband traffic explosion trends.

Section 3 covers recent improvements in TV broadcast technology which allows for the release of Digital Dividend spectrum for mobile broadband networks.

Section 4 highlights the benefits of more spectrum and mobile broadband to industries, societies and national broadband plans.

Section 5 provides alternative uses for the Digital Dividend spectrum.

Section 6 explains why LTE is the best technology for mobile broadband in the Digital Dividend spectrum.

Section 7 covers the status of Digital Dividend spectrum around the world, with some recommendations to regulators on ways for designating spectrum for mobile services.

2 CURRENT SITUATIONS/CAUSES/DRIVERS LEADING TO INCREASED SPECTRUM NEEDS

Ever since the wireless industry began to focus on initial 3G technologies like UMTS about a decade ago, there have been predictions of a wireless data explosion. However, it is only within the last several years that such predictions have finally come true and are now putting tremendous stress on the wireless network. Trends show that wireless data demands continue to increase at phenomenal rates. In fact, the ITU highlighted that mobile broadband subscriptions now materially surpass fixed broadband subscriptions, as shown in Figure 0-1, which punctuate this inflection point. Wireless networks are now expected to provide capacity for mass multimedia connectivity just like fixed networks, with some projections showing a 30-fold increase in wireless data capacity requirements over the next five years.

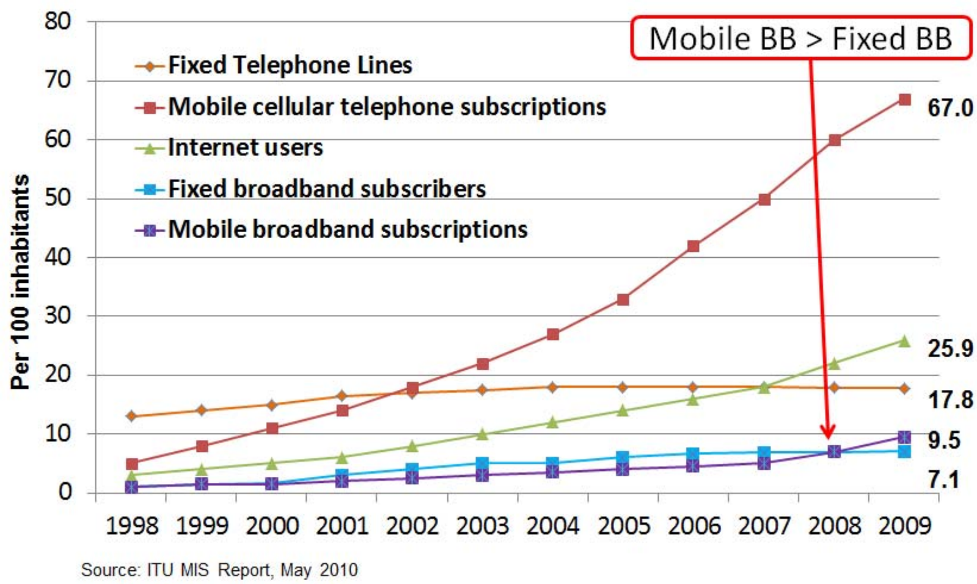


Figure 2-1: Yearly growth in broadband subscriptions

The fast-growing wireless demands experienced today beg the question, “What has changed?” and “Why is the wireless data explosion happening now?” Many elements seem to be at play after reviewing the fast rise of mobile broadband consumption. They are: devices, networks and the standards they support, available applications, and end-user needs or desires. Most people do not consider that in today’s mobile broadband networks, information is both pushed and pulled, to and from the user. Email, as one example, is driven by signaling that occurs from the device to the network and requests that email is proactively sent to the user’s device. There are many examples of applications that routinely and automatically check for updates that are subsequently sent to the user’s device—without the user’s intervention. This is a wide and growing segment of the market that is driving up bandwidth utilization. There is also data being “pulled” at the user’s request, such as PowerPoint files, songs, videos, and other applications. There is another application type categorized as a user-initiated, push-pull application, and once active, it automatically pushes updates. GPS and “live” sporting events are two such examples.

Of the several elements discussed here that contribute to the fast rise in wireless data usage, nearly all can be tied in one way or another to improvements in the quality of experience with wireless applications. New and improved devices that enable more and better applications to be used over advanced wireless networks are clearly resulting in superior wireless user experiences. This leads to an increased satisfaction and demand for wireless usage. This trend is expected to continue over the next several years, with the expectation that newer, more sophisticated devices, such as tablets (which will eventually leverage the cloud computing technologies), will drive a significant increase in demand for video intensive services as they deliver a uniquely appealing experience to the end user for applications, such as wireless video entertainment, gaming, and video communications services. Wireless data capacity demands are projected to continue to increase at an exponential rate over the next few years, which will drive the critical need for increased spectrum to support mobile broadband services.

To demonstrate the points discussed above, the following section will provide details on the device trends, application trends, and network trends which are all contributing to vastly improved user experiences and increased user demand for wireless data services. It will also provide references and examples demonstrating the unprecedented recent and projected future growth in wireless data usage that is driving the need for increased spectrum for mobile broadband applications.

2.1 MOBILE BROADBAND DEVICE TRENDS

Mobile devices, like other electronic devices, are benefiting significantly from advances in processors, screens, storage capacities, and battery technology. Gone are the days where the user is constrained by small screens—an inefficient method of consuming data. With dongles being used for laptops and with tablets, and smarter smartphones, data consumption will continue to rise. Each technological breakthrough has led to a much better user experience, resulting in very large increases in wireless data usage due to the end users having a greater desire to use intensive wireless applications on their smart devices. End users, ever on the go, are now willing and able to rely on their personal device, especially with tablets continuing to evolve, and more and more of their information being accessible via the cloud (more on this later).

Figure 2-2 demonstrates the increasing trend in wireless data usage as new, smarter devices with larger screens are introduced. As shown in the figure, monthly data usage is more than 20 times greater for tablet-type devices compared to basic feature phones. As tablet-type devices continue to penetrate the network, the amount of data traffic traversing the network will increase significantly. The following sub-sections discuss some of the key factors leading to innovations in more advanced devices and better user experiences that are some of the driving forces behind the increased adoption and penetration of high-end devices.

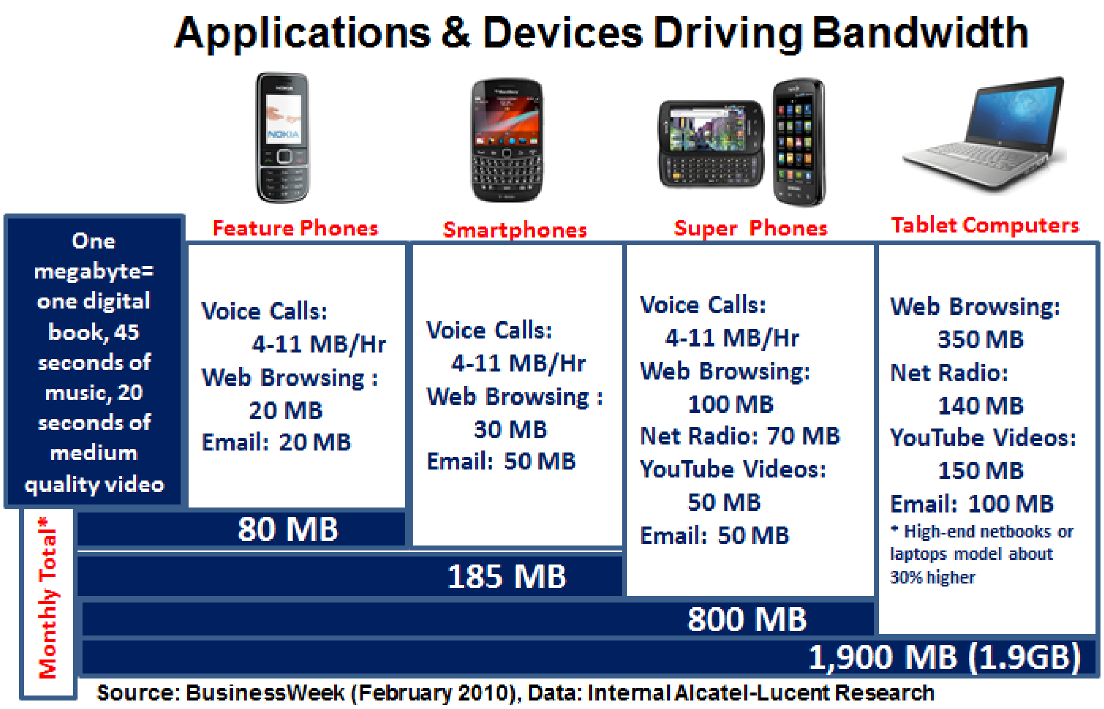


Figure 2-2: Applications & Devices Driving Bandwidth

2.1.1. PERFORMANCE/PROCESSOR TRENDS

Processor improvements largely follow Moore's law unabated. The main impact of these improvements is a better user experience with applications and content. This is clearly observed with the iPhone, where a better user experience has led to significantly higher data consumption. As shown in Figure 2-3, many smartphones have recently broken the 1 GHz barrier. (Generally, 1 GHz processors can support high definition video up to 720p). At this stage (2Q10) 1 GHz processors appear to be limited to the highest of the high-end devices (e.g., the iPhone 4 uses Apple's A4 1 GHz processor). Nevertheless, this represents a 4- to 5-fold increase in processor speed compared to typical high-end devices from five years ago.

The benefits associated with faster processor speed include:

- Faster presentation of web pages
- Ability to handle multiple data sessions
- Ability to handle higher resolution graphics
- Support for more advanced applications—particularly high-end games

Clearly, a 4- to 5-fold increase in processor speed better enables more applications, and has a very positive impact on the user experience in the areas listed. In particular, the benefits of such significant processor speed enhancements will begin to enable high definition video to the end device. As will be discussed in the next section, screen size trends are moving toward larger screens as wireless video applications become more popular. Larger screens will increase the desire by the end user for high definition video, which will greatly increase the bit rate required for video streaming and greatly increase the overall bandwidth consumed in the network by video.

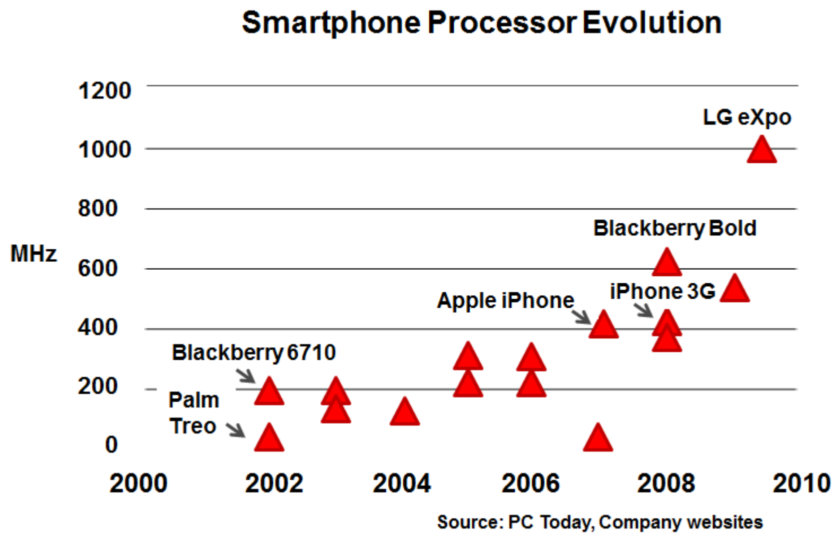


Figure 2-3: Smartphone Processor Evolution

2.1.2 SCREEN TRENDS

Most screen sizes on high-end handheld devices are close to, and in some cases more than four inches across. This would appear to be at or near the limit for smartphones, given the typical form factor for a handheld device. The next improvement seems to be occurring in screen resolution. Most of the large screen smartphones have resolutions of about 480X800 pixels. The iPhone 4, with its so called "Retina Display," actually has a resolution of 640X960 pixels.

In the future, screen size will not be limited by the size of the human hand. Flexible "electronic paper" displays exist today and have been incorporated into devices. One example is the use of E Ink's display technology in the Kindle eReader. EReader screens are not high resolution today. The 9-inch Kindle, for example, has a screen resolution of 1200X900 pixels. This represents nearly three times as many pixels as typical smartphones, which directly translates to a 3X increase in the required bit rate of the video stream for tablet-type devices. Portable, "rollup" screens are expected to be the next evolution of flexible display usage[i] . These can be used to augment mobile phone displays or as a separate class of devices. Clearly these advances in screen size and resolution continue to drive up the bandwidth required over the wireless network, providing the quality of experience expected for video streaming by the user.

2.1.3 FUTURE DEVICE TRENDS

Wireless ubiquity is taking on a new meaning with the expectation of widespread embedding of wireless modules in machines and consumer electronics. Wireless is already widely deployed in many non-phone devices today. Many vehicles have cellular-based emergency notification systems, for example, General Motors' OnStar. A large variety of consumer devices are Wi-Fi enabled, and can be expected to support 3G/4G technology in the future.

Smartphones today are a combination of ultra-mobile PC, portable navigation device, personal media player, still camera, and movie camera. They are also good for voice calls and messaging. Nevertheless, portable specialized consumer electronics continue to sell well. Many of them are Wi-Fi enabled. A handful are wireless cellular-enabled.

To effectively compete with smartphones, manufacturers of consumer electronic devices must include wireless capabilities to enable file saving, sharing and online interaction. The Internet-based “cloud” services that support this type of remote usage are thriving. Sharing sites for photographs, such as Flickr and Snapfish, provide mobile applications that simplify uploading photographs remotely. Flickr reports thousands of photo-uploads per minute. Sites such as YouTube similarly make video uploads simple.

Figure 2-4 shows the types of consumer electronics for which there is likely to be a high penetration in support of wireless 3G/4G technologies in the future.

Source: Company data, inCode, Macquarie Capital (USA), March 2009

Figure 2-4: Future 3G/4G consumer electronics

2.1.4 GROWING NUMBER OF DEVICE SUBSCRIPTIONS

All device trends discussed in the previous three sections have unleashed pent-up demand for wireless data usage. This is clearly evident from the recent increases in number of handheld and mobile PC/tablet subscriptions as shown in Figure 2-5. When extrapolated over the next five years, there will be roughly five times as many mobile PC, tablet and handheld subscriptions compared to today.

Clearly such an increase in the number of mobile broadband subscriptions will directly increase the wireless network capacity. Coupled with the fact that such advanced devices exhibit much higher data usage patterns than basic feature phones (e.g., see Figure 2-2), the capacity demand on the network will be much greater than five-fold.

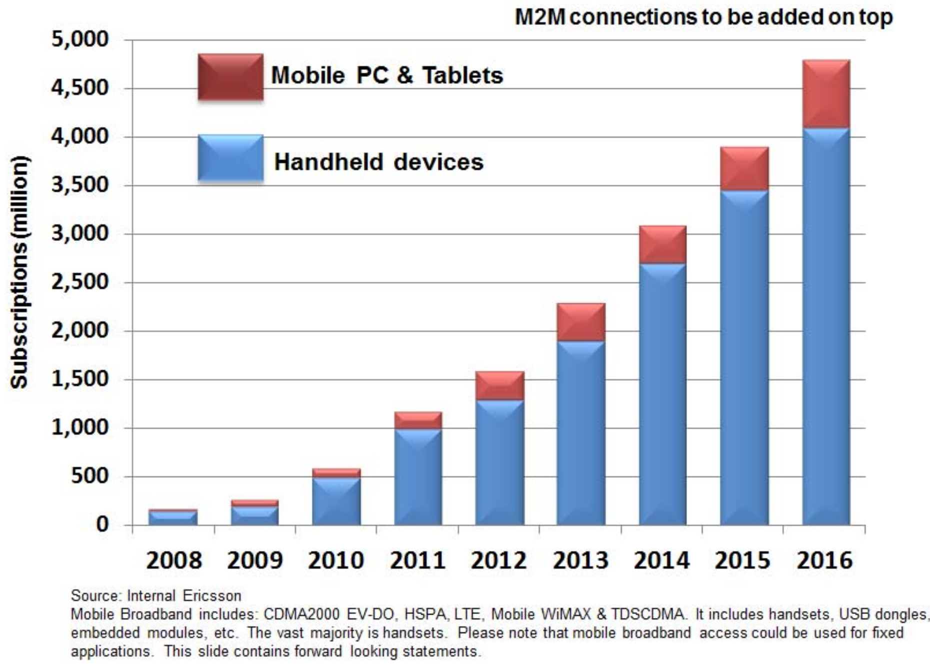


Figure 2-5: Yearly trend and projection of number of mobile broadband device subscriptions

2.2 MOBILE APPLICATIONS TRENDS

The advances in mobile devices, discussed in the previous section, have led to increased wireless application usage as well as enabling new applications' feasibility over wireless. As of May 2010, more than 240,000 applications were available from seven stores on seven different platforms. CTIA estimated that in 2010, consumers were expected to spend $6.2 billion in mobile application stores worldwide, downloading more than 8 billion apps—8 out of 10 of which were free. Figure 2-6 shows that the majority of mobile data usage to date comes from three broad application types: web browsing, file sharing and video streaming.

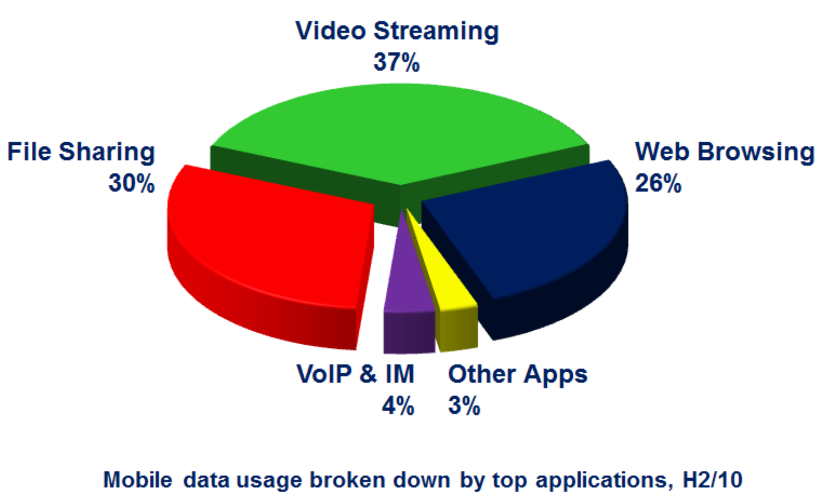


Figure 2-6: Mobile data usage by application

More specifically, the most popular applications are those that provide some form of entertainment (e.g., games, music, food, travel and sports), as well as applications that help people find information and accomplish tasks (e.g., maps and navigation, weather, news, and banking).

In a survey conducted by the wireless analyst firm *mobile*^{SQUARED}, when operators were asked to choose what they thought would be the top five most popular forms of communication in 2015, 94 percent of the 31 global operators responded that social networking would be the most popular. This was followed by 87 percent and 81 percent of operators that believed messaging and voice, respectively, will continue to play an important role in communications. It was predicted that they will remain in the top three as the most heavily used forms of communication in 2015. The study revealed that these forms of communication will be complemented rather than replaced by rising mobile Internet usage, particularly from mobile social networking. The results also showed that mobile social networking will not only be primarily responsible for the continuing rise in mobile Internet usage in the future, but it will be elevated to one of the core forms of communication. This will clearly add pressure to existing operator networks due to traffic.

According to the Cisco VNI Global Mobile Data Traffic Forecast, video will be responsible for the majority of mobile traffic growth between 2009 and 2014. Mobile video is expected to account for 66 percent of global mobile data traffic by 2014. This was further supported in a mobile trends report by Allot Communications citing that worldwide growth of mobile data bandwidth usage increased by 68 percent during the first half of 2010 and the top uses for bandwidth were streaming video, social media and VoIP. According to Allot, streaming video continues to dominate the global mobile bandwidth space and remains the largest consumer of bandwidth with a 35 percent share. In addition, video streaming is the single largest growing application type with a 92 percent increase, due in part to the ever-rising popularity of YouTube.

Vertical markets have been taking major steps to make use of the benefits offered by the mobile computing space. Significant work is taking place in areas such as mHealth, mRetail, mCommerce, mEducation, mEnergy, and others. Innovative startups have made use of the computing capabilities of devices to turn them into full-fledged medical instruments, according to Chetan Sharma. Sharma noted that, “the impact on saving lives and quality of health care will be tremendous—worldwide.” According to CTIA, the current U.S. market for wireless home-based health care applications has been estimated at $304 million. ABI Research estimates that healthcare, retail and manufacturing, each with a double-digit share, will command over 36 percent of all mobile business customer data revenues worldwide over the next five years. By 2014, data revenues derived from messaging, mobile broadband access, and applications will reach nearly $27 billion.

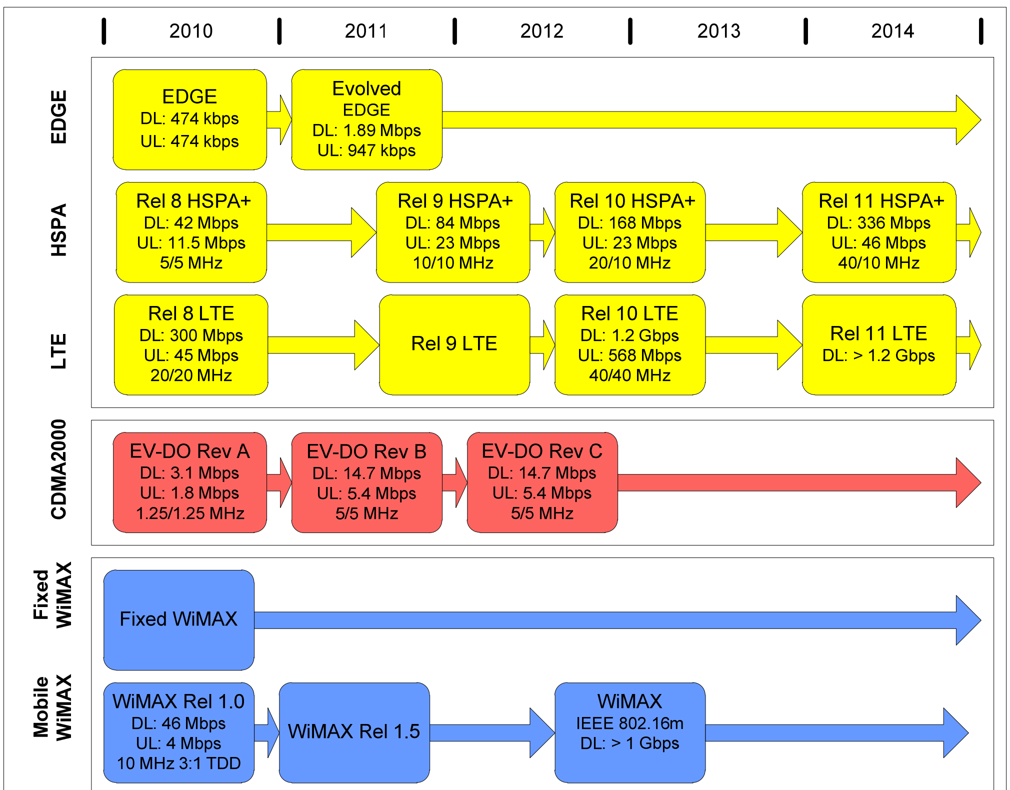
Clearly, the mobile applications space is increasing rapidly and will continue to drive unprecedented wireless data usage. But while application proliferation will continue, this paper will later show that video streaming applications will have the heaviest impact on wireless data capacity needs in the next few years.

2.3 WIRELESS NETWORK TRENDS

Wireless networks also factor into the fast-rising wireless data usage trends. This section discusses numerous network trends, from generation to generation, resulting from the evolution of wireless technology.

2.3.1 PEAK USER RATE TRENDS

Peak rates have drastically improved with each generation's technology advancements as demonstrated in Figure 2-7, which shows the peak speeds evolving over time for various wireless technologies. For instance, Rel-10 LTE (which includes LTE-Advanced enhancements) can support up to 1.2 Gbps peak rates—nearly 2500 times higher than what EDGE technology offers. Peak rates indicate the highest potential rate a user can experience under ideal channel conditions (i.e., high signal-to-interference-plus-noise ratio [SINR]) when the user is provided access to all the air interface resources. Under such conditions, evolution to LTE-Advanced provides more than three orders of magnitude better rates than EDGE provided only a decade ago.



Throughput rates are peak theoretical network rates. Radio channel bandwidths indicated.
Dates refer to expected initial commercial network deployment except 2010, which shows available technologies that year. There are no public announcements of deployment of WiMAX Rel 1.5.
X/Y MHz indicates X MHz used on the downlink and Y MHz used on the uplink.

Source: Mobile Broadband Explosion, Rysavy Research, September 2011

Note: Higher order MIMO mode has been added to the Rev-C standards for both uplink and downlink. However implementation is to be determined.

Figure 2-7: Yearly peak rate evolution for various wireless technologies

2.3.2 SPECTRAL EFFICIENCY AND AVERAGE USER RATE TRENDS

While peak rates are interesting in lightly loaded conditions (i.e., when only a few users are vying for access resources), during heavy load conditions the spectral efficiencies shown in Figure 2-8 provide a better comparison of the capacity and average user experience differences between the various wireless technologies. The figure shows that the evolution of LTE through Rel-10 (including LTE-Advanced) has the potential to double spectral efficiency compared to HSPA+. This means that, given the same number of mobile users, the average user data rates experienced would also roughly double, leading to improved user experience and, hence, an increased demand for wireless data usage.

However, the assumption that the number of users will remain constant might not be valid, and mobile applications are requiring higher and higher bit rates. Clearly it was shown in previous sections that the number of wireless broadband subscriptions is increasing at a rapid rate, and with the advances in mobile devices, video streaming is becoming the most popular wireless application, which requires significantly higher bit rates than other applications. The next section will show that this is projected to lead to more than a 30X increase in wireless data capacity requirements over the next five years. Thus, while a 2X increase in spectral efficiency with LTE-Advanced is nice, it is still 15 times less than what was projected to be needed over the next five years. This clearly demonstrates the need for additional spectrum to accommodate the mobile broadband data explosion.

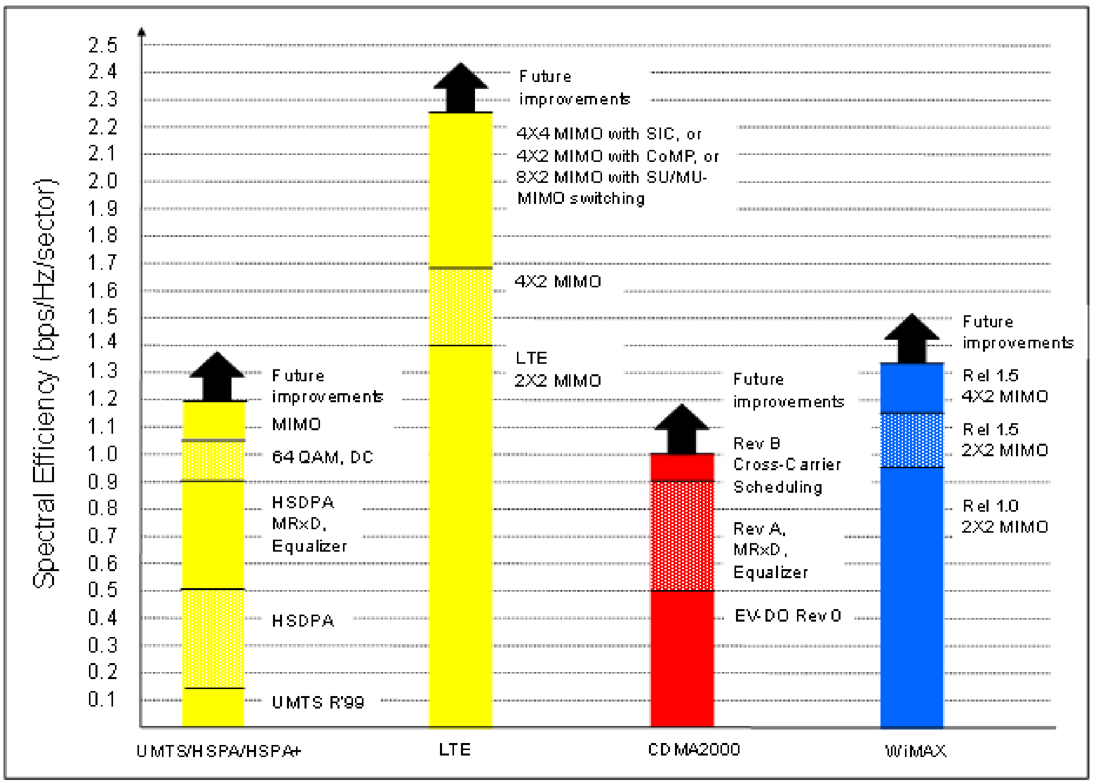


Figure 2-8: Spectral efficiency comparisons for various wireless technologies

2.3.3. LATENCY TRENDS

Another wireless network trend to consider is latency. Figure 2-9 shows how wireless technology evolution is reducing latency in the network. Such latency reductions with LTE will contribute to increased mobile broadband usage because the performance of the network improves the response time for applications, whether they are tools or entertainment, and make them more desirable to use. With each improvement in the standards, the network has improved to the point that it is no longer considered a *mobile* broadband network—but simply a broadband network.

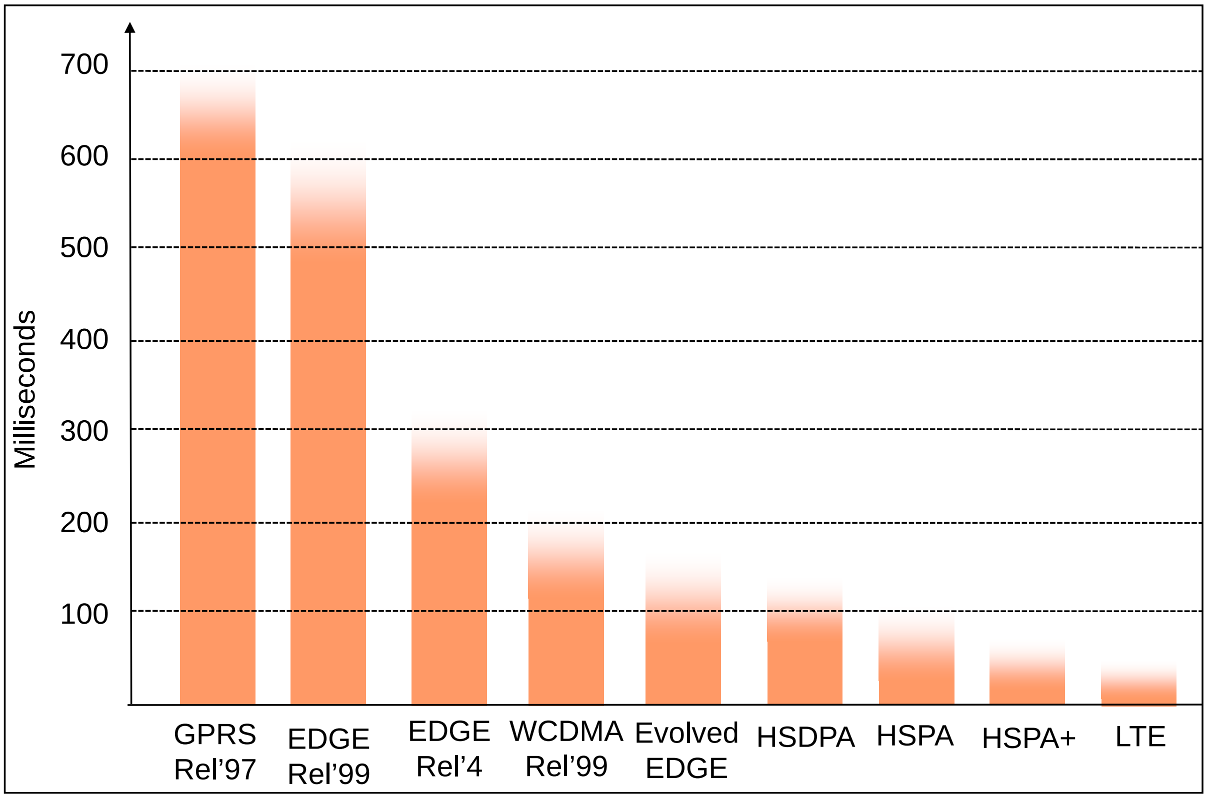


Figure 2-9: Latency comparisons of various wireless technologies

2.3.4 CLOUD COMPUTING TRENDS

Cloud computing is changing the way consumers and businesses purchase and use a wide range of computing capabilities. For decades, hardware and software have typically been installed at the end users' premises—and on individual computer devices. Now cloud computing offers a different approach: applications, platforms and infrastructure are available "on demand" by using the Internet to connect end users with online services.

2.3.4.1 WHAT IS CLOUD COMPUTING?

The main aspects of cloud computing consist of:

- **Cloud computing** – A flexible, scalable online computing environment, shared among users.
- **Cloud applications** – Real-time services accessed with a web browser. They currently range from business applications for the enterprise, with usage-based pricing, to free communication and social networking applications for consumers.
- **Cloud platforms** – Off-premises development platforms that provide "off-the-shelf" capabilities for content and application developers.
- **Cloud computing infrastructure** – Servers, data storage and processing power that provide on-demand resources for enterprise IT — or the centralized host for cloud services.
- **Cloud computing business models** – Users pay monthly subscriptions or pay on a "per-use" basis. Some capabilities are offered free to customers and are paid for by advertisers.

As a result of this real-time business model, the following observations are noted:

- Consumers can access a range of low-cost applications, anytime, anywhere, using a web browser installed on a laptop, terminal, smartphone or other connected device.
- Enterprise employees can tap into business applications for a specific task at the moment it is needed—and often the business pays only for usage.
- Application developers can turn to off-premises cloud platforms that minimize the need to purchase their own hardware and software when creating and deploying new applications.

Cloud computing is in an early stage of development. However, it is clear that cloud computing will enable more processing and computing power (from the cloud) for mobile devices. This enables more process-intensive applications to become feasible for nearly any device. More applications, and more importantly user data, will be available in the cloud and accessible from anywhere. Users having more and better access to their information, whenever and wherever they need, leads to new approaches on how people communicate, obtain information, and use the internet. From email, music, photos and storage, cloud computing allows people to have more access to their information from a variety of sources as well as a variety of devices, which ultimately drives up data usage in the network.

All of these factors combine to set the frenzied pace of data consumption seen today and predicted for tomorrow. The only limitation is spectrum, which is the invisible superhighway connection to the web. Even though technology has constantly improved, we are near the edge where we have reached the limits of Shannon's law (maximum bits per Hertz) and; where new methods have taken over such as multiple antennas, we have hit the limits of what they too can achieve without creating cost within the device itself (eight antennas per band for example). Spectrum can be allocated in different bands, but more spectrum can also be allocated within a band. This enables more capacity at the lowest cost per bit, a necessary component to reaching a larger segment of the mass market, which may include some of the have-not population.

2.4 MOBILE BROADBAND TRAFFIC TRENDS

Due to all the advances in mobile devices, applications, and wireless networks, discussed in the previous sections of this paper, wireless data usage has increased at an incredible rate. Figure 2-10 summarizes all the factors discussed, and shows the unprecedented increase in mobile broadband data demand that has resulted, and how it is expected to continue to increase rapidly over the next few years.

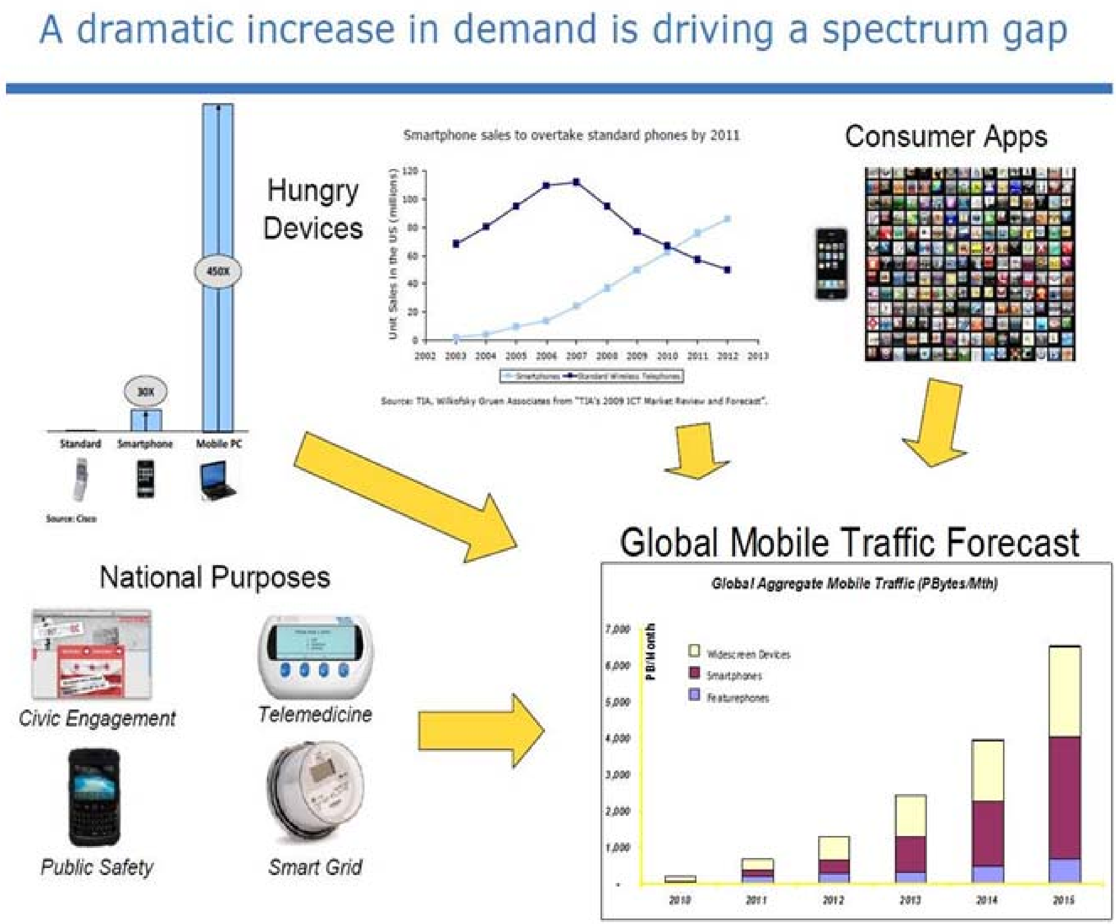


Figure 2-10: Summary of factors leading to unprecedented mobile broadband data demand

As discussed earlier, mobile streaming video is one of the biggest drivers of bandwidth utilization. Market data demonstrates significant increases in the usage of mobile video among mobile broadband subscribers, especially among smartphone and tablet users. Full-length movie streaming is on the rise, with free and subscription on-line video services, such as Hulu. Figure 2-11 demonstrates that video applications will become the largest percentage of mobile traffic, by a wide margin, in the coming years.

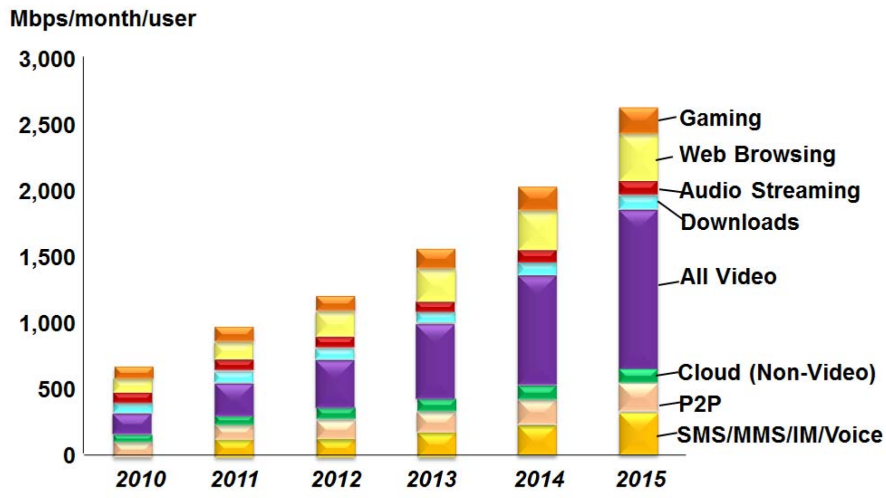


Figure 2-11: Single user monthly data consumption forecast (source: Alcatel-Lucent)

Coupling Figure 2-11 with the rapidly increasing number of mobile broadband device subscriptions, shown earlier in this paper, results in the exponentially increasing wireless data usage projections shown in Figure 2-12. This figure clearly demonstrates the greater than 30-fold increase in wireless data usage expected over the next five years, predominantly from more advanced smartphones and widescreen devices that provide an increased user experience for video applications. As discussed herein, even a ubiquitous deployment of the most advanced wireless technology (i.e., LTE-Advanced), falls far short of meeting such wireless data capacity demands—only a two-fold spectral efficiency increase over HSPA+. Clearly, additional wireless spectrum is required to meet the mobile broadband data capacity demands in the near future.

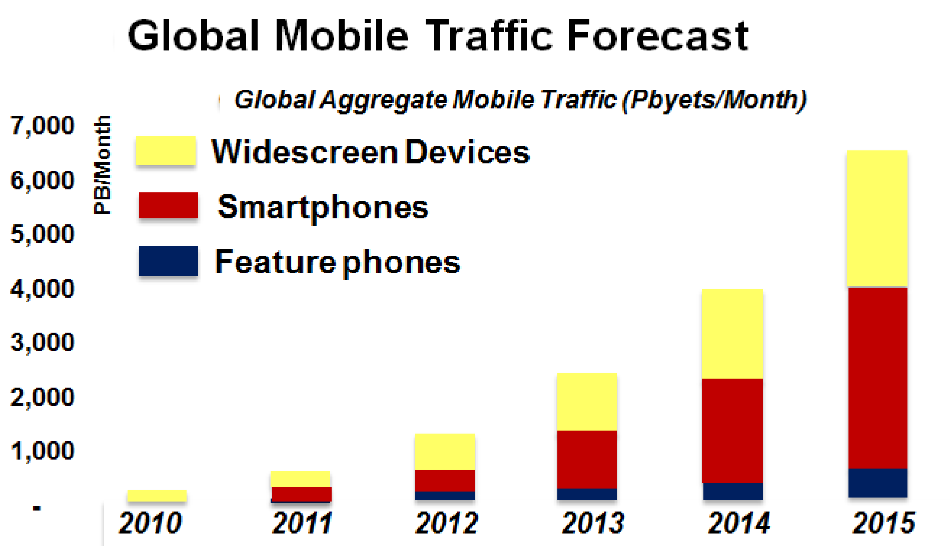


Figure 2-12: Global mobile traffic forecast (source: Alcatel-Lucent)

3. THE BACKGROUND OF DIGITAL DIVIDEND

The Digital Dividend refers to spectrum, in the 200 MHz to 1 GHz frequency range, which is freed up by the replacement of legacy analog terrestrial TV transmitters with newer digital terrestrial TV technology. For years broadcast TV has been supported by analog transmission, but digital broadcast TV has proven to be significantly more spectrally efficient. There are two main technological improvements that make digital broadcast more spectrally efficient than analog, and allow for the freeing up of spectrum. First, digital broadcast technology enables more channels to be packed into the same RF channel bandwidth used with analog broadcast technology. Second, digital broadcast enables greater frequency reuse, with much more lenient taboo rules for channel spacing, even permitting adjacent channel allocations within shorter distances. This section will provide background on the basics of analog broadcast TV, and discusses the channel packing and SFN benefits of digital broadcast TV.

3.1 BASICS OF ANALOG BROADCAST TV

The National Television System Committee (NTSC) analog broadcast television standard dates back to 1941, when the first black and white television standard was published, and to 1953, when the color standard was added. These standards have been predominant throughout the Americas, Japan and Korea, although there has been some adoption of the PAL standard in South American countries of Brazil, Argentina and Uruguay. In these early years, and into the 1980s, a mechanically tuned filter was used in the radio front-end of television receivers to filter out interference from other TV transmissions that could otherwise block or blind the receiver's LNA and receiver Automatic Gain Control (AGC) circuitry.[1] This filter did not have steep skirts to provide adjacent channel or even next-to-adjacent channel rejection at the time, there were no low-cost variable filters that could be used in a consumer electronics product, and the NTSC standard and the regulatory radio planning took this into account. In fact, the receiver's low-cost filters had a phase response that was pre-compensated for in the much more expensive broadcast station transmit filter. The cost of this implementation in the transmit filter, was of course, small on a per viewer basis.

Figure 3-1: Traditional TV tuner with variable capacitor as used from 1940s to 1980s.

These receiver limitations were reflected in the geographic placement of TV broadcast stations, and the so called, "taboo rules" used by regulators, such as the United States Federal Communications Commission (FCC). In order to protect against adjacent channel interference, harmonics, and inter-modulation products, these rules restricted the minimum geographic distances between TV channels 2, 3,

[1] Older engineers may recall the interlaced fan of capacitor elements that were a major part of the old TV turners. Turning the knob would change the amount of overlap between the cam-shaped plates, and change the capacitance accordingly; several capacitors were included in the mechanical tuning knob and were the variable parts of the front-end tuner's filter.

4, 5, 7, 8, 14 and 15 and many similar restrictions in the UHF band. The total effect of these restrictions was that, out of the possible 68 TV channels, only 10 to 20 could be used in the same market; only 15 percent to 29 percent spectral utilization. For example, New Jersey, the most densely populated state in the US, only had 15 TV stations permitted.

Filters with much better performance were developed in the 70s and 80s using Surface Acoustic Wave (SAW) devices. These became commercially available in the late 1970s.[ii,iii,iv] Receivers built with these improved filters could permit more closely spaced channel assignments, but there were hundreds of millions of television sets in use that did not have the benefits of these newer filters and so the "taboo rules" had to stay in place.[2]

It was self-evident at the time that only a single video stream could be broadcast from a TV broadcast station that would have its own transmit tower and antenna (although some special buildings like the Empire State Building had sharing agreements among the nine TV broadcasters operating from New York City.[v]) The NTSC standard provided, for secondary audio channels, stereo or multi-lingual broadcasts, but only on the audio channel.

The primary audio channel was typically driven at sufficiently high power so that at the edge of coverage, where the analog video signal was nearly unidentifiable, the audio would still be acceptable. In fact, a typical FM radio receiver could usually pick up the audio channel of TV Channel 6.

The Phase Alternating Line (PAL) standard used in some South American and Caribbean countries since 1963 is comparable to the NTSC system. The variant used in the Americas uses a 6 MHz bandwidth. French Guiana, Guadeloupe, Martinique and Saint-Pierre, and Miquelon use SECAM K, which uses 8 MHz of bandwidth. Most of these countries are planning to convert to digital-TV formats, and the most likely technology to be chosen would be the DVB-T or DVB-S/SH.

3.2 BENEFITS OF DIGITAL BROADCAST TV

A major reason for the FCC's adoption of the Advanced Television Systems Committee (ATSC) Digital TV standard was to reallocate spectrum more efficiently and economically[vi]—it was not just to provide higher definition to viewers. Part of the Digital Dividend comes from "flushing out" the restrictions inherent in maintaining backward compatibility with hundreds of millions of older television receivers that were not compatible with close channel spacing. The greater interference immunity of digital signals owes much to the modern SAW filters, but also the digital robustness of ATSC television signals.

The transition from analog to digital included an interim period in which U.S. broadcasters were required to construct new facilities for transmitting ATSC broadcasts simultaneously with their analog NTSC broadcasts. This construction led many broadcasters to collocate transmitters and antennas on the same towers with competing TV stations. By collocating with an adjacent channel transmitting antenna, interference levels are more or less constant across the service area. There are no "near/far" problems that result from some receiver locations having more interference from an adjacent channel due to proximity with the transmitters. The analog transmissions were turned off on June 13, 2009.

Consequently, the FCC has been able to assign many broadcasters in the same market to be on adjacent channels, packing the channels together much more tightly than the old "taboo rules" would have

[2] As an interesting bit of irony, the design of these higher functioning filters were challenged to reproduce the same phase non-linearity of the older filters so that they would be compatible with the predistortion introduced in the broadcast stations, to accommodate the problems of the older technology.

permitted. For example, Table 3-1 shows the station assignments within 85 km [of the author's home]—before and after the DTV transition.[vii]

We see in Table 3-1 that there are several adjacent channels located as close as 28 miles apart (Newark and West Milford), that are able to share the adjacent channel assignment. Also, note that the original spectrum used to serve this area extended to TV Channel 68, but now only goes to 51, a savings of 102 MHz. Now that the transition is complete and the analog broadcasts have ended, essentially half the channels—the most troublesome half—have been turned off, and there is great potential for more aggressive repacking of the VHF and UHF spectrum.

Broadcast channel assignments before and after DTV Transition
(within 85km of the author's home in Lincroft, NJ)

Call Sign	State	City	Original analog channel	Post DTV transition channel
WNJB	NJ	New Brunswick	58	8
WPIX	NY	New York	11	11
WNET	NJ	Newark	13	13
WMBC-TV	NJ	Newton	63	18
WLIW	NY	Garden City	21	21
WNYE-TV	NY	New York	25	24
WNBC	NY	New York	4*	28
WFME-TV	NJ	West Milford	66	29
WFUT-DT	NJ	Newark	68	30
WCBS-TV	NY	New York	2	33
WNJU	NJ	Linden	47	36
WXTV-DT	NJ	Paterson	41	40
WNJT	NJ	Trenton	52	43
WNYW	NY	New York	5*	44
WWSI	NJ	Atlantic City	62	49
WNJN	NJ	Montclair	50	51

* A gap exists between TV channels 4 and 5.

Table 3-1: Broadcast channel assignments before and after DTV Transition

In addition to these RF interference considerations, there are three other related reasons for digital broadcast TV's spectral efficiency: 1) Source coding or compression, 2) Multiplexing, and 3) Line coding.

Source coding refers to the "data compression" associated with the MPEG-2 video coding scheme used in ATSC. The raw bit rate from an HDTV camera sensor can be on the order of 1.24 Gbps (1920 pixels wide X 1080 high X 50 frames per second X 24 bits per pixel for YUV 444). The MPEG-2 video coder removes tremendous redundancy in typical video images, such as the high correlation between adjacent pixels and between successive frames. Perceptual limitations are also considered in that rapid scene changes take the human visual senses some time to "catch up." Motion estimation and tracking are also used to great effect. All told, the MPEG-2 video coder can reduce the 1.24 Gbps to under 20 Mbps, a compression factor of 62.

Multiplexing: This compression can be taken further to produce more Standard Definition (SD) videos, or conventional cameras and DVD quality sources can be used to provide multiple SD MPEG-2 transport streams (TSs) that can be combined into a single 19.267 Mbps payload. The important point here is that High Definition TV can be broadcast at certain times of the day, but multiple Standard Definition (SD) programs or even other non-video data content can be transmitted at other times. The single 6 MHz channel can support multiple combinations of virtual TV broadcasts. Typically, four SD channels are used but up to six are quite feasible -- they can even be statistically multiplexed (STATMUXed) to provide more bits for a fast moving sports event, and less bits for a cartoon channel.

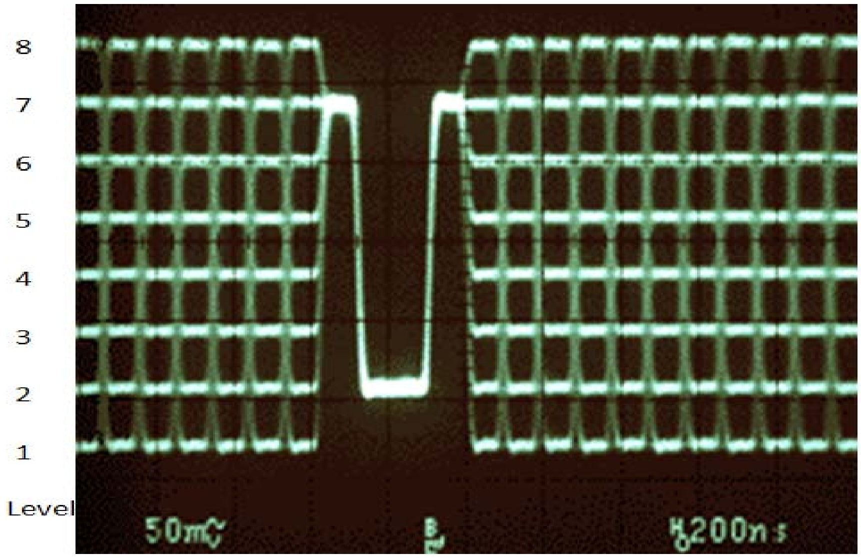
Line coding is where the MPEG-2 stream(s) are encoded, with a rate 2/3 trellis code and Reed Solomon coding added, with interleaving to provide forward error correction and protection from impulse noise, and then encoded into 8 amplitude levels to modulate a carrier. The lower-modulation-side lobe is digitally filtered to produce an 8-level vestigial sideband (8-VSB) signal to be transmitted. The numerology of this 8-VSB signal is given in Table 3-2.

8-VSB Numerology[viii]

A	Channel bandwidth	6 MHz (with an option for 7 MHz)
B	3 dB Bandwidth after Root Raise Cosine Filter	5.381119 MHz
C	Symbol rate	2 × B = 10.762238 Mbaud
D	8-level AM coding for 3 b/symbol	3 x D = 32.286714 Mbps
E	Overhead, equalizer training interval and buffer fill Reed Solomon coding (207,187)	3.386 Mbps
F	Payload net after E	28.9 Mbps
G	Usable Payload after Error Correction	2/3 x F = 19.267 Mbps

Table 3-2: 8-VSB numerology

The 8-VSB waveform is shown after demodulation and equalization in Figure 3-2.



Note: The time interval in the middle is the synchronization pulse using two levels for clock recovery and training of the equalizer.

Figure 3-2: 8-VSB eye diagram after equalization

With this line-coding scheme, the ATCS standard requires 15 dB of SINR, which is much less demanding than what is required of analog NTSC for acceptable clarity. This is an important contributor to the ability to pack channels on adjacent channels. This also allows the average DTV transmit RF power to be 12 dB below the peak NTSC power while still having the same equivalent coverage area. This reduced transmit power also contributes to improved spectral efficiency, and reduces the general interference and electromagnetic “pollution” in the community. This may even reduce the man-made-interference levels expected in the UHF band below historical values.

3.3 BENEFITS OF SINGLE FREQUENCY NETWORKING (SFN)

Single Frequency Networking, or SFN, refers to the use of multiple transmitters throughout an area of coverage where each transmitter emits the same signal, on the same frequency channel, synchronously. Given the typical distance between TV transmitters, this requires a system design that is essentially tolerant to many tens of microseconds of multipath delay spread, where the various transmissions arrive at a television set with these sorts of relative times of arrival. One potential benefit of SFN, with the proper system design, is improved coverage when the signals sent from the multiple transmitters combine constructively (e.g., through non-coherent over-the-air combining, which improves SINR) rather than interfere with each other (e.g., lowering SINR). As an example, this is accomplished in an Orthogonal Frequency Division Multiplexing (OFDMA)-based system when the multiple transmitted signals all arrive at the receiver within the cyclic prefix (or guard period) of the OFDMA system.

In SFN networks, the multiple transmitters contribute gain in the receiver, unlike cellular networks where multiple base stations interfere with each other because they are transmitting different information.[ix, x]

SFNs can be established on geographical regions of differing size, and include main transmitters as well as repeaters.

SFNs can include repeaters that use the same frequency as that used by the closest main transmitter. Energy savings are achieved as repeaters can provide coverage where the main transmitter would have required more transmit power to serve the extended coverage area.

Compared to classical multiple frequency networks (MFN) used in analog TV and ATSC, where any two transmitters leaking signals into each other's service area need to use different frequencies (although the same programs are transmitted), SFNs require only one frequency. This can greatly reduce the spectrum requirement to transmit one program multiplex over a given geographic area, as identified by the FCC.[xi]

For a nationwide service area, only a single frequency is required per program multiplex. Even for local or regional service areas, establishing one SFN per service area provides overall spectral efficiency gains. If the power and/or height of the transmitters in each SFN is reduced compared to the levels required in an MFN, then this reduces the unwanted propagation of the signal beyond its intended service area, and thus allows for loosening of the “taboo rule”—that is, co-channel as well as adjacent channel transmitters can be located closer together. This reduces the total number of frequencies required for the given services.

Apart from these advantages of SFN, adjacent channel assignment is greatly aided when all broadcasters near each other in frequency must be collocated on the same repeaters, otherwise the near/far problem of nearby adjacent channel interferers and distant desired channels will cause blocking.

Throughout the world, the many convergent advantages of transitioning to digital TV has allowed TV channel allocations to be compressed into the lower and middle part of the UHF band, with the leftover resulting in the Digital Dividend spectrum. Further compressions of these allocations can result from further “defragmentation” of the broadcast licenses, since from the time of the initial spectrum “defragmentation,” more analog broadcast channels have shut down.

4 INDUSTRY/ECONOMIC/SOCIAL BENEFITS OF USING DIGITAL DIVIDEND SPECTRUM FOR MBB AND BROADCAST

The Digital Dividend spectrum can bring game-changing benefits to all parties involved. It can serve society's greater needs in various vertical industries, such as healthcare, education and energy. It can ignite innovations in mobile broadcast, devices, applications and mobile cloud-based services. It can energize the economy with new investments, adding jobs and growing the GDP. The spectrum has ideal propagation characteristics, particularly for rural coverage, and can help bridge the digital divide and bring broadband services to the underserved and the unserved remote areas of the world. It offers the broadcast industry stakeholders a way to compete with the cable-based, satellite-based, and Internet-based TV service providers, with services for both IP-based interactive broadcast television and on-demand videos, by leveraging LTE's unique capability to support both broadband and broadcast services on a single air interface. It is the one significantly important spectrum band left that also has the best potential for spectrum harmonization globally, which will benefit consumers with a large scale device ecosystem.

This section discusses these benefits in further detail.

4.1 ELEVATES INDUSTRY

Spectrum is the key ingredient required for the increased progress of the wireless industry. Business, enterprise and consumers throughout the world are just beginning to see the new world of fast mobile broadband connections anytime, anywhere, on any device. That new connected world is just beginning, and it is recognized that it exhibits a snowball's progress that will affect all parts of society.

Some companies and analysts predict 20 to 50 billion connections by 2020. This will enable new vertical industries and enhance industries such as education, healthcare and transportation. All of this progress will only occur if governments find ways to make new spectrum available to the wireless industry.

Wireless services cannot be offered without wireless spectrum. Viable internationally harmonized spectrum is in extremely short supply for existing and new wireless entrants. According to the FCC, "Spectrum bandwidth is a necessary input to the supply of mobile wireless services. If a potential entrant were to attempt to enter the mobile wireless services market, obtaining access to spectrum is crucial." The Digital Dividend spectrum, in particular, will be a critical spectrum source for the wireless industry in many countries. This spectrum has the potential to bring new service providers into rural markets or enhance existing carriers spectrum assets, both of which could ignite innovations and create lifestyle-changing experiences, especially to the millions of underserved in those markets today.

Additional spectrum will not just give new entrants a business opportunity, but can also arm or enhance the spectrum holdings of the incumbents, allowing them to carry out their mobile broadband strategies. In many cases, the incumbent's mobile broadband business strategy cannot be executed efficiently without acquiring new spectrum. This business principle is applicable to all service providers in most countries. For example, in the U.S., AT&T, MetroPCS, and Verizon Wireless acquired the 700 MHz Digital Dividend spectrum before they could roll out LTE. With only 84 MHz of spectrum made available from the initial Digital Dividend spectrum auctions in the U.S., there remains a significant need for more spectrum. That is perhaps one reason why the U.S. government is actively working on incentive solutions; to encourage broadcast spectrum holders to agree to the repackaging of the remaining TV broadcast spectrum which would allow for additional Digital Dividend spectrum to be auctioned off for mobile broadband and broadcast services.

4.2 INCREASES JOBS AND GROWS GDP

As discussed, for many operators in the Americas region, the roll-out of mobile broadband services based on LTE technology is predicated on being able to acquire new spectrum, ideally the Digital Dividend spectrum. Early clearing of the Digital Dividend spectrum for auctions can accelerate mobile broadband deployments, drive mobile broadband innovations and mobilize industry competition, which would result in infrastructure investment, job creation, GDP growth, lifestyle changes, and improved living standards for the entire population.

Across the globe, there is little dispute that mobile broadband delivered at the 700 MHz Digital Dividend spectrum provides great economic benefits:

- In the Asia-Pacific region, it is estimated that this benefit will add approximately $750 billion to the GDP of those nations by 2020.[xii]
- In Australia, this benefit is estimated at between $7 billion to $10 billion, depending on which mobile broadband market scenario develops.[xiii]
- For the developing countries of the world, it is estimated that bringing mobile broadband penetration to the level of that found in today's Western Europe would result in $300 billion to $420 billion in contributions to these countries' combined GDP, creating an additional 10 to 14 million more jobs.[xiv]
- According to the GSMA, studies have shown there would be a 1.2 percent increase in GDP for every 10 percent increase in mobile penetration in many emerging markets.[xv]
- For the Latin America region, a jointly commissioned study by GSMA and AHCIET and conducted by Telecom Advisory Services LLC (TAS) claimed a $15 billion total economic value to the region and expansion of wireless coverage to 93 percent of the population. The same study indicated that close to 11,000 new jobs would be created.
- Another earlier study by McKinsey & Company on Latin American countries stated the combined GDP could increase by up to $70 billion, and add up to 1.7 million more jobs.[xvi]
- In the EU countries, it is estimated that the use of the Digital Dividend for mobile broadband will increase GDP by 0.6 percent annually by 2020.[xvii]

The European Commission has acknowledged that mobile broadband is "essential to creating further efficiency gains in the broader economy and is thus a key driver for economic recovery."[xviii] At CTIA's 2011 Wireless Conference in Orlando, Florida, the U.S. FCC Chairman also acknowledged, "based on past experience," consumer benefits could be 10 times greater than the value generated from the spectrum auction. These benefits could be quantified in terms of productivity gains, service cost savings, job availability, and overall quality of life improvements, among many others.

Given this consensus of the economic benefits in using the Digital Dividend for mobile broadband, there is an associated opportunity cost for delay. One study by the Spectrum Value Partners on the European markets shows a loss of around 9 percent in economic benefits with one year of delay in releasing the Digital Dividend spectrum.[xix]

4.3 DRIVES MBB INNOVATIONS (DEVICES, APPLICATIONS AND CLOUD COMPUTING)

Mobile broadband services have come a long way since the days of circuit-switched data using TDMA, GSM, and CDMA. Today's typical peak mobile broadband speed in HSPA+ networks could reach 42 Mbps (64QAM+DC), and in LTE networks, in excess of 70 Mbps (10 MHz + 2X2 MIMO). Future technology upgrades using LTE-Advanced could allow mobile broadband connections at 1.2 Gbps peak.

This network capacity evolution is very critical to support the explosion in mobile broadband traffic as forecasted in Section 1, and to allow further innovations in devices, applications and cloud services. However, due to Shannon Law limits, the 1.2 Gbps mobile broadband peak speed, and the required data capacity, will not be possible without additional spectrum.

From the early days of narrow-band packet-switched data services, we have enjoyed steady blasts of work and lifestyle enhancements as the results of device innovations, such as the QWERTY-equipped devices for corporate email, and the feature phones for access to basic news, weather, traffic and gaming download services. This was followed by touch-screen smartphones, coming along just as the mobile broadband data services adoption rate was picking up, and once again revolutionized the mobile device concept and affected how we consume mobile broadband, particularly for the non-enterprise segments.

We are now at the cusp of another major computer revolution with cloud computing, and one of the major drivers for this is the ubiquitous availability of mobile broadband. Tablets, with capabilities to access online stored contents wirelessly, are picking up market share from PC and laptop usage. Future innovations have no limits and could include a category of mass market mobile devices that are as powerful as PCs are today. It could possibly leverage processor, display, and battery innovations to deliver the power and usability of a PC with the convenience of mobility that fits in the palm of your hand. The frenzied competitions among innovators to produce such a device are the buzz in the industry today.

Machine-to-Machine (M2M) devices and applications are another area of innovation with game-changing promises. For example, imagine an intelligent electric car charger in communications with a centralized server that knows when the price of electricity is at its cheapest throughout the day to charge the car battery. Such potential for improved efficiency and lower costs for the consumers are boundless. Innovations in devices for vertical markets such as health care, enterprise, and education can raise the standards of living and increase economic productivity in a country.

The U.S. government has recognized the importance of broadband in helping modernize the country's aging infrastructure and systems. It has identified some key national priority areas requiring improvements, such as healthcare, education, energy, public safety, government transparency, civil participations, etc. It has acknowledged that each area is different in terms of the solution required. However, a common need across all areas is connectivity. In many cases, mobile broadband is the most accessible or cost effective connection to deploy for this purpose.

With additional Digital Dividend spectrum, and deployment of LTE and LTE-Advanced, mobile broadband can be made more affordable for the masses. Application innovations in remote learning, remote monitoring and diagnostics by doctors, smart grid solutions, social networking sites (e.g., Twitter, Facebook, etc.), and instant feedback for elected officials from their constituents engendering government transparency, are all on the rise. Countries that can bring affordable mobile broadband to the masses can benefit from these innovations. They can contribute to the growing research and development in these areas, which would also add jobs to the economy.

The full benefits of cloud computing are still to be realized, but there are very enticing propositions in cost reductions and other created synergies centered on the sharing of IT resources. This allows for focusing on what one does best, leaving many tasks to the IT experts. Cloud-based services will drive significant traffic on the mobile broadband pipe, which connects the device and the end user to the cloud. The speed of progress for cloud technology will depend on demand, which is linked to the capacity of the pipe and the number of connections the pipe will effectively allow. Therefore, increased mobile broadband capacity will accelerate the mobile cloud computing revolution, making innovations in cloud-based services worth the investment.

LTE mobile broadband is being rolled out now, and its future is very promising. However, the extent of its success in the future is not fully clear now. Our imagination is bounded by today's problems and their potential near-term solutions. Therefore, we must remain open and be flexible to adapt to an even greater outcome. Based on historical evidence, we are more likely to underestimate the benefits that LTE mobile broadband will bring. As Vodafone Hutchinson Australia acknowledged in their February 2010 publication, "Digital Dividend Green Paper":

> "Our experience with 3G networks is that innovation benefits do not always materialize in an expected manner; and, even where anticipated, can often exceed initial assessments. 3G networks were originally envisaged as enabling video telephony and mobile television but are now increasingly enabling whole new platforms for wireless Internet-enabled services, for example smartphones enabling several second and third degree players with innovative applications and content. Innovation over LTE networks may develop in a similarly unforeseen manner."

4.4 BRIDGES THE DIGITAL DIVIDE WITH MBB SERVICES TO THE UNDERSERVED AND UN-SERVED USERS

There are many benefits—economic, social, technological, etc.—that can be attained when any additional spectrum is made available for mobile broadband deployment. However, the Digital Dividend spectrum is very unique with its ideal propagation characteristics for mobile broadband use. It is much more economical to deploy a wireless network using the Digital Dividend spectrum. The GSMA stated that "it is approximately 70 percent cheaper to provide mobile broadband coverage over a given geographic area using UHF spectrum than with the 2100 MHz spectrum widely used for mobile broadband today."[xxiv] The cost benefits come from the ability to use fewer cell sites to provide blanket coverage geographically. Fewer cell sites mean lower equipment capital expense, lower deployment costs requiring fewer towers and facilities, and lower operational costs in terms of maintenance costs, power consumptions, site leasing and backhaul leasing.

The illustration in Figure 4-1 was extracted from a report by SCF Associates. It shows the coverage benefit from using the Digital Dividend spectrum.[xxvi]

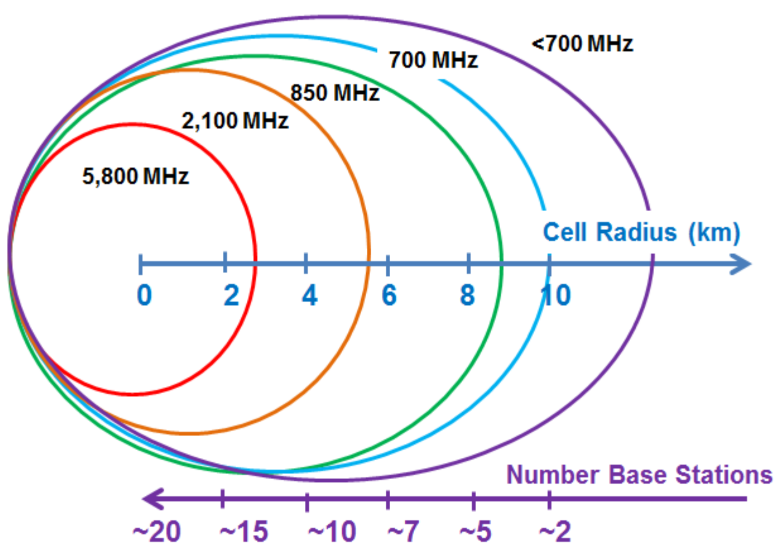


Figure 4-1: Coverage benefits of Digital Dividend spectrum

Only with such economics can one have hopes of bringing broadband to every human being on the planet. The U.S. and other developed countries still have less than optimal competition in rural markets and zero broadband services in remote areas. In developing and under-developed worlds, broadband is a luxury for the few living in dense cities; it is narrowband for most urban/suburban dwellers, and does not allow any communications for people in rural and remote locations. The fastest and most economical way to bring broadband to these regions is through wireless networks, and the least costly wireless mobile network to build and operate is one that uses the Digital Dividend spectrum.

In addition, the low frequency band can also better penetrate building walls and provide strong in-building coverage to improve the end-user experience. This advantage is particularly beneficial for those whose only means of communications is through a mobile network, but can also bring cost efficiency for the rest of the consumers in the form of service consolidation. For the first time, many consumers would be able to safely cut the cord (so to speak) and go completely wireless. Therefore, the Digital Dividend spectrum offers the pure wireless service provider a competitive edge against the fixed network operators, from which they can aggressively pursue the fixed-mobile substitution opportunity.

4.5 BENEFITS TO BROADCASTERS

Mobile broadband is an increasingly important and profitable service. To deploy a mobile broadband network requires spectrum—preferably Digital Dividend spectrum. Due to the high value of such spectrum, broadcasters stand to earn a good bit from the sale of the Digital Dividend spectrum they are holding. More strategically, and beyond the revenue from such sales, broadcasters will have every opportunity and incentive to participate in this industry.

There are several trends that broadcasters must take serious note of, and plan for, strategically. First, the television service industry is evolving toward an interactive, IP-based television (IPTV) service technology. Second, viewers are time shifting their viewing—and they only view programs that are of interest to them. This has resulted in a competitive rise in Video On Demand (VOD) services that are being offered by both the traditional TV service providers as well as by national TV networks.

To deliver these interactive TV and VOD services, the wire-, Internet- and satellite-based television service providers are leveraging bi-directional broadband networks and IP-based technology. Conversely, the broadcast technology used today, whether it is digital or analog, is a single-direction broadcast data transmission technology that limits the broadcasters' abilities to adapt to this shift away from traditional television viewing trends.

The solution for broadcast TV operators, to stay atop the IPTV and VOD services trend and stay competitive in the TV services industry, is LTE. LTE is a next generation all-IP mobile network technology that includes both a mobile broadband component that is well-suited for VOD services, and a mobile broadcast component with its enhanced Multimedia Broadcast and Multicast Systems (eMBMS) for broadcast services. In combining the mobile broadband unicast and broadcast service delivery capability of LTE, operators can also offer mobile and interactive TV.

Integrated Mobile Broadcast (IMB) is another broadcast technology option for 3G mobile broadband networks. Similar to eMBMS, IMB is an enhancement to the 3G MBMS technology designed to work with time division duplexed (TDD) spectrum. More technical information on the eMBMS and IMB solutions will be discussed in Section 0 of this paper.

One can argue that the latest broadcast technologies, such as ATSC and DVB, have included support for mobile broadcast solutions optimized for handheld devices (e.g., ATSC-M/H and DVB-H). However the key difference between these technologies and LTE is the lack of support for high-capacity, high-bandwidth IP-based mobile broadband unicast services *in combination with* mobile broadcast services. In addition, the number of LTE devices is projected to be in the tens of billions within the next 10 years, which will most likely offer much greater economies of scale for LTE/eMBMS-capable devices than any scale that ATSC-M/H or DVB-H technology could offer.

There are various possible options for broadcasters looking to enter the mobile broadband and broadcast markets, which include building out a mobile TV network, sharing a network with existing operators, and becoming a mobile virtual network operator (MVNO). With any options under consideration for broadcasters, there should be a net positive value for the broadcasters when compared to doing nothing. Broadcast TV services can be enhanced with VOD and IPTV, possibly driving more viewership and growing revenue through paid services or advertisements.

4.6 BENEFITS TO DEVICE MANUFACTURERS

The release of the Digital Dividend spectrum for mobile broadband use will provide great business opportunities and simplify life for device manufacturers.

First, the expansion of network capacity needed for mobile broadband services will be possible, facilitating the continued exponential growth in mobile broadband adoptions. Device manufacturers will continue to profit from the expansion of smartphone sales. The next-generation devices are coming our way—the potential for a new device category that can replace the personal computer, which is expected to approach 2 billion units in the next few years, presents a very exciting business opportunity. Affordable network capacity will be available to support innovations in M2M devices and is forecasted to have a potentially larger installed based than human devices at some point in the future. Figure 4-2 illustrates one view of the tremendous growth in applications, devices, and traffic by 2020.

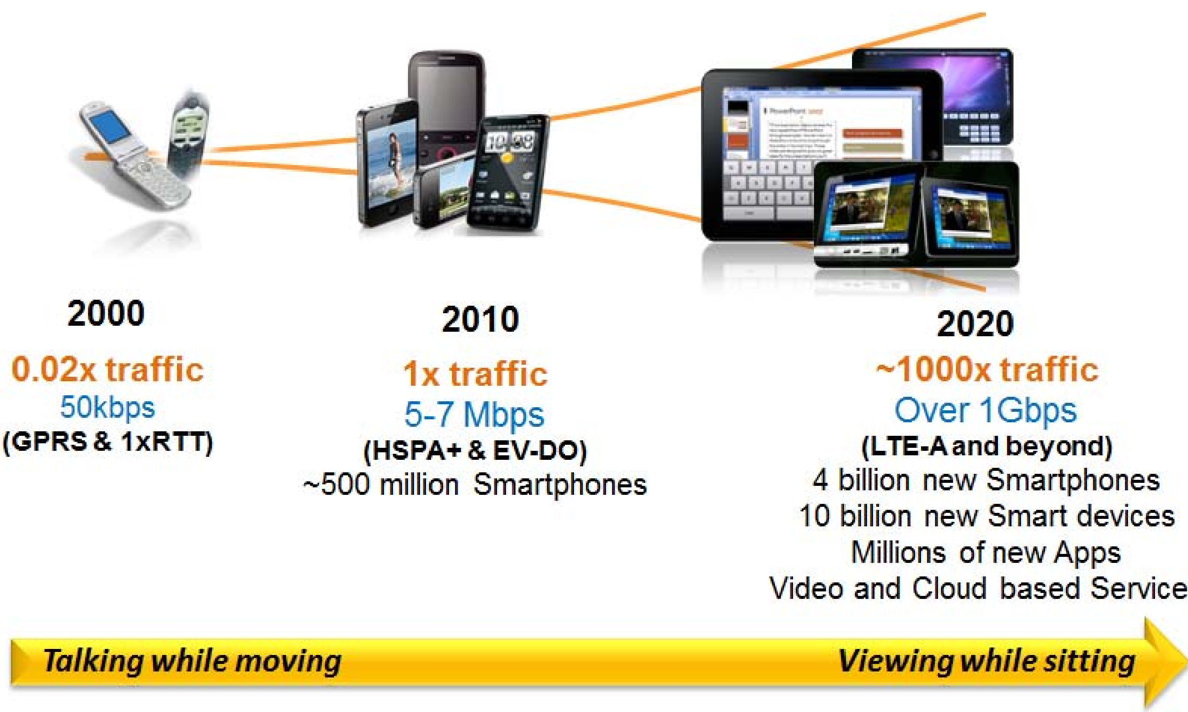


Figure 4-2: Terminals continue to shape behaviors

Second, the Digital Dividend spectrum is somewhat harmonized across the globe. As discussed in Section 3, two regions drive the main definitions for this spectrum (these are Region 1–Europe, and Region 2–North America), and mixed adoptions taken by the third region. The third region mainly follows Region 1 definitions, except for nine countries that follow the Region 2 definitions. This is what the device community has been calling for in promoting a harmonized spectrum band to reduce the complexity and cost in device design and manufacturing. After dealing with up to 10 different RF spectrums, and over 30 different band classes, as defined by 3GPP, a harmonized Digital Dividend spectrum band would be a great relief to device manufacturers.

4.7 WHY DIGITAL DIVIDEND SPECTRUM IS HIGHLY VALUABLE FOR ACHIEVING THE NATIONAL BROADBAND OBJECTIVES

In the "Announcing the National Broadband Plan" speech, FCC Chairman Julius Genachowski stated that broadband is an indispensable infrastructure of the 21st century—a foundation for the economy and democracy in the digital age. The Chairman highlighted that broadband is a platform for opportunity that can spur economic growth and job creation; a platform for innovations, a platform for solutions to national concerns in education, healthcare, energy dependence and public safety, and a platform for global competitiveness. He stressed the need to make broadband connections at very high speeds affordable so all Americans will be connected. The FCC plan is aimed at maximizing investment by unleashing new spectrum, promoting competition, removing barriers to entry and lowering the cost of investment in infrastructures. In fact, in the U.S., the FCC is asking Congress for authority to move forward with rule-making and incentive auctions for the underutilized TV broadcast spectrum.

This recognition in the importance of broadband to the economy and social infrastructures is not uniquely American. The European Commission also shares similar optimisms in the opportunity for broadband to contribute to the economic recovery.[xx] In October 2011, the European Commission, Parliament and the Council approved a plan requiring that European Union countries make the 800 MHz band available for wireless broadband services by January 1, 2013. The "Radio Spectrum Policy Program" is designed to stimulate growth in the mobile broadband market by using the radio spectrum freed up by the switchover from analog to digital TV -- also known as the Digital Dividend. In addition, new text calls for at least 1200 MHz are to be allocated to mobile data traffic after 2013 but before 2015. The Commission also must consider, by 2015, whether there is a need to harmonize additional spectrum bands in order to manage the exponential growth in wireless data traffic.

As the world is transforming to a global economy driven largely by the ability on both the supply and demand sides to have access to broadband connections for digital information sharing and execution of electronic commerce, the value of universal broadband access should be recognized and sought after by all nations in order to remain competitive on the global stage.

The Digital Dividend spectrum and LTE have all the components to provide affordable high-speed broadband to all, bridge the digital divide, bring education to remote regions, provide information access to the poor, and enable innovations to solve many national problems in education, healthcare, energy dependency and stagnated economic growth. This radio frequency band allows for the most efficient deployment of broadband, particularly to the far reaching regions where, if not for wireless technology, they would never be connected. The added capacity from releasing the needed spectrum, and the deployment efficiencies unique to the Digital Dividend spectrum, could help make broadband affordable to all. With more spectrum, there can be more mobile broadband serving societies, leading to new innovation. LTE is unique as the only mobile communications technology standard that can deliver very fast 300 Mbps (20 MHz 4X4 MIMO) mobile broadband speeds on today networks, and also has all the specifications in place to deliver extremely fast 1.2 Gbps mobile broadband speed in the near future. It is the technology of choice for all operators, including those that are using 3GPP, 3GPP2 and the IEEE. It is forecasted to have global economies of scale, with billions of users, within the next 10 to15 years. This will make mobile broadband services more affordable to the masses.

5 DIGITAL BROADCAST TECHNOLOGY OPTIONS FOR MOBILE SERVICES

The present section provides a very brief overview of various digital terrestrial broadcasting standards. The number of existing digital standards is quite high. For traditional terrestrial broadcasting to fixed receivers, the major standards in use around the globe are ATSC, ISDB-T, DVB-T and DTMB (formerly DMB-T/H), as shown in Figure 5-1. Each of these standards has in recent years obtained at least one dependent standard designed for mobile reception by handheld receivers, where antennas are typically telescopic and fixed to the device. Examples are ATSC-M/H, DVB-H, ISDB-T 1SEG, and CMMB. Finally, several cellular standards also have added support for a true broadcast transmission mode (that is, (e)MBMS for WCDMA and LTE, BCMCS for CDMA2000 and MBS for WiMAX).

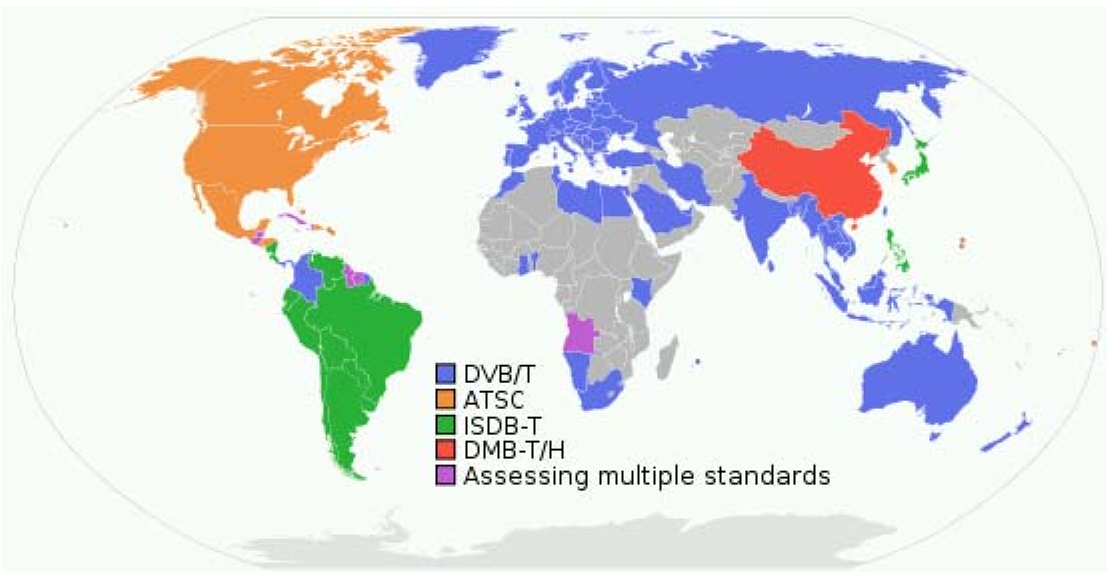


Figure 5-1: Adoption of individual digital broadcasting standards around the world

5.1 ATSC

ATSC is a set of standards developed by the Advanced Television Systems Committee for digital television transmission over terrestrial, cable, and satellite networks.

The ATSC standard was developed in the early 1990s by the Grand Alliance, a consortium of electronics and telecommunications companies that assembled to develop a specification for what is now known as HDTV. ATSC formats also include standard-definition formats, although initially only HDTV services were launched in the digital format.

For transport, ATSC uses the MPEG system specification, known as an MPEG transport stream, to encapsulate data, subject to certain constraints."[xxi]

ATSC signals are designed to use the same 6 MHz bandwidth as analog NTSC television channels. Terrestrial ATSC distribution uses 8VSB (vestigial sideband) modulation that can transfer at a maximum rate of 19.39 Mbps. 8VSB is a single-carrier modulation. In contrast to multi-carrier modulation types like OFDM, single-carrier modulation suffers more from inter-symbol interference. The receiver, therefore, needs to be more complex, implementing an equalizer. The ATSC target performance for an equalizer window is approximately 60–90 µs (depending on the definition).[xxii] 60 µs multiplied by the speed of light corresponds to a distance of 18 km. Multiple signals arriving with a traveling path difference larger than this value will degrade the reception. This, in turn, puts strong limits on the establishment of a so-called Distributed Transmission System (DTS), aka SFN. In a DTS, several transmitters in an intended coverage area radiate the same signals synchronously. However, ATSC does not provide transmitter or DTS-specific reference or training symbols. Cancelling interference from transmitters not belonging to the DTS is, therefore, difficult.

Furthermore, because of the above limitations, ATSC was not originally designed for such large multi-path delay spreads, and early receivers are not capable of operating in an SFN network. When multiple SD video streams are multiplexed with virtual channel numbers, it may appear that ATSC's Multiple Frequency Networking design is operating as an SFN, but this is currently done without multiple transmitters, and so this is not properly called an SFN. Even so, there are some proposals to use more recent receiver equalizers and the TxID field to enable SFN within ATCS, but so far this technology has yet to be commercialized.[ix] The ATSC standards group has recently published an interim standard A/110:2011 to provide for transmitter synchronization to support SFN ATSC networks.[xiii] But this interim standard expressly warns:

> "Users of this standard for SFN applications are advised that, while distributed transmission holds the potential to greatly improve the coverage and service areas of DTV transmission, it also holds the potential to cause interference within the network that some receivers, particularly early designs, may not be able to handle. Consequently, distributed transmission networks must be carefully designed to minimize the burden placed on the adaptive equalizers in such *legacy receivers* while maximizing the improvement in signals delivered to the public. The impact on any specific receiver will depend upon the receiver's location, the use of directional receiving antennas, and other factors related to the design of the receiver."

Standards work on specifying recommended practices for implementing SFN with ATSC networks has progressed as well, but only simulations appear to have been done; no actual deployments are in commercial operations.[xiii]

ATSC replaced much of the analog NTSC television system in the United States on June 12, 2009, and will replaced NTSC in late 2011, in Canada, December 31, 2015 in Mexico, and January 1, 2019 in El Salvador.

ATSC-M/H

ATSC-M/H is an extension to the available digital TV broadcasting standard ATSC A/53. The ATSC transmission scheme is not considered robust enough against Doppler shift and multipath radio interference in mobile environments. It was designed for highly directional fixed antennas. To overcome these issues, additional channel coding mechanisms are introduced in ATSC-M/H to protect the signal.

ATSC-M/H is time-multiplexed with the ATSC data stream for fixed reception on the same 6 MHz frequency carrier. The legacy ATSC receivers will ignore the ATSC-M/H part in the multiplexed stream.

ATSC-M/H bandwidth consumes fixed chunks of 917 Kbps out of the total ATSC bandwidth. Such chunks are called an M/H Group. A data pipe, called a parade, is a collection of one to eight M/H groups. A parade conveys one or two ensembles which are logical pipes of IP datagrams. Those datagrams in turn carry TV services, system signaling tables, OMA DRM key streams, and the Electronic Service Guide.

Time slicing is a technique used by ATSC-M/H to provide power savings on receivers. It is based on the time-multiplexed transmission of different services. ATSC-M/H combines multiple error protection mechanisms for added robustness. One is an outer Reed Solomon Code, used as an erasure code. The time interleaving for ATSC-M/H is one second.

ATSC-M/H provides additional training sequences that support the estimation of channels with larger delay and Doppler spread, which are typically encountered in mobile reception. The estimation and equalization of these larger spreads, however, adds additional complexity to the receiver.

ATSC-M/H has specified the supported video bitrates of 500 Kbps, 400 Kbps and 256 Kbps, as well as audio bitrates of 16 Kbps, 24 Kbps and 32 Kbps.

70+ Stations have launched ATSC M/H to date.[xxiii]

5.2 MEDIAFLO

MediaFLO is an OFDM-based mobile broadcasting technology developed by Qualcomm. In the United States, the service powered by this technology was branded as FLO TV. In the United States, the MediaFLO system used frequency spectrum 716–722 MHz, which had previously been allocated to UHF TV Channel 55.

In October 2010, Qualcomm announced it was suspending new sales of the service to consumers. Many analysts confirmed that the project was losing money. The service did not attract a sufficiently high subscriber base due to the price level (initially U.S. $15/month), and the need for MediaFLO-enabled terminals, which were limited in variety.

In December 2010, AT&T announced that it will purchase Qualcomm's FCC licenses in the 700 MHz band.[xxx] FLO TV discontinued service on March 27, 2011.[xxi]

5.3 DTMB/CMMB

DTMB

Digital Terrestrial Multimedia Broadcast (DTMB) is the standard for digital terrestrial broadcasting, mainly for fixed receivers in China, Hong Kong and Macau, as adopted in 2006. It is based on OFDM, with a special cyclic prefix that contains a pseudo-noise sequence which is used as a pilot signal. Supported bitrates on an 8 MHz carrier are between about 5 and 32.5 Mbps, depending on modulation and code rate.

CMMB

Chinese Mobile Multimedia Broadcasting (CMMB) uses frequencies in the range 2635–2660 MHz (S-band) for satellite and "gap-filler" terrestrial broadcast, with additional terrestrial broadcast in the UHF band 470–862 MHz. The channel bandwidth can be either 2 MHz or 8 MHz, depending on data rate. It has a capacity of 25 video (H.264 encoded) and 30 radio channels. CMMB uses OFDM with 4k/1k subcarriers in 8 MHz/2 MHz channels. Satellite transmission in the S band, as well as terrestrial transmission, is specified in accordance with the standard. The receivers can receive the CMMB signal from rebroadcast terrestrially or from the direct satellite signal.

CMMB is designed to enable both mobile and stationary digital TV reception with combined satellite and terrestrial broadcasting. For this purpose, a nationwide CMMB network is being set up in China; the network was already in operation in several cities during the 2008 Olympics. [xxiv]

5.4 DVB-T/DVB-T2/DVB-H/DVB-NGH/DVB-SH

DVB-T

DVB-T was first introduced by the UK in 1998. It uses OFDM for multipath immunity, specifically to enable Single Frequency Networks. DVB-T is flexible, with transmission parameters like OFDM symbol and guard interval duration, error correction code rate and modulation; so that it can be configured for a wide range of coverage targets and reception environments. According to the choice of parameters, the data rate is in the range of 4.97 Mbps to 31.66 Mbps on the physical layer, in an 8 MHz channel.

DVB-T is usually used together with MPEG-2 audio/video coding for SDTV and the MPEG-TS transport streams.

DVB-T is successfully launched in most of European countries, India, Australia, South Africa, and in some other African and Asian countries, see Figure 5-1. In several of these countries, analog terrestrial TV has already been switched off.

DVB-T2

The DVB-T2 standard was finalized in June 2008 and published on the DVB homepage as DVB-T2 standard BlueBook. It was adopted by ETSI on September 9, 2009. A major requirement was increased efficiency, at least by 30 percent, over the DVB-T standard. This has been achieved by employing state-of-the art LDPC/BCH forward error correction coding. Furthermore, DVB-T2 supports OFDM with more than 8k carriers. The new modes with 16k and 32k carriers further increase the guard interval proportionally. This allows for larger (nation-wide) SFN, even with existing sparse transmitter density and high data rates. However, the decreased subcarrier spacing is less suitable for high receiver velocity due to Doppler spread.

Multiplexing of Physical Layer Pipes (PLPs), each with its own modulation and error coding, enables DVB-T2 to transmit data for different reception conditions in the same multiplex. For example, this enables one data stream with robustness tailored for fixed reception and another data stream for mobile receivers.

DVB-T2 also supports multiplexing different transport stream formats, including Generic Stream Encapsulation for IP packets.

Besides several further features of lesser importance, DVB-T2 also supports Alamouti encoding for spatial diversity employing two antennas at the transmitter. This can be particularly useful for mobile receivers.

In July 2011, a new profile called DVB-T2 Lite was added. This profile is intended to allow simpler receiver implementations for very low capacity applications such as mobile broadcasting, although it may also be received by conventional stationary receivers. T2-Lite is based on a limited sub-set of the modes of the T2-base profile; and by avoiding modes which require the most complexity and memory, allows much more efficient receiver designs to be used.

DVB-T2 is intended to be used with H264/AVC video coding, which achieves 30-50 percent efficiency gain over MPEG-2. Together with the other increased efficiency of the DVB-T2 this enables transmission of HDTV. Due to more than five times higher raw video bit rate for HD than for SD (1080i vs 480i), an HD program will still occupy a larger part of a DVB-T2 multiplex than an SD program does in a DVB-T multiplex (up to about two times as much).

The U,K. was first to launch DVB-T2 in April 2010, since then several European countries have followed. The introduction is mostly gradual, adding one or a few multiplexes or converting them from DVB-T. In other countries, (e.g., Germany) that started late with DVB-T, the introduction of DVB-T2 is as yet uncertain and in any case several years ahead.

DVB-H

DVB for handhelds is an extension to the DVB-T standard, which addresses the specific requirements of Mobile TV. Time slicing technology is employed to reduce power consumption for small handheld terminals. IP datagrams are transmitted as data bursts in small time slots. Each burst may contain up to 2 Mb of data (including parity bits). DVB-H introduces additional Reed-Solomon forward error coding separately over each burst, called MPE-FEC. The front end of the receiver switches on only for the time interval when the data burst of a selected service is on air. Within this short period of time, data is received at a high rate and stored in a buffer. Error correction is then performed if necessary and then the data is played out from the buffer continuously at the lower rate used by audio/video decoder.

DVB-H is intended to be used with H.264 (MPEG-4 Part 10/AVC) video coding.

DVB-H is tied to a related set of specifications for IP datacast (DVB-IPDC) to enable distribution of IP packet data streams.

Furthermore, the DVB-H adds an OFDM mode with 4k subcarriers, offering additional flexibility in designing single frequency networks which still are well suited for mobile reception. DVB-H also provides an enhanced signaling channel for improving access to the various services.

DVB-H has been deployed in several countries mainly in Europe with very limited success. Netherlands, Austria, Switzerland and operator TIM of Italy have already decided to shut down the service. Germany's initial license owner meanwhile has returned the license. Ireland discontinued the licensing procedure and France has delayed the procedure.

One main reason for the DVB-H failure to take off is the availability of only a very few handsets. 32 models are listed on Wikipedia. Several do not have a DVB-H receiver integrated into them; they require an external accessory for this function. Phonegg.com lists only 22 handsets that apparently are integrated with a DVB-H receiver.

DVB-NGH

In November 2009, the DVB group made a “call for technologies” for a new DVB-NGH (Next Generation Handheld) system to update and replace the DVB-H standard for digital broadcasting to mobile devices. The plan is to finalize the standard by the end of 2011.

DVB-NGH is built on DVB-T2. Since there is no requirement for DVB-NGH to be compatible with legacy receivers, which typically have only a single antenna input, some focus is being given to MIMO transmission. Longer time interleaving on the physical layer is considered to better withstand the impulsive noise that is stronger in handheld environments. Finally, some improvements for better reception at higher receiver velocities are under study..[xxv]

Recently, the DVB technical module met with 3GPP to discuss a possible common broadcast mode between LTE and DVB. At of the time of this writing, the discussions have not yet reached agreement on how to move forward.

DVB-SH

DVB Satellite to Handhelds is intended for hybrid coverage provided directly by satellite and from a complementary terrestrial network to mobile receivers. Both the satellite and the terrestrial networks transmit in the 2170–2200 MHz band, which is adjacent to the 2110–2170 MHz 3G cellular downlink band. Depending on the DVB-SH mode, the satellite and terrestrial network can provide the same signal, on the same channel, in the same geographical area. In 2009, the European Commission selected two operators, Inmarsat Ventures and Solaris Mobile, for the service. Both operators must commercially launch services in 2011 to keep their licenses.

A geostationary satellite, Eutelsat W2A, covering Western Europe, was launched by Solaris Mobile in 2009. So far, interest in the service is very limited. At IBC 2011, Solaris Mobile announced a digital radio service and a dedicated handheld receiver device.

Inmarsat has planned to launch the EuropaSat satellite in 2011. However, the launch has been put on hold till late 2011. In the interim, Inmarsat plans to attract external investors to fund the project, and to ultimately spin it off as a separate company. [xxviii]

Since the DVB family of broadcast technologies uses OFDM schemes, they are more robust in response to long delay spreads, and have been deployed in SFNs.[xxv, xxvi, xxvii] These standards are being pursued by some specific operators in the Americas, particularly where PAL and SECAM are currently in use. Mobile Satellite Service licensee, ICO (aka Pendrell), in the United States, has also trialed SFN deployments of terrestrial repeaters using DVB-SH.[xxviii]

5.5 ISDB-T/1SEG

Integrated Services Digital Broadcasting for terrestrial, ISDB-T, was developed by ARIB and first used in Japan. Slight variants of this standard are use in most of South America. Like DVB-T, it is based on OFDM with 6 MHz channels, each divided into 13 segments. Based on OFDMA technology, ISDB-T can take advantage of SFN for coverage. ISDB-T defined 50 channels between 470 MHz and 770 MHz, with claims to accommodate high mobility speeds (100 km/h or more). It should be noted that Brazil has also adopted ISDB-T as a base for its digital TV broadcast, but adding some enhancements (e.g., MPEG4 video codecs instead of MPEG-2). The enhanced version of ISDB-T is often called “ISDB-T International.” Unlike DVB-T, services can be multiplexed in the frequency domain. Only a few multiplex combinations of up to 3 SDTV programs are standardized. If HDTV is transmitted, then only a single program fits into one channel.

The center frequency segment is used for mobile TV in a so called "OneSeg" or 1SEG mode with different transmission parameters (QPSK, OFDM with 433 subcarriers, 1/4 symbol guard interval, 2/3 code rate FEC). The Net bit rate for 1SEG is 416 Kb/s. Further 1SEG specifications are:

- Video coding H.264 (MPEG-4/AVC); Max. video resolution is 320 × 240 pixels (QVGA) with 15 f/s

- Audio coding HE-AAC
- Encapsulation in MPEG-2 transport stream

Since June 2008, the "multiple-program" arrangement has enabled the transmission of two programs per 6 MHz channel in the 1SEG mode. By the end of March 2008, the Japanese regulation required that the programs on 1SEG be fundamentally the same as those broadcasted on the equivalent HDTV channel (service is free), but since then they have liberalized the regulation. At the end of the fiscal year, March 2008, 64.2 percent of mobile phones had 1SEG reception capability. [xxviii]

5.6 3GPP MBMS

Standardization of MBMS started in 3GPP and 3GPP2 back in 2002. The first version of the standard was functionally frozen in 2005, and finalized during 2006 in 3GPP Rel-6. The MBMS evolution beyond Rel-6 is described in the following sections.[xxix]

MBMS has been specified as an add-on feature to existing cellular network technologies, namely GSM/EDGE and UMTS. Existing transport and physical radio channels of those systems were reused, to a large extent, to keep the implementation effort low.

MBMS supports two basic transmission modes for delivering IP packets: broadcast and multicast. The MBMS broadcast mode can be used to deliver IP packets to all terminals in a certain area or throughout the whole network. If the MBMS broadcast mode is used, a transmission bearer is set-up for all cells where the service is available and continuously transmitting—as long as the service is up and running. In broadcast mode, MBMS does not require an uplink connection and, therefore, can be used like any other “downlink-only” broadcast technology.

The MBMS multicast mode works very similar to IP multicasting. A terminal that wants to receive information related to a particular multicast channel “joins” one or several content channels (i.e., expresses interest to receive content associated with this channel). This information is processed in the routing layer of the core network and is used for optimizing the data delivery path. “Optimizing” means that over connections shared by receivers of the same multicast channels, data is transmitted just once. The only drawback of multicasting is the additional delay when switching from one channel to another one. Therefore MBMS multicasting is less suitable for mobile TV services, which usually require a low delay in switching TV channels. The main applications for MBMS multicasting are downloads and Podcast services.

MBMS was specified so that broadcast/multicast services can be used together with voice and data services within the same radio carrier. This provides the greatest flexibility for cellular operators.

In MBMS, it is possible to define so-called MBMS service areas (MSAs). An MSA is defined as a collection of cells. In each of the defined MBMS service areas different services can be delivered. In this way, MBMS services can be restricted to geographically limited areas.

MBMS contains an interesting mechanism called “Counting.” Counting means that an uplink signaling channel is used to inform the radio access network when a terminal requests reception of a content channel. Based on this information, the radio access network can keep track of the number of terminals currently receiving a particular content channel. This allows the radio access network to make an intelligent decision on whether a particular content channel needs to be transmitted in a cell or not, and if yes, which type of radio bearer should be used.

MBMS provides support for both streaming and download services. Hence, different types of services will benefit from the introduction of MBMS. An example would be mobile TV services that several operators have launched over existing UMTS networks and which will greatly benefit from the capacity enhancements MBMS brings. Besides mobile TV, other services will also benefit. One example is audio or video podcasting, where mobile users subscribe to a certain podcast provider. MBMS can then be used for the download delivery of the provider's audio and video clips to a large number of subscribers at the same time. Another example is public safety. Here, MBMS could be used for emergency alerts in certain areas, for example, in the event of a tsunami or earth quake.

MBMS employs three packet error recovery schemes to cope with packet losses that may occur during bad radio conditions. The most important scheme is the use of Forward Error Correction (FEC) coding, which allows recovery of lost packets without any server interaction. FEC can be used both for MBMS downloads and streaming delivery. For the MBMS download service, two additional file repair mechanisms were defined. The first one uses a point-to-point (P-t-P) connection to explicitly request the missing parts of a file. The second uses a point-to-multipoint (P-t-M) bearer to deliver missing parts to several terminals at the same time.

5.7 3GPP MBMS EVOLUTION

MBMS evolution in 3GPP 3G networks in Rel-6 is a part of the two main tracks of standards development. This is depicted in Figure 0-2 and discussed below.[xxix]

- Evolution of UMTS/WCDMA
- 3GPP long-term evolution of UTRA, called 3GPP LTE (denoted by E-UTRA in the 3GPP specifications)

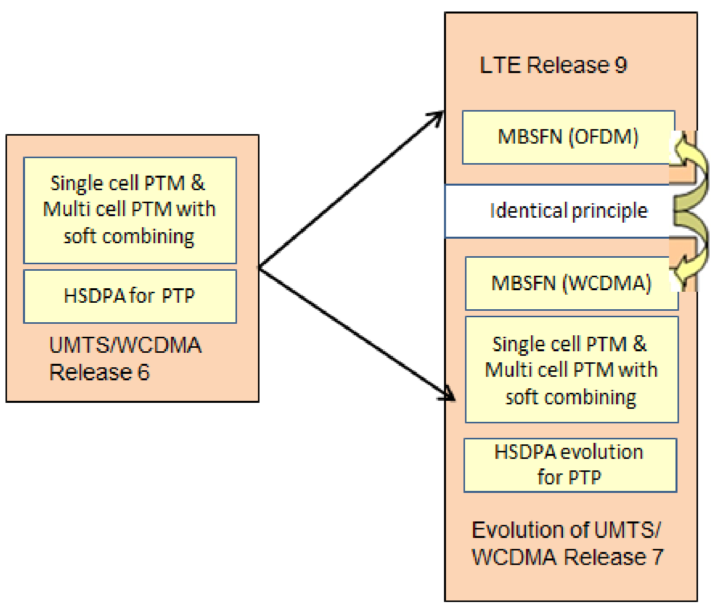


Figure 0-2: MBMS evolution tracks (3GPP releases)

The evolution of UMTS/WCDMA comprises improvements in MBMS for the P-t-M radio bearers, mainly the introduction of so called MBMS single-frequency networks (MBSFN) and HSPA evolution, which allows for higher capacity use of P-t-P radio bearers. In 3GPP, Rel-7 also supports unicast bearers, like

Streaming and OMA Push, as part of an MBMS User Service.[xxx,xxxi] The use case, which has driven the integration of unicast bearers into MBMS, is access to an MBMS service in the home network from a visited network that does not support the same MBMS services as the home network, or which does not support MBMS at all.

In a parallel track, 3GPP has standardized the long-term evolution of UTRA, called LTE (denoted by E-UTRA in the 3GPP specifications). LTE is a next-generation technology that is part of 3GPP Rel-8 and defined in the 36 series of specifications. MBMS was introduced for LTE in Rel-9 in early 2010.

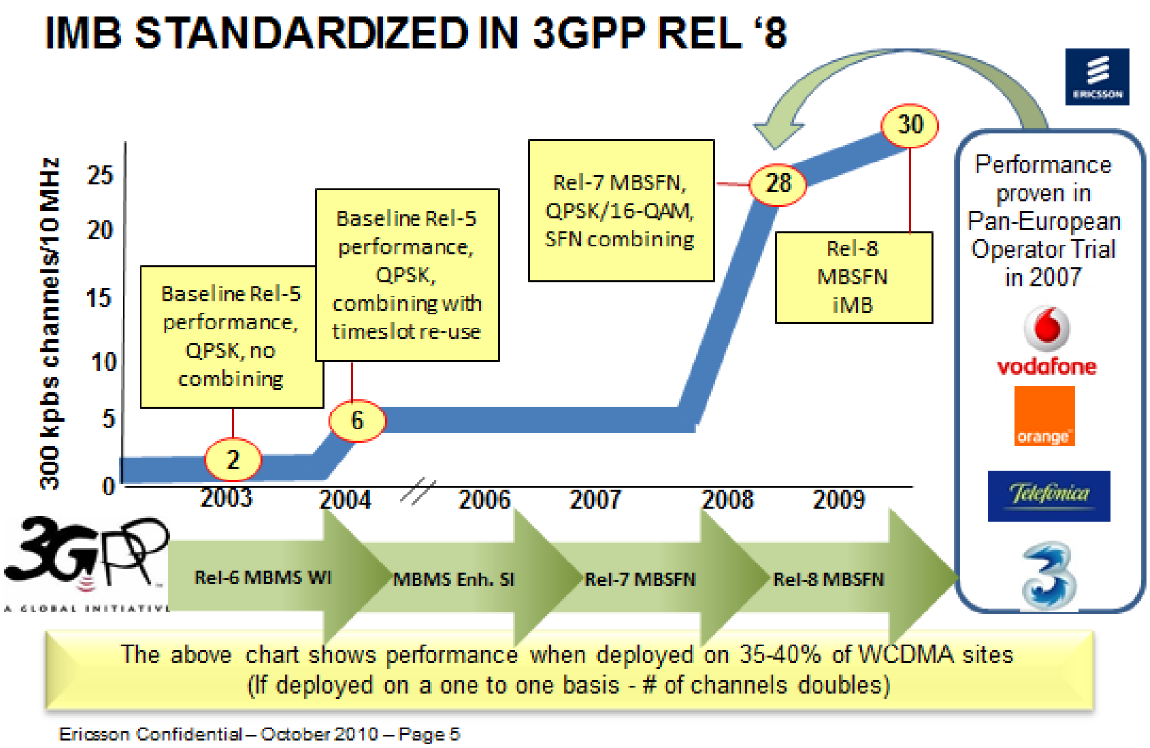


Figure 5-3: Evolution of MBMS standardization, including IMB

For UMTS, Figure 5-3 shows the development of MBMS from Rel-6 to Rel-8. 3GPP has introduced MBSFNs in Rel-7 for FDD and TDD in 2007. In the conventional UMTS downlink, all the physical channels of a cell, except for the synchronization channels, are scrambled by cell-specific primary or secondary scrambling codes. While scrambling codes are used to differentiate cells, orthogonal spreading is used to separate multiple code-division multiplexed channels within a cell. With orthogonal spreading, a receiver does not experience own-cell interference when the base station signal travels through a flat channel. State-of-the-art receivers are capable of removing own-cell interference, even in the case of a non-flat channel, e.g., linear MMSE chip equalizer or G-Rake techniques. Due to lack of signal orthogonality, however, these receivers do not suppress interference from other cells as effectively as that from own-cell. In contrast, in the MBSFN transmission mode, the same scrambling is used for all participating cells.

When different base stations use the same waveform to simultaneously send a common set of MBMS content on a common set of channels, the received signal is the same as that for a single-source transmitted signal traveling through a heavily dispersive channel, where each path corresponds to a signal path between a base station transmitter and the receiver. In this case, other-cell interference shares the same orthogonal properties as the own-cell signals. As a result, an advanced receiver (e.g., zero-forcing equalizer) not only collects the signal energy contributed by the multiple base station signals, but also gets rid of interference arising from multipaths and transmissions from multiple base stations.

To exploit the resulting high SINR, Rel-7 adds support for 16QAM on the MBMS Traffic Channel (MTCH). This significantly boosts the spectral efficiency of MBMS in a UMTS-HSPA network. To limit receiver complexity, the delay spread needs to be limited, and the cells in the MBSFN need to transmit the same signal at the same time. Synchronization on the order of a few micro seconds is required. The synchronization of the transmitting nodes (called NodeB in UMTS) is ensured by the Radio Network Controller (RNC).

In a proposed application of the MBSFN mode, cells have multiple carriers of which some operate in the MBSFN mode using cell common scrambling, and some operate in the normal non-MBSFN mode using cell-specific scrambling. Multiple MBMS physical channels can be code-division multiplexed on this dedicated carrier. However, the same channelization code is used in all of the base stations to transmit the same MBMS content channel. Furthermore, time multiplexing of MBMS radio bearers is possible.

5.8 3GPP IMB

Integrated Mobile Broadcast (IMB) allows mobile network operators to use their allocated 3G TDD spectrum to deliver broadcast services (i.e., in Europe in the bands 1900–1920 MHz and 2010–2025 MHz). Adjacent channel co-existence exists between the IMB downlink transmission and adjacent uplink bands; a guard band is needed to limit this interference.

IMB provides adaptations of the 3GPP Rel-7 FDD MBSFN mode for operations in TDD bands. This is mainly a new synchronization code for cell searches that resolve potential TDD legacy cell-search issues, and protocol additions to set up MBSFN FDD in TDD bands. Some further improvements are introduced, like time-sliced transmission with 20 percent duty cycles for efficient terminal battery savings.

The GSMA—in uniting 750 operators who voted to formally endorse IMB—provided significant industrial support to the technology. IMB was successfully trialed in the U.K. during 2011 by Orange, O2, and Vodafone.

Since 2006, the only radio access technologies that have been endorsed by the GSMA are HSPA and LTE—both are mainstream mobile broadband technologies.

5.9 3GPP E-MBMS

3GPP Rel-9 has standardized MBMS for LTE—called E-MBMS. E-MBMS has also been proposed to ITU-R as a candidate radio technology for a new ITU-R recommendation. In Rel-9, MBMS traffic is time multiplexed with unicast traffic, which can be used to enable interactivity for the broadcast services or upcoming "Hybrid-Digital-TV" services.[xxxii] In the time multiplexed configuration, up to 6 out of the 10 sub-frames of a radio frame can be dedicated to MBMS in the FDD mode (up to 5 in the TDD mode).

E-MBMS employs a single-frequency network configuration, like DVB-T, establishing a so called MBSFN. Cells in an MBSFN area have to be tightly time synchronized. E-MBMS is built on the LTE downlink OFDM physical layer, however, a longer cyclic prefix of 16.7 µs is defined, which is longer than that for LTE mobile broadband. In a further configuration, the cyclic prefix is increased to 33.3 µs. This implies that, for two transmitter sites separated by up to 10km, no interference occurs at any point between the transmitters. As the inter-site distance for typical LTE networks is typically below 10 km, reception that is free of interference from first-tier neighboring sites is possible.

A cell can belong to up to 8 MBSFN areas, allowing for overlapping nationally, regionally, and locally in MBSFN areas. Each cell supports 16 Multicast Channels (MCH), each of which can be configured with a different modulation and code rate to support tailored robustness in different reception conditions. Up to 29 multicast traffic channels can be configured per MCH.

On the transport layer, E-MBMS employs IP packets. E-MBMS provides a streaming and a file download service type. Both make use of standard IETF protocols. As retransmissions are not supported in E-MBMS, increased transmission robustness can be achieved by additional forward error correction on the application layer (AL-FEC) working on IP packets. This also achieves increased time diversity as large AL-FEC blocks are supported.

Service discovery is enabled by Electronic Service Guides. DRM for content protection is supported.

The architecture shown in Figure 5-4 shows the content delivery services that use MBMS. A discussion of the entities involved follows.

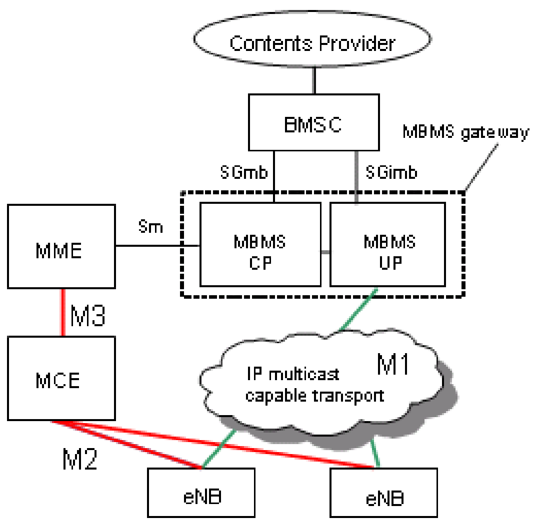


Figure 5-4: MBMS architecture

- The BMSC (Broadcast/Multicast Service Center) serves as an entry point for content delivery services that use MBMS. Part of the functionality provided by the BMSC is comparable to that of an IP encapsulator in DVB-T/DVB-H services. However, due to the dynamic bearer management in MBMS, the BMSC functionality goes beyond that of an IP encapsulator. Toward the mobile core network, it sets up and controls MBMS transport bearers and can be used to schedule and deliver MBMS transmissions. The BMSC also provides service announcements to end-devices. These announcements contain all necessary information, such as multicast service identifier, IP multicast addresses, time of transmission, and media descriptions that a terminal needs in order to join an MBMS service. The BMSC can also be used to generate charging records for data transmitted from the content provider. It also manages the security functions.

- The MBMS gateway (GW) is an entity that is located between the content provider and the evolved transmitter stations (called eNodeBs or eNBs). The Control Plane (CP) of the MBMS GW is involved in the MBMS session start/setup. The user plane (UP) is responsible for delivering the user data over the IP-multicast-capable transport network to the eNodeBs, and participates in the content synchronization for MBMS services using MBSFN. The evolved MBMS gateway is part of the Evolved Packet Core (EPC).
- In the context of MBMS, the MME (Mobility Management Entity) is responsible for session control signaling.
- The MCE (Multicell/Multicast Coordination Entity) is an entity responsible for coordinating the usage of MBSFN transmission in the LTE radio access network (RAN). This entity is part of LTE RAN. The MCE is responsible for all the eNodeBs belonging to one MBSFN area.
- The eNodeB is the evolved transmitter station in LTE responsible for multiplexing, framing, channel coding, modulation and transmission.

The following logical interfaces are defined in the RAN:

- M1 is a logical interface between the MBMS GW and the eNodeBs. The transport on this interface will be based on IP multicast. The MBMS content is transported in a frame or tunnel protocol to support content synchronization and other functionalities. IP multicast signaling is supported in the transport network layer to allow the eNodeBs to join an IP multicast group.
- M2 is a logical control interface between the MCE and the eNodeBs. This interface is used to coordinate the setting up of an MBMS service in the eNodeBs for MBSFN operation. The signaling transport layer is based on IP.
- M3 is a logical Interface between MME and MCE. It supports MBMS Session Control Signaling, including the Quality of Service (QoS) attributes of each service—it does not convey radio configuration data. The procedures comprise, for example, MBMS Session Start and Stop. SCTP is used as signaling transport; point-to-point signaling is applied.

5.10 COMPARISON OF BROADCASTING TECHNOLOGIES

Due to spectrum scarcity, high spectral efficiency is of the utmost importance for any broadcasting technology. Since the same program is usually delivered over large geographical regions, even nationwide, the establishment of a single-frequency network is a key approach for achieving high spectral efficiency. The SFN performance, in terms of coverage and supported data rate, is better the longer the delay spread that the technology can tolerate and the denser the deployment. Furthermore, for OFDM-based technologies, there is a tradeoff: The larger the delay spread tolerance the smaller the Doppler frequency tolerance—performance degrades more quickly with increasing user speed. Table 5-1 provides a qualitative assessment of these metrics.

Metric technology	Delay spread tolerance	Deployment density	SFN performance	Mobility
ATSC M/H	Medium	Sparse	Low	High
DVB-T/DVB-H	Medium–High	Sparse	Low–Medium	Low–Medium
DVB-T2 (Lite)	Medium–Very high	Sparse	Low–High	Low–Medium
eMBMS & IMB	Low	Very dense	High	Very high

Note: DVB-NGH is still in the process of standardization. It is still too early at this point to assess its performance and be included in the table, above.

Table 5-1: Comparison of key metrics of digital broadcasting technologies

One can argue that the latest traditional broadcast technologies in Table 5-1 have solutions optimized for handheld devices, such as ATSC-M/H and DVB-H, and thus should be considered for mobile broadcast services. However the key difference between those technologies and LTE with eMBMS is the lack of support for high-capacity, high-bandwidth IP-based mobile broadband services in combination with mobile broadcast services. In addition, the eMBMS solution is based on LTE radio specifications and would only require a software upgrade on the existing LTE chipset and devices for support. The number of LTE devices is projected to be in the billions within the next 10 to 15 years, and therefore would most likely offer much greater economies of scale for LTE-/eMBMS-capable devices than any scales that ATSC-M/H or DVB-H technologies could offer. eMBMS (and IMB) are designed to be deployed alongside a dense mobile broadband network, which allows it to meet the low-delay-spread requirement, and delivers high performance even for very high mobility users. Traditional broadcast technology, on the other hand, imposes significant speed limits on users and does not efficiently support mobile broadband. They also lack the global scale for mobile services.

HSPA and LTE standards are currently the only standards that are deployed, or being deployed, world-wide with at least one network available in almost every country. Thus, these standards provide the best roaming opportunities for a globally mobile society.

6 LTE TECHNOLOGY IS BEST FOR THE DIGITAL DIVIDEND SPECTRUM

6.1 BACKGROUND AND DEPLOYMENT TIMELINE

The introduction of LTE will be an evolutionary step, rather than revolutionary one, as large parts of existing infrastructure is reused, providing a future-proof technology path for flexible migration of services from 2G to HSPA and LTE mobile broadband technologies.

Even though HSPA will be the leading mobile broadband technology for at least another decade, and will offer a continuing evolution with potential 3GPP standardization for peak theoretical throughput rates of HSPA+ up to 336 Mbps, LTE will sooner or later be essential for meeting customer expectations and demand for speed and capacity. LTE will enable more bandwidth-demanding and latency-sensitive applications such as interactive TV, mobile video blogging, advanced gaming, and professional services.

LTE will be a main driver for innovation in the years to come opening doors to possibilities in a number of new areas, like utilities transport, health, and media, to name a few.

As of October 2011, there were 33 commercial LTE deployments, and at least 75 LTE networks were anticipated to be in commercial service by the end of 2012. In total, over 250 operators publicly committed to the technology, with a large number of LTE trials in operation. In October 2011, more than 200 million people had access to commercial LTE networks.[xxxiii]

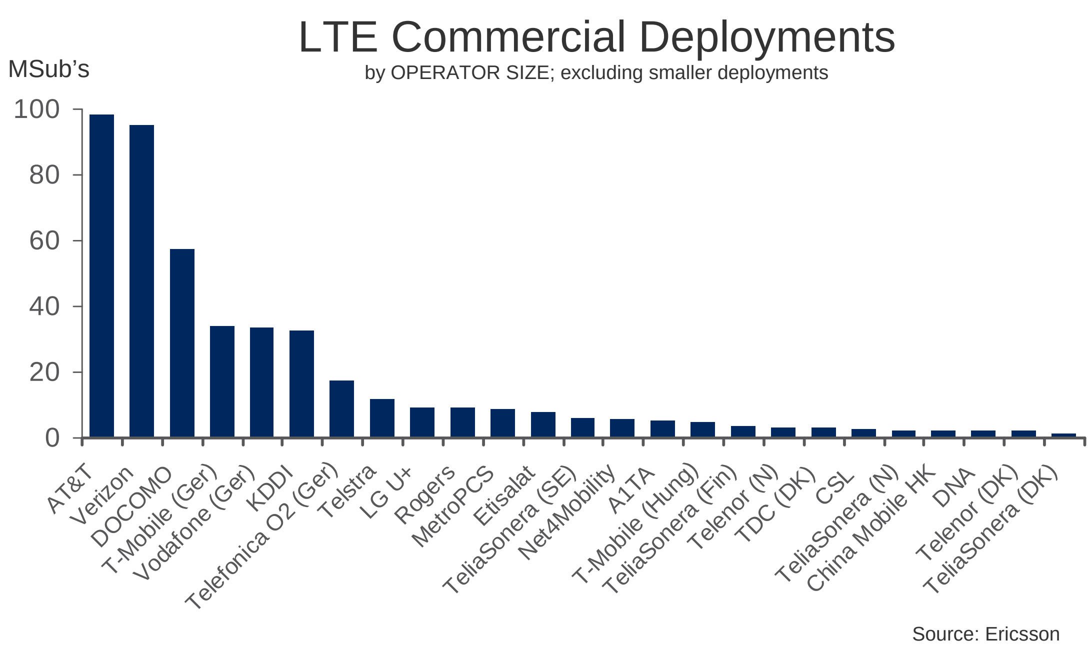


Figure 6-1: Million subscribers per operator deploying commercial LTE

6.2 GLOBALLY ADOPTED TECHNOLOGY

LTE is the global standard for the next generation of mobile networks supported by all major players in the industry. LTE offers the capacity and the speed to handle a rapid increase in data traffic with close to 5 billion mobile broadband subscriptions expected by 2016.

Performance and capacity – One of the requirements of LTE is to provide downlink peak rates of at least 100 Mbps. The technology allows for speeds of more than 300 Mbps, and the industry has already demonstrated the next step of LTE, LTE-Advanced, with theoretical peak rates up to 1.2 Gbps.

Simplicity – LTE supports flexible carrier bandwidths, from 1.4 MHz up to 20 MHz. LTE-Advanced allows for aggregation of carriers to support non-contiguous and multiband bandwidths of up to 100 MHz. LTE also supports frequency division duplexing (FDD) and time division duplexing (TDD).

Latency – The user plane latency achieved in LTE is less than in existing 3G technologies, providing a direct service advantage for highly immersive and interactive application environments, such as multiplayer gaming and rich multimedia communications.

Telephony services – In addition to the support of high-speed data, the LTE standard was also developed to include the features needed to effectively support Voice-over-IP (VoIP) media and control. Telephony services in LTE, as specified by 3GPP, are either implemented by IP Multimedia Subsystem (IMS) and Multimedia Telephony (MMTel), aka Voice-over-LTE (VoLTE), or circuit-switched fallback (CSFB).

6.3 BROAD ECONOMY OF GLOBAL DEVICES – ECOSYSTEM SCALE

LTE is already being supported in a wide range of terminals—197 LTE devices by 48 manufacturers were launched in the market by October 2011 according to GSA. In addition to LTE dongles and mobile phones, many computer and consumer electronic devices, such as notebooks, ultra-portables, gaming devices, and cameras, will incorporate embedded LTE modules.[xxix] Figure 6-2 shows the extent to which some of these LTE-enabled devices have found their way into the marketplace.

Figure 6-2: LTE-enabled devices

6.4 KEY LTE FEATURES

An overview of the key features of the LTE radio access is illustrated in Figure 6-3. The LTE downlink uses multi-carrier transmission based on Orthogonal Frequency Division Multiplexing (OFDM). The key benefits of OFDM are:

- Efficiently supports flexible carrier bandwidth
- Allows channel-dependent frequency domain scheduling
- Resilient to propagation delays, which is particularly beneficial for SFN broadcasting configurations
- Well-suited for multiple-input multiple-output (MIMO) processing

The capability to operate in vastly different spectrum allocations is essential for LTE. Different bandwidths are realized by varying the number of subcarriers used for transmission, while the subcarrier spacing remains unchanged. In this way, operation in spectrum allocations of 1.4, 3, 5, 10, 15, and 20 MHz can be supported. Due to the fine frequency granularity offered by OFDM, a smooth re-farming of, for example, 2G spectrum is possible. Furthermore, starting with Rel-10, LTE supports carrier aggregation where a terminal can be scheduled on several carriers simultaneously, even on carriers of different bandwidths and in different bands, depending on terminal capability. Frequency-division duplex (FDD) and time-division duplex (TDD) are supported to allow for operation in paired as well as unpaired spectrum.

Figure 6-3: Key LTE Radio Access Features

The recent deployment of 4G (LTE) has increased the complexity of wireless networks, which will likely combine 2G, 3G, and 4G technologies for several years to come. The only effective method to control operational expenses (OPEX) in these multi-technology networks is to introduce automation and self-optimizing capabilities that reduce or eliminate time-consuming and error prone manual processes, both during deployment as well as during continuing operations. Some of these processes may even become too complex to be managed manually at all, requiring automation to manage them. Self-Organizing Networks (SON) capability has been introduced to address this need for automation and optimization, and it is a key component of the LTE network. SON concepts have been included in the LTE (E-UTRAN) standards starting from the first release of the technology (3GPP Rel-8), and expanding in scope with subsequent releases (3GPP Rel-9 and 3GPP Rel-10).

Self-optimizing capabilities in the network will allow wireless network operators to contain and reduce network operations expense, while also leading to higher end user Quality of Experience (QoE) and reduced churn, resulting in overall improved network performance and higher subscriber satisfaction.

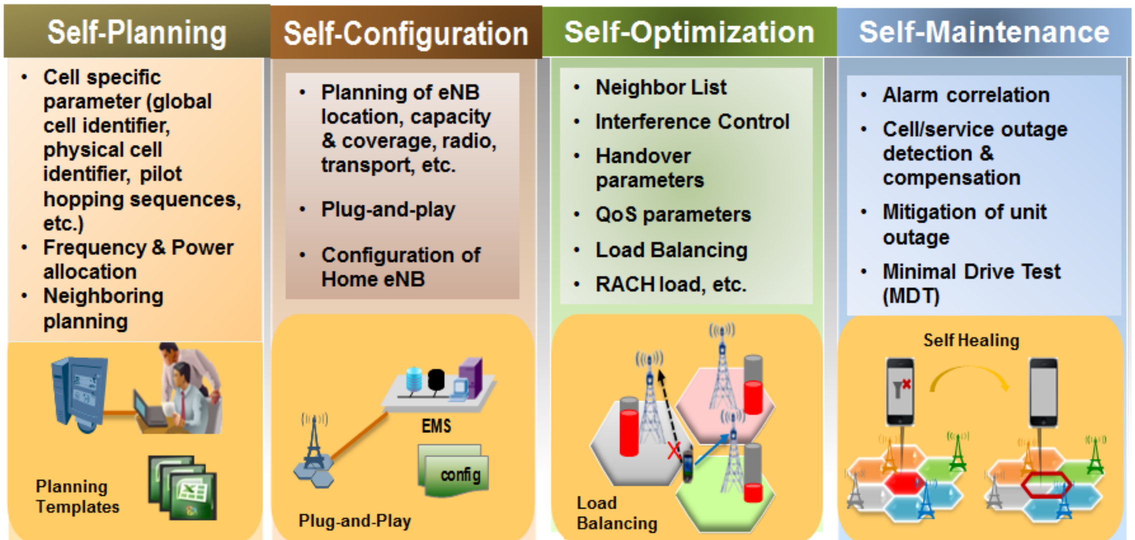


Figure 6-4: SON Improves Operational Efficiency by "Self-X"

Some important distinguishing features among technologies, listed in the previous section, and LTE is the support for mobile reception, particularly in terms of Doppler frequency, the availability of a return channel for interactive services, and the effort to integrate the technology into mobile terminals. ATSC is not suitable for mobile reception. Among the OFDM-based technologies, LTE and HSPA/UMTS have been specified for handling the highest Doppler frequencies.

6.4.1 RURAL DEPLOYMENT SUPPORT

LTE is well suited for rural as well as urban deployments. For rural deployments, where coverage range is key, LTE provides the following features:

Space Frequency Block Coding (SFBC) – SFBC is a form of open loop transmit diversity where a single information stream is coded across multiple transmit antennas at the LTE base station. SFBC uses a form of Alamouti space-time coding technique[xxxiv] but applied in the frequency domain (i.e. across LTE tones) rather than in the time domain. SFBC provides coverage improvements, typically on the order of 1-3 dB assuming two transmit antennas, which is particularly beneficial for rural deployments. These gains come from transmission of the information stream over multiple antennas resulting in:

1. Additional diversity gain
2. Additional coding gain

Random Access Channel (RACH) Optimizations – The RACH is used to provide initial access enabling LTE users to register and obtain services. Thus, optimal RACH performance is critical to providing good coverage with low delays. However, optimal RACH performance can only be achieved with optimal RACH parameter settings, which are dependent on a number of factors including cell size, cell loading, environmental characteristics, etc. LTE has defined a number of device measurements/metrics that can be reported to the BTS to indicate RACH performance (e.g. number of RACH attempts before success).

These reports can be shared between LTE base stations as well as with OAM management servers to dynamically optimize the RACH parameter settings to provide maximum coverage and minimal setup delay.

Receive Diversity in the UE and at the BTS – The initial release of LTE (Rel-8) required that all UEs support 2-branch Rx antennas in the devices to support receive diversity. 2-way Receive diversity can typically provide 3-5 dB downlink coverage gains due to increased aperture and diversity gains. At the BTS, there are no theoretical limitations to the number of Rx antennas that can be placed on the tower to improve uplink reception/coverage, but practical considerations typically limit to 4-br or 8-br UL receive antennas, which can provide 3 to 6 dB UL coverage benefits over 2-br uplink Rx. Such gains can significantly increase coverage in rural deployments.

Relays – LTE introduced support for relays in Rel-10. Relays can be used to extend coverage in rural areas by providing access in poor macro coverage areas or at the edge of macrocell coverage. The relay nodes provide access to UEs that would otherwise be outside the macro coverage area, and connect to a donor macrocell using the LTE air interface to backhaul the traffic of the users connected to the relay nodes.

6.4.2 URBAN DEPLOYMENT SUPPORT

Urban deployments benefit from the following techniques that increase the network capacity:

Carrier Bandwidths and Carrier Aggregation (CA) – LTE inherently was designed for high capacity urban deployments by defining carrier bandwidths up to 20 MHz in Rel-8. Further, CA was added in Rel-10 to allow theoretically up to five 20 MHz carriers to be aggregated (i.e. 100 MHz). Wider bandwidth support clearly provides the capability for LTE to carry much higher capacity and data traffic, critical for dense urban areas where wireless data growth has been and continues to grow exponentially.

Multiple Input Multiple Output (MIMO) – Rel-8 LTE defined seven different MIMO modes providing open and closed loop forms of transmit diversity, spatial multiplexing and beamforming with up to 4 layer transmission. Both Single User MIMO (SU-MIMO) and Multi-User MIMO (MU-MIMO) were defined in Rel-8. SU-MIMO techniques provide higher capacity and user rates through spatial multiplexing (where multiple information streams are transmitted across the multiple Tx antennas) and/or beamforming (where higher SINRs are achieved through minimizing interference between cells). MU-MIMO increases capacity by using the multiple layers/beams to send different information streams to different users who are spatially separated. MIMO enhancements have been introduced through Rel-9 and Rel-10 to increase to 8-layer transmission capabilities and enabling simultaneous spatial multiplexing and beamforming capabilities to provide further improvements in capacity through MIMO, critical for dense urban deployments.

Heterogeneous Networks (HetNet) – The extremely fast growth in wireless data traffic has led to the need for small cell deployments. A shared carrier where both the macro and small cell layers are on the same carrier frequency is commonly termed a Heterogenous Network (HetNet). One significant benefit of LTE is that the control and signaling channels in Rel-8 were designed robust enough to enable such shared carrier HetNet deployments to provide increased capacity per square kilometer. And techniques such as frequency selective scheduling and/or Inter-Cell Interference Coordination (ICIC) are supported in Rel-8 to manage interference between macro and small cell layers on the traffic channels to enhance the HetNet capacity. Studies have shown that the capacity benefits from HetNets is highly dependent on the ability to place the small cells where the traffic resides, which may or may not be possible (e.g. due to backhaul support of zoning restrictions). Therefore, Rel-10 provides enhancements to ICIC (eICIC) enabling further interference management techniques to increase the coverage and capacity served by the small cells through the use of handover biasing (i.e., handover users to the small cells earlier). Rel-11 continues to provide enhancements for HetNets by studying the benefits of interference cancellation at both the base station and UEs. Clearly, LTE has had, and continues to have strong focus on optimizing the performance of HetNets which will be an essential part of the solution for addressing future wireless data traffic growth, particularly in dense urban areas.

Co-ordinated Multi-Point (CoMP) – LTE continues to focus on techniques in Rel-11 to further increase capacity through CoMP. The idea of CoMP is to perform MIMO across different cells in the network, as opposed to only performing MIMO from the antennas of a single cell. Many different forms of CoMP are being studied including coordinated scheduling/coordinated beamforming and joint transmission between base stations with both non-coherent and coherent combining.

6.5 CAPABLE OF SUPPORTING HYBRID BROADCAST AND UNICAST SOLUTION WITH EMBMS/IMB

The rapid adoption of smartphones, and the expected increase in adoption of mobile devices such as e-books and tablets, is expected to create a sea of change in the way mobile data is consumed. The mobile industry is interested in a convergence of all means of information consumption with the econsumer and enterprise subscribers on the move. As it stands, it is expected that the mobile phone will be used to access a significant amount of video content from the Internet. As a part of this convergence, it is therefore reasonable to expect that every personal device, with capabilities equivalent to and exceeding a modern smartphone, will be able to provide access to a TV in addition to its capability to access Internet video. Furthermore, the user experience will be greatly improved with the provision of a return channel to the network, allowing operators and broadcasters to benefit from knowledge of user behavior, and for advertisers to gain direct access to viewers. [xxxi]

MBMS is tightly integrated into the LTE standard. With a firmware or software upgrade, User Equipment (UEs) can gain MBMS capability, as it uses a common physical layer and MAC layer framework with the LTE unicast (i.e., mobile broadband) services. The technology entry barrier for supporting MBMS in the general LTE UE is, therefore, particularly low. LTE-MBMS can also be used in a downlink-only fashion, which means that no return link is required from the receiver to the transmission infrastructure.

A return link is, however, useful for interactive services or upcoming "Hybrid-Digital-TV" services. HSPA and LTE terminals always support a return link. For IMB, the broadcast service is delivered on dedicated carriers, and the terminal needs to switch to unicast carriers to establish a bidirectional communication. More advanced terminals may implement a separate receiver chain for the IMB carrier and the FDD carrier, and are therefore able to continue receiving broadcast service during interactive sessions. For LTE, broadcast traffic is time multiplexed with unicast traffic. Here, simultaneous eMBMS reception and interactive sessions are supported, even by terminals supporting the reception of only one carrier at a time. Furthermore, time multiplexing supports very flexible splitting of the resource share between MBMS and unicast services—from under 1 percent to over 60 percent. This makes it particularly easy for operators to start MBMS service introductions with minimum effect on the remaining capacity for unicast services.

The HSPA and LTE standards are currently the only ones that are deployed, or being deployed, world-wide with at least one network available in almost every country. Therefore, these standards provide the best roaming opportunity for a globally mobile society.

E-MBMS and IMB, due to the support of MBSFNs and deployment in dense cellular environments, achieves very high spectrum efficiency, even for mobile handheld reception. Furthermore, for classical fixed reception, studies have shown the potential of E-MBMS to deliver the existing TV services in significantly less spectrum than currently allocated in the VHF- and UHF-to-TV distribution using ATSC.[xxxi] Deploying a dedicated, dense broadcasting network is, however, not economically viable. Deployment of LTE networks for cellular mobile broadband communication in the market has already started, and a strong build-out is expected. The presence of a substantial LTE infrastructure will obviate the need for investment in a dedicated infrastructure exclusively for TV broadcasting.

LTE unicast streaming provides high capacity to serve mobile video, except for live events attractive to a mass audience. From simulations, a spectral efficiency of 1.0 to 1.1b/s/Hz/cell is obtained.[xxxv,3] From the spectral efficiency, the addressable market penetration is calculated—depending on the user activity factor. Assuming 20,000 inhabitants per square kilometer, a site-to-site distance of 500 m, and four network operators; there would be 360 inhabitants per sector per operator. With a bandwidth of 10 MHz, spectral efficiency of 1b/s/Hz and video service rate of 512 Kb/s assumed; this yields a streaming capacity of 20 active users per cell. Assuming a 5 percent blocking probability, the network can support an offered video traffic of 15.2 Erlangs per cell. The user activity is expressed as the active time during 18 h of each day. For each active time value, the number of subscribers that can be supported, and from this the percentage of addressable markets, is calculated as follows:

P[%] = 100•active time [h] / 18 • 15.2Erlang / 360

The result is shown graphically in Figure 6-5. The graph shows that up to an active user time of 45 minutes per 18-hour day, 100 percent of the inhabitants per sector and operator, can be supported. In 3GPP Rel-9, with LTE supporting multi-user MIMO, the capacity increases further.

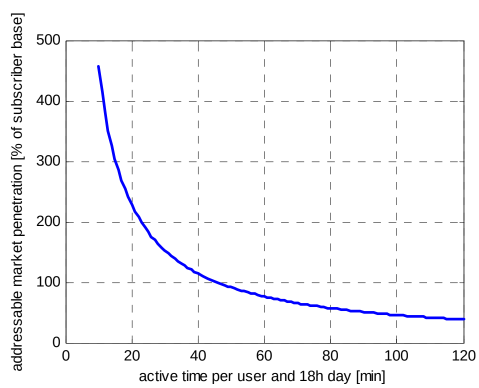


Figure 6-5: Addressable market versus active time per user for 512Kb/s video streaming

---

[3] The capacity evaluation for HTTP unicast streaming video in an urban environment is based on the following assumptions:

- 2×2 MIMO
- 5 MHz downlink channel
- Deployment scenario: 3GPP case 1 (site-to-site distance: 500 m, indoor loss: 20 dB)
- 3-second pre-buffering time at start of video session
- Users are satisfied if they experience no buffer under-run during the 30s video session
- Scheduling: essentially proportional-fair
- LTE Release-8 functionality
- System capacity: system load where 95 percent of the users are satisfied.

7 DIGITAL DIVIDEND SPECTRUM DESIGNATION AND USAGE CONSIDERATIONS

At the 2007 World Radio Conference (WRC-07), ITU identified additional spectrum for use by IMT systems within the 698–862 MHz UHF band, and allocated this spectrum to the mobile service as the primary spectrum (i.e., protected from interference caused by other services in the same band or in adjacent bands). From a technical perspective, this band is of particular interest for mobile broadband services because of favorable propagation characteristics that allow for the deployment of cost-effective wide-area networks and enhanced in-building coverage. The WRC-2007 decision identified, for each ITU Region, the following spectrum for wide-area mobile services based on IMT:

- Region 1 (Europe, Middle East and Africa) identified 790–862 MHz for mobile services
- Region 2 (Americas) identified 698–806 MHz
- Region 3 (Asia) mobile allocations are 470–960 MHz, with a number of Asian nations identifying 698–806 MHz for IMT systems.

However, for most of the world, these spectrum bands are still being occupied by TV broadcast networks and are awaiting decision by local authorities for release to use in mobile broadband networks.

Given the benefits of digital broadcast technologies, the transition from analog broadcast to digital broadcast across the world is freeing up spectrum in the Digital Dividend frequency bands (i.e., ~700–900 MHz). However, the amount of spectrum being cleared, the exact part of the Digital Dividend bands where it is cleared as well as the timing for transitioning the broadcasters from analog to digital, differs from region to region. This was to be expected since different analog and digital broadcast technologies are deployed in different regions. While harmonization is always a goal with new spectrum definition for cellular use, the legacy broadcast spectrum situations in the various regions of the world make this difficult. Thus, different Digital Dividend band plans are expected in the different regions of the world. Figure 7-1 shows the projected analog to digital switchover time for broadcast TV around the globe according to GSMA.

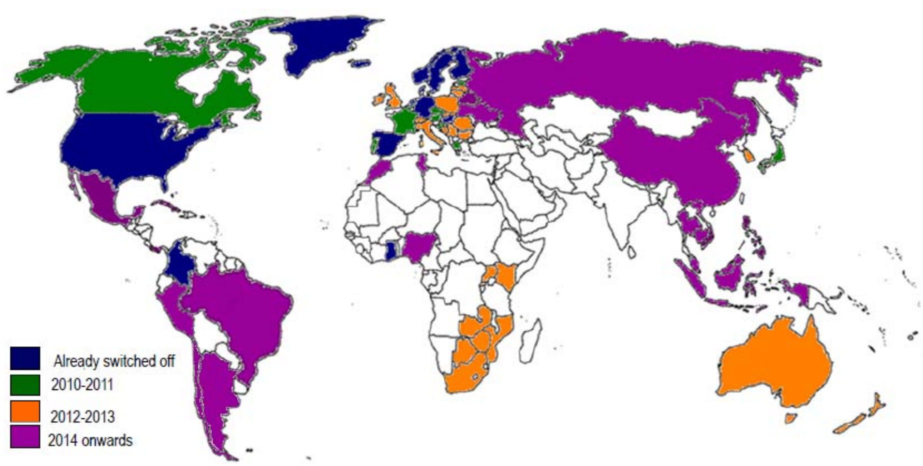


Figure 7-1: Projected analog to digital TV switchover time around the world

Figure 7-2 illustrates the definition of three regions around the globe. Region 1 is made up of Europe, the Middle East and African countries. Region 2 consists of countries in the Americas, and Region 3 contains all the Asian countries.

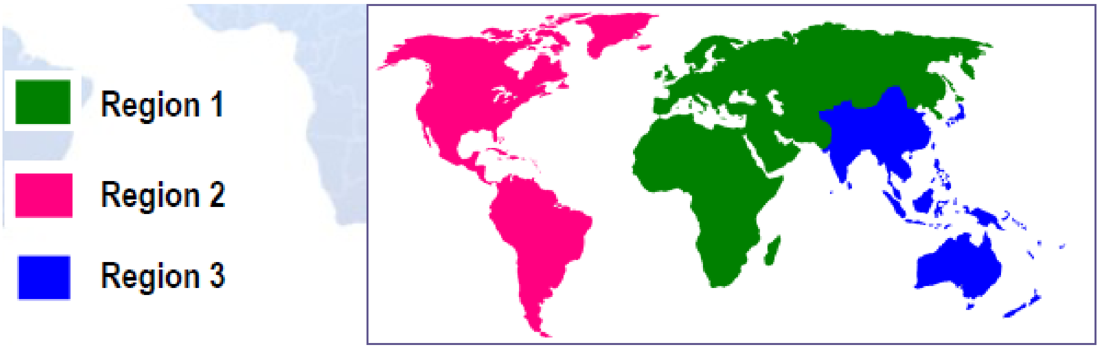


Figure 7-2: Region definition

7.1 SPECTRUM ORGANIZATION AND LICENSE BANDWIDTH SIZE CONSIDERATION

The following sections discuss the status of the Digital Dividend spectrum in the three identified regions of the world.

7.1.1 REGION 1 – EUROPE, MIDDLE EAST AND AFRICA

Within Region 1, 72 MHz of spectrum, in the 790–862 MHz range, was made available as a result of the Digital Dividend. It has been allocated for commercial mobile use. The preferred band plan developed for this spectrum supports FDD transmission with six paired blocks of 2X5 MHz, with a center gap of 11 MHz. The plan describes a reversed duplex arrangement (uplink transmission is prescribed for the upper frequencies; downlink transmission in the lower frequencies) in order to mitigate the impact of potential interference scenarios.

791–796	796–801	801–806	806–811	811–816	816–821	821–832	832–837	837–842	842–847	847–852	852–857	857–862
Downlink						Duplex Gap	Uplink					
30 MHz (6 blocks of 5 MHz)						11 MHz	30 MHz (6 blocks of 5 MHz)					

Figure 7-3: Region 1 Preferred arrangement for the 790-862 MHz Band (source: FCC)

Assignment of this spectrum via auction has begun within Europe. Included among those countries that have completed auctions are Germany and Sweden. The auctions typically permit operators to aggregate the 2X5 MHz blocks to obtain licenses of 2X10 MHz or greater.

7.1.2 REGION 2 – AMERICAS

On a worldwide basis, the Americas are the most advanced in terms of designating the Digital Dividend spectrum for IMT-based mobile services and making it available to operators for implementing networks offering mobile broadband services. However, even in the Americas, there are discontinuities as not all countries are at the same level of implementation. In addition, the Digital Dividend spectrum is, unfortunately, not organized the same way, nor is it made available in the same manner, not to mention at the same time. We now review the implementation details occurring throughout the Americas.

7.1.2.1 UNITED STATES

The United States has been the first country to mandate that the broadcasting licensees switch the transmission of content for their users from analog to digital. This happened on June 13, 2009. In parallel, the regulator (FCC) published their Digital Dividend band plan which is shown in Figure 7-4 and Table 7-1.

Significant spectrum previously allocated to broadcast TV has been reallocated for commercial wireless use, and assigned via auction. This spectrum, generally identified as the 700 MHz Band is located at 698–806 MHz (formerly TV Channels 52–69). The band plan provides three paired blocks of 2X6 MHz, one paired block of 2X11 MHz, one paired block of 2X5 MHz, and two 6 MHz blocks of unpaired spectrum. 24 MHz is allocated for public safety (763–775/793–805 MHz), with the remaining spectrum (4 MHz) allocated to guard bands.

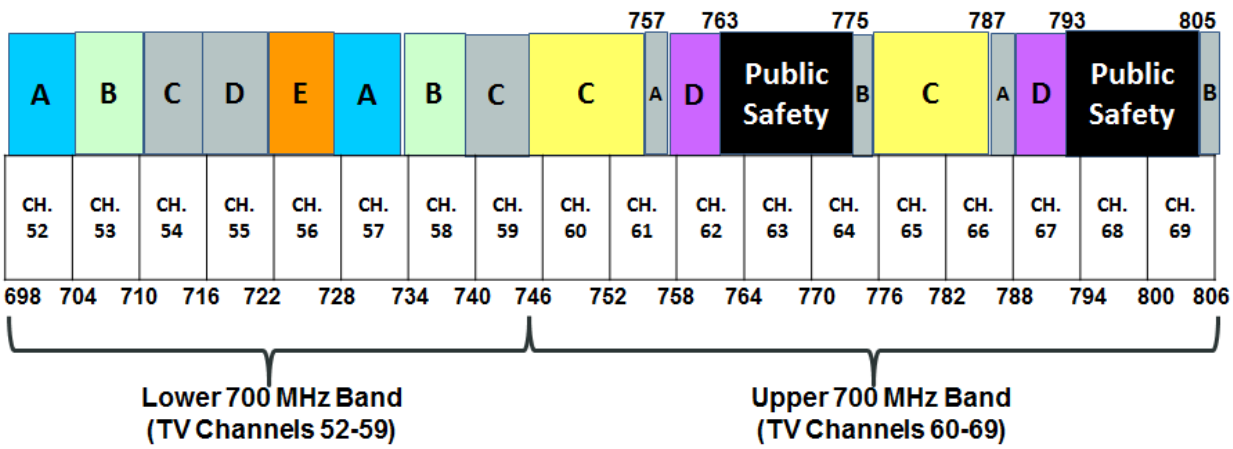


Figure 7-4: United States Digital Dividend Band Plan

Block	Frequencies (MHz)	Bandwidth	Pairing	Area Type
A	698-704, 728- 734	12 MHz	2 x 6 MHz	EA
B	704-710, 734-740	12 MHz	2 x 6 MHz	CMA
C	710-716, 740-746	12 MHz	2 x 6 MHz	CMA
D	716-722	6 MHz	Unpaired	EAG
E	722-728	6 MHz	Unpaired	EA
C	746-757, 776-787	22 MHz	2 x 11 MHz	REAG
A	757-758, 787-788	2 MHz	2 x 1 MHz	MEA
D	758-763, 788-793	10 MHz	2 x 5 MHz	Nationwide
B	775-776, 805-806	2 MHz	2 x 1 MHz	MEA

Note 1: The highlighted text in the table identifies frequency blocks auctioned prior to Auction 73 in 2008.
Note 2: Spectrum has been reserved in the upper sub band for public safety service

Table 7-1: United States Digital Dividend Band Plan

The Lower 700 MHz band uses normal duplex directions (i.e., mobile transmission in the lower frequencies; base transmission in the upper frequencies). To mitigate interference into the public safety spectrum, the Upper 700 MHz band reverses the direction of duplex transmission (base transmission in the lower frequencies; mobile transmission in the upper frequencies).

Assignment of spectrum was made through several auctions, the largest held in 2008 generated over USD $19 billion. All blocks, other than the 2X5 MHz identified as the Upper 700 MHz D Block, were successfully assigned. The Upper 700 MHz D Block is the subject of ongoing discussion concerning its association with the adjacent public safety spectrum.

It is also worth noting that 3GPP has already standardized bands in the 700 MHz frequency range, which are shown in Figure 7-5. Based on these 3GPP standardized bands, licensees of this spectrum have begun deployment of LTE in the 700 MHz band.

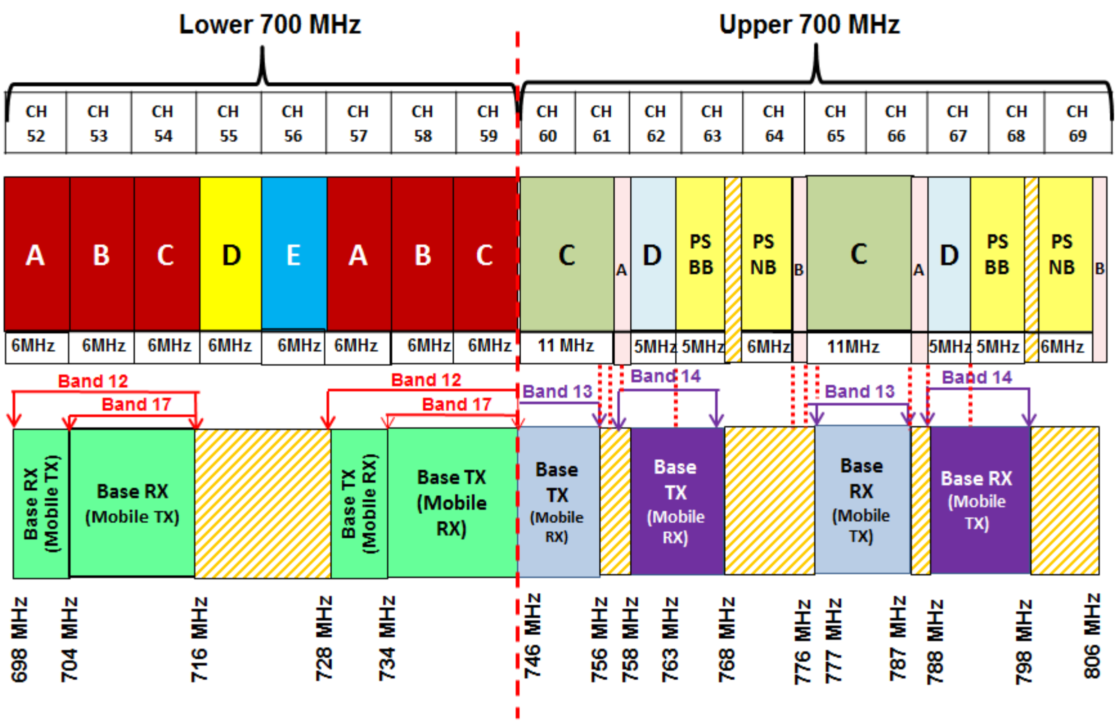


Figure 7-5: 3GPP Band Plans covering the US Digital Dividend Spectrum

Note 1: The US FCC 700 MHz band plan has been added for comparison purposes
Note 2: PS stands for Public Safety

Within the U.S., the FCC has directed in its National Broadband Plan that an additional 500 MHz of spectrum be reallocated for commercial use within the next ten years, with 300 MHz made available within five years. Included in the spectrum to be made available in the near-term, 120 MHz is to be reallocated from broadcast TV. The proposal suggests the use of "incentive" auctions, in which TV licensees would voluntarily relinquish spectrum in return for a portion of the proceeds derived from the spectrum auction.

7.1.2.2 CANADA

Canada has also mandated the broadcasting licensees to switch the transmission of content to their users; from analog to digital. This happened on September 1, 2011. In parallel, Industry Canada, the Canadian regulator, has issued a consultation on the use of the 700 MHz spectrum[4]. A decision is awaited on the band plan and how the spectrum will be used.

7.1.2.3 MEXICO

The Mexican regulator, Cofetel, issued a public consultation at the end of 2010 requesting comments on the industry interest for use of the frequency 704–806 MHz range (the 698–704 range is not currently

[4] Refer to SMSE-018-10, titled "Consultation on a Policy and Technical Framework for the 700 MHz Band and Aspects related to Commercial Mobile Spectrum," which is available at http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf09947.html

available as it is being used by TV Channel 52). Discussions are currently ongoing in regards to the possibility of freeing up the 704–806 MHz range much sooner than the initial timeframe of 2015.

7.1.2.4 CENTRAL AMERICA

In most of the Central American countries, the process of switching broadcasting from analog to digital, and reusing the freed up Digital Dividend spectrum for mobile services has not started. Regulators in a few countries have, however, provided a timeline for the mandated switch to digital transmission of over-the-air TV broadcasting service, as provided in Table 7-2.

COUNTRY	ANALOG TURN OFF	COMMENTS
Costa Rica	2018	Service assignment not expected before 2013–2014
El Salvador	2019	No indication about possible use for mobile services
Honduras	2220	No known initiative for mobile service assignment
Panama	2020[5]	700 MHz currently used for telecommunication transport service

Table 7-2: Central America planned analog turn off schedule (source: 4G Americas)

7.1.2.5 SOUTH AMERICA

Although some South American countries are more advanced than Central America in the process of making available Digital Dividend spectrum for mobile broadband services, it is still pretty much at the planning stage at this moment, as depicted in Table 7-3.

COUNTRY	ANALOG TURN OFF	COMMENTS
Argentina	2019	No 3G/4G auction expected in the short term
Chile	2016	698-806 MHz already has a mobile service allocation
Colombia	2019	Mobile service assignment planned
Paraguay	2022	No indication about possible use of mobile services
Peru	2019	No indication about possible use of mobile services
Uruguay	2015	Band reassigned for mobile and IMT services
Venezuela	2020	Currently, no plan to deploy mobile services in 700 MHz

Table 7-3: South America planned analog turn off schedule (source: 4G Americas)

[5] In Panama, part of the band is also used for telecommunications transport services.

7.1.2.5.1. BRAZIL

In Brazil, a terrestrial digital TV service based on ISDB-T was launched in 2006, and is currently reaching over 90 million people. Any transition from the current band plan usage to a new one freeing up spectrum for broadband mobile services would require about ten years. However, due to upcoming major sporting events (the 2014 World Soccer Cup and 2016 Summer Olympics Games), a debate has been initiated to speed up this process.

7.1.3 REGION 3 – ASIA-PACIFIC AND JAPAN

Some Asian Pacific nations have also identified the 698–806 MHz band as Digital Dividend spectrum, and developed their own band plan for use in the region. The plan provides a 2X45 MHz block for FDD use, with a 10 MHz center gap, and necessary guard bands, to mitigate interference into adjacent spectrum.

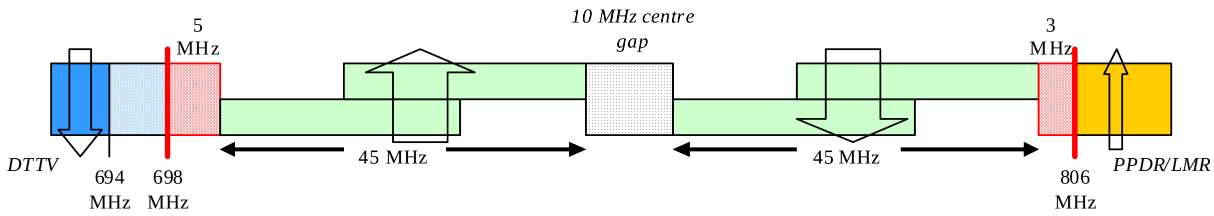


Figure 7-6: Region 3 FDD arrangement for the 698–806 MHz band

An alternative arrangement proposes the use of the band for TDD.

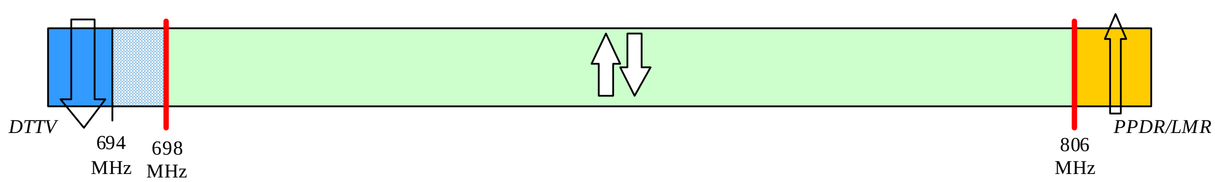


Figure 7-7: Region 3 TDD arrangement for the 698–806 MHz band

The availability of this spectrum, and the subsequent assignment of this spectrum, are dependent on the transition to digital television, and are expected to begin within the Asian-Pacific region in 2012.

7.2 INTERFERENCE CONSIDERATION

There are potential interference issues that result from the changes in spectrum use related to the Digital Dividend process. Two cases are discussed in the following sections: 1) potential interference from broadcast service below the Digital Dividend spectrum, and 2) potential interference cases arising from the specific United States band plan.

7.2.1 POTENTIAL INTERFERENCE FROM ADJACENT BROADCASTING SERVICE

Systems which will be deployed, compliant to the 3GPP band 12, will be able to operate in the lower portion of the 700 MHz band, meaning down to 698 MHz. In this case, the base station receivers may potentially be subject to interference if there is a high power DTV broadcasting station transmitting in the adjacent DTV band on Channel 51 (692 to 698 MHz). This potential interference case is of particular importance in the United States, where no guard band has been implemented between the 700 MHz band and the adjacent DTV band. The FCC has recognized this issue. On August 22, 2011, a hold was placed, pending the results of petitions from CTIA and the Rural Cellular Association, on any new applications using TV Channel 51, including low power channels.[6] The petition presents arguments regarding potential interference to the 700 MHz lower band (Block A) from TV Channel 51. Nevertheless, the FCC is still allowing the existing TV Channel 51 licensees to continue their operations.

Potential solutions to such interference case could be to implement a guard band by either avoiding the use of Channel 51 for DTV or by not fully using the 2X18 MHz, FDD, band 12.

7.2.2. POTENTIAL INTERFERENCE BETWEEN BLOCKS WITHIN THE UNITED STATES BAND PLAN

Specifically for the United States band plan, there are two potential interference cases:

1. Interference from high-power, unpaired systems in the lower 700 MHz, band D and E blocks, into adjacent upper and lower blocks.

   In this case, a high power transmitter in the D blocks can desensitize 3GPP band 12 and 17 base station receivers operating right under that, in block C. Similarly, a high power transmitter in E block can desensitize 3GPP band 12 and 17 mobile receivers operating in block A. The FCC did not make provision for guard bands between the paired and unpaired portions of the band. Furthermore, FCC technical rules explicitly state that no protection from interference between stations in adjacent frequency blocks or geographic areas is afforded. Therefore, interference issues are expected to be resolved by the licensees.

   This may cause significant interference to 3GPP-based systems deployed for mobile broadband service offerings.

2. Interference from public safety base station transmitters into broadband base station receivers operating above C block.

   In this case, the high power public safety narrowband transmitter can desensitize the 3GPP band's 14 base station receivers operating in the block just above. Even though there is a 2 MHz guard in this case, it is uncertain that this would be enough to prevent interference.

[6] Public notice "General Freeze on the Filing and Processing of Applications for Channel 51 Effective Immediately and Sixty (60) Day Amendment Window for Pending Channel 51 Low Power Television, TV Translator and Class A Applications," available at http://transition.fcc.gov/Daily_Releases/Daily_Business/2011/db0822/DA-11-1428A1.pdf

7.3 SPECTRUM PLANNING CONSIDERATIONS

This section presents principles in the area of spectrum allocation and assignment. 4G Americas believes that, although this set of principles is generic, it should animate the development of strategies to ensure the continued vitality of mobile broadband services in the Americas by using LTE in the Digital Dividend band.

1. CONFIGURE LICENSES WITH WIDER BANDWIDTHS

   Upcoming technologies, such as LTE, will require wider bandwidth than current technologies to take advantage of spectral efficiency and, therefore, support ever more supple mobile broadband capability. This is required to meet consumer demand for bandwidth-intensive and content-rich services. Spectrum allocations should, therefore, be in sufficiently large, contiguous blocks to accommodate the future development of mobile broadband networks. Allocations should focus, at a minimum, on 2X10 MHz blocks, particularly in urban and suburban areas.

   One of the main reasons OFDM was selected as the multiplexing technique for LTE is its ability to substantially increase spectral efficiency when the transmitted RF signal is composed of a relatively large number of orthogonal subcarriers. The latter, therefore, requires a relatively large amount of contiguous spectrum. From an operational standpoint, OFDM-based technologies, like LTE, can exhibit a significant increase in spectral efficiency if the occupied spectrum is at least 10 MHz (or 10X10 MHz if considered on a paired basis).

2. GROUP LIKE SERVICES TOGETHER

   Current spectrum allocation frameworks tend largely to compartmentalize spectrum by types of services. The grouping of like services can reduce complexity and cost, and allow more flexibility in the form factor of the subscriber equipment. For example, by allocating the whole 700 MHz band for similar services, such as LTE using the Asian-Pacific band plan, the number of bands that a device must support is reduced. This would facilitate development of user equipment, accelerating their availability at low cost due the economies of scale from using standard band plans. Mixing LTE service with high-power, downlink-only service is not recommended as this would be creating spectrum band usage inefficiency and increase complexity in both network infrastructure and, specifically, end-user devices.

3. BE MINDFUL OF GLOBAL STANDARDS

   Technical standards are the foundation service providers and manufacturers use in developing competitive products and services to take of advantage of worldwide economies of scale that lower costs for infrastructure equipment, as well as devices. Furthermore, global standards contribute to faster and broader technology deployment. Without global standards, device diversity would be reduced which has been seen to impede customers' interest in consuming services. From an operator's perspective, deployment based not on globally accepted standards introduces a risk factor. If customers are not interested by its service offerings, it would mean a lesser return on investment, which, in turn, would slow down the network operator's capacity and coverage investments. This overall would diminish GDP growth. In addition, standards promote growth and maximize opportunities for innovation. In many instances, globally accepted standards take into consideration coexistence with adjacent services to optimize its usage. In the case of digital dividend, this means it would minimize the impact of adjacent broadcasting services below the 700 MHz band.

Therefore, whether certain spectrum bands have been harmonized, and whether a standard exists should be factored into spectrum allocation decision making.

4. PURSUE HARMONIZED/CONTIGUOUS SPECTRUM ALLOCATIONS

Spectrum allocation must be made, to the greatest extent possible, in accordance with international allocations. It must promote innovation and investment by creating critical economies of scale. Similarly, harmonization facilitates global roaming, and helps countries that share borders to manage cross-border interference. Without harmonization, a technology is not widely used, preventing the sharing of development costs globally. Overall, this increases product and service costs, limits their proliferation, and delays their availability in reaching the marketplace.

5. EXHAUST EXCLUSIVE-USE OPTIONS BEFORE PURSUING SHARED USE

"Exclusive-use" option should be the recommended and preferred model for cost effective and rapid deployment of services, benefiting all parties involved: infrastructure vendors, device makers, service providers and most importantly, customers. The "exclusive use" model refers to a framework in which a licensee has rights that are exclusive, flexible, and transferable, while at the same time inheriting specific responsibilities that come with these rights that would benefit country's economy. Licensees are also afforded protection from interference and may use the spectrum in a flexible manner consistent with the terms of the license. Moreover, the certainty provided by the exclusive use licensing approach encourages investment (both in the network and the services) by promoting an environment in which interference and system capacity can be predicted.

In a spectrum-sharing environment, spectrum resources are made available based on established technical "etiquettes" or regulations that set power limits, and other criteria for operation of devices, to mitigate potential interference (such as geographic "protection" zones and temporal restrictions). Successful sharing arrangements must be tailored to the specific conditions in the band—on a band-by-band basis. These conditions must be known at the inception of the design to avoid inappropriate and costly technology development. Because each sharing environment is unique, technology research and development suitable for the services sharing frequency bands and knowledge of the specific sharing constraints are required; otherwise, investment and innovation will be impeded by such operational uncertainties.

Therefore, if spectrum sharing is to be considered over exclusive use of the 700 MHz band (in fact, for any other band), such a proposal needs to be closely examined. Each envisioned spectrum sharing opportunity should weigh the foreseen benefits and opportunities provided by a variety of factors including service viability, technology support, and adequate knowledge of the operating environment before being implemented. Any uncertainty about its positive outcome should be a signal to rather consider carefully an exclusive use to maximize benefit to all parties: services providers, customers and country's economy.

6. NOT ALL SPECTRUM IS FUNGIBLE – ALIGN ALLOCATION WITH DEMAND

Future networks will, in all likelihood, be "networks of networks," consisting of multiple access technologies, multiple bands, and widely varying coverage areas, all self-organized and self-optimized. Part of the consideration to support the development of such networks, and the evolution of data services, will be the availability of suitable spectrum, spacing of cell sites, and increases in spectral efficiency to support an increase in the number of users and an increase in the data throughput available to each user. These networks will rely on multiple-access technologies, supported by a variety of spectrum bands, to address both coverage and capacity needs. This will require suitable lower frequencies to support in-building coverage, as well as sparsely populated areas, in addition to higher bands supporting capacity objectives through a mix of macrocell, microcell and picocell deployments. Propagation characteristics are sometimes overlooked, but their impact can be tangible and very significant to overall design and performance.

Suitable lower-band frequencies, such as 700 MHz, have the ability to provide services more efficiently—they have the appropriate propagation characteristics to penetrate walls of buildings—and have a significant coverage range across a broadly defined geographic area without requiring the mobile handset to support an unwieldy antenna. Therefore, 700 MHz spectrum is essential to serve rural and isolated areas, where the population density is low.

8 CONCLUSION

At this juncture in our human technological understanding, and with the leading edge technologies that we have achieved, the Digital Dividend spectrum and LTE mobile broadband technology provides the most ideal solution for delivering universal mobile broadband access. The Digital Dividend radio frequency bands allow for the most efficient deployment of broadband, particularly to the far reaching regions where, if not for wireless technology, mobile connectivity would not be achieved. The added capacity that would result from the release of needed spectrum, and the deployment efficiencies unique to the Digital Dividend spectrum, could help make broadband affordable to all. With additional spectrum, there can be more mobile broadband serving societies, leading to new innovations. LTE is unique as it is the only mobile communications technology standard that can deliver very fast 300 Mbps (20 MHz 4X4 MIMO) mobile broadband speeds on today's networks, and also has all the specifications in place to deliver extremely fast 1.2 Gbps mobile broadband speeds in the near future. It is the technology of choice for all operators, including those that are using 3GPP, 3GPP2 and the IEEE. It is forecasted to have global economies of scale with billions of users within the next 10 to 15 years.

The Digital Dividend spectrum and LTE have all the components to provide affordable high-speed broadband to all, to bridge the digital divide, bring education to remote regions, provide information access to the poor and enable innovations as part of the solutions for education, healthcare, energy dependency and stagnated economic growth. Given the consensus on the economic benefits in using the Digital Dividend spectrum for mobile broadband, there is an associated cost for delay. One study by Spectrum Value Partners on the European markets shows a loss of around 9 percent in economic benefits associated with a one year delay in releasing the Digital Dividend spectrum. In addition, these economic benefits can only be maximized with the use of the Digital Dividend spectrum for mobile broadband, and would be decreased by several factors such as higher spectrum bands and time delay. Therefore, it is financially critical for nations and regions to move forward as quickly as possible and remove all barriers—through whatever means necessary.

9 ACKNOWLEDGEMENTS

The mission of 4G Americas is to promote, facilitate and advocate for the deployment and adoption of the 3GPP family of technologies throughout the Americas. 4G Americas' Board of Governor members include Alcatel-Lucent, América Móvil, AT&T, Cable & Wireless, CommScope, Ericsson, Gemalto, HP, Huawei, Nokia Siemens Networks, Openwave, Powerwave, Qualcomm, Research In Motion (RIM), Rogers, T-Mobile USA and Telefónica.

4G Americas would like to recognize the significant project leadership and important contributions of Si Nguyen of Huawei, as well as representatives from the other member companies on 4G Americas' Board of Governors who participated in the development of this white paper.

10 ACRONYMS

Acronym	Description
µs	microsecond
1xRTT	One Times Radio Transmission Technology (CDMA 2000)
3G	3rd Generation (wireless/mobile communications)
3GPP	3rd Generation Partnership Project
3GPP2	3rd Generation Partnership Project 2
4G	4th Generation (wireless/mobile communications)
8VSB	8-Level Vestigial Sideband
AHCIET	Association Hispanoamericana de Centros de Investigacion y Empresas de Telecomunicaciones
AGC	Automatic Gain Control
AL-FEC	Application Layer Forward Error Correction
AM	Amplitude Modulation
ARIB	Association of Radio Industries and Businesses (Japan)
ATSC	Advanced Television Systems Committee
ATSC H	Advanced Television Systems Committee-Handheld
ATSC M	Advanced Television Systems Committee-Mobile
AVC	Advanced Video Coding
b	bit
B	Billion
BB	Broadband
BCMCS	Broadcast and Multicast Services
BMSC	Broadcast and Multicast Service Center
CDMA	Code Division Multiple Access
CMMB	Chinese Mobile Multimedia Broadcasting
CP	Control Plane
CSFB	Circuit-Switched Fallback
CTIA	Cellular Telecommunications Industry Association
DMB-H	Digital Multimedia Broadcast-Handheld
DMB-T	Digital Multimedia Broadcast-Terrestrial
DTMB	Digital Terrestrial Multimedia Broadcast
DTV	Digital Television
DVB	Digital Video Broadcasting
DVB-H	Digital Video Broadcasting-Handheld
DVB-IPDC	Digital Video Broadcasting - Internet Protocol Datacasting
DVB-NGH	Digital Video Broadcasting-Next Generation Handheld
DVB-S	Digital Video Broadcasting-Satellite
DVB-SH	Digital Video Broadcasting-Satellite to Handheld
DVB-T	Digital Video Broadcasting-Terrestrial

DVB-T2	Digital Video Broadcasting-Second Generation Terrestrial
EDGE	Enhanced Data-rates for Global Evolution
eMBMS	enhanced Multimedia Broadcast and Multicast Service; also (e)MBMS
EPC	Evolved Packet Core
ETSI	European Telecommunications Standards Institute
E-UTRA	Evolved UMTS Terrestrial Radio Access
EvDO	Evolution Data Optimized, Evolution Data Only
FCC	United States Federal Communications Commission
FDD	Frequency Division Duplexing
FM	Frequency Modulation
Gbps	Gigabits per Second
GDP	Gross Domestic Product
GHz	Gigahertz
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
GSMA	GSM (Groupe Spéciale Mobile) Association
GW	Gateway
HDTV	High Definition Television
HE-AAC	High-Efficiency Advanced Audio Coding
HSPA	High Speed Packet Access
HSPA+	Evolved High Speed Packet Access
HSDPA	High Speed Packet Data Access
HSPA	High Speed Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IMB	Integrated Mobile Broadcast
IMS	IP Multimedia Subsystem
IMT	Integrated Mobile Broadcast
IP	Internet Protocol
IPTV	Internet Protocol Television
ISDB-T	Integrated Services Digital Broadcasting-Terrestrial
ITU	International Telecommunications Union
km	kilometer
LDPC	Low-Density Parity Check
LTE	Long Term Evolution
LTE-A	LTE-Advanced
LNA	Low-Noise Amplifier
M	Million
M2M	Machine-to-Machine
Mbps	Megabits Per Second
MBMS	Multimedia Broadcast and Multicast Service
MBS	Mobile Broadband System

MBSFN	MBMS Single-Frequency Network
MCE	Multicell/Multicast Coordination Entity
MCH	Multicast Channel
MFN	Multiple Frequency Networks
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MME	Mobile Management Entity
MMSE	Minimum Mean Square Error
MMtel	Multimedia Telephony
MPEG	Moving Picture Experts Group
MPEG-2	Moving Picture Experts Group-2
MPEG-4	Moving Picture Experts Group-4
MPEG-TS	Moving Picture Experts Group-Transport Stream
MSA	MBMS Service Area
MTCH	MBMS Traffic Channel
MVNO	Mobile Virtual Network Operator
NTSC	National Television System Committee
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiplexing Access
OMA	Open Mobile Alliance
p-t-m	Point-to-Multipoint
p-t-p	Point-to-Point
PAL	Phase Alternating Line
PC	Personal Computer
PTM	Point-to-Multipoint
PTP	Point-to-Point
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QVGA	Quarter Video Graphics Array
RAN	Radio Access Network
RF	Radio Frequency
RNC	Radio Network Controller
SAW	Surface Acoustic Wave
SCTV	Slow Scan Television
SD	Standard Definition (video)
SDTV	Standard Definition Television
SECAM	Système Electronique Couleur avec Memoire (French: Electronic Color with Memory)
SFN	Single Frequency Networking
SINR	Signal-to-Interference-plus-Noise Ratio
STATMUXed	Statistically Multiplexed
TDD	Time Division Duplexing

TDMA	Time Division Multiple Access
TS	Transport Stream
TV	Television
TVoD	TV-on-Demand
TxID	Transmit Identification
UHF	Ultra-high Frequency
UMTS	Universal Mobile Telecommunications System
UP	User Plane
UTRA	UMTS Terrestrial Radio Access
VNI™	Visual Networking Index (a Cisco product)
VOD	Video On Demand
VoIP	Voice-over-IP
VoLTE	Voice-over-LTE
VSB	Vestigial Sideband
WCDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

11 REFERENCES

[i] Wired, October 2008.

[ii] Devries, A.J.; Dias, J.F.; Rypkema, J.N.; Wojcik, T.J.; "Characteristics of Surface-Wave Integratable Filters (Swifs)," *Broadcast and Television Receivers, IEEE Transactions on*, vol. BTR-17, no. 1, pp. 16–23, Feb 1971.
DOI: 10.1109/TBTR1.1971.299526
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4079890&isnumber=4079880

[iii] Shreve, W.R.; Stigall, R.E.; "Surface Acoustic Wave Devices for Use in a High Performance Television Tuner*," *Consumer Electronics, IEEE Transactions on*, vol. CE-24, no. 1, pp. 96-104, Feb 1978.
DOI: 10.1109/TCE.1978.267002
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4043035&isnumber=4043015

[iv] Ash, D.L.; "High Performance Receiver," *Consumer Electronics, IEEE Transactions on*, vol. CE-24, no. 1,
pp. 39–46, Feb 1978.
DOI: 10.1109/TCE.1978.266995
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4043028&isnumber=4043015

[v] Thomas R. Haskett, "Broadcast Antennas on the Empire State Building," Broadcast Engineering magazine, Aug 1967, pp. 24–31.

[vi] ATSC, "Standard A/110: Synchronization Standard for Distributed Transmission," Advanced Television Systems Committee, Washington, D.C., July 2004.

[vii] FCC License Database accessed June 24, 2011.
http://transition.fcc.gov/fcc-bin/tvq?state=&call=&arn=&city=&chan=&cha2=51&serv=DT&type=3&facid=&list=1&dist=85&dlat2=40&mlat2=19&slat2=24&dlon2=74&mlon2=7&slon2=30&size=9

[viii] Richard Citta, Gary Sgrignoli, "ATSC Transmission System: VSB Tutorial," Montreuz Symposium, June 12, 1997.
http://choudeng.com/ChrisUniData/uni%20work%200506/Uni2005/Enel332/VSBTutorial.pdf

[ix] Koutitas, G.; "Green Network Planning of Single Frequency Networks," Broadcasting, IEEE Transactions on , vol. 56, no. 4, pp. 541–550, Dec 2010.
DOI: 10.1109/TBC.2010.2056252
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5512558&isnumber=5623279

[x] Koutitas, G.; "DVB Network Optimisation for Energy Efficiency," The 12th International Conference on Advanced Communication Technology (ICACT), 2010, vol. 1, no. 1, pp. 809–814, 7-10 Feb 2010.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5440169&isnumber=5440112

[xi] US Federal Communications Commission (FCC): Spectrum Analysis: Options for Broadcast Spectrum; OBI Technical Paper No. 3; June 2010.

[xii] GSMA/Boston Consulting Group, "Socio-economic Impact of Allocating 700 MHz Band to Mobile in Asia-Pacific," October, 2010. http://gsmworld.com/documents/bcg_report_2010.pdf

[xiii] Spectrum Value Partners/Venture Consulting for Australian Mobile Telecommunication Association, "Getting the Out of the Digital Dividend in Australia—Allocating UHF Spectrum to Maximize the Economic Benefits for Australia," April 2009. http://gsmworld.com/documents/SVP_Australia_report.pdf

[xiv] McKinsey & Company, "Mobile Broadband for the Masses: Regulatory Levers to Make It Happen," Feb 2009. http://gsmworld.com/documents/McKinsey_Mobile_Broadband_for_the_Masses.pdf

[xv] Global System Mobile Associations (GSMA), "Digital Dividend for Mobile: Bringing Broadband to All."

[xvi] McKinsey & Company, "Mobile Broadband for the Masses: Regulatory Levers to Make It Happen," February, 2009. http://gsmworld.com/documents/McKinsey_Mobile_Broadband_for_the_Masses.pdf)

[xvii] "The Mobile Provide: Economic Impacts of Alternative Uses of the Digital Dividend," Summary Report, Sept 2007, SCF Associates, LTD. http://gsmworld.com/documents/SCF_Associates_report_The_Mobile_Provide.pdf

[xviii] European Commission, Information Society and Media Directorate-General, "Consultation Document—Transforming the Digital Dividend Opportunity into Social Benefits and Economic Growth in Europe", July 10, 2009.

[xix] Spectrum Value Partners, "Getting the Most Out of the Digital Dividend," March 2008. http://www.valuepartners.com/VP_pubbl_pdf/PDF_Comunicati/notizie%20e%20idee/2008/Spectrum-Getting-the-most-out-of-the-digita-dividend-2008.pdf

[xx] SCF Associates; "The Mobile Provide—Economic Impacts of Alternative Uses of the Digital Dividend," Summary Report, Sept 2007, LTD. http://gsmworld.com/documents/SCF_Associates_report_The_Mobile_Provide.pdf

[xxi] Wikipedia: http://en.wikipedia.org/wiki/; retrieved Aug 2011.

[xxii] ATSC: ATSC Recommended Practice – Receiver Performance Guidelines; Document A/74:2010, 7 April, 2010.

[xxiii] Mark S. Richer: Mobile DTV in the United States; ATSC World 2011.

[xxiv] Rohde & Schwarz: Test signals for the New CMMB and DVB-SH Mobile TV Systems; Retrieved Aug 29, 2011. http://www2.rohde-schwarz.com/en/technologies/broadcast_tv_radio/mobile_broadcast/cmmb/information

[xxv] Cohen, M.; le Floch, C.; Hanriot, J.; Wilkus, S.; Pousset, G.; "DVB-SH Field Trials Measurements Results," 2010 5th Advanced Satellite Multimedia Systems Conference (ASMA) and the 11th Signal Processing for Space Communications Workshop (SPSC), 201, pp. 530–537, 13-15 Sept 2010.
DOI: 10.1109/ASMS-SPSC.2010.5586847.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5586847&isnumber=5586844

[xxvi] Tormos, M.; Tanougast, C.; Dandache, A.; Masse, D.; Kasser, P.; "Evaluation Performance Analysis of DVB-T2 in a SFN Network, "I/V Communications and Mobile Network (ISVC), 2010 5th International Symposium on, vol., no., pp.1-4, Sept 30, 2010–Oct. 2, 2010.
DOI: 10.1109/ISVC.2010.5656209.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5656209&isnumber=5654712

[xxvii] Lanza, M.; Gutierrez, A.L.; Barriuso, I.; Domingo, M.; Perez, J.R.; Valle, L.; Basterrechea, J.; , "Optimization of Single Frequency Networks for DVB-T Services Using SA and PSO, "Proceedings of the 5th European Conference on Antennas and Propagation (EUCAP), pp.702–706, 11-15 April 2011.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5782530&isnumber=5780481

[xxviii] Wilkus, S. A.; Bailey, J.D .; Brown, D. G.; Dave, R.; Dorn, R. L.; Hanriot, J.; Hoffman, M.; Kulkarni, A.; Lee, C. S.; Meader, L. R.; Polakovic, J. M.; Sullivan, J.; "Field Measurements of a Hybrid DVB-SH Single Frequency Network With an Inclined Satellite Orbit, "IEEE Transactions on, vol. 56, no. 4, pp. 523–531, Dec 2010.
DOI: 10.1109/TBC.2010.2056270.
http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=5559402&isnumber=5623279

[xxix] F. Hartung, U. Horn, J. Huschke, M. Kampmann, and T. Lohmar: MBMS—IPMulticast/Broadcast in 3G Networks; Hindawi; December 2009.

[xxx] E. Dahlman, S. Parkvall, J. Skold; 4G: LTE/LTE-Advanced for Mobile Broadband; Academic Press, Elsevier; 2011; ISBN: 978-0-12-385489-6.

[xxxi] J. Huschke, J. Sachs, K. Balachandran, J. Karlsson: Spectrum Requirements for TV Broadcast Services using Cellular Transmitters; IEEE DySPAN conference; Aachen; May 2011.

[xxxii] Wikipedia

[xxxiii] Data from Global mobile Suppliers Association (www.gsacom.com) and Ericsson; July 2011.

[xxxiv] S. Alamouti, “A Simple Transmit Diversity Technique for Wireless Communications”, IEEE Journal on Selected Areas of Communications, Vol. 16, No. 8, October 1998, pp. 1451-1458.

[xxxv] J. Huschke: Facilitating Convergence between Broadcasting and Mobile Services using LTE networks; ITU Telecom World; Geneva; October 2011 [to appear].