The Benefits of Digital Dividend

4G Americas

September 2012

CONTENTS

EXECUTIVE SUMMARY

The World Radio Congress (WRC-07) identified 108 MHz of Digital Dividend Spectrum from 698-806 MHz for ITU-R Region 2[1] and nine countries in Region 3[2], including China, India, Japan and Korea (Rep. of). There are three major band plans; one in the U.S. and two harmonized band plans in TDD and FDD mode in the Asia Pacific Telecommunity (APT).

The U.S. was the first market in the world to identify and auction the 698-806 MHz spectrum and therefore has an advantage of early deployment of mobile broadband networks. Major service providers in the U.S. have launched commercial LTE services in 2010-2011. The U.S. band plan also accommodates some U.S. specific requirements for public safety and broadcasting. The U.S. band plan has an early lead on implementation of LTE-Advanced features and Canada has announced it will follow a modified U.S. plan.

In September 2010, as the result of an extensive study, the APT reached an agreement on two harmonized band plans at 698-806 MHz for Region 3. Given the huge potential for economies of scale, these bands plans will represent another vast ecosystem for the Digital Dividend.

While Region 2 countries have two options for harmonization, with the APT band plans they can also adopt the U.S. band plan to take advantage of the already available terminal equipment. Alternatively, they can align with one of the APT band plans and it is expected that equipment will be manufactured for this band plan in a reasonable time frame. Japan has started implementing the APT plan and is expected to offer LTE services by 2015.

One advantage of the 700 MHz deployments across regions is the common adoption of LTE, either FDD or TDD. The LTE chipsets typically will also support services in bands other than 700 MHz, such as 3GPP Bands 2, 4 and 5[3]. However, while there are distinct differences between the U.S. and APT bands in terms of operating channel bandwidths, channel locations, duplex spacing and interference environments, the spectral overlap provides some opportunities for manufacturing economies of scale for equipment operable across both plans. Advances will be made in technology and components will drive down cost and improve the chances for increased economies of scale across multiple bands and radio formats.

Regional harmonization of the 700MHz in Region 2 promotes roaming and for developing economies of scale. In the case of two border countries adopting different channelization options, they should bilaterally discuss and agree on the cross-border issues such as roaming and signal interference.

[1] **Region 2** covers the Americas, Greenland and some of the eastern Pacific Islands.
[2] **Region 3** contains most of non-former-Soviet-Union Asia, east of and including Iran, and most of Oceania.
[3] Band 2 is commonly known as PCS, Band 4 as AWS and Band 5 as Cellular Bands

1. INTRODUCTION

The term "Digital Dividend" usually refers to the spectrum released by the switchover from analog to digital TV broadcasting. Digital dividend spectrum is ideally suited to providing cost-effective mobile and broadband wireless services representing a significant and important asset for a country's economic and social development. Freeing up globally harmonized spectrum for mobility offers the potential for economies of scale for the production of mobile devices, as well as for easing international roaming. Table 4 in the Appendix gives the analog switch out dates for some of the selected countries in Region 2.

A review of some of the studies and papers on the subject of harmonizing Digital Dividend spectrum for mobile broadband shows significant impact on regional and national economics[4]

- According to a recent Boston Consulting Group report, the digital dividend for the Asia-Pacific region could be worth almost US $1 trillion in additional GDP by 2020[5]In Australia, this benefit is estimated at between $7 billion and $10 billion, depending on which mobile broadband market scenario is realized.
- For developing economies, 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.
- World Bank studies show 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.[6]
- Another earlier study by McKinsey & Company on Latin American countries stated that the combined GDP could increase by up to $70 billion, and add up to 1.7 million more jobs.[7]
- 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.

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[4] 4G Americas report "The benefits of using LTE in Digital Dividend Spectrum " November 2011 http://www.4gamericas.org/documents/Benefits%20of%20LTE%20in%20Digital%20Dividend_11.08.11.pdf

[5] http://www.gsma.com/spectrum/wp-content/uploads/2012/07/277967-01-Asia-Pacific-FINAL-vf11.pdf

Global System Mobile Associations (GSMA), "Economic benefits of the digital dividend for Latin America" [5]http://www.gsma.com/documents/economic-benefits-of-the-digital-dividend-for-latin-america-executivesummary-english/19816

[6] "Digital Dividend for Mobile: Bringing Broadband to All."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

2. THE STATUS OF THE DIGITAL DIVIDEND SPECTRUM IN REGION 2

The U.S. was the first market in the world to identify and auction the 698-806 MHz spectrum. In the auctions, AT&T and Verizon secured allocations for their LTE deployments, which they and other operators are rolling out. The U.S. band plan accommodates some requirements for public safety and broadcasting. There is a rich and growing ecosystem of chipsets, devices and infrastructure. Canada also announced its decision to adopt a modified version of the U.S. plan. Across the rest of the region, countries are assessing their options. Many see the benefits of allocating additional spectrum to mobile and of harmonizing spectrum allocations. CITEL recommends both the U.S. and the APT band plans for broadband mobile services.[8] The APT band plan ecosystem is expected by many stakeholders to develop rapidly as countries in Region 2 and Region 3 identify and auction spectrum with this frequency arrangement.

Argentina: The spectrum between 614 MHz and 806 MHz is allocated to broadcasting on a primary basis. Although the use of this segment is low and therefore appealing as a 3G or 4G candidate band, the fact that it is allocated for broadcasting implies a political conflict between two different enforcement authorities: The Federal Authority of Audio Visual Communication Services (AFSCA, a body replacing the Federal Broadcasting Committee, COMFER) and the Communications Secretariat (SECOM). Argentina has launched Digital TV under the ISDB-T standard and is expected to enforce analog black-out by 2020. Apart from this, channels 55-66 have been temporarily assigned to DTV (universities and municipalities in Buenos Aires province). Argentina plans to auction the AWS spectrum first in 2013 and go on with an award of the 700 MHz band in 2014.

Brazil: In Brazil, the 700 MHz band is currently utilized for television although only 10 percent of the municipalities have their 700 MHz spectrum heavily used.[9] Introduction of Digital TV (ISDB-T) in 2006 is gaining momentum – by December 2010, it had coverage for 89.5 million people in 425 cities. Plans call for a 10-year transition from analog to digital broadcasting, which would indicate 2016 availability for spectrum. The Brazilian regulatory body Anatel has created a working group with the target of producing a study on 700 MHz by the end of 2012. Besides industry pressure, Anatel is facing pressure within government entities like the Ministry of Defense to expedite the release of 700 MHz prior to the 2016 target. The Brazilian minister has announced the possibility of auctioning the 700 MHz in 2013. The majority of rural areas would have the spectrum available. In those big cities where the transition to DTV might prevent use of the spectrum for mobile short term, the licenses should be given, considering the possibility of using the band only after 2016 (switch off Analog TV). The government will present a study about the use of 700 MHz by December 2012. Decisions like the use of Digital Dividend for mobile communications, the channelization and time of license process will be announced at this time.[10]

Canada: In February 2012, Canada adopted a band plan for Digital Dividend spectrum that closely follows the U.S. plan. A total of five paired bands (three 6 MHz and two 5 MHz) will be auctioned along with two 6 MHz unpaired bands. The adopted band plan is a modified version of the U.S. band plan, namely with the U.S. upper 700 MHz C band and split into two 5 MHz paired bands – C1 and C2. This

[8] Final Report from the CITEL PCC.II meeting in the Dominican Republic contains PCC.II/REC. 30 (XVIII-11) "FREQUENCY ARRANGEMENTS OF THE 698–806 MHZ BAND IN THE AMERICAS FOR BROADBAND MOBILE SERVICES

[9] Ref CPQD: http://www.bnamericas.com/news/telecommunications/700-mhz-refarming-needed-in-less-than-10-of-municipalities-says-cpqd

[10] http://www.bnamericas.com/news/telecommunications/700-mhz-spectrum-could-be-tendered-in-2013-says-minister

facilitates cross-border frequency coordination, minimizes cross-border interference, which is a significant issue due to the close proximity of major Canadian population centers to the U.S. border, leverages economies of scale on equipment, and facilitates roaming[11].

Chile: The distribution of the 698-806 MHz band is allocated to Digital TV broadcasting and fixed and mobile service. In April 2012, Chilean regulator body Subtel announced that it will auction 90 MHz of spectrum in this band during the second half of 2013 and will adopt the APT band plan. The license will be assigned end of 2013, and commercial service is expected in 2014 to 2015.

Colombia: Colombia has changed the primary allocation of this band to mobile services and on May 30, 2012, ANE and MINTC announced the adoption of APT band plan[12]. The license will be assigned end of 2013 and commercial service is expected in 2014 to 2015.

Costa Rica: This band is primarily assigned for Broadcasting TV UHF channels and secondarily for IMT services. Once migration from Analog TV signals to Digital TV signals is finalized by 2017, the band will have an IMT primary use, as per their NFAP. However, it is likely that there will be a revision for this date so that the digital switchover can take place at an earlier time. Costa Rica's regulatory body, SUTEL, has recommended the adoption of the APT band plan to the Ministry of Environment, Energy and Telecommunications[13] and this is awaiting final approval by the Executive Branch.

Ecuador: There are UHF terrestrial coded TV systems (686-806 MHz) working in 6 MHz sub-bands.

El Salvador: The band is dedicated to broadcasting (614-806 MHz). There is still no news regarding its possible use for next generation mobile systems.

Guatemala: The allocation for the 700 MHz band (614-806 MHz) is for TV UHF broadcasting services between channels 39 and 69.

Honduras: Allocated for broadcasting. There are no known initiatives for attributing this band to future mobile systems.

Mexico: This band is currently being utilized for TV channels 60-69 in the frequency range 746-806 MHz. The Mexican government has indicated this band could be considered for radio communication services. 3G/4G is a possibility but it would be costly to clear the band. Mexico adopted the APT option through COFETEL press release 38 of September 19, 2012.[14]

Nicaragua: Currently the 698-806 MHz band is allocated to mobile services. Telefonica and Entel Nicaragua have both been assigned spectrum in this band following the U.S. band plan.

[11] http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/sf10122.html
[12] http://www.mintic.gov.co/index.php/mn-news/1246-colombia-adoptara-el-estandar-apt-para-el-desarrollo-de-la-tecnologia-de-4g
[13] Doc 1198-SUTEL-DGC-2012, March 2012.
[14] http://www.cft.gob.mx:8080/portal/2012/09/cofetel-recomienda-adoptar-el-modelo-asia-pacifico-para-la-segmentacion-de-la-banda-700-mhz-comunicado-3812/

Panama: The frequencies between 698-806 MHz host UHF channels 52 to 69 broadcast TV. The frequencies are also used for telecommunication transport. In July 2012, ASEP, Panamanian regulator issued a public inquiry on APT adoption.

Paraguay: Frequencies between 614-806 MHz are allocated to broadcasting. In the 470-806 MHz frequency band, allocated to UHF television, 12 channels are set aside to develop the beginning of digital television in its terrestrial mode. TDT started broadcasting in May 2011.

Peru: The Ministry of Transport and Communications allocated on a primary basis the 700 MHz band to mobile services in March 2011.[15] The document addressed both APT and U.S. band plan without making a final decision. The 700 MHz band is currently utilized for broadcasting and radio communication. However, a portion of this band has been reserved. In April 2009, the Ministry of Transport and Communications selected the ISDB-T standard for terrestrial Digital TV broadcasting. Since then, MTC, the Peruvian regulator have indicated that they plan to auction the AWS band later on in 2012 before getting into the specifics of 700 MHz although they have expressed their preference to adopt the APT band plan.

Dominican Republic: The 470-806 MHz band is allocated to television broadcasting. Past the deadline for the transition from analog to digital terrestrial television, the 470-698 MHz band will be allocated to the television broadcast service and all broadcasts must be made in digital format; the 698-806 MHz band will be allocated on a primary basis to the mobile service.

Uruguay: The 700 MHz band is currently being utilized for radio and TV (512-806 MHz.) On July 2011, the Uruguayan regulatory body URSEC allocated 700 MHz for IMT-Advanced and mobile services. Prior to auction the 700 MHz band, the Uruguayan government is scheduling the auction of spectrum in 900 MHz, 1900 MHz and AWS bands for the second part of 2012. URSEC has unofficially stated they will follow the APT band plan.

Venezuela: This band is currently utilized for broadcast TV. There are no future plans to deploy cellular services in this band. Spectrum in the 1800 and 1900 MHz bands is being assigned to the three established mobile operators and the regulator is expected to continue with AWS auction next and then the Digital Dividend at a date that is not defined yet.

3. DIGITAL DIVIDEND SPECTRUM IN OTHER REGIONS

Australia: In June 2010, Australia's minister for Broadband Communication and the Digital Economy identified the frequency band from 694-820 MHz for Digital Dividend. The Auction date is scheduled for April 2013 in full alignment with APT band plan as per 2X45 MHz FDD arrangement. The Australia Digital Dividend spectrum will become available after the analog TV switch-off on December 31, 2013, and its auction will take place in April 2013, in a single process together with the spectrum in 2.5 GHz band. Both spectrum bands are expected to be restacked during 2014, with possible mobile network rollouts starting late 2014. The spectrum caps are 2X20 MHz for 700 MHz and 2X40 MHz for 2.5 GHz bands. Auction method will use a combinatorial clock, with both bands to be auctioned simultaneously.

[15] Ministerial Resolution 190-2011-MTC/03

New Zealand: In early 2011, New Zealand announced 700 MHz band for mobile services. A complete switch-off of analog services and freeing-up of spectrum will take place by December 2013. There was public consultation on the usage of spectrum available after the switchover, from August to October 2011. The consultation document assumes the implementation of the APT band plan (2X45 MHz FDD) as the most likely outcome. Many stakeholders expect them to follow Australia and to adopt the APT band plan.

Indonesia: Indonesia is looking into allocating the 700 MHz band (694 -806 MHz) for mobile broadband.

Malaysia: Malaysia considers broadcasting on parts of the band.

Singapore: Singapore plans to commit, but is concerned about potential interference with Malaysia.

Thailand: The 700 MHz band has been allocated to mobile services as of April 2012.

India: On April 23, 2012, the Telecom Regulatory Authority of India (TRAI) officially endorsed the APT band plan, and recommended to auction the 700 MHz spectrum preferably in the first half of financial year 2014-2015, when the ecosystem for LTE in that band is reasonably developed, as to be able to realize full market value of the spectrum. On the issue of amount of spectrum, which a licensee can bid for, as per the information available, the entire spectrum in 698-806 MHz band is likely to become available for assignments for commercial telecom services. Since some agencies have raised doubts regarding this position, it appears safe to assume availability of about 2X30 MHz of spectrum in this band. At the time being, both FDD and TDD duplex alternatives are still being considered, and to be decided later.

China: China has agreed to use the 700 MHz for mobile, but has proposed to adopt time division duplexing (TDD).

South Korea: South Korea will allocate 700 MHz to LTE services after switchover in December 2012.

Japan: MIC announced on June 27, 2012, that the 700 MHz band was awarded to eAccess, NTT DoCoMo, and KDDI for mobile systems after completing a beauty contest process. There are three FDD licenses (10 MHz x2 each) are the arrangement is harmonized with APT700 (718 – 748 MHz UL, and 773 – 803 MHz DL). The commercial LTE services are expected from 2015 after re-farming of the band. KDDI will have 718 - 728 MHz and 773 - 783 MHz, DoCoMo 728 - 738MHz and 783 - 793 MHz, and eAccess 738 - 748 MHz and 793 - 803 MHz.

Papua New Guinea: Papua New Guinea has adopted the APT 2X45 MHz band plan and allocated 2X22.5 MHz (the lower block) to Digicel PNG in April 2012.

Tonga: Tonga has adopted the APT band plan and is in the process of allocating one 2X15 MHz block to an operator.

Europe, the Middle East and Africa (collectively Region 1[16]) are now also looking at the 700 MHz band as a second Digital Dividend.[17] One Administration (Ofcom, UK) identifies the 700 MHz band as "the most

[16] **Region 1** comprises Europe, Africa, the Middle East west of the Persian Gulf including Iraq, the former Soviet Union and Mongolia

[17] The first Digital Dividend in Europe is the frequency range 790-862MHz, called the 800MHz band.

attractive option for providing additional lower frequency spectrum."[18] The Telecommunication Regulatory Authority of the United Arab Emirates has published a consultation in which they propose to award the 700 MHz band alongside the 800 MHz band, using the lower part of the APT 700 MHz band plan and the full CEPT 800 MHz band plan. Some African countries have proposed to adopt the APT 700 MHz band plan or a part of the plan, depending on the existing usage of the 800 MHz and 850 MHz bands.

4. CONSIDERATIONS FOR DIGITAL DIVIDEND SPECTRUM

4.1 SPECTRUM POLICY

In developing a comprehensive Digital Dividend spectrum strategy for new mobile broadband spectrum, the Government policy makers should adhere to guiding principles for spectrum allocations and assignments. (These principles are discussed in greater detail in a paper published by 4G Americas last year.[19])

Configure Licenses with Wider Bandwidths. The band plan should include contiguous spectrum blocks large enough to take advantage of the enhanced efficiencies of Long Term Evolution (LTE). In addition, the policymakers should make allocations in such a manner as to avoid harmful interference and maximize spectrum resources and efficiencies, also recognizing the limitations of state-of-the-art RF component technology in being able to support large bandwidths given the practical constraints of cost, size, current, and performance of mobile devices. For greatest economies of scale, harmonization, and roaming opportunities, the spectrum blocks allocated by the regulators should take into consideration how they can be defined as a band supporting multiple licensee blocks with wide LTE channel sizes.

Group Similar Services Together. As a rule, like services should be placed near each other, as interference mitigation is simplified when adjacent services have similar characteristics. The grouping of like services can reduce complexity, cost, and spectrum utilization and can create efficiencies in developing infrastructure equipment and consumer devices. Mixing LTE mobility services with high power downlink-only service would create spectrum band usage inefficiencies and increase complexity of both the network infrastructure and end user devices therefore is not recommended.

Pursue Global Standards and Ecosystem Development. Technical standards are the foundation service providers and manufacturers use in developing competitive products and services to take advantage of worldwide economies of scale that lower costs for infrastructure equipment and devices. Global standards contribute to faster and broader technology deployment. Globally accepted standards address technical consideration like coexistence with adjacent services, duplex separation and duplexer pass band.

Consider Regional Harmonization of Digital Dividend Spectrum. Ensuring spectrum allocations are, to the greatest extent possible, in accord with international regional 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. According to a recent published

[18] Ofcom Consultation "*Securing long term benefits from scarce spectrum resources*" March 2012. http://stakeholders.ofcom.org.uk/consultations/uhf-strategy/

[19] http://www.4gamericas.org/UserFiles/file/White%20Papers/4G%20Americas%20Mobile%20Broadband%20Spectrum%20Requirements%20March%202011.pdf

GSMA report, non-compliant countries would experience 5 percent less economic gain, 30 percent less job growth, 30 percent less new business and 18 percent less government revenue. Countries neighboring non-compliant countries would also lose up to 3 percent of GDP growth, up to 10 percent of job creation, up to 11 percent of new business growth and up to 12 percent government revenue.[20]

Align Spectrum 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 building and have a significant coverage range. Therefore, 700 MHz spectrum is essential to serving rural and isolated areas, where the population density is low.

4.2 NETWORK CONSIDERATIONS

Spectrum Fragmentation is a Killer. In 2007 there were nine RF duplex-spaced cellular frequency bands between 800 MHz and 2.6 GHz specified by 3GPP. Five years later in 2012 this had expanded to 40 bands including twelve additional TDD bands. A recent report from the GSMA Wireless Intelligence Service[21] predicts that at least 38 different radio frequency combinations may be used in LTE deployments in the next few years. Devices built for one band of radio frequency will not operate on a network that uses a different band which means more radios must be supported in devices to allow for international roaming. Adding new RF bands to devices will result in increased cost, lower performance and additional delay for device makers and operators.

Technology and Spectrum Band Support. Today's broadband wireless operators are faced with the challenge of developing or supporting an ecosystem by strategically selecting spectrum bands, technologies and duplex modes (LTE FDD or LTE TDD) when transitioning their networks from 3G to 3G+ to 4G. The choice of frequency, guard bands between allocations and duplex separation of uplink and downlink within each individual band have a profound influence on the architecture of the phone.

LTE allows operation in 1.4, 3, 5, 10, 15 and 20 MHz channel sizes. All LTE channel sizes offer the comparable spectral efficiency at the physical layer in terms of bits/second/hertz since they all use the same modulation and coding formats, however, a larger bandwidth channel will benefit from lower overhead due to control channels and has the advantage of better performance in terms of speed and data throughput as experienced by the user depending on network conditions.[22]

LTE can be used in both paired spectrum for Frequency Division Duplex (FDD) mode and unpaired spectrum for Time Division Duplex (TDD) mode. LTE FDD and LTE TDD are quite similar in terms of signal generation, coding, modulation and demodulation. Their major differences lie in different duplex modes and slightly different frame formats.

Duplexer limitation at 700 MHz. The current state-of-the-art allows for a maximum FDD duplexer size of around 4 percent of the center frequency of the band. This allows for a duplexer bandwidth in the order of 30 MHz in the Digital Dividend spectrum band. Therefore, given the present state of the technology, a minimum of two duplexers are required to cover the entire spectrum range of Digital Dividend spectrum.

[20] http://www.prnewswire.co.uk/news-releases/gsma-announces-asia-pacific-could-generate-us1-trillion-in-gdp-through-spectrum-harmonisation-for-mobile-broadband-161754645.html
[21] GSMA Wireless intelligence reports that global rollout of LTE will accelerate to 2015 , but spectrum fragmentation must be addressed http://www.4gamericas.org/index.cfm?fuseaction=pressreleasedisplay&pressreleaseid=3401
[22] : *http://www.4gamericas.org/documents/4G%20Americas%20Mobile%20Broadband%20Explosion%20August%2020121.pdf*

Dual duplexer-implementation allows flexibility to administrations in their national spectrum planning, but it comes at a cost of additional complexities in terminal design.

LTE-Advanced Carrier Aggregation 3GPP Band Combinations with 700 MHz band Operators in ITU Region 2 own slices of spectrum in different blocks with varying bandwidth. Carrier aggregation is a feature in LTE-Advanced that enables the network to send data using two or more frequency bands at the same time to achieve high speed and greater throughput while maintaining backward compatibility. Operators in Region 2 should consider carrier combination scenarios with existing and Digital Dividend spectrum bands; these scenarios are currently analyzed and specified in 3GPP. Region 2 operators can benefit from the ecosystem development and carrier combinations already standardized with respect to 700 MHz bands or new band combinations that can be specified.

Most countries in Region 2 support 3GPP Band 2, Band 4, and Band 5 that are common with U.S. bands. as summarized in Table 6.

Public Safety Support. The 700 MHz band could meet public safety requirements for reliability and coverage deep into buildings. Some stakeholders consider that public mobile networks could support public safety applications using the 700 MHz band on a priority basis whereas other administrations prefer to assign spectrum for an independently operated public safety network. In addition, countries in Latin America usually allocate spectrum for public safety in spectrum bands others than 700 MHz

4.3 PROTECTION FROM INCUMBENT SYSTEMS

In the U.S. Band Plan, Band 12 allows 1 MHz guard band at 698 MHz to protect IMT base stations from DTV 51 transmissions. Current FCC rules place restrictions on mobile transmissions in lower A block and provides exclusion zone to prevent interference to DTV receivers.[23]

Asia-Pacific Telecommunity Wireless Forum (AWF) study recommends 5 MHz of guard band from 698–703 MHz to mitigate interference between DTV and IMT systems and 3 MHz of guard band at 803–806 MHz to protect PPDR. [24]

Both the U.S. and the APT band plans recommend use of adequate filters and site engineering practices to mitigate interference to adjacent systems.

[23] Section 27.60(b), allows 700 MHz licensees to select one of four methods to meet the TV/DTV protection requirements. These methods are: (1) geographic separation; (2) modified geographic separation if using higher powers/tower heights than the separation tables permit (would not be applicable in this case as the interference would be from mobile transmitters in the 700 MHz A Block to TV 51 receivers); (3) use of an engineering study to justify separations; or (4) concurrence of the affected TV station licensee. Additionally, Section 27.60(b) provides further guidance on the geographic separation requirements for control and mobile stations operating in the 698-757 MHz band (which would include the Lower A Block). Section 27.60(b) (2)(ii)(C) and 27.60(b)(2)(ii)(D) note that mobile operations must provide a minimum of 5 miles (8 km) separation distance from all adjacent channel TV/DTV hypothetical or equivalent Grade B contours and further notes that all mobiles must keep a 60 mile (95 km) minimum distance from all adjacent channel TV/DTV stations.

[24] Contribution to AWF UHF Correspondence Group, "HARMONIZED 700 MHZ BAND PLAN FOR REGION 3: DETAILED GUARD-BAND AND STRUCTURAL ISSUES" by Telecom NZ, Telstra Corporation Ltd, Nokia, Nokia Siemens Networks, Alcatel-Lucent, Qualcomm, Samsung, and Ericsson

4.4 DEVICE MANUFACTURER CONSIDERATIONS FOR DIGITAL DIVIDEND SPECTRUM

Chipset Support for Low and High Bands. There are limits on the number of low (below 1 GHz) and high (above 1 GHz) bands that can be supported by the chipset in a device. A decision to support RF bands is a complex process between operators and handset vendors as it involves support of legacy and new technologies in addition to bands for international roaming.

Multiband Multi-Technology Device Support. Besides 700 MHz band support, operators have to consider support for legacy bands and technologies for a fallback option to ensure maximum coverage and roaming options. In reality, the mobile handsets will be derived from existing designs that include operation in multiple bands (e.g. PCS, Cellular, AWS) and formats including support for other bands for cellular services (e.g. GSM, CDMA, EDGE, UMTS and HSPA/HSPA+) and radio technologies (e.g. Bluetooth, WiFi, GPS and NFC).

5. BAND PLAN DESCRIPTION

5.1 EXISTING BAND PLANS

5.1.1 U.S. 700 MHZ BAND PLAN

The U.S. 700 MHz band plan divides the 698–806 MHz frequency range into a lower 700 MHz portion and an upper 700 MHz portion. FDD Band 12 and FDD Band 17 have been defined in the lower 700 MHz band, whereas FDD Band 13 and FDD Band 14 have been defined in the upper 700 MHz band in 3GPP for LTE operation. The block definitions are shown below in Figure 1.

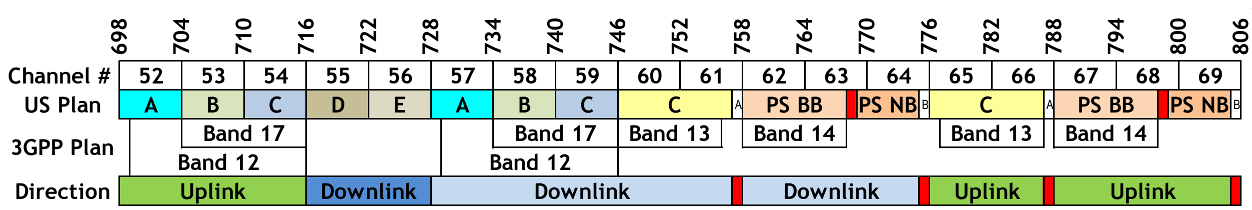

Figure 1: U.S. 700 MHz Band Plan

To support the 700 MHz band plan in the U.S., 3GPP RAN4 has defined the following bands in LTE and the technical specifications are listed in Table 1.

Table 1: Band Definitions and Supported LTE Channel Bandwidth for U.S. 700 MHz Band Plan

3GPP band number	FCC blocks	Duplex	Uplink Frequency	Downlink Frequency	Supported channel bandwidths					
					1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
12	Lower A, B, C	FDD	699 – 716 MHz	729 – 746 MHz	Yes	Yes	Yes	Yes		
13	Upper C	FDD	777 – 787 MHz	746 – 756 MHz			Yes	Yes		
14	Upper D, PS	FDD	788 – 798 MHz	758 – 768 MHz			Yes	Yes		
17	Lower B, C	FDD	704 – 716 MHz	734 – 746 MHz			Yes	Yes		
700 SDL[25] (TBD)	Lower D, E	FDD SDL	N/A	717 – 728 MHz			Yes	Yes		

Key performance specifications for the UE including reference sensitivity and maximum output power have been specified in 3GPP taking into account an allowance for passband insertion loss of the duplexer due to the narrow Tx-Rx separation as well as the additional design constraints on the filter to provide rejection for coexistence with services in adjacent bands. For the base station, reference sensitivity and emissions specifications are the same for all of the 700 MHz bands [26] with the addition of special emission requirements which may apply to comply with local or regional regulatory requirements.[27]

Interference scenarios may exist for the lower 700 MHz bands due to services in adjacent bands; particularly those shown in Figure 2.

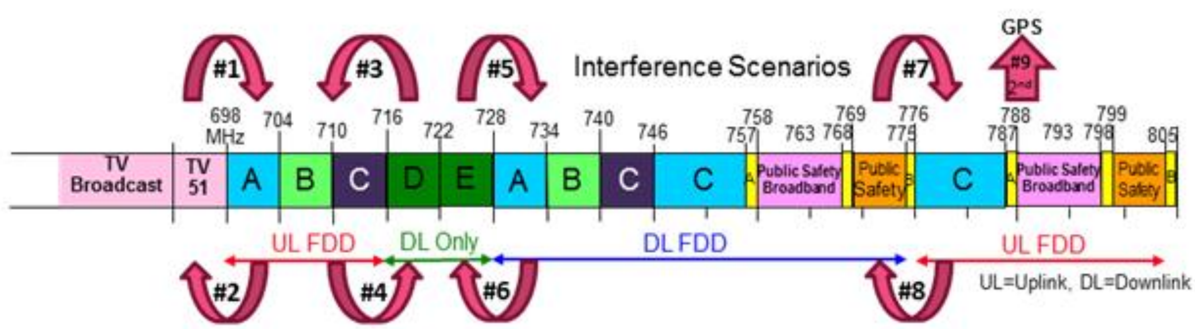

Figure 2: Interference scenarios for the U.S. 700 MHz band plan

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[25] SDL means supplemental downlink spectrum.
[26] 3GPP Bands 12, 13, 14 & 17 for U.S. plan. Band 28 and 44 for APT FDD and TDD plan *LTE system specifications defined by 3GPP in TS 36.101 for the UE and TS 36.104 for the BS*
[27] Reference to table 5 in appendix

- Scenario 1 and 2: DTV broadcast in the frequency range 692–698 MHz (channel 51)[28]
- Scenario 3 and 4: LTE-Advanced supplemental downlink in the frequency range 716–728 MHz (700 SDL),[29] and
- Scenario 5 and 6: DTV or other high-power broadcast in the frequency range 722–728 MHz (E block)[30]
- Scenario 7 and 8: Narrow band public safety downlink at 769–775 MHz[31]

The upper 700 MHz bands also face coexistence challenges with other adjacent services. In the U.S., there are public safety services operating in adjacent and nearby bands which require protection.

- Scenario 9: Second harmonic interference into GNSS receive bands

Lastly, UEs operating in Band 13 and 14 have the potential to generate interference with GNSS satellite navigation receivers. Nonlinearities within the transmitter elements of UE's operating in Band 13 and especially Band 14 have the potential to generate second order harmonic spurious products, which land just out-of-band of the GPS frequency range. Careful filtering in addition to other mitigation methods are necessary to ensure reliable GPS reception while transmitting in Band 13 or Band 14.[32]

Interference scenarios 1, 3 and 7 are related to BS-to-BS interference, while interference scenarios 2, 4, and 8 are related to UE-to-UE interference. BS-to-BS interference may be present since base stations typically employ high antennas with potential line-of-sight path to the victim base station receiver. On the other hand, UE-to-UE interference may be present since the separation between UE's can be small in public transportation (e.g., trains, subways, etc.) or hot spots (e.g., airports, shopping malls, etc.). UE duplex Tx/Rx filters typically have a passband covering the whole band (i.e., multiple blocks) and as a practical matter due to size and cost limitations, UEs may not provide sharp roll-off to mitigate interference with and from other band UE. The BS-to-BS interference could be mitigated by implementing various techniques, such as appropriate guard bands, BS transmitter emission mask improvements, receiver selectivity enhancements, vertical isolation etc. It should be noted that tradeoffs exist between the guard band, spectrum efficiency, and filter insertion loss/roll-off/cost/size/weight/waveform quality.

The UE-to-UE interference issue could be alleviated by various techniques, such as appropriate guard bands, UE transmitter emission mask improvements, receiver selectivity enhancements, limiting the UE

[28] RF filtering methods are employed in the UE and base station designs to help facilitate coexistence issues, but the effectiveness of these methods is dependent on many factors including the received power level of the interference, the required emissions limit to the adjacent frequency band, and the frequency separation between the LTE and adjacent services, to name a few

[29] Stringent base station filters and other network deployment-based solutions as vertical isolation between antennas may also be advisable depending on the circumstance.

[30] On the receive side, the 3GPP specifications require a Band 12 or 17 UE be able to withstand a blocker with no more than 6dB degradation in receiver sensitivity. The blocker is specified to be received at a power level of -30dBm at the UE antenna port and centered at 719 MHz (D block) and at 725 MHz (E block) where it is anticipated that high power broadcast transmissions may be present. The blocker from E block is only applicable to Band 17, whereas the blocker from D block is applicable to both Band 12 and Band 17.

[31] To protect narrow band public safety in the upper 700 MHz bands between Band 13 and 14 UE, emissions over these frequency ranges must be limited to below -35 dBm when measured in a 6.25 kHz measurement bandwidth.

[32] Furthermore, for Band 13 devices, the emissions limit can be tightened even further to -57 dBm when measured in a 6.25 kHz measurement bandwidth upon network signaling of the NS_07 additional spectrum emissions information element. In this case, the UE is also allowed significant power backoff in order to be able to comply with the more stringent emissions limit since RF filtering alone may not be sufficient. Band 13 and 14 BS emissions are also limited to -46 dBm when measured in a 6.25 kHz measurement bandwidth in order to protect 700 MHz public safety operation.

transmit bandwidth at the maximum power, Over-Provisioning Physical Uplink Control Channel (OP-PUCCH, i.e., moving the uplink LTE control channels away from channel edges), Additional Maximum Power Reduction (A-MPR), etc. Substantial guard band (potentially more than the guard band needed for BS-to-BS interference mitigation) may be required to minimize UE-to-UE interference.

The FCC has issued a Notice of Proposed Rulemaking (NPRM) inviting comments on the consideration of interoperability in the U.S. 700 MHz bands and the effects of interference due to services in adjacent bands.[33]

5.1.2 APT 700 MHZ BAND PLAN

The APT 700 band plan is the configuration for LTE in 700 MHz adopted within the APT. Current specifications under development in 3GPP were completed in June 2012 and can be found in 3GPP TS 36.101 v11.1.0 for the UE and 3GPP TS 36.104 v11.1.0 for the Base Stations**.** There are two variants – one for FDD that offers 2X45 MHz of contiguous spectrum and the other for TDD. Both cover the same frequency range from 698–806 MHz as the U.S. 700 MHz band plan.

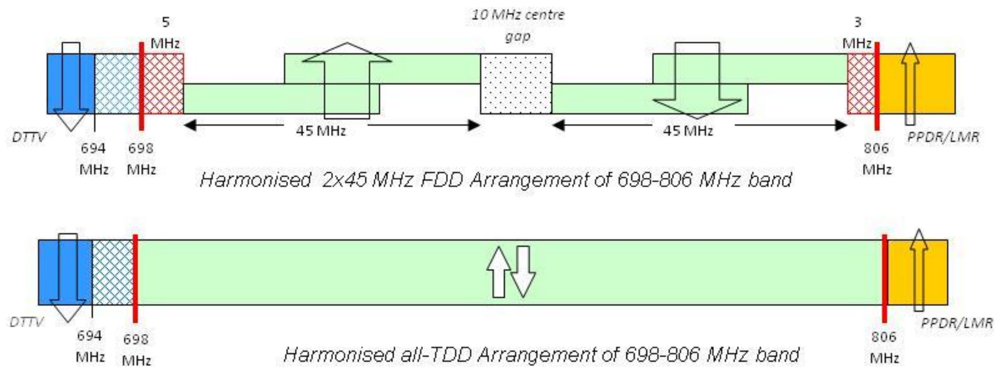

Figure 3: Possible Asia Pacific Telecom (APT) 700 MHz band plans, FDD and TDD variants are shown

Two APT 700 MHz band plans have been developed in 3GPP with the band definitions shown in Figure 3. As defined in 3GPP, both the FDD and TDD bands include a minimum guard band of 5 MHz and 3 MHz at their lower and upper edges, respectively. Furthermore, it should be noted that in many countries the broadcast spectrum will be cleared down to 694 MHz, due to the size of the TV channel rasters, so there will be a guard band of up to 9 MHz on the low side.

[33] Promoting Interoperability in the 700 MHz Commercial Spectrum, WT Docket No. 12-69, Notice of Proposed Rulemaking, 27 FCC Rcd 3521 (2012). 77 Fed. Reg. 19575 (Apr. 2, 2012).

Table 2: Band Definitions and Supported LTE Channel Bandwidths for APT 700 MHz Band Plan

3GPP band number	Duplex	Uplink Frequency	Downlink frequency	Supported channel bandwidths					
				1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz
28	FDD	703 – 748 MHz	758 – 803 MHz		Yes	Yes	Yes	Yes	Restrictions apply
44	TDD	703 – 803 MHz	703 – 803 MHz		Yes	Yes	Yes	Yes	Yes

For the APT 700 FDD configuration, the passband bandwidth for Band 28 is 45 MHz with a 10 MHz duplex gap. Due to limitations in current state-of-the-art filter technology, it is not technically feasible at the present time to manufacture in large scale a single filter capable of supporting the entire 45 MHz passband bandwidth while simultaneously providing minimum insertion loss over the passband and sufficient isolation between Tx and Rx. Therefore, the implicit assumption is that the implementation in the UE will require two overlapping filters to cover the entire band. Channel bandwidths up to 15 MHz can be supported anywhere within the band, but channel bandwidths of 20 MHz are limited to the upper and lower parts of the band and may not be employed in the mid-portion of the band where the filters overlap as shown in Table 2.. [34]

While the differences in the specifications between the U.S. 700 MHz bands and the APT 700 MHz bands are well documented, the differences in the actual performance of devices are not yet known.

The coexistence and interference issues related to the APT 700 band can be separated to those below the band and those above the band and are illustrated in Figure 4.

[34] Reference sensitivity and maximum output power specifications are the values in square brackets indicate they are subject to further confirmation in 3GPP

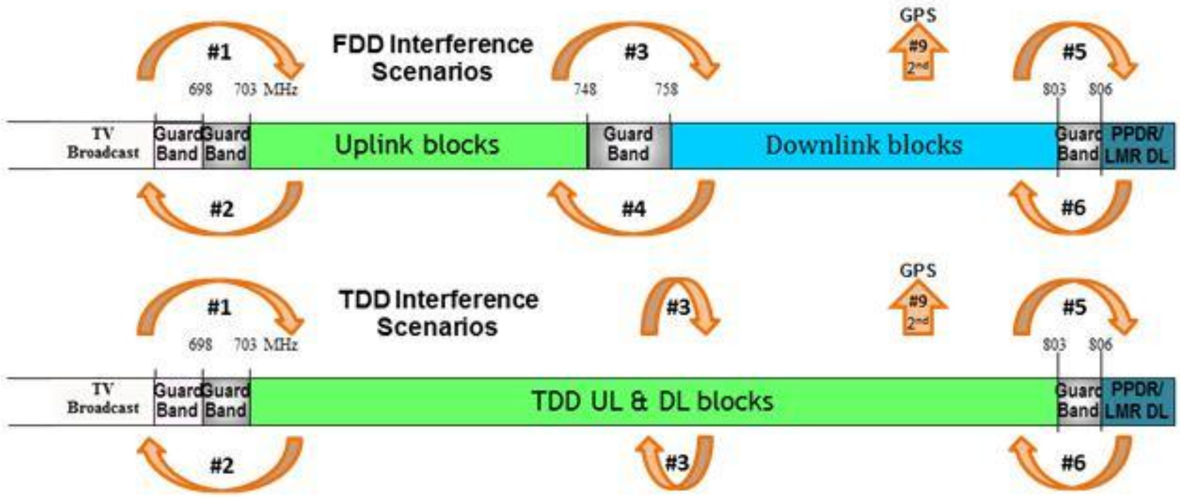

Figure 4: Interference Scenarios for FDD and TDD APT band plans

- Scenario 1 and 2: DTV broadcast below 698 MHz or 694 MHz.[35]
- Scenario 3 and 4: Self-band interference from uplink to downlink.
- Scenario 5 and 6: Coexistence with public safety PPDR, land mobile radio, and other services above 806 MHz.[36]

In Japan, DTV broadcast has been identified to extend up to 710 MHz with additional spurious emission requirement specified in 3GPP.[37]

Under the APT 700 FDD band plan there is potential second harmonic interference from base station transmitters falling into the GPS L1 band. In the case of APT 700 TDD, the interference terms can fall directly in-band to GPS receive frequencies. It is advisable to provide filtering or other means to limit the

[35] Below the band, interference to DTV broadcast may be a consideration with LTE UE Tx potentially interfering with DTV receivers, especially for countries with 6 MHz TV rasters up to 698 MHz. Leveraging the analysis and study performed in the APT Wireless Group (AWG), 3GPP has defined the UE emission limit from Band 28 and Band 44 devices to be -26.2 dBm when measured in 6 MHz bandwidth and -25 dBm when measured in 8 MHz bandwidth, respectively, over the frequency range from 662 MHz to 694 MHz. An NS network signaling option enables the Band 28 network to extend this protection limit up to 698 MHz, but with an allowed transmit power backoff for the UE

[36] Above the APT 700 band, the interference considerations involve public safety and land mobile radio services. The public safety services utilize frequencies above 806 MHz for uplink whereas the APT 700 band uses the upper band for downlink. Therefore, the primary interference mechanism identified and studied in the AWG is the impact of blocking on the APT 700 UE receiver in the presence of a nearby public safety transmitter. Frequencies above 807 MHz may also be allocated for wideband technologies (3GPP has currently identified Band 27 as 807-824 MHz UL and 853-869 MHz DL).

Another interference scenario is potential 3rd order passive intermodulation (PIM) with 850 MHz systems, a topic which is currently under study in 3GPP.

[37] Additional spurious emission requirement is defined in 3GPP. of -26.2 dBm in a 6 MHz measurement bandwidth has been specified over the frequency range from 470 MHz to 710 MHz by NS network signaling.

Band 44 UE emissions into the GNSS receive bands to better than -50 dBm/MHz. Furthermore, due to the time division nature of TDD systems, UE transmissions and receptions are interleaved in time so there are natural gaps where there would be no interference with GPS receivers. These gaps in time may further allow the GPS receiver to function while the Band 44 device is transmitting.

Techniques for mitigating interference concerns include the use of internal guard bands as part of the band definition. An internal guard band of at least 5 MHz has been created to allow for filter transition and larger frequency offset between APT 700 uplink and DTV reception, while an internal guard band of 3 MHz exists between the edge of the APT 700 downlink band and the lowermost edge where public safety may operate.

The 3GPP specifications also include provisions to facilitate coexistence for the APT 700 bands. Emissions limits to protect DTV receivers from UE transmissions below the band have been defined for various scenarios and frequency ranges. Network signaling options are available to provide protection up to 698 MHz and 710 MHz for countries with DTV service extending beyond 694 MHz.

6. CROSS BORDER COORDINATION

As radio waves are not bound by national borders and can cause interference to system operating in neighboring countries, it is important to develop a policy and technical framework for the 700 MHz band to ensure spectrum coordination between countries sharing large geographic borders.

From interference management there are 2 scenarios to consider:

Both countries implement the same band plan. Adoption of similar band plans by neighboring countries will ensure alignment of uplink and downlink spectrum blocks and co channel or adjacent channel interference scenarios can be managed by existing 3GPP specifications and existing bilateral treaties between the countries.[38]

Both countries implement different band plans. The U.S. and APT FDD band plans are incompatible in their assignment of uplink and downlink spectrum therefore careful coordination of spectrum is required along the border areas. Due to overlapping base and mobile transmission of one band plan with base and mobile receiving frequencies of the other band plan, four major categories of interference scenarios can be found along the border, as described in

[38]Reference Appendix B: APPENDIX B: 700 MHz International Coordination with the U.S.

Table 3. The most problematic scenario base to base interference from co- and adjacent channels will require exclusion zones along the border. Mobile to mobile coexistence is probabilistic but on the other hand it is difficult to control. The scenarios described below are not covered by 3GPP specifications and existing treaties, therefore, new measures need to be developed to mitigate these interference scenarios as part of bilateral discussions.

Table 3: Incompatibility between APT and U.S. 700 MHz band plans

Interference Scenario	Potential Mitigation Techniques
Co-channel APT UE to USA UE Co-channel USA UE to APT UE Adj. channel APT UE to USA UE Adj. channel USA UE to APT UE	Coordination between mobile to mobile is probabilistic and difficult to control along the border
Co-channel APT BS to USA BS Co-channel US BS to APT BS Adj. Channel US BS to APT BS Adj. Channel APT BS to USA BS	Could require separation distances along the border along with site engineering.(see Table 7 in appendix) Filtering on BSs and separation distances
Co-Channel UE to BS Adjacent Channel UE to BS	Usually considered to be of limited impact because of lower UE Tx power, isolation with victim BS, etc. May require guard bands
Co-Channel and Adjacent Channel BS to UE	Usually covered by existing treaties (Refer to Mexico and Canada border agreement

The most challenging case includes co-channel base station coexistence, which can occur as a result of the overlapping of BS Tx and BS Rx bands when using different band plans across borders. There are real and severe physical effects when one system is transmitting on frequencies that a neighboring system is trying to receive, and these impacts are not easily solved either technically or operationally. This challenging scenario will define the extent of exclusion zones at the border or be relaxed by the BS deployment coordination in antenna orientation, down tilt or power control between service providers from both countries. The size of the sharing or transition zone would need to be determined by the regulators and operators using certain assumptions on BS transmit power, allowable interference threshold, BS receiver sensitivity propagation loss, antenna gains, antenna heights, site engineering measures (e.g., antenna down tilting), terrain topography, etc. An example link budget, as shown in Table 7 in the appendix represents a typical LTE deployment. The approximate minimum path loss required for base-to-base coexistence in a typical macrocell deployed network is calculated to be approximately 171 dB.[39] This path loss can be further reduced by co coordinating networks and deploying network best practices along the border. Interference zone coordination should be part of the bilateral discussions between the two countries.

[39] Table 7: LTE Downlink: 10 MHz LTE Channel Link Budget for Base to Base coexistence scenario

7. ECOSYSTEM

7.1 U.S. BAND PLAN: CURRENT DEVICES & CHIPSET ROADMAP

According to the recent (July 2012) GSA survey, the U.S. 700 MHz ecosystem has grown rapidly to include 193 LTE device products including Modules for M2M, notebooks, phones, routers for hotspots, tablets and USB modems supported by over 18 manufacturers.[40] 3GPP defines a number of bands in 700 MHz: Band 12: (Lower 700 MHz) 699 MHz-716 MHz /729 MHz-746 MHz; Band 13: (Upper C 700 MHz) 777 MHz-787 MHz /746 MHz-756 MHz; Band 14: (Upper D 700 MHz) 788 MHz-798 MHz /758 MHz-768 MHz; Band 17: (Lower B, C 700 MHz) 704 MHz-716 MHz /734 MHz-746 MHz. An LTE device confirmed by GSA as operating in 700 MHz may operate in only one of these bands, and in some cases will operate in more than one of these bands.

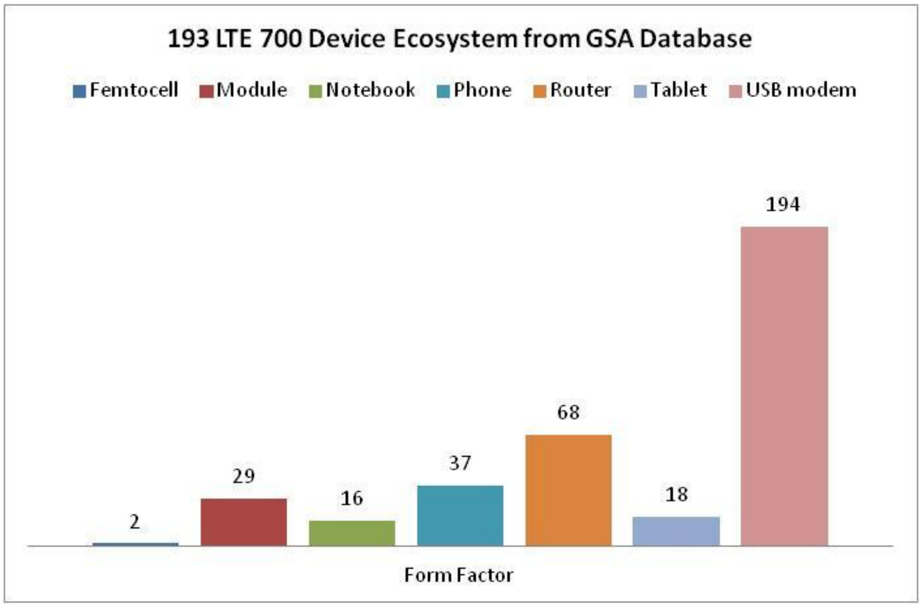

Figure 5: Ecosystem of U.S. Band Plan

7.2 APT Band Plan

Many stakeholders expect the APT band plan ecosystem to develop rapidly as countries in Region 2 and Region 3 identify and auction spectrum with this frequency arrangement.

[40] *GSA Confirms LTE User Devices Tripled in 12 Months, 417 Products Announced""The majority of LTE user devices operate in the 700 MHz band since LTE networks using this spectrum are the most extensively developed today, driven by market developments in the USA."* http://www.gsacom.com/news/gsa_354.php

8. SPECTRUM HARMONIZATION AND ECONOMIES OF SCALE

As seen in previous figures, the 698-806 MHz frequency range of the U.S./Canada and the APT FDD/TDD 700 MHz band plans substantially overlap. The 3GPP EUTRAN has designated four operating band numbers defined for the U.S./Canada band plan (viz. Band 12, 13, 14, 17, all FDD) and two band numbers defined for the APT band plan (viz. Band 28 for FDD and Band 44 for TDD). There are distinct differences among the operating bands. They have different operating channel bandwidths, channel locations, duplex spacing and interference environments that must be considered, particularly for the design of mobile devices. Although the spectral overlap provides some opportunities for manufacturing economies of scale for equipment operable across both plans, there are important technical considerations that may constrain practical RF designs to specific operating configurations. In this section we discuss the potential for components and designs to be adapted for the various bands, the impact on filters, power amplifiers and chipsets and the implications of regional and international roaming coordination among carriers.

Early solutions tend to be unique for a particular carrier and their technology configuration both within the 700 MHz band and in their other bands. As more carriers deploy, manufacturers of base stations and handsets will reduce costs through commonality of designs across multiple networks and regions. Chipsets and radio architectures will be developed to work for more than one band or band plan. Technological advances will also eventually overcome the most crucial problems (with various degrees of success), and these will improve performance.

Discussion of the issues involved with the design of an LTE 700 MHz mobile transceiver can be separated into baseband and RF. One advantage of the 700 MHz deployments is the common adoption of LTE, either FDD or TDD. As the chipset vendors plan to design FDD and TDD into the same LTE chipset, these baseband chipsets may be shared by all devices regardless of their band of operation. These LTE chipsets will typically also support services in bands other than 700MHz, such as 3GPP Bands 2, 4 and 5. The technological advances in baseband processing by the silicon industry will benefit all devices for economies of scale for manufacturing.

The RF designs, however, will not share such commonality, at least initially. Each transceiver design will generally require a unique antenna design and RF front-end components for its operating and interference environment. To analyze the commonality and differences of RF front-end components, and to better understand the technical challenges involved, consider a simplified RF circuit configuration for a mobile device as illustrated in Figure 6: Simplified diagram of the mobile device RF front-end functionality for channels of Band 17. Note the placement of the detailed configuration may vary according to implementation, with some elements being discrete and some being integrated within chips. The local oscillators and mixers, for example, are typically integrated on a chipset and may be common across multiple bands. The antenna matching circuitry, the duplexer and the channel selection filters are typically the components that will differ between devices to accommodate different bands. Not shown in this illustration are the switches and other circuitry that may be used to enable the base-band processes to be connected to one of several antennas and RF front ends to accommodate operations among multiple bands and radio access technologies.[41] Typically, a mobile handset will contain multiple antennas within

[41] According to the later releases of the LTE standard, a minimum of two receive antennas are required for UE, and so each of the illustrated receiver elements are duplicated for each antenna in a basic mobile device.

practical limits and associated RF front ends to enable operation in multiple bands to facilitate roaming in different coverage regions both locally and globally.

There are five RF components uniquely tailored for each 700 MHz band plan: the antenna and its matching circuits, duplexers, low-noise amplifiers (LNAs), power amplifier (PAs) and bandpass filters. These components are highlighted in Figure 7 together with the details of Band 17. In this illustration, the bandpass filters associated with the LNA and the PA may be incorporated within the duplexer but are highlighted here to illustrate their frequency sensitive role. The 734-746 MHz and 704-716 MHz numbers are unique to band 17. Similarly, the 12 MHz filters shown after the mixer may be lowpass if a “zero-IF” mixer configuration is used or bandpass if a non-zero intermediate frequency is used.

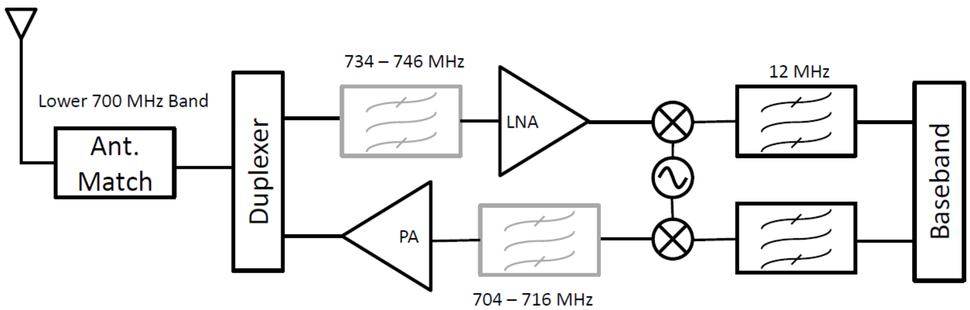

Figure 6: Simplified diagram of the mobile device RF front-end functionality for channels of Band 17

Antenna design for the 700 MHz band is challenged by the reality of physics. The efficiency of an antenna depends directly on its size and the space available in a mobile device. Thus, to maintain the same antenna efficiency and bandwidth at 700 MHz as, for example, at 2100 MHz, then the antenna design will be more challenging due to constraints on space and relative bandwidth.[42] These issues are most severe for small handheld mobile devices and may not be as significant for designs in laptops and tablets.

A matching circuit is connected to the antenna [Ant. Match] that matches the antenna to the duplexer of the transceiver circuitry. Because of the wavelength of the 700 MHz signals, practical antennas within mobile devices are much smaller than a wavelength; therefore need careful matching to maintain performance for the desired operating channel. For example, the antenna and matching circuit for the lower U.S. 700 MHz band (i.e. band 17 or band 12) would likely be different from one designed in the U.S. upper 700 MHz band (i.e. band 13 or band 14). An antenna for both the upper and lower U.S. 700 MHz bands would typically have excess variation across this range and it may be preferable to use antennas that are matched for each band to ensure the best performance for all channels.

Returning to Figure 6 we see the duplexer is attached to the antenna matching circuitry. The main purpose of the duplexer is to separate transmit and receive signals from the antenna. Duplexers may be considered as two filters operating in parallel, one for the transmit signal and one for the receive signal. The size of the passband and the steepness of the filter’s roll-off is a function of the carrier’s operating band.

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[42] Relative bandwidth is the ratio of the band-plan bandwidth to the centre frequency of operation. In the case of the Band 17, for example, the front end bandwidth is 42 MHz and the centre frequency is 725 MHz. This is a relative bandwidth of about 5.8 percent.

Band 17's duplexers, for example, will have bandwidths of roughly 12 MHz and an uplink/downlink gap of roughly 18 MHz. To meet the same requirements, duplexers are more difficult to design for Band 12 than for Band 17 for two reasons: one is that the gap between the filters in the duplexer is smaller for band 12 and the other is that the interference environment is more challenging due to other signals in the adjacent "E" block and the TV channel 51.[43] The Band 12 filters, for example must have a bandwidth of 18 MHz with a duplex gap of about 12 MHz. Both of these reasons lead to a duplexer filter that needs to have steeper roll-offs. This means that the order of the filters used must increase and with increasing order there is an increase in the passband loss in the circuit (i.e. increased insertion loss).

Insertion loss is undesirable because every extra decibel of insertion loss means that the transmitter power amplifier (PA) needs to transmit another decibel (dB) of power to meet the radio link budget resulting in a corresponding loss of receiver sensitivity. As power levels increase, for example, when a mobile is at the cell edge, the PA power must be high and the current drawn by the PA will increase. If there are no changes in linearity or distortion of the signal at higher power levels, a 1.5 dB increase in power will translate to about 40 percent higher current draw by the PA. This would translate directly to reduction in talk-time and also some effect on the standby time if there is a synchronization requirement between the mobile device and the base station.

In summary, the challenges of 700 MHz band RF front-end design come from the following:

- Antenna requirements for relatively broad bandwidths at these frequencies require precise matching
- Duplexers that demand sharp roll offs and relatively broad bandwidths that lead to high insertion loss
- High insertion loss that must be overcome by increased power leading to reduced battery lifetime and a reduction in receive sensitivity

This means, initially, devices for Bands 12, 13, 14 and 17 will likely be unique, each having its own antenna/duplexer/filter combination to meet the carrier's performance requirements. Over time, as antenna, duplexer and PA component technologies improve, the RF front-end performance will be developed so a design may be extended to cover multiple band plans and economies of scale may be possible within the 700 MHz band. A possible pairing may be Band 12 and Band 17. Similarly, Band 13 and Band 14 could be combined into a single RF front end. If necessary, mobile devices common for Band 12/17 and Band 13/14 would be possible by utilizing two RF front ends.

Band 28 (APT-FDD plan) and band 44 (APT-TDD plan) devices will not be deployed as soon as those for the U.S. plan, therefore will benefit from design experience from meeting the challenges in the U.S. deployments. The APT 700 MHz band plans, being continuous over the whole 698-806 MHz band (with included guard bands) will benefit from having no adjacent or in-band interferers and a wide duplex spacing. Device costs will shrink as the large international acceptance and deployments of the APT plan equipment grow globally yielding improved economies of scale. These additional sales will benefit the designs intended for the U.S. Bands 12, 13, 14 and 17 in that PA and LNA technology and the antenna

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[43] In Canada, the usage of TV channel 51 and the "D" and "E" differs slightly from the U.S. Industry Canada has placed a moratorium on all new and inactive channel 51 assignments. However, channel 51 is used in a number of major metropolitan centers and some rural low power configurations.

designs can be shared. Although, it is unlikely there will be any commonality of detailed RF designs[44] between the APT and U.S. plans as they are unlikely to be required to be interoperable due to different carrier network technology configurations. At the time of this writing, the plan for deployment of the TDD version (Band 44) of LTE is unknown, but these deployments will benefit from the common LTE chipsets and RF front ends developed or the FDD version (Band 28). By the time of introduction of devices for the APT band services, it is expected that a single antenna configuration may be used for the full band. Taken together, the whole ecosystem of the U.S. and the APT 700 MHz plans will benefit from the commonality of the frequency band and the LTE technology.

Up to this point in the discussion, the RF front end design has been discussed as if the 700 MHz radio is the only one in a mobile device. In reality, the mobile handsets will be derived from existing designs that include operation in multiple bands and formats. Support for multiple bands for cellular services (e.g. GSM, CDMA, EDGE, UMTS, HSPA/HSPA+ and LTE) and further radio technologies (e.g. Bluetooth, WiFi, GPS and NFC) are already incorporated in mobile devices to enable services to users wherever they roam. Operation in the 700 MHz band will be an addition to the capabilities in existing mobile devices. Manufacturing economies of scale will develop as each unique 700 MHz carrier configuration is able to be combined with the multiple roaming plans for multiple carriers.

In summary, the opportunities for manufacturing economies of scale for individual devices depend critically on practical considerations such as device size and the full suite of the supported bands and radio access technologies and, of course, the overall numbers of devices deployed. The 700 MHz band and LTE is but one of many band and radio format combinations devices are expected to support. The carriers' choice of technologies, spectrum bands, performance requirements, and roaming coordination between carriers also play a major role in the economies of scale across multiple bands. Nonetheless, over time, the challenge in the design of antennas, their matching circuitry and duplexers in the 700 MHz band will drive engineers to improve technologies that will benefit the 700 MHz LTE ecosystem. Advances will be made in technology and components that will drive down cost and improve the chances for increased economies of scale across multiple bands and radio formats.

8.1 3GPP LTE-ADVANCED FEATURES

8.1.1 CARRIER AGGREGATION

Carrier Aggregation is an LTE-Advanced feature published in Release 10 of the 3GPP LTE standards. It significantly influences terminal and base station entities as well as the scheduler of the base band processing present in eNodeBs.

Current average wireless traffic patterns are very heavy in the downlink (over 90 percent of the payload is downlink). Forecasters predict mobile video streaming will continue to grow at a faster pace than other applications so this asymmetry in traffic will only increase dependence upon the downlink. The aggregation of carriers improves peak user data rates, increases average data rates, reduces latency, and provides better load balancing and trunking efficiency. This technique improves spectrum utilization

[44] Except by means of using two RF front ends.

by potentially packing carriers more densely with reduced guard bands between contiguous carriers and improving access to otherwise difficult spectrum (including unpaired blocks).

There are 28 different CA combinations and additional CA combinations will likely be proposed in future 3GPP meetings.[45] Fifty percent of the combination studied in 3GPP are of particular interest to Region 2 as it includes combinations with the U.S. 700 MHz bands (bands 12, 13, 17, and 716-728 MHz [downlink-only]). A North American operator has treated the lower-700MHz D and E blocks (716 to 728 MHz) as an FDD Carrier but without any uplink carrier, the early implementations will consist of aggregations of downlink channels only. Release 10 supports uplink CA but performance improvements to enable effective UL CA is unlikely to be completed for several years. This implies that UL CA is unlikely to be commercially available before 2016.

Just as 40 or more specific bands are defined in 3GPP and new ones must be added when additional spectrum becomes available, so too, must the carrier aggregation combinations be added to the standards. The process includes vetting the technical feasibility in light of problems such as component carriers that are harmonics of each other, creation of intermodulation products at problem frequencies, or generally lack of support or interest. Even so, the number of work items to add new CA configurations has exploded with dozens of contributions as seen in 3GPP.

In terms of performance, under full load, with all carriers and time slots active, there can be no gain from carrier aggregation in the typical network However, where demand is less than capacity, the individual users experience substantial gains from CA, in both transfer rates and latencies. The biggest gains are in the ability to use spectrum that has otherwise been left stranded, such as the 716-728 MHz downlink-only band (lower 700 MHz D&E block). .

CA requires many new resources, particularly in the UE. Handsets are challenged to support additional bands of operations, even without the requirement that they be supported simultaneously. Additional bands typically require additional front end modules (unless bands are sufficiently close together), which include local oscillators, mixers, RF power amplifiers, RF filtering, combining/switching, Low Noise Amplifier (LNA) filters, demodulators, LO, A/D converters etc. All these functions affect cost, size, weight, reliability, and battery life.

8.2.2 SUPPORT FOR MULTI–FREQUENCY BAND INDICATOR

3GPP RAN plenary approved the Multi-Frequency Band Indicator extension in the System Information Blocks (SIB) to allow UEs of different but overlapping bands to camp and operate on the cell. This has been adopted into Release 8 LTE specifications as a “release independent” feature to allow implementation even by Release 8 UEs. This is particularly relevant to the overlapping Band 12 and Band 17 and enables A block UEs (band 12) to roam onto systems only supporting B and C block (band 17). The change request (RP-120732) approved in June 2012, extends the SIB to signal up to eight additional frequency band indicators for the current cell as well as for the neighbor cells. There is significant interest in multiple frequency band indicators particularly for Band 12/17 roaming The change will allow band 12

[45] Table 8: Carrier Combinations defined in 3GPP

eNodeBs to transmit both band 12 and band 17 capability, allowing new Band 17 UEs to roam into Band 12's B and C blocks.

9. LTE IN OTHER BANDS IN REGION 2

9.1 OTHER BANDS USED/PLANNED FOR LTE IN REGION 2

Deployment of LTE in the Americas moved to a higher plane in 2011, with a handful of launches in the U.S. and Canada, and numerous trials underway in Latin America. The ability to take advantage of new spectrum allocations and the opportunity to potentially refarm existing spectrum will enable extensive LTE deployments in Region 2.

In addition to the 700 MHz band, there are several other bands that are being used or considered for LTE usage. Other bands already in use for LTE include:

- 2.6 GHz (Band 7 / 38 / 41)
- AWS 1.7/2.1 GHz (Band 4)
- PCS 1.9 GHz G Block (Band 25)

In the longer term, it is expected that frequency bands currently used for 2G/3G systems in Region 2 will migrate to LTE technology. These include:

- 450 MHz (not yet specified in 3GPP)
- 850 MHz (Band 5/ 26/ 27)
- 900 MHz (Band 8)
- PCS 1.9 GHz (Band 2)
- 1800 MHz (Band 3)
- 2.1 GHz (Band 1)

There is also the expectation that other bands will be used for LTE in Region 2. These include:

- Extended AWS 1.7/2.1 GHz (Band 10)
- 2.3 GHz (Band 40)
- 3.5 GHz (Band 22 / 42 / 43)

9.2 HOW IT PROMOTES ROAMING

The adoption of common frequency bands across different nations and regions facilitates roaming by allowing devices to work in multiple geographical areas without the need for additional components (and therefore cost). From a spectrum standpoint, the initial focus in the Americas region has been on the 700 MHz, AWS 1.7/2.1 GHz, and 2.6 GHz bands. Initial deployments have targeted overlays of individual operator macro networks where demand was predicted to be especially keen.

There is a need for operators to identify their key roaming partner territories in order to assess the number of frequency bands that are required to enable roaming on LTE as well as 2G/3G technologies.

There is a need for vendors to identify the most commonly used frequency bands and to develop equipment that meets the largest number of requirements in the most cost effective way. There will inevitably be a tradeoff between incorporation of all the frequency bands in use across all geographical areas and technologies and the cost and complexity of user equipment. Indeed, state of the art technology is currently unable to implement all frequency bands specified by 3GPP for LTE. The NGMN Alliance has launched the project “multi-band multi-mode" together with all major international chipset and device manufactures to enable knowledge transfer across players and to work on a roadmap towards multi-band multi-mode devices.[46]

10. CONCLUSION

U.S. and APT Band Plan

The U.S. band plan has an early lead on LTE ecosystem development. There are open interoperability proceedings at the FCC examining interoperability in the lower 700 MHz band and the FCC could take corrective steps to resolve the interference issues from DTV 51 and high power E block that has led to U.S. Band fragmentation. Alternatively, carriers could work cooperatively to address interference issues. Canada has adopted a modified version of the U.S. plan and Canada could potentially avoid the lower 700 MHz band plan fragmentation by adopting service rules that allow compatibility between adjacent systems.

A number of countries (Chile, Colombia, Jamaica and Mexico) in Region 2 and others in Region 3 have announced their commitment or shown interest to adopt the APT plan while Japan and New Guinea have recently awarded licenses based on that plan. Rapid adoption and alignment could potentially generate cost efficiencies in the network and device ecosystem.

Economies of Scale

The opportunities for manufacturing economies of scale for individual devices depend critically on practical considerations such as device size and the full suite of the supported bands and radio access technologies and, of course, the overall numbers of devices deployed. The 700 MHz band and LTE are but one of many band and radio format combinations devices are expected to support. It is expected that most of the devices need to be backwards compatible so that they can operate in areas where the LTE build out has not been fully completed. The carriers’ choice of technologies, spectrum bands, performance requirements, and roaming coordination between carriers also play a major role in the economies of scale across multiple bands. Nonetheless, over time, the challenge in the design of antennas, their matching circuitry and duplexers in the 700 MHz band will drive engineers to improve technologies that will benefit the 700 MHz LTE ecosystem.

Cross Border Coordination

Bilateral cross border coordination needs to take place to address several technical and regulatory issues.

[46] http://www.ngmn.org/news/ngmnnews/newssingle2/article/the-ngmn-alliance-addresses-top-requirements-for-global-success-of-mobile-broadband-649.html?tx_ttnews%5BbackPid%5D=66&cHash=e41186

APPENDIX A: TABLES 4-8

Table 4: Selection of TDT Systems and Date of Analog Blackout, Selected Markets

ISDB-T	Analog	DVB	Analog	ATSC	Analog
Brazil, Chile	2016	Panama	2020	El Salvador	2019
Peru, Venezuela	2020	Colombia	2019	Honduras	2022
Argentina	2019			Mexico	2015
Paraguay	2022				
Costa Rica	2018				
Uruguay	2015				

Table 5: Band Definitions and Supported LTE Channel Bandwidths

3GPP band number	Reference sensitivity (10 MHz bandwidth)	UL configuration for reference sensitivity	Maximum output power
12	-94 dBm	20 RB	23 dBm ± 2 dB[1]
13	-94 dBm	20 RB	23 dBm ± 2 dB
14	-94 dBm	15 RB	23 dBm ± 2 dB
17	-94 dBm	20 RB	23 dBm ± 2 dB
700 SDL	TBD	TBD	N/A
28	-95.5 dBm	25 RB	23 dBm +2/-2.5 dB
44	[-95] dBm	50 RB	23 dBm +2/[-3] dB

Table 6: 3GPP Band Class Support in ITU Region 2

Note * 700 MHz bands in U.S. include – Band 12, 17, 13 and 14

	3GPP Bands				
Antigua and Barbuda	2			5	8
Argentina	2		4	5	
Bahamas	2		4		
Barbados		3	4		8
Belize	2			5	
Bolivia				5	
Brazil	2		4	5	
Canada	2		4	5	
Chile	2		4	5	
Columbia	2		4	5	
Commonwealth Of Dominica	2			5	8
Costa Rica		3	4	5	
Cuba					8
Dominican Rep	2		4	5	8
Ecuador	2		4	5	
El Salvador	2			5	8
Grenada		3		5	8
Guatemala	2		4	5	8
Guyana			4		8
Haiti		3	4		8
Honduras	2			5	
Jamaica		3	4	5	8
Mexico	2		4	5	
Nicaragua	2		4	5	
Panama	2		4	5	
Paraguay	2		4	5	8
Peru	2			5	
ST Vincent And The Grenadines		3		5	8
Suriname		3			8
Trinidad And Tobago		3		5	8
United States of America	2		4	5	
Uruguay	2		4	5	
Venezuela			4	5	8

Table 7: LTE Downlink: 10 MHz LTE Channel Link Budget for Base to Base coexistence scenario

Parameter	Values for 700 MHz	Comments
Frequency , MHz	740	Center frequency for the band
Channel	10	Channel bandwidth either 5 , 10 , 15 , 20 MHz
# of Resource	50	A RB is the basic time frequency in LTE = 1.0 ms in time & 180 kHz in frequency
# of RBs used	50	5 MHz = 25 RB, 10 MHz = 50 RB
TX bandwidth , MHz	9	The TX bandwidth = the # of RBs used times 180 kHz. The RX bandwidth = TX bandwidth for purposes of calculating the SNR.
# of TX Antennas	2	Number of eNB antennas required to support initial 2x2 MIMO operation
PA (W)	30	Typical base station power in Watt (40 W PA is also supported by ALU)
Total TX power dBm	44.77	Nominal value is 44.77 dBm = 30 watts, which for 2 TX antennas corresponds to a total eNB transmit power of 47.78 dBm = 60 watts.
TX Cable loss, dB	0.5	Assumes RRH located on tower top
TX antenna gain	14	Nominal values for the designated bands
TX antenna gain	-4.5	Assuming a Powerwave antenna with a 8-9 degree downtilt
TX EIRP, dBm	56.78	TX EIRP = 10*log10(# of TX antennas) + TX power per antenna - TX cable loss + TX antenna gain + 10log10(# of RBs used/# of RBs). This formula assumes that the TX power is evenly distributed across all possible RBs.
RX noise figure, dB	2	Nominal value for base station noise figure.
Uplink Iot, dB	3	Typical of a moderately loaded network in 700 MHz with Suburban grid
RX noise floor,	-99.46	RX noise floor = -174 + RX noise figure + 10*log10(RX bandwidth
Acceptable	1	1 – 3 dB maximum tolerable rise in the Iot due to interfering eNodeB
RX sensitivity, dBm	-105.33	The RX sensitivity = acceptable degradation + RX noise floor
RX Diversity Gain	0	2 Receive antennas (no gain since the interfering eNodeB is not coherently
RX antenna gain	14	Average estimated gains of primary RX for base stations
RX antenna gain	-4.5	Assuming a Powerwave antenna with a 8-9 degree downtilt
RX cable loss , dB	0.5	Cable loss
Minimum Separation Pathloss dB	171.11	MAPL uncoord = TX EIRP - RX sensitivity - RX cable loss

Table 8: Carrier Combinations defined in 3GPP

Case #	Lower Band #	Higher Band #	Common Name	Rapporteur
1	1	Intra-band	"2100"	Completed in R10
2*	3	Intra-band	"1800"	SK Telecom
3*	7	Intra-band	"2600"	China Unicom
4*	25	Intra-band	PCS+G	Sprint
5*	38	Intra-band	MBS of 2.6	Huawei
6*	40	Intra-band	WCS IMT2k	Completed in R10
7*	41	Intra-band	BRS/EBS	Clearwire
8	1	5	2100+cell	Completed in R10
9	1	7	2100+2.6	China Telecom
10	1	18	2100+ESMR	KDDI
11	1	19	2100+800	NTT Docomo
12	1	21	2100+1.5G	NTT Docomo
13*	2	17	PCS+B&C	AT&T
14*	2	FLO[47]	PCS +D&E	AT&T
15*	3	5	1800+cell	SK Telecom
16	3	7	1800+2.6	TeliaSonera
17*	3	8	1800+900	KT
18	3	20	1800+DD	Vodafone
19*	4	5	AWS+cell	AT&T
20*	4	7	AWS+2.6	Rogers Wireless
21*	4	12	AWS+ABC	Cox
22*	4	13	AWS+upC	Ericsson
23*	4	17	AWS+B&C	AT&T
24*	5	12	Cell+ABC	US Cellular
25*	5	17	Cell+B&C	AT&T

[47] FLO indicates the [716-728] Mhz downlink-only band (lower 700 MHz D and likely E in the US band plan

26	7	20	2.6+DD	Huawei
27	8	20	900+DD	Vodafone
28	11	18	PDC+ESMR	KDDI

*Asterisk signifies both component carriers are used in the Americas region

APPENDIX B: 700 MHZ INTERNATIONAL COORDINATION WITH THE U.S.

CANADA

A. Mobile Communications

(As of May 1, 2012, Canada had not set a date to auction the 700 MHz band for mobile broadband)

1. General Rule. Power flux density ("PFD") from a station into the other country shall not exceed –96 dBW/m^2 in any 1 MHz bandwidth unless both licensees in the adjacent areas and both countries' agencies agree to a higher value.

2. Coordination Rules for Licensees Operating Stations within 120 km (75 mi) of the Border.

   a. No coordination required if the PFD at ground level in the other country is at or below –116 dBW/m^2 in any 1 MHz bandwidth.
   b. Coordinate with a counterpart licensee in the other country that is operating within 120 km (75 miles) of the border if the PFD at ground level in the other country exceeds –116 dBW/m^2 in any 1 MHz bandwidth.
   c. If no counterpart licensee operates a station in the other country within 120 km (75 miles) of the border, the PFD shall not exceed –106 dBW/m^2 in any 1 MHz bandwidth in the other country unless agreed to by both countries' agencies except for stations operating in Macomb, Monroe, St. Clair, and Wayne County, MI, and stations in Erie and Niagara County, NY, which may produce a PFD across the border of up to - 96 dBW/m^2 in any 1 MHz without requiring additional agreement between administrations.
      i. If a licensee operating higher than – 116 dBW/m^2 in any 1 MHz bandwidth pursuant to this provision is notified by the licensee of the issuance of a new license on the other side of the border, it shall seek coordination within 30 days.
      ii. In this situation, if licensees cannot agree on a solution within 90 days after receipt of notice of the new license, the PFD may not exceed – 116 dBW/m^2 in any 1 MHz bandwidth. Either licensee may also request a country's agency to facilitate a resolution.
   d. The following is the coordination process for a new or modified station:
      i. Calculate maximum PFD value at and beyond the border that could be produced by a single transmitting station.
      ii. Communicate with counterpart licensee across the border by registered mail (or other mutually acceptable method) with the date.

iii. Licensees are encouraged to exchange contact information, station location, EIRP, ground elevation, antenna AGL, center frequency, polarization, antenna pattern/tabulation of pattern, azimuth of maximum antenna gain, and bandwidth and emission designation.

iv. The recipient must object by registered mail (or other mutually acceptable method) within 30 days of receipt:

1) If no objection, the initial licensee can proceed with deployment.
2) If objection is raised:

    a) the licensees must collaborate to develop a solution;
    b) the initial licensee cannot operate at PFD in excess of -116 dBW/ m^2 until a solution is agreed upon;
    c) If a solution cannot be reached, the initial licensee can request its country's agency to facilitate a resolution.

MEXICO

A. <u>Mobile Communications</u>.

1. <u>PFD Limits/Coordination</u>.
    a. No coordination required if the PFD at ground level in the other country is at or below –96 dBW/m^2 in any 1 MHz bandwidth.[48]
    b. If the PFD at ground level in the other country exceeds –96 dBW/m^2 in any 1 MHz bandwidth, coordination with a counterpart licensee in the other country that is operating within 110 km (68.35 miles) of the border and prior notice to the FCC and Mexican authorities, either of which may at any time advise the operator to return to the PFD limit, is required.
    c. If no counterpart licensee operates a station in the other country within 110 km (68.35 miles) of the border, the PFD may exceed –96 dBW/m^2 in any 1 MHz bandwidth in the other country with agreement of both countries' agencies. When notified of startup operations on the other side of the border, an operator exceeding the –96 dBW/m2 in any 1 MHz PFD limit must coordinate with the new counterpart operator.

2. <u>Out of Band Emission Limits</u>. OOBE into 764-776 MHz and 794-806 MHz (700 MHz Public Safety) bands shall not exceed -120 dBW/m^2 per 1 kHz at or beyond the border.

[48] Maximum (peak) composite transmitter power output shall be measured over any interval of continuous transmission using instrumentation calibrated in terms of root mean square (RMS) equivalent voltage. The measurement results shall be adjusted appropriately for any instrument limitations such as variations in detector times, limited resolution bandwidth capability when compared to the emission bandwidth, or other related characteristics, in order to obtain a true maximum composite measurement for the emission in question over the full bandwidth of the channel.

FIGURES

TABLES

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, Entel, Ericsson, Gemalto, HP, Huawei, Nokia Siemens Networks, Openwave Mobility, Powerwave, Qualcomm, Research In Motion (RIM), Rogers, T-Mobile USA and Telefónica.

4G Americas would like to recognize the project leadership and important contributions of Neeti Tandon of AT&T, as well as representatives from the other member companies on 4G Americas' Board of Governors who participated in the development of this white paper.