Nokia Solutions and Networks APT700 Discussion Paper

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Introduction

The national benefits of high quality mobile broadband networks that deliver wide area coverage and capacity are well understood and as such attract the interest and support of governments around the world.

Mobile broadband network operators face the challenge of delivering up to 1GB/user/day and a large increase in the number of connected devices by 2020. In some networks this will require a 1000-fold increase in capacity.

To meet this challenge, the industry is considering a ten-fold increase in the number of sites, a ten-fold increase in the efficiency of use of spectrum and a ten-fold increase in the amount of spectrum available (10x10x10=1000).

Although LTE is a globally accepted standard, 3GPP has needed to specify over 26 FDD and 12 TDD spectrum bands to try to address the demand for spectrum and fit in with national availability and regulation. Global spectrum harmonization would bring significant benefit to both developed and developing countries.

This harmonization would give manufacturers confidence that a particular spectrum band would have a large addressable market and could achieve significant economies of scale. This in turn enables early availability and the choice of a wide variety of affordable devices that can be sold and/or roam around the world.

The Digital Dividend is an on ongoing and unique opportunity to introduce a low band (less than 1 GHz) LTE variant to complement the current most commonly used high band LTE1800 (2Q13). Many countries are considering use of the 700 MHz spectrum band and an APT700 channel arrangement for future mobile broadband use.

This paper provides some background and looks at issues of interest to parties considering implementing an APT700 mobile broadband network.

APT700 Momentum

Spectrum resources are highly prized by many industries around the world. In particular, sub 1 GHz spectrum is valued because of its excellent indoor and outdoor propagation performance. This gives technical advantages and the ability to support high quality signals and wider coverage using fewer base stations/ broadcast sites.

Globally, many countries are moving from Analog TV to Digital Terrestrial TV (D-TV), offering the chance to re-farm part of the sub 1 GHz UHF band for mobile broadband (700 and 800 MHz bands). This ‘Digital Switchover’ has produced what has been called the ‘Digital Dividend’.

The ‘Digital Dividend’ has been widely touted to bring significant socio-economic benefit as a key enabler in bringing mobile broadband services to the community. Numerous studies have quantified this significant benefit, for instance, ‘Boston Consulting Group: Socio-economic impact of allocating 700 MHz to mobile in Asia-Pacific’, points to the generation of an additional US$729bn GDP across Asia Pacific nations by 2020. Analysys Mason: ‘Exploiting the Digital Dividend, a European approach’, suggests that adoption of the 790-862 MHz band across all EU member states could generate an additional €44bn in NPV over 15 years.

Management of Digital Dividend spectrum resources involves global bodies (ITU-R), regional bodies (e.g. CEPT, APT) and national bodies (e.g. ACMA (Australia), BNetzA (Germany)). Each represents the best interests of their members, although ultimately a nation’s use of spectrum is decided by its national body and government.

It is universally accepted that harmonized spectrum used on the largest possible scale will have enormous benefits for everyone by providing certainty, scale, ease of roaming and simpler devices.

During World Radio Congress 2007, the first step in realising a harmonized Digital Dividend, issues such as spectrum incumbency led to a need for regional variants (800 MHz band in ITU region 1 and 700 MHz band in ITU regions 2 and 3) rather than the harmonized global band that was hoped for.

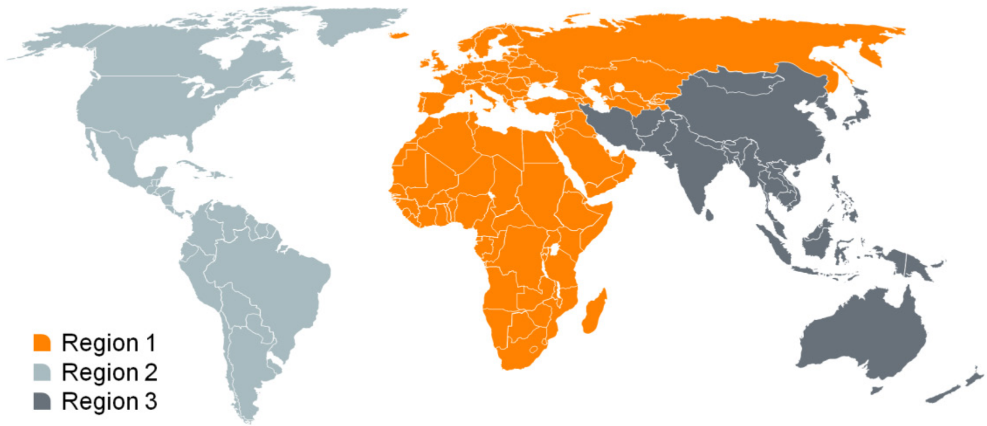
Following subsequent WRC meetings, numerous countries have agreed to adopt 700 MHz in full or in part in the FDD APT700 format. In May 2013, the South Asian Telecom Regulatory Council (SATRC) who’s members represent over 2 billion people and 1 billion mobile connections (2Q13), announced the joint adoption of APT700. Those member countries join a growing global list that now includes Australia, Afghanistan, Bangladesh, Brazil, Brunei, Indonesia, India, Japan, Malaysia, Maldives, Mexico, Nepal, New Zealand, Papua New Guinea, Singapore, South Korea, Taiwan, Tonga and the United Arab Emirates.

Along with Mexico and Brazil, other Latin American countries are also looking favorably at the APT700 band plan including Chile, Columbia, Costa Rica, Ecuador, Panama and Uruguay. In addition the African Telecommunications Union members are also reporting interest in adopting the APT700 band once the spectrum becomes available in that region.

Spectrum Management

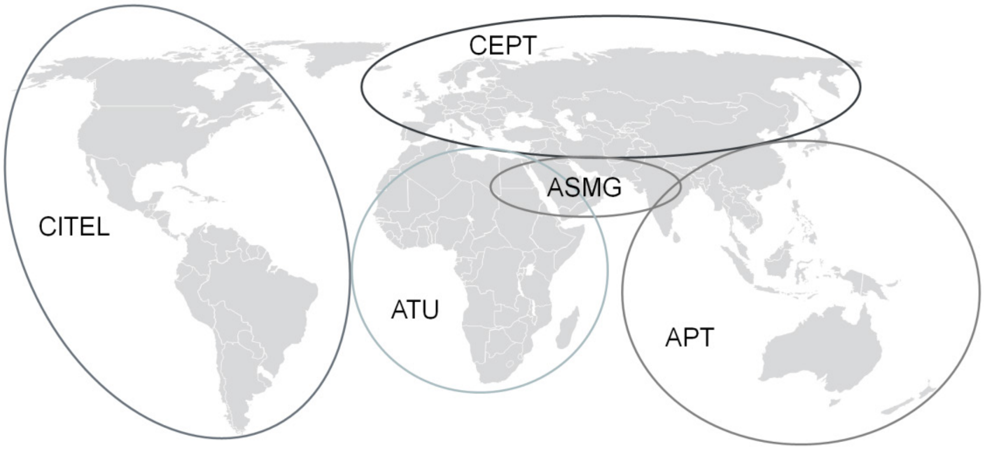
The ITU (International Telecommunications Union) is a United Nations body involved with issues pertaining to information and communication technologies

(ICT). The ITU coordinates radio spectrum and promotes international co-operation, global standards and improved telecommunications. There are three sectors within the ITU. One of these sectors, the ITU-R Radio-communications sector, handles radio spectrum resources and promotes and coordinates the development of a global broadband multimedia international mobile telecommunications system, known as IMT-2000 and IMT-Advanced.



International Radio Regulations are decided at ITU-R World Radio-communication Conferences (WRC), held every three to four years. The decisions include appropriate frequency spectrum allocations and the conditions of use of that spectrum. These decisions are then ratified by international law.

Ahead of WRC there are many ITU-R Study Groups, Working Parties and Policy Groups, with representatives providing support, research and background for Radio Regulation proposals.



Contributors include regional Spectrum Management Organisations: CITEL (Inter-American Telecommunications Commission), CEPT (European Conference of Postal and Telecommunications Administrations), ATU (Africa Telecommunications Union), ASMG (Arab Spectrum Management Group) and APT (Asia-Pacific Telecommunity).

The Spectrum Management Organizations represent their member countries and their National Regulatory Authorities along with telecommunications providers and the regional industry. APT for instance has over 38 member countries and hundreds of affiliate members from the private sector, research organizations and industry associations.

Within this structure, responsibility ultimately remains with each country's National Regulatory Authority (NRA) for spectrum management and the regulation of its own telecommunications sector. NRAs will typically consult with all interested parties and seek to release as much spectrum as possible to allow the country to benefit from global economies of scale, interoperability, interference minimization (including with neighbor countries), international roaming and alignment with regional and global agreements.

There are typically a number of interested parties lobbying to gain management rights to spectrum. The NRAs must consider many factors, such as each country's socio-economic benefit. An example would be the direct economic benefit of Mobile Telecommunications compared with less direct economic purposes that nevertheless benefit society, such as Public Protection and Disaster Recovery Services (PPDR).

The Digital Dividend

The 700 and 800 MHz band is part of the spectrum (≈470-862 MHz) that has been used for analog UHF broadcast TV around the world for many years. The current and gradual introduction of digital TV, which is more spectrally efficient (and supports enhanced services), has enabled traditional TV spectrum to be released for other purposes, a process known as the Digital Switchover (DSO). The resulting yielded spectrum has been termed the 'Digital Dividend'.

ITU-R WRC-07 agreed to allocate the 700 MHz and 800 MHz for IMT-2000 and IMT-Advanced. This had to be done on a regional basis because of incumbent use, as follows:

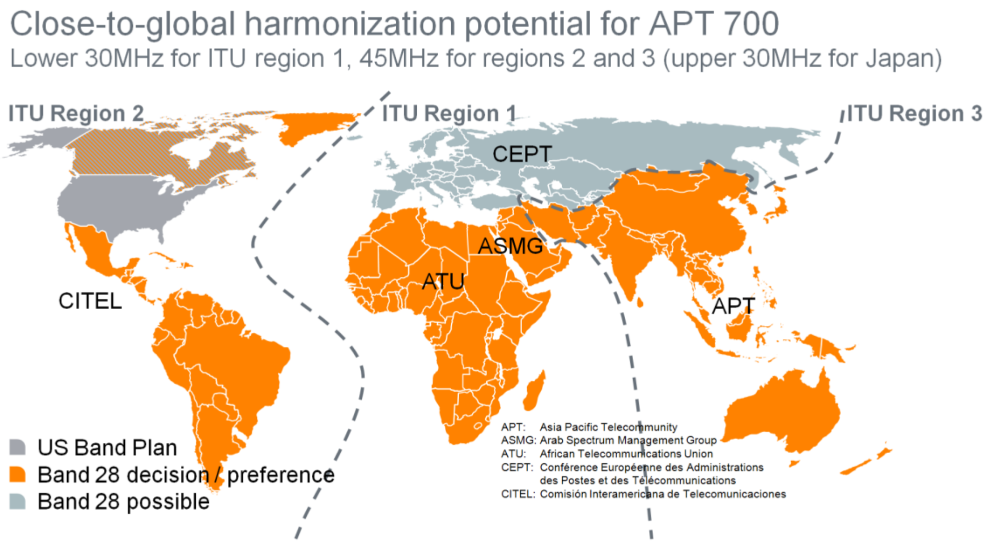
- 790-862 MHz, the 800 MHz band aka CEPT800 aka EU800 aka 3GPP Band 20 in ITU region 1.
- 698-806 MHz, the 700 MHz band aka APT700 and addressed by 3GPP Bands 12, 13, 14, 17 and 29 in some region 2 countries and by 3GPP bands 28 or 44 in the rest of region 2 and all of region 3

In region 1, digital terrestrial TV was already underway by 2007 and that region had identified 790-862 MHz to be its 'Digital Dividend'. Yet, in regions 2 and 3, part of that band was already in use for mobile telecommunications i.e. UMTS850 / CDMA850 and so the alternative 698-806 MHz was identified as their 'Digital Dividend'.

This regional allocation was unfortunate since it prevented the aspiration of a global harmonized IMT band with all the associated benefits of scale and the possibility of transparent operation across developing and developed markets.

The situation has driven a 'rethink' and subsequently ITU-R WRC-12 has agreed a provisional resolution to co-allocate spectrum in the 69x-790 MHz range (with the lower band edge subject to final decision in WRC-15) for Digital TV Broadcasting as well as IMT services in region 1. This is planned to be ratified in ITU-R WRC-15. Discussions are in progress for region 1 to use part or the entire lower duplexer APT700 FD-LTE band, since part of the downlink of the CEPT800 band already overlays the top duplexer APT700 FD downlink band.

ITU-R WRC-15 will ratify the technical and regulatory conditions considering the largest possible harmonization of the 700 MHz band. Joint Task Groups have been established and are looking at the possibilities of using both the 700 MHz and 800 MHz bands in all three regions. This could mean co-primary spectrum band sharing along with further optimization of Digital TV Broadcasting. Within parts of ITU region 1, it is possible that the 700 MHz band could be made available towards 2015. However, this is more likely to start in 2017 and in certain countries not until 2020 or later due to the complexity of the current digital terrestrial TV environment there.



There are many examples that reflect the ITU-R Region 1 push for a harmonized approach to the 700 MHz band.

In January 2013, DIGITALEUROPE, which represents over 10,000 members of the European ICT industry, issued a paper 'DIGITALEUROPE position on the 700 MHz band' in support of harmonization of the 700 MHz band for mobile broadband. It considers that a transition towards DVB-T2 is sufficient to release the 694-790 MHz band. In support of harmonization, the paper suggests the adoption of APT700 channel arrangement in the lower duplexer band as a way forward.

In March 2013 the European Commission issued a "mandate to CEPT to develop harmonized technical conditions for the 694-790 MHz ('700 MHz') frequency band in the EU for the provision of wireless broadband electronic communications services and other uses in support of EU spectrum policy priorities".

In June 2013, the German Federal Network Agency (BNetzA) announced an open consultation process to determine the provision of spectrum post 2017 for broadband rollout in Germany (the largest market in the EU) that will include the 700 MHz band. Similarly, in June 2013, the Finnish regulator Ficora highlighted plans to make the 700 MHz band available for mobile communications after 2017. In November 2012, the UK regulator OFCOM declared its intention to support the international process to enable a harmonized global approach in the 700 MHz band for Mobile Broadband use, and there are similar indications from many other countries throughout ITU region 1.

Member countries within the GSMA have considered these options and the GSMA has decided to promote its preferred band plan for 700 MHz in region 1 based upon the lower duplexer of the APT band plan, 703-733 MHz (uplink) and 758-788 MHz (downlink). A key criterion for making this decision was the desire to achieve maximum international harmonization.

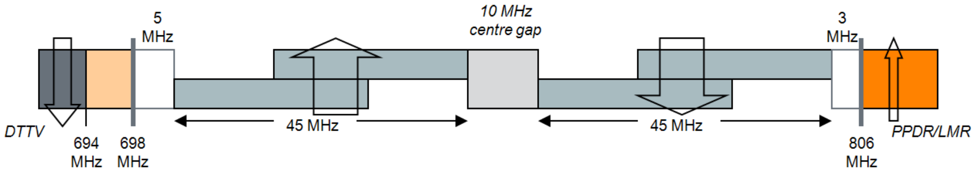
In May 2013, TRA UAE (Telecommunications Regulatory Authority, United Arab Emirates), took a decisive step to lead harmonization and announced its intention to offer both the 700 MHz (30 MHz lower duplexer APT700) along with 800 MHz (30 MHz CEPT800) by the end of 2013.

Evolution of the APT700 Standard

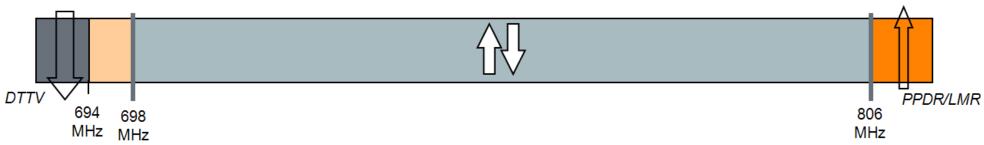
Following the adoption of 700 MHz for IMT by the ITU-R in WRC-07, in March 2008 the Asia-Pacific Telecommunity (APT) Wireless Group (AWG) initiated a study of the UHF band to determine a harmonized approach in that band for the region.

In September 2010, the harmonization work was finalized and documented in APT Report 14. This work presented a format for the 698-806 MHz band with the following characteristics

- 10 MHz duplex gap.
- 2 x 45 MHz duplex frequencies.
- Uplink is the lower 45 MHz.
- 3 MHz Guard band at the top of the band and 5 MHz at the bottom of the band.
- Some countries using a 7 or 8 MHz TV channel framework may have a natural channel boundary at 694 MHz, leaving an additional 4 MHz guard band at the bottom of the band.
- The dual duplexer arrangement was deemed necessary to facilitate mobile device implementation whilst the overlap affords flexibility to NRAs with their national spectrum planning.
- The report also noted that device out-of-band emissions towards adjacent Digital Terrestrial TV channels needed to be specified and that further study was required.



- The report also specified use of the entire 698-806 MHz band as a TDD arrangement



In September 2011, the AWG issued APT Report 24. This report provides guidance on the necessary mobile device out-of-band emission levels in order to ensure coexistence with adjacent band Digital Terrestrial TV services. The report concluded that considering technical and economic factors associated with mobile equipment (UE), that the average out-of-band emissions of the IMT UE, measured over the bandwidth of the applicable TV channel in the country of deployment, must not exceed -34 dBm/MHz below 694 MHz.

The ITU-R subsequently adopted the APT frequency arrangements in their Recommendation M.1036-4 (March 2012).

3GPP incorporated the APT700 band plan (with notes) during TSG-RAN WG4 meeting #56, #63 (June'12) with Change Requests for 3GPP specifications 36.101 v11.1.0 2012-06 (for the UE) and 36.104 v11.1.0 2012-07 (for the E-UTRA BS) introducing Band 28 (FDD) and Band 44 (TDD).

For reference, 3GPP has also issued Technical Report TR36.820 v11.2.0 (2012-12) LTE for 700 MHz Digital Dividend (Rel11).

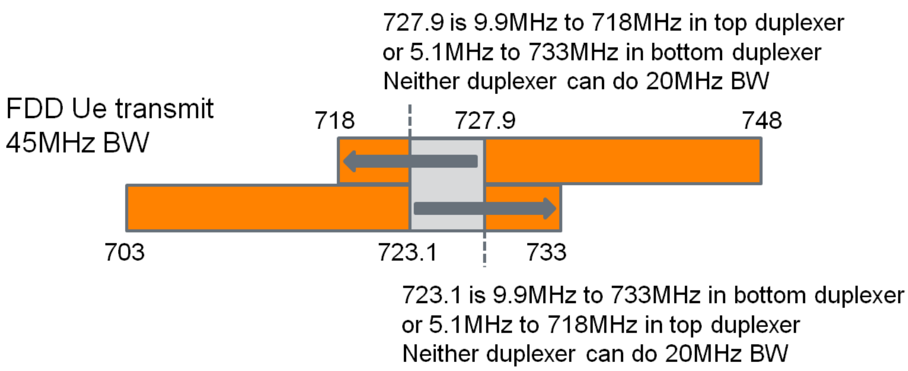
APT700 Technical Considerations

FDD Duplexer Requirements

The APT700 FDD band is 45 MHz wide in both the uplink and the downlink. For the UE, the current state-of-the-art SAW/BAW filter design allows the implementation of a stable duplex filter with a bandwidth limited to approximately 4% of the centre frequency at reasonable cost. For the uplink (downlink), 4% of the centre frequency 725.5 (780.5) ≈ 30 MHz and therefore a single duplexer of approximately 30 MHz can be achieved cost effectively with acceptable form factor.

To cover the 45 MHz duplex band, a UE therefore requires two 30 MHz duplex filters, one at the top of the band and one at the bottom with a 15 MHz overlap. The 15 MHz overlap means that an LTE 20 MHz channel bandwidth cannot be used with center frequencies between 723.1 and 727.9 MHz (within this range, the complete 20 MHz cannot be handled by one of the two filters). At the cost of complexity, UEs will need to support both duplex filters to maximize their addressable market volume. In some instances, UEs are required to do this by regulation to support porting from one competitive mobile network operator to another in the same market using a different part of the APT700 band.

Most regulatory authorities would auction/distribute their spectrum in 5 MHz blocks and therefore, in that grid, a center frequency of 725.5 would be the only center frequency that would prevent a 20 MHz option with one of the duplexers.

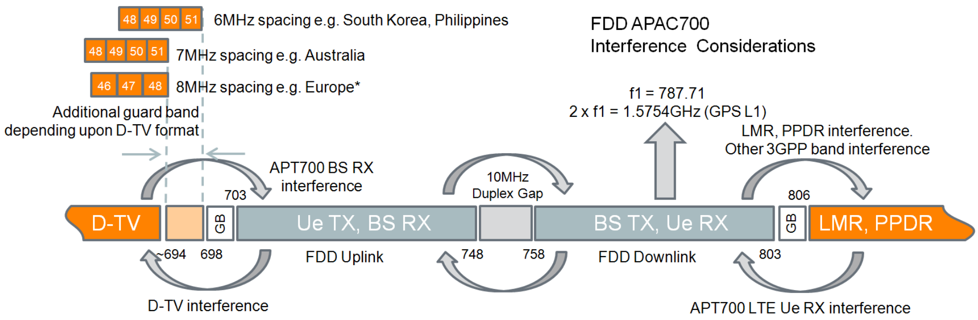


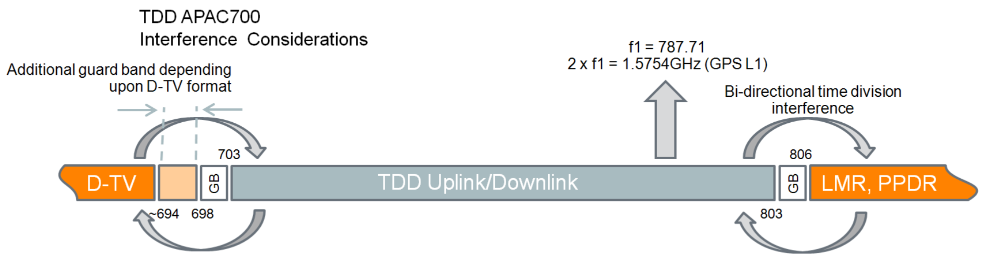
A similar approach to duplexing has been taken by most base station manufacturers. While the base stations can accommodate a larger size and cost to provide additional temperature stability and performance, it remains costly to provide a single duplexer to cover the entire 45 MHz and so most provide more than one sub-band frequency variant. There are also potential benefits in avoiding intra-duplexer intermodulation by limiting their bandwidth to 30 MHz sub-bands (see later discussion).

In the case of the base stations, although there are some exceptions e.g. having non-contiguous channels either end of the 45 MHz, operators will typically have spectrum in either the lower band or the upper band and will therefore, unlike the UE, only require one duplexer.

Interference Management

Interference susceptibility and perpetration needs to be considered with the introduction of the APT700 band. This can be a challenge in the uplink, with the uncertain and variable location of the UE, and in the downlink with the higher power transmission where intermodulation products must also be considered.





It's also necessary to specifically consider the APT700 TDD case, since with TDD a single channel can be transmitting at one moment in time and potentially causing interference, and the same channel at another moment in time can be receiving and be susceptible to interference.

Interference with spectrum below APT700

The band below APT700 is mostly dedicated to TV broadcasting in the four global variants (ATSC, DVB-T(2), DTMB and ISDB-T). These are then supported by UHF channels with a country specific raster (difference between neighboring channels in a frequency band) of 6, 7 or 8 MHz.

Concerns would be that mobile (FDD & TDD) UEs transmitting in the low part of the APT700 band could interfere with the near channel D-TV broadcast receivers in people's homes. Also, in the case of TDD, the base stations will transmit in the lower part of the band some of the time and so they could be a source of interference with the D-TV broadcast receivers. The D-TV transmitters could interfere with the FDD Base Station receivers, particularly given the very high power (up to a Megawatt) that D-TV transmitters can emit.

These problems were recognized by APT. Its original submission, adopted by the ITU-R, recommended a 5 MHz guard band along with guidance that the average out-of-band (OOB) emissions of the IMT UE, measured over the bandwidth of the applicable TV channel in the country of deployment, must not exceed -34 dBm/MHz below 694 MHz.

There is also some variance between countries. In countries that have D-TV operating with a 7 or 8 MHz raster, there is a natural channel boundary at 694 MHz since there is no room for an additional D-TV channel. Therefore, an additional 4 MHz guard band can be introduced. This is used as something of a default situation, hence the above out-of-band limit is from 694 MHz.

However, some other countries use a 6 MHz raster and this can support D-TV channels immediately adjacent to the APT700 band at 698 MHz. In fact, some countries have not made the entire APT band available after DSO, for example Japan, which has D-TV channels to 710 MHz.

To meet these country specific challenges, the 3GPP specifications (TS36.101 v11.4.0 2013-03 sect 6.2.4) introduce additional requirements that need to be met in certain deployment scenarios, in addition to the non-band specific requirements of the specifications. The additional requirements are signalled to the UE from the base station using Network Signalling (NS) Values. NS_17 and NS_18 are specific to Band 28 (FDD APT700) whilst NS_19 is specific to Band 44 (TDD APT700).

When considering the low probability of a base station close to a D-TV Broadcast tower using the top few channels of the D-TV band, along with the fact that there are some 3GPP performance guidelines already in place, the most practical approach to overcome any associated interference problems is to use site specific solutions.

Intra/Inter 3GPP band Interference considerations

The 3GPP specifications (TS36.104 v11.4.0 2013-03 sect 6.6.4.2) detail spurious emission limits for FDD base stations to protect their receivers from interference from their own or different base station transmitters. This is supported by duplexer isolation characteristics, and wide duplex separation (55 MHz for APT700 FDD).

For wide area Base Stations, the standards limit spurious emissions to -96 dBm when measured across the full receive frequency band using a 100 kHz measurement window at the TX port (shared or separate TX, RX ports). There are additional (country optional) band specific spurious emission standards within (TS36.104 v11.4.0 2013-03 sect 6.6.4.3) which address the issue of spurious emissions to other systems and other 3GPP E-UTRA networks. The topic is also explored with specific regard to the 700 MHz digital dividend in 3GPP TR36.820 v11.2.0 (2012-12).

Reasons for spurious emissions include, but are not limited to, intermodulation products which can occur in any non-linear systems with two or more different frequencies. The intermodulation products occur at integer multiples of the original frequencies as well as multiples of the sum and difference of the original frequencies.

In the FDD APT700 scenario, with respect to the Base Station TX interfering with the RX, then intermodulation products could be seen at ($\pm$M x f1 $\pm$ N x f2) where f1 min would be 758 MHz and f2 max would be 803 MHz and the order of the modulation being |M+N| with the third order product of the highest power.

The channel arrangement for FD APT700 is such that any two sub-channels within a 20 MHz channel bandwidth (or smaller) on the same duplexer will only produce third order products outside of its own reciprocal RX band. With a 20 MHz or less channel bandwidth, the fact that intermodulation products occur in alternate duplexers but not with the same duplexer in the APT700 arrangement is a reflection of good technical design.

Example base station TX: Upper duplexer band. BS TX/UE RX 773-803 MHz and UE TX/BS RX 718-748 MHz

- f1=773 and f2=793 then $(2f_1 - f_2)$ = 753 MHz (APT700 full band 10 MHz guard band)
- f1=773 and f2=793 then $(2f_2 - f_1)$ = 813 MHz (upper, out-of-band)
- f1=783 and f2=803 then $(2f_1 - f_2)$ = 763 MHz (lower duplexer BS TX/UE RX band)
- f1=783 and f2=803 then $(2f_2 - f_1)$ = 823 MHz (upper, out of band)

Example base station TX: Lower duplexer band. BS TX/UE RX 758-788 MHz and UE TX/BS RX 703-733 MHz

f1=758 and f2=778 then ($2f_1 – f_2$) = 738 MHz (upper duplexer BS RX/UE TX band)
f1=758 and f2=778 then ($2f_2 – f_1$) = 798 MHz (upper duplexer BS TX/UE RX band)
f1=768 and f2=788 then ($2f_1 – f_2$) = 748 MHz (APT700 full band 10 MHz guard band)
f1=768 and f2=788 then ($2f_2 – f_1$) = 808 MHz (upper, out of band)

All scenarios should be checked. From these examples, care must also be taken to avoid Passive Intermodulation (PIM) in certain scenarios, such as an operator with both the upper and the lower duplexer spectrum using the same antenna line.

Similarly, a shared site or a single RAN solution with other adjacent 3GPP bands i.e. Band 26 (uplink RX band 814-849 MHz) should avoid sharing the same antenna line with Band 28 TX (upper duplexer). In the scenario where an operator has an entire 30 MHz duplexer spectrum in use then that can produce intermodulation products in its reciprocal RX band i.e. BTS upper duplexer TX f1=773 and f2=803 then ($2f_1 – f_2$) =743 MHz (BTS upper duplexer RX band).

Passive intermodulation (PIM) is low power, typically >100 dB below the source carrier, but it cannot be filtered out as easily as intermodulation products can from active components. In mobile broadband networks, passive intermodulation can have a significant impact on performance in systems where both the transmitter, Tx and the receiver, Rx use the same antenna and common feeder cable.

In order to avoid or minimize the effects of PIM, good quality passive antenna line components (including coaxial cable) are recommended, particularly in high power parts of the antenna line. Even then, care is needed to avoid PIM problems due to poor connections as a result of incorrectly torqued or aged connectors.

GPS L1 interference

Many of today's smartphones include built-in Global Navigation Satellite System (GNSS) receivers for location based applications and emergency locations. Those GNSS receivers need to receive signals from typically four of the 24 orbiting GPS satellites in order to work correctly. All the GPS satellites operate using two frequencies, Band L1 at 1.57542 GHz and Band L2 at 1.22760 GHz.

Under the APT700 FDD band plan, there is potential for second harmonic interference from the base station transmitters falling into the GPS L1 band (2f = 1.57542 GHz, so f = 787.71 MHz). Unless this harmonic is appropriately filtered, it can cause interference with nearby GPS devices - this includes the base station itself if it is using GPS for synchronization.

In the case of APT700 TDD, the UE can transmit at 787.71 MHz and the interference can fall directly in-band to GPS receive frequencies. In this case, the filtering needs to be addressed within the APT700 TDD capable device.

Interference with spectrum above APT700

The spectrum immediately above the APT700 band (above 806 MHz) is used for Land Mobile Radio Systems (LMR) and Public Protection and Disaster Recovery Systems (PPDR), as well as other 3GPP mobile network bands.

The PPDR industry shares many of the challenges of the commercial mobile network industry. It has had a high reliance on mobile communications for narrowband voice and it now has an increasing demand to support mobile broadband. The ITU-R and regional spectrum management agencies are reviewing how this mobile broadband requirement can be addressed ahead of ITU-R WRC-15.

In the WRC-15 conference, the PPDR industry is seeking spectrum that is geographically harmonized in order to benefit from scale.

Current PPDR spectrum allocations are regional:

ITU Region 1: 380-470 MHz (380-385 and 390-395 MHz as preferred band for current PPDR activities) ITU Region 2: 746-806MHz, 806-869 MHz, 4940-4990 MHz

ITU Region 3: 406.1-430 MHz, 440-470 MHz, 806-824 and 851-869 MHz, 4940-4990 MHz, 5850-5925 MHz

This PPDR spectrum debate is relevant to the APT700 topic in several aspects.

Firstly, the use of the 758-798 MHz band in ITU Region 2 (specifically the US and Canada) to support 3GPP band 14 PPDR mobile broadband services hinders the adoption of APT700 Band 28 in Region 2 for the foreseeable future since it is spread across the Band 28 DL (as are Bands 12 and13). Additionally, Bands 13 and 14 are Uplink/Downlink reversed to APT700 Band 28.

Secondly, ITU Region 1 (Europe) PPDR current spectrum allocation is predominantly for narrowband services with work in progress to establish the best strategy for more spectrum to support mobile broadband services, including the expansion of current use to 380-470 MHz. This region plans a second Digital Dividend beyond 2015. The original purpose of the second Digital Dividend was to harmonize Region 1 with the APT700 band as a global LTE band with volume and roaming benefits. As an option, further work will determine if and how the second Digital Dividend could support both PPDR (mobile broadband) and APT700 global harmonization.

Thirdly, in ITU Region 3, APT700 is widely adopted albeit some countries have left part of the band available for future purposes that could include PPDR mobile broadband, or for current trunked radio services such as iDEN (e.g. Korea, Vietnam, India). Typically, those countries have adopted either the lower or higher duplexer 30 MHz for APT700. Other countries have determined the 800 MHz band (ITU-R resolution 646) for PPDR in Region 3, although most channel plans are yet to be settled. This spectrum does align with 3GPP E-UTRA Bands 27 and 26.

Fourthly, there is a strong case that given the prevalence and wide footprint of commercial mobile networks, these are perhaps a better option for PPDR non-critical services (no lives at risk and high percentage of traffic) rather than dedicated solutions. Critical services would remain with existing PPDR networks in existing spectrum. LTE networks support QoS management with 15 pre-emption and reciprocal vulnerability levels that could allow a mobile network operator to offer a pseudo-dedicated solution with Service Level Agreements towards the PPDR industry as might be needed.

Lastly, whilst the full APT700 FD band has a duplex gap of 10 MHz, if only one of the duplexer bands are used then the duplex gap is 25 MHz. With appropriate interference management, this has been another suggested (TD-LTE) option for future PPDR use.

Interference between the APT700 band and the spectrum above it is then predominantly between the upper part of the APT700 (Band 28) band, which is the downlink, and the bottom of Band 27 (807-824 MHz) and Band 26 (814-849 MHz), both of which are uplink. The major concern about interference would be APT700 UE receivers being blocked in the presence of nearby public safety transmitters. Another concern is the APT700 base station transmitting spurious emissions towards the base station receivers for Bands 26/27.

Antenna Considerations

With respect to antennas, the 700 MHz band has the disadvantage of a large wavelength, requiring relatively large physical antennas to achieve reasonable gain i.e. 2-3 times longer and heavier than an equivalent 1800 MHz antenna. For example:

Commscope LNX-4514DS-VTM

X-pol 698-896 MHz 15dBi (LxWxD) 1308x389x163 mm weighing 13.4 kg

Commscope LNX-6515DS-VTM

X-pol 698-896 MHz 16.7dBi (LxWxD) 2449x301x181mm weighing 22.8 kg

The size and weight of mast furniture is an increasingly important issue for mobile network operators as more frequencies are introduced. The problem is multiplied as LTE MIMO and LTE-A high order MIMO is introduced to networks, as these solutions require multiple antennas or antenna arrays for each band.

The practical implication of the size of 700 MHz band antennas for some mobile broadband networks is that it will restrict the MIMO order that can be supported in that band. This is a challenge for the base stations, as well as restricting the number of antennas that the UE can support.

FD-LTE700 Radio Performance

Initial network planning typically begins with link budget calculations to arrive at the maximum allowed signal attenuation path loss, or MAPL, maximum allowed path loss. Once the MAPL is known, the threshold limit can be set for suitable empirical propagation models such as Okumura Hata or COST231-Hata. These models provide cell range estimates as a function of antenna heights and frequency in different environments such as urban, rural, and suburban.

For many mobile network operators, it is useful to compare FD-LTE700 with other LTE frequencies and other radio access technologies to determine whether their existing site grids might be suitable for FD-LTE700 deployment with acceptable cell edge performance. Co-location and/or single RAN solutions can produce significant savings in network deployment costs.

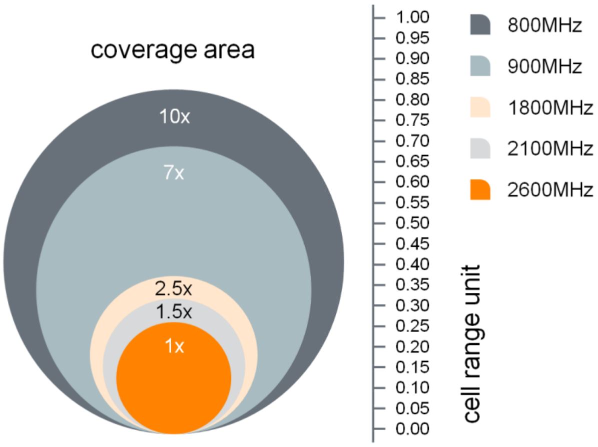
A simple link budget analysis for GSM and LTE can show that both technologies can achieve similar MAPL using appropriate solutions such as Receive Diversity, MIMO, Antenna gains and output power, provided that the quantified cell edge performance is acceptable.

Since it is possible to achieve the same MAPL with both GSM and LTE, it is also possible to achieve the same coverage footprint when overlaying LTE on top of a GSM site grid, provided that the LTE frequency is the same (or less than GSM) and the other factors highlighted in the link budget are valid.

The diagram below represents the relative outdoor coverage areas of LTE in different frequency bands, with all other factors equal in the link budget.

In a coverage driven network deployment, the multiplication factor reflects the reciprocal of the number of relative sites required at different frequency bands.

This propagation diagram does not consider building penetration losses, which also vary depending upon the frequency in use. A comparative estimate of single wall in-building performance would give a ≈ 4 dB advantage to the 700 MHz solution over an 1800 MHz solution.



Alternatively, the table below compares link budgets, relative to the 1800 MHz band. APT700 FD-LTE performance has a gain in the order of 8-12 dB better than LTE1800 depending upon the demographic. And here again, in-building performance would give an additional 4 dB advantage to 700 MHz compared to 1800 MHz.

Path loss delta (dB), 1800Mhz as reference					
	700MHz	900MHz	1800MHz	2100MHz	2600MHz
Dense Urban	-12.64	-9.79	0	2.26	5.4
Urban	-12.64	-9.79	0	2.26	5.4
Suburban	-10.01	-7.8	0	1.77	4.19
Rural	-8.2	-6.38	0	1.39	3.23

In a deployment with the same coverage requirements and an FDD APT700 overlay on an existing 1800 MHz site grid, this 8-12 dB will give throughput improvement, as well as increase cell and cell edge spectral efficiency, which in turn provides a better mobile broadband customer experience.

Conclusion

By 2020, mobile broadband networks need to deliver up to 1GB/user/day profitably for mobile network operators. One important requirement to achieve this is a ten-fold increase in the amount of spectrum that is available, much of which will come from spectrum bands greater than 1 GHz. The higher bands are very important in increasing the capacity because of greater bandwidth availability and smaller antenna size to support technologies such as MIMO and small cells.

Along with the capacity demands of 1GB/user/day, customers also expect ubiquitous coverage in most indoor and outdoor locations. Mobile operators need to provide this profitably and the spectrum that best achieves this is in bands less than 1 GHz. The lower bands are very important for coverage reasons. The simple example in this paper demonstrates a ten-fold increase in the number of cells required to cover a given outdoor area using LTE2600 compared to LTE700.

Multiband, multilayer solutions are starting to be deployed along with advanced features that can bring the advantages of the high and low bands together. An example is Carrier Aggregation with Band 3 (1800 MHz) and Band 28 (APT700 band), now scheduled for 3GPP Release 11. This will bring together the most prevalent LTE band used today with potentially the most common band of the future – APT700.

This paper has recognized that there is a desire around the world for a harmonized mobile broadband solution. The global footprint of the digital dividend has offered a unique opportunity to achieve that goal with a low band solution that delivers cost efficient indoor and outdoor coverage.

For national and regional reasons, the first realization of the digital dividend produced three variants, FCC700, EU800 and APT700. Subsequently, ITU region 1, which implemented the EU800 band, has indicated that it will also look to adopt the 700 MHz band for mobile broadband use in the future in support of global harmonization.

The APT700 band channel arrangements offer a great many technical advantages that allow a simpler adoption in many circumstances. Of note are the dual duplexer arrangements that deliver several benefits, such as cost effective coverage of the band in the UE. It also offers convenient separation that allows harmonized adoption in countries such as Japan that will only use the top duplexer. The APT700 duplexer split would also deliver benefits in countries that already have EU800, since with a small guard band, EU800 is conveniently adjacent to the APT700 lower duplexer band.

There is significant momentum in the adoption of APT700 around the world. This is matched by the commitment from many countries that are currently unable to adopt APT700 but will study how they can implement it in the future.

It is therefore likely that APT700 will eventually support mobile broadband sessions in more countries around the world than any other spectrum band.

Nokia Solutions and Networks
PO Box 1
FI-02022 Nokia Solutions and Networks
Finland

Visiting address:
Karaportti 3, 02610 Espoo, Finland

Telephone +358 71 400 4000 (Finland)
Telephone +49 89 5159 01 (Germany)