TDD SPECTRUM WHITE PAPER

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Annex A: Document History

Date	Meeting #	Revision Contents	Old	New
2013.06.05	GTI 7th workshop	Draft for discussion		1.0
2013.07.18		Internal review of Spectrum WG	1.0	2.0

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Abstract

To provide information and suggestions for facilitating the efficient utilization and fast deployment of TD-LTE globally, this white paper summarizes the status of TDD spectrum, TDD deployment and product availability. Further, the spectrum related issues in TD-LTE application and network deployment are discussed and the corresponding solutions for the commercial deployment are presented. To facilitate fast development of TD-LTE global deployment, this white paper also proposes some recommendations and suggestions as below for operators/standardization organizations/regulators,

- With the maturity of TD-LTE ecosystem, a fast process of allocation and assignment of TDD spectrum will facilitate the commercial deployment and spectrum utilization;
- Since 1.9GHz/2.3GHz/2.6GHz/3.5GHz/3.7GHz have become the global bands for TDD, full TDD band plan is recommended for the countries/areas where those spectrum has not been planned or allocated;
- Contiguous TDD spectrum allocation in large blocks is beneficial for improved mobile broadband experience and enlarging the global market scale;
- Spectrum exchange and merger of small spectrum blocks among operators is expected to promote the TDD spectrum utilization, e.g. 1.9GHz in EU;

- Since synchronized TDD networks leads to best spectrum utilization and the corresponding solutions are matured, the synchronized operation among multiple TD-LTE network is the most preferred option while the guard band is also applicable to ensure the coexistence of unsynchronized TDD;
- To provide fast and cost effective network deployment, low frequency bands (e.g. L-band and 700MHz) and harmonized allocation should be considered for TDD in future.

As the fast progress in the industrialization and commercial deployment, the latest information will be captured in the later version.

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1 Introduction

1.1 Background

TD-LTE growth is accelerating around the world in terms of operator commitments and commercial launches as well as subscriber numbers. By June 2013, 17 TD-LTE networks were commercially launched in 13 countries with over 3 million commercial users. Many more operators are deploying commercial TD-LTE systems, or are engaged in trials and studies, especially China Mobile are building the world's largest TD-LTE network which will cover over 100 cities in China with over 200,000 base stations and more than 500 million population in 2013.

TD-LTE has already been a mainstream technology supported by a very well established and fast growing ecosystem. It has set up a complete end-to-end industry chain involving widespread participation of global industries and highly matured products including system equipment, chipset, user devices and test instrument. By achieving maximum commonality with LTE FDD and offering comparable performance characteristics, TD-LTE can share global market scale with LTE FDD and speed up the network deployment and commercial launch. According to the GTI Plan & Actions announced in Feb. 2012, over 500,000 TD-LTE base stations will be constructed to cover over 2 billion population by 2014.

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Spectrum always plays a foundation role for mobile communication. Much unpaired spectrum has been allocated as TDD in many countries, which provides spectrum conditions for the coming boom in TD-LTE market. In the 6th GTI workshop on 21-22 February, 2013, the Spectrum Working Group was established which is dedicated to facilitate the efficient utilization of TDD spectrum and TDD deployment by providing optimization solutions for spectrum related issues. It is expected that the spectrum WG will provide spectrum allocation and coordination proposals for regulators/operators/standardization organizations. As a basis, Spectrum WG will develop GTI spectrum white paper which is expected to provide suggestion and reference for TDD spectrum and deployment to TDD operators and facilitate their commercial deployment.

1.2 Benefits of TDD Technology

With increased recognition of its value, TD-LTE has gained wide ecosystem acceptance and backing from leading operators, infrastructure and device vendors. TDD technology presents three advantages as below:

1) <u>Flexible spectrum utilization</u>

TDD spectrum is much easier to release than FDD, which needs to be paired. This benefit is becoming increasingly important as the globally available supply of spectrum falls, meaning the process of releasing new spectrum can be greatly speeded up by designating it as TDD.

What's more, capacity benefits of TDD comes in the size of available TDD spectrum bands often allocated in large blocks. It isn't unusual to see TDD spectrum auctioned off in 30MHz slices, even wider. From a capacity perspective, this is an advantage over the typical 2x10MHz configuration found in FDD spectrum.

2) <u>High spectral efficiency for adaptive UL/DL configuration</u>

The asymmetric nature of TDD brings a number of advantages. One key advantage of TDD's asymmetric nature is the flexibility it allows in the adjustment of the downlink and uplink resource ratios. Commonly employed downlink-to-uplink ratios are 8:1, 3:1, 2:2 and 1:3, and the heavily downlink-oriented configuration fits perfectly with current user behavior, where streaming and downloading take up a high proportion of downlink resources. Cisco previews a dramatic increase of the downlink-centric applications. Based on this prediction, the DL-centric application will generate more than 90% of the mobile traffic in 2017.

Some FDD operators recognize the asymmetrical nature of DL/UL data traffic ratio too and seek to address asymmetrical traffic by aggregating DL only spectrum with paired FDD spectrum. Compared to the simple adaptive TDD frame configuration, this approach relies on highly complicated inter-band carrier aggregation, and the options of supported downlink-to-uplink ratios are constrained by the availability of DL-only spectrum. Clearly, TDD enjoys advantage over FDD to cope with inherent asymmetrical traffic in a simple yet effective manner.

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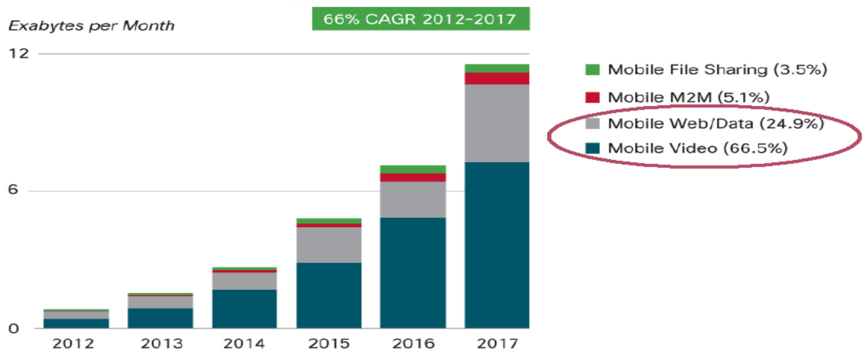

Figure 1-1: Cisco mobile forecast

3) <u>Interference suppression</u>

Thanks to uplink and downlink channel reciprocity (ensured by the fact that the same portion of spectrum is used in both link directions), TDD technology has unique coordination abilities, such as Beamforming, which improves system performance by utilising channel state information to achieve transmit-array gain. FDD requires very high signal overhead to obtain DL channel state information at the eNBs, thus making it difficult to implement Beamforming. Network testing results show that single Layer, dual-Layer and multi-user Beamforming can generate cell throughput gains of 15%, 15% and 10% respectively. Adoption of Beamforming and Coordinated Multi-Points (CoMP), called 'Co-ordinated Beamforming' (CBF), can further enhance network performance because interference is mitigated between inter-eNodeBs.

1.3 Objectives of this white paper

The objective of this white paper is to provide information and suggestions to facilitate the TDD spectrum utilization and network deployment. It will include the aspects as listed below:

- To summarize the latest status of TDD spectrum in the world and the progress of TDD commercial deployment and industrialization
- To identify the existing issues and challenges on TDD spectrum and the corresponding network deployment
- To provide the possible solutions to facilitate TDD spectrum utilization
- To form some recommendations and proposals about TDD spectrum utilization for operators/standardization organizations/regulators.

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1.4 Terminology

Term	Description
BWA	Broadband Wireless Access
CA	Carrier Aggregation
CDMA	Code Division Multiple Access
CoMP	Coordinated Multi-Point
CSPC	Coordinative schedule Power Control
DCMS	Department for Culture, Media and Sport
eICIC	Enhanced Inter-cell Interference Coordination
GSM	Global System for Mobile Communications
LSA	Licensed Shared Access

LTE FDD	Long Term Evolution Frequency-Division Duplexing
MBB	Mobile broadband
MIIT	Ministry of Industry and Information Technology of China
MoD	Ministry of Defence
NBTC	National Broadcasting and Telecommunications Commission
NPRM	Notice of Proposed Rulemaking
NTIA	National Regulatory Authority
PCT	Protocol Conformance Testing
PHS	Personal Handy-phone System
PMSE	Programme-Making and Special Events
RCT	RF conformance testing system
RRM	Radio resource management
TD-LTE	Time Division Long Term Evolution
TD-SCDMA	Time Division-Synchronous Code Division Multiple Access
WCDMA	Wideband Code Division Multiple Access
WCS	Wireless Communication Service
WGFM	Working Group for Frequency Management
WiMAX	Worldwide Interoperability for Microwave Access

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2 TDD Spectrum in the world

This section describes the latest status of TDD spectrum in the world and discusses its trends in next 5 years.

2.1 Overall of TDD spectrum

1) <u>Global situation of TDD spectrum issuing</u>

To date, more than 120 countries and regions in the world have issued TDD spectrum with 600 TDD licenses released, covering over 80% of the global population. According to statistics, currently more than 74 operators among global 150 leading ones have obtained TDD licenses.

With the maturity of TDD ecosystem and the decreasing of available FDD spectrum, the global leading operators tend to pay more attentions on TDD spectrum resource and be more active in the auction of TDD spectrum. Thus, the sustained growth of TDD licenses will provide substantial foundation for global TDD development.

2) TDD spectrum bands

Currently there are at least 12 bands identified for TDD in the world (see Table 2-1), though most available spectrum is concentrated at or around the 1.9GHz/2.0GHz, 2.3GHz, 2.6GHz, 3.5GHz and 3.7GHz bands. The major countries and regions focus on frequency bands for TD-LTE (see Table 2-2).

Table 2-1: Bands accepted as standardized by the 3GPP for TDD

3GPP band	Frequencies (MHz)	Bandwidth (MHz)
Band 33	1900–1920	20
Band 34	2010–2025	15
Band 35	1850–1910	60
Band 36	1930–1990	60
Band 37	1910–1930	20
Band 38	2570–2620	50
Band 39	1880–1920	40
Band 40	2300–2400	100
Band 41	2496–2690	194
Band 42	3400–3600	200
Band 43	3600–3800	200
Band 44	703–803	100

Table 2-2: TDD bands in major countries and regions

Frequency	Region
1.9GHz/2.0GHz	Australia, China, Europe, Japan, Russia, South Africa, South Asia
2.3GHz	Africa, Canada, China, India, Latin America, Russia, South Korea, South Asia, The Middle East
2.6GHz	Africa, Brazil, China, Europe, Japan, India, Latin America, North

	America, Saudi Arabia
3.5GHz/3.7GHz	Australia, Europe, Latin America, North America, Russia

The TDD spectrum shows imbalance in the three ITU regions as below. Thus, similar to FDD, TD-LTE has to perform global roaming on multiple bands.

- **Region 1**: Band 33 (1900-1920MHz), Band 34 (2010-2025MHz), Band 38 (2570-2620MHz), Band 42 (3400-3600MHz) and Band 43 (3600-3800MHz)
- **Region 2**: Band 41 (2496-2690MHz), Band 42 (3400-3600MHz) and Band 43 (3600-3800MHz)
- **Region 3**: Band 34 (2010-2025MHz), Band 39 (1880-1920MHz), Band 40 (2300-2400MHz), Band 38 (2570-2620MHz), Band 41 (2496-2690MHz), Band 42 (3400-3600MHz) and Band 43 (3600-3800MHz)

Figure 2-1: ITU Regions Map

While FDD has a large amount of low and medium frequency spectra, TD-LTE is short of low and medium frequency spectra which are suitable for wide coverage. Table 2-3 analyses the band characteristics of major TDD bands, which are adapted to the different applications and scenarios. Thus, bands 1.9GHz/2.0GHz/2.3GHz/2.6GHz can be used for coverage or capacity, and 3.5GHz/3.7GHz are more applicable for small cell to offload traffic in indoor and hotspot while some operators also consider for coverage.

Table 2-3: Characteristics of major TDD bands

TDD Band	Allocation	Characteristics
1.9GHz/2.0GHz	Region 1 and region 3	Small bandwidth (15MHz~20MHz) with low propagation loss and penetration loss
2.3GHz	Ongoing discussion in region 1, Wireless Communication Service (WCS) in region 2, IMT in region 3	Large bandwidth (100MHz) with relatively low propagation loss and penetration loss
2.6GHz	Relatively small bandwidth (Band 38: 50MHz) in EU and large bandwidth (Band 41: 194MHz) in US and (Band 41: 190MHz) in China	Relatively high propagation loss and penetration loss
3.5GHz/3.7GHz	Ongoing discussion in 3 regions, and some countries have identified 3.4~3.6GHz and 3.6~3.8GHz for IMT	Very large bandwidth, relatively high propagation loss and penetration loss

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2.2 Allocated TDD spectrum[1]

2.2.1 Region 1 (mainly Europe, Middle East and Africa)

1) 1.9GHz/2.0GHz

In ***EU***, on the one side, some of 1900-1920MHz (Band 33) and 2010-2025MHz (Band 34) are currently allocated to TDD networks and the total number of 1.9GHz/2.0GHz licenses allocated by TDD or neutral mode surpasses 100. On the other side, most of the spectrum remains unused throughout the EU for the fragmented allocation. The European Commission has already issued a Mandate to CEPT to study suitable alternative applications and develop appropriate technical conditions and sharing arrangements.

A few countries in ***Africa***, such as Kenya and Zimbabwe, issue 1.9GHz spectrum but it is unused. In ***South Africa***, it is noted in the National Frequency Allocation table that, while the 1900-1920MHz (Band 33) is currently used for FWA, it could be used for IMT.

[1] Some information and data from GSA Evolution to LTE report, 2013/05/13

2) 2.3GHz

2.3GHz (Band 40) is a 100MHz block of unpaired spectrum from 2300 to 2400MHz, which was identified for IMT at the World Radiocommunication Conference 2007 (WRC-07). It is a major unpaired frequency band identified for IMT on a worldwide basis.

In many ***European*** countries the 2.3GHz band is shared with military organizations. Furthermore, in the CEPT region 27 countries use parts of the band for programme-making and special events (PMSE) applications. However, there is a strong desire from mobile operators and policymakers to reallocate the spectrum for mobile broadband services. CEPT will create a project group within the Working Group for Frequency Management (WGFM) to discuss the 2.3GHz band. This group will ultimately provide guidance to national authorities on harmonisation of the band and which regulatory framework is appropriate for the band. Currently, a concept called LSA (licensed shared access) is hot issue in the discussion in possible usage ways for this band. This concept envisions dynamic use of spectrum in times and places where it is not used by the incumbent. This would be on a shared and non-interference basis and would require the license holder to authorize the secondary user via a secondary license agreement.

Table 2-4: Current spectrum usage in the 2300–2400MHz band in the EU

Sector	Allocation
Aeronautical/maritime	2300–2400MHz
Defence systems	2310–2450MHz
Mobile systems	2290–2400MHz
PMSE	2300–2400MHz

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In ***Denmark***, the national regulatory authority (NTIA) published a public consultation document in May 2011 entitled "A strategy to find an extra 600MHz for broadband" in which it suggested that the 2300MHz spectrum band would be available to mobile operators by 2015.

In ***Sweden***, the regulator is considering an auction of licenses in the 2.3GHz band to meet a policy target of releasing up to 500MHz of spectrum before 2020. Two consultations have already taken place and an auction may take place in 2013. What's more, it's reported that a 2.3GHz TDD trial network will be available in mid 2013.

In ***UK***, the 2.3GHz band was described as a "prioritized band for release" in the spectrum strategy document issued by the Department for Culture, Media and Sport (DCMS) in March

2011. The Ministry of Defence (MoD) currently occupies 90MHz in the 2.3GHz band (2310–2400MHz) and plans to auction the spectrum in 2014.

In ***Russia***, the deployment of TDD in this band is already permitted. Base Telecom, OAO Voentelecom and Rostelecom have been reported to be interested in deploying TDD networks in this Band 40.

In ***South Africa***, the operator Telkom Mobile (formerly 8ta) has 70 MHz of 2.3 GHz TDD spectrum (band 40). A free user trial ran in Guateng from November 1, 2012 to March 31, 2013. TD-LTE service was commercially launched alongside new data tariffs on April 21, 2013.

3) 2.6GHz

There are two bands embracing 2.6GHz. Most of regions and countries in the world (USA, India, Saudi Arabia, China and so forth) have adopted Band 41 with total 194MHz (2496-2690MHz). Another is Band 38, a 50MHz block of unpaired spectrum in the band 2570-2620MHz. Earlier allocation for this band is WiMAX, but now the band has been already allocated to LTE application. Many operators hold the spectrum more than 20MHz in this band.

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In ***Sweden***, Hutchison 3 is deploying an LTE FDD network and also using 50 MHz of 2.6G TDD spectrum bought from Intel. Network technical readiness was announced by its infrastructure vendor on December 15, 2011. Commercial TD-LTE service was launched on April 23, 2012, including areas in Stockholm, Gothenburg, Malmo and Lund.

In ***Germany***, E-Plus has completed TD-LTE trials in 2.6 GHz.

In ***Poland***, In November 2009 Aero2, a member of the Global TD-LTE Initiative, acquired 50 MHz in Band 38 for TD-LTE. After testing in Aleksandrów Łódzki and Łódź, Aero2 announced launch of their TD-LTE network in May 2011 and start of availability of their dual LTE network, since Aero2 had already deployed an LTE FDD network in 1800MHz as stated above.

In ***Finland***, WiMAX operator Datame is preparing to introduce TD-LTE using 2.6G spectrum.

In ***Belgium***, the new entrant operator BUCD (backed by Asian investors) won 45MHz of 2.6GHz TDD spectrum, and is planning to deploy commercial TD-LTE network.

In ***Russia***, on February 2, 2012, the operator MTS announced the company had been awarded the first license to provide LTE services in Moscow and the Moscow region. The license granted is for TD-LTE deployment in the 2595 – 2620 MHz range (in band 38) and is valid until December 29, 2016. MTS announced commercial launch of its TD-LTE service (replacing its WiMAX service) on September 1, 2012 initially covering most of Moscow and 40 population in the surrounding Moscow region. The operator Megafon acquired WiMAX operator Synterra in 2010, and commercially launched TD-LTE using 2.6 GHz (band 38) spectrum in Moscow on September 1, 2012.

In ***UK***, BT and Vodafone were each assigned unpaired 2.6GHz spectrum in the auction held in 2013 that is suitable for TD-LTE technology.

In ***Nigeria***, Zoda Fones is deploying a commercial TD-LTE network in 2.6 GHz (band 38).

In ***South Africa***, it’s a great possibility that the entire 190 MHz of spectrum in the 2500-2690MHz is allocated for TD-LTE deployments.

4) 3.5GHz/3.7GHz

In ***Europe***, the band 3400-3600 MHz is used primarily for FWA deployments, and this band has numerous country-specific frequency arrangements. To facilitate the introduction of mobile and fixed communications networks, the Electronic Communications Committee of the European Conference of Postal and Telecommunications Administrations has adopted harmonized frequency-division duplexing (FDD) and TDD frequency arrangements for the band 3400-3600 MHz, and one TDD frequency arrangement for the band 3600-3800MHz in ECC Decision (11)06 in December 2012. It should be noted that 3400-3600 MHz should be subject to review no later than end 2013 with the aim to identify a preferred frequency arrangement.

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More details about utilization in European countries can be found below based the feedback to ECC PT1 in 2010.

Table 2-5 3400-3600MHz status in EU

Country	Uplink frequency range [MHz]		Downlink Frequency range [MHz]		Duplex arrangement	Duplex separation for FDD	Block sizes [MHz]
Belgium	3450	3500	3550	3600	FDD, TDD	100 MHz	25
Bosnia, Herzegovina	3410	3494	3510	3594	FDD	100 MHz	21
Czech Republic	3410	3480	3510	3580	FDD, TDD	100 MHz	3.5 (raster)
France	3432.5	3495	3532.5	3595	FDD, TDD	100 MHz	15
Germany	3410	3494	3510	3594	FDD, TDD	100 MHz	21
Hungary	3410	3494	3510	3594	FDD, TDD	100 MHz	14
Ireland	3410	3500	3510	3600	FDD, TDD	100 MHz	11, 25, 35

Italy	3425	3500	3525	3600	FDD, TDD	100 MHz	21
Macedonia	3410	3494	3510	3594	FDD, TDD	100 MHz	31.5, 14
Norway	3413.5	3500	3513.5	3600	FDD, TDD	100 MHz	3.5 (raster)
Portugal	3410	3438	3510	3538	FDD, TDD	100 MHz	28
Russian Federation	3400	3450	3500	3550	FDD, TDD	100 MHz	
Sweden	3410	3494	3510	3594	FDD, TDD	100 MHz	28
Switzerland	3410	3497.5	3510	3597.5	FDD, TDD	100 MHz	17.5, 21, 28
United Kingdom	3480	3500	3580	3600	FDD, TDD	100 MHz	20

(Some general commonalities:

1) FDD arrangements are possible in all listed countries, TDD arrangements in all but two (Bosnia & Herzegovina);

2) For FDD arrangements, the duplex separation is consistently 100 MHz;

3) Block sizes generally larger than 14 MHz;

4) For many countries, the frequency range 3400-3410 MHz is designated as a "guard band" (only one country has frequency blocks below 3410 MHz);

5) Most countries have frequency ranges ending at 3494 (and 3594) MHz, a few have the whole range up to 3600 MHz designated.)

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In ***Croatia***, Velatel (Novi-net) holds 42 MHz spectrum in 3.5 GHz and is deploying an TD-LTE network since Q2 2012.

In ***France***, WiMAX operator Bollore Telecom plans to introduce TD-LTE system in band 42 (3.5 GHz) and is a member of the Global TD-LTE Initiative.

In ***Belgium***, b•lite Telecom BVBA (ex- Clearwire Belgium) plans to launch a 3.5 GHz TD-LTE system (band 42).

In ***UK***, 3.5GHz and 3.7GHz bands have been licensed in the same way – both are technology and service neutral. The operator UK Broadband is rolling out TD-LTE network on both Band 42 and 43 to provide mobile and fixed services.

In ***Ireland***, Imagine Group has about 220 MHz of 3.5 GHz spectrum (bands 42, 43) in all strategic parts of the country and is currently operating a WiMAX 802.16e network nationally. The company has its intention to upgrade this network to TD-LTE in 2013 and is currently conducting trials of LTE. Imagine is a member of the Global TD-LTE Initiative.

In ***Russia***, the operator TransTeleCom has licenses for the deployment of WiMAX in 25 cities, but the operator plans to eventually migrate to LTE. Moreover, the operator Smoltelecom is planning to introduce TD-LTE on the 3.5G band and is a member of the Global TD-LTE Initiative.

2.2.2 Region 2 (North and South America)

1) <u>2.3GHz</u>

In ***US***, the band was assigned to WCS service in 1997. Now part of the band is planned to be used as mobile service.

In ***Costa Rica***, ***El Salvador***, ***Guatemala and Nicaragua***, Pan Latin American WiMAX operator IBW International is planning to migrate its operations to 2.3 GHz TD-LTE technology.

2) <u>2.6GHz</u>

In ***USA***, Clearwire Corp. controls the majority of 194 MHz spectrum in 2496-2690MHz (Band 41) which TD-LTE trials have been carried out since August 2011 in Phoenix, Arizona. Clearwire intends to have its first wave of TD-LTE deployed by end of 2013. .

In ***Canada***, the 2600 MHz band is facilitated by Inukshuk Wireless and SaskTel. Inukshuk Wireless, the partnership company of Rogers and Bell, built a network using pre-WiMAX technology but was later shelved, and now is studying the use for TD-LTE technology. SaskTel has awarded a trial contract using TD-LTE in this band to help determine the feasibility of wireless broadband and voice services for customers in predominantly rural locations. The trial is being conducted in rural locations in Saskatchewan and runs from December 2012 until August 2013.

In ***Brazil***, this spectrum (Band 38) is used by SKY Brasil Services and On Telecomunicacoesin their LTE networks, which respectively was commercially launched in December 2011 and in March 2013. SKY had previously used this spectrum for MMDS, but now uses it for TDD to compete with its rivals that are able to offer triple-play packages including broadband. The operator On expands its commercial TD-LTE footprints in Itatiba, Louveira, Valinhos and Vinhedo, and will serve as a test bed for possible expansion to all of Sao Paulo state in the future.

In ***Puerto Rico***, the operator Aeronet Wireless Broadband is deploying a TD-LTE network for backbone and customer access using leased 2.6 GHz spectrum.

3) <u>3.5GHz/3.7GHz</u>

In the ***United States***, the radiolocation service operates in the band 3400-3650MHz. The fixed and mobile services operate in the band 3650-3700 MHz, which is used for the deployment of terrestrial wireless broadband applications. As part of the National Broadband Plan, the band

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3550-3650 MHz is under review for a potential reallocation that would allow for the introduction of wireless broadband applications. This reallocation may be subject to large geographic limitations (known as exclusion zones) along the coasts and near specific military sites, owing to the presence of high-power government radar systems. In December 2012 the FCC issued a Notice of Proposed Rulemaking (NPRM) to allow operators to deploy small cells in the band on a shared basis. If the proposals are accepted, the band will become known as the citizens' broadband service band. The NPRM proposes three categories of spectrum users for the band: Incumbent users, Protected access users and General authorized access users. At the time of this document's publication, the FCC had not made a decision on this band.

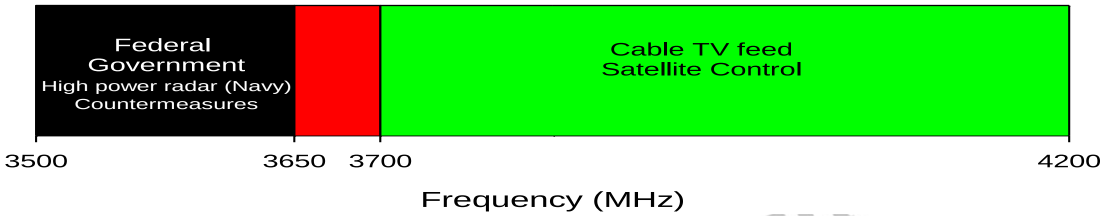

Figure 2-2 3.5G status in United States

In ***Canada***, between 2004 and 2009, Industry Canada auctioned the FWA Blocks D, E, F and G in the band 3475-3650MHz. The 175 MHz of spectrum was auctioned in three paired 25 + 25 MHz blocks (D and H; E and J; F and K) and one stand-alone 25 MHz block (G). As identified in the Canadian Table of Frequency Allocations, the services (radiolocation, mobile, fixed and fixed satellite) have primary allocations or co-primary allocations, or both, in various sub-ranges of the band 3400-3800MHz. The mobile service only has a co-primary allocation in the band 3650-3700MHz. The band 3475-3650 MHz was licensed for fixed wireless access by auction. The band 3400-3450 MHz is allocated to radiolocation for the exclusive use of the Government of Canada. Rural WiMAX operator Xplornet Communications announced on December 8, 2011 completion of TD-LTE tests in 3.5 GHz band. The trials demonstrated a seamless TD-LTE option over existing WiMAX infrastructure, offering a smooth migration path from WiMAX to TD-LTE. The current network has 380 tower sites (early 2013).

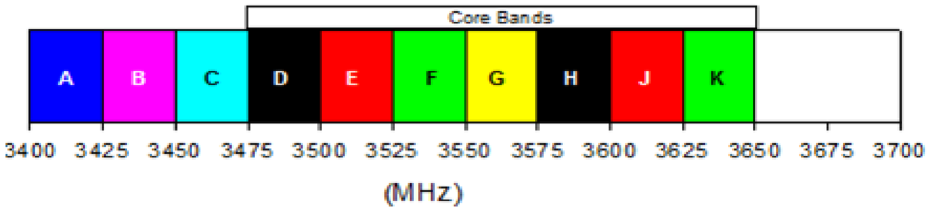

Figure 2-3 3.5G spectrum blocks in Canada

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In ***Latin America***, 3400-3600MHz already has been licensed for fixed wireless access in some countries with technology neutrality. In ***Argentina***, ***Mexico*** and ***Peru***, the band 3400-3600MHz is allocated based on blocks of 25MHz.

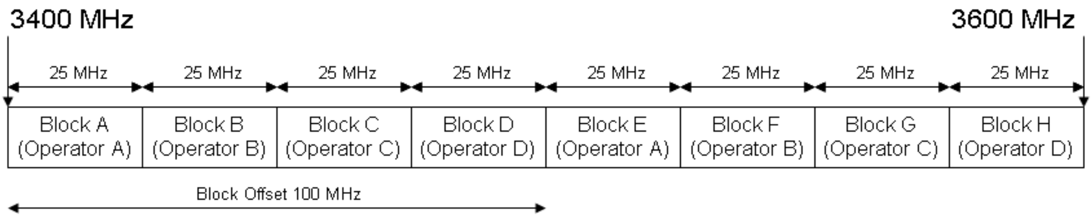

Figure 2-4 3.5G spectrum blocks in Argentina, Mexico and Peru

In ***Argentina,*** Direct TV is rolling out TD-LTE in band 43 and plan to cover Cordoba and then capital and other cities.

In ***Chile***, Wireless internet service provider Entel Chile has begun conducting trials of LTE using 100MHz of spectrum in the 3400–3600MHz range.

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2.2.3 Region 3 (mainly Asia and Australia)

1) 1.9GHz/2.0GHz

From the technology point, in band 1.9GHz/2.0GHz 3G TDD (TD-SCDMA) was deployed only in China. In other bands TD-LTE is the only choice.

Spectrum of 1880-1920MHz is allocated as Band 39 for TD-LTE in ***China***. However, 1900-1920MHz within this band is currently occupied by PHS in China. Up to Oct. 2012, there are still over 13 million subscribers in the PHS network. Ministry of Industry and Information Technology of China (MIIT) has confirmed that the spectrum shall be cleaned up for deployment of TD-LTE and announced in Sep. 2012 that the TD-LTE license will be issued in about one year. This band will play an important role for TD-LTE development in China. At present, there are at least three cities (Hangzhou, Guangzhou and Shenzhen) entering pre-commercial TDD stage. China Mobile disclosed that it will invest $6.7 billion, part of a much larger $30 billion CAPEX budget outlined by China Mobile for 2013, in rolling out TDD in 2013. This investment will look forward to ending 2013 with more than 200,000 TDD base stations in nearly 100 cities, up from the 20,000 base stations it had deployed by the end of 2012.

In ***Japan***, Softbank occupies more than 20 MHz of 1880-1920MHz, used for Personal Handy-phone System (PHS).

In ***Australia***, 1900-1920MHz is licensed to UMTS TDD and Optus, Telstra and Vodafone have part of the band.

2) 2.3GHz

Portions of the 2.3GHz range have been awarded for broadband wireless access (that is, WiMAX) in many countries in Asia. Consequently, TDD is expected to be deployed in this band in a number of APAC countries as operators migrate away from WiMAX.

In ***China***, because of earlier military application, the band was only used in indoor scenario before. MIIT in China formally announced that 2.3GHz can be used for outdoor scenario after permission in Sep. 2012.

In ***Australia***, NBN is operating a TDD network on the 2300MHz band to provide a next-generation service to serve rural Australia with download speeds of up to 12 Mbps and upload speeds reaching 1 Mbps, ensuring a significant improvement on existing services. The operator Optus has opened its trial network for TD-LTE at the Optus Campus in Macquarie Park and St Marys in western Sydney, using the 2.3GHz spectrum it acquired from Vivid Wireless.

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In ***Hong Kong***, the operators China Mobile Hong Kong (CMHK), H3G and 21Vianet each won 30MHz Band 40 spectrum licenses in an auction in February 2012. In Dec 18, 2012, CMHK launched TD-LTE/LTE FDD converged network that brought CMHK customers a seamless 4G experience and peace of mind for international roaming when travelling between Hong Kong and China.

In ***India***, Bharti Airtel launched a TDD network on the 2.3GHz in April 2012. Another operator Reliance also plans to deploy 2.3GHz TDD networks. This operator is notable because it has more than 150 million subscribers, and it shelved plans made in July 2010 to deploy a WiMAX network in Band 40 in favour of TDD. The operator Aircel won BWA spectrum in eight circles and plans to commercially launch TD-LTE service in 2013, initially in Chennai and Tamilnadu. The operator Reliance Industries Ltd (RIL) is deploying a TD-LTE network for commercial launch in 2013 and plans to trial VoLTE.

In ***Saudi Arabia***, the operator STC commercially launched TD-LTE service in Riyadh and Dammam on September 14, 2011 in band 40 (2.3 GHz).

In ***Oman***, the operator Omantel launched commercial TD-LTE service on July 16, 2012 in band 40 (2.3 GHz). The operator Nawras showcased LTE in March 2012 and began deploying a 2.3 GHz TD-LTE network.

In ***Thailand***, the state-owned operator TOT has requested permission from the National Broadcasting and Telecommunications Commission (NBTC) to allow it deploy a wholesale LTE 4G mobile broadband network using 64MHz of its existing 98MHz 2.3GHz spectrum.

In ***Indonesia***, PT Indosat Mega Media (IM2), subsidiary of PT Indosat Tbk (ISAT), selected TD-LTE technology in 2.3 GHz (2360 – 2400) spectrum won in an auction for a BWA license in 2009, planning commercial service in 2013. There are two other WiMAX Operators namely PT Berca Gloabl Access and Sitra of PT First Media have similar TDD spectrum could be planning to deploy TD-LTE. What's more, the regulator SDPPI is consulting on the use of 2300 – 2360 MHz spectrum (part of Band 40) for BWA services, which could lead to licences being awarded.

In ***Philippines***, the operator Smart is conducting TD-LTE technology trials in the 2330 – 2360 MHz spectrum.

In ***Malaysia***, WiMAX operator Packet One Networks P1 (Malaysia) is upgrading its 2.3 GHz network with an TD-LTE overlay. P1 says it will focus on TD-LTE from 2013. P1 base stations are dual-mode WiMAX and TD-LTE capable and by end 2012 had 2,000 WiMAX sites, 50% are TD-LTE ready. P1 expects to have 4,000–5,000 TD-LTE sites by 2015. P1 and YTLC each has 30MHz in Band 40 and 20MHz in Band 38.

In ***Singapore***, For the 2.3 GHz band, 50 MHz was allocated and can be used for deployment of TD-LTE.

In ***Nepal***, Nepal Telecom is deploying a 2.3 GHz TD-LTE network following spectrum assignment in 2011. Deployment is scheduled to be completed within 1 year of contract sign date (announced Feb 2012). At completion, 58 municipalities and all 3,915 VDCs will be connected (a VDC is the lower administrative part of its local development ministry).
In ***Sri Lanka***, Dialog Axiata commercially launched a TD-LTE network in 2.3 GHz (band 40) on December 30, 2012 in Colombo.

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3) 2.6GHz

In the TDD Technology and Spectrum Workshop at ITU Telecom World 2012 in Dubai on October 14th, 2012, ***China***'s Ministry of Industry and Information Technology announced that the entire 190 MHz of spectrum in the 2.5/2.6 GHz band will be allocated for TDD deployments in China. Such an announcement at the most authoritative meeting offered great confidence in the development of TDD to the global industry and market, and helped point out the way for other nations that were going to plan and allocate frequency resources of mobile broadband in the near future. Currently, China Mobile holds the band 2570-2520MHz for LTE-TDD trial network. It can be estimated that existing status will be maintained in future and more than one operator may also come in and hold some of the band.

In ***Japan***, Softbank Mobile commercially launched XGP/TD-LTE services on February 24, 2012 via its affiliated company Wireless City Planning which followed a pre-commercial pilot service starting on November 1, 2011 and which owns the operating license. The coverage area includes Sapporo, Saitama, Chiba, Tokyo, Yokohama, Kawasaki, Nagoya, Osaka, Kobe, Fukuoka, Fukuoka City, Kitakyushu City and covers 30 cities. The first device offered was the "ULTRA WiFi 4G SoftBank 101SI" portable router. A smartphone was introduced in October 2012. The network is deployed in 20 MHz of 2.5 GHz spectrum (band 41) bought from Willcom (PHS operator) and had 1,216,800 subscribers and nearly 30,000 eNodeBs deployed by April 2013.

In ***Saudi Arabia***, Etisalat (Mobily) commercially launched TD-LTE on September 14, 2011 via its Bayanat subsidiary, in Najran, Jazan, Al Kharj, Ras tanoura, Algurayat and Aldudam in band 38 (2.6 GHz). After 2 weeks the service had been extended to 31 cities. As of Aprial 2013, the TD-LTE subscribers reached to 1,500,000.

In ***India***, BSNL had acquired BWA spectrum licenses in the 2.6 GHz band in 22 circles for $1.6 billion. BSNL and MTNL are studying introducing TD-LTE possibly in addition to current WiMAX deployments.

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4) 3.5GHz/3.7GHz

In ***China***, the C-band has been extended to the lower bands, which has lead to satellite transponders now working in the band of 3.4~3.7 GHz. Two parts of this band, 3400-3430/3500-3530 MHz, are used for fixed wireless access services. 3600-4200 MHz band is used for microwave links. China is studying and researching the TD-LTE small cell enhancement at 3.5GHz band. One project founded by the government is being performed to validate the field performance of TD-LTE small cell enhancement in 3.5GHz.

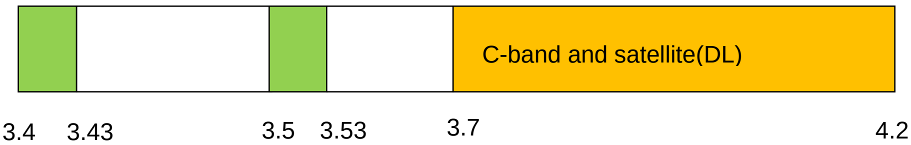

Figure 2-5 3.5G status in China

In ***Japan***, the 3400–3600MHz band is used for the fixed and fixed-satellite services, amongst other uses. The Ministry of Internal Affairs and Communications is studying the technical issues associated with sharing and co-existence between LTE and those usages in the 3.5GHz band, with its plan to allocate 3400-3600MHz to LTE for the commercial services from 2015. Softbank is performing TD-LTE-Advanced trial with 3.5GHz in Tokyo.

In ***Korea***, the band 3400-3500MHz is used for the radiolocation service, and the band 3500-3600MHz is reserved for the mobile services. The band 3400-3600MHz is the candidate band to be used as mobile service under the national broadband plan, called “Mobile Gwangaeto Plan” announced in 2011.

In ***Australia***, the band 3400-3600MHz is used for radiolocation and fixed services. In the sub-bands 3425-3492.5MHz and 3542.5-3575MHz long terms (15 years) technology-neutral licenses have been issued in capital cities and regional areas only and are mainly used to provide fixed/broadband wireless access services. The 3600-4200MHz band is used for fixed point-to-point link services and C-band satellite downlink services. The extended C-Band, i.e. below 3700 MHz, is less extensively used for downlink services in Australia.

In ***New Zealand***, the band 3400–3600MHz is allocated predominantly to the fixed and radiolocation services and is managed under a property rights based spectrum management regime and utilized for fixed wireless access applications. The band 3600–4200MHz is allocated to the fixed and fixed-satellite services and utilized for coordinated fixed links and C-band satellite applications.

In ***Bahrain***, WiMAX operator Menatelecom is deploying a nationwide 3.5 GHz TD-LTE network, targeting commercial service by June or July 2013.

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2.3 TDD license plan and future spectrum

The number of LTE frequency bands was increased significantly in last several years with the progress of ITU’s LTE spectrum planning. Overall, among newly increased mobile broadband spectrum around the world, TDD spectrum resources are getting adequate. However, on the whole, an obvious gap still exists between TDD and FDD, and the shortage of low TDD spectra is also considerable.

However, a tremendous amount of TDD spectrum in the core 1.9GHz, 2.3GHz, 2.6GHz and 3.5GHz bands are expected to become available over the next few years. The new TDD licenses in a number of countries in Europe, Asia Pacific, Africa and North America, will potentially create even greater global synergies for the TDD industry (see Table 2-6).

Table 2-6 Expected TDD-spectrum licensing activity (2013-2015)

Country/District	Band	Low frequency	High frequency	Bandwidth/MHz
China	2.6G	2500	2690	190
Japan	3.5G	3400	3600	200

	2.6G	2625	2655	30
	2.6G	2545	2555	10
Europe	3.5G	3400	3600	200
Nigeria	2.3G	2360	2400	40
South Africa	2.6G	2565	2690	125
Thailand	2.3G	2306	2370	64
Indonesia	2.3G	2300	2360	60
Czech Republic	2.6G	2570	2620	50
Sweden	2.3G	2300	2400	100
United Kingdom	2.3G	2350	2390	40
	3.5G	3400	3600	200
Philippines	3.5G	*unknown*	*unknown*	*unknown*
Singapore	2.3G	2300	2340	30
	2.6G	2570	2620	30
United States	3.5G	3550	3700	150
Canada	3.5G	3475	3650	175
	2.3G	2305	2320	15
	2.3G	2345	2360	15
South Korea	2.3G	2360	2390	30
Italy	2.3G	2300	2400	100
France	2.6G	2570	2620	50
Germany	2.3G	2300	2400	100
Portugal	2.3G	2300	2400	100
Spain	2.3G	2300	2400	100
Ireland	2.3G	2300	2400	100
Norway	2.3G	2300	2400	100
Mexico	2.6G	2500	2690	190

Under the agenda item 1.1 of WRC-2015, it is estimated that 900MHz to 1200MHz of new spectrum is required to meet the growing demands of mobile broadband services over the next decade. TDD spectrum promises to make a major contribution, such as L band, TDD part of 700MHz spectrum and 400MHz-700MHz which are expected to compensate low band to TDD, and 3400MHz-3800MHz as well as the part above 3.8GHz which are proper for hotspot scenarios. Not only is it in plentiful supply in most of the world's major regions, it is also concentrated in a relatively small number of key bands, providing a high degree of synergy, and its asymmetric properties are attractive for a range of mobile broadband services.

3 TDD commercial deployment

This section describes the situation of TDD spectrum utilization in the world, especially the TDD commercial deployments, and analyzes the trend derived from market development.

3.1 TDD commercial deployment status

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Since the world's first commercial TD-LTE network was launched by Mobily of Saudi Arabian in September 2011, a total of 17 TD-LTE networks are commercially launched successively by June 2013 (see Table 3-1).

Table 3-1 Commercial launched TD-LTE networks (2013/06)

Country	Operator	TDD frequency	TDD band
Australia	NBN Co.	2.3 GHz	40
	Optus	2.3 GHz	40
Brazil	On Telecomunicacoes	2.6 GHz	38
	Sky Brasil Services	2.6 GHz	38
Hong Kong	China Mobile Hong Kong	2.3 GHz	40
India	Bharti Airtel	2.3 GHz	40
Japan	Softbank	2.6 GHz	41
Oman	Omantel	2.3 GHz	40
Poland	Aero2	2.6 GHz	38
Russia	Megafon	2.6 GHz	38
	MTS	2.6 GHz	38
Saudi Arabia	Mobily	2.6 GHz	38
	STC	2.3 GHz	40

South Africa	Telkom Mobile (8ta)	2.3 GHz	40
Sri Lanka	Dialog Axiata	2.3 GHz	40
Sweden	3 Sweden	2.6 GHz	38
UK	UK Broadband	3.5 GHz	42, 43

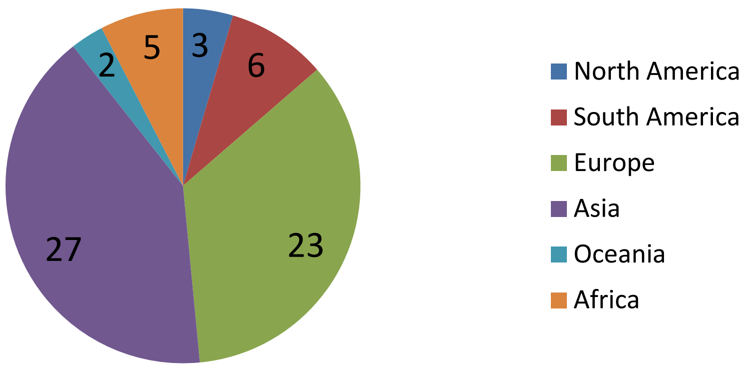
(Source: GTI, June 07, 2013.)

Besides the commercial networks, 30 operators have publicly announced 47 TD-LTE commercial contracts (see Table 3-2 for some information), and many other operators are engaged in TD-LTE trials and studies. It is reported that 66 Trial Networks have been deployed in the world (see Figure 3-1).

Table 3-2 38 TD-LTE commercial networks in deployment or planned (2013/05)

Country	Operator	Band	Country	Operator	Band
Australia	Optus	40 (Launched in June)	Ireland	Imagine Group	42, 43
Bahrain	Menatelecom	42	Italy	AFT-Linkem	42, 43
Belgium	b-lite	42	Madagascar	Blueline	40
Belgium	BUCD	38	Malaysia	Asiaspace	40
China	China Mobile	Various	Malaysia	P1	40
Costa Rica	IBW Intl	40	Montenegro	Velatel	42
Croatia	Velatel	42	Nepal	Nepal Telecom	40
Denmark	3 Denmark	38	Nicaragua	IBW Intl	40
El Salvador	IBW Intl	40	Nigeria	Zoda Fones	38
Finland	Datame	38	Poland	Milmex	42
France	Bollore	42	Puerto Rico	Aeronet	38
Germany	DBD	42	Romania	2K Telecom	38
Guatemala	IBW Intl	40	Russia	Osnova Tel.	40
Hong Kong	3 HK	40	Russia	Rostelecom	40
India	Aircel	40	Russia	Smoltelecom	42
India	RIL	40	Russia	Vainakh	40
India	Tikona Digital	40	Spain	COTA	38
Indonesia	IM2	40	UK	NSV (BT)	38
Iraq	MaxyTel	*To be confirmed*	USA	Clearwire	41

(Source: GSA, Status of the Global LTE TDD Market, May 21, 2013.)



(Source: GTI TD-LTE Industry Briefing April 2013.)

Figure 3-1 TD-LTE trial in the world

3.2 TD-LTE deployment trend

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Although the TD-LTE's commercial launches only accounts for a small proportion of the whole LTE market[2] in current stage, there is no doubt that TD-LTE is gaining market traction globally. It can be foreseen that the TD-LTE will lead a fast growing market and energize the whole mobile broadband market with strong driving force. It could be observed from several aspects as below,

1) **The global deployment of TD-LTE network is already appeared which will grow fast in coming years.**

Even only considering the commercial launches, the scale of TD-LTE commercial networks and user base has been enlarged to a large extent (see Table 3-3). TD-LTE commercial users had over 3 million by May 2013. Furthermore, the capability of global roaming has also been proven, it can be concluded that a TD-LTE global deployment is primarily formed (see Figure3-2).

Table 3-3 Progress of some commercial launched TD-LTE networks

Country/area	Operator	Band	Launch	Comments

[2] It is reported that 175 LTE operators have commercially launched services in 7 countries (GSA, Evolution to LTE report, May 13, 2013).

			date	
Australia	Optus	2.3 GHz TDD+ 1.8 GHz FDD	Jun-13	Aiming for 70% coverage of Australia’s metro population by mid-2014
Hong Kong	China Mobile HK	2.3 GHz TDD+ 2.6GHz FDD	Apr-12	7 subways coverage
India	Bharti Airtel	2.3 GHz TDD	Apr-12	7,000 eNodeBs deployed by the end of 2012, and aiming for 16.4% population coverage
Japan	Softbank	2.6 GHz TDD	Feb-12	1,216,800subscribers by April 2013, and over 17,000 eNodeBs deployed by October 31, 2012.
Oman	Omantel	2.3 GHz TDD+ 1.8GHz FDD	Jun-12	Aiming for 100% population coverage
Poland	Aero2	2.6 GHz TDD+ 1.8GHz FDD	Sep-10	Aiming for 100% population coverage
Russia	MTS	2.6 GHz TDD	Sep-12	Planning to cover 96% population in Moscow and 80% in the surrounding region
Saudi Arabia	Mobily	2.6GHz TDD	Sep-11	31 cities covered, 1,500,000 subscribers by April 2013
Saudi Arabia	STC	2.3 GHz TDD+ 1.8GHz FDD	Sep-11	2,500 eNodeBs deployed
Sweden	3 Sweden	2.6 GHz TDD+ 2.6GHz FDD	Dec-11	Aiming for 100% population coverage and 1,000 eNodeBs
UK	UK Broadband	3.5 GHz TDD	Feb-12	Continuing to roll out coverage.

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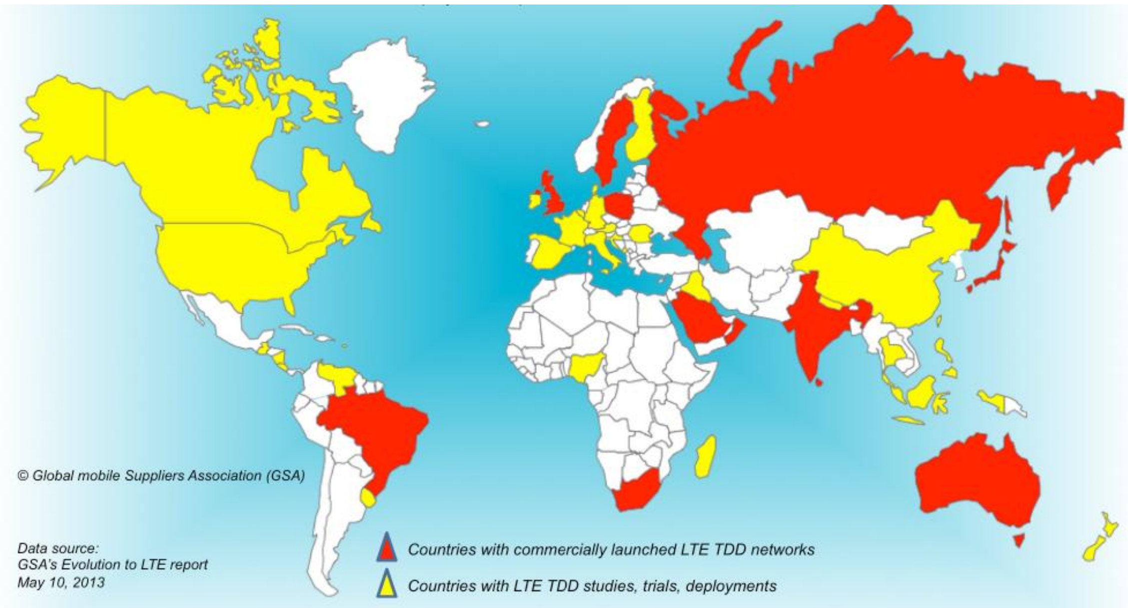

(Source: GSA, Status of the Global LTE TDD Market, May 21, 2013.)

Figure 3-2 TD-LTE investment worldwide

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Besides TD-LTE independent deployment, the combination of LTE FDD and TDD will also contribute greatly for the development of TD-LTE market. As shown in Table 3-3, 6 operators have deployed joint FDD/TDD network. The joint deployment of LTE FDD and TDD could meet the requirements of both the cities with high population density and traffic demand and the rural areas with low traffic demand and wide coverage. By achieving a maximum of commonality between LTE TDD and FDD, the combination has unparalleled advantages in cost and efficiency, which will attract more operators' investment and lever up the whole LTE market in the future.

According to the GTI Plan & Actions announce in Feb. 2012, it was initiated to construct over 500,000 TD-LTE base stations in 2014 covering over 2 billion population. The global commercialization of TD-LTE has seen a great leap forward. TD-LTE networks will show a giant market scale according to the potential population covered by current TDD bands as shown in Table 3-4 which only accounting announced operator commitments, commercial launches, network deployments and trials. While considering future TD-LTE deployment in the counties which already allocated TDD spectrum, the market scale is expected to be expanded further (see Table 3-5).

Table 3-4 Estimation for population coverage on major TDD bands according to network deployment and trial by 2013 Q2

Band	Countries with TD-LTE deployment/trial by 2013 Q2	Population (Million)
39	China	1344
40	Australia, China, Hong Kong, India, Oman, Russia, Saudi Arabia, South Africa, Sri Lanka, Costa Rica, EI Salvador, Guatemala, Indonesia, Madagascar, Malaysia, Nepal, Nicaragua	4515.8
41	China, Japan, Poland, USA	1823
38	Russia, Saudi Arabia, Sweden, Brazil (two states and capital), Belgium, Denmark, Finland, Germany, Italy, Puerto Rico, Romania (only de Murcia), Spain, UK	486.6
42	UK, Bahrain, Belgium, Croatia, France, Germany, Ireland, Italy, Montenegro, Poland, Russia	472.6
43	UK, Ireland, Italy	128.3

(Note: only accounting the counties announced operator commitments, commercial launches, network deployments and trials, and only the area with spectrum license included.)

Table 3-5 Estimation for population coverage according to TDD spectrum allocation

Frequency	Major region/country with TDD spectrum	Population (Million)
1.9GHz/2.0GHz	Australia, China, Europe, Japan, Russia, South Africa, South Asia	2748.2
2.3GHz	Africa, Canada, China, India, Latin America, Russia, South Korea, South Asia, The Middle East	5161.7
2.6GHz	Africa, Brazil, China, Europe, Japan, India, Latin America, North America, Saudi Arabia	5457.3
3.5GHz/3.7GHz	Australia, Europe, Latin America, North America, Russia	1852.7

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2) **Some operators in the world's most important markets in value terms and subscriber terms are aligned in the TD-LTE development.**

Softbank, Japan's third largest MNO, launched its TD-LTE network in 2012 February. Softbank planes to provide nationwide coverage and has announced that its TD-LTE subscribers have climbed to 1,216,800 till Arial 2013.

Clearwire committed to deploy a TD-LTE overlay using 2496-2690 MHz spectrum in August 2011, and will rollout around the USA by adding LTE modules to its large existing WiMAX network. It is expected that the TD-LTE network will be deployed in 20 MHz of spectrum by end of 2013.

Significantly, China decided to adopt the all-TDD band plan for 2500-2690MHz in 2012 November. China Mobile has engaged in TD-LTE trial since 2011. It finished TD-LTE large scale trial in 6 cities in May 2012, and started an expanded trial in July 2012, which deploy 20,000 TD-LTE base stations in 10 cities before the end of 2012. Three other cities are added to the trial at the beginning of 2013. In the expanded TD-LTE trial, 1.9GHz (Band 39) and 2.6GHz (Band 38) are utilized for outdoor coverage and 2.3GHz (Band 40) for indoor coverage. The number of cities, network scale and frequency bands are much larger compared with the previous TD-LTE large scale trial. The trial's purpose is elevated to the pre-commercial deployment, network operation and friendly user test.

According to China Mobile's new 4G plan announced in 2013 February, China Mobile will build the world's largest 4G network covering over 100 cities in China with over 200,000 base stations and more than 500 million populations. China mobile will purchase more than 1 million 4G terminals by this year. It shows that China is engaged to boost up a nationwide commercial deployment of TD-LTE network, which provides a tremendous market for TD-LTE devices and equipment and will insure a long-term giant ecosystem.

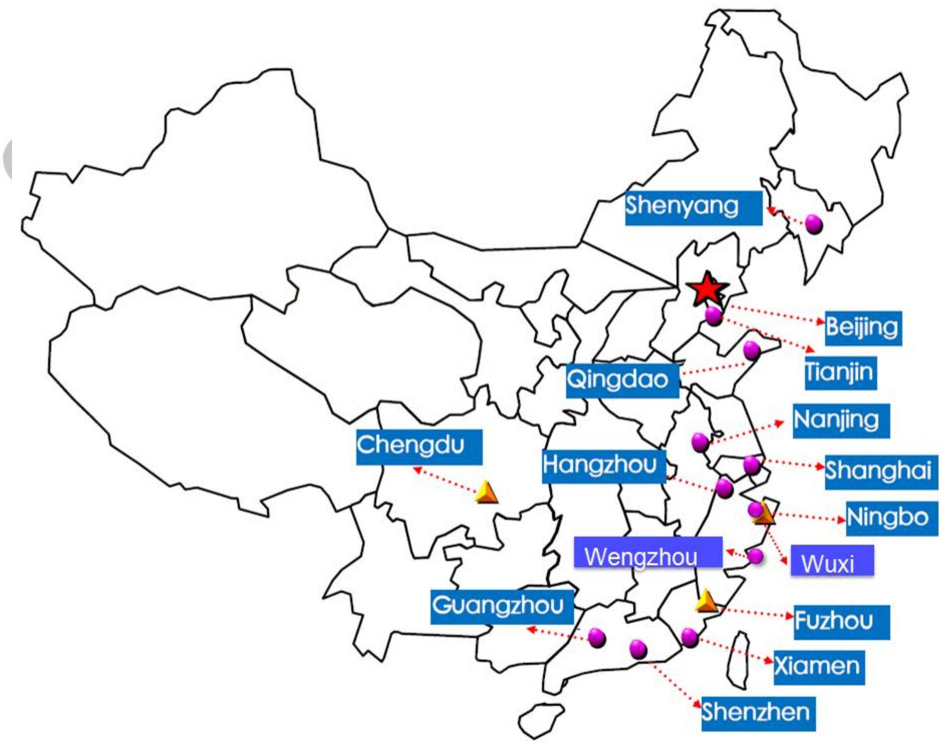


Figure 3-3 Pre-commercial trial in China

3) TDD spectrum attracts increasing attentions from operators.

Much TDD spectrum has been allocated world widely. In 3G stage, the auction price of TDD spectrum is usually much lower than FDD spectrum and even free. At the beginning of LTE spectrum auction, the cost of TDD spectrum is only 20% of FDD spectrum in 2011. However, with the maturity of TDD ecosystem and the decreasing of available FDD spectrum, TDD spectrum wins wide acceptance from operators. Consequently, the price for TDD spectrum is climbed to close to the FDD spectrum's price. It reported that TDD spectrum prices in Europe get an increase of 13 times in 2009-2011.

In October 2012, Softbank, which has already deployed a massive TD-LTE network in Japan, initiated activities to acquire a significant portion of Sprint that will see the operator greatly expand its businesses overseas. Such a blockbuster deal is no doubt stirring interest in TDD spectrum the world over, both in those who have it and those who want it.

Therefore, analysts predicted that 25 per cent of all LTE connections will be on TD-LTE by 2016.

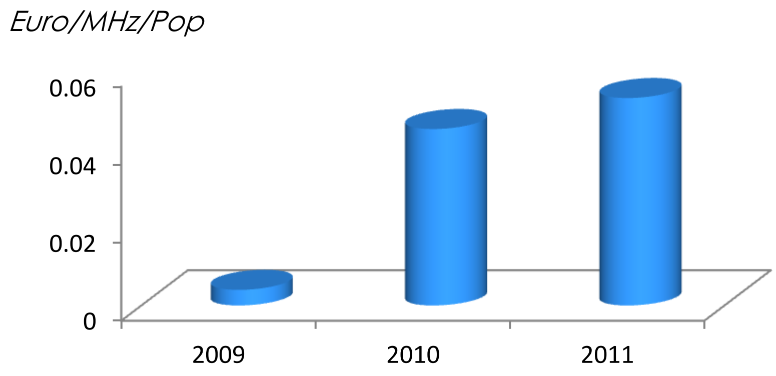


Figure 3-4 Price of TDD spectrum in Europe

4 Product availability

TD-LTE has already been a mainstream technology with global acceptance backed with a huge industrial commitment and supported by a very well established and fast growing ecosystem. Currently, the system equipment for all 1.9GHz/2.3GHz/2.6GHz/3.5GHz/3.7GHz bands are matured with commercial operation ability, and the user devices for 1.9GHz/2.3GHz/2.6GHz bands are sufficient to meet various customer requirements while user devices for 3.5GHz/3.7GHz is accelerating. TD-LTE has set up a complete end-to-end industry chain involving widespread participation of global industries and highly matured products.

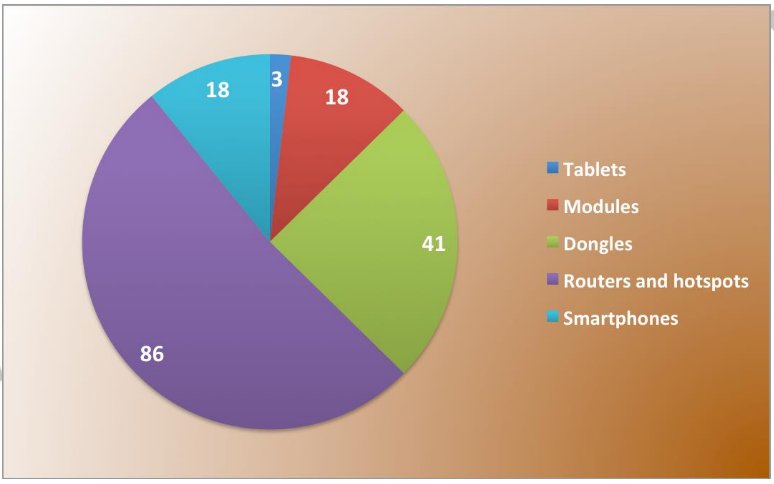
This section presents the status of TDD industrialization including the chipset, user devices and system equipment.

4.1 User devices and chipset

1) Latest status

According to GSA's Status of the LTE Ecosystem report published on March 27, 2013, 821 LTE user devices including frequency and carrier variants have been announced by 97 manufacturers. 166 user devices can operate using the TD-LTE mode, which accounted for 20% of the total 821 devices.

TD-LTE devices are available in all form factors including smart phones, dongles, routers, portable hotspots, embedded modules, and mobile tablets (see Figure 4-1).



(Source: GSA, Status of the Global LTE TDD Market, May 21, 2013.)

Figure 4-1 TD-LTE user devices - form factors

TD-LTE networks are deployed globally in several bands. GSA's analysis of how the main TD-LTE bands are supported by the devices ecosystem is shown in Table 4-1. It shows that the device ecosystems of band 38 (2.6 GHz), band 40 (2.3 GHz), band 41 (2.6 GHz) and band 39 (1.9 GHz) are matured and devices are also available for 3.5 GHz (bands 42) and 3.7GHz (band 43).

Table 4-1 TD-LTE Operating Frequencies (2013/05)

Frequency	Band	Device number	Status

1900MHz	39	30	Matured and in accelerating
2300MHz	40	112	Matured
2600MHz	38	123	Matured
	41	31	Matured and in accelerating
3400MHz-3800MHz	42 & 43	7	In accelerating

(Source: GSA.)

To meet the requirement of the decentralization characteristic of global TD-LTE frequency distribution, it is important for TD-LTE chipset and terminal to support multi-band frequency. At the same time, to achieve economies of scale and global roaming, it will also require to support multi-mode, especially LTE FDD.

With the joint efforts by global chip vendors, the technologies for TD-LTE multi-mode multi-band smart phones are getting mature increasingly. Currently, multi-mode multi-band TD-LTE dongles and CPEs are commercially available from all major chipset and device manufacturers. At the summit in Barcelona Feb. 2013, China Mobile and its industry partners, including Huaiwei, ZTE, Samsung, HTC and LG, jointly launched 5 models (TD-LTE/LTE FDD/TD-SCDMA/WCDMA/GSM) of TD-LTE multi-mode multi-band smart phones. It was reported that the success rate of over 1400 tests on 5-mode 12-band MiFi available for the entire band of 2.6GHz reached 98%, with power consumption same as the level of FDD LTE.

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2) Development trend

To meet the requirements of the global deployment of TD-LTE networks, following trends are obviously for the user devices and chipset.

- **Currently, the device ecosystems of almost all TDD bands are mature, while the devices for band 39/41 will be accelerated** in 2013-2014, with the strong stimulation of China's full TDD band plan for 2500-2690MHz and china mobile's large scale deployment on band 39/41.
- **The devices for 3.5GHz/3.7GHz will also be a focus of chip and device vendor** since a large number of network operators are studying or committed to deploying TD-LTE systems in bands 42, 43. It is expected that another three chip vendors will provide multi-mode multi-band chipset supporting bands 42 and 43 in 2014 H2.
- **It will continue to make improvement in chip and device integration to reduce power consumption and terminal size.** It is expected that in 2013 H2, the majority of global

chip vendors will be able to support 28nm multi-mode engineering samples supporting GSM/UMTS/TD-SCDMA/TD-LTE. While the highly integrated RF front-end will be the next focus, it is estimated that the PA and filter supporting FDD all band and TDD all band will appear in 2013 H2.

- **TD-LTE terminal is transited from data terminal to mobile terminal.** It is expected that by 2014, TD-LTE smart phone will be applied commercially on large scale.

In 2013, GTI will further promote the development of highly integrated multi-mode/band RF front-end products and multi-mode/band smart phones. It is estimated that booming development of TD-LTE terminals will be realized in a diversified, large-scale manner in the coming two years. Beside high-end mobile phones, middle and low end mobile phones will enter into the market. This will provide consumers with enriched choices while allowing seamless global roaming.

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4.2 System equipment

TD-LTE is under the transition from industrialization to commercial operation. Currently, the situation of TD-LTE System Equipment shows [1],

- **TD-LTE system equipment for all 1.9GHz/2.3GHz/2.6GHz/3.5GHz/3.7GHz bands**, including equipment products such as RAN, CN and network management, etc., **is mature as a whole and has commercial operation ability**.
- **The maturity level of TD-LTE system equipment is close to that of LTE FDD, with basically the same industry support**. In terms of RAN products, the maturity degree of TD-LTE is close to that of LTE FDD; in CN and network management, TD-LTE is almost the same as LTE FDD; in commercial operation, the gap between TD-LTE and LTE FDD is rapidly narrowing.
- **Multi-vendor supply pattern of TD-LTE system equipment has already formed**. As of the end of 2012, all those 10 mainstream system equipment vendors have provided the products meeting R8 standard technical requirements, of which, six vendors' system equipment achieves R9 standard and reaches commercial deployment requirements.

Table 4-2 Multi-vendor Supply Situation of TD-LTE System Equipment

Vendor	Commercial Network	Band
Huawei	China Mobile	1.9GHz
	Bharti AirTel in India, China Mobile, Dialog Axiata in	2.3GHz

	Sri Lanka, Omantel in Oman, STC in Saudi Arabia, Telkom Mobile (8ta) in South Africa	
	Aero2 in Poland, China Mobile, Hi3G in Denmark, Mobily in Saudi Arabia,On Telecom in Brazil, Softbank in Japan	2.6GHz
	UK Broadband in UK	3.5GHz/3.7GHz
Ericsson	China Mobile	1.9GHz
	China Mobile, China Mobile Hong Kong, NBN in Australia, Omantel in Oman, STC in Saudi Arabia	2.3GHz
	China Mobile	2.6GHz
Nokia Siemens	Bharti AirTel in India, China Mobile, STC in Saudi Arabia	2.3GHz
	China Mobile, Megafonin and MTSRussia, SKY TV in Brazil	2.6GHz
ZTE	China Mobile	1.9GHz
	Bharti AirTel in India, China Mobile, China Mobile Hong Kong	2.3GHz
	China Mobile, Hi3G in Sweden, Softbank in Japan	2.6GHz
Alcatel-Lucent	China Mobile, STC in Saudi Arabia	2.3GHz
	China Mobile	2.6
Datang	China Mobile	1.9GHz, 2.3GHz, 2.6GHz

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(Source: GTI)

For more information and analysis about TD-LTE system equipment, please refer to GTI "Network White Paper".

5 Issues relevant to TDD spectrum and deployment

Despite the fact that TDD is growing rapidly and becoming the mainstream technology around the globe, there remain several key areas that the industry has to pay attention and improve. This section aims to summarize the potential challenges with TDD based on the current market status. Solutions and study findings will be further elaborated in Section 6 in this paper.

5.1 Large TDD spectrum block demanded

Larger bandwidths for the development of LTE will be needed, and preferably based on contiguous bands. As TDD possesses a rich bandwidth in general, many mobile operators put increasing emphasis on TDD spectrum and its usage. Current core bands for TDD are 1.9GHz/2.0GHz, 2.3GHz, 2.6GHz and 3.5GHz/3.7GHz, totally about 840MHz in terms of bandwidth. According to market information (Figure 5-1), most operators possess a contiguous TDD spectrum of 20MHz bandwidth or more. Some of them could have over 100MHz across these major TDD bands except 1.9GHz/2.0GHz (94% of which have fragmented bandwidth).

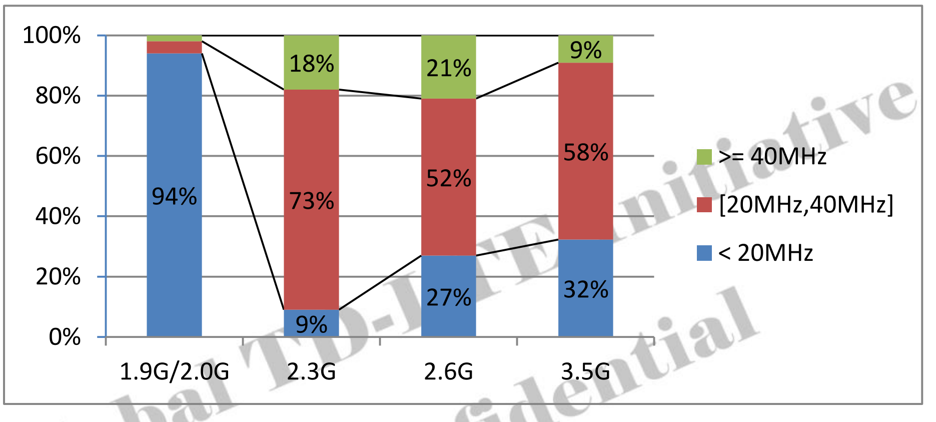

Figure 5-1 TDD spectrum block continuity

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Most of these fragmented bands, especially 1.9GHz in EU, tend to remain unused. We take one EU country for example shown in the Table 5-1. Each operator possesses only 5MHz bandwidth of 1.9GHz, meanwhile no guard bands exist between the 5 MHz allocations. For operators, it is hard to get enough income if they invest in deploying 5MHz network, which is recognized a competitive disadvantage. What's more, it will pose a challenge for manufacturers looking at which bands to support in their devices.

Table 5-1 TDD spectrum allocation of 1.9GHz in some EU country

Operator	Frequency downlink	Frequency uplink	Bandwidth/MHz
Operator-1	1900	1905	5
Operator-2	1905	1910	5
Operator-3	1910	1915	5
Operator-4	1915	1920	5

1900-1920MHz (Band 33) throughout EU and 2010-2025MHz (Band 34) in some EU countries are currently allocated to UMTS TDD networks but remain unused or are not yet licensed. These fragmented bandwidths will create more difficulty in LTE era where the focus is on providing traffic in Gigabytes. Furthermore, the licenses will mostly expire in the next few years, and will be recovered if still no network deployment for this spectrum. The European Commission has already issued a Mandate to CEPT to study suitable alternative applications and develop appropriate technical conditions and sharing arrangement.

The small granularity of licensed TDD spectrum leads to problems for mobile broadband application and sufficient deployment. The existing spectrum fragmentation should be addressed to make the spectrum usable which also shall be avoided in future spectrum plan.

5.2 TDD spectrum harmonization

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Spectrum harmonization can ensure:

- Economies of scale for standardised products;
- Smoother cross-border coordination;
- Easy roaming within the region where harmonisation is implemented.

More generally, regulatory certainty is the key for the development of innovative and competitive services across the globe as it facilitates the development of a healthy and innovative ecosystem. The shortage of spectrum harmonization represents a key challenge for the LTE ecosystem including FDD and TDD, potentially preventing vendors from delivering globally compatible LTE products such as devices and chipsets.

Therefore, **harmonization shall be carefully considered in on-going and future spectrum allocations.** For example, full-TDD band plan in 2.3GHz/2.6GHz/3.5GHz/3.7GHz is recommended for the countries/areas where those bands have not been planned or allocated.

5.3 Coexistence issues

In modern network deployment scenarios, the coexistence issues of multi-layer networks start to appear. Thus, dealing with the coexistence issues is of utmost importance to be seriously considered.

The most commonly coexistence issues related to TD-LTE deployment can be classified into the following scenarios:

- Between multiple TD-LTE networks (see Figure 5-3)
- Between TD-LTE network and LTE FDD network
- Between TD-LTE network and WiMAX network
- Between TD-LTE network and WiFi network
- Between TD-LTE network and Satellite network

For those same duplexing mode coexistence scenarios, such as between TD-LTE networks or between TD-LTE network and WiMAX network, synchronization is the most economical at the same time feasible way to manage the coexistence issues. It could use all spectrum resource and avoid guard band between two TDD networks. However, if the synchronization operation is not feasible in some network deployment, the operator will need to rely on adequate guard bands, stringent RF requirements and careful site engineering to mitigate the coexistence interference.

For other coexistence scenarios, usually between TD-LTE and LTE FDD or between TD-LTE and WiFi, there may be interference if no guard band is reserved.

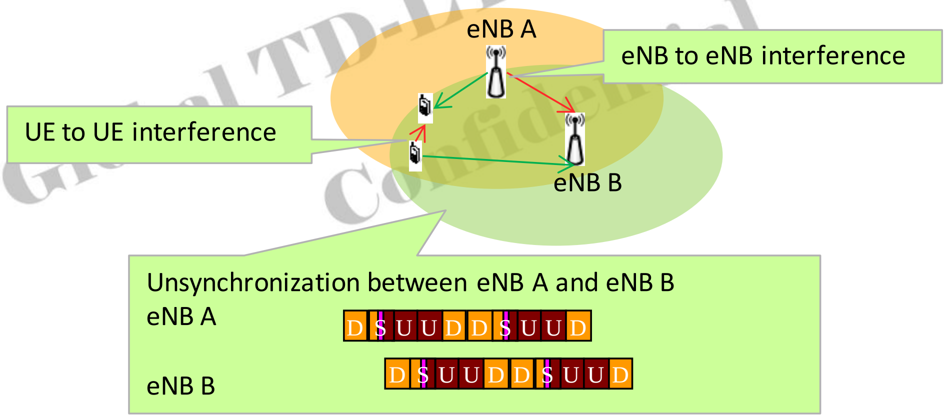

Figure 5-2 Interference introduced by unsynchronization

The coexistence issues between TD-LTE operators and TD-LTE with other radio systems are critical for the successful deployment. High efficiency and practical solutions shall be used to minimize coexistence interference and obtain a good network performance.

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6 Solutions to facilitate TDD spectrum utilization

This section shall discuss the possible solutions of the issues and challenges as summarized in Section 5.

6.1 Solutions for large spectrum block

Three solutions are considered to cater the fragmented spectrum issue:

- Spectrum exchange/merger
- Carrier aggregation

6.1.1 Spectrum exchange/merger

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Spectrum swap has been a common practice in telecom industry, even in 2G. In India, regulators allow mobile phone companies to be able to swap frequencies within the same band. This would allow telcos to barter frequency spots to cover up patchy network in circles where there may not be contiguous spectrum after the airwaves are allotted. It helps companies in case there are areas where spectrum is not contiguous. In May 2012, Bharti, the Indian giant that owns TDD licenses in four coverage zones, kicked off its joint venture with India Qualcomm in a deal worth USD165 million, enabling the operator to extend its TD-LTE coverage to another four zones, including such potentially huge markets as Mumbai and Delhi.

In LTE where demand for wide bandwidth is higher than ever, the swap or acquire of frequency among operators is not only aim for solving fragmented spectrum but also as a key strategy to be the king of spectrum. For instance, Australia Optus acquired 98MHz of 2.3GHz TDD spectrum from Vivid Wireless making the operator in a very competitive position to build a high quality TD-LTE/FDD convergence network.

Therefore, spectrum exchange and merger will be a considerable approach for operators to look to regroup their ecosystem resources and improve the utilization efficiency of TDD spectrum.

6.1.2 LTE Carrier Aggregation

CA (carrier aggregation) means coordination transmission and coordination reception at two or more carriers in the same band or different bands. Signals at these aggregated carriers are dealt with together at the same baseband unit. CA is classified with intra-band CA and inter-band CA, with intra-band CA including contiguous CA and non-contiguous CA. Intra-band non-contiguous CA and inter-band CA provides feasible solutions to aggregate operator's fragmented spectrum.

3GPP RAN4 studies intra-band carrier aggregation and inter-band CA according to operators' actual requirements. There are over 30 work items on intra-band and inter-band CA in 3GPP RAN4 which shows strong interests of operators to better utilize their existing spectrum.

Table 6-1 TDD Intra-band CA WIs in 3GPP RAN4

Intra-band CA WIs in 3GPP RAN4	Bandwidth	Duplex mode
LTE Advanced intra-band contiguous Carrier Aggregation in Band 40	2300-2400	TDD
LTE Advanced intra-band contiguous Carrier Aggregation in Band 38	2570-2620	TDD
LTE Advanced intra-band contiguous and non-contiguous Carrier Aggregation in Band 41	2496-2690	TDD
LTE Advanced intra-band contiguous Carrier Aggregation in Band 39	1880-1920	TDD

Summary

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Based on the status of the solutions mentioned in this section, spectrum exchange/merger is the mainstream solution to handle fragmented spectrum at current stage. It shall encourage the licensed spectrum exchange/merger among operators to integrate fragmented spectrum and obtain wider contiguous bandwidth. Intra-band CA is also an option available in R10 provided that the fragmented spectrums are owned by the same operator. Inter-band CA would be a relative longer term solution.

Table 6-2 Solutions for larger TDD bandwidth

	Spectrum exchange/merger	Intra-band CA	Inter-band CA
1.9GHz	Yes	R12	R11 (Band41/39)
2.3GHz	Yes	Product ready (chipset and RAN)	To be specified
2.6GHz	Yes	R10	R11 (Band39)

3.5GHz	Yes	To be specified	To be specified

(*3GPP RAN4 studies these topics based on operator requirement)

6.2 Coexistence solutions

This subsection will discuss the solutions for two TDD-LTE networks' coexistence, and TD-LTE coexisting with LTE FDD, WiMAX and Satellite network.

6.2.1 Coexistence between multiple TDD networks

There are several possible techniques for improving coexistence between TDD networks like:

- Synchronization
- Sub-band filtering
- Site coordination
- Restricted blocks

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The use of sub-band filtering and restricted blocks methods are obviously methods which lead to spectrum wastage. Sub-band filtering method also increases the number of base station types even within the same band and destroy the economies of scale. Site coordination method will bring very complicate site plan and site construction. Therefore, a better way to avoid interference is to synchronize neighbour BSs in order to make them transmit and receive at the same time. Synchronization is not only needed for the cells operated in the same frequency, but also for the cells operated in the same band if there is no sufficient guard band reserved.

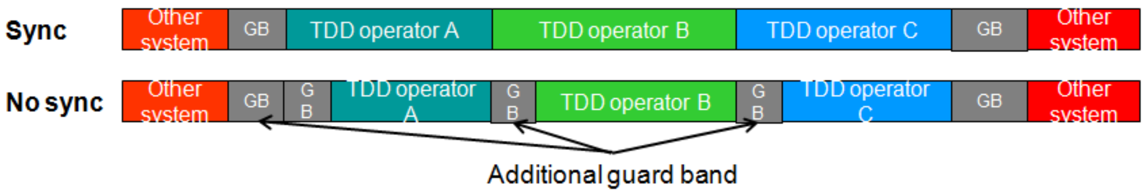

Figure 6-1 Example comparing the usable spectrum of sync and no sync

Network synchronization has abundant benefits as below,

- In general, the benefit resulting from synchronization is to facilitate the coexistence between TDD networks, and improve the efficiency of the use of spectrum. If the TDD networks are synchronized, no guard band is required and all spectrum resources are fully utilized.

- From the view of LTE future evolution, network synchronisation is also a must. That's because a few LTE-advanced features, such as Inter eNodeB CoMP (Coordinated Multi-Point), eICIC (Enhanced Inter-cell Interference Coordination) and CSPC (Coordinative schedule Power Control), need time synchronisation to achieve the best performance, even for LTE FDD.
- For some other techniques such as advanced receiver at UE, the synchronized network would be beneficial to improve the receiver performance. For example, according to RAN4 study, the UE demodulation performance with MMSE-IRC under synchronized network would be better than that under un-synchronized network as summarized in [4].

The synchronization solution has two points, to synchronize the start of frame and to configure compatible frame structures. Several methods could be used to synchronize the start of frame. For outdoor base stations like macro/micro cells, it is easy to get synchronization by GNSS (like GPS, Galileo, Glonass, BeiDou, etc.), and IEEE 1588v2 and over-the-air synchronization approach could be used for indoor base stations.

According to the latest statistics results, over 90 percent of commercial TDD networks adopt the same Downlink/Uplink ratio (3:1), which is best suited for user behaviour of mobile broadband era. It is most likely expected that in future TDD commercial networks, the same frame structures will be widely adopted. Therefore, it is feasible to coordinate the frame structures.

A brief discussion for the synchronization solutions is presented in Appendix 1, and the detailed information could be found in GTI White Paper on TDD Synchronization [8].

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It can be concluded that the network synchronization not only has a lot of benefits, but also is indeed feasible in real network implementations with matured solutions. The unsynchronized operation will need to rely on adequate guard bands, stringent RF requirements and careful site engineering to mitigate the coexistence interference.

6.2.2 Coexistence between TDD and FDD

Some region and countries used FDD and TDD mixed frequency arrangement, such as Europe, Canada, Brazil, Chile, Columbia, Australia, New Zealand, Vietnam etc. Mix of FDD and TDD in the same geographical area gives adjacent up and downlink transmissions, which will bring significant BS-BS and UE-UE interference.

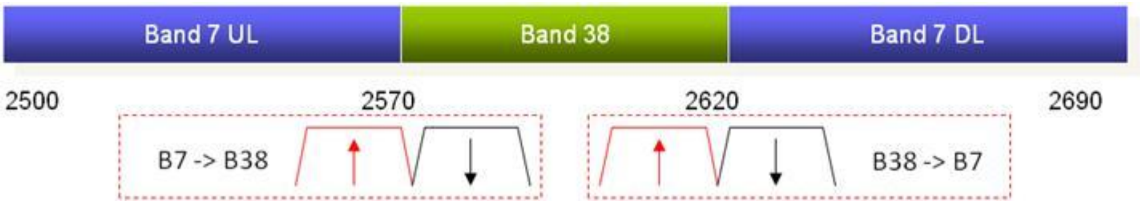

Figure 6-2 Coexistence between TDD and FDD in 2.6GHz

According to the CEPT's rule, to avoid the BS-BS interference, two 5MHz guard bands shall be reserved between TDD and FDD, and advanced filters with high cost shall be mounted on the base stations while it still need careful site deployment. However, according to the test conducted by China Mobile[5], the UE-UE interference still can't be solved at all due to cost and volume limitation of UE, which may result in high interference when UEs are closed to each other. Some additional approaches, such as limiting UE data rate, could be considered to mitigate the interference (see Appendix 2).

Although the coexistence between FDD and TDD can be solved, **the band plan of mixed FDD and TDD should be avoided in the future to avoid difficult interference scenarios and inefficient spectrum use.** Countries which have no plan in 2.6GHz are suggested to adopt full TDD arrangement.

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6.2.3 Coexistence between TDD and WiMAX

For the different TDD systems that have different frame structure, coordination is needed to align the uplink and downlink between the two different systems. TD-LTE could coexist with WiMAX by frame configuration and symbol puncturing according to the UL/DL ratio of WiMAX system.

The coexistence solutions for most used 32:15(31:15) or 29:18 or 35:12 ratio in WiMAX system are presented in Appendix 3. **It shows that the coexistence between TD-LTE and WiMAX could be performed only by the configuration of network management, which also facilitate the WiMAX evolution to TD-LTE.**

6.2.4 Coexistence between TD-LTE and WiFi

WiFi is working in 2.4GHz, which is neighbour to 2.3GHz TD-LTE and 2.6GHz LTE FDD/TDD system including Band40 (2300-2400MHz), Band41 (2496-2690MHz), Band38 (2570-2620MHz) and Band7 (2500-2570MHz). Thus, it will cause interference when WLAN and TD-LTE system are deployed at the same place, and will also cause in-device coexistence interference for LTE UEs equipped with WiFi module.

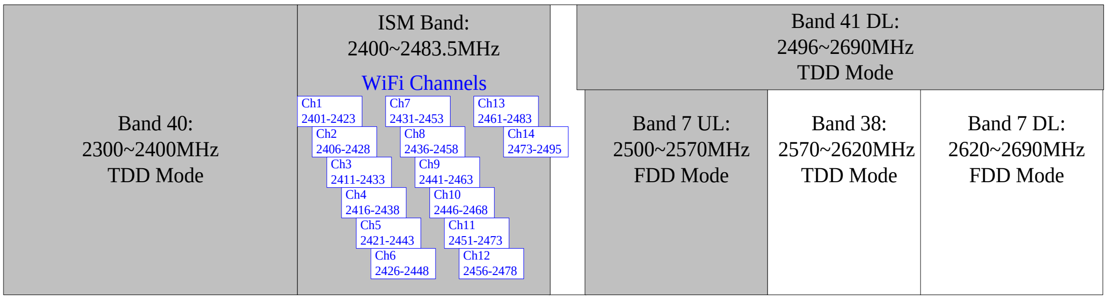

Figure 6-3 3GPP frequency bands around ISM band

For the coexistence of WLAN and TD-LTE system deployed at the same place, the interference from TD-LTE to WLAN is mainly blocking interference while TD-LTE suffering less interference from WLAN for TD-LTE's high RF performance. According to the field test of China Mobile which eNB is on 2320~2370MHz, both WLAN AP and station will be interfered severely (see Appendix 4). Actually, WiFi devices will also be severely interfered when coming into the TD-LTE/LTE FDD coverage in 2.6GHz band. Thus, new WiFi blocking index should be defined and certified for WLAN AP and station to mitigate the RF interference from LTE, which are discussed in OMTG of WiFi Alliance [6].

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For the in-device coexistence, 3GPP has developed several solutions to avoid the interference between WiFi and LTE, such as separating the transmission of the two radios in frequency domain or time domain, and reducing LTE transmission power (see Appendix 4 for the detailed discussion).

6.3 New band allocation

Under the agenda item 1.1 of WRC-2015, it is estimated that 900MHz to 1200MHz of new spectrum is required to support the demand of mobile broadband services over the next decade. TDD spectrum is regarded as an important part for its ease in spectrum release and high efficiency in spectrum use. It is highly expected to achieve global harmonized spectrum allocation.

Below table is the possible band for IMT to consider at WRC-15. Among these bands, GTI suggests these bands could be the potential global mainstream band for TDD in the future.

Table 6-4 Possible candidate bands for IMT under WRC-15 Agenda Item 1.1

Description	Spectrum	Incumbent user	WRC-15 target
Low candidate bands (<1GHz)	Parts of 500-600MHz [470-around 694MHz]	TV PMSE	WRC-15 regional identification for IMT usage Need cooperation with Broadcasting industry
	700MHz [694-790MHz]	TV PMSE	WRC-15 Regional IMT identification: Region 1 (AI 1.2)
Low-to-mid candidate bands (1GHz-3GHz)	Parts of 1.4 GHz [1350-1525MHz]	D-Radio Fixed Link Scientific	WRC-15 global identification for IMT usage Scientific use, only in a part of frequencies and some parts of regions
	2700-2900 MHz	Radar	WRC-15 global identification for IMT usage
Mid-to-high candidate bands (3GHz-6GHz)	3.4-3.6 GHz	IMT (In some countries) Sat.	WRC-15 global identification for IMT usage
	3.6-3.8 GHz	IMT Sat.	WRC-15 global identification for IMT usage
	Parts of 3.8-4.2GHz	Sat.	WRC-15 global identification for IMT usage
	Parts of 4.4-4.99 GHz	Sat.	WRC-15 global identification for IMT usage

1) Low candidate bands (<1GHz)

The low candidate bands (470-694/698MHz and 700MHz) provide great propagation characteristics for coverage and indoor penetration. For the time being, these low bands are widely usually used for broadcasting service, but parts of this band are also considered for mobile broadband under national broadband plans globally. Along with the progress of broadcasting analogue-to-digital migration and the finalization of band clearing of 700MHz and 800MHz, these "Digital Dividend" bands will become available for TD-LTE for the flexible allocation of TDD.

2) Low-to-mid candidate bands (1GHz- 3GHz)

The L-band (1350-1525 MHz) may provide good coverage and complement below 1 GHz bands which may not be sufficient to address the growing capacity demand. Currently allocated by the ITU Radio Regulations (WRC-12 revision) on a primary and/or secondary basis to the Mobile Service, Fixed Service and Broadcasting Satellite Service, the band has clear potential for Global/Regional harmonization, with specific reference to the 1427-1525 MHz and/or 1525-1660MHz ranges (excluding the 1400-1427MHz portion).

Although the band (1350-1525 MHz) is considered as key candidate band for IMT, many efforts are necessary because the band is also the important band for other services and applications, including GPS and DAB applications.

3) <u>Mid-to-high candidate bands (3GHz- 6GHz)</u>

The band 3400-3800MHz decided for Broadband Wireless Access (BWA) is already widely available for licensing and a few TD-LTE deployments in Europe have been announced. The 400MHz in the 3800-4200 MHz range offers an important opportunity to fulfil the growing capacity demand. Located in a higher frequency range, while still below the 6GHz boundary, this range is especially suitable for small coverage with denser cellular allowing focused capacity with a higher degree of frequency reuse. Regarding the band 3800-4200MHz, the spectrum sharing between IMT and FSS should be advocated with low power IMT network.

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7 Recommendations for TDD spectrum utilization

The growth in mobile data traffic is a well-documented phenomenon which calls for more spectrum. As an important part of LTE, TDD has the unique value of global, asymmetric and synergetic, making it fast become a mainstream LTE technology.

In order to accelerate the TDD development and boost operators' commercial success, we herein advocate the following suggestions as below.

1) <u>Fast process of allocation and assignment of TDD spectrum will facilitate the spectrum utilization and satisfy operators' spectrum requirement</u>

With the maturity of TDD ecosystem and rapid advancing of global commercial network deployment, TDD spectrum attracts increasing attention from operators. Thus, it is expected to speed up the process of allocation and assignment of underused TDD spectrum. For example, 2.3GHz and 3.5GHz for European countries, 3.5GHz/3.7GHz for North American, 2.3GHz for Southeast Asia, and 2.6GHz for China and South Africa, etc.

2) <u>Full-TDD band plan in 2.3GHz/2.6GHz/3.5GHz/3.7GHz is recommended for the countries/areas where those bands have not been planned or allocated.</u>

1.9GHz, 2.3GHz, 2.6GHz and 3.5GHz have become the global bands for TDD. Full TDD band plan will avoid the complicated coexistence and low spectrum utilization of mixing of FDD and TDD duplexing modes in one band. The unified global TDD allocation will enlarge the global market scale for standardised products and facilitate the global roaming.

For 2.6GHz (Band 41) and 1.9GHz (Band 39), the TDD only allocation will get support from the fast growing ecosystem stimulated by China Mobile's adoption.

For 3.4-3.8GHz (Band 42 and 43), the 400MHz portion of available spectrum will play a key role in helping to meet the mobile data demands. As an ideal capacity layer, TDD is the best choice for this spectrum.

3) **Contiguous TDD spectrum allocation in large blocks is beneficial for improving mobile broadband experience and enlarging the global market scale.**

The contiguous broad spectrum is of utmost importance to TDD success, while fragmented allocation induces low spectrum usage and is hard to support high data rate and heavy traffic. According to the quantity of spectrum resource and the deployment purpose for wide coverage or high capacity, it is suggested that a proper bandwidth could be 1.9/2.0GHz≧10MHz, 2.3GHz/2.6GHz≧20MHz, and 3.5GHz/3.7GHz≧40MHz.

4) **Spectrum exchange and merger of small spectrum blocks among operators are expected to promote the TDD spectrum utilization.**

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For the operators licensed with small blocks of TDD spectrum, spectrum exchange and merger could be applied to regroup the fragmented spectrum and improve the usability, e.g. 1.9GHz in EU. Moreover, the regulators and operators can further assist the process by releasing, reallocating or acquiring unused or ineffective spectrum in the 1.9GHz band for TDD.

5) **The synchronized operation among multiple TD-LTE networks is recommended for best spectrum utilization while the guard bands can also be used to ensure the coexistence of unsynchronized TDD.**

The synchronization operation is the most economical and feasible way for the spectrum utilization and coexistence management of TDD networks, while the corresponding solution are matured and validated in network deployment. According to statistics, over 90 percent of commercial TDD networks adopt DL/UL ratio = 3:1, which is expected to be commonly used in the operators' TDD networks. The unsynchronized operation is also applicable, which will need to rely on adequate guard bands, stringent RF requirements and careful site engineering to mitigate the coexistence interference.

6) **To provide fast and cost effective network deployment, low frequency bands (e.g. L-band and 700MHz) and harmonized allocation should be considered for TDD in future.**

It is foreseen that future spectrum are difficult to be paired. Thus, TDD would be an ideal option to speed up the new spectrum release, e.g. L-band and 700MHz in particular for lower bands which is one of the most urgent demands for operators.

8 Reference

[1] TDIA, "TD-LTE Industry Development Report (2012)", http://www.tdia.cn, January 2013.
[2] GSA, "Status of the Global LTE TDD", http://www.gsacom.com, May 21, 2013.
[3] GSA, "Status of the LTE Ecosystem report", http://www.gsacom.com, March 27, 2013
[4] TR36.829, Enhanced performance requirement for LTE User Equipment (UE).
[5] R4-125214, "Band 7 and Band 38 UE-UE coexistence test".
[6] WiFi Alliance OMTG, "Coexistence Requirement between WLAN(2.4GHz) and TD-LTE(2.3GHz)", March 4, 2013.
[7] TR 36.816, "Study on signalling and procedure for interference avoidance for in-device coexistence".
[8] GTI, "White Paper on TDD Synchronization", July, 2013.

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9 Appendix

9.1 Appendix 1: solutions for TDD synchronization

Some supervisors also make the synchronization between operators as mandatory rules to guarantee the co-existence. It can be explained to two points as below:

- Synchronizing the beginning of the frame;
- Configuring compatible frame structures, i.e. configure the length of the frame, the TDD UL/DL ratio and guard period so that all radios stop transmitting before any neighbour radio starts receiving.

According to the latest statistics results, over 90 percent of commercial TDD networks adopt the same Downlink/Uplink ratio (3:1), which is best suited for user behaviour of mobile broadband era. It is most likely expected that in future TDD commercial networks, the same frame structures will be widely adopted. Therefore, it is feasible to coordinate the frame structures.

There are several methods for synchronization of the start of frame as below,

- Synchronization by GNSS (like GPS, Galileo, Glonass, BeiDou, etc.), which is suitable for base stations that have an outdoor component and therefore can receive a GNSS signal.
- Synchronization over backhaul network (like Synchronous Ethernet and IEEE 1588 v2), which needs good backhaul conditions to ensure the good synchronization accuracy.
- Synchronization through the radio-interface (like network listening), by which a cell can determine its timing with the help of radio-interface based signals.

For outdoor base stations like macro/micro cells, it is easy to get synchronization by GPS. But with the development of heterogeneous network, more and more base stations are planning to be deployed indoor to improve the hotspot throughput. GPS and IEEE 1588 are not always available or suitable for small cells. In this case, over-the-air synchronization approach can be used, which is not limited by the coverage of GNSS signal or the backhaul condition. This approach can also be used for the BSs not only within a single operator but also between different operators with multiple layers sharing the same band. The following figure shows a feasible way to implement over-the-air synchronization across different operators.

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Table A-1 Comparison of different synchronization solutions

	Synchronization by GNSS	Synchronization over backhaul network	Over-the-air synchronization
Synchronization Accuracy	High (100ns order)	Good (sub-microsecond order)	Depends on detection/tracking accuracy at eNB/UE side;
Synchronization Overhead	-	-	For network listening: Reserved DL resource for listening slots; For UE-assisted synchronization: Overhead at UE side and on the backhaul resource
Cost/Complexity	High hardware cost	High backhaul cost	For network listening: Additional receiver in DL and possible additional transmitter in UL for FDD system For UE-assisted synchronization: Additional UE complexity if this solution is not transparent to UEs for both TDD and FDD system
Others	Not applicable to indoor;	Need good backhaul such as operator	Can be applied to scenarios where synchronization by GNSS and over backhaul do not work

		controlled fibber / Ethernet	

3GPP will still further enhance the current synchronization mechanisms for the scenario of multi-carriers and multi-layers in the later releases. Therefore, synchronization of the start of frame is obviously feasible.

9.2 Appendix 2: solutions for UEs coexistence

The UE-UE interference can't be entirely eliminated due to cost and volume limitation of UE, which may result in high interference when UEs are closed to each other. According to the test conducted by China Mobile, Band 7 and Band 38 UE-UE interference is serious in some scenarios, especially in far->far scenario, while near->near almost surviving. The interference can be mitigated if proper solutions are adopted [5].

- Extending the guard band (to 10MHz) can mitigate the interference in most scenarios, however, it is not an attractive solution due to low spectrum efficiency. Therefore, it proposed to set 5MHz guard band and use additional spatial or time dimension isolation for interference mitigation.
- Limiting UEs data rate (e.g. 2Mbps to 10Mbps) of both the aggressor and victim systems in special coexistence scenarios can significantly mitigate the interference
- Increasing UEs' spatial isolation can significantly mitigate the interference, when UE is near to its own base station or the separation is more than 3m, there is no interference. Although it's hard to control, the interference will be acceptable in statistical sense for the terminal mobility.

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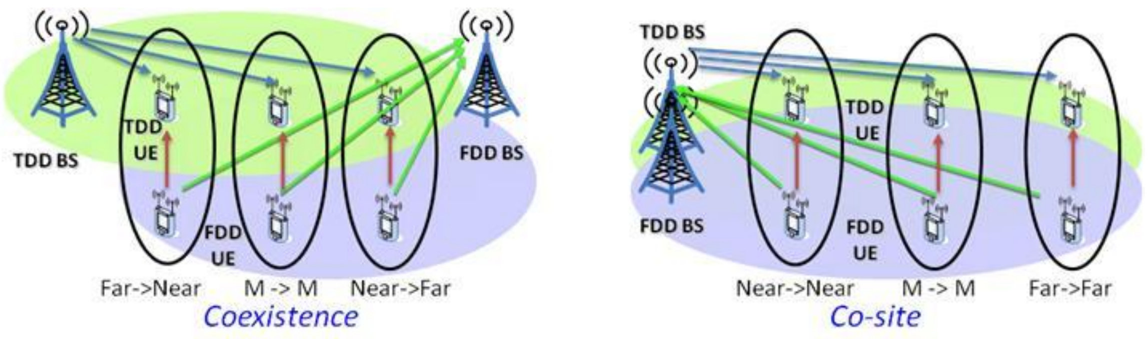

Figure A-1 Coexistence test for 2.6GHz FDD/TDD

9.3 Appendix 3: solutions for coexistence between TD-LTE and WiMAX

Because most of the WiMAX system uses 32:15(31:15) or 29:18 or 35:12 ratio, the coexistence with TD-LTE is show as below.

1) <u>WiMAX (32:15) can coexist with TDD just by frame configuration</u>

For WiMAX, it does not need to change.

For TDD, the ratio is 3DL: 1UL, and special frame configuration is 3:9:2.

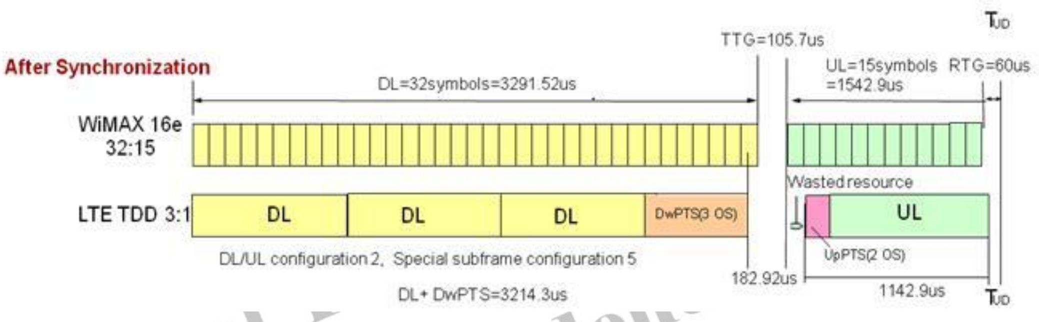

Figure A-2 Coexistence between TDD and WiMAX (32:15)

2) <u>WiMAX (29:18) can coexist with LTE-TDD by symbol puncturing</u>

For WiMAX, the last two downlink symbols need to be punctured.

For TDD, the ratio is 2DL: 2UL, and special frame configuration is 10:2:2.

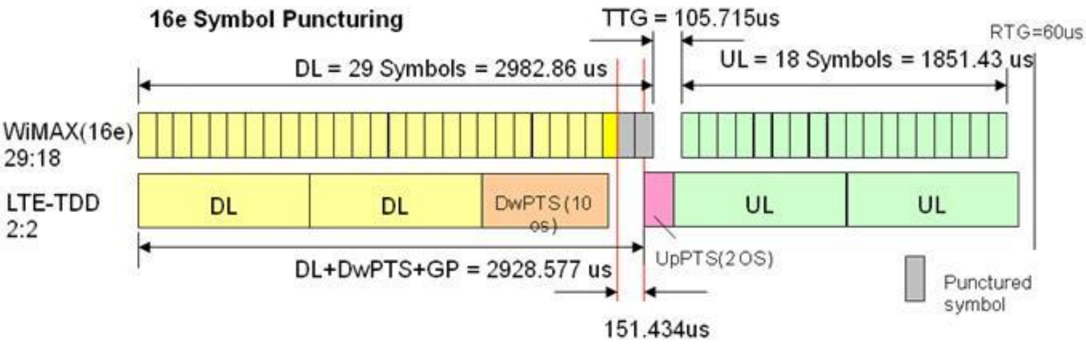

Figure A-3 Coexistence between TDD and WiMAX (29:18)

The alternative is to leave WiMAX intact and blank LTE symbols which helps those operators migrating to LTE as LTE systems will be lightly loaded at launch.

3) WiMAX (35:12) can coexist with LTE-TDD just by frame configuration

For WiMAX, the last two downlink symbols need to be punctured.

For TDD, the ratio is 3DL: 1UL, and special frame configuration is 3:9:2.

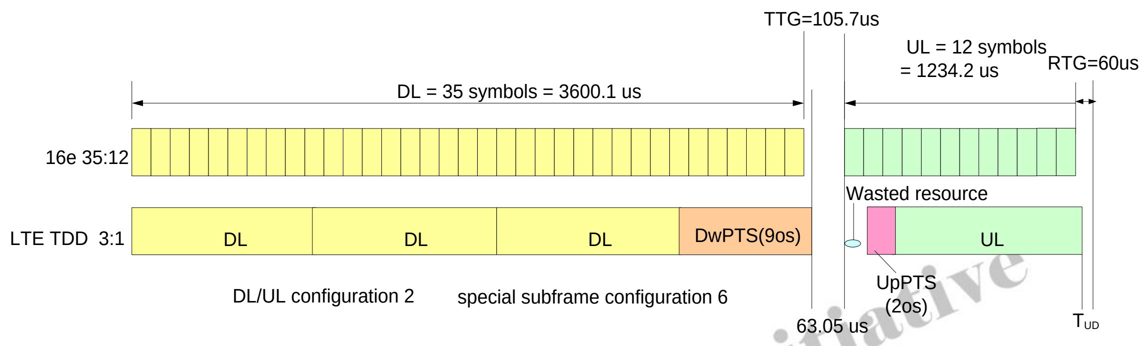

Figure A-4 Coexistence between TDD and WiMAX (35:12)

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9.4 Appendix 4: solutions for coexistence between TD-LTE and WiFi

1) WiFi coexistence with TD-LTE network

The interference from TD-LTE to WLAN is mainly blocking interference while TD-LTE suffers less interference from WLAN due to TD-LTE's high RF performance. According to the field test of China Mobile which eNB is on 2320~2370MHz, both WLAN AP and station will be interfered severely as below (see Figure 6-8).

- eNB interference to AP
  - When eNB-AP distance increases from 1m to 3m, interference will decrease, but it's still serious. AP performance cannot be guaranteed and WiFi coverage will shrink significantly.
- UE interference to STA
  - When UE-STA distance increases from 0.2m to 1m, interference will decrease. When UE works with high power and the STA RSSI is poor, the throughput of STA will decrease significantly.

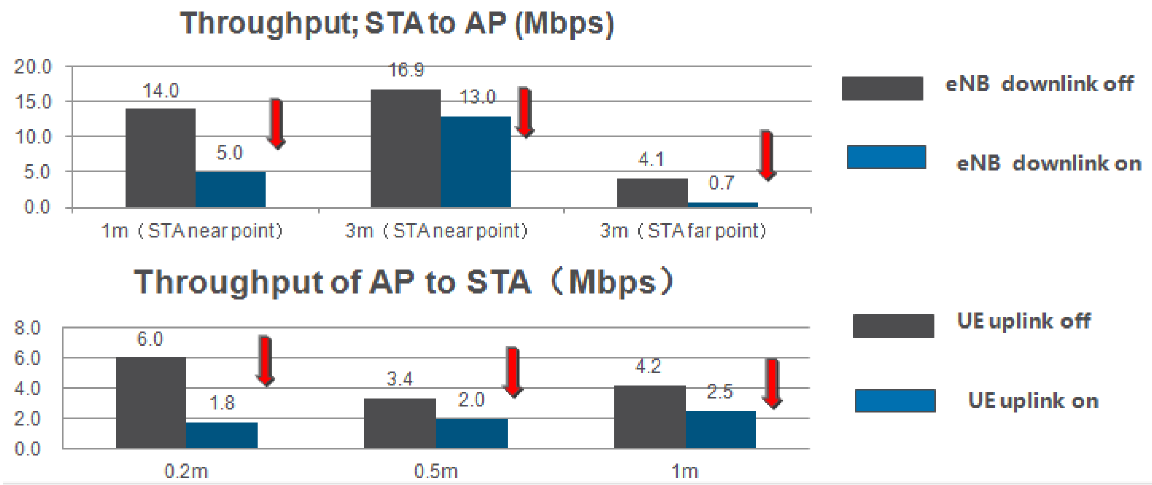

Figure 6-9 Test results for coexistence between TDD and WiFi

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Based on current WiFi industry, WiFi devices will be severely interfered when coming into TD-LTE coverage (2.3GHz, 2.6GHz) and LTE FDD coverage (2.6GHz). In order to reduce the RF interference from TD-LTE, new WiFi blocking index should be defined and certified for WLAN AP and station, which are discussed in OMTG of WiFi Alliance [6] to reach a consensus with Equipment Manufacturers.

2) In-device coexistence

An increasing number of UEs are equipped with multiple radio transceivers, which brings challenge lies to avoid in-device coexistence interference between those radio transceivers. The interference scenarios of LTE in-device coexistence include LTE coexisting with WiFi, Bluetooth, and GNSS.

There are two kinds of solutions for in-device coexistence interference avoidance, LTE network-controlled UE-assisted solutions and UE autonomous solutions [7]. For the former, WiFi within the UE is aware of possible coexistence problems and the UE can inform the network about such problems, and it is then mainly up to the network to decide how to avoid coexistence interference. For the latter, the UE coordinates itself between WiFi and LTE, and the network is not aware of the coexistence issue possibly experienced by the UE and is therefore not involved in the coordination.

Some details for the solutions are presented as below, and these solutions are suitable for both LTE FDD and TD-LTE.

- LTE network-controlled UE-assisted solutions
  - FDM solution

It avoids interference from one radio to another radio by frequency separation, which will lead WiFi radio signal away from LTE frequency band in frequency domain or lead LTE signal away from ISM band in frequency domain. The UE informs the E-UTRAN when transmission/reception of LTE or WiFi signal would benefit or no longer benefit from LTE not using certain carriers or frequency resources.

- TDM solutions

It avoids interference from one radio to another radio by time separation of their activities. The UE can signal the necessary information, e.g. interferer type, mode, and possibly the appropriate offset in subframes to the eNB. Based on such information, the final TDM patterns are configured by the eNB.

- LTE power control solutions

To mitigate coexistence interference to WiFi DL reception, it reduces LTE transmission power. The UE can report the need for power reduction to the eNB.

- UE autonomous solutions
  - TDM solutions

UE can autonomously deny LTE resources due to some critical short-term events of ISM side and protecting ISM data packets during stable situation of ISM operation. Also, UE can autonomously deny ISM transmissions to ensure successful reception of important LTE signalling.

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