GTI TDD Spectrum White Paper

GTI

http://www.gtigroup.org

GTI TDD Spectrum White Paper

Version	V4.0
Deliverable Type	□ **Procedural document** **√ Working document**
Confidential Level	**√Open to GTI operator members** **√Open to GTI partners** **√ Open to public**
Program	**4G evolution**
Working Group	**Spectrum WG**
Project	**Project 1: TDD Spectrum Whitepaper**
Task	TDD Spectrum Whitepaper
Source Member	CMCC, Huawei, Ericsson, CICT, UNISOC, ZTE
Support Member	
Last Edit Date	6-5-2019
Approval Date	DD-MM-2019

Document History

Date	Meeting #	Version #	Revision Description
6-5-2013		V1.0	Draft for discussion
7-18-2013		V2.0	Internal review of spectrum WG
6-27-2016		V3.0	Updated the WP in spectrum WG.
9-2-2016		V3.1	Updated the WP in spectrum WG.
5-6-2019		V4.0	Updated the latest status and recommendations.

Table of contents

1. Executive Summary

To provide information and suggestions for facilitating the efficient utilization and fast deployment of TD-LTE globally and smooth evolution to 5G NR, this white paper summarizes the advantages of TDD spectrum, driving forces of rapid TDD network deployment and fast TDD spectrum allocation for 5G. Further, spectrum-related issues on TDD applications and network deployment are discussed and corresponding solutions for commercial deployment are presented. Also, this white paper identifies major TDD market trends as follows:

- TDD spectrum is becoming more and more important with new values: the rapid development of new technologies such as massive MIMO and mature industry ecosystem and smooth evolution to 5G.
- F As the demand for unlimited packages and wireless home broadband grows, TDD network deployment is accelerating around the world to effectively resolve capacity and experience issues with evolution capabilities.
- TDD spectrum allocation has become a major concern of national regulators. TDD spectrum (for example, 2.3 GHz, 2.6 GHz, 3.5 GHz, and 4.8 GHz) allocation is accelerating , not only to meet the network requirements in the short term, but also to meet the strategic requirements for telecommunication industry development in the long term.

To facilitate fast TD-LTE and NR deployment , this white paper also provides the following recommendations and suggestions for operators, standardization organizations, and regulators:

- **Accelerate the allocation of TDD spectrum (especially 2.3 GHz, 2.6 GHz, 3.5 GHz, and 4.8 GHz bands) to break through the 4G traffic bottleneck and quickly evolve to 5G.**
- **Guide reasonable spectrum pricing and issue nationwide exclusive licenses with a 15- to 20-year validity period. This plays a fundamental role in maintaining the flourishing development of the mobile industry while advancing rapid deployment of wireless infrastructure.**
- **Contiguous TDD spectrum assignments employing wide blocks is beneficial for improving mobile broadband experience and spectrum efficiency of networks. 2.6 GHz (band 41) is recommended for contiguous TDD spectrum allocation leveraging the large bandwidth**
- **New spectrum assignments must be technology and service neutral**
- **Synchronized operation amongst TDD networks is recommended for best spectrum utilization**
- **Speed up the reclaiming of TDD spectrum still occupied by old technologies or satellites and re-assign these resources to improve spectral efficiency and contribute to economic development.**

2. Abbreviations

Term	Description
TDD	Time Division Duplexing mode
TD-LTE	Time Division Long Term Evolution
5G NR	5G New Radio
FWA	Fixed Wireless Access
CA	Carrier Aggregation
MIMO	multiple-input multiple-output
CAGR	Compound Annual Growth Rate
LSA	Licensed Shared Access
LTE FDD	Long Term Evolution Frequency-Division Duplexing
MBB	Mobile broadband
MIIT	Ministry of Industry and Information Technology of China
ITU-R	International Telecommunication Union - Radio communication Sector
WRC	World Radio communication Conferences
IMT	International Mobile Telecommunications

3. Introduction

3.1 Background

Today, TD-LTE growth is accelerating around the world in terms of operator commitments and commercial launches as well as subscriber numbers. By Nov, 2018, 147 TD-LTE networks were commercially launched in 73 countries. The growth rate has reached 145% CAGR in the past six years in terms of TD-LTE network quantity. China Mobile has deployed the world's largest TD-LTE network, which serves 723 million TD-LTE subscribers and contains more than 2 million TD-LTE base stations. Many other operators are about to deploy commercial TD-LTE systems, or are engaged in trials and studies.

As 5G is entering the commercialization stage, unpaired spectrum (TDD, or Time Division Duplexing mode) is increasingly crucial. 224 operators in 88 countries are investing in 5G networks in the form of tests, trials, pilots, planned and actual deployments, most of which are using 3.5 GHz (band 42/43 or n77/78) and 2.6 GHz (band 41 or n41) TDD spectrum.

TD-LTE has already become 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 mature products including system equipment, chipsets, 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. Statistics show that by the end of March 2019 there were over 5889 TD-LTE terminals and 3973 of them are TD-LTE smartphones.

Spectrum always plays a central role in mobile communications. A significant amount of unpaired spectrum has been assigned for TDD networks, facilitating deployment of TD-LTE and 5G NR networks with smooth evolution.

3.2 Objectives

The objective of this white paper is to present a common view amongst GTI members about TDD Spectrum availability and utilization for both TD-LTE and 5G NR with smooth evolution. Aligning the views allows the TDD Industry to work towards the same targets and achieve economies of scale resulting in cost efficient network deployments and affordable services.

This White paper covers:

- Drivers for TDD spectrum demand
- Acceleration of TDD network deployment
- Acceleration of TDD spectrum allocation
- TDD network deployment aspects
- TDD standardization roadmap
- TDD related recommendations for regulators and operators

4. What is driving the demand for TDD spectrum

Utilization of TDD technology offers significant advantages with respect to spectrum efficiency, network performance and capacity and it offers a viable evolution path from 4G towards 5G networks and services.

4.1 Advantages of TDD technology

TDD facilitates advanced antenna solutions, like 8T8R and Massive MIMO

Due 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 great advantages in multiple-antenna technologies.

TDD 8T8R uses 8 transmit antennas and 8 receive antennas for better capacity and coverage. 8T8R has already become the major deployment mode for TDD networks. TDD 8T8R can improve network capacity by up to 1.7 times (vs 4T4R).

Massive MIMO has been widely regarded as an ever energizing technology since 4G rollout. It leverages the unrivaled advantages of LTE TDD spectrum to achieve revolutionary breakthroughs in network performance for operators. By adopting massive antenna arrays, massive MIMO brings about three- to five-fold increase in spectral efficiency when compared with traditional macro sites.

TDD supports traffic asymmetry efficiently and flexibly by adaptive UL/DL configuration

The UL/DL adaptivity of TDD allows for the adjustment of the downlink and uplink resource ratios. Downlink-to-uplink ratios can be e.g. 8:1, 3:1, 2:2 and 1:3. A downlink-oriented configuration fits perfectly with the current and foreseeable user behavior where streaming and data downloads use more downlink resources than uplink resources.

There are several predictions about the future trends for the traffic asymmetry. Cisco forecasts that there will be a dramatic increase in the downlink-oriented applications and that the use of DL-centric applications will result in more than 90% of mobile traffic being in the downlink in 2017.

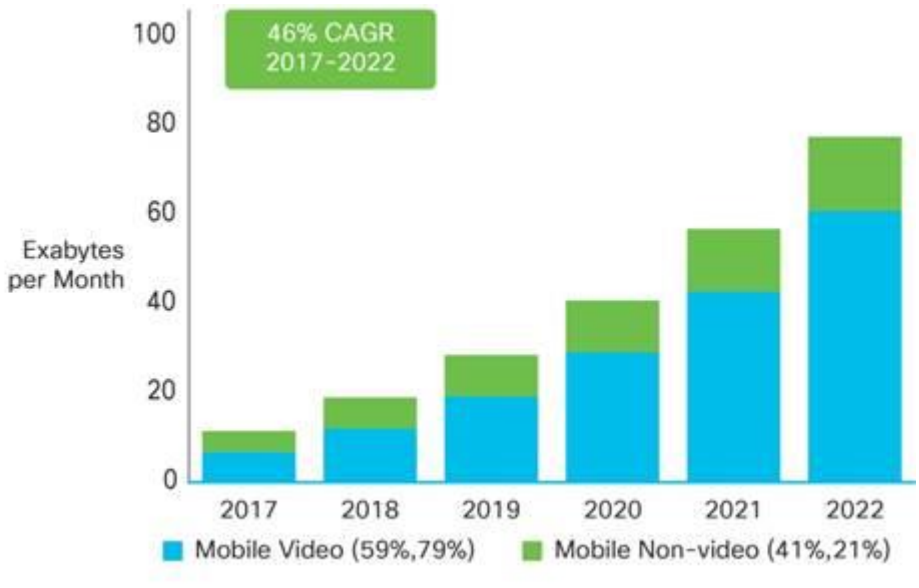


Figure 1: Cisco mobile traffic forecast

There are also other developments trying to solve the issue of traffic asymmetry for the FDD networks. There is an approach where additional bands have been designated for FDD DL only (also referred to as Supplementary Downlink or SDL). Such arrangements can provide some room for asymmetry. However in this case there is a technological limit for the achieved asymmetry, which means that for achieving high asymmetry there needs to be significantly more spectrum for DL traffic than for UL traffic. Spectrum allocations/assignments would need to be changed if efficient spectrum use is to be maintained; such changes require a time-consuming regulatory process and significant changes to network deployment. Clearly TDD enjoys an advantage over the FDD approach in dealing with traffic asymmetry and TDD's adaptivity allows for system characteristics to match the data traffic characteristics they are serving.

Unpaired TDD bands can be made available more easily than paired bands

High performing mobile networks requires wide channel bandwidths; currently spectrum between 2GHz to and 5GHz are the best candidates for obtaining these wide channels. From a spectrum management perspective there are challenges making sufficient spectrum and wide channels available. Unpaired spectrum bands are generally easier to make available than paired bands simply because re-farming of one band is easier than re-farming two equally wide bands. This benefit is becoming increasingly important as re-farming of spectrum is the main source of new mobile spectrum.

From a worldwide regulatory perspective WRC-19 (part of ITU-R) is expected to identify a significant amount of new, additional spectrum for IMT which will be used by 5G. This new spectrum will undoubtedly include unpaired bands that can be used by TDD.

4.2 The driving force of accelerating TDD network deployment

Since the release of last version of TDD spectrum white paper in 2016, TDD network deployment has paced up. The driving forces come from the MBB traffic surge, growing fixed wireless broadband demand, and 5G network deployment.

TDD Breaks Through Network Capacity Bottleneck and Improves User Experience

With the growing popularity of mobile networks and explosive growth of smartphones, users' usage habits have dramatically changed, especially as more and more unlimited tariffs are launched in the market. The exploration of mobile broadband access capacity significantly stimulates the demand for mobile networks and boosts the growth in mobile data services, which in turn increases the demand for mobile network capacity.

TDD has large bandwidth advantage naturally. There will be a total of 1540 MHz spectrum resources and 100 – 400 MHz bandwidth per frequency band by 2020. The average bandwidth of TDD spectrum owned by global operators exceeds 60 MHz. Investments in TDD spectrum can lead to multiple-fold increase in capacity. Therefore, more and more TDD networks are deployed based on existing sites to meet the large traffic demand and improve user experience.

For example, TDD networks have been rapidly deployed in the Indian market due to the mobile broadband traffic surge since 2016. Currently, there are 500,000 TDD sites in the Indian market. Similar conditions occur in Indonesia and Thailand.

TDD Boosts Fixed Wireless Broadband Rapid Development

Over the past five years, 230 operators in 124 countries around the world have deployed fixed wireless broadband networks for 75 million households, enterprises, schools and hospitals. More than 70% of operators with over one million fixed wireless broadband users uses TDD technologies during deployment. Their networks leverage large bandwidth of TDD spectrum to quickly improve site capacity and use multiple-antenna technologies to improve spectral efficiency. As a result, the cost per bit for fixed wireless broadband networks is reduced significantly, which is the key to business profitability.

FMA+Mobile convergence is a trend for FMC strategies adopted by operators. More and more hybrid networks are emerging to support both mobile broadband and fixed wireless broadband services. These networks usually leverage large bandwidth of TDD spectrum and multiple-antenna technologies to significantly reduce the cost per bit for fixed wireless broadband services and improve user experience of mobile broadband services.

TDD Supports Smooth Evolution to 5G NR and Provides 4G and 5G Services Simultaneously

The main 5G spectrum used during initial deployment is 3.5 GHz (band 42/43 or n77/78) and 2.6 GHz (band 41 or n41) bands, both of which are TDD spectrum. According to the industry vendor survey, TD-LTE and 5G share the same hardware, including end-to-end network infrastructure such as RF and baseband modules and power supply system.Lastly, the flexible Software Defined Radio technology enables the smooth evolution from TD-LTE to 5G NR. Thus, TD-LTE and 5G networks can be jointly planned, deployed and optimized.

It takes time to establish the 5G ecosystem. Many operators deploy TDD networks for both current revenue and smooth evolution to 5G NR in the future. Some operators choose the strategy called One Network, Dual Usage, i.e. performing both 5G and 4G services on the same network, mainly on 2.6 GHz or 3.5 GHz band. This strategy is a method for operators to obtain higher return on investment.

1) In the early stage of network deployment, 4G services are mainly provisioned, which brings quick return and a better brand image for 5G services.
2) The LTE TDD and 5G NR spectrum sharing technology can dynamically allocate the spectrum for LTE TDD or 5G NR based on the traffic load to maximize the spectrum value.
3) In the late stage of network deployment, spectrum can be refarmed for 5G NR when the penetration rate of 5G terminals reaches a preset threshold.

5. TDD spectrum in the world

TDD spectrum availability depends on regulatory decisions made at both the global level and on the national level and is usually based the market demand. While ITU-R is responsible for spectrum allocations globally, national administrations are responsible for licensing and assigning spectrum for operators. In some cases there is also relevant regulation on the Regional level, like within the European Union.
In addition to the regulatory process, the issue of spectrum is addressed also by standardization. 3GPP defines spectrum bands for TDD based on how the products will need to use the spectrum. This chapter addresses how TDD bands are defined both within regulation and standardization.

5.1 ITU progress

The ITU-R Radio Regulations (RR) identifies the spectrum for IMT (International Mobile Telecommunications), which comprises of IMT-2000, IMT Advanced and IMT-2020 technologies, also known as 3G, 4G and 5G cellular technologies. A commonly used term for both 3G and 4G is Mobile Broadband or “MBB”.
Spectrum identifications are done individually for each of the three ITU Regions. In some cases the allocations and identifications are global, covering all three Regions.
The ITU-R has identified the spectrum for IMT in several World Radio communication Conferences (WRCs), and currently identified spectrum for IMT is a result of decisions taken by WARC-92, WRC-2000, WRC-07, WRC-12, and WRC-15.
In addition to the allocations and identifications, the ITU-R developed spectrum arrangements for all bands identified for IMT which are presented in the ITU-R Recommendation M.1036. The spectrum arrangements define whether TDD or FDD arrangements are to be used in a particular band. There is a clear trend that more recently identified bands are unpaired bands and have TDD band plans defined for them.

Frequency Band (MHz)	Footnotes identifying the band for IMT		
	Region 1	Region 2	Region 3
450-470	**5.286AA**		

Frequency Band (MHz)	Footnotes identifying the band for IMT		
	Region 1	Region 2	Region 3
470-698	**-**	**5.295, 5.308A**	**5.296A**
694/698-960	**5.317A**	**5.317A**	**5.313A, 5.317A**
1 427-1 518	**5.341A, 5.346**	**5.341B**	**5.341C, 5.346A**
1 710-2 025	**5.384A, 5.388**		
2 110-2 200	**5.388**		
2 300-2 400	**5.384A**		
2 500-2 690	**5.384A**		
3 300-3 400	**5.429B**	**5.429D**	**5.429F**
3 400-3 600	**5.430A**	**5.431B**	**5.432A, 5.432B, 5.433A**
3 600-3 700	**-**	**5.434**	**-**
4 800-4 990	**-**	**5.441A**	**5.441B**

In the study period WRC-19, considering identification of frequency bands for the future development of International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution **238 (WRC-15)** was conducting under WRC-19 Agenda Item 1.13. The most likely outcome is that new, additional spectrum will be identified for IMT at WRC-19 and that the spectrum arrangements for the identified bands will be developed around 2020. Until that time the currently identified bands need to fulfil new spectrum requirements. There are currently 11 candidate bands in the range above 24 GHz. Most of them can offer very wide bandwidths, much wider than those. It is expected that most, if not all of the new spectrum bands will be unpaired with TDD playing a significant role.
TDD spectrum availability is different in the three ITU Regions due to different identifications, but also due to different national availability. The regional difference can be generalized as shown below. Thus, similar to FDD, TD-LTE devices have to perform global roaming in multiple bands.

WRC-19 AI 1.13 searches for the frequency band within the 24 – 86 GHz of the IMT system. The candidate frequency bands include 24.25 – 27.5 GHz (26 GHz), 31.8 – 33.4 GHz (32GHz), 37 – 43.5 GHz (40 GHz), 40.5 – 43.5 GHz, 45.5 – 47 GHz, 47.2 – 50.2 GHz, 50.4 – 52.6 GHz, 66 – 71 GHz, 71 – 76 GHz and 81 – 86 GHz.

5.2 3GPP LTE TDD bands specifications

3GPP defines TDD bands and their variants that are to be implemented in actual products (see Table 2-1). Most of the current TDD products operate at frequencies around 1.9GHz, 2.3GHz, 2.6GHz, 3.5GHz and 3.7GHz.

Table 2-1: LTE TDD and FDD Bands standardized by the 3GPP R15 3GPP TS 36.101 V15.0.0 (2017-09); 3GPP R15 09-2017

TDD LTE BANDS & FREQUENCIES		
LTE BAND NUMBER	**ALLOCATION (MHz)**	**Bandwidth (MHz)**
33	1900–1920	20
34	2010 – 2025	15
35	1850 – 1910	60
36	1930 – 1990	60
37	1910 – 1930	20
38	2570 – 2620	50
39	1880 – 1920	40
40	2300 – 2400	100
41	2496 – 2690	194
42	3400 – 3600	200
43	3600 – 3800	200
44	703 – 803	100
45	1447 – 1467	20
46	5150 – 5925 (unlicensed) Note: "offload" use only	775
47	5855 – 5925 (unlicensed) Note: "offload" use only	70
48	3550 – 3700	150

5.3 3GPP 5G NR bands specifications

An overview of 3GPP NR bands in sub-6GHz frequency range are provided in Table 2 and Table 3 below, for refarming bands and new bands, respectively. Those bands are defined in Rel-15, and have been selected based on operators‘ requests (subject to time available to complete all the UE/BS RF requirements of the band). Additional bands will be defined in later release but in release independent manner, if requested by operators.

Overview of 3GPP 5G bands specified in Rel-15 (as of Sept 2018)

- **FR1 (frequency range 1)**

NR operating band	Uplink (UL) operating band BS receive / UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit / UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n34	**2010 MHz – 2025 MHz**	**2010 MHz – 2025 MHz**	**TDD**
n38	**2570 MHz – 2620 MHz**	**2570 MHz – 2620 MHz**	**TDD**
n39	**1880 MHz – 1920 MHz**	**1880 MHz – 1920 MHz**	**TDD**
n40	**2300 MHz – 2400 MHz**	**2300 MHz – 2400 MHz**	**TDD**
n41	**2496 MHz – 2690 MHz**	**2496 MHz – 2690 MHz**	**TDD**
n50	**1432 MHz – 1517 MHz**	**1432 MHz – 1517 MHz**	**TDD**
n51	**1427 MHz – 1432 MHz**	**1427 MHz – 1432 MHz**	**TDD**
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL
n77	**3300 MHz – 4200 MHz**	**3300 MHz – 4200 MHz**	**TDD**
n78	**3300 MHz – 3800 MHz**	**3300 MHz – 3800 MHz**	**TDD**
n79	**4400 MHz – 5000 MHz**	**4400 MHz – 5000 MHz**	**TDD**
n80	1710 MHz – 1785 MHz	N/A	SUL
n81	880 MHz – 915 MHz	N/A	SUL
n82	832 MHz – 862 MHz	N/A	SUL
n83	703 MHz – 748 MHz	N/A	SUL
n84	1920 MHz – 1980 MHz	N/A	SUL
n86	1710 MHz – 1780 MHz	N/A	SUL

- **FR2 (frequency range 2)**

Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
n257	26500 MHz	–	29500 MHz	26500 MHz	–	29500 MHz	TDD
n258	24250 MHz	–	27500 MHz	24250 MHz	–	27500 MHz	TDD
n260	37000 MHz	–	40000 MHz	37000 MHz	–	40000 MHz	TDD
n261	27500 MHz	–	28350 MHz	27500 MHz	–	28350 MHz	TDD

Currently core bands for TDD are 1.9GHz, 2.0GHz, 2.3GHz and 2.6GHz, which accounts totally about 440MHz bandwidth spectrum. In future, new candidate bands e.g. 3.5GHz and 3.7GHz would bring additional 400MHz bandwidth spectrum for TDD.

5.4 Latest Status of Dedicated band

1.9 GHz/2.0 GHz

Allocated in Region 1 and region 3, Small bandwidth (15MHz~20MHz) with low propagation loss and penetration loss.

In region 1, 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.

In region 3,Spectrum of 1880-1920MHz is allocated as Band 39 for LTE TDD in China.

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.

2.3 GHz

For 2.3GHz, non-mobile service is operated at the band in most countries and only in small number of countries, mobile service is operated.

In EU, current usage is complex. LSA (licensed shared access) is hot issue in the discussion in possible usage ways, but and maybe, could be static (without consequence on the 3GPP standard). According to ECC WG FM questionnaire, there are 12 countries that have no plan in addition to use current non-MBB and 5 countries that might support an EC/ECC harmonization.

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

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

Region	Country	Operator	Band	Bandwidth(MHz)
Region1	Saudi Arabia	STC	TDD band 40	100
Region3	Thailand	DTAC	TDD band 40	60
Region3	India	Bharti Airtel	TDD band 40	30
Region3	Indonesia	Telkomsel	TDD band 40	30
Region1	Oman	Omantel	TDD band 40	30
Region3	China	China Mobile HK	TDD band 40	30
Region3	China	3HK	TDD band 40	30
Region3	Sri Lanka	Dialog	TDD band 40	75
Region1	South Africa	Telkom	TDD band 40	60
Region3	Australia	Optus	TDD band 40	98
Region1	Nigeria	Spectranet	TDD band 40	20
Region3	China	China Mobile	TDD band 40	50
Region3	Sri Lanka	Lanka Bell	TDD band 40	16
Region3	Philippines	Smart	TDD band 40	60
Region3	Philippines	Globe	TDD band 40	30
Region1	Côte d'Ivoire	Orange	TDD band 40	30
Region3	India	VIL	TDD band 40	10
Region1	Oman	Ooredoo Oman	TDD band 40	30
Region2	Peru	Americatel (Entel)	TDD band 40	30
Region3	Indonesia	Smartfren	TDD band 40	30
Region1	Tanzania	TTCL	TDD band 40	70

It is recommended that 2.3 GHz and 2.6 GHz frequency bands be allocated at the same time in a coordinated way. It helps get large contiguous bandwidth for more operators in a fair way. The Saudi Arabian regulatory authority has already allocated 2.3 GHz and 2.6 GHz at the same time, one operator getting 100 MHz bandwidth of band 40 while the other two share 190 MHz bandwidth of band 41.

2.3 GHz is supported by a large proportion of LTE terminals. By March 2019, up to 80.4% of LTE terminals support 2.3 GHz.

2.6 GHz

This band was earlier allocated to WiMAX. Many operators hold the spectrum more than 20MHz. In recent years, the band already is allocated to LTE application in Europe, US, China, etc. Although the band is intended for global harmonization, actually there are two streams for allocation.

- Option1: sandwich allocation, mainly in EU (Region1)

In case of coexistence between TDD BS and FDD BS with the same class, guard band is necessary to avoid interference. Guard band ranges from 5 MHz to 10 MHz depending on the scenarios.

- Option2: all band for TDD, or there is no FDD allocation in the band, mainly in the US and China

It can be estimated that operators may share the TDD band.

There are two bands embracing 2.6 GHz. Most of the countries and regions in the world (such as the USA, India, Saudi Arabia, and China) have adopted band 41 with a total of 194 MHz (2496 – 2690 MHz). Another is band 38 with a total of 50 MHz bandwidth (2570 – 2620 MHz).

During earlier spectrum allocation in most countries, the 2.6 GHz band was allocated using band 38. Now, it is allocated using band 41 for smooth evolution to 5G as large contiguous bandwidth is required for 5G.

Region	Country	Operator	Launch	Band	Remarks
Region1	Poland	Aero2	2011	TDD band 38	
Region3	Japan	SoftBank（WCP)	2011	TDD band 41	
Region2	Brazil	Sky Brazil	2011	TDD band 38	
Region1	Sweden	3 Sweden	2012	TDD band 38	
Region1	Russia	Megafon/Yota	2012	TDD band 38	
Region1	Russia	MTS Russia	2012	TDD band 38	
Region2	Brazil	On Telecomunicacoes	2013	TDD band 38	
Region1	Spain	COTA (Murcia4G)	2013	TDD band 38	
Region1	Uganda	MTN Uganda	2013	TDD band 41	
Region1	Spain	Vodafone	2013	TDD band 38	
Region2	USA	Sprint	2013	TDD band 41	
Region2	Canada	Sasktel	2013	TDD band 41	
Region3	Japan	KDDI(UQ Communications)	2013	TDD band 41	
Region3	China	China Mobile	2013	TDD band 41	
Region1	Ghana	NITA(National Information Technology Agency)	2014	TDD band 41	
Region3	China	China Telecom	2014	TDD band 41	
Region3	China	China Unicom	2014	TDD band 41	
Region1	Madagascar	Blueline	2014	TDD band 41	
Region2	Colombia	DirecTV Colombia	2014	TDD band 41	
Region1	Angola	Net One	2014	TDD band 41	
Region1	Ghana	Blu Telecoms(G-kwiknet)	2014	TDD band 41	

Region3	Bangladesh	Banglalion	2014	TDD band 41	
Region1	Canada	Xplornet	2014	TDD band 38	
Region2	Trinidad and Tobago	TSTT	2014	TDD band 41	
Region3	Philippines	Smart	2014	TDD band 41	
Region3	Philippines	Globe	2014	TDD band 41	
Region1	Uganda	Vodafone (Afrimax)	2015	TDD band 38	
Region2	Dominican R.	Wind Telecom	2015	TDD band 41	
Region1	Romania	Idilis/2K Telecom	2015	TDD band 38	
Region1	USA	Speedconnect	2015	TDD band 41	
Region1	USA	Redzone Wireless	2015	TDD band 41	
Region1	Finland	Ukko Mobile	2015	TDD band 38	
Region1	Romania	DigiMobil (RCS & RDS)	2015	TDD band 41	
Region1	Netherlands	T-Mobile Netherlands	2015	TDD band 38	
Region1	Cameroon	MTN	2015	TDD band 41	
Region1	Saudi Arab	Mobily	2018	TDD band 41	
Region1	Saudi Arab	ZAIN	2018	TDD band 41	
Region3	India	VIF	2019	TDD band 41	
Region1	Bahrain	ZAIN	2019	TDD band 41	To be released
Region1	UAE	DU	2019	TDD band 41	To be released
Region1	South Africa	Telkom	2019	TDD band 41	To be released
Region3	Sri Lanka	Dialog	2019	TDD band 41	To be released
Region3	Thailand	DTAC	2019	TDD band 41	To be released

C-Band 3.5 GHz has been used by satellites or for military purpose in many countries such as Vietnam, Thailand and Malaysia. The 2.6 GHz band featuring large contiguous bandwidth and good propagation characteristic facilitates evolution to 5Gcompared with mmWave spectrum.

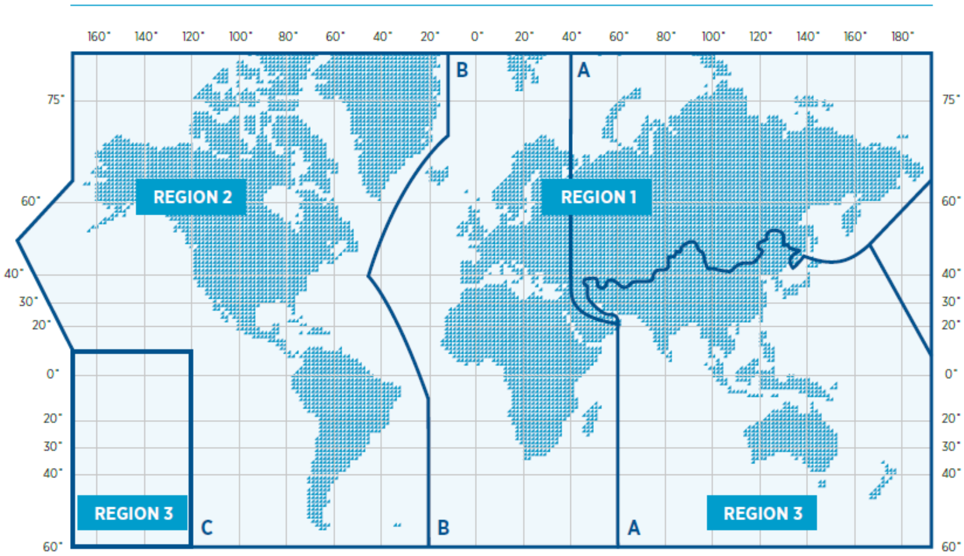
3.5 GHz

The 3.5 GHz IMT range between 3.3 GHz and 3.8 GHz. The band will be one of the first frequencies to carry 5G traffic, making it a critically important band for mobile operators seeking to offer the power of next generation mobile services to consumers and businesses. And in the process, give their respective national economies a boost.

After the identification of part of the range at WRC-07, a much broader identification was achieved at WRC-15 with a harmonised International Mobile Telecommunication (IMT) identification for 3.4-3.6 GHz throughout Regions 1 and 2 and in many countries in Region 3.

In addition to this, large parts of Africa along with some countries in Latin America and Asia

Pacific added the 3.3-3.4 GHz band to the range and some countries in Region 2 added 3.6-3.7 GHz to their IMT identifications at WRC- 15. European Union countries have decided to also use 3.6-3.8 GHz for mobile broadband services. A number of major Region 3 countries have announced their intention to also make available the 3.6-3.7 GHz band for IMT, as part of their allocation to the mobile service.



Where is your 3.5 GHz IMT range?

3.3-3.4 GHz	A majority of Africa, some countries in Regions 2 and 3
3.4-3.6 GHz	Region 1, Region 2 and large parts of Region 3
3.6-3.7 GHz	Some countries in Region 2. Some countries in Region 3 (including Australia, Korea, Japan, New Zealand) have also indicated interest.
3.6-3.8 GHz	Harmonised for mobile broadband use throughout the European Union by European Decision. GCC countries have also indicated interest.

Source:https://www.gsma.com/spectrum/wp-content/uploads/2018/12/Considerations-for-the-3.5-GHz-IMT-range-v2.pdf

4.8 GHz

3GPP has defined band n79 (4.4 – 5.0 GHz) for 5G.

In China, 4.4 – 4.5 GHz is revised in the updated Chinese Frequency Table so that mobile services can be performed on such band. China has proposed this band as one of 5G frequency bands. However, the existing systems working on this band still need to operate

for some time and refarming this band for 5G allocation will take more time.
In China, 4800 – 5000 MHz are allocated as IMT-2020 operation bands in the current MIIT released public consultation for the notification on 5G IMT system (IMT-2020).
In Japan, 4400 – 4900 MHz was allocated to be a 5G band.
Strong demand from China and Japan may drive the equipment availability since the specifications are finalized. GTI will continue to drive the product maturity as soon as possible for operators to deploy network on these bands.

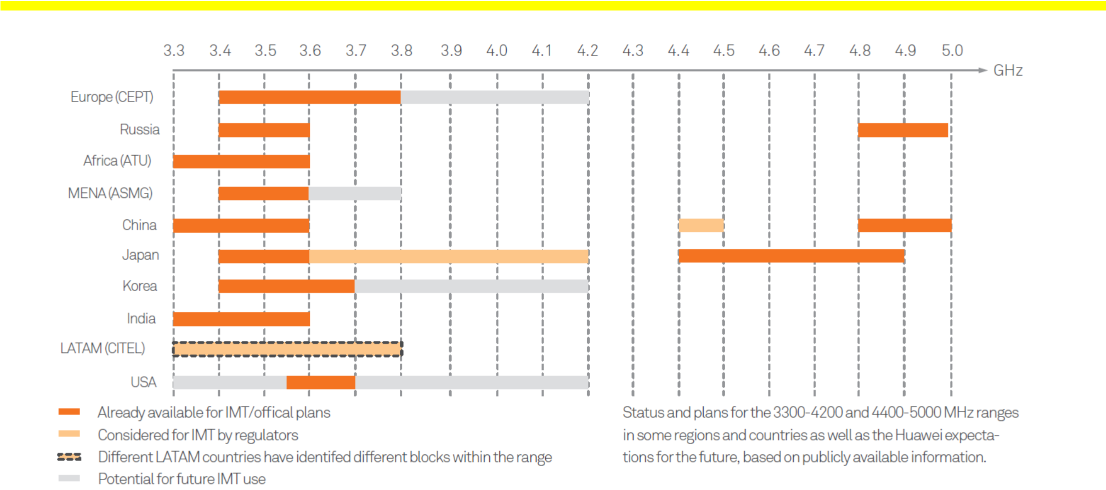
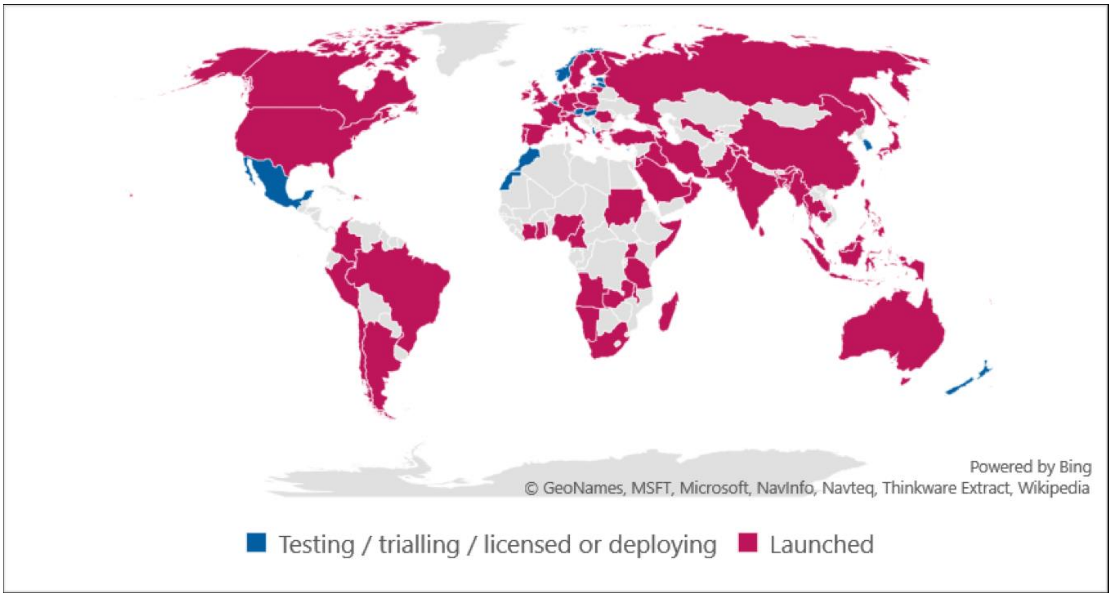


Figure 2: Global availability and planning of the 3300-4200 MHz and 4400-5000 MHz frequency ranges

6. TDD commercial deployment

Since the world‟s first commercial TD-LTE network was launched by Mobily of Saudi Arabian in September 2011, a total of 147 TD-LTE systems are commercially launched in 73 countries by November 2018.
By 8 April 2019, 13 operators have announced the launch of 3GPP-compliant 5G mobile or FWA services, most of which are using 3.5GHz (band 42/43 or n77/78) and 2.6GHz (band 41 or n41) TDD spectrum.



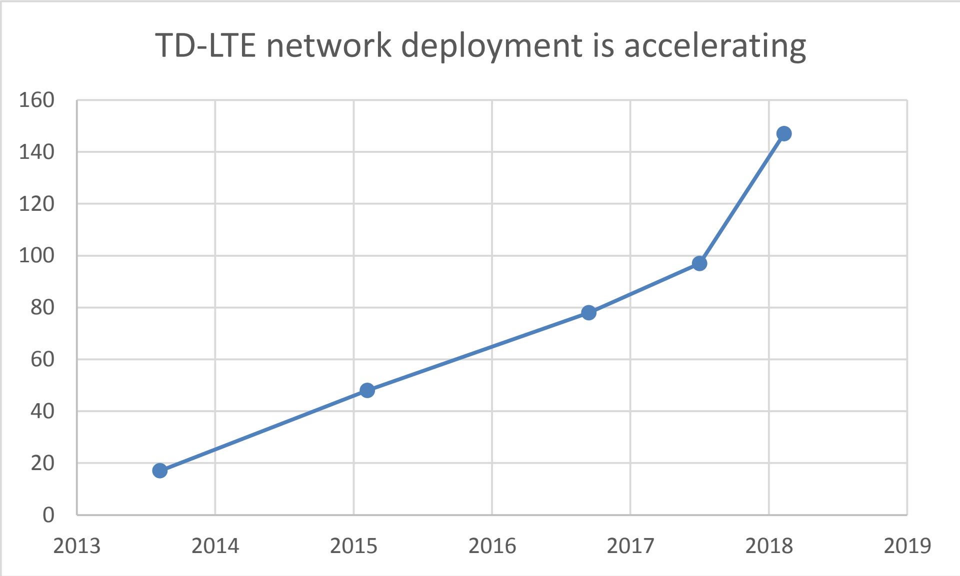
TDD has become a key LTE technology. GSA has identified:

- 219 operators that are investing in TD-LTE networks
- 207 operators in total hold licences to use TDD spectrum for LTE services
- 147 operators in 73 countries have launched TD-LTE networks
- A further 72 operators are either trialling, hold licences to use TDD spectrum, or are actively deploying TD-LTE networks
- Operators are investing in TD-LTE in some form or another in 87 countries

6.1 TDD network deployment is accelerating

The demand for larger mobile network capacity and better user experience is increasing dramatically when more and more unlimited tariffs are launched in the market and becoming the mainstream charging policy in the 4G era. Such capacity and experience demand results in fast TDD network deployment.

According to the industry information, all TDD hardware is ready for 5G and able to evolve to 5G smoothly. Operators can mitigate the network capacity bottleneck with 5G-ready TDD networks, so the total cost of ownership is reduced during 5G evolution.



6.2 Massive MIMO technology has already been widely deployed on TDD spectrum

Massive MIMO leverages the advantages of LTE TDD spectrum to achieve revolutionary breakthroughs in network performance for operators. By adopting massive antenna arrays, massive MIMO brings about three- to five-fold increase in spectral efficiency when compared with traditional macro sites.

Since the first products launched in 2016, massive MIMO has been widely adopted by operators and its capacity gain is validated on commercial networks. Nowadays, massive MIMO has already been deployed on more than 50 networks working on 2.3 GHz, 2.6 GHz, 3.5 GHz TDD spectrum.

6.3 TDD terminal penetration is accelerating

By the end of March 2019, the LTE-TDD user device ecosystem is well established with 5,889 devices, that is, 43% of LTE devices support the LTE-TDD (TD-LTE) mode, supporting the growing number of LTE operators using unpaired spectrum. The smartphone (3973 smartphones) is the largest device category supporting TDD.

Bands 40 (2.3 GHz) and 38 (2.6 GHz) have the largest choice of TDD terminals with bands 39 and 41 also being mature.

- Terminal support for band 40 = 80.4% (of LTE-TDD devices)
- Terminal support for band 38 = 62.0%
- Terminal support for band 41 = 59.7%
- Terminal support for band 39 = 45.1%

There is a good choice of multi-band and dual-mode FDD-TDD devices.

As a large scale of networks are deployed on band 41 (2.6 GHz), the number of devices supporting band 41 increases very quickly. iPhone6 and later models support band 41 since 2014. Main stream Android smartphone brands, such as Huawei, Samsung, Xiaomi, and Oppo support band 41 since July 2017.

Countries launched band 41 already covered over 3.2 billion population

Country	Operator	Population
China	China Mobile	1.4 billion
India	VIL (Vodafone， IDEA)	1.36 billion
Myanmar	Amara	54.2 million
Sri Lanka	SLT	21 million
Sri Lanka	Dialog, Mobitel (applying)	
Japan	KDDI（UQ Communications ）	1.26 billion
Japan	SoftBank	
United states	Sprint(SoftBank)	3.28 billion
Philippine	Smart(PLDT)	1.07 billion
	Globe Telecom	
UAE	Du	9.66 million
Saudi Arabia	Mobily(Etihad Etisalat)1	34 million
	Zain(Saudi Arabia)0	
Lebanon	OGERO	6.06 million
Iraq	Tishknet	40.27 million
Trinidad and Tobago	bmobile(TSTT) 1	1.37 million
Columbia	DTV	49.8 million
Angola	Net One	31.66 million
Algeria	Algeria Telecom 0	42.59 million
Guinea	Orange(Guinea)	13.35 million
	MTN	
	ETI	
Cameroon	MTN(Cameroon)	25.23 million
	Orange	
Cote d'Ivoire	MTN(Cote d-Ivoire)	25.53 million
Thailand	**Planned in 2019**	69.29 million

TDD band 41 ecosystem is already mature, and operators can easily improve the band41 device penetration rate in a short time. For example, Japan market deployed networks working on band 41 in 2016. The band 41 device penetration rate improved significantly, up to 90% by the end of 2018.

7. TDD Network deployment related aspects

This chapter summarizes some key issues and solutions related to TDD network deployment to be taken into account when TD-LTE networks are deployed globally.

7.1 TDD Bandwidth Requirements

Assignment of large contiguous bandwidths or large blocks is strongly recommended when spectrum is made available since they are better able to provide high data rates and cope with continued traffic growth.

Current bands for TDD are 1.9GHz/2.0GHz, 2.3GHz, 2.6GHz and 3.5GHz/3.7GHz. In total there is 755MHz of potential spectrum available. According to market information, the latest allocation for TDD bands are large contiguous bandwidths over 40 MHz or more which is also strongly recommended. Table 6-1 shows the newest allocation.

Table 6-1

Region	Country	Operator	Range(MHz)	Bandwidth(MHz)	Band
Region3	China	China Mobile	2515-2675	160	TDD Band 41
Region3	China	China Mobile	2320-2370	50	TDD Band 40
Region1	Saudi Arab	STC	2300-2400	100	TDD Band 40
Region1	Saudi Arab	Mobily	2500-2600	100	TDD Band 41
Region1	Saudi Arab	Zain	2600-2690	90	TDD Band 41
Region3	Philippines	Smart	2629-2690	61	TDD Band 41
Region3	Philippines	Globe	2500-2520 2555-2595	60	TDD Band 41
Region3	Thailand	TOT	2310-2370	60	TDD Band40

Besides contiguous bands, some operators have a few fragmented TDD bands. Most of these bands remain unused, especially 1.9 GHz in the EU. Table 6-2 shows an example of how TDD spectrum is assigned to operators in a European country. Each operator possesses only 5 MHz bandwidth of 1.9 GHz with no guard bands. For operators the economics of deploying a 5 MHz network are questionable. Narrow bands of 5MHz also pose a challenge for manufacturers to choose which bands to support in their devices.

Table 6-2

Operator	Downlink Frequency	Uplink Frequency	Bandwidth (MHz)
operator-1	1900	1905	5
operator-2	1905	1910	5
operator-3	1910	1915	5
operator-4	1915	1920	5

1900 – 1920 MHz (band 33) is licensed throughout the EU and 2010 – 2025MHz (band 34) is licensed in some EU countries but some spectrum remains unused.
Spectrum exchanges/pooling or use of carrier aggregation technology are potential solutions to utilize fragmented spectrum. Spectrum swaps (where they are allowed from a regulatory perspective) are common. CA (carrier aggregation) also provides a feasible solution to help aggregate an operator's fragmented spectrum.

7.2 TDD spectrum harmonization

Spectrum harmonization can help the TD-LTE ecosystem to gain from economies of scale and facilitate global roaming. Harmonized spectrum could also help manufactures to reduce the complexity of equipment design and boost investment in TDD infrastructure and devices.
The whole industry ecosystem of TD-LTE to deliver globally compatible LTE products, devices and chipsets is not a challenge now. Most of the cellphones support TDD band 40 and TDD band 41.
In the early stage of 5G service provisioning, the price of 5G terminals is high. Operators can deploy TDD and 5G at the same time to reduce costs. Therefore, the market has certain requirements for (CPE,MIFI) terminals of TDD 3.5G.

7.3 Coexistence issues

As TD-LTE grows in popularity more regulators are looking to make TDD channel assignments. Before the release of the spectrum and during the TD-LTE network deployment, some operators and regulators seek help from the GTI to resolve some coexistence issues they face. In this section, we summarize the common issues that are mentioned by regulators and operators and also recommend solutions to make TD-LTE deployment easier.
The most common coexistence issues related to TD-LTE deployment can be classified into the following scenarios:

- Between multiple TDD networks
- Between TD-LTE networks and LTE FDD networks
- Between TD-LTE networks and 5G networks
- Between TD-LTE networks and Satellite networks
- Between TD-LTE networks and Radar deployments
- Defragmentation needed as existing allocation is paired allocation in some administrations with Fixed broadband operation.

Multiple TDD networks coexistence issues

When several TDD networks are overlaid in the same geographic areas in the same band with adjacent channels, severe interferences of DL to UL or UL to DL may happen if the networks are uncoordinated. Using techniques like synchronization, sub-band filtering, site coordination and restricted blocks can efficiently resolve interference between TDD networks.

A better way to avoid interference is to synchronize neighbor BSs in order to make them transmit and receive at the same time. There are three mechanisms which are often used and have been mostly standardized by 3GPP, including synchronization by GPS/GNSS, synchronization over the backhaul network, and over-the-air synchronization. Synchronization is not only needed for the cells operating in the same frequency, but also for the cells operating in the same band if the guard band is not sufficient. This way to avoid interference is not only suitable for multiple LTE TDD networks but also suitable for multiple 5G networks, which actually have the same interference as LTE TDD networks.

TD-LTE network and LTE FDD network coexistence issues

Some regions and countries' operators have deployed large-scale LTE FDD networks. In these areas, TD-LTE and LTE FDD network interference need to be considered. BS-BS and UE-UE interference both exist in the mixed network.

According to the CEPT's rule [6], to avoid the BS-BS interference, two 5MHz guard bands shall be reserved between TDD and FDD, costly filters should be used at base stations, and thoughtful site deployment utilized. However, according to tests conducted by China Mobile [1], UE-UE interference still can't be solved due to cost and volume limitations of UE, which may result in high interference when UEs are close to each other. Additional approaches such as limiting UE data rates can be considered to mitigate the interference.

Although the coexistence between FDD and TDD can be solved, the band plan of mixed FDD and TDD should be avoided in general to avoid difficult interference scenarios and inefficient spectrum use.

TD-LTE network and 5G coexistence issues

LTE network and 5G network coexistence will last a long time when 5G begins and some regions and countries have already deployed 5G network on 2.6GHz and 3.5GHz, where there're already TD-LTE network deployed for many years, like China and UK etc.

The interference between TD-LTE and 5G NR can be easily mitigated by the synchronization operation with aligned sub-frame configuration.

For LTE TDD, frame configuration 2 is the most widely used frame structure, i.e., 3:1 DL/UL ratio with 5-ms DL/UL switching period, over 90 percent of commercial TDD networks adopted such configuration according to statistics. Then, the frame structure of 8:2 DL/UL ratio with 5-ms DL/UL switching period can be adopted for NR to attain synchronization with LTE TDD. In addition, the slot format configuration in NR is very flexible which can match all the configurations of special subframes in LTE. The only modification is to adjust the starting point of the frame as shown in below:

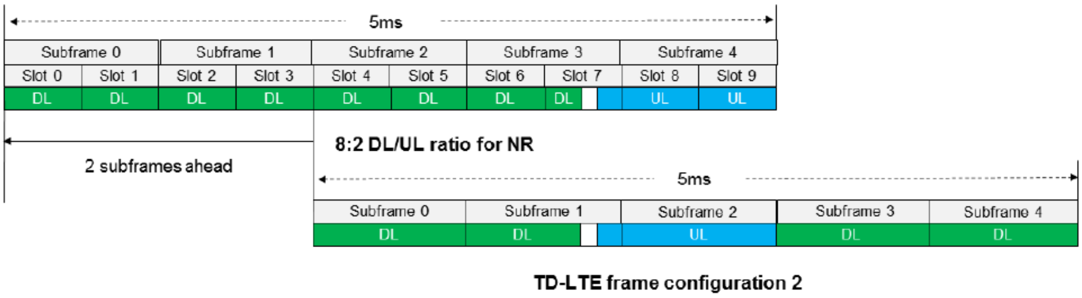


Figure 3: Frame structure of 5 ms DL/UL switching period

if 8:2 DL/UL is not applied to 5G configuration, extra guard bandwidth together with extra transceiver filters is required to mitigate Intra-site adjacent-frequency interference.

Between TD-LTE networks and Radar deployments

Military land based, ship-borne & airborne Radar's operate below 3400 MHz and will need to be protected from Interference from mobile use in adjacent band. Whilst is possible to avoid interference to fixed land based & ship based Radar's with exclusion zone around Radar deployments, avoiding interference to airborne Radar's may require guard bands between mobile and Radar allocation nationally. Co-existence is facilitated with a frequency separation between the Radar system and the Mobile allocation or with additional power restrictions. E.g. In UK, allocation starts at 3410 MHz whilst in Germany, frequency within 3400-3420 MHz has additional power restriction.

A common approach to start of mobile allocation across different administrations would benefit filter design and overall eco-system.

8. TDD Standardization Roadmap

LTE is a release-based technology family. In every one to two years, a new release of various key features is specified to meet the requirements of emerging use cases,
to support technologies from latest researches, and to address practical issues seen during real deployments.
In the past decade, the LTE family has grown to include LTE, LTE-Advanced, LTE-Advanced Pro and now its further evolution towards satisfying IMT-2020 (a.k.a. 5G) requirements and use cases. On one hand, LTE standards are evolving to ensure ubiquitous evolved mobile broadband (eMBB) experience in terms of delay, coverage, and throughput. On the other hand, LTE standards continue to develop to enable business expansion into vertical markets, e.g., IoT, V2X, unmanned aerial vehicles (UAVs), and industry automation by means of ultra-reliable low-latency communication (URLLC). In addition, LTE is evolving to support the operation of other RATs by means of technologies such as E-UTRAN/NR Dual Connectivity (EN-DC).

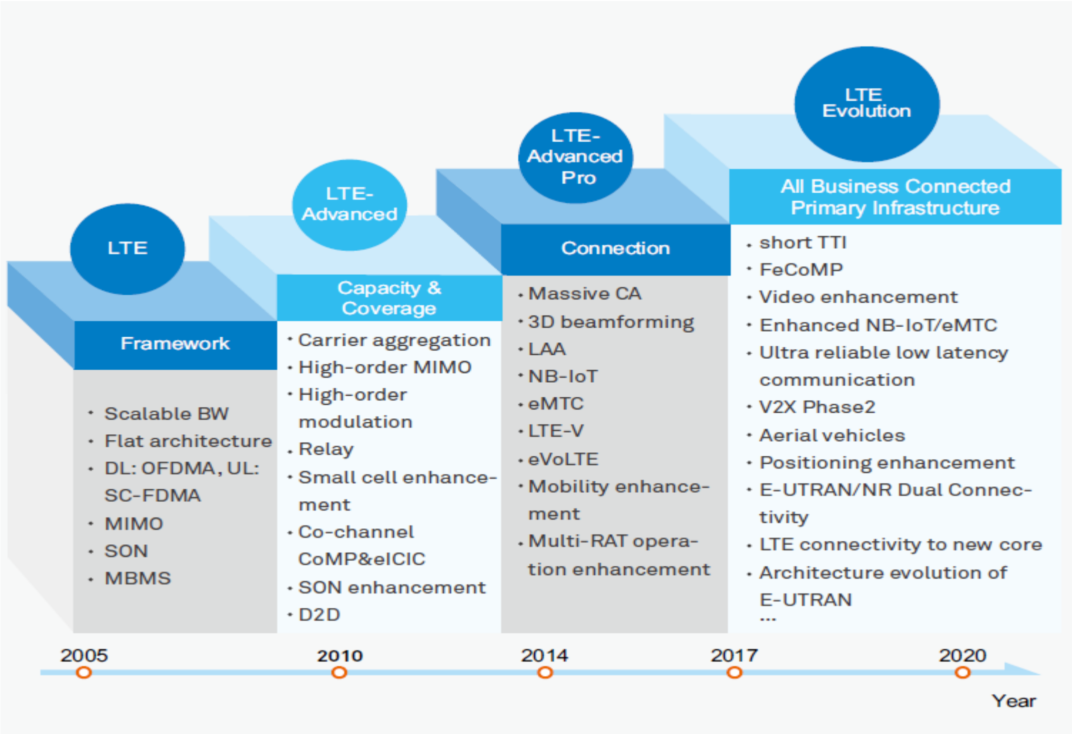


Figure 4: Key features of LTE and its evolution

Thanks to its technology advancement and well established ecosystem, LTE is the fastest developing mobile communications system ever. More than 700 LTE networks have been deployed for commercial use, serving 3.2 billion users (78% of the global population) and contributing to 66% of the operators' revenues on average. With its all business capabilities from voice to data and IoT, it is no surprise that LTE will gradually replace 2G and 3G as the foundation for the next decade in the 5G era.

SRS-related enhancements

SRS-related enhancements have been widely discussed in 3GPP in the previous releases as below.

- In Rel-8, SRS was specified to be transmitted in the last one symbol of the normal subrame and 1-2 symbols in the special subframes with antenna switching 1T2R.
- In Rel-13, with FD-MIMO features introduced, the SRS capacity could not satisfy the demands of the systems any more since more antennas need to be sounded to acquire the CSI. To increase the SRS capacity, the number of SRS symbols in special subframes increased from 2 symbols to at most 4 symbols and the Comb was also extend from 2 to 4 to support more users.
- In Rel-14, SRS carrier-based switching was supported to boost the downlink MIMO performance in asymmetric CA scenarios, e.g., DL 5CC with UL 2CC. In addition, up to 6 symbols in the special subframes were supported for SRS transmission.
- In Rel-15, the antenna switching of SRS was enhanced for 1T4R and 2T4R to achieve full CSI of each antenna at the UE side.
- In Rel-16, it was agreed that all the symbols (1 to 14 symbols) in the normal subframe

can be used for SRS transmission in order to further enhance the downlink performance. The capacity of SRS was 14 times larger than that in Rel-8. In this way, both the capacity and coverage performance of SRS could be significantly enhanced.

Large-Bandwidth Technology

Large bandwidth is one of the key technologies of 5G NR, up to 100 MHz in one carrier. The large-bandwidth technology reduces the guard band and increases scheduling efficiency, improving user experience.

LTE can also use large-bandwidth technologies to combine several carriers as a larger-bandwidth one.

Seamless joint of intra-band contiguous carriers can be utilized by the interference compensation and noise cancellation technologies to utilize the LTE guard band spectrum without increasing interference. It can reuse the guard band and release more RBs with large contiguous bandwidth.

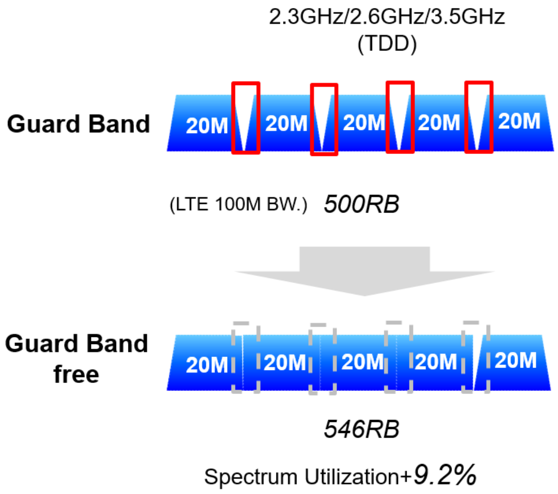


Figure 5: seamless joint of intra-band contiguous carriers

Furthermore, multiple carriers can be scheduled as one large-bandwidth single-carrier by artificial intelligence (AI) virtual grid technology with an inter-frequency information library. UE-level inter-frequency information and spectral efficiency can be predicted to perform rapid and accurate carrier selection. Secondary component carriers (SCCs) can be intelligently pre-scheduled based on the packet prediction model, and scheduling can be rapidly performed following an optimal scheduling path on the entire frequency band. In this way, the effect of small-bandwidth multi-carrier scheduling is similar to that of large-bandwidth single-carrier scheduling. The CA activation rate increases, and the user-perceived data rate improves by 20%–30%.

Interworking with NR/NG Core

Several network architecture options of the migration path were proposed during 5G study to enable smooth evolution towards 5G.

These options can be categorized as follows:
• Standalone NR connected to 5G new core (Option 2, no LTE involved)
• Standalone LTE connectivity to 5G new core (Option 5)
• LTE-NR DC (Options 3/4/7)
• Option 3 series: LTE as an anchor (EN-DC)
• Option 4 series: NR as an anchor (NE-DC)
• Option 7 series: NG-LTE as an anchor (NG EN-DC)
In R15, Option 3 was standardized at the end of 2017, Option 2/5 was standardized by June 2018, and Options 7/4 are planned to be finished before June 2019.

Massive MIMO

Massive MIMO is a key 5G feature which uses the beamforming technique to concentrate signals on each user, thereby increasing data rates, and reducing interference. It adopts large-scale antenna arrays that can control the width and tilt, both vertical and horizontal, for 3D beamforming. With the application of massive MIMO, regulatory masks need to be revised to support the statistical nature of massive MIMO antenna systems, and spectrum regulation management in terms of time , spatial, and direction domains need to be enhanced.

Duplex flexibility

Duplex flexibility is another important feature in 3GPP 5G standardisation providing flexible and dynamic use of paired and unpaired frequencies. The duplex flexibility allows smooth adaptation to the service requirements by allowing the DL spectrum resource to be used for UL transmission and vice versa.
The general concept of this fully flexible radio interface design will be introduced in 3GPP Release 15 specifications. The related band definition is likely to be part of Release 16 specifications.
Given the expected regulatory implications, the analysis at regulatory side should start in the near future to get regulatory frameworks prepared when the duplex flexibility feature is available.

9. Recommendations for TDD Spectrum Utilization

In order to accelerate the TDD development and boost operators' commercial success in 4G and 5G eras, we herein advocate the following suggestions.

1. Accelerate the allocation of TDD spectrum (especially 2.3 GHz, 2.6 GHz, 3.5 GHz, and 4.8

GHz bands) to break through the 4G traffic bottleneck and quickly evolve to 5G.

Spectrum management and regulations are recommended to harmonize the spectrum allocation to ensure quick and sufficient spectrum release and gurantee its value and competitiveness in markets. Release mid bands: C-band, TDD 2.6 GHz/2.3 GHz/4.8 GHz first, and then release other frequency bands step by step to meet different requirements.

You are advised to develop both 4G and 5G on TDD spectrum band 41 (2.6GHz) and C-Band (band 42/43) for a higher return on investment. It takes time to establish the 5G ecosystem. Many operators deploy TDD networks for both current revenues and smooth evolution to 5G NR in the future. Some operators choose the strategy called One Network, Dual Usage, i.e. performing both 5G and 4G services on the same network, mainly on 2.6 GHz or 3.5 GHz band. This strategy is a method for operators to obtain higher return on investment.

2. **Guide reasonable spectrum pricing and issue nationwide exclusive licenses with a 15- to 20-year validity period. This plays a fundamental role in maintaining the flourishing development of the mobile industry while advancing rapid deployment of wireless infrastructure**

High spectrum prices reduce incentives of MNOs for investment, which lowers the quality of networks and reduces take-up of mobile data services . It also increases the consumer prices for mobile broadband data. The excessive spectrum price of 3G has given a heavy burden on the operators and greatly impeded their business development. Fortunately, the spectrum price of 4G decreases significantly, which leads to the business success of 4G. Therefore, it is strongly recommended that 5G total spectrum price be comparable to 4G in each country.

New licenses should be granted for 15 to 20 years, at least, to give investors adequate time to realize a reasonable return on their investment. Allow spectrum license sharing and trading to increase spectral efficiency and investment.

Nationwide exclusive licensing is a preferred authorization model. This is of critical importance to avoid undermining investment certainty due to the lack of guarantee concerning spectrum quality, which inevitably leads to unpredictable quality of experience for end users.

3. **Contiguous TDD spectrum assignments employing wide blocks is beneficial for improving mobile broadband experience and spectrum efficiency of networks. 2.6 GHz (band 41) is recommended for contiguous TDD spectrum allocation leveraging the large bandwidth**

Contiguous wide spectrum assignments are critical to TDD performance, while fragmented assignments may not be able to support the highest data rates and offer sufficient capacity. Operation in fragmented spectrum requires more complex and costly technical solutions. It is suggested that a minimum assigned block size for each operator should be ≧40 MHz in the 2.3 GHz and 2.6 GHz bands, and ≧60 MHz in the 3.5 GHz/3.7/4.8GHz bands.

2.6GHz spectrum allocated using band 41 is recommended for large bandwidth and smoother 5G evolution. It should be available for use by endorsing the TDD configuration of LTE band 41

instead of the alternative hybrid FDD/TDD configuration of LTE bands 7/38. The 2.6 GHz allocated using band 41 features large bandwidth and requires no guard band. It can provide large capacity (2.1 Gbit/s@60 MHz; massive MIMO) and support massive MIMO.
In markets where the first 5G spectrum band – the 3.5 GHz spectrum band – is not available in the near term because it is currently allocated to satellite services and cannot be shared, band 41 is an alternative.

During spectrum allocation, multiple frequency bands (such as 2.3 GHz, 2.6 GHz, and 3.5 GHz) can be allocated at the same time to provide contiguous large bandwidth in a fair way. For example, Saudi Arabian regulatory authority has already allocated 2.3 GHz and 2.6 GHz at the same time, with one operator getting 100 MHz of band 40 while the other two share 190 MHz of band 41.

There is increased interest in by several verticals to dedicate spectrum that is regional or local that leads to inefficient use of spectrum. Careful consideration is required to ensure this does not limit contiguous spectrum available for 5G. This includes consideration to approach such as sub-leasing of spectrum from MNO's, use of license-exempt frequencies or use of higher frequency bands (e.g. 26GHz) instead

- Industry 4.0 players spectrum needs (e.g. 3.5 GHz)
- FWA providers arguing that they need it to provide rural broadband with legacy paired allocation that restricts defragmentation (e.g. 3.5GHz)
- Transport (FRMCS) citing future spectrum needs (e.g. 1900-1920 MHz etc).
- Neutral host/indoor coverage providers and other shared users requiring spectrum to be available as shared access (e.g. in 2.3 GHz)

4. New spectrum assignments must be technology and service neutral

Spectrum assignment for specific mobile technologies (e.g. 2G, 3G, 4G and 5G), and in some countries for specific services (e.g. voice, data, fixed wireless broadband), can no longer keep up with the speed of market demand for new network capabilities and for new services with enhanced performance. Spectrum allocation needs to be technology and service neutral for the deployment of 2G/3G/4G/5G and the future mobile technology to improve spectral efficiency.
In 2006, the UK first promoted technology neutral spectrum management, and allocated spectrum based on market mechanismse. This is regarded as a best practice by by ITU and rapidly accepted all over the world.
The principle of service and technology neutrality is a best practice that has been followed by many countries. Such an approach has allowed operators to swiftly respond to the changes in market demands and bring benefits for end users.

5. Synchronized operation between TDD networks is recommended for best spectrum utilization

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.

For 4G and 5G networks on the same frequency band, 8:2 DL/UL is configured for 5G while 3:1 DL/UL (which is applied in most TDD networks) is configured for TDD.

6. **Speed up the reclaiming of TDD spectrum still occupied by old technology or satellite and re-assign these resources to improve spectral efficiency and contribute to economic development**

Accelerate the return and re-provisioning of TDD spectrum resources occupied by the old technology.

Currently in some country, TDD spectrum was occupied or utilized in a poor efficiency. For example , 2.3/2.6G Spectrum was occupied by Military in MEA & Africa and 3.5G was occupied by Satellite in Asia-pacific. In some country of Asia-Pacific, TDD spectrum is allocated to the small ISP and cannot provide large-scale network construction and communication services. In addition, spectrum fragmentation also affects the investment efficiency of operators.

Regulatory agencies and operators can plan spectrum allocation, clear frequencies in advance, reclaim and release invalid spectrums, and use fragmented spectrum reshuffling to improve spectral efficiency.

10. References

[1] GSMA- Considerations for the 3.5GHz IMT range: getting ready for use May, 2017

[2] CCSA, Research Report on the coexistance of 3400-3600MHz band IMT indoor coverage system and FSS system

[3] ITU-R, Techniques designed to increase the potential for sharing between IMT systems and FSS networks in the 3 400-3 600 MHz band

[4] ITU-R Recommendation M.1036-5 “Frequency arrangements for implementation of the terrestrial component of International Mobile Telecommunications (IMT) in the bands identified for IMT in the Radio Regulations (RR)”

[5] GTI -5G SUB-6GHZ SPECTRUM AND REFARMING White Paper Feb, 2018

[6] WPC-Powered Evolution to 5G Oct, 2018

[7] GSA Evolution to LTE report, April 7,2016

[8] LTE and 5G Market Statistics – 8 April 2019 Global mobile Suppliers Association

Status of the LTE Ecosystem - March 2019 Global mobile Suppliers Association