GTI 5G SUB-6GHZ SPECTRUM AND REFARMING

White Paper

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5G SUB-6GHZ SPECTRUM AND REFARMING WHITE PAPER

V 1.1

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Executive Summary

This white paper introduces the recent progress of global 5G spectrum and the suitability of the 5G frequency bands under consideration for sub-6 GHz spectrum range. In addition it highlights the development of legacy 2G/3G/4G sub-6GHz bands and the possible migration to 5G in order provide ambitious services and adequate coverage, especially assisting the GTI groups for their product design and initiatives identified. And special attention is given to trials and commercial roll-outs of 5G technology in several countries.

The availability and selection of the right 5G frequencies is of crucial importance to the current on-going international standardisation, to GTI industry stakeholders 5G roadmap planning and also it addresses GTI member companies views towards overall 5G spectrum planning for sub-6GHz and refarming of the bands from 2G/3G/4G.

- The white paper provides introductions and study results on expected 5G scenarios providing discussion of needed bandwidths, coverage, and availability of suitable radio frequencies. Based on the white paper analysis, at current stage GTI supports the following candidate bands: 2300MHz, 2600MHz, 3300-3800MHz, 3400-4200MHz and 4400-5000MHz, as the kick-off bands for 5G deployment in sub-6GHz.
- It provides guidance to industry players and regulators to provide pioneer bands for 5G trials and early commercial and pre-commercial deployments. It lists the sub-6GHz frequency bands which are suitable and currently considered in many countries, regions, around the world for 5G services. Moreover it summarizes key actions being needed to make these sub-6GHz bands available in time.
- A specific section addresses more radical studies for spectrum management, such as spectrum sharing study, coexistence requirements and RF parameters that the industry needs to protect the other incumbent services.
- The white paper promotes study results in the spectrum area and setting up of references between GTI projects concerning potential synergies and common interests across projects in spectrum related issues. It pursues the convergence of results on spectrum topics from the different projects to maximize the achievable outcome towards relevant technical bodies,
- Finally the white paper liaises with the regulatory bodies and works for improved understanding of collaborative spectrum research importance in the sub-6GHz spectrum range.

Key findings for 4G LTE sub-6GHz bands:

- Comprehensive MBB Solution Using both FDD & TDD Bands
- Encourage TDD Synchronization
- Light Touch Regulation
- Consider more TDD possibility for Smoother Evolution

. Key findings for 5G sub-6GHz bands:

- A multi-layer spectrum approach is required to address such a wide range of usage scenarios and requirements
- The C-band is the primary band for the introduction of 5G globally

- 3GPP has already specified initial bands for the 5G NR (TS 38.101-1; @12-2017) to successfully launch 5G services by 2019
- Candidates of 5G bands: Based on the analysis in previous sections, at current stage GTI supports the following candidate band: 2300MHz, 2600MHz, 3300-3800MHz, 3400-4200MHz and 4400-5000MHz, as the kick-off bands for 5G deployment in sub-6GHz.

Table of Contents

1 Introduction

1.1 Background

Since last year, a number of local initiatives have been taken for 5G spectrum, actions plans from the leading region and countries were made, both for commercial deployments and test beds. In some cases, local spectrum needs have different timing than that of ITU-R process, and some other cases frequency bands not on the ITU-R list have been identified for 5G locally. And in addition, bands that already have IMT identification below 6GHz may be used for 5G deployments.
From GTI point of view, after we complete the previous work, pushing for global harmonization of TDD band, making 2 white papers on future spectrum and TDD spectrum, we would start to think of the concrete bands for coming 5G deployment and trials taking into account the different market requirement, trying to get more synergy towards our future spectrum and product deployment plans and solutions of coexistence with the existing services and systems and also influence to the local government decision for licensing etc.

Migration of existing operators network and spectrum for future is another key aspect for operators 5G road path. How to refarm existing operator 2G/3G/4G spectrum to 5G is important. And continue pushing for our existing TDD core spectrum in some particular regions and market for 2017 is also key area for the GTI short term plan.

Based on the high level goad, 2 tasks were established for sub-6GHz spectrum and coexistence and TDD spectrum promotion and refarming issues for 5G eMBB sub-6GHz and 4G evolution smooth evolution projects. In this white paper we will address these 2 issues for sub-6GHz for 5G and TDD spectrum promotion and refarming issues.

Schedule of the white paper draft:
We propose to work first on pioneer band in 2017, targeting for trials and commercial network by 2020, and next year, start to work for the bands for deployment of 5G after 2020-2021 and in 2019, looking into the band plan deployed after 2021.

1.2 Objectives of this white paper

The objective of this white paper for sub-6GHz spectrum would be:

- Promote GTI positions and recommendations on sub-6GHzs spectrum for 5G via White Paper, to influence the Regulator and Industry for
  - Timely standardization of the bands to enable product implementation
  - Timely availability of national spectrum regulation rules within the internationally harmonized spectrum allocations
  - Well established ecosystem and synergy of product implementation based on spectrum harmonization
- External liaison to invite more inputs or influence the expectation of Regulator

- External liaison to push Standardization Bodies for certain bands that GTI operators need, if necessary

Objectives of the work-TDD Spectrum promotion and Refarming issues:

- Draft a White Paper to
  - Continue to push the core TDD spectrum for some regions and markets, e.g. UK (2.3/3.5GHz), Thailand(2.6GHz), Indonesia (2.3GHz), South Africa (2.3/2.6GHz), Korea (2.3/2.6GHz), Bangladesh (2.3/2.6GHz), Myanmar (2.6GHz), Mexico (2.6GHz)
  - Provide GTI understandings on existing spectrum refarming for 4G evolution and 5G with the target of global harmonized spectrum usage, and
  - Suggest strategies dealing with operator refarming of their existing spectrum
- External liaison to invite more inputs or influence the expectation of Regulator
- Pushing for timely standardization of the bands and product availability

2 Existing sub-6GHz development situation

This section describes the existing sub-6GHz spectrum development from different regions and countries.

2.1 3GPP LTE TDD and FDD bands specifications

3GPP defines TDD, FDD 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,

E-UTRA 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}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6[1]	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	699 MHz	–	716 MHz	729 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			FDD
16	Reserved			Reserved			FDD
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
22	3410 MHz	–	3490 MHz	3510 MHz	–	3590 MHz	FDD
23[1]	2000 MHz	–	2020 MHz	2180 MHz	–	2200 MHz	FDD
24	1626.5 MHz	–	1660.5 MHz	1525 MHz	–	1559 MHz	FDD
25	1850 MHz	–	1915 MHz	1930 MHz	–	1995 MHz	FDD
26	814 MHz	–	849 MHz	859 MHz	–	894 MHz	FDD
27	807 MHz	–	824 MHz	852 MHz	–	869 MHz	FDD
28	703 MHz	–	748 MHz	758 MHz	–	803 MHz	FDD
29	N/A			717 MHz	–	728 MHz	FDD[2]
30	2305 MHz	–	2315 MHz	2350 MHz	–	2360 MHz	FDD
31	452.5 MHz	–	457.5 MHz	462.5 MHz	–	467.5 MHz	FDD
32	N/A			1452 MHz	–	1496 MHz	FDD[2]
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD

40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	2496 MHz		2690 MHz	2496 MHz		2690 MHz	TDD
42	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD
43	3600 MHz	–	3800 MHz	3600 MHz	–	3800 MHz	TDD
44	703 MHz	–	803 MHz	703 MHz	–	803 MHz	TDD
45	1447 MHz	–	1467 MHz	1447 MHz	–	1467 MHz	TDD
46	5150 MHz	–	5925 MHz	5150 MHz	–	5925 MHz	TDD[8]
47	5855 MHz	–	5925 MHz	5855 MHz	–	5925 MHz	TDD[11]
48	3550 MHz	–	3700 MHz	3550 MHz	–	3700 MHz	TDD
50	1432 MHz	-	1517 MHz	1432 MHz	-	1517 MHz	TDD[13]
51	1427 MHz	-	1432 MHz	1427 MHz	-	1432 MHz	TDD[13]
…							
64	Reserved						
65	1920 MHz	–	2010 MHz	2110 MHz	–	2200 MHz	FDD
66	1710 MHz	–	1780 MHz	2110 MHz	–	2200 MHz	FDD[4]
67	N/A			738 MHz	–	758 MHz	FDD[2]
68	698 MHz	–	728 MHz	753 MHz	–	783 MHz	FDD
69	N/A			2570 MHz	–	2620 MHz	FDD[2]
70	1695 MHz	–	1710 MHz	1995 MHz	–	2020 MHz	FDD[10]
71	663 MHz	–	698 MHz	617 MHz	–	652 MHz	FDD
72	451 MHz	–	456 MHz	461 MHz	–	466 MHz	FDD
74	1427 MHz	–	1470 MHz	1475 MHz	–	1518 MHz	FDD
75	N/A			1432 MHz	–	1517 MHz	FDD[2]
76	N/A			1427 MHz	–	1432 MHz	FDD[2]

NOTE 1: Band 6, 23 is not applicable

NOTE 2: Restricted to E-UTRA operation when carrier aggregation is configured. The downlink operating band is paired with the uplink operating band (external) of the carrier aggregation configuration that is supporting the configured Pcell.

NOTE 3: A UE that complies with the E-UTRA Band 65 minimum requirements in this specification shall also comply with the E-UTRA Band 1 minimum requirements.

NOTE 4: The range 2180-2200 MHz of the DL operating band is restricted to E-UTRA operation when carrier aggregation is configured.

NOTE 5: A UE that supports E-UTRA Band 66 shall receive in the entire DL operating band

NOTE 6: A UE that supports E-UTRA Band 66 and CA operation in any CA band shall also comply with the minimum requirements specified for the DL CA configurations CA_66B, CA_66C and CA_66A-66A.

NOTE 7: A UE that complies with the E-UTRA Band 66 minimum requirements in this specification shall also comply with the E-UTRA Band 4 minimum requirements.

NOTE 8: This band is an unlicensed band restricted to licensed-assisted operation using Frame Structure Type 3

NOTE 9: In this version of the specification, restricted to E-UTRA DL operation when carrier aggregation is configured.

NOTE 10: The range 2010-2020 MHz of the DL operating band is restricted to E-UTRA operation when carrier aggregation is configured and TX-RX separation is 300 MHz The range 2005-2020 MHz of the DL operating band is restricted to E-UTRA operation when carrier aggregation is configured and TX-RX

	separation is 295 MHz.
NOTE 11:	This band is unlicensed band used for V2X communication. There is no expected network deployment in this band so both Frame Structure Type 1 and Frame Structure Type 2 can be used.
NOTE 12:	A UE that complies with the E-UTRA Band 74 minimum requirements in this specification shall also comply with the E-UTRA Band 11 and Band 21 minimum requirements.
NOTE 13:	UE that complies with the E-UTRA Band 50 minimum requirements in this specification shall also comply with the E-UTRA Band 51 minimum requirements.
NOTE 14:	A UE that complies with the E-UTRA Band 75 minimum requirements in this specification shall also comply with the E-UTRA Band 76 minimum requirements.

2.2 Commercial TDD and FDD development

Currently, the system equipment for all TDD and FDD bands are matured with commercial operation ability, and the user devices for TDD and FDD bands are sufficient to meet various customer requirements.

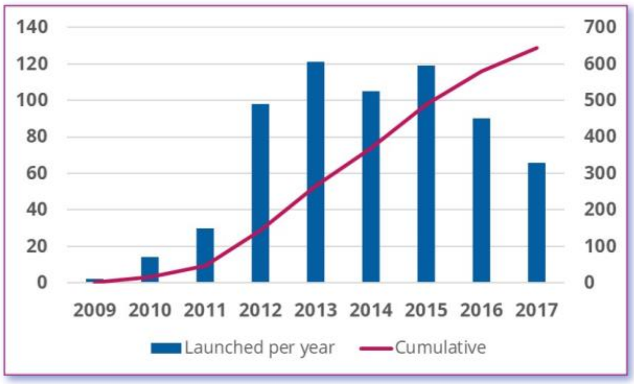


Fig 2-1-1 LTE networks launched each year by October 2017
(Source: www.gsacom.com)

Furthermore, more and more user devices are produced to meet the increasing customer requirements.

By April 2017, there were totally 7847 kinds of LTE user devices, including module, tablet PC, notebook, smart watch, PC card, projector, femto-cell, phone, drone, router inc., hotspot, dongles, camera, and car hotspot, belonging to 546 manufacturers. The majority of LTE user devices are phone accounting for about sixty five percent. There are 77% more LTE devices than February 2016 and 1800 MHZ for FDD has largest devices ecosystem.
The detail of the user devices are shown below.

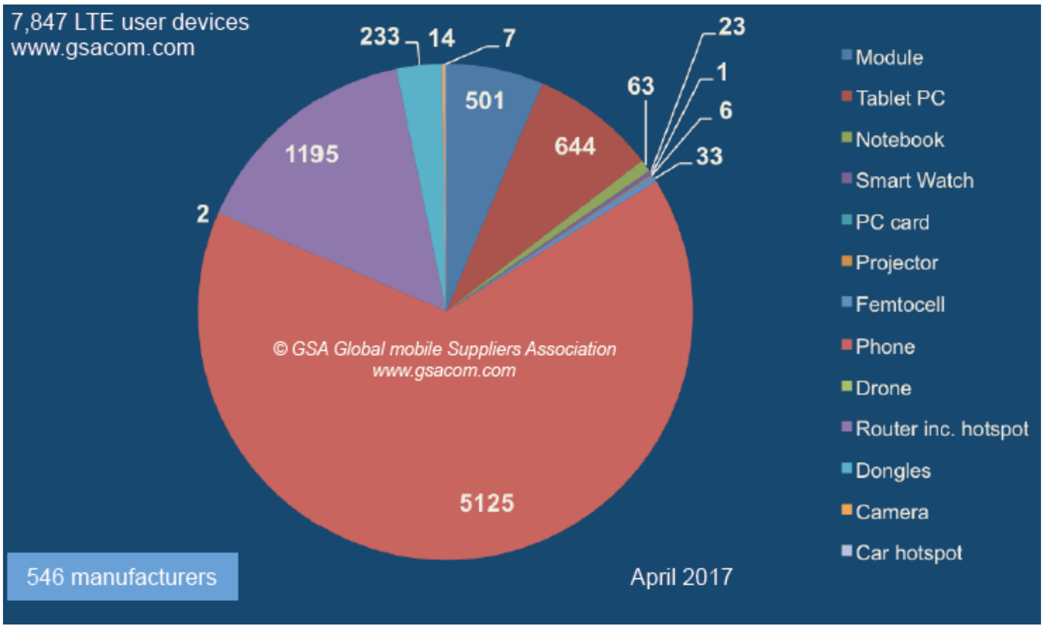


Fig 2-1-2 LTE user devices by April 2017(Source: www.gsacom.com)

LTE has set up a complete end-to-end industry chain involving widespread participation of global industries and highly matured products. The details of the LTE FDD and LTE TDD operating bands and devices are shown below.

LTE FDD	
1800 MHz band 3	4,872 devices
2600 MHz band 7	4,502 devices
2100 MHz band 1	3,885 devices
800 MHz band 20	2,784 devices
800/1800/2600 tri-band	2,655 devices
850 MHz band 5	2,179 devices
AWS band 4	2,048 devices
900 MHz band 8	1,959 devices
1900 MHz band 2	1,802 devices
700 MHz band 17	1,572 devices
700 MHz band 13	809 devices
APT700 band 28	639 devices
700 MHz band 12	539 devices
1900 MHz band 25	358 devices

LTE TDD	
2300 MHz band 40	2,369 devices
2600 MHz band 38	1,889 devices
2600 MHz band 41	1,733 devices
1900 MHz band 39	1,454 devices
3500 MHz band 42	118 devices
3600 MHz band 43	93 devices

Fig 2-1-3 LTE FDD and LTE TDD bands and devices (suggestion to double check if GTI has some latest data to update the TDD devices statistics?)

(Source: www.gsacom.com)

It is important to note that the device number in the GSA GAMBOD report referred to accumulated commercial products. Commercial device ecosystem for B7 started around 2008/09, mainly driven by Europe, whereas the commercialization of B41 started around 2012/13. As a result of this 4-5 year gap, there are in total more devices supporting B7 in GSA report.

3 TDD being the key component in future

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.

3.1 TDD facilitates advanced antenna solutions

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 unique coordination abilities which are used in a number of technical areas including Beamforming. Beamforming improves the system performance by utilising channel state information to achieve transmit-array gain. FDD requires a very high signal overhead to obtain DL channel state information at the eNB thus making it less efficient when implementing Beamforming.

Network test results show that single-layer, dual-layer and multi-user Beamforming can generate cell throughput gains of 15%, 15% and 10% respectively. Adoption of both Beamforming and Coordinated Multi-Point operation (CoMP), an approach called 'Co-ordinated Beamforming' (CBF), can further enhance network performance because interference is mitigated between eNodeBs.

Other advanced antenna solutions like massive MIMO and Distributed MIMO (D-MIMO) also utilise TDD's uplink and downlink channel reciprocity to improve performance and capacity.

3GPP has standardized "4.5G", under the name LTE Advanced Pro, which employs some of these advanced features including Massive MIMO. Massive MIMO will also be deployed also in the 5G.

3.2 TDD supports traffic asymmetry efficiently and flexibly

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. The use of DL-centric applications represented more than 90% of mobile traffic being in the downlink in 2017.

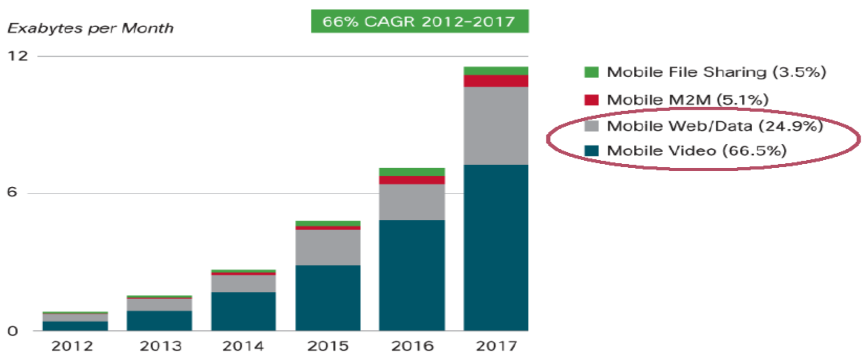


Figure 3-2-1 (Figure Numbering to be checked): Cisco mobile forecast

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.

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

High performing mobile networks require wide channel bandwidths; currently spectrum bands between 1800MHz to 5GHz, where most of the harmonized mobile bands are TDD ones, 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 Global 5G sub-6GHz development progress

This section describes the latest status of global 5G spectrum development from different regions and countries. Furthermore, TDD is chosen by more and more operators and vendors for 5G NR.

4.1 ITU progress

In addition to the limited spectrum bands already in use, it is anticipated that ITU will identify further new bands for IMT in order to meet the traffic increase. 3400-3600MHz has been considered to be a global IMT harmonized spectrum band. What's more, many countries and regional bodies have shown their support on 3.5GHz and surrounding spectrum in WRC15 agenda item 1.1as below in Fig.2. In the future, if other services such as Fixed Satellite Service (FSS) are migrated out of this band to other bands or if can share the frequency bands with mobile services, there is potential for additional 800MHz of spectrum within the frequency range of 3.4 to 4.2GHz, and additionally 600MHz in 4.4 to 5GHz, for mobile services.

Frequency Band	APT	ASMG	ATU	CEPT	CITEL	RCC
1 - 470-694/698 MHz	A	A	A	A		A
2 – 1 350-1 400 MHz	A	A	C	A		A
3 – 1 427-1 452 MHz	C	A	C	C	C	A
4 – 1 452-1 492 MHz		C	C	C	C	A
5 – 1 492-1 518 MHz	C	C	C	C	C	A
6 – 1 518-1 525 MHz	A	A		A		A
7 – 1 695-1 710 MHz	A	A	A	A		A
8 – 2 700-2 900 MHz	A	A			A	A
9 – 3 300-3 400 MHz		A		A		A
10 – 3 400-3 600 MHz	A	B&C		B&C	B&C	A
11 – 3 600-3 700 MHz	A	A	A	B&C	A	A
12 – 3 700-3 800 MHz	A	A	A	B&C	A	A
13 – 3 800-4 200 MHz	A	A	A	A	A	A
14 – 4 400-4 500 MHz		A	A	A		C
15 – 4 500-4 800 MHz	A	A	A	A	A	A
16 – 4 800-4 990 MHz		A		A		C
17 – 5 350-5 470 MHz	A	A	A	A	A	A
18 – 5 725-5 850 MHz	A	A	A	A		A
19 – 5 925-6 425 MHz	A	A	A	A	A	C

A/B/C: Method A/B/C used in WRC-15 Oppose Support

Figure 4-1-1 Regional positions on WRC15 agenda item 1.1

WRC-19 Agenda Item 1.13 addresses further spectrum for IMT. 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 defined 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 channel bandwidths. It is expected that most, if not all of the new spectrum bands will be unpaired with TDD playing a significant role.

4.2 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.

Table 4-1: 3GPP NR bands in Rel-15 - refarming bands

from 3GPP TS 38.101-1 ver 15.0.0, 12-2017)

Operating band	Duplex mode	Total spectrum (MHz)	Uplink (MHz)	Downlink (MHz)
n1	FDD	2x60	1920-1980	2110-2170
n2	FDD	2x60	1850-1910	1930-1990
n3	FDD	2x75	1710-1785	1805-1880
n5	FDD	2x25	824-849	869-894
n7	FDD	2x70	2500-2570	2620-2690
n8	FDD	2x35	880-915	925-960
n20	FDD	2x30	832-862	791-821
n28	FDD	2x45	703-748	758-803
n38	TDD	50	2570-2620	2570-2620
n41	TDD	194	2496-2690	2496-2690
n50/51	TDD	90	1427-1517	1427-1517
n66	FDD	70+90	1710-1780	2110-2200
n70	FDD	15+25	1695-1710	1995-2020
n71	FDD	2x35	663-698	617-652
n74	FDD	2x43	1427-1470	1475-1518
n75/76	SDL	1x90	-	1427-1517

Table 4-2: 3GPP NR bands in Rel-15 - new bands

from 3GPP TS 38.101-1 ver 15.0.0, 12-2017)

Operating band	Duplex mode	Total spectrum (MHz)	Uplink (MHz)	Downlink (MHz)
n77	TDD	900	3300-4200	3300-4200

n78	TDD	500	3300-3800	3300-3800
n79	TDD	600	4400-5000	4400-5000
n80	SUL	1x75	1710-1785	-
n81	SUL	1x35	880-915	-
n82	SUL	1x30	832-862	-
n83	SUL	1x45	703-748	-
n84	SUL	1x60	1920-1980	-

It is important to notice that in 3GPP R15 there are 4 duplex modes being defined including FDD, TDD, SDL and SUL for 5G NR services. FDD, TDD and SDL are already defined and used for 4G LTE services in past years. Similar band definition principles are set for 5G NR as well. SUL is a new duplex mode being included into 3GPP R15. It may benefit the C-band in term of coverage for the 5G NR uplink. An example of SUL is depicted into the following figure.

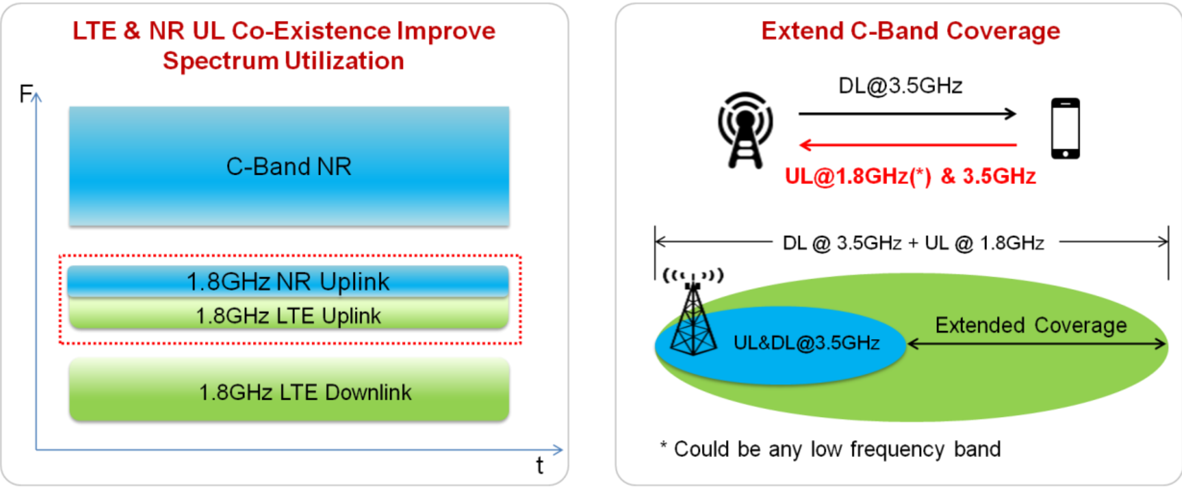


Figure 3 An example of SUL

In addition to frequency bands, similar as in LTE, 3GPP will also define the supported band combinations. In Rel-15 the combinations include

- LTE-NR DC combinations for LTE x CC + NR 1 CC, with x=1,2,3,4,5
- intra-band NR CA (xDL/1UL)
- inter-band NR CA combination (2DL/1UL)
- band combination for UL sharing
- LTE-NR DC combinations for LTE x CC + NR 2 CC, with x=1,2,3,4

The number of band combinations is quite huge, and due to the limited space, one does not list all combinations in this paper, but interested readers can refer to 3GPP TS 38.101 (3GPP R15) for the full information. Similar as for frequency bands, additional band combinations will be defined in later 3GPP release but in release independent manner, if requested by operators.

4.3 America 5G

In the U.S. on 14th July 2017 FCC issued Report and Order (R&O) based on previous Notice of Proposed Rulemaking (NPRM), making the following spectrum bands available for 5G.

- 27.5-28.35GHz: licensed
- 37-38.6GHZ: hybrid licensed (licensed for outdoor)
- 38.6-40GHz: licensed
- 64-71GHz: unlicensed

At the same time, mobile operators are also considering to use LTE bands for 5G.

In May 2017, T-Mobile US announced the plan to use 600MHz band it acquired in the recent auction for national wide 5G deployment. The operator is in the view that 600MHz 5G network will deliver increased radio efficiency, immense numbers of connected devices, lower latency and improved battery life and reliability. The operator expects to deploy 5G in its low-band 600 MHz spectrum quickly across its existing nationwide macro network. With first version of 5G standards available from mid-2018, the 5G rollout is expected to begin in 2019 with a target of 2020 for full nationwide coverage.

In May 2017, Sprint announced that it is developing technologies for 5G, including the 3GPP New Radio (NR) standard in Band 41 (2.5GHz) for accelerated wide-scale 5G deployments.
The companies plan to provide commercial services and devices in late 2019. The operator mentioned that Band 41 is included as a sub-6GHz band for the 3GPP 5G standard in the first release. 2.5 GHz TDD-LTE is one of the largest global wireless ecosystems used by some of the most influential operators in the world and it believes there is huge value in building a strong 5G ecosystem early on around the band. The operator considers sub-6GHz spectrum such as 2.5 GHz will be foundational for providing nationwide 5G coverage.

Early 2017, Dish Networks also indicated a plan to build out a 5G only network focusing on IoT services using their licensed spectrum by 2020 or 2021. In particular, Dish Network proposed in 3GPP to define Band 66 (1710-1780MHz/2110-2200MHz) and Band 70 (1695-1710MHz/1995 -2020MHz) as NR bands. The operator believes the 5G technologies can enable lower latency, faster throughput, and in particular IoT use cases.

There are other low spectrum bands under consideration in the U.S. In November 2016, the National Telecommunications and Information Administration (NTIA) published a report "Quantitative Assessments of Spectrum Usage". The report includes the quantitative access of the spectrum use across 5 frequency bands, 1300-1390 MHz, 1675-1695 MHz, 2700-2900 MHz, 2900-3100 MHz, and 3100-3550 MHz, by the government agencies, including the existing and projected usage. One aim of the report is to facilitate the Administration to further evaluate the possibility/feasibility to repurpose the bands for shared use between government and commercial services, including 5G. Some of the evaluated bands are interesting to mobile operators, for example 1300-1390MHz.

Other mid-band spectrum is also under consideration in the U.S. The Mobile Now Act released in March 2017 suggested to study the possibility to sue 3100-3550 MHz and 3700-4200 MHz for 5G in addition to 3550-3700 MHz already being opened for mobile use. The U.S. DoC and NTIA in their report November 2016 concluded that the 3100-3550 MHz band could be examined more closely to determine if it can be used by commercial providers although the band's heavy use. FCC is considering a possible proceeding in 2017 with respect to 3700-4200 MHz pursuant to a request for rulemaking to modify its rules to promote the more effective and efficient use of spectrum, where shared usage is being considered.

In Canada, the administration will start series of consultations on 600MHz, 3.5GHz and mmWave.

In LAT countries, some low-band spectrum with well-established LTE ecosystem is being considered for allocation/auction, e.g. 700MHz and 2.6GHz. Considering the timeline, those spectrum bands may be used/refarmed for 5G. Although there was not much activity in the region regarding mid-band spectrum, operators and regulators are supporting the harmonization of the newly identified 3300-3400 MHz and the sharing opportunities in the 3400-3600/3700 MHz range.

4.4 Australia 5G

In Australia, an update on the mobile broadband program and planning for significant technology developments out to 2020—such as 5G and the Internet of Things (IoT)—are the key elements of the Australian Communications and Media Authority(ACMA) Five-year spectrum outlook (FYSO) in 2017,. Moreover, based on the program, The ACMA has released a combined discussion paper on planning issues in 1.5 GHz and 3.6 GHz bands in the coming weeks. The ACMA is bringing forward consideration of the 3.6 GHz band. This is in response to increasing worldwide interest in the band, which has been identified for possible use for 5G mobile telecommunications. Meanwhile, The ACMA also invited comments on the questions listed in the consultation document Spectrum for broadband in the millimetre wave bands or any other relevant issues—in particular on whether spectrum in the 26 GHz mmWave band (24.25-27.5 GHz) is a candidate for accelerated consideration for 5G broadband purposes.

As to 3.6 GHz, the ACMA conducts an initial investigation and scoping of potential options for domestic re-farming of a band. If the 3.6 GHz band is to be re-farmed for MBB services, the type of spectrum arrangements to implement need to be considered.

The ACMA has already implemented TDD arrangements in spectrum- and apparatus-licensed segments of the 3400–3575 MHz frequency range, and in regional and remote areas for the 3.6 GHz band. Although there are FDD arrangements defined for the 3425–3442.5/3575–3492.5 MHz frequency ranges, these were developed for legacy technologies and no longer align with international standards. Due to existing spectrum and apparatus licence arrangements in the 3400–3600 MHz band, the ACMA believes the options for the 3575–3600 MHz frequency range are limited to TDD arrangements only. The 3600–3700 MHz band is also restricted to TDD arrangements, as there are no FDD arrangements defined for the frequency range. A possible advantage of TDD arrangements is the flexibility they could provide in identifying all or part of the 3.6 GHz band for MBB in different locations. For example, only the 3575–3625 MHz frequency range could be made available for MBB services in one area, while the entire band is made available in others. This is something that could be considered to provide compatibility with incumbent services.

4.5 China 5G

China government has their policy to promote building strong network for their country and create the strategic objectives of Made in China 2025 and Industrial Internet 4.0 in which 5G would be one of the key element for information industry and the digitalization of the China industry upgrades. According to the China government 13th 5 year planning, China will allocate no less than 500MHz spectrum for 5G by 2019. And since last year they released 3.5GHz band 200MHz for 5G trial and LTE-V2X spectrum trial frequency in 5.8GHz band. According to their current 5G spectrum planning plan:

- Below 6GHz:
    - China is trying for getting of 3.3-3.4GHz, 4.4-4.5GHz and 4.8-4.99GHz for IMT (totally 390MHz) – it seems that there are few differences if comparing to the following MIIT information: http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757020/c5907905/content.html , currently they are actively pushing for this coordination and the frequency coordination has got some progress. Relevant sharing requirement have been studied.
    - Refarming existing spectrum
    - MBB, mMTC and URLLC could make use of bands below 6GHz and in case of extreme coverage requirements they could take advantage of spectrum below 1GHz
- Upper 6GHz:
    - Due to WRC-19, should be used after WRC-19 and frequency plan should be under WRC-19 framework
    - 20-40GHz is the important band, but the band upper than 40GHz is easier. Currently China is dong the sharing study for 26GHz and 40GHz.
    - Spectrum sharing is the basis

Other key considerations for Sub-6GHz spectrum use in China:

- Broadband Dedicated Network Frequency planning:
    - 1.4GHz: has allocated 20MHz for dedicated government business network e.g. public security and police, run on one network consisting multiple core networks
    - 1.8GHz: Current use of both 2G/2.5G and 4G LTE services in that band
- IoT spectrum: Public network, or dedicated network or shared spectrum (short range lower power network), and other based on WiFi and Bluetooth

  - 230MHz narrow band IoT for Electrical Power Smart Grid network, supporting Zhejiang, Fujian and Chongqing for trial, using radio recognition technology and carrier aggregation.
  - Short range radio applications for RFID, some detection, Wifi, WAN
  - If operators require, and after Government approval they could use their existing 850/900MHz bands for NB-IoT use
  - 2*2.3MHz for dedicated NB-IoT network in the current data transmission spectrum
- Trial for LTE-V2X:
  - 5805-5925MHz in Shanghai, Beijing, Chongqing, Hangzhou and Changchun, trial spectrum assigned to TIAA and IMT-2020 PG
  - 77-81GHz: car radar

On June 6th, 2017 China MIIT released a public consultation for the notification on 5G IMT system (IMT-2020) using 3300-3600MHz and 4800-5000MHz (http://www.miit.gov.cn/n1146295/n1652858/n1652930/n3757020/c5907905/content.html). The consultation deadline would be by July, 7th. The notification includes:

1. 3300-3600MHz and 4800-500MHz are allocated as IMT-2020 operation bands.
2. IMT-2020 system in 3300-3400MHz should be limited to indoor use only in principle. Without any harmful interference to the radio location service station in use, it can be used for outdoor deployment.
3. The station of IMT-2020 system in 3400-3600MHz band should not cause any harmful interference to FSS (Fixed Satellite Service) earth stations operating in the same frequency band with effective license. Regarding the satellite earth stations for the telemetry service with the expired license operating in 3400-3600MHz and its adjacent bands, some protection should be provided to the same extent. The specific measures should be coordinated and resolved between IMT-2020 system operators and the relevant satellite operators.
4. The stations of IMT-2020 system operating in 4990-5000MHz band should not cause any harmful interference to the radio astronomy stations listed in the footnote CHN12 in the “People’s Republic of China regulations on the radio frequency table”.
5. The above bands are used as IMT-2020 operating frequency bands and are managed by the national radio regulatory authority. Specific regulations of the frequency allocation, RF technical requirements and radio station management will be developed and released in future.

On June, 8th, 2017, China MIIT issued another public consultation request on 5G system frequency planning over 24.75-27.5GHz, 37-42.5GHz (or other millimetre wave bands). The deadline of the consultation was Aug. 7th 2017.

The request includes:

1. Detail list the information of the frequency usage status, the future plan and the critical time point for the bands 24.75-27.5GHz and 37-42.5GHz or the frequency bands that you proposed to use. Please propose the comments on how to plan the above frequency bands for 5G system.
2. The major technical issues are for 5G deployment in these bands, such as RF components, chipset, test equipment, etc and the feasible solutions and time schedule.
3. If the relevant coexistence study has been conducted, it can be attached in the form of a report. The

report should include the detailed system parameters, space stations' orbit and relevant information. The methods and results of the coexistence study should be provided in the report.

4. How to use 5G system in co-channel and adjacent channel with the incumbent systems? What technical and frequency management methods can facilitate the compatibility of 5G system and other incumbent systems within the same frequency band or in adjacent bands?

5. Other issues that you would like to explain and comment.

The Official MIIT notification on 5G IMT system (IMT-2020) using 3300-3600MHz and 4800-5000MHz was issued in November 2017.

4.6 Europe 5G

Europe Commission published the EC 5G Action Plan in September 2016. It presents an action plan for timely and coordinated deployment of 5G networks in Europe through a partnership between the Commission, Member States, and industry. It calls for coordination approach to help shape a global consensus as regards the choice of technologies, spectrum bands and leading 5G applications effective and commercial 5G service launch.

The Plan is quite aggressive, showing that Europe is trying to take the lead again, with field trials, early deployments and large-scale deployments by 2017, 2018 and 2020 respectively. For example, one action of the Plan is *ensuring that every Member State will identify at least one major city to be "5G-enabled" by the end of 2018 and that all urban areas and major terrestrial transport paths have uninterrupted 5G coverage by 2025*.

Making 5G radio spectrum available is an important aspect of the Plan.

- The Commission will work with Member States to identify by the end of 2016 a provisional list of pioneer spectrum bands for the initial launch of 5G services.
- The Commission will work with Member States to agree by end of 2017 on the full set of spectrum bands (below and above 6 GHz) to be harmonized for the initial deployment of commercial 5G networks in Europe, based on a planned RSPG opinion on 5G spectrum. The final spectrum harmonisation at EU level will be subject to the usual regulatory process once relevant standards have been developed.
- The Commission will work with Member States to work towards a recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz, taking due account of the opinions of BEREC and RSPG. An early indication of technical options and feasibility should be available through CEPT studies by end 2017.

RSPG under European Commission published its Opinion on spectrum related aspects for next-generation wireless systems (5G) in November 2016. In particular, RSPG identified the following pioneer bands spectrum bands for the initial launch of 5G services.

- Between 1GH and 6GHz: 3400-3800MHz
- Below 1GHz: 700MHz
- Above 6GHz: 24.25-27.5GHz

It is expected that the first major commercial deployment will be based on lower frequencies. The implementation of frequency bands above 24 GHz remains needed to ensure all the performance targets of 5G, for example multi gigabit per second data rates.

In December 2016, EC mandated to CETP to develop harmonized technical conditions for spectrum use in support of the introduction of 5G terrestrial wireless systems in the Union, including 5G usage scenarios and take into account needs for shared spectrum use with existing or prospective incumbent uses.

CEPT conducted a questionnaire on the availability of the 3400-3800 MHz band for 5G, which closed on 30th November 2016. The questions cover the authorization, the current and planned utilization of 3400-3800MHz in its member administrations, as well as the services that are targeted in this band. The feedback was promising, with 22 out of 30 administrations who responded to the questionnaire indicating the plan to use at least part of the band for 5G. The Mobile Industry also indicated that this band will be one of the primary bands for enhanced mobile broadband (eMBB), for the provision of high capacity (order of Gbit/s) using small cells. The propagation properties of this band are noted as suitable for dense urban coverage (indoor and outdoor).

ECC PT1 has already created work item on C-band including review the harmonized technical conditions applicable to the 3.4-3.8 GHz frequency band, as a 5G pioneer band and to assess the suitability of the harmonized technical conditions of ECC DEC (11)06, applying to MFCN in the band 3.4-3.8 GHz, to 5G. Existing technical conditions are investigated, and proposals for 5G put forward. Frequency arrangement is also studied.

4.7 Japan 5G

MIC (Ministry of Internal Affairs and Communications) in Japan released a report for their radio policy 2020 in July 2016. This report covers several topics including 5G spectrum and 5G trials.
Japan 5GMF set up the 5G Field Trial Promotion Group (5G-TPG) in January, 2017 and started their trial activities. More than 40 5G Utilization projects have been proposed by members of the 5G-TPG and respective committees of the 5GMF.
Japan targets to commercially launch 5G by July, 2020.
In MIC report, the statistic of average monthly mobile data traffic shows that the increase of mobile data traffic increased approximate 13 times over the past 5 years. And they foresee that the traffic speed will be 10,000 times faster in 30 years for the future evolution of mobile communications system. They strongly promote 5G technology and standardization and target to implement 5G by 2020. The 5G System Trial to test radio access, networks, and applications for 5G will be started in Tokyo and other cities in Japan in FY2017.

Based on all the market growth and Japan strategy of promotion of new mobile technology including 5G, MIC established their radio policy vision towards 2020s and set up their new goals for frequency allocations to mobile communication systems:

- For below 6GHz: Promote frequency sharing with public service systems and others and to ensure a total bandwidth of 2700 MHz, Including bandwidth for wireless LAN, by 2020.

- For above 6GHz: Push ahead with R&D and international standardization while targeting a total bandwidth of about 23 GHz

The key element of their strategy to secure necessary spectrum for 5G is that:

- Harmonization and Cooperation with Other Countries
  - International harmonization and cooperation with major countries who share their views about the frequency demands of 5G
  - Start consideration in accordance with global trends without waiting for WRC-19
  - Utilize chances such as international conferences on standardization/bilateral consultations/international events
- Consider frequency reallocation or frequency sharing with existing systems, in IMT / 3GPP Bands which are currently allocated for other systems
  - Draw out the scheme to promote efficient frequency sharing
- R&D Promotion
  - Promote the leading technology R&D of the effective utilization of frequency
  - Promote R&D in the comprehensive demonstration experiment environment
- Enhancement of Wireless LAN (WLAN) frequency
  - Promote sharing frequency among 5GHz WLAN and other systems

The strategy for each frequency:

- Below 3.6GHz (IMT/3GPP Band):
  - 1.7GHz band, 2.3GHz band: Consider frequency sharing with or reallocation of public services
  - 2.6GHz band: Promote consideration of frequency sharing with the next mobile satellite communication systems
  - 3.4GHz band: Consider the use of promotion of termination acceleration measures
- 3.6GHz-4.9GHz:
  - 3.6GHz-4.2GHz:
  - 4.4GHz-4.9GHz: Promote comprehensive consideration in accordance with international harmonization, domestic/ international R&D trends, and frequency sharing with existing systems
- 5GHz (WLAN):
  - 5.15GHz-5.35GHz: Promote frequency sharing with other systems outdoors in accordance with global trend
  - LAA, LTE-U, MulteFire etc.: Observe global trend
- Above 6GHz :
  - 24.25GHz-86GHz (11bands*), *Frequency considered in WRC-19 (IMT-2020): Promote comprehensive consideration in accordance with international harmonization, domestic/international R&D trends and frequency sharing with existing systems
  - 27.5GHz-29.5GHz: Promote comprehensive consideration in accordance with U.S and Korea etc.

They think toward 5G realization by 2020, it is necessary to consider and identify candidate frequencies for 5G in order that telecom equipment manufacturers can start to develop new devices and equipment. And they need to cooperate with major countries who share their views about frequency demands for 5G and to consider and identify candidate frequencies towards 5G deployment by 2020.

The report proposes frequency bands used to realize 5G under consideration with strategy for each frequency band:

- Below 6GHz (3.6-4.2GHz and 4.4-4.9GHz): promote consideration in terms of making frequencies which have features such as wide coverage etc. below 6GHz available toward 5G realization in accordance with international harmonization, the prospect of procuring devices and the status of considering frequency sharing with existing system. Ref 3.6-3.8GHz band: 3GPP bands and is identified for IMT in U.S. etc. However, it is necessary to share the frequencies with satellite communication systems in Japan. 4.4-4.9GHz band: it is desirable to consider securing frequency and to promote international harmonization and cooperation.
- Frequency above 24GHz:
  - Frequencies to be considered in WRC-19 (IMT-2020) 24.25-86GHz (11 bands): ensure enough bandwidth for mobile communication system securing international harmonization in accordance with the progress of R&D and frequency sharing with existing systems.
  - Frequencies considered in U.S and Korea etc. (27.5-29.5GHz): encourage international harmonization, promotes consideration in accordance with progress of R&D and capability securing wide band toward early 5G realization.

MIC started a new committee in October 2016 for 5G. This new committee published the first report on 5G in September, 2017. This report describes the direction of 5G Spectrum allocation below 6GHz in Japan as follows Toward the launch of 5G in 2020:

- Aiming to allocate 3.7GHz band (3.6-4.2GHz) and 4.5GHz band (4.4-4.9GHz) to 5G systems by around the end of FY 2018 (i.e. by around the end of March 2019);
- Aiming to allocate 500MHz bandwidth at the maximum in 3.7GHz band and/or 4.5GHz band, considering the frequency sharing with incumbent radio systems;
- Aiming to allocate 3.4GHz band (3.4-3.48GHz) to the mobile communication systems by around the end of FY 2017 (i.e. by around the end of March 2018)

4.8 Korea 5G

Korean National Broadband Plan 1.0 in Jan, 2012 is to provide 600MHz of bandwidth for mobile until 2020, National Broadband Plan 2.0 in Dec, 2013 is to provide minimal additional 1000MHz of bandwidth for mobile until 2023 including 500MHz in the bands above 6GHz. And the “K-ICT Spectrum Plan” which is going to be published in Oct, 2016 will extend to all areas to meet emerging needs of industries (e.g. IoT, Drone and public safety). Korea will introduce pre-5G trial at PyeongChang Winder Olympic Games in Feb, 2018.

Korea think IMT should be provided both lower and higher frequency bands to fulfill 3 usage scenarios in 5G Vision developed by ITU.

- Bands below 6GHz are essential for coverage and capacity:
  - WRC-15 AI 1.1
  - Congested use of incumbent services below 6GHz

- Heavy traffic in dense urban area (e.g. 'hot-spot')
- Demands on maximized efficiency of data delivery

- Bands above 6GHz, esp. above 24GHz are more important for higher performance
  - WRC-19 AI 1.13
  - Wide contiguous bandwidth
  - Facilitation of multi-beamforming in higher frequency
  - Tolerable path loss within small cells.

Korea Position for Spectrum Policies to 5G Era:

- 5G can use the bands below 6GHz as well as above 6GHz
  - Wide coverage would be achieved below 6GHz
  - High data rate multimedia would be implemented in higher frequency bands.
  - Flexible and efficiency spectrum use below 6GHz
  - Encourage spectrum sharing
  - Competitive license for IMT spectrum
- 5G Eco environments for higher bands
  - Prepare early 5G market and facilitate commercial 5G
  - Achieve global/regional harmonization in 24.25-86GHz at the WRC-19 taking into account technical solution
  - Spectrum below 6GHz
  - Spectrum Auction for IMT was finished in Apr. 2016
    - 5 blocks: 40MHz in 700MHz, 20MHz in 1.8GHz, 20MHz in 2.1GHz, 60MHz (40MHz TDD+20MHz FDD) in 2.6GHz bands
- Considerations of WRC-15 identification
  - 3.4-3.6GHz (hopefully up to 3.7GHz): plan to clear
  - 470-698MHz: still useful for broadcasting, esp. UHDTV transition from HDTV
  - 1452-1492MHz: supported but not yet decided
  - 3300-3400MHz: use for existing services/applications
  - 4800-4990MHz: use for existing services/applications
- Preparation for pre-5G trial
  - Korea will introduce pre-5G trial at PyeongChang Winder Olympic Games in Feb, 2018
  - 28GHz band will be a practical solution considering foreseen market
  - 28GHz is already allocated to MS on a co-primary basis
  - Small cell coverage and large path loss would make easy to coexist with other services
  - In the U.S., NPRM on 5G spectrum includes 28GHz at present, more than 20 stations using 28GHz band are testing in Seoul and PyeongChang and others
  - Test (trial) purposes of 28GHz (26.5 – 29.5 GHz) usage at Olympic will be allowed as scheduled. But Korean three operators have preference on channel B (27.5 – 28.5 GHz). So the trial area will be selected considering geographical harmonization.
  - Commercial 28 GHz are under discussion by MSIP. One of operators expects 28GHz commercialization allocation as early as possible. But the others are not. MSIP wants to have any evidence of 28GHz global harmonization so the determination may be delayed,
- Preparing for WRC-19, the provisional preferred bands from Korea point of view is that:
  - Preferred bands among 11 candidate bands

- 24.25-27.5GHz
  - 25.25-27.5GHz is allocated to MS globally, but 24.25-25.25GHz is only available in R3
  - Res. 238 does not recognize additional MS allocation at WRC-19 in the band 24.25-25.25GHz
  - Res. 238 highlights the need of protection of EESS and SRS in 25.5-27GHz,
- 31.8-33.4GHz
  - Need of additional allocation to MS at WRC-19
- 37-40.5GHz
  - Global allocation to MS

The Ministry of Science, ICT and Future Planning (MSIP) issued '**K-ICT Spectrum Plan**' which is an official roadmap for pioneering domain of future frequencies in Korea including 5G spectrum on January 18, 2017.

- According to the K-ICT Spectrum Plan
  - The Republic of Korea considers 3.5GHz and 28GHz frequency ranges for the 5G spectra
  - The Korean regulator plans to provide 300MHz bandwidth in the band 3.4-3.7GHz and 3 GHz bandwidth in the band 26.5-29.5 GHz by 2018 when 5G systems are available, at the latest by 2021
  - Additional 1 GHz bandwidth in the band above 24.25 GHz will be allocated by 2026 taking into account WRC-19 results.

4.9 UAE 5G

In 2017 there were several official announcements from UAE Government Representative about the country strategy to leverage 5G connectivity within the Emirates. In particular on 12-2017 the UAE TRA has officially announced that it will fully support the suitability of some bands in order to prepare the launch before the year 2020; these short listed bands are:

1427 - 1518MHz
3300 - 3800MHz
24.25 – 27.5GHz

For more detailed information on works of UAE National Committee for IMT 2020 (5G), please visit: *https://www.tra.gov.ae/en/uae-5g.aspx*
https://www.tra.gov.ae/en/media-hub/press-releases/2017/12/23/%D9%87%D9%8A%D8%A6%D8%A9-%D8%AA%D9%86%D8%B8%D9%8A%D9%85-%D8%A7%D9%84%D8%A7%D8%AA%D8%B5%D8%A7%D9%84%D8%A7%D8%AA-%D8%AA%D8%AF%D8%B4%D9%86-%D8%B9%D8%B5%D8%B1-%D8%A7%D9%84%D8%AC%D9%8A%D9%84-%D8%A7%D9%84%D8%AE%D8%A7%D9%85%D8%B3-%D9%81%D9%8A-%D8%AF%D9%88%D9%84%D8%A9-%D8%A7%D9%84%D8%A5%D9%85%D8%A7%D8%B1%D8%A7%D8%AA.aspx

Recently in its edition of 24-12-2017 Gulf News has highlighted the latest Government as well as mobile operators' statements for preparing the country to officially launch 5G services. "The UAE is expected to be one of the first countries to get 5G networks, after the country's Telecommunications Regulatory Authority (TRA) announced on Sunday the launch of 5G technology, with mobile operators in the country expected to start deploying 5G networks from early 2018.

In a statement on Sunday, TRA said that licensees from mobile operators in the country will start deploying the technology in several phases, allowing for the development of information and communications technology infrastructure.

Following the announcement from TRA, telecom provider Etisalat confirmed it will be rolling out 5G technology, as du said it will commence advanced field trials of the technology in the first quarter of 2018. In its statement, Etisalat said it plans to offer 5G to consumers and businesses at high speeds and low latency. A spokesperson from Etisalat told Gulf News on Sunday, however, that no mobile device currently available on the market supports 5G, and that it will be up to phone manufacturers to come up with updates or new devices to support the 5G technology. The spokesperson added that, when rolled out, 5G will be available for Etisalat consumers to use on their home wifi packages, and that the technology will initially be aimed mostly at artificial intelligence and big data.

The launch of 5G across the UAE is expected to benefit various industries including education, healthcare, energy, and manufacturing, among others, TRA said …"

The complete Gulf News article can be found via:

http://gulfnews.com/business/sectors/telecoms/tra-launches-5g-technology-in-uae-1.2146028

5 Coexistence solutions on the existing IMT spectrum

As TDD IMT grows in popularity more regulators are looking to make TDD channel assignments. Before the release of the spectrum and during the 5G sub-6GHz 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 5G sub-6GHz deployment easier.

The most common coexistence issues related to TDD IMT deployment can be classified into the following scenarios:

- Between multiple TD-LTE networks
- Between TD-LTE networks and LTE FDD networks
- Between TD-LTE networks and WiFi networks
- Between TD-LTE networks and Satellite networks
- Between 5G sub-6GHz NR and Satellite networks

5.1 Multiple TD-LTE 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 neighbour 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.

5.2 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 utilised. 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.

5.3 TD-LTE networks and Satellite networks coexistence issues

3GPP has defined a TDD arrangement for the bands 3400MHz-3600MHz (Band 42) and 3600MHz-3800MHz (Band 43). The 3.4-3.6GHz band is also used for Fixed Satellite Service (FSS), Fixed Service (FS) and Wireless Broadband Service around the world. TD-LTE working on 3.5GHz must avoid causing harmful interference to FSS when there is FSS using the same or adjacent band.

Table 5-2 ITU allocations for the band 3400-3600 MHz
Source: ITU-R Radio Regulations

Region 1	**Region 2**	**Region 3**
3400-3600MHz Fixed Fixed-Satellite (space-to-earth) Mobile 5430A Radiolocation	**3400-3500MHz** Fixed Fixed-Satellite (space-to-earth) Amateur Mobile 5431A Radiolocation	**3400-3500MHz** Fixed Fixed-Satellite (space-to-earth) Amateur Mobile 5432B Radiolocation 5433

According to CCSA (China Communications Standards Association) WG8 report[2]on IMT system coexistence with FSS system which working on 3400-3600MHz spectrum and ITU-R S.1432-1 Recommendation, Earth stations of FSS may be interfered by LTE base-stations or devices which are working in 3.5GHz.

According to ITU-R Recommendation [3], techniques are recommended to increase the potential for sharing between IMT base stations and FSS earth stations:

- Sector disabling
- Multi antenna techniques (e.g. adaptive beam forming, MIMO technique)
- Site shielding of earth stations
- Antenna down tilting
- Geo-location and database access

Sector disabling can reduce the transmitted output power of LTE base stations in the direction of the interfered-with FSS earth station. Disabling the antenna sector that points towards the FSS earth station can efficiently reduce the transmitted output power level in the direction of interfered-with

FSS earth stations. Using antenna techniques, such as MIMO, could also reduce the interference. The technique of site shielding of earth stations can reduce the interference from LTE transmitters.

Antenna down tilting of LTE base stations is another method to improve the possible of coexistence. A tailored antenna down tilt can mitigate the interference from LTE base stations.

The technique of Geo-location and database access may provide a higher level of protection because it can reduce interference from LTE terminals. Geolocation and database access can support FSS-IMT co-existence that allows each LTE base station in an area, based upon the prior agreed conditions by the neighbouring administration regarding protection requirements for FSS earth stations, to dynamically determine which frequencies are available for use in its coverage area and under which conditions.

5.4 TD-LTE network and WiFi coexistence issues

WiFi works in 2.4GHz, which is neighbour to the 2.3GHz TD-LTE and 2.6GHz LTE FDD/TDD systems including Band40 (2300-2400MHz), Band41 (2496-2690MHz), Band38 (2570-2620MHz) and Band7 (2500-2570MHz). Better filtering in devices can efficiently solve the interference from LTE on the 2.3GHz band to WiFi. However, legacy WiFi devices will have a range of different receiver filtering characteristics and some may be vulnerable to interference.

When TD-LTE networks and WLAN are deployed at the same place, the WLAN with poor filter could suffer blocking interference from TD-LTE while TD-LTE receive less affect from WLAN because of its better RF performance. According to field tests done by China Mobile LTE and Wi-Fi devices can coexist in most cases if LTE is operated below 2370MHz. Wi-Fi APs receiving performance (uplink) will decrease by 64% when there’s a LTE eNB within 1 meter. Wi-Fi client device receiving performance (downlink) will decrease by 41% when there’s a LTE UE within 0.5 meters. We propose that in some scenarios extending the guard band or space distance between LTE and WiFi will reduce interference risks.

5.5 Highlights of 5G NR networks coexistence with other systems

Several cases should be considered for the 5G NR co-existence with other systems. Indeed key standards organizations (e.g. ITU-R, ECC PT1, 3GPP, etc.) are actively preparing official framework policies and regulations to address possible scenarios which could happen when 5G NR will be deployed by the end of 2018. Examples of such on-going studies are:

- **ECC PT1** is preparing a report titled “*Analysis of the suitability of the regulatory technical conditions for 5G MFCN operation in the 3400-3800 MHz band*”
- **ITU-R** is working on the coexistence study on bands below 6GHz, including 3300-3400 with radar, 4800-4990 with aeronautical mobile, 1427-1518MHz with mobile satellite.

In this section one provides a summary about some of the most important recommendations related to the 5G NR co-existence which are currently under preparation.

5G NR and Other non-LTE Systems Co-existence (e.g. ITU-R, ECC PT1, …)

In general the understanding is that if LTE can co-existence with other non-LTE systems (e.g. Satellite, WiFi, 3G, Radar, etc.), then 5G NR can co-exist as well. There are 2 scenarios to be considered:

1. The condition would be similar to LTE if Massive MIMO is not deployed.
2. The condition can be even better (i.e. less strict) if Massive MIMO is deployed (so called beamforming to avoid direct interference to many type of other radio services).

In Europe ECC PT1 is working on a report to address the co-existence of 5G NR (in considering 3.4~3.8GHz) with other radio systems. This work is on-going and the final ECC PT1 material has not been released yet. A draft material is currently available (under review by ECC PT1 members involved into that study). The final report should be published in 2018. This ECC PT1 report suggests possible solutions to guarantee the 5G NR co-existence with other systems as follows:

- Annex 2: Studies on the interference between synchronized MFCNs
- Annex 3: Studies on the interference between unsynchronized MFCNs
- Annex 4: Studies on the coexistence between AAS MFCN and Radiolocation systems
- Annex 5: Studies on the coexistence between AAS and Radio Astronomy systems

Another study has been conducted by CMCC for addressing the 5G NR co-existence with satellite in the 3400-3600MHz spectrum range. Indeed 3400-3600MHz has been considered to be a global IMT harmonized spectrum band in WRC15 agenda item 1.1. The 3.4-3.6GHz band is also used for Fixed Satellite Service (FSS), Fixed Service (FS) and Wireless Broadband Service around the world. IMT working on 3.5GHz must avoid causing harmful interference to FSS when there is FSS using the same or adjacent band.

Table 5-2 ITU allocations for the band 3400-3600 MHz
Source: ITU-R Radio Regulations

Region 1	Region 2	Region 3
3400-3600MHz	**3400-3500MHz**	**3400-3500MHz**
Fixed	Fixed	Fixed
Fixed-Satellite	Fixed-Satellite	Fixed-Satellite
(space-to-earth)	(space-to-earth)	(space-to-earth)
Mobile 5430A	Amateur	Amateur
Radiolocation	Mobile 5431A	Mobile 5432B
	Radiolocation	Radiolocation 5433

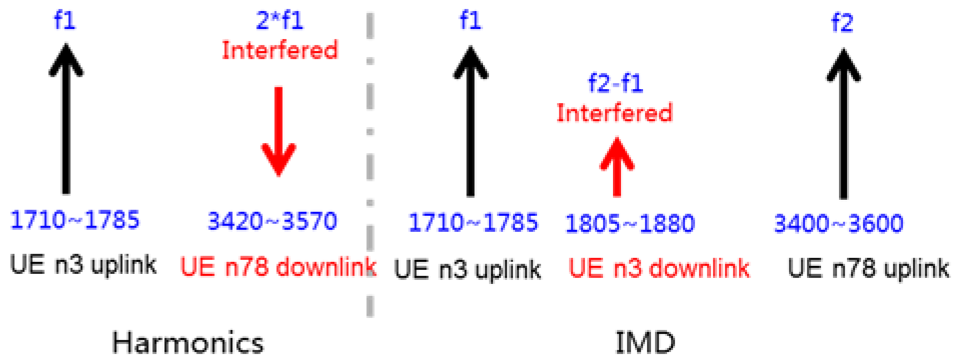
The coexistence study has been done between sub-6GHz 5G NR and satellite system at 3.5GHz by CMCC. Different from TD-LTE network and satellite networks coexistence issues, 5G NR could coexist with satellite networks with negligible interference to each other. The broader bandwidth, directional antenna gain and higher carrier frequency contribute to the less interference.

5G NR and LTE Systems Co-existence in Uplink (3GPP)

In R15 3GPP has defined LTE and 5G NR co-existence to allow the sharing of the LTE uplink channel among both 5G NR and LTE at the same time. This co-existence targets a single MNO assuming that the MNO's own spectrum resources are split into 5G NR Uplink and LTE Uplink.

Let's shortly discuss the situation for inter-modulation and harmonics situation.

This following figure helps to understand harmonics and inter-modulation (IMD),



Inter-modulation: The inter-modulation is due to the dual uplink operation which interferes the own downlink reception, for specific bands combination.

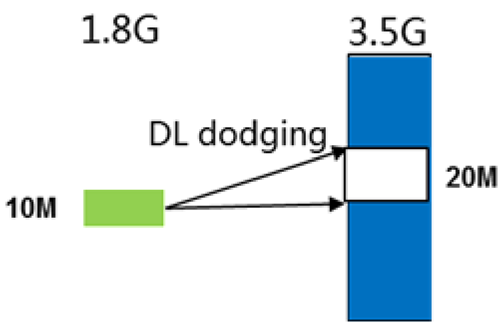
There is no IMD issue if there is no dual transmission in n3 & n78, e.g. in single Tx mode.

Harmonics: Harmonics are caused by uplink transmission which interferes the own downlink reception, for specific band combination. It's a common issue for SUL, DC and CA scenarios.

There are 2 main methods to avoid this issue,

Method 1: Operators can select unaffected spectrum.

Method 2: UL and DL FDM based on network implementation



In the figure above one assumes that 1.8GHz uplink interferes with 3.5GHz band for a dedicated user. Since interference occurs only when UL and DL transmit data simultaneously, DL dodging is designed to eliminate the interference. Therefore for this user one avoids to schedule on the DL part being interfered.

Harmonics is per user and we can re-use the 20MHz with interference for scheduling another user.

In addition if only one user exists, DL power converging can offer remaining bandwidth more power.

6 Sub-6GHz band development progress

This white paper intents to study and follow up the development of sub-6GHz band for both LTE evolution and 5G NR. In this section, it will summarize the different sub-6GHz bands development situation from various regions, countries and investigate the possible operator deployment plan for these bands. We also look at the specification of 3GPP for these bands and follow up the possible regulatory requirement and coexistence situation for these bands from various countries.

6.1 600/700MHz:

5G will need to be deployed also in the bands already harmonized below 1GHz (APT 700), including particularly new band in 700MHz, in order to provide national and indoor 5G coverage.
This band is identified by some regions for 5G while some other regions and countries planned for other applications due to the existing service; one of them being 4G LTE.

It will be made available in all EU countries no later than 2020 (EC Decision). It's already auctioned in several countries in Europe (Finland, France, Germany, Italy, etc.). It may initially be used for LTE deployment and later for 5G in order to provide consistent coverage experience and accommodate IoT usage.

In Korea, 2x10 MHz (718-728/773-783 MHz) is allocated for PPDR (PS-LTE), and 2x20 MHz (728-748/783-803 MHz) is available for mobile and plans to secure 24 MHz in stages dedicated for IoT within below 1 GHz. (The band is not specified yet.)

In Japan, this band was [is used 718-748/773-803 MHz, 10 MHz per operator]. PLEASE RESTRUCTURE THIS SENTENCE AS THE MEANING IS NOT VERY CLEAR.

In China, this band is used for broadcast service.
In the U.S. this band [is covered by Band 12, 699-716/729-746 MHz, will be extended to 698-716/728-746 MHz, NB-IoT likely in the lowest 1 MHz, B13, 777-787/746-756 MHz used nationwide, B14, 788-798/756-766 MHz, for public safety (and possible shared commercial use). Bands 12/13/14 are not yet specified for NR by 3GPP]

The following bullets summarize the current development status of APT700 at the end of 2017:

- In 2012 3GPP has officially approved APT700 band 28 (FDD mode) for wireless communications as part of 3GPP R11. It represents a bandwidth of 2x45 MHz of spectrum resources providing excellent coverage for indoor scenario and rural coverage.
- Globally 42 operators have already successfully deployed APT700 band 28 for 4G LTE and 4.5G services. Carrier aggregation scenarios are already used in combining APT700 band 28 and several other bands (band 1, band 3, band 4 and band 7).
- 5 more countries have allocated APT700 band 28 to operators in 2017 including Australia (TPG, VHA), Mexico (Altan Consortiums), Saudi Arabia (Atheeb, STC KSA), Singapore (M1, SingTel and Starhub) and Uruguay (Claro, Movistar). Totally there are 27 countries having already auctioned APT700 band 28 to operators. LTE networks using APT700 band 28 have been deployed in 21 of these 27 countries.

- 741 4G LTE terminals support APT700 band 28 (including near 600 smartphones).
- In several markets there are LTE smartphones around US$100 price range (from several suppliers) allowing an easier adoption among LTE users.
- APAC and LATAM regions are leading the number of LTE networks using APT700 band 28 representing ~85% of the overall total of LTE700 networks; with respectively 20 LTE networks in APAC and 16 LTE networks in LATAM region.
- Digital switchover (DSO) needs to be encouraged. Especially DSO seems to be one of the remaining challenges for boosting the allocation of APT700 band 28 to operators. Two examples for Europe and Vietnam are highlighted in showing how DSO can be structured and implemented to vacate APT700 band 28 for mobile communications.
- It is highly recommended that APT700 band 28 could be allocated as a "technology neutral" band allowing operators to select the relevant 3GPP RAT release as per their market situation and strategy. Indeed 3GPP has defined specifications for using APT700 band 28 on LTE, 4G, 4.5G and 5G.

Finally note that in May 2017, T-Mobile US announced the plan to use 600MHz band [Band 71, 617-652/663-698 MHz] it acquired in the recent auction for national wide 5G deployment. [Band 71 will also be specified for NR]
And Canada is consulting for the use of 600MHz for 5G services.

6.2 800MHz

There are 2 bands to be considered here; they are DD800 (3GPP band 20) and 850MHz (3GPP band 5). Both bands are widely and successfully used for cellular services around the world as follows:

- DD800: Region 1 (4G LTE)
- 850MHz: Region 2 (3G mainly and few 4G networks) and Region 3 (3G/4G in several leading countries like Australia, China, Japan, Korea, Philippines)

In addition 3GPP has recognized these bands for 5G NR services as well and they have been included into 3GPP R15 5G NR bands list as follows:

- DD800, n20 (FDD mode)
- DD800, n82 (SUL mode)
- 850MHz, n5 (FDD mode)

6.3 900MHz

900MHz is mainly used for operators' 2G/3G services; with some operators having already refarmed 900MHz for LTE. In long term 900MHz should be a 5G band as well. 3GPP has already included 900MHz into the list of 5G NR bands (3GPP R15 TS 38.101) . There are 2 options for 900MHz being part of 3GPP R15 for 5G NR services; they are n8 (FDD mode) and n81 (SUL mode).

6.4 L-band

The L-band (1427-1518 MHz) is another 5G candidate band that has the potential to be allocated to mobile in most countries in the world. CEPT and CITEL regions have adopted the SDL (Supplemental Down Link) scheme for this band. The requirement for standalone operation in the band (both UL and DL transmissions) has emerged in some other regions. In the case of standalone 5G systems, a TDD access scheme is a potentially appropriate option, which can accommodate traffic asymmetry in the UL/DL directions with good potential for economies of scale. The same 5G NR equipment can serve both the TDD and SDL markets.

6.5 1800MHz:

This is the band for operators 2G/4G services at the time being. However there is already indication that some operators would like to use this band for 5G services (in particular for the uplink). 3GPP has defined this band for 5G NR services in R15 (3GPP TS 38.101). They are n3 (FDD mode) and n80 (SUL mode).

6.6 1900MHz/2100MHz:

This band is mainly used for operators' 3G services all around the world. Some of them have already refarmed it for LTE services. It would be in long term a band for 5G as well. 3GPP has already included this band into 3GPP R15 for 5G NR services; they are n1 (FDD mode) and n84 (SUL mode).

6.7 2300MHz:

This band is widely used for TD-LTE services globally including APAC, Middle East and Africa regions. There are on-going discussions in 3GPP for adding 2300MHz TDD into the list of 5G NR bands.

6.8 2600MHz:

This is band 41 for TD-LTE. So far it has been mainly used for TD-LTE Advanced services in several countries. Some operators now plan to deploy (or refarm) this band for 5G NR. 3GPP has already included this band into the list of 5G NR bands in 3GPP R15.

In Europe it is band 38 for TD-LTE and it has been defined for n38 for 5G TDD.

6.9 3300-3800MHz:

It has been defined as n78 band in 3GPP. It's a global core band for 5G with momentum in Asia, Europe/Africa and America and seen as important 5G pioneer band for different regions and countries. In the European Commission (EC) mandate7 on 5G to the European Conference of Postal and Telecommunications Administrations (CEPT), it is noted that the frequency range 3400-3800 MHz is prime spectrum suitable for the introduction of 5G-based services across the European Union. Given that this spectrum is already harmonized for the CEPT countries for mobile networks

(IMT-Advanced) and offers wide channel bandwidth it can be used before 2020. The CEPT is now working to revise and amend the existing harmonized technical conditions for this range, to ensure suitability for 5G terrestrial wireless systems. The work will be completed by June 2018 while stable results are expected during 2017.

The CEPT is also working on guidelines to help Administrations ensure the availability of the largest contiguous blocks, starting from the current fragmented situation in which smaller blocks have been assigned to different services and operators, sometimes at regional and local levels. The EC recently published their 5G Action Plan proposing a harmonized roadmap towards 5G across the European Union: trials from 2018, initial commercial launches in 2020 (at least in one city per country) with wider coverage expected in all major cities and communication paths by 2025.

It targets for large bandwidth possible (~100 MHz per operator) and decent coverage for operators. Some Indications from key countries

- Germany: 3400 – 3800 MHz available by 2021 – 2022, 3700 – 3800MHz for regional use
- France: 3460 – 3800 MHz to be made available
- UK: The auction for parts of 3400 – 3600 MHz is expected to held soon in early 2018, parts of 3600 – 3800 MHz later

The 3400-3600 MHz band is already broadly identified for IMT in African countries, although its predominant use today is fixed wireless accessservices. Countries are in the process of transitioning regulations to allow mobile use.

The future use of the 3400-3600 MHz range for 5G as well as the possible use of the 3600- 3800 MHz range is now being considered by several countries in the Middle East and North Africa. To the extent of the currently available knowledge, the 3400-3600 MHz range has been used for WiMAX and then re-farmed to LTE in several countries from the region. Countries like Bahrain, Egypt, Saudi Arabia, Morocco, Qatar and UAE are considering this band for 5G.

In Region 2, at the 28th CITEL PCC.II meeting one proposal of frequency arrangements for the 3300-3700 MHz was submitted aiming at the entire 3300-3700 MHz frequency range for IMT with TDD mode taking into account the benefits of the global harmonization and the potential economies of scale. Previously Colombia, Ecuador, Canada and Brazil presented similar proposals for different ranges with the objective to leverage the global IMT harmonization.

A number of major Region 2 countries have now announced their intention to make

available parts of the 3300-3700 MHz band for IMT.

In the U.S., the 3550-3700 MHz has been allocated for spectrum sharing under a 3-tier construct; Incumbent Users, Priority Access License (PAL) users and General Authorized Access (GAA) systems. Commercial deployments of GAA systems are expected at the beginning of 2018. Competitive bidding for PAL licenses in the 3550-3650 MHz range is expected during the second half of 2018. For further information on this see the chapter on Sharing vs. Clearing.

In Region 3, A number of countries are also working to make available a portion of 3300- 3700 MHz band for IMT; for example, India is in the process of updating the National Frequency Allocation Plan (NFAP) to include identification of 3300-3600 MHz for IMT.

In China, MIIT released a public consultation for the notification on 5G IMT system (IMT-2020) using 3300-3600MHz. The final spectrum allocation for 5G in the band and the technical conditions for sharing with other services would expected by the end of this year.
According to the current consultation:

- IMT-2020 system in 3300-3400MHZ should be limited to indoor use only in principle. Without any harmful interference to the radio location service station in use, it can be used for outdoor deployment.
- The station of IMT-2020 system in 3400-3600MHz band should not cause any harmful interference to FSS (Fixed Satellite Service) earth stations operating in the same frequency band with effective license.

In Japan, 3480-3600 MHz has been allocated to three mobile operators (NTT DoCoMo, KDDI and Softbank, 40 MHz each) in December 2014, and TD-LTE operations started in 2016. 3400-3480 MHz is to be allocated in March 2018 for TD-LTE. The operators may continue their TD-LTE Advanced development for the band.
3600-4200MHz is the candidate range for 5G, and a parts of them is to be allocation before March, 2019.

In Korea, 3.4 – 3.7 GHz is identified as 5G according to the latest national broadband plan early 2017. Co-existence with incumbents like UWB, radar and satellite is under investigation.
Operators show the intention for early commercial roll-out early 2019, and that makes the regulator consider early allocation around mid 2018 or earlier. Specific band plan and auction rule including pricing and deployment obligation are under development. Allocating 100MHz per operator is simple guess, but the regulator is looking at other possibilities with more options to encourage competition at frequency auction.

In Austria, the 3.6GHz band is 3575-370MHz (125MHz BW). From 3.4-3.575 GHz is currently allocated (OPTUS ~100MHz, NBN for FWA). ACMA (Australian Communications & Media Authority) released public consultations for the 3.6GHz band. This has gone through several stages over the past year; from 'monitoring' to an announcement this week (26th Oct.), of a ' Draft spectrum reallocation recommendation for the 3.6 GHz band'.This spectrum is expected to be available late 2018, via auction.

In 2017 Hong Kong will consult on the 3400- 3700 MHz band with a view to reallocating it to IMT.

In Singapore, 3.5GHz (3.4GHz to 3.6GHz) is prime candidate for 5G as coverage layer. It is no timeline for 5G auctions yet but IMDA has announced waiver of 5G trial spectrum fees to encourage 5G trials in Singapore.

The C-band is the primary band for the introduction of 5G globally (n78) with uplink coverage assistance from frequencies below 2 GHz. The C-band is emerging as the primary frequency band for the introduction of 5G NR by 2020, providing an optimal balance between coverage and capacity for cost efficient implementation. The availability of at least 100 MHz channel bandwidth per 5G network with the adoption of massive MIMO will boost peak, average and cell edge throughput with affordable complexity. Lower frequencies already licensed for mobile use (e.g. 700, 800, 900, 1800 and 2100 MHz) may be exploited in combination with 3300-3800 MHz (utilising the LTE/NR uplink co-existence feature of 3GPP standards) allowing operators to benefit from faster and cost-efficient deployment of C-band, thus delivering enhanced capacity without incurring network densification costs.

In addition all leading chipset suppliers will release commercial 5G NR products supporting n78 in 2018 as per 3GPP R15 compliance. Definitely 3300~3800MHz will be the key band for launching 5G NR services in 2019/2020.

6.10 3300-4200MHz

3GPP has defined band n77 for 5G NR services to support global roaming for 5G devices. In Japan, 3600-4200MHz is the candidate range for 5G, and a part of it will be allocated to 5G operators before March, 2019.

It is obvious that the strong market commitments behind band n78 can also partly benefit the eco-system development of the band n77 (in particular the lower part of the band).

6.11 4400-5000MHz

3GPP has defined band n79 for 5G for 4.4-5.0GHz.

In China, 4.4-4.5GHz is revised in the updated Chinese Frequency Table to include mobile service in that band. China has proposed this band as one of the 5G candidate band. However, the incumbent system in this band would still need to be operations for some time and refarming this band for 5G allocation will take more time and so far not identified yet.

In China, 4800-5000MHz are allocated as IMT-2020 operation bands in the current MIIT released public consultation for the notification on 5G IMT system (IMT-2020). The final spectrum allocation for 4800-5000MHz in China would be expected to be finalized by the end of 2017.

In Japan, 4400-4900 MHz is candidate ranges for 5G, and a part(s) of them may be allocated before March 2019.

7 High Interested Operator deployed LTE-Evolution and 5G-NR bands and Equipment Availability Analysis

7.1 2600 MHz

In 2017 Sprint announced their trial for 2600GHz Band 41 for 5G-NR, pushing standardization for 3GPP. In 2019, they plan to introduce 5G-NR in part of the 2600MHz, coexistingwith current LTE-Advanced network in the band.

7.2 3300-3800MHz and 3300-4200MHz

Parts of 3300-4200 MHz range are being considered for early trials in a number of countries/ regions in the world: trials in the 3400-3800 MHz band are being prepared for 2018 in Europe.
There are ongoing 5G NR trials in China (3400-3600 MHz) as part of China 5G IMT-2020 Project and Japan (3600-4200 MHz)
Trials are also planned in Australia for 3400-3600 MHz ahead of the spectrum allocation for this band in 2018.

The 3300-4200 MHz band range is supported by both LTE Evolution and 5G-NR. Different operators may have their own strategy for selecting the technologies and deployment towards 5G either by LTE Evolution or 5G-NR. Both of the solutions will be supported by 3GPP specifications.
According to the global suppliers association analysis, 29 deployed LTE networks in the 3400-4200 MHz range and several operators are committed to deploying LTE globally in 3GPP bands 42 and 43. And there are 118 devices, including smartphones28, which are commercially available in the 3400-3600 MHz band (3GPP band 42), and 93 devices are commercially available in the 3600-3800 MHz band (3GPP band 43).
A broad range of 5G products will be available in 3300-4200 MHz to meeting the market demand to support operators' deployment both for urban wide area and indoor hotspots scenarios. End user equipment ranging from wireless routers to smartphones, as well as wireless modules will be integrated into a broader range of devices. Chipset suppliers are fully committed to supporting the 3300-4200 MHz range. They have prepared for quite some time for 3.5GHz chipset since GTI was established.
5G trials and interoperability testing (both LTE Evolution and 5G-NR) in the 3300-4200 MHz range have already started in late 2017. Commercial readiness of the 5G-NR ecosystem is expected in 2018,targeting broader 5G NR commercialization by 2019.

7.3 4400-5000MHz

China frequency planning for 4800-5000GHz will be formalized soon by the end of this year. Japan may allocate part(s) of the band 4400-4900 MHz before March, 2019. Strong demand from China and Japan may drive the equipment availability since the specifications are finalized. GTI will continue drive for the product maturity as soon as possible for operators to deploy network in this bands.

The Official China MIIT notification on 5G IMT system (IMT-2020) using 3300-3600MHz and 4800-5000MHz will be finalized by the end of this year.

Japan MIC started a new committee in October 2016 for 5G. This new committee published the first report on 5G in September, 2017. This report describes the direction of 5G Spectrum allocation below 6GHz in Japan with the target to launch 5G services by 2020:

- Aiming to allocate 3.7GHz band (3.6-4.2GHz) and 4.5GHz band (4.4-4.9GHz) to 5G systems by around the end of FY 2018 (i.e. by around the end of March 2019);
- Aiming to allocate 500MHz bandwidth at the maximum in 3.7GHz band and/or 4.5GHz band, considering the frequency sharing with incumbent radio systems;
- Aiming to allocate 3.4GHz band (3.4-3.48GHz) to the mobile communication systems by around the end of FY 2017 (i.e. by around the end of March 2018)

8 GTI Operator Plans of 5G trial and schedule

GTI members like China Mobile has shared their 5G trial plan in the last GTI Test Summit in Barcelona, introducing their 5G trial plan towards 2020 commercial launch.

Towards the target of commercialization in 2020, China Mobile is leading the 5G development in technology, standardization and industrialization,

In 2016, China Mobile set up the 5G joint innovation center serving the objective of cross-industry ecology system, and at least 11 key technique validations have been finished in 2016.

In 2017, China Mobile has launched the 5G field trial in Beijing, Shanghai and Guangzhou. The initial field trial results satisfied the 5G requirements well including system spectral efficiency, peak data rate, air interface latency and No. of connections simultaneously.

5G POC system mainly include 5G NR base station and device. The capabilities of both base station and device should align with 3GPP Rel-14 NR SI framework. The key configurations of POC system are specified below:

Table 8-1 BS prototypes

band	3.4-3.6GHz
SCS	15kHz
bandwidth	100/200MHz
Tx power	200w
Antenna element	192/128
RF transceiver	64TR

Table 8-2 UE prototypes

TRx	8T8R/4T8R/2T4R (different configuration are used for different test cases)
Tx power/transceiver	23dBm

For the 5G coverage, higher frequency means more path loss. Therefore, differences between NR systems (3.5G/4.8GHz) and LTE systems (1.9G/2.6GHz) are analysed. The test and theoretical coupling loss discrepancies between 3.5/4.8GHz and 1.9/2.6GHz (corrent LTE bands) in outdoor and O2I scenario are shown below.

Table 8-3 coupling loss of NR and LTE system and band compared to 1.9GHz TD-LTE(dB)

Scenario			1.9GHz TD-LTE	2.6GHz TD-LTE	3.5GHz NR	4.8GHz NR
Outdoor		Theoretical	0	-4.3	-6.38	-10.71
		Test	0	-4.3	-7.3	-9.76
O2I	Low Penetration	Theoretical	0	-6.3	-10.38	-16.71
		Test	0	-6.5	-10~-10.5	-17.7~-18.2
	High Penetration	Theoretical	0	-	-	-
		Test	0	-9	-13.5~-15.5	-24.2~-27.2 (*can reach -34.1 in some scenarios)

The predicted control coverage after applying coverage enhancement schemes, such as beam sweeping, PDCCH 16 CCE, PUCCH/PRACH new format, is shown below.

Table 8-4 predicted control coverage

Device: 1T2R 23dBm						
Baseline-4G coverage / NR control coverage	outdoor		O2I Low Penetration		O2I High Penetration	
	1.9GHz	2.6GHz	1.9GHz	2.6GHz	1.9GHz	2.6GHz
3.5GHz	Yes (close to)	yes	no	yes	no	no
4.8GHz	no	yes	no	no	no	no

Device: 2T4R 26dBm						
Baseline-4G coverage / NR control coverage	outdoor		O2I Low Penetration		O2I High Penetration	
	1.9GHz	2.6GHz	1.9GHz	2.6GHz	1.9GHz	2.6GHz
3.5GHz	yes	yes	no	yes	no	yes
4.8GHz	Yes (close to)	yes	no	no	no	No

After applying coverage enhancement schemes in control channel, 3D-MIMO can effectively boost 5G throughput. Moreover, 3.5GHz provides much better coverage than 4.8GHz achieving signficant gain in DL/UL throughput.

Table 8-5 Single site RSRP

RSRP (dBm)	3.5GHz	4.8GHz
Outdoor NLOS	-102.63	-105.18
O2I (Outer-doors to indoors)	-66.76	-75.99

For 5G throughput, single-user peak throughput and cell peak throughput as shown below are used as the key performance indicators to measure the throughput performance.

Table 8-6 The single-user peak throughput

Trial results	Maximum DL stream/UE	Modulation	Theoretical throughput(Gbps)	Test results(Gbps)
Vendor1	8	64QAM	2.10	1.86
Vendor2	4	64QAM	1.05	0.9
Vendor3	4	256QAM	1.36	1.22
Vendor4	4	256QAM	1.36	1.21

Table 8-7 The cell peak throughput

Trial results	Maximum layers	Modulation	Cell peak throughput(Gbps)	Cell peak throughput/ Layer(Gbps)	Theoretical throughput/layer(Gbps)	Discrepancies between trial/theoretical
Vendor1	8	64QAM	5.91	0.25	0.26	6.74%
Vendor2	4	64QAM	7.57	0.27	0.26	-2.41%
Vendor3	4	256QAM	4.31	0.27	0.34	21.33%
Vendor4	4	256QAM	7.22	0.26	0.34	24.80%
Scheduling algorithms (esp vendor 3,4) still have room for improvement						

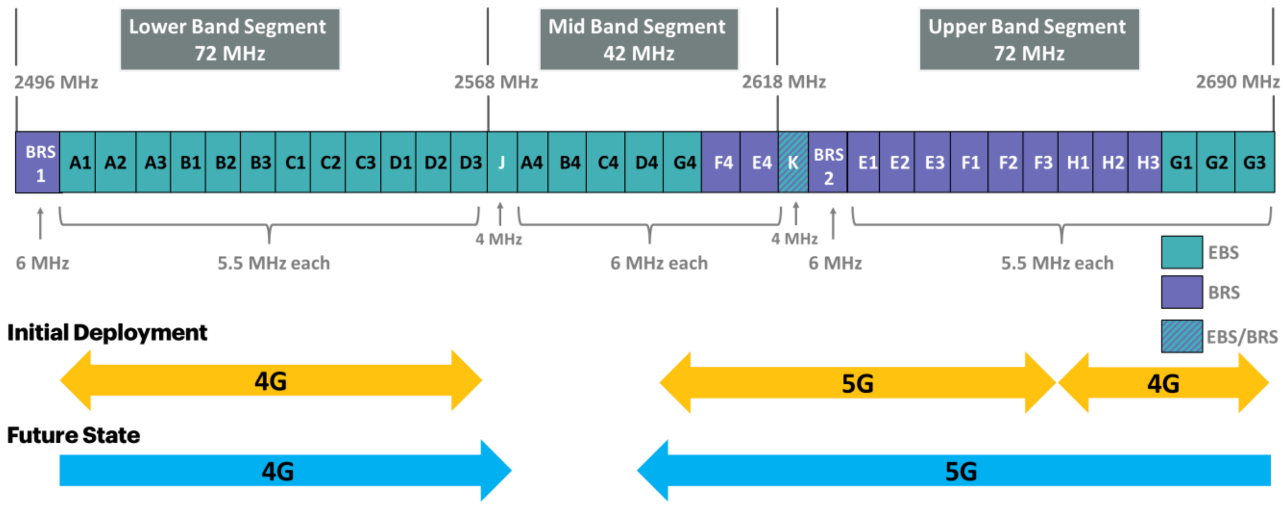
For 5G latency, ITU minimum requirements for user plan latency are 4ms for eMBB and 1ms for URLLC. The details of the trial latency are shown below which meets all the latency requirements. However, performance with other SCS/conditions needs to be further evaluated.

Table 8-8 One-direction air-interface latency(ms)

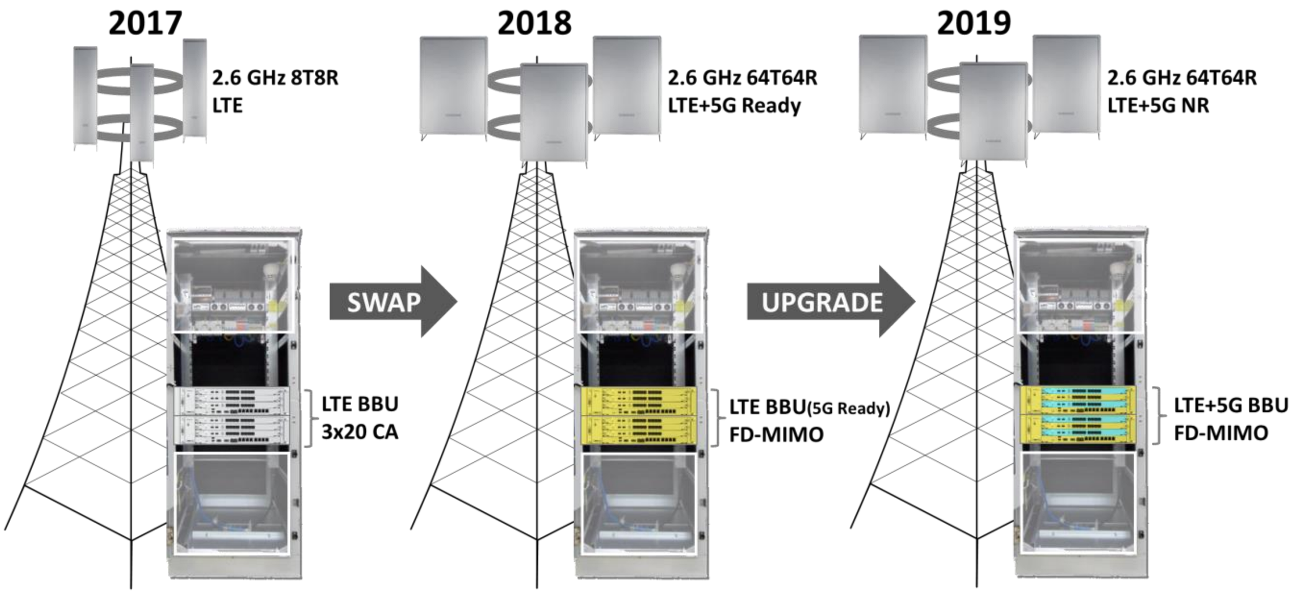
One-direction air-interface latency(ms)	UL	DL
Vendor1	0.42	0.41
Vendor2	0.43	0.43
Vendor3	0.65	0.66
Vendor4	0.44	0.43

CMCC will start the large-scale field trial in 2018 and pre-commercial trial in 2019, and finally realize the 5G commercialization in 2020.

Sprint also plans for their 4G evolution and 5G deployment in 2.6GHz Band. The initial deployment and future plan are depictured in the following figure.



Their plan for network evolution is deploy LTE with 64T64R for 4G evolution and prepare for 5G in 2018 and deploy LTE+5G 64T64R in 2019.



For their exiting trial:

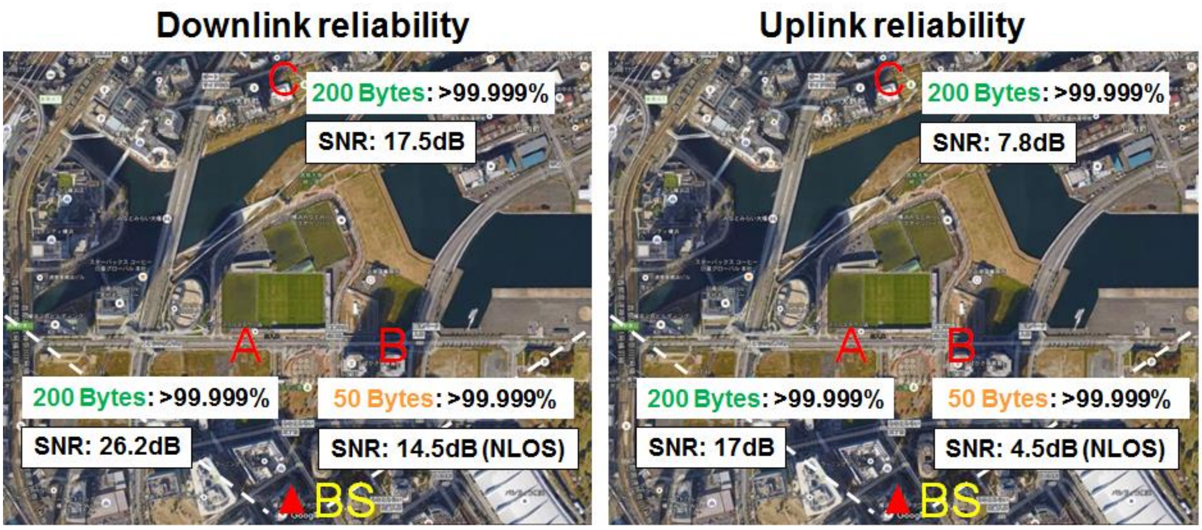
- TDD LTE Massive MIMO technology was tested in Band 41 in Sprint network in Seattle, USA.
- A 64T64R radio was tested with three 20 MHz carriers in Frame Configuration 2, supporting maximum 8 layers.
- Significant performance benefits were seen relative to current 8T8R system.
- The commercial 16-layer 64T64R System is expected to improve performance further.

Expected 64T64R Massive MIMO 16-Layer Capacity

Peak Capacity		Single 20 MHz	2x20 MHz CA	3x20 MHz CA
Single Sector (Mbps)	256 QAM	960	1920	2880
256 QAM 3-Sector Site (Gbps)		2.88	5.76	8.64

In Japan, subsequent to the successful release and commercial deployment of 120MHz at 3480-3600MHz since 2014, Japan Ministry of Internal Affairs and Communications (MIC) has further announced the start of 5G field trials in May 2017. 3 mobile operators (NTT DoCoMo, KDDI, SBM) , one fixed network operator (NTT Communications) and 2 national research institutes (ATR and NICT) will carry out 5G field trial on 6 different use-cases, based on 3.6-4.2GHz, 4.4-4.9GHz and 27.5-29.5GHz.

In Nov 2017, Docomo completed the world's first 5G field trial with 4.5GHz in Yokohama, focused on the Ultra-Reliable and Low-Latency Communication (URLLC) use-case with a macro base station on the 4.5 GHz frequency band (C-Band) using a new radio interface of similar features such as 3GPP 5G New Radio (NR) air-interface. This test demonstrated that the current 5G trial system over 4.5 GHz can meet the performance requirements for URLLC as defined by the International Telecommunication Union - Radio Communication Sector (ITU-R). The completion of the trial has paved the way for large-scale macro cell deployment to support URLLC, while laying a solid foundation for the extensive application of 5G NR across various vertical industries.



9 Recommendations

Transparent and in advance spectrum planning would enable operators to build a more solid business model and facilitate development towards 4G and 5G. As development momentum may vary across regions, this section aims to summarize the discussion in previous chapters

Key findings for Sub-6GHz LTE Spectrum

Comprehensive MBB Solution Using both FDD & TDD Bands: New 4G LTE spectrum allocation as well as the re-farming of existing 2G/3G bands (e.g. 900/1800/2100MHz) for supporting 4G would benefit to the development of MBB services. Here TDD bands can perfectly accommodate the capacity needs and guarantee a comprehensive user experience at a lower per GB cost. Indeed TDD spectrum can play a vital role for 4G growth and below are some key recommendations to facilitate the effective use of TDD spectrum.

Encourage TDD Synchronization: Furthermore experience over time has demonstrated that when there is a real willingness to use the spectrum, full synchronization between operators is a key enabler in the successful deployment of IMT networks in unpaired spectrum. A downlink/uplink ratio of 3:1 (configuration 2 in TD-LTE) is currently the mainstream configuration for commercial LTE TDD deployments, and adapts well to real world traffic environments including China, Japan and India.

Light Touch Regulation: In some regions, current TDD license (such as WiMAX) is limited to Broadband Wireless Access, which restricts MNOs to develop smartphone subscription. To encourage spectrum to be effectively used, light touch regulation for service neutrality is encouraged, to allow diversify for all types of business models including personal, household and IoT markets. On the other hand, application of technology neutrality to support 2/3/4/5G and less restriction on equipment transmission power will also benefit the evolution to 5G, such as adoption of massive MIMO.

Consider more TDD possibility for Smoother Evolution: For 2.6GHz, there are currently 2 band plans in 3GPP standard. GTI suggests future new release or refarm countries should consider using pure TDD mode (Band41) whenever possible, which already massively adopted in global big countries including China, India, Japan, US and so on. Band 41 has multiple benefits including better network performance, smoother 5G evolution and gain ecosystem economy of scale with big countries (Details refer to Section 6.8) Band 41 is an ideal choice for countries who need more spectrum, especially for countries whose C-Band may not be adequate or may take long time to refarm for IMT.

Key findings for Sub-6GHz 5G Spectrum

A multi-layer spectrum approach is required to address such a wide range of usage scenarios and requirements:

- The "Coverage Layer" exploits spectrum below 2 GHz, especially below 1GHz (e.g. 700 MHz) providing wide-area and deep indoor coverage.
- The "Coverage and Capacity Layer" relies on spectrum in the 2GHz to 6 GHz range (e.g. C-band) to deliver the best compromise between capacity and coverage.

• The "Super Data Layer" relies on spectrum above 6 GHz (e.g. 24.25-29.5 and 37-43.5 GHz) to address specific use cases requiring extremely high data rates. Note that mmWave bands are not the focus of this document.

5G networks will leverage the availability of spectrum from these 3 layers and administrations should focus on making available contiguous spectrum in all 3 layers in parallel, to the greatest extent possible.

The C-band is the primary band for the introduction of 5G globally. M-MIMO, High Power UE, 2TX, 4RX, or SUL/DC/CA with bands below 2GHz can all be used as the assistance method in some deployment scenarios depending on the coverage or the capacity requirements from the operators.

3GPP has already specified initial bands for the 5G NR (TS 38.101-1; @12-2017). In addition, 3GPP has set early scenarios for bands combinations including carrier aggregation, LTE/NR uplink coexistence (SUL scenario) and dual connectivity. This is fully part of 3GPP Release 15.

Candidates of 5G bands

Based on the analysis in previous sections, at current stage GTI supports the following candidate band: 2300MHz, 2600MHz, 3300-3800MHz, 3400-4200MHz and 4400-5000MHz, as the kick-off bands for 5G deployment in sub-6GHz.