GTI
Sub-6GHz 5G Deployment White Paper

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1 Abbreviations

Abbreviation	Explanation
2/3G	The 2/3rd Generation Telecommunication Technology
3GPP	The 3rd Generation Partnership Project
4G	The 4th Generation Telecommunication Technology
5G	The 5th Generation Telecommunication Technology
AR	Augmented Reality
CC	Component Carrier
CP	Control Plane
CPE	Customer Premise Equipment
DC	Dual Connectivity
eMBB	Enhanced Mobile Broadband
gNB	NR node
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
MIMO	Multiple-Input Multiple-Output
mMTC	Massive Machine Type Communication
mmWave	Millimeter Wave
MR	Mixed Reality
MU-MIMO	Multi-User MIMO
NAS	Non Access Stratum
NG Core	Next Generation Core Network
NR	New Radio
NSA	Non-Standalone
OFDM	Orthogonal Frequency Division Multiplexing
PLMN	Public Land Mobile Network
PoC	Proof of Concept
RLC	Radio Link Control
RRC	Radio Resource Control
SA	Standalone
UE	User Equipment
UP	User Plane

URLLC	Ultra-Reliable and Low Latency Communications
VR	Virtual Reality

2 Overview

The objective of this white paper is to layout the high level view on the business motivation to drive 5G commercialization, the spectrum availability at sub-6GHz frequency bands and the possible deployment scenarios might be considered by worldwide operators.

Thanks to the success of 4G mobile broadband, the mobile cellular technology has significantly changed human life in these years. Numerous mobile applications and elegant smart devices have become a necessity in most people's life every day. It has changed the face of the global economy today and has become the foundation to evolve human society. All these changes further stimulate the demand on 5G, and indirectly make it happens faster than expected.

Compared with 4G era, 5G arrives faster than expected. The commercialization plan is now being actively evaluated by worldwide operators and governments, even before the specification was finalized. However, this also results in the risk of ecosystem fragmentation if the technical requirement and deployment scenarios by the operators in different regions are too diverse.

Therefore, the GTI, as an industry consortium, hope to provide a platform for concerned parties to exchange their views and to develop the consensus for ecosystem guidance. This white paper will serve as a platform to initiate 5G deployment strategy discussions within the GTI and be continuously updated based on the progress and consensus.

3 References

The following documents contain provisions which, through reference in this text, constitute provisions of the present document.

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4 Business Driver & Opportunities

4.1 Introduction

Mobile broadband traffic is expected to increase eight times by 2023, according to the Mobility Report[10]. At the same time, the number of IoT/MTC devices is set to explode. Despite mobile subscriber growth and rising demand for mobile data, mobile service revenues have flattened. Mobile network operators (MNOs) are looking for ways to monetize the growing usage of mobile data services into greater revenues and are challenged. According to strategy consultancy CIMI Corp., 2017 was expected to be the year when the cost-per-bit would surpass revenue-per-bit for some services of MNOs.

MNO's are looking to and relying on 5G to relieve some of this pressure and to open up new services, business models and sources of revenue. The sheer volume and variety of 5G data traffic forecasts will break today's cost per-bit models as current networks cannot cost-effectively scale to meet the demand nor can they provide the flexibility to allow rapid introduction of revenue-generating services.[12] The capabilities that will be introduced with 5G technology can provide operators with the agility and scale they will need to realize the huge financial opportunities that 5G presents.

It is not just the surging amount of data that MNOs will have to handle, but also the sheer volume of devices and variety of traffic types that will have different requirements for bandwidth, reliability and latency. According to the GSA report, "The Road to 5G" (2015), there are two major factors that will drive development of 5G technology. The need to support increasing demand for broadband services of many kinds that cannot be achieved by advancing today's 4G networks alone. Second will be the need to both support and create services for the Internet of Things (IoT) including for machine-to-machine (M2M) applications. 5G is being specified to support the key use case scenarios that are anticipated. These key use case scenarios include enhanced mobile broadband (eMBB), Massive Machine-Type Communication (mMTC) and Ultra-Reliable Low Latency Communications (URLLC), also known as mission critical communications.

4.2 Factors Driving for Initial 5G deployments

This section will focus on the key aspects that will drive the initial 5G deployments. While some of the initial use cases attributed to 5G will be supported by the technology advancement of LTE (LTE Advanced), there will be significant limits on the type services and scale of devices that can be supported.

At the forefront is the need for operators to manage the ever exploding volume of data with the resources that they have. Making efficient use of their network and spectral resources is critical. MNO's progress in preparing their networks through densification and infrastructure upgrades are key factors toward supporting commercial 5G networks.

Certainly common standards and the timing of the 5G standardization is a must to enable these new services and to prevent or minimize industry fragmentation. Based on the operator and industry priorities, the first standards release for 5G (Rel. 15) will primarily be focused on realizing eMBB and the corresponding use cases. With eMBB, operators can offer services ranging from 4K Ultra HD streaming to virtual and augmented reality to 3D modeling.

Digitalization of our world is creating globally connected people and industries. Many industries are taking advantage of trend to better compete and serve their customers. Many 5G use cases will be driven by this digital transformation and specifically industry digitalization. Adopters are seeing huge revenue opportunities and this is an area that operators can connect and serve to help drive revenue generating services for both parties. According to Ericsson, the largest opportunity will be seen in the energy and utilities industry, closely followed by the manufacturing and public safety sectors[11].

Supporting both network efficiencies and the digital economy is virtualization of the network with distributed architecture and cloud based services. These capabilities will bring a more efficient use of resources, lowering cost models and allowing operators to deliver on a broad set of URLLC use cases. The realization of these aspects will grow over time as the standards become complete and operators are able to evolve their networks.

Certainly spectrum availability will be a key factor in the ability to support the initial 5G use cases. The spectrum section below outlines the current 3GPP defined Sub-6GHz bands as well as the current allocation status by region.

Last, but certainly not least, will be the operators ability to generate revenue from the use cases and services enabled. It will be vital to look at the ability to create revenue opportunities based on the service and at the industries in need of those services to advance.

4.3 Top/Initial Use cases Driving early 5G deployment

At this time, there is no killer app or single driver for early 5G deployment beyond the need for higher capacity and speed and reduced latency. While it is still early to narrow the potential use cases, there are a few that can be used as examples of what can be done initially.

There are three main classes of new 5G applications: Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communications (URLLC) and Massive Machine Type Communication (mMTC). mMTC can mostly be fulfilled by modification and optimization of existing cellular technologies such as NB-IoT, however URLLC and eMBB require new technologies to break new bandwidth and latency boundaries. These will unlock new, potential applications and services that require 5G infrastructure.

5G infrastructure has significant implications for a number of applications that are already limited in some capacity by existing 4G services. However this is only the beginning, as every generational shift that grants more capacity and speed always grants unforeseen and unpredictable applications that will only be realized later. The Ericsson Mobility Report (Nov 2017) illustrates some of these use cases and their supporting technology across various industry segments.

	Current services	On the road to 5G	5G experiences
Enhanced mobile broadband	Browsing, social media, music, video	Fixed Wireless Access, interactive live concerts and sport events	4K/8K videos, mobile AR/VR gaming, immersive media
Automotive	Wi-Fi hotspots, on-demand GPS map data	Predictive vehicle maintenance, capturing real-time sensor data for different services	Autonomous vehicle control, cooperative collision avoidance, vulnerable road user discovery
Manufacturing	Connected goods, intra-inter enterprise communication	Process automation and flow management, remote supervision and control of machines and materials	Remote control of robots, augmented reality support in training, maintenance, construction, repair
Energy and utilities	Smart metering, dynamic and bidirectional grid	Distributed energy resource management, distribution automation	Control of edge-of-grid generation, virtual power plant, real-time load balancing
Healthcare	Remote patient monitoring, connected ambulance, electronic health records	Telesurgery, augmented reality aiding medical treatment	Precision medicine, remote robotic surgery

In its latest Mobility Report, equipment vendor Ericsson covered some of the potential use cases for 5G.

The following are emerging application examples which can be benefit from significantly increased bandwidth speeds and/or ultra-low latency.

1. Augmented reality (AR), Mixed Reality (MR) and Virtual Reality devices
2. Mobile Media: 360-degree, 4K/8K resolution live entertainment and sports
3. Tele-education services

1. Augmented Reality (AR), Mixed Reality (MR) and Virtual Reality (VR) devices

One of the biggest upcoming technological revolutions is AR, MR or VR devices. ABI Research forecasts that the AR smart glasses installed base will reach 48 million units in 2021, with the VR device installed base numbering over 200 million units globally.

Each reality-mode has its own unique applications and opportunities, and while basic implementations of these formats can be delivered through 4G networks, expected large-scale adoption will soon congest 4G LTE infrastructure and render the user experience intolerable. 5G eMMB will help meet this need and unlock new opportunities for these formats.

As smartphone performance increases, they are transforming into devices that can be used with VR/AR headsets. For example, Google's Tango technology uses a Visual Positioning Service1 (VPS) for in-door navigation, but it relies heavily on local Wi-Fi networks to define its location and the spaces it maps out. Use of 5G technologies will enable more consistent signal coverage allowing VPS to be mapped via a combination of camera(s), cellular location and GPS.

Potential Requirements

While VR devices now operate at 1200 x 1080 @ 90fps resolution (per eye), the next generation devices with 4K and even 8K @90-120fps displays (per eye) are being developed to increase fidelity and immersiveness. This amplifies the required video data bandwidth by several magnitudes (depending on any lossless-compression used).

Generally speaking, AR/MR/VR are all performance hungry, which translates to power and battery limitations in smartphones and wearable devices (for example: Samsung Gear VR[2] or Microsoft Hololens[3]). A revolutionary 5G use-case could instead offload the AR/MR/VR sensor inputs and graphics rendering to a Cloud server, which would require only a much simpler, low power user-device that acts only as sensor recorder, 5G cellular transmitter and video decoder. This design would significantly lower the cost of ownership, enabling a much greater market potential and service-style models based on Cloud-server use time.

To enable next generation AR/MR/VR devices and 6DoF video it's expected that 200Mbps-1Gbps steaming bandwidth and sub-10ms motion-to-photon latency are required to avoid motion sickness.

2. Mobile Media: 360-degree, or 4K/8K resolution live entertainment and sports

Major sporting and entertainment events are both big value investments and have historic precedent. The potential market is very significant, with regular events in the hundreds of millions of viewers: the 2017 American Super Bowl had 111.3 million people watching8, F1 motorsport has 425 million fans globally9, and Manchester United soccer club alone has over 650 million global fans10.

They are also frequently the perfect opportunity by the host to showcase the latest technologies. For example, at the 2018 Winter Olympics in South Korea pre-commercial 5G systems will be used to provide 5G-like experiences, and the event organizers and operators are making investments in a range of different event-related apps and the Tokyo Olympics in 2020 is already set to become the first sporting event to broadcast in 8K11, and one of the first to have 5G network coverage12.

Smartphones displays are moving towards ever higher resolutions with HDR quality, with video streaming services such as Netflix following as sufficient devices reach the hands of consumers. NTT DOCOMO President has already committed to the 2020 Olympics streamed over 5G to VR devices16, which will let users feel like they are actually in the stadium with the athletes.

Current 360 degree video experiences are from a three degrees of freedom position (3DoF) that allows the user to rotationally look around from a fixed position. Future experiences will migrate to 6DoF, allowing the watcher to move around.

Potential Requirements

While 4K streaming requires typically only 25-75Mbps, 8K expectations range from anywhere between 100Mbps to 500Mbps, depending on the encoding choice and multi-channel sound mix. 6DoF, 360-degree video is expected to require even more bandwidth at 400-600+Mbps with a latency of just 20ms, depending on factors such as the resolution, compression, user feedback performance expectations (fast/slow movement) and field of movement available.

3. Tele-education services

While tele-education services are not a new concept, the increasing use of mobile devices and their native use by young people offers a way to encourage education services at all levels (basic, supplementary or further study). It's especially useful to deliver tele-education services to remote and rural areas, where students getting to school can be more difficult and teaching staff are sometimes not available for all ages.

5G mobile services can offer fast connectivity to remote and rural areas (see FWA), where streaming high quality (4K UltraHD) video will allow teachers to express a full whiteboard of text and diagrams without fine details being lost to compression or low resolution. It will allow students to zoom into areas and still read them clearly.

VR-style services (where smartphone devices are strapped into headsets) will give a native classroom style immersive experience, allowing students and teachers to interact naturally and effectively.

Potential Requirements

These services will require 100-200Mbps streaming data and low-latency (sub-20ms) to each user to ensure there is comfortable real-time interaction without delay.

For various applications, each has different throughput or latency requirements. An NR system design allows reasonable user end (UE) implementation flexibility. The processing functions within the UE device can either focus on achieving maximum throughput (data rate) or minimum (stringent) latency parameters.

Opportunity	Use Cases	5G Requirements
Personal	1. Augmented reality (AR), Mixed Reality (MR) and Virtual Reality devices	200Mbps to 1Gbps streaming bandwidth depending on compression and device resolution, with reliable sub-20ms motion-to-photon latency for VR
Personal	2. Mobile Media: 360-degree, 4K/8K resolution live entertainment and sports	100-500Mbps streaming bandwidth for 8K with sub-20ms latency; 360-degree 6DoF 400-600Mbps streaming bandwidth with sub-10ms latency to avoid motion sickness
Education	3. Tele-education services	100-200Mbps reliable streaming bandwidth with low latency (sub-20ms)

4.4 Key Challenges / Barriers to 5G Deployment

Similar to key factors driving initial Sub-6GHz 5G Deployment are the key challenges and barriers to 5G deployment.

MNOs are under great pressure to meet growing demand for data while containing costs and launching new services in highly competitive environments. The types and number of competitors is expanding in an all-IP world. Many of these new competitors can offer services at a lower cost basis with much more flexible development environments allowing faster time to market.

To survive in the 5G era, mobile operators need new ways to build networks and deliver services today that are cost efficient, flexible, and agile -- and they need new business models that will be critical to drive increased service revenue growth.[12]

For 5G Deployment, the question is not of the technology or use case’s value, but instead for MNOs, the question is how to build-out and monetize 5G. The #1 barrier to upgrading to 5G, according to a survey by IHS Markit, is an “undefined business model”. The early adopters in North America and Asia will begin to pave that way.

4.5 Operator Forecasts

Early 5G deployments are anticipated in several markets, including the US, South Korea, Japan and China. There are a number of trials ongoing across these regions on pre-standards 5G systems. The first commercial networks are expected to go live in 2019, with major network deployments from 2020 and beyond. All major infrastructure and device manufacturers have been partnering with operators to trial and develop commitments for 5G commercial launches.

Many operators plan to use 5G technologies to showcase enhanced spectator experience at upcoming events. Pre-commercial 5G technology will be on display, giving us a peak into the future at the upcoming 2018 Winter Olympics in Pyeongchang, South Korea. Commercial 5G networks and services will be highlighted at the 2020 Summer Olympics in Tokyo. Large events present an opportunity for operators and organizers to provide visitors with additional digital services throughout the entire experience.

South Korea, with its jumpstart to 5G using pre-commercial 5G technology for the 2018 Olympics, have announced that commercial 5G networks will be launched in 2019.

Two operators in the US have announced plans for commercial 5G networks using sub-6GHz 5G and both are focusing their investments in mobile 5G. Sprint Corporation plans to launch commercial 5G services using its 2.5GHz spectrum in 1H2019. T-Mobile USA announced plans to use some of its newly acquired 600MHz spectrum to deploy a 5G mobile broadband network starting in 2019, with the aim of full nationwide coverage in 2020.

China is taking a very aggressive stance on 5G technology, which some analysts say could mark the country's most expensive build-out of telecommunications infrastructure. China Mobile, the world's largest mobile network operator, announced plans in March to start building trial 5G networks in major mainland cities from next year and launch full commercial services in 2020. Many of these trials have focused on a variety of IoT use cases.

The 3 largest Japanese MNOs have begun 5G trials, looking to launch new services using the technology by 2020, as noted in time for the 2020 Summer Olympics. Softbank Mobile has planned or conducted a number of 5G Use case trials including eMBB related trials, ultra high definition video and low latency robotic control.

It is anticipated as the first release (Rel. 15) of the standards completes in mid-2018, we will see both more operator announcements of trials and commercial launches. As 2019 approaches and the first 5G commercial networks launch, there will be more clarity of the initial use cases addressed.

5 Spectrum Availability

5.1 Candidate Frequency Bands and Global Development

5.1.1 2300MHz

2300MHz 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. India is pushing for this band for 5G NR, coexisting with their existing LTE-Advanced system.

5.1.2 2600MHz

This is the 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. Sprint has been announced their trial for 2600GHz band 41 for 5G-NR. They plan to introduce 5G-NR in part of the 2600GHz, coexistence with existing LTE-Advanced system.

5.1.3 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: parts of 3400 – 3600 MHz auctioned 2018/2017(?), 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 access services. 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 Aurthority) 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.

5.1.4 3400-4200MHz

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).

5.1.5 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.

5.2 Standardized Bands by 3GPP

5.2.1 5G NR (New Radio)

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 will be defined in Rel-15, and are 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 2: 3GPP NR bands in Rel-15 - refarming bands (from 3GPP TS 36.101-1 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 3: 3GPP NR bands in Rel-15 - new bands (from 3GPP TS 36.101-1 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 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 mode being included into 3GPP R15. It directly benefits the C-band in term of coverage for the 5G NR uplink. The principle is depicted into the following figure.

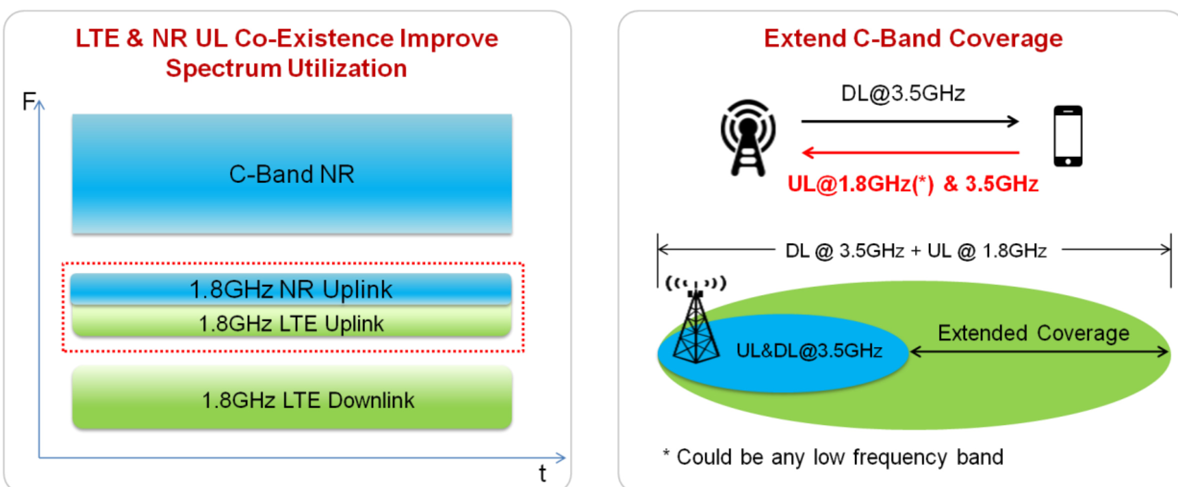

Figure 1 Outlook of 3GPP R15 SUL Feature

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.

5.2.2 LTE & NR Band Combinations

3GPP has already identified initial bands for the 5G NR as well as bands combinations between LTE and 5G NR. There are 2 cases being considered by 3GPP as per R15 specifications:

- Case A: Bands combinations for LTE / 5G NR dual connectivity (DC)
- Case B: Bands combinations for LTE / 5G NR with Supplemental UL (SUL)

Band combinations for LTE/NR dual connectivity

This 3GPP functionality is based on the users data split at the PDCP layer and allows the data traffic to be split across both LTE and 5G NR cells and sent in parallel. It works for uplink and downlink.

3GPP has identified several hundreds of band-combinations for LTE/NR (Dual Connectivity). Several categories are being defined, based on the number of LTE and/or 5G NR component carriers (CC) to be combined, including 8 combinations for non-standalone SUL, 7 combinations for standalone SUL, 113 combinations for LTE 1 CC + NR 1 band, 162 combinations for LTE 2 CC + NR 1 band, 116 combinations for LTE 3 CC + NR 1 band, 58 combinations for LTE 4 CC + NR 1 band, 9 combinations for LTE 5 CC + NR 1 band, 38 combinations for LTE 1 CC + NR 2 CC, 9 combinations for LTE 2 CC + NR 2 CC, 8 combinations for LTE 3 CC + NR 2 CC, and 1 combination for LTE 4 CC + NR 2 CC.

In addition, 3GPP also agreed to reuse existing LTE band numbers for future long term migration from LTE to NR in the respective bands.

Bands combinations for LTE/NR with SUL

Low frequencies (below 2 GHz) will continue to be essential to extend the 5G mobile broadband experience to wide areas and in deep indoor environments; mMTC and URLLC usage scenarios will also greatly benefit from the low frequencies' extended coverage. The available low frequency bands (e.g. 700, 800, 900, 1800 and 2100MHz) may be exploited by means of SUL in combination with 5G NR on the C-band to allow operators to ensure faster and cost-effective deployment of C-band.

Therefore 3GPP has agreed upon a number of LTE-NR combinations with SUL where the UL direction of some low frequency bands (e.g. 700, 800, 900, 1800 and 2100 MHz) is paired with the 3300-3800 MHz band.

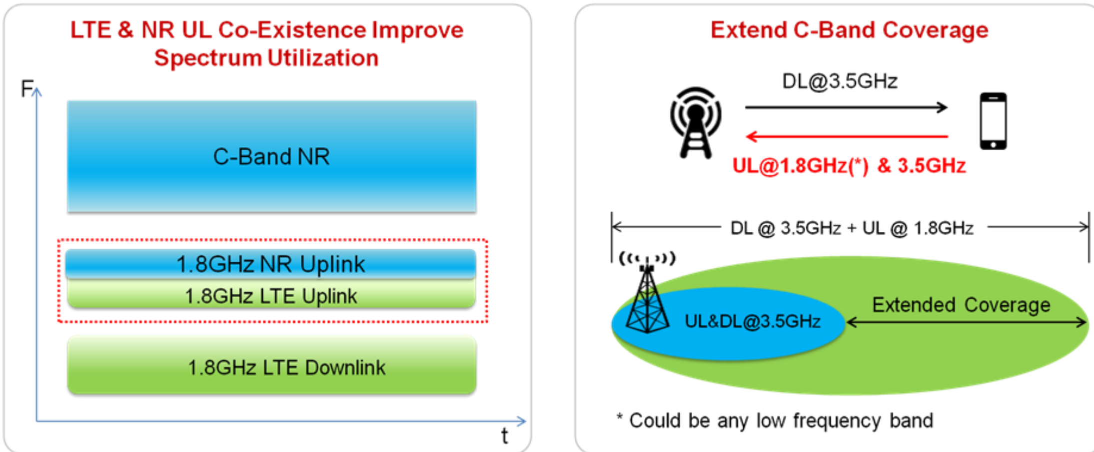

Figure 2 An example of using SUL in the deployment

5.3 Example Trial Results

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 coverage, throughput, latency and mobility management.

China Mobile did the PoC trial last year. The 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. 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 analyzed. 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 significant gain in DL/UL throughput. The trial also tested for 5G throughput, single-user peak throughput and cell peak throughput as the key performance indicators to measure the throughput performance. 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 tested and meet all the latency requirements. However, performance with other SCS/conditions needs to be further evaluated.

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 plans for their 4G evolution and 5G deployment in 2.6GHz band and trial has been taken in 2.6GHz band in 2017, showing TDD LTE Massive MIMO technology and 64T64R radios with three 20

MHz carriers in Frame Configuration 2, supporting maximum 8 layers. Significant performance benefits were seen relative to current 8T8R system. They will prepare for 5G in 2018 and deploy LTE+5G 64T64R in 2019.

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.

6 Deployment Scenarios

Network deployment needs to consider both business needs and industry capabilities, so this chapter first reviews the business needs in chapter 5, then analyses industry capabilities from three dimensions: standards, spectrum, and products, and finally discusses deployment scenarios in two phases.

6.1 Business Requirements

As we all know, 5G application scenario is divided into three scenarios, eMBB /URLLC and mMTC ,as described in chapter 5, the eMBB services requirements which mainly includes AR/MR/VR, 360-degree/4K/8K HD video and distance education are relatively in need currently. The main demand for the network is 100 Mbps above data rate and delay no more than 20ms, generally speaking, the occurrence of the above services mainly concentrated in urban hot spots. URLLC business, such as autopilot, is expected to take some time to mature. mMTC is expected to be satisfied by NB- IOT and its enhancements.

Operators will work with industry to explore more industry applications and launch more 5G killer applications.

6.2 Ecosystem Maturity

6.2.1 Standardization Progress

As a result of joint efforts by industry, the first version of the 5G NSA standard on the wireless side was released by 3GPP at the end of 2017, ASN. 1 is expected to be frozen in March 2018. The first version of the 5G SA standard is expected to be released in June 2018, and ASN. 1 is expected to be frozen by September 18. The first version of the core network side will be frozen by June 2018.

Although the standardization is still on progress and not finished yet, it is anticipated that the 3GPP Rel-15 5G NR specification will be matured soon and NR enhancement features for Rel-16 will gradually initiate the corresponding standardization work.

6.2.2 Spectrum Availability

As concluded by Chapter 5, China, Japan, South Korea, Europe and many countries/regions have identified the candidate spectrum for possible allocation to 5G deployments, where 3.5GHz band is common candidate in most countries and expected to become global 5G roaming band. For example, China has already announced 3.5 GHz and will allocate 4.9 GHz bands for 5G deployment, and the allocation results should be determined in the first half of this year.

This white paper does not address the spectrum for >6GHz (i.e. mmWave), it may be clarified by other GTI white paper.

6.2.3 Product Maturity

Because of the joint efforts by GTI members, 3.5GHz 5G end-to-end product prototypes have been available and demonstrated from GTI 20th workshop. It is expected the pre-commercial 5G gNB product solution will be available in 2018, while the 5G core (5GC) network product solution will be available by 2019. The terminal availability will be around similar time frame, expect some chipset solution available by 2018/2019 for the device (e.g. mobile phone) commercialization by 2020.

6.3 Deployment Scenarios

Consider the balance of business motivation, CAPEX investment and ecosystem maturity, 5G deployment may be generally planned into two phases:

- Phase I: from 2020, target to rapidly roll out 5G services, focus on mature business such as eMBB.
- Phase II: from 2025, target to achieve 5G full coverage and optimize network performance, fully cover eMBB, URLLC and mMTC business requirements.

6.3.1 Phase I

5G deployment at this phase is meant to improve network capacity and service data rate through larger system bandwidth, multi-antenna and other technologies. It can also shorten the air interface latency through flexible frame structure (e.g. mini-slot, HARQ timing…), scheduling and other technologies, which can also fulfill the demand on some new business and application such as high definition video and AR / VR.

If continuous coverage and shallow indoor coverage could be achieved with mature 5G core network product, SA network architecture can be considered. Compared with NSA network architecture, SA can perform end-to-end 5G capabilities such as end-to-end slicing and IP flow level QoS capabilities. So that it can better meet the demand by vertical industry and enable new business for revenue growth. In addition, SA deployment can also simplify the terminal complexity and network deployment plan. For example, avoiding simultaneous 5G and 4G connections can save UE design complexity as well as power consumption. From deployment perspective, 5G SA could be independently deployed and no need to further upgrade 4G network (e.g. eLTE). On the other hand, NSA deployment has its advantage by leveraging existing LTE infrastructure without the need of continuous NR coverage and core network upgrade. This may be suitable for the hot spot deployment at the initial stage.

For initial 5G SA deployment, macro base station should be deployed first in order to shallow wide contiguous coverage in urban area. Interworking functionality will be required when user moves out of 5G coverage. For 5G NSA deployment, it is more suitable for hotspot coverage and able to avoid frequent handover by keeping RRC connection over 4G network.

6.3.2 Phase II

In this phase, the design and optimization of URLLC and mMTC features have been completed by 5G standards, some business breakthroughs such as autopilot are also expected at that point of time. By leveraging the infrastructure developed for eMBB services, operator can further integrate the network with vertical industry and lead to far-reaching impact on people's production and life.

In order to fully exploit end-to-end 5G capability to support various URLLC and mMTC applications, 5G SA deployment is recommended for this phase. This assumes the 5G coverage already expend to certain level at this stage and the product solutions have been quite matured.

In this stage, more micro-/pico- base stations may be deployed for 5G network capacity and coverage optimization. Deployment over lower frequency bands (e.g. 900MHz) will be able to much improve the network coverage. Hierarchical (3D) network deployment by high-low band will be able to balance the coverage over macro cell and the capacity over hotspot. This will allow operators satisfy both service continuity and high throughput demands from users by 5G network.

6.4 Migration Scenarios

How to migrate the network from 4G to 5G is very essential but complicated topic for each operator. From very high level perspective, two scenarios could be identified: One Step and

Multiple Steps.

6.4.1 One Step Migration

In this scenario, operator directly deploys 5G NR network in standalone manner (i.e. Option#2). The main benefit of this migration scenario is simpler network migration path, compare with multiple steps scenario. The challenge comes from higher investment level at initial stage, both RAN and core network need to be upgraded to NR and 5G Core at the same time. This would be more ambitious strategy with higher engineering challenges, which may be more suitable for large scale 5G roll out with contiguous service coverage. It may also be more economical from long-term perspective.

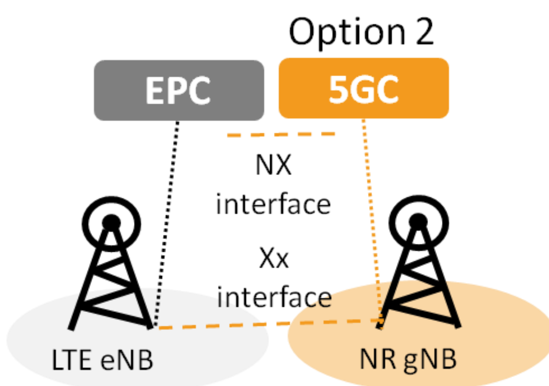

Figure 3 One step migration from 4G directly to 5G option#2 architecture

6.4.2 Multiple Steps Migration

In this scenario, operator start from 5G NSA architecture option #3 with coverage layer anchored on LTE. 5G NR only offers the user plane connection as a kind of additional bandwidth for data rate boosting. The main benefit of this deployment scenario is to reuse existing LTE coverage and EPC for initial 5G roll out. The challenge will come from the further overload to 4G network by 5G overhead and traffic, further migration will be needed by some point of time and multiple options may diverse the ecosystem support level.

As shown in Figure Y, few possible intermediate options (e.g. option 4/5/7) are possible base on 3GPP specification. The main challenge of these intermediate options will be the requirement of eLTE, i.e. LTE eNB and UE need to be upgraded to support 5GC and new NAS protocol. The final goal should still be option #2 for 5G network to operate in standalone manner.

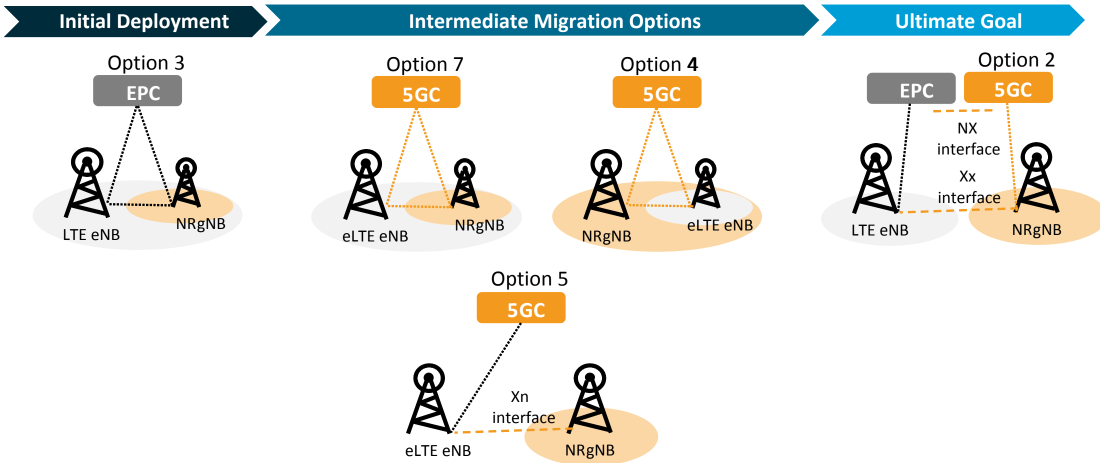

Figure 4 Multiple steps migration from 4G to 5G with intermediate migration options

7 Summary

This white paper summarizes the initial views by GTI members on 5G deployment, from business motivation, spectrum availability to possible deployment scenarios. This is the start point to trigger further discussion on 5G deployment strategy within GTI, the views and contents are subject to be updated later based on discussion progress and consensus.