Considerations on 6 GHz Spectrum for 5G-Advanced and 6G

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Introduction

Latest Progress of Global 5G Development

A recent report [1] by the GSA concluded that 153 operators from 64 countries and regions had launched 3GPP-based 5G services by the end of March 2021, which will put it on track to reach another 3 billion subscribers by 2025 to service more than 30 percent of the population. 5G has made noticeable progress in China [2], with the total number of 5G base stations and connected 5G phones reaching 819,000 and 280 million, respectively, by April 2021, making up 70 percent and over 80 percent of their respective global market share.

Trends of 5G and 5G Evolution in the Next 10 Years

(1) 5G provides a premium experience that drives a rapid increase in mobile data of usage (DoU). A study by the ITU shows that monthly DoU will exceed 250 GB globally and 390 GB in China [3] by 2030. This trend of fast DoU increase justifies the necessity of more spectrum to meet the surging demand for network capacity.

(2) 5G enables industrial digitalization, in turn requiring 5G networks to provide reliable connections of higher quality. Smart city, manufacturing and other vertical services enabled by operators will cause mobile data traffic to increase drastically. Deloitte pointed out in one of their reports that one self-driving car will generate about 4 TB of data a day [4]. This huge data demand highlights the urgent need to upgrade technology and adequate spectrum resources.

(3) 5G capabilities of very low latencies and very high data rates are required to enable applications such as Virtual Reality, Augmented Reality, and Mixed Reality. These applications serve high-definition multimedia and high user density by cellular networks, which are increased in many indoor and outdoor open areas, such as stadiums, main events for entertainment, sports, etc. Video quality is changing for the better from 4K 30 fps to 16K 120 fps, further enhancing the immersive experience. These growing resolutions and frame rates demand much higher data rates, lower latency and higher capacity [5]. Therefore, 5G evolution to support services including NR Multicast/Broadcast, high-interactive broadband communication, etc., is needed.

Considering the tremendous demand in the future, Coleago Consulting released a report [6] that concluded, to fulfill the IMT-2020 vision that aims to provide a wide area high-capacity coverage of downlink 100 Mbps and uplink 50 Mbps in 2025–2030, 1000 to 2000 MHz of additional mid-bands spectrum is required based on an analysis of 11 cities with a population density of 9000 people per km^2 or more. The selected cities have characteristics that also apply to a broad number of other larger cities. This means that each operator will need an extra 500 MHz of spectrum to meet the rapidly growing eMBB demand in larger cities over the coming 10 years.

1.3 6 GHz Is the Key Band for 5G and 5G Evolution

The trends of 5G and 5G evaluation show that the tremendous demand requires extra spectrum. mmWave is regarded as key 5G and 5G evolution spectrum that could provide high capacity to meet demand for hotspot areas. However, using mmWave for continuous wide area coverage requires heavy investment in network deployment because of its limited coverage. This discourages operators from investing and affects service development. One potential solution is to use low-band and mmWave to provide basic coverage and higher data rate, respectively. However, the narrow bandwidth of low-band limits its data rate. Consequently, the huge data rate gap causes fluctuations in service experience, hindering the popularization of next-generation technologies. To address these issues, we must find a mid-band with sufficient bandwidth that can provide the required coverage and capacity. The 6 GHz band happens to meet all these requirements and has become a candidate for 5G-Advanced and even 6G.

Feasibility Analysis over 6 GHz for IMT

6 GHz Allocation Status

The IMT industry has accelerated the pace in which it applies to the ITU for new frequencies, as it considers the service requirements of individuals and verticals mentioned above. WRC-19 agreed to establish a new WRC-23 agenda item (AI) 1.2 to study possible IMT identification for the frequency band of 6425–7025 MHz for ITU Region 1 (Europe, Middle East and Africa) and 7025-7125 MHz globally. Furthermore, 5925-6425MHz is also a promising IMT spectrum in some countries such as China, where the national standard association (CCSA) is now elaborating the feasibility study of IMT systems using the 5925-7125MHz frequency band [7]. Furthermore, NIIR of the Russia Federation is planning to conduct tests by the end of 2021 to determine the possibility of deployment of 5G networks in the frequency band of 6 GHz (6425-7100 MHz) [8].

Meanwhile, the Wi-Fi industry is also actively promoting the allocation of 6 GHz as unlicensed spectrum. For example, countries/regions such as the US, EU, Canada, UK, UAE, Chile, Peru, South Korea, Saudi Arabia, and Brazil have opened part of the 6 GHz band for unlicensed use. Other countries such as Mexico, Egypt, and Australia have also issued consultations proposing to open the band for unlicensed operation.

Currently, divisions emerge globally over the future usage of the 6GHz band. Both the “licensed” approach and “unlicensed” approach have their own pros and cons. We highly recommend to the industry that before making any final decision on the 6GHz band, a full exploration of the potential capability of 6 GHz for IMT should be conducted based on WRC-23 AI 1.2.

6 GHz Feature Analysis

The frequency affects coverage performance. Therefore, it can be expected that 6 GHz will have greater path and penetration losses than the primary 5G bands such as 2.6 GHz and C-band. Table 1 shows a comparison of link budget and the large-scale propagation characteristics between 6 GHz and several other bands in non-line-of-sight (NLOS) scenarios with the downlink cell edge rate at 100 Mbps and uplink at 1 Mbps.

Conclusion: The downlink coverage of 6 GHz is much better than that of 26 GHz and close to that of 4.9 GHz, but inferior to that of 2.6 GHz, which is used by China Mobile as the primary band for 5G network deployment. The high path and penetration loss in 6 GHz need to be compensated to greatly improve coverage if it is to catch up with current primary mid-bands in co-site scenario.

Frequency	Number of Antenna Element	Bandwidth MHz	BS Power dBm	UE Power dBm	Penetration loss dB	Noise Factor dB	Uplink ISD(O2I) M	Downlink ISD(O2I) M
2.6GHz	192	100	53	26	16	7 (BS)/ 4 (UE)	633	487
4.9GHz	192	100	53	26	22	7 (BS)/ 5 (UE)	236	192
7.1GHz	192	100	53	26	25	7 (BS)/ 5 (UE)	197	160
26GHz	128	800	38	23.04	37	13 (BS)/ 7 (UE)	5.8	5.8
					NA(O2O)	13 (BS)/ 7 (UE)	65	65

Table 1. Propagation characteristics of different bands in NLOS scenarios.

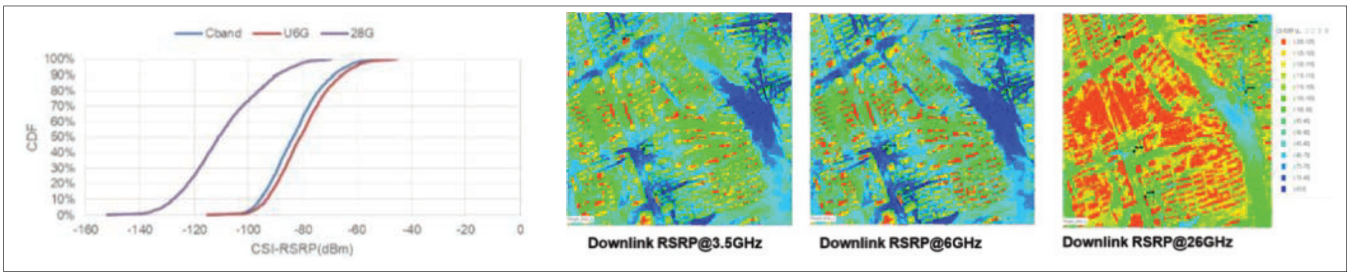

Figure 1. RSRP distribution of C-band, 6 GHz, and 26 GHz (CDF).

6 GHz Coverage Performance Analysis

Bridging the above-mentioned coverage gap requires enhanced base stations, UEs, and air interfaces. Base station or UE enhancement alone cannot achieve this goal.

- For base stations, use a larger-scale antenna array to obtain a larger array gain and then provide a higher equivalent isotopically radiated power (EIRP).
- For UEs, introduce analog beamforming (ABF) to improve gain and use UEs with higher EIRPs to improve uplink coverage.

The enhancement of standards and algorithms can improve the coverage of common channels and the receiver at a low signal-to-noise ratio (SNR).

A simulation was conducted to verify the effect of the above approaches on coverage. It took place on a network deployed in the Wulin area, that is, a central business district (CBD) with the highest traffic density in Hangzhou. The simulation assumes that five macro base stations are deployed in an area of 1 km^2 (1 km in length and 1 km in width) and compares the 3.5 GHz, 6 GHz, and 26GHz bands.

Simulation parameters for 5G base stations were set as follows:

(1) Base station total radiated power (TRP):
- 49 dBm at 3.5GHz and 6GHz (200 MHz)
- 35 dBm at 26 GHz (800 MHz)

(2) ISD: 200–680 m

(3) Base station height: 24–54 m

Simulation results are shown in Fig. 1, and we can find out that with the higher rank massive MIMO antenna, 6GHz could achieve the same coverage level as 3.5GHz.

6 GHz Availability Analysis

Coexistence with Satellite Services: Among the incumbents on the 6GHz band, Fixed Satellite Service (FSS) in 6425-7025MHz is the most predominant. They work on the 6425–7075 MHz band, which covers uplinks used by the geostationary satellite orbit (GSO) FSS networks in all regions. Unlike 3.5GHz, the 6GHz band must alleviate aggregate interference of IMT systems to space satellite receivers (FSS system uplink).

To achieve this, sidelobe suppression can be used for base stations to mitigate the intensity of the upper sidelobe interference toward satellites, thereby reducing aggregate interference from ground IMT systems. Along this technical direction is a focus on low sidelobe antenna array architecture and sidelobe suppression algorithms. In addition, coexistence evaluation models can be optimized to loosen requirements on base stations. Relevant work has been conducted in ITU-R WRC-23 Agenda Item 1.2, which was set up to study the feasibility of 6425-7025 MHz in Region 1 and 7025-7125 MHz globally for IMT at ITU WRC-19 in 2019. The 1st Conference Preparatory Meeting for WRC-23 (CPM 23-1) also specified the responsible group (ITU-R WP 5D), contributing groups (including ITU-R WP 3K and WP 3M), and key phases for ITU-R WRC-23 Agenda Item 1.2 6 GHz. Specifically, all ITU-R working groups were expected to complete the formulation of coexistence parameters and models by July 23, 2021, and the responsible group (ITU-R WP 5D) will study coexistence and submit Agenda Item 1.2 CPM texts to chapter rapporteurs by October 2022. CPM 23-2 is scheduled to be held in Q2 2023, when the WRC-23 CPM report will be finalized for WRC-23.

Coexistence with Microwave Services: Microwave services on the 6 GHz band have a relatively small deployment scale around the world in comparison with other mid-bands [9]. Microwave services on the 6 GHz band have the following characteristics:

- The densities of microwave links working on the 5925–6425 MHz and 6425–7125 MHz bands vary significantly between countries.
- The deployment scenarios (urban or rural areas) of microwave links working on the 5925–6425 MHz and 6425–7125 MHz bands vary significantly between countries.

Therefore, IMT base stations and microwave links need to be coordinated based on real-world deployment conditions. As both IMT services and microwave services (FS, Fixed Service) are spectrum-licensed, these may be implemented as follows:

- Ensure that IMT base stations do not point their main lobe at microwave links. As 6 GHz microwave links are long-haul and most of them are deployed in suburban/rural areas, geographical isolation can be a viable solution for coexistence.
- Careful plan of the deployment of IMT base stations in built-up areas.

In addition, 6 GHz microwave services could be removed to higher bands to obtain higher rates.

Allocating 6 GHz Band for IMT

This section offers suggestions relating to 6 GHz IMT deployment that can unlock the potential of this band for IMT services with maximum spectral efficiency.

6GHz allocation plan with contiguous large bandwidth as soon as possible: As MBB services emerge and rapidly develop in the 5G era, spectrum allocation has turned to a large and continuous bandwidth mode, from 80 MHz to 100 MHz, and even to 400 MHz in some cases. This requires regulators to plan the spectrum allocation five to 10 years in advance to have enough time to resolve the co-existence issue and then obtain pure continuous spectrum with large bandwidth. For example, China's Ministry of Industry and Information Technology (MIIT) started planning for 2.6 GHz, C-band, and 4.9 GHz IMT in 2009, and issued temporary licenses in 2018 and commercial licenses in 2019. This enabled Chinese operators to quickly launch commercial 5G services. It is suggested to plan 6 GHz spectrum allocation in advance to obtain contiguous spectrum with large bandwidth.

6 GHz allocation pace: Given that 7025 to 7125 MHz spectrum is only deployed for quite a limited number of satellites, the regulators could release testing spectrum to facilitate research and technology testing. The performance and coexistence research of this spectrum will pave the way for studying the feasibility of coexistence and spectrum clearance on the 6425–7025 MHz and 5925–6425 MHz bands [7]. After the completion of research and test, the schedule of commercial spectrum license could be determined. A three-step allocation plan is suggested considering the complexity of co-existence:

- The first step: release 7025–7125 MHz (100MHz) as 5G capacity enhancement spectrum, promoting 6GHz band ecosystem maturity.
- The second step: release 6425–7125 MHz (700 MHz) as 6G testing and initial commercial spectrum.
- The third step (regional recommendation in particular countries/regions such as in China): release 5925-7125 MHz (1200 MHz) as 6G commercial spectrum

Free of charge and low-price modes: The 6 GHz band can provide 200–400 MHz spectrum for each operator. The auction and charging modes of low frequency and narrow bandwidth for FDD will no longer be suitable for 6 GHz auctioning and charging. If the price of spectrum per Hz is reduced, and operators can use spectrum free of charge during the first few years of network construction, they will be more willing to build networks on this band and promote the development of the upstream and downstream industries. For example, in 2019, the MIIT allocated 5G spectrum free of charge for the first three years, and the charging ratios over the next four years would be increased gradually by 25 percent, 50 percent, 75 percent, and 100 percent, respectively.

6 GHz deployment pace: To meet the rapid increase of DoU, which necessitates additional spectrum, the 6 GHz band can be preferentially deployed in hotspot areas from 2025 to 2030, thereby satisfying hotspot service requirements and aiding the development of the eco-system. From there to between 2030 and 2035, 6 GHz will be widely used to provide basic network coverage, maximizing its large capacity and wide coverage advantages.

Key directions for 6 GHz capacity improvement: Studies should be conducted to explore how to leverage the huge bandwidth of the 6 GHz band and combine it with massive MIMO and MU-MIMO to further improve capacity, hopefully by 10 times as much as the current main mid-band (100 MHz). In addition, compared with C-band and mmWave, 6 GHz supports both large bandwidths while displaying strong multi-channel characteristics, which requires stronger computing capabilities. As such, methods to simplify processing should be researched, in order to reduce both power consumption and costs.

Conclusion

Considering the existing services on the 6 GHz band and interference to its IMT deployment with incumbent services, it is recommended that the upper part spectrum (7025–7125 MHz) of the 6 GHz band be preferentially allocated to 5G-Advanced in order to accelerate industry development. Low-end frequencies are recommended to be gradually allocated if they are justified to be feasible for IMT application after technology and coexistence research. For example, 600 MHz (6425–7025 MHz) and 500 MHz (5925-6425 MHz) are recommended to be released in sequence to form the 5G-Advanced and 6G spectrum resource pools. In addition, 6 GHz spectrum allocation should be planned to ensure that the spectrum can be allocated with large bandwidth, low price, and concessional payment. In this way, the spectrum can be used more efficiently, and operators will be more willing to deploy networks.

Lastly, to promote the 6 GHz IMT industry and achieve sustainable development of the mobile communications industry over the next decades, we hope that industry partners and regulators can:

- Support the coexistence research within the ITU-R and promote the formation of IMT identification for this band in WRC-23 AI 1.2.
- Promote the R&D of key NR technologies in the 6 GHz band, promote 3GPP standardization, and develop the E2E industry chain.
- Establish 6 GHz working groups in key industry organizations such as GTI, NGMN, and GSMA to promote industrialization.
- Encourage spectrum allocation for field tests, and conduct tests to verify key technologies.
- Encourage countries to update frequency allocation plans to incorporate 6 GHz as the IMT spectrum in the long-term spectrum roadmap.

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