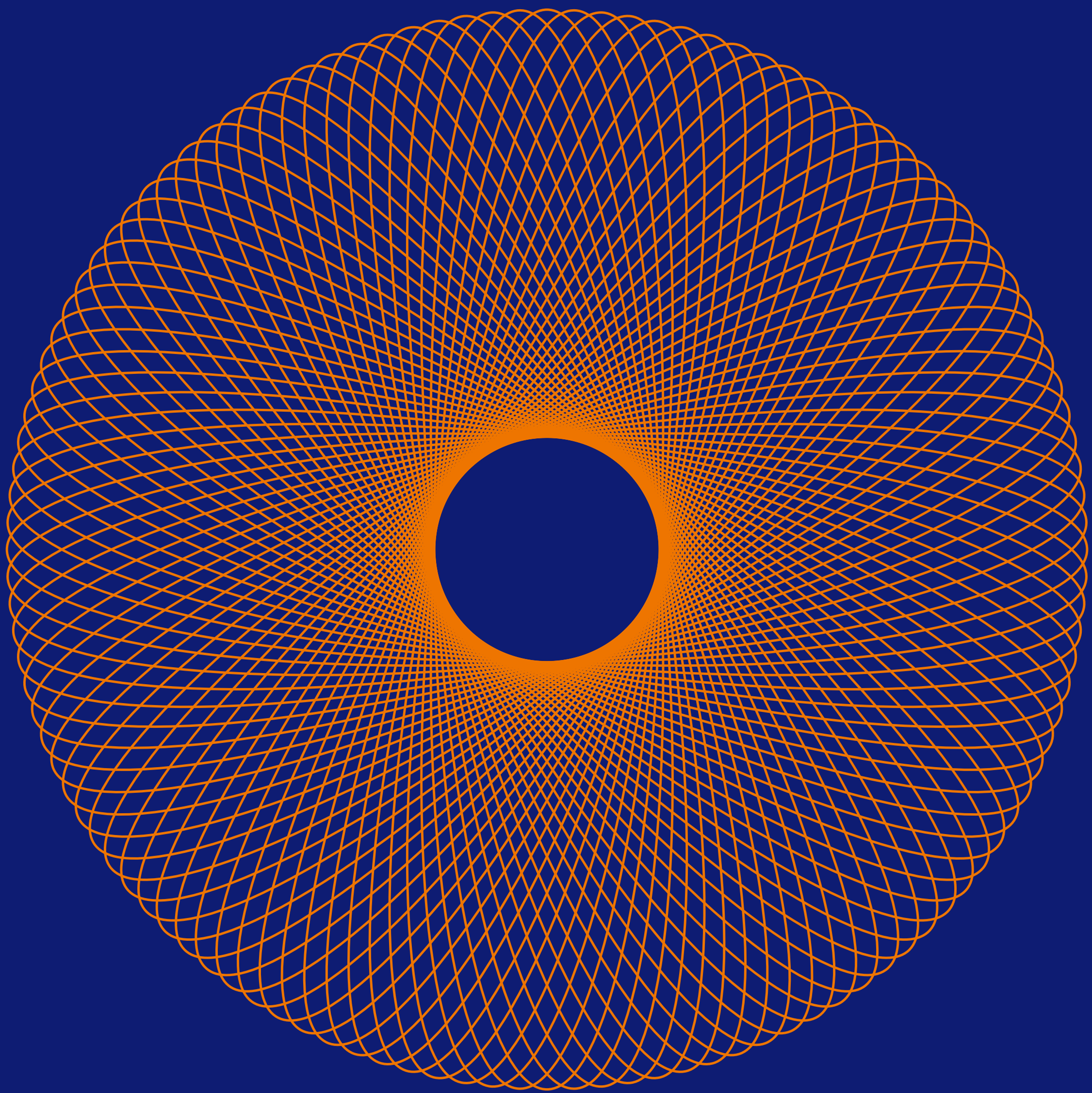
SAMSUNG

6G

Spectrum
Expanding the Frontier



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Preface

Expanding the boundaries of what is possible in spectrum has been our passion at Samsung. The mobile industry has continued to defy the doubters and demonstrated that mobile technologies are technically and commercially feasible in higher and higher frequency ranges. As we embark on 6G, the next generation of mobile communications, the mobile industry will once again explore new frontiers and push the boundaries and capabilities of mobile technologies in the low, mid and high bands.

Extending the art of the possible is what we do at Samsung. Sub-THz is a new frontier of exploration as we try to understand what is possible in addition to the low, mid and high bands, as the industry develops 6G targeting initial deployments around the year 2030 onwards. In this 6G spectrum journey, Samsung looks forward to working with industry, regulators and academia from around the world to help realize the global 6G vision and bring benefits to the world's citizens and environment.

6G is facing a formidable challenge to be significantly greater than evolved 5G, serving 7 billion citizens in all locations around the world as well as 500 billion devices and things [1]. To do this will require new spectrum from sub-1 GHz to sub-THz, in addition to the continued reuse of existing spectrum in the low, mid and high bands. Global cooperation will also be required to develop and realize the spectrum vision.

With the commencement of 5G commercialization, administrations, regional research projects, industry, academia, etc. are now embarking on their research for 6G. This research is targeting 6G to be born with initial deployments around the year 2030.

Samsung Research has published the 6G vision white paper entitled "6G, The Next Hyper-Connected Experience for All." [2],[1] where we presented our vision that 6G will provide an ultimate experience for all through hyper-connectivity involving humans and everything. As a follow-up of the vision white paper, we in this white paper explore how to enable 6G to be realized around 2030 from a spectrum's perspective.

[1] Available at https://news.samsung.com/global/samsungs-6g-white-paper-lays-out-the-companys-vision-for-the-next-generation-of-communications-technology, July 2020.

1 Why 6G Spectrum

6G spectrum should be ready before 2030 to support 6G commercialization around 2030.

Mobile communication systems have evolved over multiple generations from 3G to 5G with a new technology generation around every 10 years. Early commercialization of 6G could happen before 2030, while massive commercialization may begin to occur around 2030. In order to realize 6G commercialization around 2030, spectrum should be ready before 2030.

Each generation has taken a big step forward and introduced significant new technologies in order to increase the performance of networks and devices to support the constantly enriched services.

Representative usage scenarios of 5G services, i.e., enhanced mobile broadband (eMBB), ultra-reliable and low latency communications (URLLC), and massive machine-type communications (mMTC) will continue to improve as they move towards 6G. New services will emerge due to advances in communications as well as other technologies in the area of sensing, imaging, displays, and AI. Those new services, such as truly immersive extended reality (XR), high-fidelity mobile hologram, and digital replica etc., will be introduced through hyper-connectivity involving humans and everything and provide the ultimate multimedia experience. All of them will be enabled by 6G.

Hundreds of MHz to tens of GHz bandwidth are required to fulfill the increasing performance requirements of 6G, e.g., tens of GHz bandwidth are required to realize up to 1 Tbps data rate for enabling some ultimate experience services.

The challenge of wireless capacity always exists and drives to increase performance from 3G.[2] Performance targets for 6G are currently under study to enable ultimate experience services such as truly immersive XR, high-fidelity mobile hologram and digital replica, which may require data rates in the range of up to 1 Tbps [2].[3] Accordingly, hundreds of MHz to tens of GHz spectrum are required to fulfil the performance requirements of the network.

To realize the full experience of 6G, the spectrum should cover a range of frequencies to facilitate enhanced coverage as well as enhanced capacity. Various applications and services require access to the spectrum in low, mid and high bands. The existing bands below 6 GHz currently used by 2G/3G/4G/5G are optimal for coverage, and could be re-farmed to be utilized for 6G.

Spectrum for 6G will be required in low, mid and high bands, especially the new spectrum in mid-band and sub-THz band.

With the 6G vision, new spectrum is necessary as we could foresee that the current spectrum in low, mid and high bands will not be sufficient to meet all of the 6G capacity demands. Therefore, additional and new spectrum in the mid-band will be required. The new spectrum area, also known as sub-THz, with its enormous available bandwidth, will also play a vital role in 6G spectrum exploration.

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[2] 3G is designed to achieve up to 2 Mbps as defined in Recommendations ITU-R M.687 and M.816, 4G is designed to achieve up to 1 Gbps as defined in Recommendation ITU-R M.1645, and 5G is designed to achieve up to 20 Gbps as defined in Recommendation ITU-R M.2083.

[3] 1 Tbps could be achievable based on technical assumptions such as

- 62.5 GHz bandwidth with 256 QAM and MIMO rank-2 ideally, while the required bandwidth becomes 83 GHz assuming 25% overhead
- 25 GHz bandwidth with 1024 QAM and MIMO rank-4 ideally, while the required bandwidth becomes 33.3 GHz assuming 25% overhead
- 22.8 GHz bandwidth with 2048 QAM and MIMO rank-4 ideally, while the required bandwidth becomes 30.4 GHz assuming 25% overhead

2 Concept of 6G Spectrum

As addressed in Section 1, it is clear that 6G spectrum requires all frequency ranges from low to high bands.

Through this white paper, as an initial step to design the 6G spectrum concept, three groups of bands, i.e., low, mid and high bands are defined as shown in Figure 1.

- Low-Band: Frequency range below 1 GHz is to emphasize the spectrum requirement for extremely large area and deep indoor coverage of the network.
- Mid-Band: Frequency range from 1 GHz to 24 GHz taking into account the following.

  1) the band from 1 GHz to 7 GHz, generally called mid-band today,
  2) the need for extension of mid-band up to 24 GHz,
  3) various rulemaking processes,[4]
  4) discussion progress in mobile industry-based organizations such as 3GPP and GSA, and
  5) IMT bands identification and candidate bands being studied in ITU-R.[5]
- High-Band: The upper boundary needs to be extended beyond that for 5G, so that the frequency range 24-300 GHz is grouped as high-band. In addition, this frequency range can consist of two sub-frequency ranges, i.e., the mmWave band (24-92 GHz) to be used as an important band not only for 5G but also for 6G and the sub-THz band (92-300 GHz) as a new frontier band for 6G. It is noted that this white paper focuses on the sub-THz band up to 300 GHz at this stage, while we expect that the full range of terahertz spectrum up to 3 THz could be considered in future.

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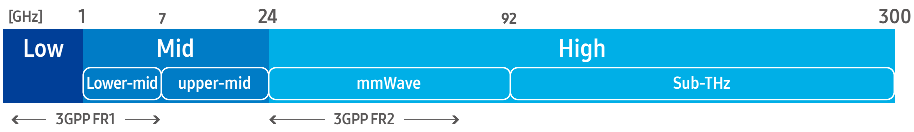
[4] An example is available at https://www.fcc.gov/document/fcc-seeks-comment-maximizing-efficient-use-12-ghz-band.

[5] International Mobile Telecommunication (IMT) is the generic term used by the ITU to designate broadband mobile systems. It encompasses IMT series such as IMT-2000, IMT-Advanced and IMT-2020 which are called 3G, 4G and 5G respectively in the market. WRC has identified specific frequency bands for the deployment of IMT systems in general (i.e., identification as IMT band). In general, IMT bands have been identified among frequency bands allocated to Mobile Service defined in ITU-R Radio Regulations.

Figure 1
6G spectrum grouping.[6]



Samsung's definition on 6G spectrum grouping

- Low-band: below 1 GHz
- Mid-band: 1-24 GHz
  - Lower mid-band: 1-7 GHz
  - Upper mid-band: 7-24 GHz
- High-band: 24-300 GHz
  - mmWave band: 24-92 GHz
  - Sub-THz band: 92-300 GHz

In order to realize the 6G vision, it is very important to ensure the availability of appropriate spectrum. In consideration of the spectrum usage in 6G, several key factors should be taken into account, such as coverage, new service needs, high throughput, QoS, and so on.

The low-band (below 1 GHz), while not easy to secure wide bandwidth compared to other bands, could provide wide area coverage and deep indoor penetration thanks to its outstanding propagation characteristics.

The mid-band (1-24 GHz) has the merit of offering relatively sizable contiguous bandwidth (hundreds of MHz) to balance coverage and capacity, but the bandwidth is still not sufficient to support throughput-hungry environments such as hotspot scenarios with congested connection density.

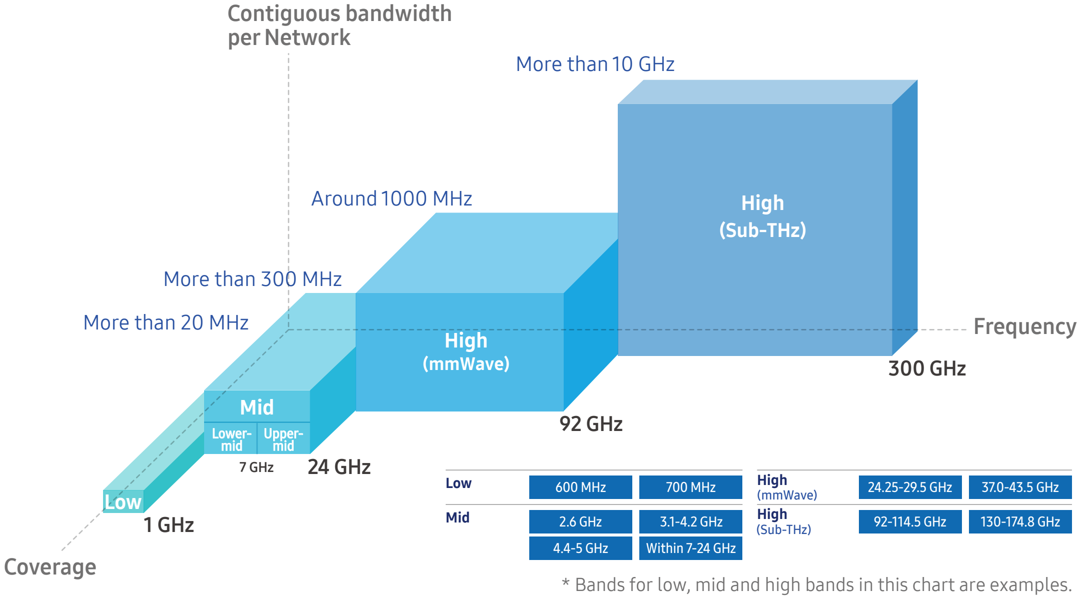
The frequency range within 24-92 GHz of the high band, commonly known as mmWave band, enables high capacity services with wide contiguous bandwidth to be delivered although it may have coverage limitations. Sub-THz frequency range within 92-300 GHz of the high-band would be appropriate for existing services and new services with the ultimate experience (such as hologram and XR) which require ultra-high capacity and ultra-low latency.

In order to investigate 6G spectrum in depth, we analyse these three band groups further in three dimensions, namely, coverage, contiguous bandwidth and frequency, which are principal measures to determine service usage scenarios. Our starting point to investigate 6G candidate spectrum is illustrated in Figure 2.

6 Band grouping of low, mid, high bands and naming follows Samsung's internal definition.

Figure 2

Three dimensions of 6G spectrum grouping.



Low	600 MHz	700 MHz
Mid	2.6 GHz	3.1-4.2 GHz
	4.4-5 GHz	Within 7-24 GHz
High (mmWave)	24.25-29.5 GHz	37.0-43.5 GHz
High (Sub-THz)	92-114.5 GHz	130-174.8 GHz

* Bands for low, mid and high bands in this chart are examples.

3 Candidate Bands

6G in new and additional bands as well as bands refarmed from previous generations.

Over the progress of previous generations from 3G to 5G, the frequency bands have been getting higher and wider. The 2 GHz band is being used for 3G, the bands 2.3 GHz and 2.5 GHz are additionally used for 4G, and the 3.5 GHz and mmWave band are used for new services including diverse vertical applications in 5G era. Among these frequency bands, some have been refarmed for use by the later generations of mobile communications technology. Generally, the initial launch of a new generation of mobile communication system is usually in a new frequency band, and additional bands as well as bands refarmed from previous generations are then utilized further for the network expansion as the ecosystem expands. The same approach is envisaged for 6G as well.

As mentioned earlier, 6G will be able to provide various services, where various requirements in different geographical areas are expected, namely, wide coverage with low capacity, wide coverage with high capacity, wide coverage with low latency, low coverage with high capacity and low coverage with low latency. Additionally, 6G would see new requirements and measures for precise positioning, energy efficiency and distributed computing. In light of this, various frequency bands, from low to high bands, as depicted in Figures 1 and 2 above, will all be utilized in future 6G services.

Due to difficulty and complexity to use the limited frequency resources, selective use of spectrum in a flexible manner will be important.

Meanwhile, it is becoming more and more difficult to use frequency bands exclusively for mobile communication. Therefore, it will be very important to use the limited frequency resources from low-band to high-band efficiently, and it is expected that selective use of frequency bands in a flexible manner spatially and temporally will be more significant in 6G era, as further detailed in Section 5. In addition, regulatory approaches are mostly used to resolve interference issues within in-bands or adjacent bands among different services. Since 6G should amplify spectrum competency as much as possible, innovative new technologies for spectrum sharing and adjacent band compatibility would be one of the crucial technologies.

This section presents which bands can be considered based on the aforementioned spectrum grouping to realize 6G services.

3.1 High-band "24-300 GHz"

Sub-THz band "92-300 GHz"

As discussed in the 6G white paper released in 2020, Samsung has a view that the sub-THz technology will be one of the candidate technologies for 6G.

According to Shannon's theory, in order to improve the data rate, a significantly improved spectrum efficiency compared to the existing communication should be technically supported. However, it should be noted that there are many technical limitations to the improvement of spectrum efficiency by several orders of magnitude. Therefore, it is very important not only to increase the spectrum efficiency but also to secure wide bandwidth spectrum. As introduced in Section 1, it is envisaged that the Tbps-class data rate services would be realized by a contiguous wide bandwidth in the order of tens of GHz spectrum. With that, we believe that this dreamlike technical advancement can be realized by using the sub-THz bands providing huge wider spectrum bandwidth. In addition, it is noted that the higher the frequency is, the shorter the wavelength will be, which will enable high spatial re-use by pencil-point sharp beamforming and miniaturization of RF components such as antennas.

New opportunity in sub-THz band in 92-300 GHz and technical measures to overcome the challenges.

In order to successfully realize sub-THz communications in practice, some fundamental and technical challenges need to be overcome. One key issue among these is the sharply decreased transmission distance of sub-THz band due to higher propagation path loss and absorption rate of water vapour than those of low and mid-band used for existing mobile communication. But, it can be compensated to some extent by utilizing antenna panels consisting of a large number of antenna elements at base stations, namely ultra-massive MIMO. Other technical challenges and the counter-back measures are described in the 6G white paper published in 2020.

Today, the mobile communication industry, 6G research projects and academia are considering sub-THz bands, as an important frequency range for 6G [3], and the R&D is in progress. Nevertheless, the R&D for utilizing sub-THz for communication is still in the initial stage. For the commercialization of 6G around 2030, it is therefore very important to discuss and plan for the use of sub-THz band for mobile applications from this point onwards.

In this section, we look at which bands could be considered for communication within the frequency range 92-300 GHz. As shown in Figure 3, the frequency range 92-300 GHz[7] is allocated globally for many services including mobile services in accordance with the ITU-R Radio Regulations.

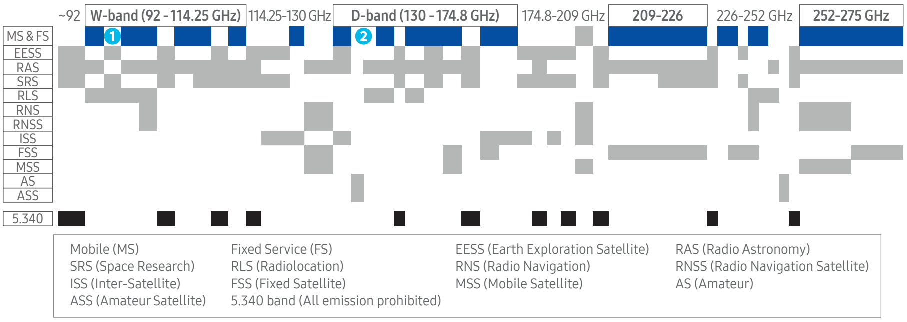


Figure 3
Global allocation of the 92-275 GHz spectrum range.

The contiguous wide frequency ranges with mobile services allocation should be considered as candidates, taking into account some frequency ranges with the potential possibility to be allocated additionally to mobile services, such as ❶ and ❷ as depicted in Figure 3.

On the other hand, some bands may have some restrictions as set in ITU-R Radio Regulations. Especially, according to No. 5.340 of the Radio Regulations, all radio emissions are prohibited in certain bands for the protection of passive services. However, it is also important to consider Resolution 731 (REV.WRC-19), which promotes the "Consideration of sharing and adjacent-band compatibility between passive and active services above 71 GHz."

W-band (92-114.25 GHz) and D-band (130-174.8 GHz) are recommended as potential candidate bands for 6G. Other bands, e.g., 220-275 GHz or up to 300 GHz, would also be worth considering.

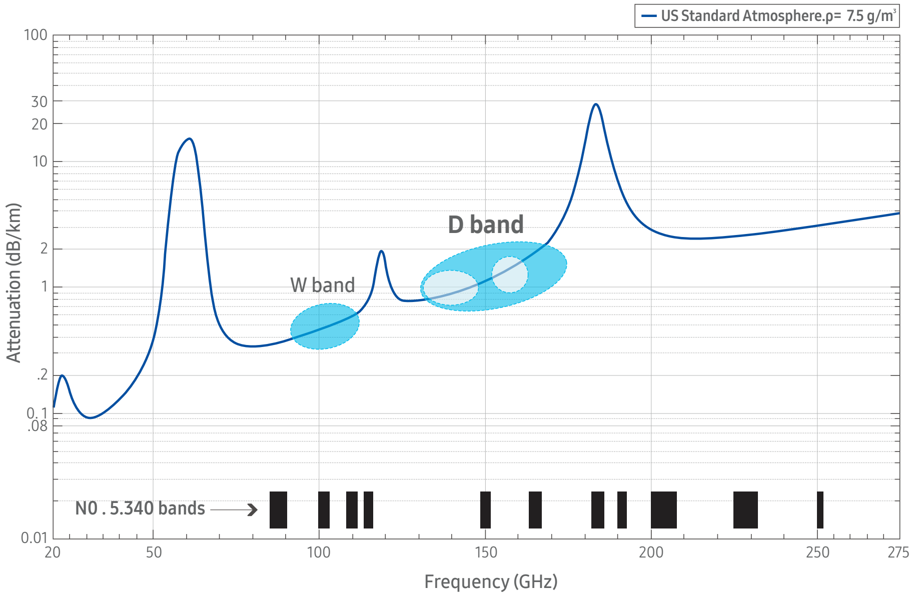
In addition, we further look at propagation characteristics such as atmospheric and rainfall attenuation. There are some specific bands with high absorption or reflectivity by air and water vapour [4][5] leading to a reduced propagation distance which lower these specific bands' suitability for 6G. With the radio wave characteristics in consideration, the bands 92-114.25 GHz

[7] Note that the frequency allocation table in the ITU-R Radio Regulations contains up to 275 GHz. Meanwhile, some bands within 275 GHz to 450 GHz were identified to land mobile service and fixed service in accordance with a footnote of 5.563A (WRC-19).

and 130-174.8 GHz, so called W- and D-band respectively in the market, are recommended for further investigation as potential candidate bands for 6G. It is noted that the W-band has been reviewed preliminarily in 3GPP together with other frequency bands above 52.6 GHz for seeking new spectrum opportunity for 5G new radio (NR) as described in 3GPP TR 38.807.

W-band has better propagation characteristics than D-band, however, W-band may have some difficulties to provide contiguous spectrum bandwidth over 10 GHz considering the restriction of No. 5.340. Meanwhile, D-band having slightly worse propagation characteristics than W-band may have more opportunities to provide large contiguous spectrum bandwidth with more than tens of GHz. Additionally, the 220-275 GHz band is also worth considering, but the propagation characteristics are not worse compared to the W- and D-bands as shown in Figure 4.

Figure 4
Specific attenuation due to atmospheric gases [4][5].



All options should be kept on the possibility of using sub-THz, particularly D-band, for 6G.

There are some opinions on considering the utilization of sub-THz, especially D-band, to support applications in fixed services such as backhaul. Various technical feasibility studies and tests on whether these two bands can be used by mobile application are currently being conducted globally. Traditional applications under fixed and mobile services are highly likely to be able to coexist with certain conditions. Before drawing conclusions, all feasible options should be kept on the possibility of using sub-THz for mobile applications. In the future, it will be necessary to study how to use the sub-THz band for mobile service while efficiently sharing the frequency with the passive and fixed services.

6G technology using sub-THz band will provide new spectrum opportunities and utilizing sub-THz bands is feasible for 6G.

In this regard, Samsung is carrying out various research studies including channel measurement campaigns and demonstrations [6][7][8][9][10]. Based on the initial results of those studies, we are of the view that 6G technology using sub-THz band will provide new spectrum opportunities and utilizing sub-THz bands would be feasible for 6G.

mmWave band “24-92 GHz”

The continued growth of mobile data traffic in dense urban areas and/or in peak time points to the use of mmWave band, as mmWave band can accommodate more capacity and bandwidth than mid-band and low-band.

Several sub-bands in mmWave band were identified for IMT in WRC-19, as shown in Figure 5. In particular, the 28 GHz band, which is the 5G frontier band,[8] has been commercially deployed in some countries including the US, Republic of Korea, and Japan.

mmWave band will continue to contribute for 5G and 6G.

The mmWave band is now becoming more widely available.[9] Countries such as Australia, Brazil, Finland, Germany, Italy, Japan, Republic of Korea and the US have already released mmWave spectrum for 5G, and more countries are about to consider mmWave band for their 5G deployment, or are in the process of band planning and consultation development.[10] The mmWave bands currently support 5G roll out and will also play a very important role in 6G.

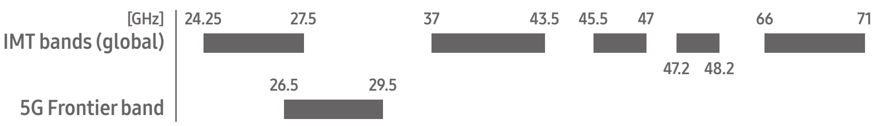


Figure 5
Availability of mmWave bands.

[8] Refer to http://5g-28frontier.org/.

[9] Refer to GSA report on mmWave summary December 2021 – Spectrum Update, December 13, 2021.

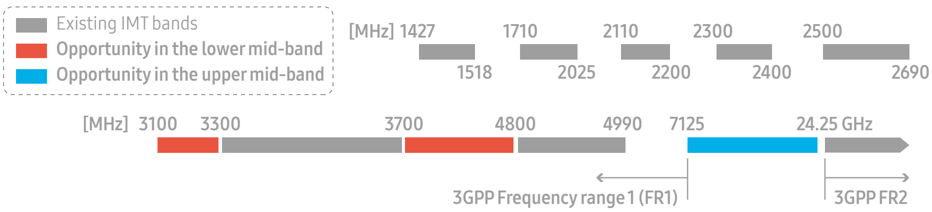
[10] For instance, New Zealand’s consultation on “24-30 GHz use in New Zealand” in June 2021. Available at https://www.rsm.govt.nz/projects-and-auctions/ consultations/24-30-ghz-use-in-new-zealand/.

3.2 Mid-band "1-24 GHz"

The value of mid-band spectrum is in its combination of coverage and capacity, and in this sense, mid-band spectrum will continue to play an important role in 6G era. Over multiple generations from 3G to 5G, mid-band deployments have been getting higher in terms of frequency and wider in terms of bandwidth, and additional mid-band spectrum is very important for network expansion. However, it is not easy to have additional mid-band spectrum for exclusive use, since many incumbent services are in-use in the frequency range from 1 to 24 GHz. It is fundamentally important to explore global harmonized frequency bands from the perspective of economies of scale, thus enabling affordable devices and services, and at the same time, to consider aspects of regional/local use of the mid-band spectrum in a flexible manner by sharing wherever appropriate.

We note that global studies on 6G spectrum are of great interest in the mid-band spectrum. Compared to high-band consisting of mmWave band and sub-THz band, existing IMT bands below 6 GHz have a propagation advantage for coverage enhancement. With the work carried out in earlier WRCs, particularly in WRC-07 and WRC-15, several frequency ranges were identified for IMT. The decisions from WRC-19 have consolidated the acceptance of several bands globally by adding a number of countries to the IMT footnotes.

Figure 6
Existing IMT bands and opportunity in the mid-band.



In case of the mid-band, we define two-sub frequency ranges as lower mid-band in the frequency range 1-7 GHz and upper mid-band in frequency range 7-24 GHz, taking into account WRC-23 agenda item, FCC's rulemaking process[11] and 3GPP frequency ranges.

[11] Available at https://www.fcc.gov/document/fcc-seeks-comment-maximizing-efficient-use-12-ghz-band.

Upper mid-band "7-24 GHz"

Upper mid-band, i.e., 7-24 GHz, is expected to play a key role for 6G, and further studies for this frequency range should be conducted.

Figure 7 shows how the spectrum in the frequency range 7-24 GHz is allocated to different services on a primary basis. It should be noted that while a big portion is allocated to mobile and fixed services, many other services are allocated the overlapping spectrum. We also note that the frequency range 7-24 GHz are currently heavily used for other purposes rather than mobile communication.

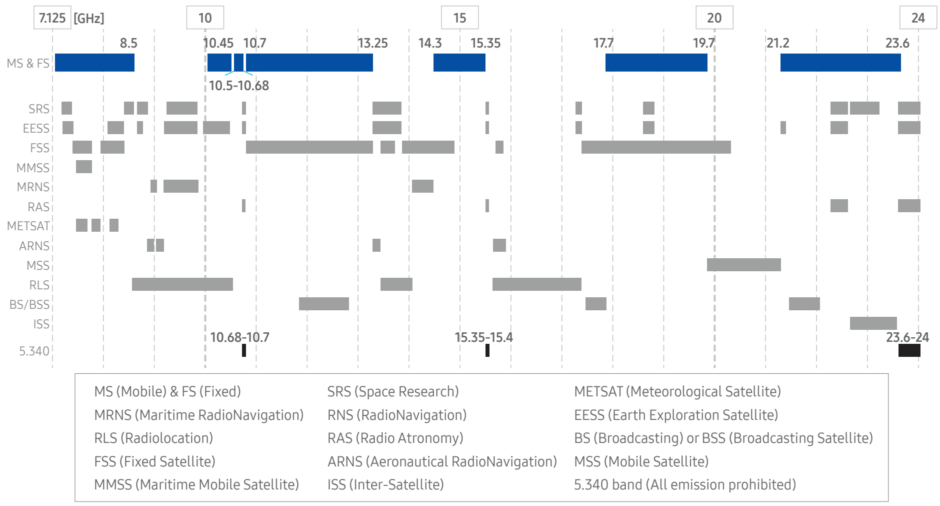


Figure 7
Allocation status in 7-24 GHz.

Spectrum sharing between mobile and other services would need to be explored for flexible and efficient utilization of the upper mid-band for 6G.

Considering the current spectrum allocation and usage, it may be challenging to choose which bands could be used for 6G in the frequency range 7-24 GHz. As the starting point, the frequency bands allocated to the mobile service on a primary basis can be considered for 6G. Sharing of those bands with other services in a flexible and efficient manner should be also explored to maximize the amount of spectrum for 6G.

In terms of licensing, an exclusive licensing for nationwide public network is recommended to achieve high spectrum efficiency and mature ecosystem for 6G services. Meanwhile, we also recognize the potential difficulty for regulatory bodies to balance the utilization of the limited spectrum resource among different services. In that case, the flexible licensing (e.g., local licensing) and spectrum sharing can be exploited to enable the coexistence of 6G with incumbent services.

We believe that an in-depth study is needed on how to use the frequency range 7-24 GHz for 6G, taking into account its enormous potential in terms of coverage and capacity. In particular, it would be important to continue investigation on the bands allocated to mobile service on a primary basis such as 7.125-8.5 GHz, portions of 10-13.25 GHz, 14.3-15.35 GHz, 17.7-19.7 GHz and 21.2-23.6 GHz.

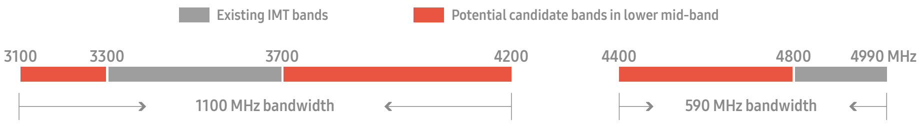
Lower mid-band "1-7 GHz"

Many existing bands in the lower mid-band 1-7 GHz could be refarmed, but additional and new spectrum within the range should be considered.

Currently, some of those frequency bands in lower mid-band are widely used for IMT deployment. Refarming the spectrum of previous generations (e.g., 2G, 3G and 4G) would be an effective way to secure spectrum for 6G. However, the whole procedure for spectrum refarming could take a long time. In addition, the amount of existing spectrum is far from enough to support 5G expansion and 6G. A recent GSMA study on mid-band spectrum needs in 36 cities shows an average of 2 GHz of mid-band spectrum is required [11].

Therefore, we cannot rely only on refarming of the existing bands, but also need to further consider exploring new spectrum for 6G. It would be particularly useful if we could find new spectrum around the bands that were already identified for IMT. In the process of exploring new spectrum, it would especially be important to prioritize the bands that exist just next to an existing band so that larger contiguous bandwidth could be provided. This would be useful to provide very high data rate and drastically improve system capacity so that 6G could be well differentiated from 5G in terms of user experience. For example, by utilizing 3100-3300 MHz and 3700-4200 MHz, it becomes possible to utilize 3100-4200 MHz that provide the contiguous bandwidth of 1100 MHz as shown in Figure 8. Another example in Figure 8 is to add 4400-4800 MHz to the existing 4800-4900 MHz band, resulting in the contiguous bandwidth of 590 MHz. It may be worth noting that the final allocation could be different in each country or region. For example, the US is considering 3100-3450 MHz.

Figure 8
Potential candidate bands in lower mid-band.



Taking into account global effort on securing new bands as above, 3GPP has already defined 3300-4200 MHz as band n77 for deploying 5G NR systems, which would help achieve great economies of scale. All those lower mid-band spectra aim to be used for 5G roll out and expansion and will also provide enormous opportunities to support 6G networks. On the other hand, there would be large differences in terms of timeline when a certain band could be available in different countries and regions mainly due to incumbent services. Taking into account continuing technical development and potential measures, such as spectrum sharing, antenna technologies and license regimes, the available frequency bands should be used for mobile communications and other services in a fair and flexible manner so that the efficiency of frequency utilization and social benefit can be maximized.

3.3 Low-band "Below 1 GHz"

The low-band below 1 GHz will continue to be important to enable wide area coverage.

Each new generation of communications technologies, from 2G to 5G, has had a low-band spectrum component to enable wide area coverage outside of the cities as well as improved deep indoor penetration within cities to provide a consistent user experience. It is anticipated that 6G will also require low-band spectrum. Re-use of the existing mobile low-band spectrum is envisaged but it is also important to investigate whether additional low-band spectrum will be required from spectrum bands below 1 GHz. A number of the existing users of this low-band spectrum could be impacted such as the utilities industry, IoT, emergency and military systems, broadcasting networks, and wireless microphones. Investigations are needed to see if 6G can meet the needs of these users in addition to the mobile operators as well as if techniques can be developed to enable sharing of this spectrum with incumbent services and minimize interference. WRC-23 will be looking into the UHF spectrum in Region 1[12] and whether this spectrum is also allocated to mobile and IMT so that administrations have the future flexibility for the option for 5G and/or 6G within this range depending upon how the market and technologies develop.

[12] For the allocation of frequencies, the world has been divided into three regions in accordance with the ITU-R Radio Regulations. Region 1 comprises Europe, Africa, the Middle East West of the Persian Gulf including Iraq, the former Soviet Union and Mongolia.

4 Timeline for 6G Spectrum

- Study on 6G spectrum has to start now to support commercialization of 6G around 2030.
- Initial launch of 6G in new frequency bands, followed by the refarming of existing ones in a later phase.

In the light of the experience from previous generations, it takes around 10 years to make the spectrum available for use, and hence, in order to support 6G commercialization around 2030, discussion on 6G spectrum has to start now.

6G spectrum needs to be secured through exploring new bands as well as refarming of existing bands. Generally, the refarming of existing mobile spectrum takes a long time and the exact timeline would depend on the traffic load of current generation, user migration process, and plan for deploying the new generation network. It would be ideal to use a new frequency band(s) for the initial launch of a new generation system. Refarming of the existing bands could be performed later for the network expansion to additional frequency bands as the ecosystem expands.

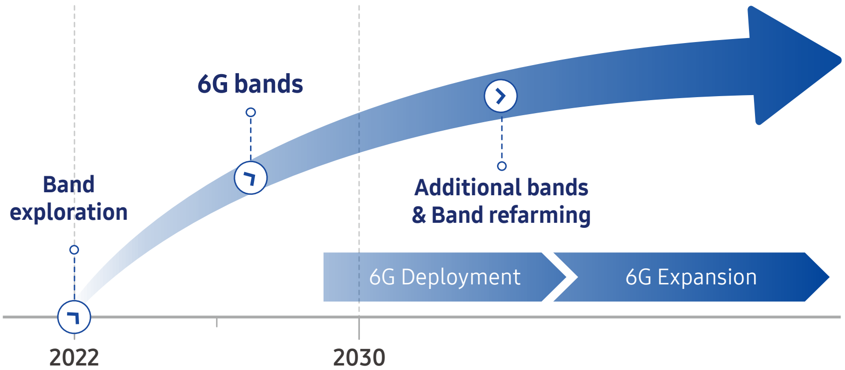


Figure 9
Timeline for 6G spectrum.

6G spectrum allocation before 2030.
Both WRC and market-driven approach can be worthy for securing 6G spectrum.

In order to realize 6G commercialization around 2030, spectrum should be ready before 2030. Global/regional frequency harmonization has various benefits such as equipment compatibility, roaming, economies of scale, as well as fast global industrial promotion. Therefore, long before commercialization, the preparation of 6G spectrum policies by each administration/regulatory organization and its allocation to the industry would have a significant net effect on 6G R&D.

The WRC path is a good approach to realize global/regional frequency harmonization. As mentioned above, we would like to recommend that 6G spectrum be defined before 2030. With that, the WRC in 2027 would be very important for 6G spectrum. In parallel, the market driven approach for 6G spectrum may also be worth considering.

5 Approach for Securing 6G Spectrum

In Section 3, we addressed what candidate bands for 6G should be taken into account. In this section, we discuss how to secure those bands for 6G with focus on mid-band and sub-THz band, as shown in Table 1.

Table 1
Possible approaches for securing licensed spectrum for 6G.

Band \ Approach	New band exploration (NOTE 1)	Spectrum clearing	Spectrum refarming
Lower mid-band	✓	✓	✓
Upper mid-band	✓	✓	
Sub-THz band	✓		

(NOTE 1) including spectrum sharing approach.

Technical solutions and regulatory regime to secure 6G spectrum:

- New band exploration including spectrum sharing
- Spectrum clearing
- Spectrum refarming

New frequency band exploration

Exclusive use for mobile communications in the limited frequency resources is becoming more and more difficult. It leads us to examine sub-THz band to find massive amount of greenfield contiguous spectrum. In addition, it also offers us the opportunity to investigate innovative technical solutions and regulatory regime that enable efficient and flexible use of limited spectrum resource under the condition of incumbent services.

Generally speaking, it remains important in all the low, mid and high bands that spectrum is licensed. This helps create a global mass market bringing the benefits of economies of scale and enabling high-quality services to be efficiently and predictably delivered. Some examples to use the limited frequency resources in a flexible manner can be seen through the rules of upper microwave flexible use service (UMFUS) and citizens broadband radio service (CBRS) both in the US as well as licensed shared access (LSA) model in Europe. The local licensing regimes, e.g., e-Um 5G in Korea, have been announced by some regulators, which makes spectrum available on a local area basis to enable 'verticals' to have their own spectrum regionally. In our view, regulators that make any local area spectrum available could consider to also allow the option for mobile operators as well as

Example bands for each approach includes
- Exploring new bands: Candidate bands addressed in Section 3
- Spectrum clearing: within 7-24 GHz
- Spectrum refarming: existing bands for 2G to 5G

verticals to access local area spectrum to help enable a mass market ecosystem. Looking forward to 6G, particularly in the mid-band and sub-THz band given the anticipated shorter propagation ranges, it could be envisaged that some of the spectrum should be locally licensed enabling both operators and verticals.

Although 6G may seem a long way off, it will take many years to prepare and execute a spectrum plan that will enable 6G to be commercially deployed around 2030. As part of this plan, it is important to consider at a relatively early stage how new spectrum could be licensed along with possible sharing approaches with other incumbent services such as satellites, public, fixed links, broadcast networks, etc. in in-band and/or adjacent bands. To assimilate feasible sharing and associated requirements, engagements within the standards and regulations at an early stage are encouraged.

Spectrum clearing

Taking into account the equipment life cycle and the licence term of incumbents, as well as the market demand on additional and new frequency bands, regulators have also been supplying the market through the introduction of spectrum clearing policies. For example, for C-band auction in the US, satellite operators agreed to clear the spectrum in exchange for relocation costs and incentive payments for clearing the spectrum on an accelerated timeline, which led the auction as a new FCC record.

The upper mid-band, 7–24 GHz, is an important candidate band for 6G but already congested with other services. Spectrum clearing might be one of the options in this range in addition to spectrum sharing. To do this, the regulatory process should be considered at early stage, since there is a lead time between the spectrum clearing process and releasing spectrum to the market.

Spectrum refarming

For the deployment of 6G networks, it would be natural to consider refarming of the spectrum used for 2G, 3G, and 4G. There could still be many 5G devices when the deployment of 6G networks starts and hence it would be important to prepare a long-term plan for smooth migration of spectrum from 5G to 6G taking into account commercial needs.

In addition to the licenced spectrum approaches mentioned above, it is also considered that the use of unlicensed (licence-exempt) spectrum could also be a part of the 6G spectrum mix and is an interesting area for further research and investigation particularly in some of sub-THz bands.[13]

[13] For instance, in the US, total spectrum of 21.2 GHz across the 116-123 GHz band, the 174.8-182 GHz band, the 185-190 GHz band and the 244-246 GHz band are defined for unlicensed use under the Spectrum Horizons rules in 2019.

6 Concluding Remarks

We at Samsung are excited and proud to be once again helping lead the development of a new generation of mobile telecommunication technology. 6G has a formidable task ahead of us, to not only be better than 5G but also address major societal, environmental and business challenges.

Spectrum, as a natural and increasingly congested resource, is a fundamental pre-requisite. Bringing suitable spectrum into the marketplace to help enable 6G will take many years of planning, and hence, this is the best time to commence global discussions as we target its commercialization around the year 2030 onwards. Spectrum from the low, mid and high-band should be explored. Particularly, sub-THz band and upper mid-band represent new frontiers in wireless mobile communications research.

We look forward to working with industry, regulator, government and university partners from around the world to help realize the availability of spectrum for 6G.

References

[1] Cisco, Cisco Edge-to-Enterprise IoT Analytics for Electric Utilities Solution Overview, Available at https://www.cisco.com/c/en/us/solutions/collateral/data-center-virtualization/big-data/solution-overview-c22-740248.html.

[2] Samsung, 6G The Next Hyper – Connected Experience for All, Available at https://research.samsung.com/next-generation-communications#6gPop, December 2020.

[3] Ofcom, Event entitled Unlocking the potential of Terahertz spectrum, July 2021 Available at https://www.ofcom.org.uk/about-ofcom/latest/events and https://www.techuk.org/what-we-deliver/events/ofcom-unlocking-the-potential-of-terahertz-spectrum.html.

[4] ITU-R, Recommendation ITU-R P.676-12 on Attenuation by atmospheric gases and related effects, August 2019 Available at https://www.itu.int/rec/R-REC-P.676-12-201908-I/en.

[5] FCC, ET Docket No. 18-21 on Notice of Proposed Rulemaking and Order in the matter of Spectrum Horizons, February 2018 Available at https://www.fcc.gov/document/oet-establishes-et-docket-no-18-21.

[6] N. A. Abbasi, J. Gomez-Ponce, S. M. Shaikbepari, S. Rao, R. Kondaveti, S. Abu-Surra, G. Xu, C. Zhang, and A. F. Molisch, Ultra-wideband double directional channel measurements for THz communications in urban environments, in ICC 2021-2021 IEEE International Conference on Communications (ICC). IEEE, 2021.

[7] Available at https://news.samsung.com/global/samsung-electronics-and-university-of-california-santa-barbara-demonstrate-6g-terahertz-wireless-communication-prototype.

[8] Samsung, News article on Samsung Electronics and University of California Santa Barbara Demonstrate 6G Terahertz Wireless Communication Prototype, June 2021 Available at https://news.samsung.com/global/samsung-electronics-and-university-of-california-santa-barbara-demonstrate-6g-terahertz-wireless-communication-prototype.

[9] Shadi Abu-Surra, et al., End-to-end 140 GHz Wireless Link Demonstration with Fully-Digital Beamformed System, IEEE ICC 2021 Workshop – TeraCom.

[10] Shadi Abu-Surra, et al., End-to-end 6G Terahertz Wireless Platform with Adaptive Transmit and Receive Beamforming, to be published at IEEE ICC 2022 Workshop – TeraCom.

[11] GSMA, Estimating the mid-band spectrum needs in the 2025-2030 time frame, Available at https://www.gsma.com/spectrum/wp-content/uploads/2021/07/5G-Mid-Band-Spectrum-Needs-Vision-2030.pdf.

Abbreviations

3GPP	3rd Generation partnership project
AI	Artificial intelligence
CBRS	Citizens broadband radio service
eMBB	Enhanced mobile broadband
FCC	Federal Communications Commission
FR	Frequency range
GSA	Global mobile suppliers association
GSMA	GSM association
IMT	International mobile telecommunication
IoT	Internet of Things
ITU-R	International telecommunication union-Radiocommunication sector
LSA	Licensed shared access
mMTC	Massive machine-type communications
NR	New radio
RF	Radio frequency
TR	Technical report
UMFUS	Upper microwave flexible use service
URLLC	Ultra-reliable and low latency
WRC	World radiocommunication conference
XR	Extended reality