

**Before the
Federal Communications Commission
Washington, D.C. 20554**

In the Matter of)	
)	
Use of Spectrum Bands Above 24 GHz For Mobile Radio Services)	GN Docket No. 14-177
)	
Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band)	RM-11664
)	

**COMMENTS OF SAMSUNG ELECTRONICS AMERICA, INC. AND SAMSUNG
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I.	INTRODUCTION AND SUMMARY	2
II.	A SUCCESSFUL EVOLUTION TO 5G NETWORKS AND SERVICES WILL REQUIRE GLOBAL COOPERATION.....	3
A.	5G Services Have the Potential to Revolutionize the Mobile Experience	3
B.	5G is a Global Initiative and International Harmonization Will Be Essential.....	9
1.	Samsung Is Leading 5G Initiatives Around the World	9
2.	Governments Around the Globe are Collaborating on 5G Efforts.....	14
3.	International Harmonization Will Be Essential to 5G Networks’ Success.....	17
C.	The Commission Should Continue to Examine Bands Below 6 GHz.....	19
III.	EFFORTS ARE WELL UNDER WAY TO DEVELOP TECHNOLOGIES THAT WILL SUPPORT MILLIMETER WAVE SERVICES	20
A.	As a General Matter, Use of Spectrum Above 24 GHz to Provide Mobile Services is Entirely Feasible.....	20
B.	Samsung Is Testing Antennas That Will Support 5G Millimeter Wave Services	26
C.	Samsung’s Testing Experience on Bandwidth, Duplexing, Modulation, and Multiple Access.....	30
D.	Samsung’s Recent Testing Demonstrates the Performance and Coverage Potential of 5G Networks.....	32
E.	5G Millimeter Wave Networks Will Involve a More Distributed Network Architecture	33
F.	Technical Rules.....	35
G.	Millimeter Wave Licensees Should Have the Flexibility to Provide a Variety of Services.....	35
IV.	SEVERAL BANDS ABOVE 24 GHZ ARE PROMISING CANDIDATES FOR 5G SERVICES	38
A.	The Commission Should Focus on Particular Characteristics When Identifying Spectrum for Millimeter Wave Services.....	38
B.	Several Spectrum Bands Are Viable Candidates to Support 5G.....	40
1.	LMDS Spectrum	41
2.	39 GHz Spectrum.....	43
3.	37/42 GHz Spectrum	44
4.	60 GHz Spectrum	45
V.	CONCLUSION	47

APPENDICES

- Appendix A ITU and International Harmonization Efforts for 5G
- Appendix B Samsung Testing and Measurements in Bands Above 24 GHz
- Appendix C Sharing and Compatibility Studies into Fixed Systems from Mobile Broadband System
- Appendix D Compatibility Studies Between Mobile Broadband Uses and Incumbent Services (Fixed Satellite Service) in Bands Adjacent to LMDS
- Appendix E Compatibility Studies Between Mobile Broadband Uses and Fixed Satellite Service in the 39.5-40 GHz

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Samsung hereby responds to the Commission’s *Notice of Inquiry* on the potential provision of Fifth-Generation (5G) mobile services in spectrum bands above 24 GHz.¹ 5G services have the potential to revolutionize how we communicate. As detailed below, industry efforts and investments to develop 5G are well under way and have already borne amazing results. Globally, governments have also begun to study the 5G transition, with the FCC already playing a key role through the work of the Spectrum Frontiers working group of the Technological Advisory Council. The *Notice of Inquiry* reflects the Commission’s keen understanding of 5G and seeks input on important questions about the spectrum and technical rules needed to make 5G succeed. The comments below answer these questions and reflect insight Samsung acquired through its 5G research and development. Ultimately, Samsung asks the Commission to focus on two key points, both critical to 5G’s future success. First, the Commission should focus primarily on the provision of licensed mobile broadband systems in the 28 GHz and 39 GHz LMDS bands as well as 37/42 GHz bands for 5G, with a secondary eye

¹ *Use of Spectrum Bands Above 24 GHz For Mobile Radio Services*, Notice of Inquiry, FCC 14-154 (Oct. 17, 2014) (“*Notice of Inquiry*”). For purposes of these comments, “Samsung” refers to Samsung Electronics America, Inc. and Samsung Research America, collectively.

toward other bands such 60 GHz. Second, the Commission should actively lead global 5G efforts to promote international harmonization.

I. INTRODUCTION AND SUMMARY

5G services have the potential to revolutionize the mobile experience. 5G services will offer unprecedented data rates, experience lower latency, promote both spectrum and energy efficiency, and achieve unprecedented mobility. Samsung expects that 5G systems will also support groundbreaking applications that demand exceptionally high-speed wireless connections, a fully-realized Internet of Things, simplified wireless network design, and enhanced versions of existing mobile services. To realize these benefits, 5G systems will differ fundamentally from their predecessors from a spectrum and technology perspective. Unlike existing commercial mobile services, 5G networks will rely on higher frequencies, wider bandwidths, and higher-density deployments. For this reason, and as detailed further below, Samsung strongly supports proposals by the Commission to make spectrum above 24 GHz available for 5G.

Samsung's vision for 5G is a global vision, and Samsung believes that a global effort will be necessary for 5G services to reach their full potential. There are numerous initiatives around the globe focusing on millimeter wave technologies, and Samsung is at the forefront of nearly all of them. Samsung is pleased by the global collaboration demonstrated thus far and hopes this will culminate in the adoption of a truly internationally harmonized 5G ecosystem. In a 5G world, international harmonization will be more important than ever before, and Samsung asks the Commission to take a leadership role in promoting international harmonization for 5G.

While frequencies above 3 GHz have not historically hosted commercial mobile services, Samsung believes that using spectrum above 24 GHz to provide mobile services is entirely feasible. Numerous technical improvements have combined to address this spectrum's historical limitations and to transform these bands into powerful drivers of mobile technologies. Samsung

has extensively tested 5G services in high-frequency bands and is extremely encouraged by the results. Based on this testing, Samsung has provided input below on various technical issues relating to 5G. Samsung has also identified several bands that are viable candidates to host 5G services. In particular, the Commission should study how to enable licensed mobile broadband in the 28 GHz and 39 GHz LMDS as well as the 37/42 GHz bands for 5G. Secondary attention should also be paid to spectrum at 60 GHz.²

II. A SUCCESSFUL EVOLUTION TO 5G NETWORKS AND SERVICES WILL REQUIRE GLOBAL COOPERATION

A. 5G Services Have the Potential to Revolutionize the Mobile Experience

Samsung shares the Commission’s vision of 5G services as a significant improvement over predecessor wireless systems. As explained below, 5G systems will enable higher data rates, lower latency, greater spectral and energy efficiency, and unprecedented mobility.

Samsung believes that 5G systems will, among other things, enable the “Internet of Things” and revolutionize the way mobile services are integrated into daily life.

Just this week, President Obama affirmed his administration’s commitment to higher-speed broadband, stating that “high-speed broadband is not a luxury,” but rather “a necessity” and citing faster Internet speeds as key to America’s global competitiveness.³ President Obama also called for the adoption of policies that spur broadband deployment and enhanced

² Despite the great promise of 5G services, Samsung does not believe that this in any way reduces the needs for the Commission to aggressively pursue opening other bands below 3 GHz for mobile broadband services (such as AWS-3, 600 MHz and 3.5 GHz).

³ Krishnadev Calamur, “Broadband A ‘Necessity,’ Obama Says, As He Pushes FCC To Expand Access,” National Public Radio (Jan. 14, 2015), *available at* <http://www.npr.org/blogs/thetwo-way/2015/01/14/377230778/obama-pushes-fcc-to-expand-broadband-access>.

competition.⁴ The development of mobile broadband services at gigabit speeds can help to meet all of these objectives. Samsung envisions that 5G service will serve as a viable competitor to fixed broadband, providing consumers with additional choices in the marketplace. And, Samsung is excited by the plethora of new and improved applications and services that will be possible with access to 5G.

To support this level of performance, 5G networks will be fundamentally different from their predecessors – relying on higher frequencies, greater bandwidth, and higher density cell deployments. Several standards-setting organizations have begun to focus on developing these 5G technologies, and based on the technical criteria explained below have focused on high-frequency spectrum to support these services.

5G Delivers Unprecedented Speeds. Samsung envisions that 5G systems will have significantly higher data rates than their predecessors. As a baseline, 5G systems will provide gigabit-rate data services regardless of user mobility and/or location. Specifically, 5G systems will support a 1 Gbps cell edge data rate to provide a uniform high-data-rate experience and will support data rates of at least 10 Gbps and as much as 50 Gbps for low-mobility users.⁵ Already, Samsung has completed a 5G network test in the 28 GHz band that achieved network data transmission rates of 7.5 Gbps.⁶ Not only will 5G network speeds be much higher than 4G

⁴ The White House, Office of the Press Secretary, “FACT SHEET: Broadband That Works: Promoting Competition & Local Choice In Next-Generation Connectivity” (January 13, 2015), at <http://m.whitehouse.gov/the-press-office/2015/01/13/fact-sheet-broadband-works-promoting-competition-local-choice-next-gener>.

⁵ Wonil Roh, Ph.D, “5G Mobile Communications for 2020 and Beyond: Vision and Key Enabling Technologies,” IEEE WCNC 2014, Istanbul, at 10 (April 2014) (“WCNC 5G Keynote”), available at http://wcnc2014.ieee-wcnc.org/sites/wcnc2014.ieee-wcnc.org/files/u21/WCNC2014_Keynote_Samsung.pdf

⁶ News Release, Samsung, “Samsung Electronics Sets 5G Speed Record at 7.5Gbps, Over 30 Times Faster Than 4G LTE” (Oct. 15, 2014), available at

speeds, but users will also enjoy a more uniform high-speed experience throughout the entire 5G network. Indeed, the increased density of 5G networks will ensure that data rates do not drop as dramatically when users move further away from wireless base stations.

5G Is a Critical Input for Next-Generation Applications. The high data rates achieved by 5G systems will also help support myriad innovative applications that are already in the market or in development. For example, enabling virtual reality viewing of sport events through both end user and content capturing devices will need to leverage high bandwidth mobile services. The technology is here today as exemplified by Samsung’s Gear VR and Project beyond camera. Samsung’s Gear VR is a virtual reality headset that provides users with a 96 degree viewing angle, which allows users to view films, games, and content beyond their peripheral vision.⁷ Likewise, Samsung’s Project Beyond Camera—the world’s first true 3D 360 degree camera—captures and streams omniview videos in high-resolution 3D.⁸ For example, each car in a NASCAR race could be equipped with the camera. This would enable race fans to share the same perspective as their favorite drivers, for a truly immersive experience. Capturing and delivering these exciting experiences in a mobile environment, however, will require significant data rates, and it is essential that wireless networks evolve in a timely manner to support these types of emerging applications. 5G will play an essential role in bringing these experiences to consumers.

<http://www.samsung.com/uk/news/local/samsung-electronics-sets-5g-speed-record-at-7-5gbps-over-30-times-faster-than-4g-lte>.

⁷ http://www.samsung.com/global/microsite/gearvr/gearvr_features.html

⁸ Beyond captures the world around using 16 stereoscopic cameras and a top-view camera in stunning full HD. In all, 35 megapixels per frame – over a gigapixel per second – is captured and processed. <http://thinktankteam.info/beyond/>

5G Ensures Lower Latency. 5G systems will also experience much lower latency than previous generations of wireless technology. Specifically, 5G networks will deliver end-to-end latency of less than 5 milliseconds and air latency of less than one millisecond – one-tenth the comparable latency of a 4G network.⁹ This will help support a variety of services with very low latency requirements. Critical infrastructure monitoring, for example, currently requires service levels achievable only on dedicated wireline networks. But the development of 5G technologies could make these service levels achievable over wireless networks.¹⁰ Likewise, low-latency networks will support pre-crash sensing, which enables vehicles to sense imminent collisions and exchange relevant data that could mitigate a collision’s impact.¹¹ Other low-latency services enabled by 5G could include self-driving cars, public safety communications systems, augmented reality, and “tactile internet.”¹²

5G Promotes Spectral Efficiency. 5G systems will also make extremely efficient use of spectrum, which the Commission has highlighted as a key element of network design.¹³ Specifically, 5G networks are expected to have spectral efficiency levels of 10 bps/Hz, as compared to 1-3 bps/Hz on 4G networks. This is achieved in two ways. First, 5G networks will

⁹ WCNC 5G Keynote.

¹⁰ 4G Americas, *4G Americas’ Recommendations on 5G Requirements and Solutions* at 7 (Oct. 2014) (“*5G Requirements and Solutions*”), available at http://www.4gamericas.org/documents/4G%20Americas%20Recommendations%20on%205G%20Requirements%20and%20Solutions_10%2014%202014-FINALx.pdf

¹¹ *Id.* at 9.

¹² *See Generally 5G Requirements and Solutions.*

¹³ *See, e.g., Amendment of the Commission’s Rules With Regard to Commercial Operations in the 1695-1710 MHz, 1755-1780 MHz, and 2155-2180 MHz Bands*, Report and Order, 29 FCC Rcd 04610, ¶ 49 (2014) (“*AWS-3 Order*”) (citing “providing for the efficient use of spectrum” as a key goal of the Communications Act).

use MIMO and advanced coding and modulation schemes,¹⁴ including using multiple base station antennas to simultaneously serve multiple users using the same frequency resource.¹⁵ Second, 5G systems will employ a new waveform design to exploit the non-Gaussianity of a channel and increase spectral efficiency.¹⁶

5G Promotes Energy Efficiency. 5G systems will be highly energy efficient – 50 times more efficient than 4G. Ultimately, 5G systems should have a reduced cost and energy usage per bit as a result of low-cost network equipment, lower deployment costs, and enhanced power saving functionality on the network and user equipment sides.

5G Services Will Be Highly Mobile. First, as noted above, greater consistency of data rates throughout a 5G cell’s coverage area will enable users to move about with little (to no) impact on device performance. Second, 5G technologies will cope efficiently with all degrees of mobility by providing “mobility on demand” based on each device’s and service’s needs.¹⁷ Specifically, because 5G networks will perform at very high speeds, they will support services such as vehicular Internet access, vehicle-to-vehicle communications, fitness tracking, and Internet access aboard aircraft and trains. Finally, the mobility of user equipment should be guaranteed to be at least the same level as the legacy system. Ultimately, Samsung envisions that 5G systems will support mobility even at speeds from 300 to 500 kilometers per hour.

The Internet of Things Will Depend on 5G. In addition to enhancing user-to-user and user-to-machine communications, 5G systems will help make the “Internet of Things” a reality.

¹⁴ WCNC 5G Keynote at 19.

¹⁵ *5G Requirements and Solutions* at 20.

¹⁶ WCNC 5G Keynote at 18.

¹⁷ *5G Requirements and Solutions* at 12.

5G systems will be able to connect virtually all connected devices without human intervention, and 5G systems will be able to support 1 million simultaneous connections per square kilometer.¹⁸ This will support a variety of machine-to-machine services, including wireless metering, mobile payments, smart grid and critical infrastructure monitoring, connected home, smart transportation, and telemedicine.

To support this level of performance, 5G networks will have fundamentally different needs than their predecessors and will require that very large contiguous channels be allocated to a service provider. In particular, 5G will have extensive bandwidth requirements to provide the expected gains over 4G services. As explained in the attached Appendix A, increasing bandwidth in a wireless network greatly increases the number of users who can enjoy speeds of 1 Gbps. It would be desirable to secure at least 500 MHz of bandwidth, and 1 GHz or more bandwidth would be preferable as many applications (like virtual reality) will require this amount of spectrum to deliver the capacity and data rates desired. For this reason, as explained below, higher frequency bands would be very well-suited for the provision of these services. Indeed, several standards and research organizations have begun to focus on higher-frequency bands to support 5G. For example, the 3rd Generation Partnership Project (“3GPP”) held a workshop in June 2012 where individual members expressed their interests in the possibilities and needs of higher frequency bands for mobile broadband.¹⁹ More recently, 3GPP has introduced a new study item for evaluating the technical feasibility of using bands above 6 GHz

¹⁸ WCNC 5G Keynote at 8.

¹⁹ 3GPP Meeting Documents, at http://www.3gpp.org/ftp/workshop/2012-06-11_12_RAN_REL12/ (last visited November 18, 2014).

for mobile broadband.²⁰ Particularly in light of these efforts, Samsung applauds the Commission for commencing this investigation of frequencies for 5G technologies. Allocating the large amounts of bandwidth required by 5G will require a significant effort from both the Commission and the global community.

B. 5G is a Global Initiative and International Harmonization Will Be Essential

1. Samsung Is Leading 5G Initiatives Around the World

Samsung has been a leader in numerous programs oriented toward research and development of 5G services. Through this involvement, Samsung has been on the bleeding edge of 5G development and testing. The migration to 5G is truly a global effort, and Samsung encourages the continued efforts of the global wireless community.

United States. In 2012, New York University launched the NYU Wireless Program. NYU Wireless is a research environment designed to “create next-generation mass-deployable devices across a wide range of applications and markets.”²¹ NYU Wireless is currently examining millimeter wave technologies and conducting other 5G research efforts. For example, NYU Wireless recently conducted a millimeter wave test that involved the placement of base stations on rooftops in 75 locations in Manhattan and eight in Brooklyn, finding “excellent propagation up to 700 feet away with power levels lower than those of today’s base stations.”²²

²⁰ 3GPP, Liaison Statement to External Organizations: Technical Feasibility of IMT in the Bands Above 6 GHz (Feb. 19, 2014), *available at* http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_63/docs/RP-140401.zip.

²¹ NYU Wireless, “About Us”, at <http://nyuwireless.com/about-us/> (last visited November 16, 2014).

²² Jessica Lipsky, “5G Research Widens MM Waves,” EE Times (Sept. 11, 2014), *available at* http://www.eetimes.com/document.asp?doc_id=1323851&&_mc=sm_eet_editor_jessicalipsky.

Samsung is one of the key supporters of this program and expects that it will be actively involved in upcoming research efforts.

Korea. The Korean government has been playing a leading role in assisting the development of 5G, as well as encouraging domestic and international research activities and partnerships. Korea's Ministry of Science, ICT and Future Planning ("MSIP") established a 5G Forum, of which Samsung is an executive board member.²³ The 5G Forum's strategy is to lead global standards development with next-generation original radio technology, to build an information welfare infrastructure for Korea, to create a new mobile service, and to develop a national policy for the development of 5G technology.²⁴ The 5G Forum has announced its plan to demonstrate 5G technologies at the 2018 Pyeongchang Winter Olympics.²⁵ Samsung Electronics is also a chair company of the "Spectrum Forum" – a private advisory forum for the MSIP that engages in strategy and planning regarding mobile technology and spectrum. In this capacity, Samsung assists in researching issues such as traffic estimation, spectrum requirements, and spectrum sharing.

Samsung Electronics is a member of several advisory and study groups organized by MSIP. Samsung is a member of the "Advisory and Study Group for 5G Spectrum Strategy and Policy." It also was a member of the study group for "Mobile Broadband Plan 2.0," a plan to secure additional mobile communications spectrum totaling 1190 MHz in addition to the existing

²³ 5G Forum, "Members List", at <http://www.5gforum.org/eng/main/main.php?categoryid=12&menuid=01&groupid=00> (last visited November 16, 2014).

²⁴ 5G Forum, "Vision," at <http://www.5gforum.org/eng/main/main.php?categoryid=11&menuid=02&groupid=00> (last visited November 16, 2014).

²⁵ Kim Si-so, "The 5G Forum Launches Its Journey Into the Era of Ultra-Connectivity," etnews.com (May 31, 2013), at http://english.etnews.com/communication/2775695_1300.html.

390 MHz of assigned spectrum by 2023. This plan includes at least 500 MHz of spectrum in frequency bands above 6 GHz for mobile broadband.²⁶ Samsung also serves as a member of the Strategy Committee for 5G Mobile Communications in Korea, which focuses on standardization, spectrum, globalization, and related issues. Samsung is also a participant in the Korean ITU Preparatory Group, assisting the Korean government in preparation for ITU World Radiocommunication Conferences.

In Korea, Samsung currently plays a variety of research roles in 5G efforts. Samsung has actively participated in the “Giga Korea Project” since 2013. This project is one of the key initiatives of MSIP and boasts a budget of KRW 550.1 billion (approximately US \$525 million) to support efforts through 2020. The Giga Korea project is focused on developing 1 Gbps mobile broadband connections by 2020.²⁷ As part of the Giga Korea Project, Samsung is focused on research and development of antenna technologies for 5G systems based on millimeter wave. Samsung also works in conjunction with KAIST, a public research university, as well as other leading universities in Korea to synchronize technical and academic perspectives on 5G.

Japan. To promote cooperation among industries, academia, and administration for the acceleration of research, development, and standardization of 5G, the “Fifth Generation Mobile Communications Promotion Forum” (“5GMF”) was established on September 30, 2014.²⁸

²⁶ “Korea Unveils Plan to Boost Spectrum for Mobile Services,” *Telecompaper* (Dec. 31, 2013), at <http://www.telecompaper.com/news/korea-unveils-plan-to-boost-spectrum-for-mobile-services--988009>.

²⁷ “Govt. Comes Up With ‘Giga-KOREA Project,’” *NewsWorld* (Sept. 30, 2012), at <http://newsworld.co.kr/detail.htm?no=436,%20>

²⁸ International Telecommunications Union, *Activities Related to IMT in Region 3* (Oct. 2014), available at <http://www.itu.int/md/R12-WP5D-C-0831/en> (account required).

Previously, the Association of Radio Industries and Businesses “2020 and Beyond Ad Hoc” (“20B AH”) was established to study terrestrial mobile communications systems in 2020 and beyond.²⁹

China. The Chinese government set up the IMT-2020 Promotion Group in February 2013, which was organized to coordinate all 5G activities in China.³⁰ The IMT-2020 Promotion Group’s objectives are to promote the development of 5G technologies in China and to facilitate cooperation with foreign companies and organizations.³¹ Within this group, a “High Frequency Band Working Group” is studying spectrum above 6 GHz for 5G services. In China, government activity on these bands is still at the initial research stage, and there are no specific allocation plans as of this date. However, the IMT-2020 Promotion Group is studying radio applications from 6 to 100 GHz. Samsung is coordinating with a research institute under the Chinese Ministry of Industry and Information Technology to conduct high-frequency band testing. Samsung is leading an effort to test the feasibility of millimeter wave bands for 5G systems. Samsung is also leading a Study Item on channel models for high frequency bands through the Chinese Communications Standards Association.

United Kingdom. Nationally, the UK government recognizes the contribution that spectrum plays in developing and maintaining a successful economy. In March 2014, the UK government published “The UK Spectrum Strategy – Delivering the Best Value From Spectrum for the UK,” in which it recognizes the diverse roles that future 5G networks can play and their

²⁹ See “Views on IMT Beyond 2020,” at http://www.itu.int/dms_pub/itu-r/oth/0a/06/R0A0600005E0001PDFE.pdf.

³⁰ IMT-2020 (5G) Promotion Group, “IMT Vision Towards 2020 and Beyond” (Feb. 2014), at http://www.itu.int/dms_pub/itu-r/oth/0a/06/R0A0600005D0001PDFE.pdf,

³¹ *Id.* at 3.

economic contribution.³² The UK has committed to facilitate the development of advanced communications technologies and ensure the availability of suitable spectrum and other mechanisms wherever possible. Samsung is also a founding member of the 5G Innovation Centre (“5GIC”), a joint research program between the UK government and the communications industry.³³ The 5GIC is tasked with research into technology components of 5G, as well as providing guidance to the government regarding spectrum.

Germany. Samsung is a member of the Conference Preparatory Group for CEPT’s European Communications Committee. This group is responsible for developing briefs, studies, and European Common Proposals for the World Radiocommunication Conference. As one of the contributors, Samsung proposed new agenda items to the German administration. As a result of these activities, Germany is considering the future of broadband communications and has recognized the potential of mobile technology in frequencies above 6 GHz. Germany has submitted a new agenda item to CEPT’s Electronic Communications Committee, proposing that ECC Project Team 1 consider spectrum in the 6-100 GHz range as a target for study.³⁴ Germany added that “it might be necessary to consider the technical aspects for the needed contiguous spectrum bandwidth for beyond 2020” and that by exploiting higher frequency bands, “wider contiguous bandwidths will be available to achieve very high peak and cell edge rates.”³⁵

³² Department for Culture Media & Sport, *The UK Spectrum Strategy: Delivering the Best Value From Spectrum for the UK* (Mar. 10, 2013), at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/287994/UK_Spectrum_Strategy_FINAL.pdf

³³ University of Surrey, “The 5G Innovation Centre,” at <http://www.surrey.ac.uk/5gic/>.

³⁴ CEPT ECC, “Technical Consideration of IMT in the Bands Above 6 GHz” (Apr. 23, 2014) at [http://www.cept.org/Documents/ecc-pt1/17623/ECC-PT1\(14\)060_Technical-Consideration-of-IMT-in-the-bands-above-6-GHz](http://www.cept.org/Documents/ecc-pt1/17623/ECC-PT1(14)060_Technical-Consideration-of-IMT-in-the-bands-above-6-GHz).

³⁵ *Id.*

2. Governments Around the Globe are Collaborating on 5G Efforts

While individual governments around the world have been actively engaged in the development of next-generation systems, nations have also begun collaborating on 5G research matters. Samsung has worked to support these efforts and encourages their continued work. This degree of collaboration demonstrates the global shared vision for 5G and the need for international harmonization and standards work.

Korea has entered into a variety of international agreements regarding 5G development. Korea and China, for example, have formed a Memorandum of Understanding between Korea's 5G Forum and China's IMT-2020 Promotion Group that addresses research partnerships.³⁶ The countries "agreed to establish Korea-China standardization cooperation mechanism and to hold technical exchange meetings."³⁷ In June 2014, Korea and the European Union adopted a joint statement on research and development collaboration. The two sides agreed to work closely to develop technologies, standards, and policies for 5G.³⁸ These efforts include a joint working group, which will plan and set up joint development projects.³⁹ And Korea's 5G Forum and the European Union 5G Public-Private Partnership Association ("5G PPP Association," a research initiative focusing on 5G communications infrastructure) have signed a Memorandum of

³⁶ 5G Forum, "Major Achievements," *at* <http://www.5gforum.org/eng/main/main.php?categoryid=11&menuid=04&groupid=00> (last visited November 16, 2014).

³⁷ *Id.*

³⁸ "Korea, EU to Develop 5G Mobile Network," *The Korea Herald* (June 16, 2014), *at* <http://www.koreaherald.com/view.php?ud=20140616000858>.

³⁹ *Id.*

Understanding and are currently discussing spectrum harmonization matters and a variety of potential research partnerships.⁴⁰

As noted above, the European Union has created the 5G Infrastructure PPP Association (“5G PPP”), of which Samsung has been elected as an associate member.⁴¹ The 5G PPP has been preparing for large-scale 5G research and development projects as part of the European Commission’s Horizon 2020 program. These efforts include activities related to 5G communications infrastructure, standardization, research and development, and other 5G development matters. The 5G PPP consists of 36 industry members, the research community, universities, and other subject matter experts.⁴² Samsung provides input and advice on strategic research priorities in the 5G PPP Association and contributes to various working groups within the Association. Within the framework of the 5G PPP Association, Samsung is involved in building a number of large industry-led research consortia covering 5G research in system architecture, new air interfaces, and new spectrum for 5G systems in spectrum above 6 GHz.

The European Union has also created the Mobile and Wireless Communications Enablers for the Twenty-Two Information Society (“METIS”) which is committed to laying the foundation of 5G.⁴³ METIS was one of several organizations to present during the ITU’s recent

⁴⁰ The 5G Infrastructure Public Private Partnership, “Landmark Agreement Between the European Commission and South Korea on 5G Mobile Technology” (June 16, 2014), *at* <http://5g-ppp.eu/landmark-agreement-between-the-european-commission-and-south-korea-on-5g-mobile-technology/>.

⁴¹ The 5G Infrastructure Public Private Partnership, *at* <http://5g-ppp.eu> (last visited November 16, 2014).

⁴² The 5G Infrastructure Public Private Partnership, “5G Association Members,” *at* <http://5g-ppp.eu/our-members/> (last visited November 16, 2014).

⁴³ The METIS 2020 Project, *at* <https://www.metis2020.com/> (last visited November 16, 2014).

workshop: “Research Views on IMT Beyond 2020” and express interest in higher frequencies for mobile broadband use.⁴⁴ In August 2013, METIS also published a document stating that to achieve an “extreme capacity requirement,” use of higher-frequency millimeter wave bands will be necessary.⁴⁵

Samsung was also a contributor to the European Commission’s ICT COST Action IC1004, which addresses research issues in the field of cooperative radio communications.⁴⁶ The primary focus of this effort is propagation modeling and channel measurements, including initial models above 6 GHz. Samsung is also on the advisory board of the European Commission’s FP7 project MiWaves, “Beyond 2020 Heterogeneous Wireless Networks with Millimetre-Wave Small Cell Access and Backhauling.” The CEPT is already considering the spectrum challenges of the next five years and has identified key strategic research topics. These include designating additional spectrum for 5G wireless broadband, proposing initiatives to support the development of advanced broadband technologies at high frequencies, and obtaining contiguous spectrum in substantial blocks. The European Commission has also started processes to form its own opinion on 5G spectrum needs and has scheduled its first workshop to gather views from all interested parties. Samsung intends to be an active participant in this effort.

Samsung is pleased with the collaboration achieved by nations around the world as the technology industry looks to the next generation of wireless services. Samsung has been playing

⁴⁴ ITU-R Working Party 5D Workshop, “Research Views on IMT Beyond 2020” (Feb. 2014), available at http://www.itu.int/dms_pub/itu-r/oth/0a/06/R0A060000630001MSWE.docx.

⁴⁵ METIS, *Deliverable D5.1: Intermediate Description of the Spectrum Needs and Usage Principles* at 45 (Aug. 30, 2013), available at https://www.metis2020.com/wp-content/uploads/deliverables/METIS_D5.1_v1.pdf.

⁴⁶ COST, “Cooperative Radio Communications for Green Smart Environments, at http://www.cost.eu/COST_Actions/ict/Actions/IC1004 (last visited November 16, 2014).

a leadership role in these efforts and believes they will help to promote a more unified 5G ecosystem. To that end, Samsung strongly supports a focus on international harmonization of 5G spectrum bands, believing that such harmonization is essential for 5G technologies to reach their full potential.

3. International Harmonization Will Be Essential to 5G Networks' Success

As indicated above, 5G networks will have spectrum requirements very unlike their predecessor technologies. In particular, 5G networks will require contiguous and very wide bandwidth to provide ultra-high data rates and to support the high volume of traffic that is expected in a 5G ecosystem. While carrier aggregation can aggregate fragmented frequency bands and simulate contiguity of spectrum, carrier aggregation will reach its limits in the currently allocated spectrum. Where wide bandwidths are required to support a wireless service, international harmonization is even more essential. For this reason, Samsung supports the ongoing efforts of WRC working groups with respect to high-frequency spectrum and stresses that WRC must focus on achieving international harmonization in these higher frequencies.

Samsung submits that the relevant WRC working groups should continue their focus on the use of spectrum above 6 GHz for 5G millimeter wave services, with an eye toward achieving harmony in spectrum allocations around the globe. 5G will require international harmonization at a level that has not been achieved with other mobile broadband spectrum bands. This is particularly important in light of the wide bandwidth required for such services at these frequencies. While international harmonization is obviously a greater challenge with larger blocks of spectrum, the rewards have the potential to be tremendous.

Global harmonization of mobile broadband spectrum is critically important when taking into account the economies and scale and global compatibility that becomes attainable through international harmonization of spectrum. This harmonization promotes global interconnection,

roaming, and interoperability. It also makes the implementation of mobile and base station antennas much simpler and minimizes interference issues between operators and countries. Indeed, the Commission has frequently highlighted international harmonization of spectrum as a key policy goal and has endorsed the benefits of global harmonization.⁴⁷

Current frequency bands for mobile communications are highly fragmented, creating significant challenges for equipment manufacturing. Because of a lack of common band plans among regulatory administrations, a complex set of regulations and requirements for mobile devices has emerged. This fragmentation greatly increased the flexibility not only of mobile device development, but also of base station equipment design.

Fragmentation of spectrum resources will become a particular problem when deploying 5G services. As explained in the attached Appendix A, the number of users who can experience speeds of 1 Gbps is greatly reduced when less bandwidth is available. Even when 100 MHz of bandwidth is available, very few users can be served at a 1 Gbps peak data rate. While spectrum fragmentation can be overcome through the use of carrier aggregation technologies, this is not an ideal result, and the global wireless community should endeavor to avoid this outcome. Carrier aggregation technology is capable of combining fragmented spectrum bands into one integrated, wider band. However, as explained further in the attached Appendix A, the result would be technical inefficiencies and increased cost.

It is clear, then, that global harmonization is extremely important to reduce the problems associated with spectrum fragmentation. Regional preparatory groups (such as CEPT's Conference Preparatory Group in Europe and the Asia-Pacific Telecommunity Conference

⁴⁷ *AWS-3 Order* ¶ 42 (“International harmonization will enhance international roaming, create economies of scale that lowers device costs, speed deployment, and reduce interference potential near international borders.”).

Preparatory Group) are currently discussing the proposal of a new agenda item during the upcoming WRC-15 to examine the use of bands above 6 GHz for 5G in the years leading up to WRC-19. Samsung believes that a new agenda item should be adopted at WRC-19 to seek global and harmonized spectrum bands for 5G between all regions and to avoid future fragmentation challenges. Samsung is convinced that the Commission's *Notice of Inquiry* and the Commission's decisions regarding a new allocation of spectrum above 24 GHz for mobile radio service would also significantly benefit discussions at the international level and help reach the goal of global harmonization.

C. The Commission Should Continue to Examine Bands Below 6 GHz

While this proceeding is focused on the investigation of high-frequency bands for next-generation mobile services, Samsung takes this opportunity to emphasize that these frequencies are not substitutes for bands below 6 GHz and that the Commission should continue its efforts to allocate lower-frequency bands. Based on Samsung's research efforts around the globe, it is clear that spectrum bands above 6 GHz will play a vital role in meeting future spectrum needs. However, a near-term focus on bands below 6 GHz remains appropriate.

We envision that initial deployment of 5G networks will be done on an overlay basis with respect to 4G and Wi-Fi networks. This type of deployment can provide key services to these systems via the provision of backhaul services. As 4G networks grow to include increased use of channel bonding and other means to increase data throughput, there will be a corresponding significant increase in the need for backhaul to 4G networks. Initial 5G networks can meet those needs.

Spectrum bands above 6 GHz, when unleashed, have the potential to enable incredible, innovative new services. For example, and as explained above, these frequencies have the potential to support key emerging services such as connected cars and M2M. However, unlike

predecessor technologies, 5G is not expected to require a complete Radio Access Network (“RAN”) change-out to be deployed. Rather, it is expected that 5G will provide a complementary role to existing 4G services to respond to capacity needs in densely populated areas. Therefore, it is critical to support 5G services not only with spectrum above 24 GHz but also to ensure that mobile broadband operators have access to sufficient spectrum resources below 3 GHz to respond to coverage issues for consumers.

Since the adoption of the National Broadband Plan in 2010, the Commission has made the identification and allocation of spectrum below 6 GHz a key policy priority. Samsung applauds this focus on spectrum allocation. Samsung also supports the Commission’s recent efforts to make AWS-3, broadcast television, U-NII and 3.5 GHz spectrum available for mobile services. The Commission must not slow its efforts in these proceedings as it further develops the record on higher-frequency bands and their potential to support next-generation technologies and services.

III. EFFORTS ARE WELL UNDER WAY TO DEVELOP TECHNOLOGIES THAT WILL SUPPORT MILLIMETER WAVE SERVICES

A. As a General Matter, Use of Spectrum Above 24 GHz to Provide Mobile Services is Entirely Feasible

In the *Notice of Inquiry*, the Commission posed a variety of questions about the feasibility of providing mobile services in bands above 24 GHz.⁴⁸ In particular, the Commission asks whether mobile services above 24 GHz will be dependent on complementary services in lower frequency bands, and how the use of higher frequencies will dictate technology choices.

As explained below, technological advances in beamforming, phased antenna array deployment in mobile devices, and other areas have made the use of spectrum above 24 GHz for

⁴⁸ *Notice of Inquiry* ¶ 17.

mobile broadband achievable. Samsung bases this conclusion on its extensive research and testing in this area, which itself is based on considerations of coverage, mobility support, and implementation feasibility.⁴⁹ Samsung envisions millimeter wave technologies initially complementing mobile services in lower bands, then eventually growing into stand-alone services. In fact, several bands that already are allocated for mobile could provide a viable location to transition from fixed services to mobile, millimeter wave services to host 5G technologies.

Coverage and Link Budget. For mobile use of millimeter wave frequencies to be achievable, the system must provide sufficient coverage. Bands above 24 GHz have generally been perceived as inappropriate to cover the size of a macrocell. As cells get smaller to provide larger cell capacity in dense areas, the use of higher frequency bands is more feasible. Further, a feasibility analysis requires a consideration of signal power attenuation due to propagation loss over the air. The inverse Friis equation for isotropic radiators relates the free space path loss of an RF carrier as proportional to the square of its frequency. Free space path loss also increases proportional to the square of the distance between the transmitter and receiver. As such, a 30 GHz signal transmitted over a distance of 20 meters loses 88 dB of power covering the distance from the transmitter to the receiver. At 100 meters, the loss is increased to 102 dB. Applying various methods for calculating link budgets in various environments,⁵⁰ Samsung has determined that a low-power base station can provide 1 Gbps service using 1 GHz of bandwidth for outdoor

⁴⁹ *Id.*

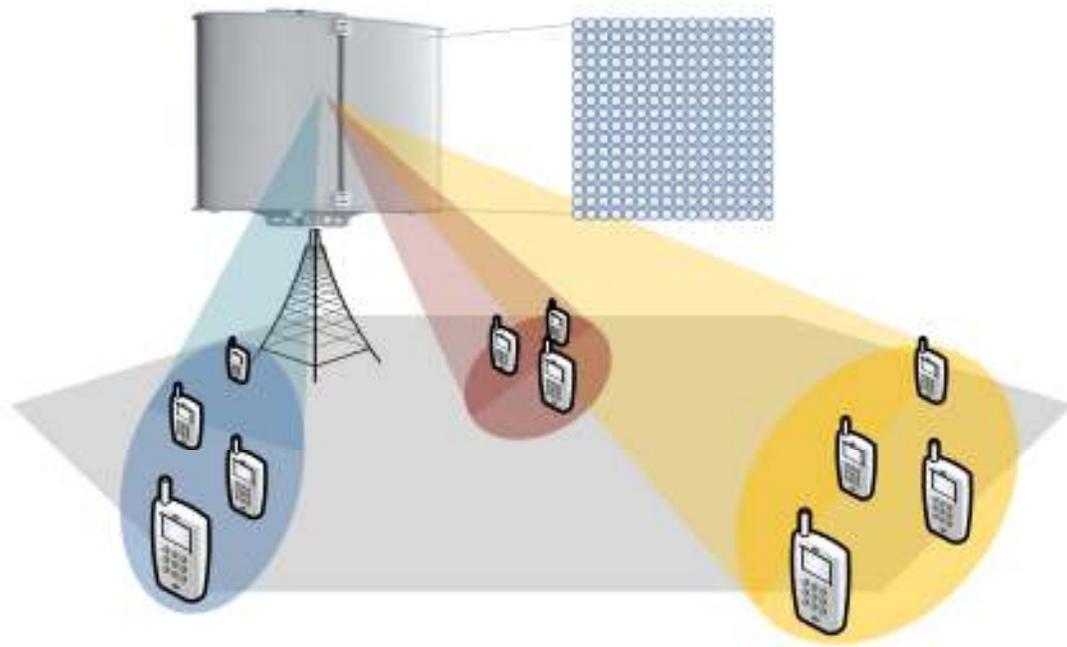
⁵⁰ S. Hur, et al., “Millimeter-wave Channel Modeling based on Measurements in In-building and Campus Environments at 28 GHz”, will be presented on COST IC1004 10th Meeting, May 2014; Y. Chang, et al., “A Novel Two-Slope mmWave Channel Model Using 3D Ray-Tracing Technique in Urban Environments”, submitted to IEEE PIMRC 2014; M. K. Samimi, et al., “Ultra-Wideband Statistical Channel Model for Non Line of Sight Millimeter-Wave Urban Channels,” submitted to IEEE Globecom 2014.

coverage over a cell radius of tens to hundreds of meters, depending on the cell environment. The more open the path, the farther the signal is able to travel. If a channel link is clearly secured without any obstacles between the transmitter and the receiver, the distance would greatly increase. These coverage areas are achievable using already-deployed infrastructure, and thus Samsung believes that 5G services in millimeter wave spectrum are achievable and that carriers can realistically deploy cells sufficient to provide seamless coverage. Moreover, as discussed below, beamforming techniques—which are feasible for relatively small antenna arrays at these high frequencies—can mitigate propagation loss.

Beamforming. Beamforming is a signal processing technique that can be used in conjunction with phased antenna arrays to provide more directional signal transmissions and reception.⁵¹ Beamforming allows the elements of a phased array to be combined – which means that signals at certain angles have constructive interference while others will have destructive interference. Importantly, beamforming can be utilized at both the transmitter and receiver to provide better spatial diversity within the communications system (i.e., will provide gain to the propagated signal). The figure below provides a visual example of the use of beamforming at the transmit (base station) side of a mobile communications system.

To achieve this large directional gain to overcome the path loss inherent to millimeter wave spectrum, beamforming with a phased antenna array must be employed. Because of the small wavelength of millimeter wave signals, large phased array antennas are able to offer large beamforming gain while keeping individual antenna elements small and inexpensive. These antennas also enable adaptive alignment of transmit and receive beams electronically.

⁵¹ See e.g., http://ehm.kocaeli.edu.tr/dersnotlari_data/saldirmaz/GSM%20dersi/Proje/5G/06736750.pdf (last visited Nov. 18, 2014) for more detailed discussion of beamforming and its application for 5G services in the millimeter wave bands.



The benefits of beamforming for implementation of a mobile system in the millimeter wave bands are numerous. Use of beamforming techniques allows an increase in capacity as it will increase the signal-to-interference-plus-noise ratio (“SINR”) of the network. An increase in the SINR will increase the capacity of the network and permit higher user densities. Shaping the transmission through use of beamforming also allows the signal to be more robust and resistant to multipath issues that are faced in the dense urban markets where millimeter wave spectrum is likely to be used. With directionality and spatial separation, beamforming also can be used to reduce interference to an adjacent coverage cell, even without coordination between the adjacent base stations.

Phased Antenna Arrays. As described in more detail below, Samsung has initiated work in phased antenna array technology that could be deployed not only in the fixed base station but also within a mobile device. Such technology had typically been difficult to deploy in mobile

devices due to size of the wave length of spectrum used for mobile services (i.e., below 3 GHz). The larger wave lengths within these mobile spectrum ranges would not allow for small phased arrays to be easily deployed in the form factors expected for mobile devices. However, at frequencies above 24 GHz, wave lengths are much shorter, enabling the creation of phased antenna arrays that are much smaller without any self-interference or other inhibiting factors. The clear benefits of utilizing many dozens of antenna elements into a handset are that each of these individual antennas can be electronically phased to send and receive communications more efficiently and effectively.

Mobility. One of the historic challenges associated with using high-frequency spectrum to provide mobile services, particularly in a mobile environment, is that higher bands experience a greater Doppler shift, hindering network performance. Because the Doppler shift is a linear function of the velocity and the operating frequency, frequency bands above 6 GHz experience a much greater Doppler shift than lower frequencies. For example, if the velocity of a mobile station is 120 kilometers per hour, a signal at 30 GHz would give a 3.33 kHz Doppler shift, which is 10 times higher than it would be at 3 GHz. And because the channel path between the base and mobile station typically consist of multipath components, each path has its own Doppler shift. However, improvements in beamforming have helped to remedy this issue. Because narrow beamforming reduces the multipath effect, the Doppler shift effects are mitigated in the millimeter wave spectrum when utilizing this capability. Further, using large bandwidths – which would be the case above 6 GHz – would reduce the feedback loop latency and improve performance in mobile environments.

Semiconductor Technology Improvements. Historically, semiconductor technology of frequencies above 6 GHz for terrestrial mobile applications has been developed toward academic

or non-commercial purposes. However, this has recently changed. Circuits, antennas, and communications protocols have been developed to take advantage of the greater bandwidth available above 24 GHz. Further, hardware has been developed that will exploit the features of higher-frequency spectrum for mobile use. For example, Multiple Gigabit Wireless Systems (“MGWS”) is using the 60 GHz band to enable applications such as HD video and cordless computing. Silicon-based complementary mobile oxide semiconductor technologies are implementing integration system-in-package including mixers, LNAs, Pas, and IF amplifiers in bands above 24 GHz. Cost-effective uses of these technologies have facilitated the use of the 60 MHz band for millimeter wave applications. Gallium Arsenide MMIC technologies are also mature enough to have a dominant presence for power amplifiers, low noise amplifiers, switches for digital attenuators and phase shifters, voltage controlled oscillators, and passive components at frequencies as high as 100 GHz. Finally, use of Radio Frequency Integrated Circuit (“RFIC”) technology provides highly integrated solutions that allow for a reduction in cell size, power consumption, and cost.⁵²

Initial Deployment of Millimeter Wave. Samsung envisions that millimeter wave technologies will initially complement mobile services at lower frequencies by overlaying existing mobile networks. Later, the millimeter wave ecosystem will grow to provide fully-mobile services. Initial uses for millimeter wave could be to provide high capacity wireless backhaul for small cells that operate in lower frequency bands. In the initial phase, millimeter wave small cells would be rolled out on top of the existing network to form an overlay network architecture. The existing macrocell layer would provide coverage, while the millimeter wave

⁵² Theodore S. Rappaport, and el al., “Millimeter Wave Mobile Communications for 5G Cellular: It Will Work!” IEEE Access, vol.1, pp.335-349, May 2013; Theodore S. Rappaport, and el al., “28GHz Propagation Measurements for Outdoor Cellular Communications Using Steerable Beam Antennas in New York City”, ICC 2013, June 2013.

small cell layer would provide capacity. At the next phase, standalone millimeter wave small cells would be deployed seamlessly over a designated area for provisioning of full mobile services. Advanced antenna technology will enable the deployment of compact antennas with massive antenna elements that will provide high beamforming gains. This will reduce path loss and interference. This technology, combined with the wide bandwidth of millimeter wave systems, will permit small cell deployments that provide throughput orders of magnitude higher than existing macrocell networks.

B. Samsung Is Testing Antennas That Will Support 5G Millimeter Wave Services

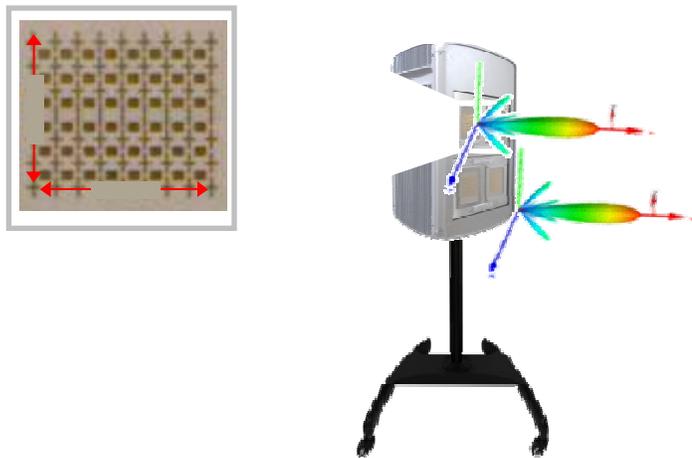
The Commission seeks input on the current development of antenna technology in the millimeter wave bands, and the potential timeline for implementing these technologies.⁵³ As the Commission correctly observes, “[t]he use of higher frequency bands for advanced mobile services, as well as other new service applications, will likely be dependent on new advanced antenna technologies.”⁵⁴ And “[t]hese antenna technologies may be among the key factors for overcoming some of the challenging propagation characteristics of mmW bands and could increase efficiency, allow for higher data rates, and provide reasonable coverage for mobile broadband services.”⁵⁵ Samsung has conducted extensive testing on antenna technologies and agrees that antenna design and technology will be crucial to the success of 5G millimeter wave networks. Samsung therefore takes this opportunity to describe the base and mobile antennas tested, as well as to provide an overview of their operation.

⁵³ *Notice of Inquiry* ¶ 19.

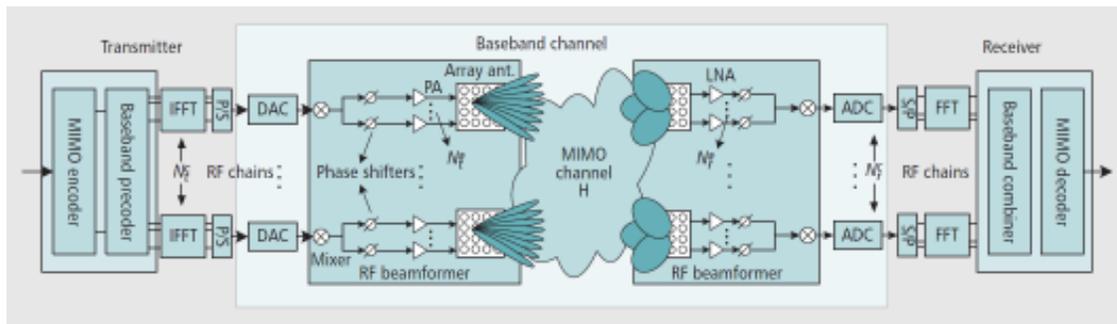
⁵⁴ *Id.*

⁵⁵ *Id.*

Base Station Antennas. Samsung recently tested a prototype of a millimeter wave beamforming antenna at the 28 GHz band. The prototype antenna is comprised of 48 antenna elements arranged in the form of a uniform planar array with eight horizontal and six vertical elements, confined within an area of 45 millimeters by 42 millimeters.



As discussed in the section above, this small antenna size is made possible by the short wavelength of the carrier frequency at 28 GHz. The array antenna is connected to the RF unit, which contains a set of phase shifters, mixers, and related RF circuitry. The figure below provides a schematic overview of the equipment tested.

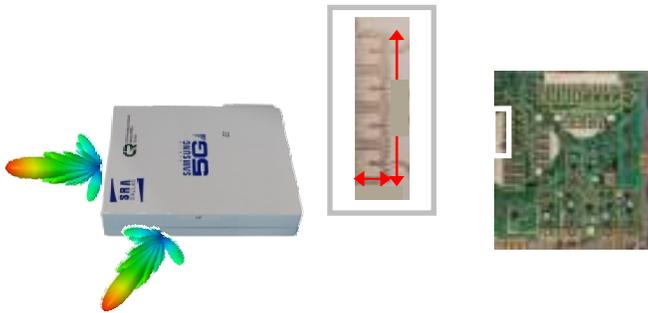


The phase shifters control the phases of the signals sent to the antennas to form a desired beam pattern. By setting the phase shifter values to a particular set, transmit and receive array antennas are capable of forming a sharp beam pattern at the intended horizontal and vertical

angles. The resulting full width at half maximum of the beam at the antenna boresight is approximately 11 degrees horizontally and 11 degrees vertically, with an overall beamforming gain of 21 dBi. The base station system is designed for 37 dBm maximum transmit power at the 21 dBi array gain. Based on a 58 dBm EIRP limit, satisfactory communications links were attained even in non-line-of-sight scenarios more than 200 meters away. However, a few locations used in Samsung's test were unable to establish a proper link. To address this issue, coverage solutions will be necessary such as optimized cell deployment, intercell coordination, relays, or repeaters.

Mobile Station Antennas. At the receive end, antenna array architectures are used to achieve large gain with high directivity. Mobile station antennas must be capable of covering a relatively wide radius to communicate with other stations, regardless of their locations. Traditional antenna architectures are generally not capable of combining wide angle coverage with high directivity, creating a challenge for antenna design in the mobile environment. Samsung's test bed revealed a potential antenna array architecture that provides simultaneous flexibility in form factor choice, beam steering, and high array gain in a cost-effective manner. This architecture involves constructing modular, composite antenna arrays. Each module is implemented traditionally with a dedicated RFIC chip serving several antenna elements and a beamforming unit. The array antennas can then be placed at several locations around the edge of the mobile unit to cover all directions. In the testing conducted by Samsung, antenna arrays composed of 4 elements are placed at two side edges of the mobile device within an area of 25 millimeters by 5 millimeters. The antenna, which is composed of four antenna elements, covers a 90 degree range in horizontal angle and approximately 80 degrees vertical. This provides the

maximum 27 dBi antenna gain. Therefore, two array antennas can cover a wider (approximately 180 degree) range in horizontal angle, which is essential for mobile antennas.



Antenna Operation. As noted above, beamforming plays an essential role in millimeter wave network performance, and both digital and analog beamforming are possible under the antenna design tested by Samsung. Digital beamforming is achieved through digital pre-coding that multiplies a particular coefficient to the modulated baseband signal per RF chain. When combined with an orthogonal frequency-division multiplexing system, digital beamforming is carried out on a subcarrier basis before the inverse fast Fourier transform (“IFFT”) operation at the transmitter and after the fast Fourier transform (“FFT”) operation at the receiver. Analog beamforming, meanwhile, involves the application of complex coefficients to manipulate the RF signals by means of controlling phase shifters and/or variable gain amplifiers. Unlike digital beamforming, analog beamforming is performed in the time domain after the IFFT operation at the transmitter and before the FFT operation at the receiver. In general, digital beamforming provides a higher degree of freedom and offers better performance, but involves increased complexity and cost. Analog beamforming, on the other hand, is a simple and effective method of generating high beamforming gains from a large number of antennas, but is less flexible than digital beamforming. In light of this trade-off between performance and simplicity, Samsung recommends the use of hybrid beamforming architectures. Hybrid beamforming is particularly

beneficial where, as in millimeter wave bands, a multitude of antennas is required. In Samsung's proposed hybrid beamforming architecture, the sharp beams formed with analog beamforming (phase shifters) compensate for the large path loss in millimeter wave bands, and digital beamforming provides the necessary flexibility to perform advanced multi-antenna techniques such as multi-beam MIMO. The result is enhanced antenna performance.

C. Samsung's Testing Experience on Bandwidth, Duplexing, Modulation, and Multiple Access.

Samsung has developed several network observations based on its testing of millimeter wave mobile services. The Commission has sought comment on a variety of technical issues such as block size, duplexing, modulation techniques, and multiple access schemes.⁵⁶ While Samsung does not offer specific recommendations at this time, it takes this opportunity to share with the Commission the specifications employed in its recent successful test of 5G services.

In the *Notice of Inquiry*, the Commission seeks comment on how much contiguous spectrum will be needed to support advanced mobile services and other contemplated services in bands above 24 GHz.⁵⁷ As the Commission notes, Samsung has demonstrated 500 MHz systems in the 28 GHz band with data rates ranging from 260 Mbps to 1 Gbps.⁵⁸ More recently, Samsung testing achieved speeds of 7.5 Gbps using 800 MHz of bandwidth. The test bed system used OFDM in TDD manner for the downlink and uplink duplexing and 64 QAM modulation was adopted to provide the high spectral efficiency. Unlike the test in 2013, multi-user MIMO operation with 2 streams transmission per user was successfully demonstrated, providing a 7.5

⁵⁶ *Notice of Inquiry* ¶¶ 30-33.

⁵⁷ *Id.* ¶ 30.

⁵⁸ *Id.*

Gbps downlink data rate from the transmitter.⁵⁹ As a general matter, Samsung submits that the Commission should strive for the widest possible bandwidths in millimeter wave spectrum, as the performance gains will be considerable. Further, the Commission should endeavor to allocate large, contiguous blocks to millimeter wave technologies. While carrier aggregation does help to achieve some benefits of wide-bandwidth services among disparate blocks, as noted above carrier aggregation is no substitute for truly contiguous spectrum.

The Commission also notes that most 5G proposals or demonstrations using spectrum above 24 GHz are based on Time-Division Duplexing.⁶⁰ Samsung employed TDD in its test bed and generally agrees with the Commission's assessment that TDD works well in higher frequency bands. However, Samsung appreciates the Commission's focus on examining whether flexible-use policies are appropriate in millimeter wave spectrum.⁶¹

As the Commission observes, mobile systems have evolved over time and a variety of modulation and multiple access schemes have been used in wireless networks.⁶² In its test bed, Samsung employed Orthogonal-Frequency-Division-Multiple-Access, which has also been implanted in predecessor systems.

⁵⁹ See 5G Live Demonstration, at <http://www.youtube.com/watch?v=0MVZyr7-cj0>

⁶⁰ Notice of Inquiry ¶ 31.

⁶¹ *Id.* (“In light of the advantages of a flexible use policy, it would appear to be appropriate to allow licensees to choose their methods of duplexing for mobile wireless use in higher frequency bands.”).

⁶² *Id.* ¶¶ 32-33.

D. Samsung's Recent Testing Demonstrates the Performance and Coverage Potential of 5G Networks

The Commission has asked for information regarding the performance metrics that could be expected under advanced mobile services in the millimeter wave bands.⁶³ Samsung is extremely encouraged by the performance of the 5G millimeter wave system deployed in its recent test bed. Samsung carried out extensive indoor and outdoor testing and notes that the performance and coverage results were very positive.

As explained above, using the millimeter wave adaptive beamforming prototype antenna, Samsung conducted comprehensive indoor and outdoor field tests using millimeter wave frequencies. An aggregated peak data rate of 1.056 Gbps was achieved in the laboratory with negligible packet error using two channels at the base station supporting two stationary mobile stations with 528 Mbps each.⁶⁴ In an outdoor line-of-sight test, the communication range (with negligible errors) was verified up to 1.7 kilometers with 10 dB transmission power headroom. Samsung believes that ranges much larger than 1.7 kilometers are possible, but that limitations in the testing environment prevented Samsung from testing longer distances.

Samsung also investigated communication between an outdoor base station and an indoor mobile station. This is one of the most important operational scenarios in practical cellular networks, and therefore this scenario was of great importance to Samsung. An outdoor base station was tested in connection with an indoor mobile station placed inside a typical modern office building with heavily tinted glass. These types of buildings are representative of presenting highly unfavorable propagation (penetration) conditions even for current cellular

⁶³ *Id.* ¶ 34.

⁶⁴ Wonil Roh, et. al., "Millimeter-Wave Beamforming as an Enabling Technology for 5G Cellular Communications: Theoretical Feasibility and Prototype Results," IEEE Comm Magazine, Feb 2014

frequency bands below 6 GHz. A quality communications link was established at more than 150 meters' separation. More details regarding this testing can be found at Appendix B.

Samsung is extremely pleased with the results of its recent test bed and believes that this testing proves millimeter wave spectrum's ability to "create opportunities for new applications that do not exist today or ameliorate network congestion that would otherwise occur due to anticipated growth in traffic."⁶⁵ Samsung looks forward to reviewing the submissions by other parties in this proceeding and offering further comment on the performance and coverage potential of 5G systems.

E. 5G Millimeter Wave Networks Will Involve a More Distributed Network Architecture

As the Commission observes, there are two predominant models of wireless network deployments.⁶⁶ One is the "service provider model" that involves licensed spectrum and a single operator deploying and managing a network.⁶⁷ The other is the decentralized, Wi-Fi like deployment, in which network elements are mostly deployed by end users.⁶⁸ As wireless networks transition from 4G to 5G millimeter wave services, Samsung envisions an evolution to a hybrid of the service provider model and the end-user model, which will be a more distributed and flat network architecture than is being implemented today.

As wireless networks transition away from 4G, millimeter wave systems can be used to augment existing 4G deployments operating largely under the "service provider model." 4G systems in lower frequency bands provide wide coverage and reliable connections with a

⁶⁵ *Notice of Inquiry* ¶ 34.

⁶⁶ *Id.* ¶ 36.

⁶⁷ *Id.*

⁶⁸ *Id.* ¶ 37.

relatively small number of cells. To create a transitional deployment, 5G systems can be deployed in high traffic areas on top of conventional systems and used to provide high data rate communications while conventional systems provide control signaling and traffic types, such as VoIP, that require a more reliable connection.

However, to fully accomplish the key requirements of 5G, 5G networks must evolve toward a more distributed and flat architecture with elements of both the service-provider and end-user models. This flat network architecture manages the mobility of users and services efficiently and in a dynamically scalable fashion. This is achieved by “pushing” functionality to the edges of the network and even onto mobile terminals. A distributed mobility management system will provide the shortest data path between a mobile terminal and the Internet without the need to traverse the core network. This will significantly reduce signaling and data transmission delay. The 5G “flat” network provides a highly scalable solution compared to the “service provider model,” which requires a single core network gateway to maintain the whole traffic from/to mobile terminals. The distributed network architecture envisioned by Samsung also will facilitate the integration of heterogeneous radio access technologies, such as Wi-Fi, in the 5G network.

One advantage of the distributed network architecture is that it avoids the risk of a single point of failure in the network. This is because, in the “flat” network architecture, the breakdown of one network gateway need not significantly interfere with the operations of other gateways. Programmable network design technologies, such as Software Defined Networking, might also be considered in developing a flat 5G network. The Commission has repeatedly emphasized the need for mobile networks to be robust and resilient under circumstances such as

severe weather events that may cause network outages. The distributed framework for 5G is consistent with this policy emphasis by the Commission.

F. Technical Rules

Key technical rules that the Commission should consider in the next stages of the rulemaking process include the power levels permitted at both the base station and mobile station, the amount of spectrum that will be licensed to each 5G operator, and associated rules to ensure compatibility with adjacent services. As a starting point, the Commission should evaluate the permitted operations in each band and consider technical rules that are consistent with those current systems. As an example, the current rules for the 28 GHz LMDS set a maximum allowed EIRP of 85 dBm, with subscriber stations' EIRP limited to 85 dBm or 72 dBm/MHz.⁶⁹ Samsung recommends that if the Commission moves forward with permitting 5G mobile networks in the LMDS band, that base stations be permitted to operate at the same power levels (85 dBm) and that mobile stations be permitted to operate at the subscriber station power levels. This would allow the 5G network to provide similar or better services than what a current licensee is serving. The Commission should also develop power strength levels between two geographic boundaries similar to that defined under 27.55 to enable sharing between licensees in adjacent markets.

G. Millimeter Wave Licensees Should Have the Flexibility to Provide a Variety of Services

As the Commission correctly notes in the *Notice of Inquiry*, some parties may wish to employ non-mobile services in the millimeter wave bands.⁷⁰ The Commission seeks comment

⁶⁹ 47 C.F.R. § 101.113.

⁷⁰ *Notice of Inquiry* ¶ 44.

on the compatibility of incumbent services with new mobile services.⁷¹ Samsung submits that both current and new millimeter wave licensees should be given the freedom to provide mobile and/or fixed services. Because the same licensee would be operating both the mobile and the fixed network in a given area, the licensee will have the ability to dynamically steer the millimeter wave beams such that compatible operations are ensured. However, Samsung recognizes that the Commission is considering a variety of licensing mechanisms for the millimeter wave bands and that the chosen mechanism could impact the interactions of mobile and fixed uses in the band. Samsung discusses each of these mechanisms in turn.

The first option discussed by the Commission is to license vacant spectrum by auctioning exclusive rights to geographic service areas.⁷² As the Commission notes, this would extend to mobile services the status quo for the 24 GHz, LMDS, and 39 GHz bands. While not stated explicitly, Samsung assumes that the Commission intends to extend to incumbent licensees the ability to provide mobile as well as fixed services.⁷³ While this approach has key advantages – namely, familiarity and flexibility – it could result in spectrum lying fallow in low-traffic areas. Possible solutions to this issue are to permit secondary market leasing, license spectrum in small license area sizes, and adjust performance requirements.

The Commission’s second suggested approach is to adopt nonexclusive licensing rules using automated frequency coordination.⁷⁴ As the Commission states in the *Notice of Inquiry*, “[i]n principle, tightly-packed base stations with dynamic beamforming capabilities should be

⁷¹ *Id.*

⁷² *Id.* ¶ 92.

⁷³ *Id.* ¶ 92 (“This option would extend to mobile services the status quo for the 24 GHz, LMDS, and 39 GHz bands. . . .”).

⁷⁴ *Id.* ¶ 97.

able to share the same channels without causing mutual interference by pointing their means in non-interfering directions.”⁷⁵ The Commission envisions that as an alternative, dynamic spectrum databases could monitor the activities of mobile stations in real-time and coordinate actions. Again, the Commission does not provide clarity as to the status of incumbent licensees under this framework. While a database approach shows promise, the rights of incumbent licensees must be upheld. At this time, Samsung does not support this spectrum access method for 5G services, as it will constrain 5G development and deployment.

Third, the Commission proposes to authorize mobile operations pursuant to Part 15 of the rules.⁷⁶ In making this proposal, the Commission appears to be focusing on bands that do not contain incumbent operations. To the extent that the Commission authorizes Part 15 mobile operations in bands containing fixed incumbents, actions must be taken to protect incumbent users from interference. Moreover, the Commission should recognize that a purely unlicensed, non-exclusive framework for mobile operations may result in less investment in 5G network deployment because of the uncertainty of parties about their prospects for obtaining a return on their investment.

Finally, the Commission proposes other sharing options, such as “use it or share it” requirements for primary licensees, limited opportunistic use of licensed bands, or consumer deployment of Wi-Fi-like access points.⁷⁷ All of these options will require a careful balancing of incumbent protection, optimal investment, and new entrant flexibility.

⁷⁵ *Id.*

⁷⁶ *Id.* ¶ 100.

⁷⁷ *Id.* ¶ 101.

Samsung notes that there is another option not considered by the Commission that could promote more harmonious use of bands above 24 GHz for mobile services. Specifically, if the Commission is willing to drastically change the licensing framework in these bands, it could invoke its Congressional authority to conduct incentive auctions in these bands. This would provide for re-auctioning and re-licensing of bands above 24 GHz while properly compensating incumbents, and potentially raising additional funds for the Federal treasury.

IV. SEVERAL BANDS ABOVE 24 GHZ ARE PROMISING CANDIDATES FOR 5G SERVICES

A. The Commission Should Focus on Particular Characteristics When Identifying Spectrum for Millimeter Wave Services.

The Commission should consider several factors in identifying bands as future homes for millimeter wave services. As the Commission stated, “most of the candidate bands above 24 GHz are already shared and, most likely, will continue to be shared by other services” and therefore “it is important to determine whether or not those services are compatible with advanced mobile services in the mmW bands.”⁷⁸ Further, “in selecting the most suitable bands above 24 GHz for mobile services, we must determine whether advanced mobile operations in a given band are consistent with our country’s goals of encouraging highly efficient use of spectrum, as well as promoting innovation, investment, and America’s global competitiveness.”⁷⁹ These are just some of many criteria that the Commission should consider when evaluating candidate bands for 5G millimeter wave service. Among these considerations are: (1) international harmonization, (2) the ability of the band to support geographic-based licenses, and (3) the ability of the band to host multiple licensees.

⁷⁸ *Notice of Inquiry* ¶ 46.

⁷⁹ *Id.*

First, as noted above, international harmonization should be key to the Commission’s decision-making. As the Commission correctly notes, “in a global economy there will often be a need for single devices to operate seamless throughout more than one, or perhaps even many different countries.”⁸⁰ And, critically, “global harmonization of regulatory and technical requirements will promote global economies of scale in equipment manufacturing.”⁸¹ The Commission should therefore strive to identify or designate spectrum with a mobile co-primary allocation that has the same allocation worldwide. To enable this international harmonization, work must begin on a WRC-15 agenda item to be finalized at WRC-19.

Second, millimeter wave spectrum bands should be able to support geographic-based licenses. As Samsung explained above, initial 5G deployments will likely be used to supplement 4G networks. By adopting a geographic-based licensing scheme, the Commission will allow licensees to acquire licenses that complement and serve their existing networks. And even once the transition to 5G is complete, geographic area licenses provide licensees with the flexibility to develop deployment strategies tailored to areas that meet their strategic needs.

Third, to ensure continued competition in mobile, millimeter wave spectrum must be able to support multiple licensees. The Commission has repeatedly cited the presence of multiple licensees in a market as a key to promoting competition. However, a key challenge with 5G is that each licensee will require several hundred megahertz of contiguous spectrum, at a minimum. This means that the Commission should focus on large, contiguous blocks of spectrum. It should also endeavor to allocate a maximum amount of spectrum to ensure that multiple entities are able to hold licenses while each having access to a sufficient amount of spectrum.

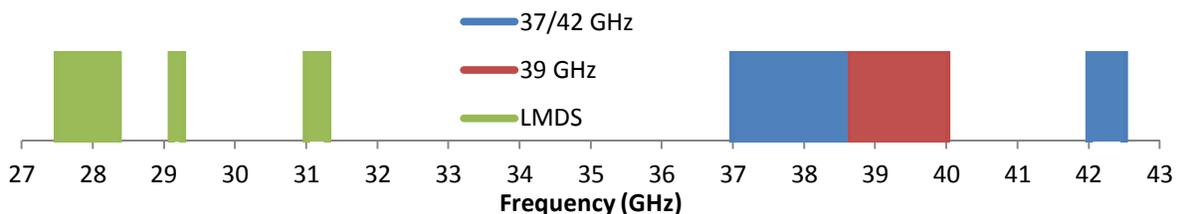
⁸⁰ *Id.* ¶ 48.

⁸¹ *Id.*

As the Commission states in the *Notice of Inquiry* and as explained below, there are several spectrum bands above 24 GHz that meet the criteria above and are capable of supporting 5G services. By considering the criteria above, the Commission will help to promote a spectrum environment that promotes innovation, competition, and growth in both the U.S. and global wireless marketplaces.

B. Several Spectrum Bands Are Viable Candidates to Support 5G

5G services have the potential to truly revolutionize mobile services. In 2020 and beyond, wireless will continue its expansion into new market segments such as smart grid, mobile health, traffic control, and telematics. These market areas will bring new requirements that will require new spectrum allocations. Critically, future networks and devices will need to support considerably greater bandwidth than their predecessors. Greater spectral efficiency will also be essential. The contiguous, wide bandwidth to support these services can be secured in several bands above 24 GHz. While these bands have been perceived as inappropriate to support a macrocell deployment, cell sizes are getting smaller to provide larger cell capacity in dense areas. In those environments, higher frequency bands can fully cover the cell area. Samsung submits that several higher frequency bands can play a critical role in supporting future services. Samsung supports the identification and allocation of bands above 24 GHz. Samsung hereby provides additional information about several of these bands.



As the above chart shows, there currently exist several swaths of spectrum in the 28 GHz, 39 GHz, and 37/42 GHz bands that could support new 5G millimeter wave services. Each of these

bands offers the wide bandwidth potential and technical characteristics that are necessary to support 5G. The 28 GHz and 39 GHz LMDS bands are currently home to several existing licensees, who could be permitted by the FCC to provide these new services. However, there are several licenses in these bands that are not currently assigned, and in those markets, the Commission could permit new entrants to offer these services. In the 37/42 GHz band, the Commission could conduct a new auction to allow for new licensees to be accommodated and develop 5G services. Other bands, such as the 60 GHz band, also hold promise for 5G.

1. LMDS Spectrum

The LMDS band consists of 1,300 megahertz spread across five sub-bands of spectrum (the A1 Band at 29.1-29.25 GHz, the A2 Band at 29.1-29.25 GHz, the A3 Band at 31.075-31.225 GHz, the B1 Band at 31-31.075 GHz, and the B2 Band at 31.225-31.3 GHz).⁸² This spectrum is allocated on a co-primary basis for both fixed and mobile services. Indeed, the Commission itself has noted that there are no obstacles to permitting mobile services in this spectrum. Samsung has studied this spectrum for 5G and submits that new 5G mobile services would be compatible with existing uses. The Commission should make investigation of this band for 5G a top priority.

The Commission has long envisioned the LMDS bands as playing host to mobile services. When the Commission first adopted service rules for LMDS in 1997, it noted that “our significant allocation of spectrum under such a broad and flexible service definition should permit licensees to satisfy a broad array of their customers’ communications needs, whether through one or multiple service offerings.”⁸³ The Commission further stated that it knew of no

⁸² *Notice of Inquiry* ¶ 51.

⁸³ *Local Multipoint Distribution Service, Second Report and Order, Order on Reconsideration, and Fifth Notice of Proposed Rulemaking*, 12 FCC Rcd 12545, ¶ 207 (1997).

reason why it would not allow mobile operations if a party proposed them and the Commission was able to obtain a record in support of such an allocation.⁸⁴ The Commission also correctly observed that developments in the LMDS services and equipment may demonstrate a need for changing its rules and allowing for both mobile and fixed services in the bands.⁸⁵ Samsung submits that the time has come for the Commission to permit mobile services in the LMDS band and expects that this proceeding will produce the supportive record contemplated by the Commission in 1997.

LMDS spectrum meets all of the key criteria identified above for 5G millimeter wave spectrum. The majority of the LMDS spectrum has co-primary allocations for both fixed and mobile. The band is already licensed on a geographic basis and consists of large contiguous bands of spectrum. Because a LMDS system's beam direction can be readily adjusted, an licensee can deploy fixed services (i.e. LMDS) services and 5G millimeter wave services within their geographic boundaries.

The LMDS band is also adjacent to Fixed Satellite Service ("FSS") spectrum bands. In the attached Appendix D, Samsung provides results from its preliminary compatibility study that examined the coexistence of 5G millimeter wave services with Federal fixed and mobile satellite services in bands adjacent to LMDS. These bands include the 30-31 GHz band and the 31-31.3 GHz band. In Table 1 below, the maximum allowable number of mobile and base stations to provide coverage to New York, New York while protecting the SNR of the FSS uplink are listed.

⁸⁴ *Id.*

⁸⁵ *Id.*

**Table 1: Maximum Number of Base and Mobile Stations
to Protect FSS Uplinks in New York City**

	Very Small Aperture Terminal	Large Terminal
Maximum Number of Base Stations	2,552,459	66,747,522
Maximum Number of Mobile Station	1,396,236	36,511,960

The land area of New York City is 790 square kilometers. Assuming that the cell radius of a mobile station is 0.2 kilometers, 13,430 base stations will be required to cover New York City. The maximum number of allowable base stations that would not cause interference to satellite VSAT is 2,552,459 under the worst interference scenario (mobile station transmitting at maximum power in the line of sight of a satellite). In other words, although a single beam spot of a FSS receiver covers the land area of 711 major cities, a mobile base station in the adjacent channel does not cause significant interference to space station FSS.

2. 39 GHz Spectrum

The 39 GHz spectrum is another strong candidate for millimeter wave mobile systems. This band, which extends from 38.6-40 GHz, is currently licensed by Economic Area and consists of fourteen paired blocks of 50 x 50 MHz channels.⁸⁶ Only 859 out of 2,464 possible EA licenses are currently licensed.⁸⁷ This band also has a co-primary allocation for fixed and mobile services.⁸⁸ Like the LMDS band, the 39 GHz spectrum shares the characteristics that Samsung values in potential millimeter wave spectrum. Appendix C is a preliminary analysis evaluating the impact of sharing with common carrier fixed service operations in the 39 GHz band and finds that exclusion zones or other mitigation methods may be required to avoid

⁸⁶ *Notice of Inquiry* ¶ 56.

⁸⁷ *Id.*

⁸⁸ *Id.* ¶ 58.

interference. Appendix E provides a preliminary compatibility study with 39 GHz FSS satellite downlinks and finds that geographical separation may be required to avoid interference. If the Commission does move forward with this band, Samsung recommends that the current band plan of 50 x 50 MHz channels be reconfigured to allow for much wider bandwidth channels. This process will also need to consider existing licenses being transitioned to wider channels.

3. 37/42 GHz Spectrum

The 37/42 GHz bands consist of 1600 contiguous MHz of spectrum from 37 to 38.6 GHz and 500 contiguous MHz of spectrum from 42-42.5 GHz.⁸⁹ Like the LMDS and 39 GHz bands, these are strong candidate bands for millimeter wave services. While co-primary allocations for terrestrial mobile services currently exist for these bands, the Commission has not adopted service rules to authorize mobile services.⁹⁰ These bands also contain several of the characteristics identified by Samsung as being essential for the provision of millimeter wave services. As an initial matter, the size of these bands is considerable, providing 1600 and 500 MHz of bandwidth. Because the 37-38.6 GHz band segment is adjacent to the 39 GHz LMDS band, an even larger contiguous block of spectrum could be created by combining the bands. Samsung urges the Commission to consider the adoption of mobile service rules for these bands, with the millimeter wave services discussed by Samsung and others in mind. Samsung recognizes that work will need to be done to evaluate Federal use of this band and determine appropriate service rules, and it looks forward to participating in such an effort.

⁸⁹ *Id.* ¶ 62.

⁹⁰ *Id.* ¶ 65.

4. 60 GHz Spectrum

The 60 GHz bands consist of two 7 GHz segments: 57-64 GHz and 64-71 GHz. There are currently no licensed operations in these bands, and each has co-primary mobile allocations.⁹¹ The 57-64 GHz band is the common unlicensed spectrum for wireless services in Europe, the U.S., and Korea. The Commission has proposed amending its rules to allow Part 15 unlicensed operations in the 64-71 GHz band segment, or to allow licensed operations in this band. Samsung is developing technology for this band that would support mobile services without interference to inter-satellite operations. While Samsung believes that the 28 and 39 GHz bands should be the Commission's top priorities at this time, the 60 GHz band also holds promise as a home for licensed 5G services.

As a result of the explosive growth in mobile data traffic over the past several years, the Commission and the wireless industry have focused on identifying more licensed bands for mobile services. However, the lower portion of the 60 GHz band is currently allocated for unlicensed, while the upper segment is only governed by the Commission's rule regarding Inter-Satellite licenses (there are, however, no current ISS licenses). If the Commission is investigating harmonized, wide spectrum bands above 24 GHz, the 60 GHz spectrum is an obvious choice. In fact, because each 60 GHz band segment has a bandwidth of 7 GHz, these blocks are particularly promising for millimeter wave services. While these bands should receive lower priority than the LMDS or 39 GHz spectrum, they are suitable bands for mobile operation.

The current state-of-the-art specifications with regard to unlicensed operations in the current 57-64 GHz band are the IEEE 802.11ad specifications. These specifications are designed

⁹¹ *Id.* ¶¶ 71-72.

for relatively short-range, low-mobility applications, yield a maximum physical layer data rate of 6.76 Gbps over an operating bandwidth of approximately 2.3 GHz. Commercial products available for this band support physical layer data rates of up to 4.62 Gbps over 2.3 GHz operating bandwidth. The channel propagation characteristics of this band are well-understood, and thus this band is a promising ecosystem for 5G.

The channel propagation characteristics in the 64-71 GHz band may be similar to the well-understood channel propagation characteristics of the 57-64 GHz band and yield the same data rates. A channel-bonding-based extension of the IEEE802.11ad specifications could yield short-range, low-mobility systems on 6 bands of 2.3 GHz each that yield scaled data rates of 40.56 Gbps, or 27.72 Gbps in the case of commercially available products. Extensions using multiple transmit and receive antennas may result in even higher data rates.⁹² This could support a number of applications, including wireless backhaul. By replacing wired backhaul links with high data rate wireless connections, significant benefits will be achieved including flexibility and ease of deployment, access, and maintenance.

Samsung believes that use of 60 GHz bands for 5G services could result in better interference avoidance due to the additional directivity provided by higher frequencies. By authorizing operations in the 64-71 GHz band segment, the Commission could issue three additional 2.3 GHz licensed blocks, increasing flexibility for users and lowering the potential for interference. Further, because transmissions in the 64-71 GHz band are expected to be highly directional, systems could be engineered to support indoor operations over short ranges, allowing for prevention of interference to other applications co-existing in the band.

⁹² IEEE 802 has already commenced a study group standardizing next-generation technologies in the current 57-64 GHz band. Throughput-boosting mechanisms such as channel bonding and MIMO are being considered, and formal working group activities are expected to commence in May 2015.

V. CONCLUSION

For the reasons articulated above, Samsung is tremendously excited about the potential of 5G and urges the Commission to take a leading role in bringing these services to market. In particular, the Commission should focus on allocating the 28 GHz and 39 GHz LMDS bands as well as 37/42 GHz for 5G, with a secondary eye toward other bands such as 60 GHz. By adopting a global approach to 5G that maximizes the potential of each candidate frequency band, the Commission will unleash spectrum above 24 GHz to create unparalleled mobile experiences for the American public, and the rest of the world.

Respectfully Submitted,

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January 15, 2015

Appendix A

ITU and International Harmonization Efforts for 5G

It is envisaged that 5G arriving from the year 2020 onwards¹ will require contiguous and very wide bandwidth (e.g. hundreds of MHz, even GHz bandwidth) to provide ultra-high data rate service and to support traffic volume capacity, in order to overcome traffic explosion. In other words, the growth of IMT/mobile broadband network data traffic is expected to be accelerated in the coming years, driven by new devices and capabilities as well as new applications and services. Especially services requiring high-speed data rate transmission and the real-time delivery of large data files are needed in dense urban areas in small cell areas. Additionally, IMT technologies, services and applications such as machine-to-machine and device-to-device (M2M/D2D) will be widely deployed in the near future.

In this regard, ITU-R WP 5D had discussed the frequency bands above 6 GHz as a suitable frequency ranges for IMT services during the July 2012 to July 2013 meetings. At the October 2013 meeting industry members of WP 5D proposed jointly that WP 5D should study the technical feasibility on frequency bands above 6 GHz to use IMT/mobile broadband in the future. This proposal was approved by WP 5D. In accordance with the workplan, the Report ITU-R M.[IMT ABOVE 6 GHz] on the technical feasibility of IMT in the bands above 6 GHz will be completed by its 22nd meeting on June 2015.

In addition, Region 1² and Region 3³ is discussing frequency bands above 6 GHz as a preliminary Agenda Item for WRC-19 predicated in the WRC-12 Resolution 808, in order to usage bands above 6 GHz for IMT/mobile broadband in preparation for the 5G era from the year 2020 onwards.

The fragmentation of the existing identified IMT bands each country and region is a serious problem. This problem led to complicated regulation in each country and region; furthermore the problem significantly increases complexity of device in supporting global roaming.

As shown in Figure A-1, several bands had been identified for IMT by WRCs (WARC-1992, WRC-2000 and WRC-2007). However those bands are used on a fragmented basis as shown in Figure A-1. The importance of global harmonization is emphasized in section 2.5.1 in Recommendation ITU-R M.[IMT.VISION].⁴

¹ As results of its 19th and 20th meeting, ITU-R WP 5D (#19 and #20) agreed that future IMT (tentatively used, “[IMT-2020]”) will appear from 2020 and onwards. [Att. 3 of 5D/726 and Att. 2.12 of 5D/836] => need ITU TIES account to see two documents

² Annex 6 of ECC PT1(14)115, “Working Document: Proposals for a new WRC-18 Agenda Item, Future IMT systems above 6 GHz”, October 27, 2014

³ APG15-3-OUT-09, “Preliminary Views of Agenda Item 2, 4, 8, 9.1.4, 9.1.6, 9.1.7 and 10”, June 12, 2014 → need APT account

⁴ ITU-R Recommendation M.[IMT.VISION], “Framework and overall objectives of the future development of IMT for 2020 and beyond.”

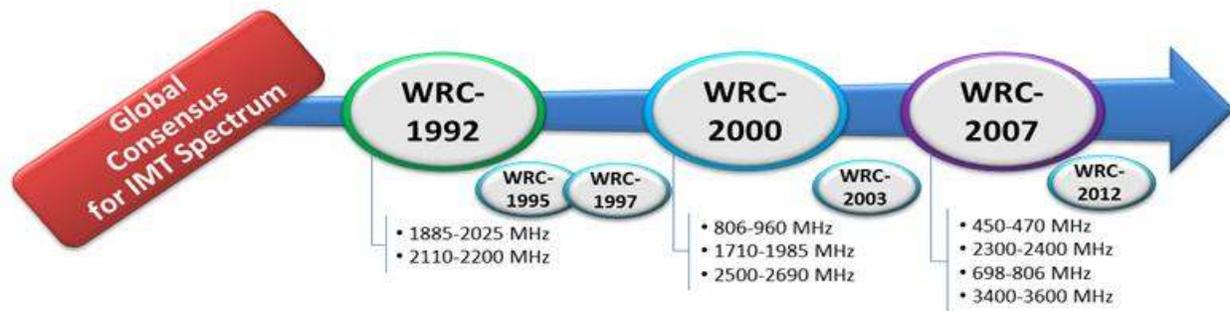


Figure A-1: Identified IMT Bands by WRCs

The Report ITU-R M.2134⁵ defined requirements related to technical performance for IMT-Advanced radio interfaces, in particular, up to 100 MHz bandwidth as scalable bandwidth is encouraged to implement for 1 Gbps peak data rate as the ultimate goal of IMT-Advanced. According to Recommendation ITU-R M.1645: “It is predicted that potential new radio interface(s) will need to support data rates of up to approximately 100 Mbit/s for high mobility such as mobile access and up to approximately 1 Gbit/s for low mobility such as nomadic/local wireless access, by around the year 2010.”⁶ However, it is difficult to support this peak data rate uniformly across the network when a number of users access simultaneously and to satisfy the user’s Quality of Experience (QoE) described in Recommendation ITU-R M.1645.⁷

Figure A-2 indicates the Cumulative Distribution Function (CDF) curve of user data rate and shows how few users can be served at a 1 Gbps peak data rate when the entire 100 MHz bandwidth is used. It is clear that only a few users can enjoy the high data rate which is close to 1 Gbps when 100 MHz bandwidth is assumed.

⁵ Requirements related to technical performance for IMT-Advanced radio interface(s), November 2008.

⁶ Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000, June 2003.

⁷ Recommendation ITU-R M.1645.

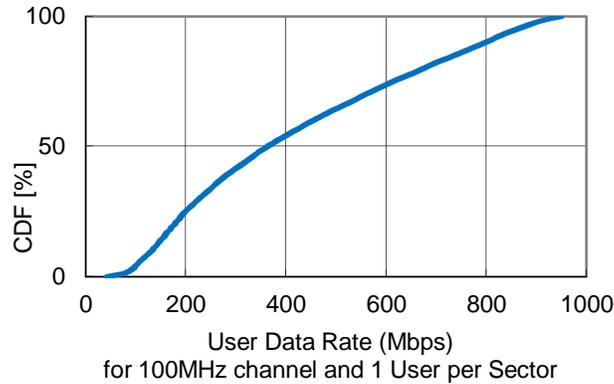


Figure A-2: Limited Number of Users for Peak Data Rate

To overcome the limitation of fragmented spectrum resources in existing bands and to extend the operating bandwidth, carrier aggregation technology is a good approach to aggregate resources from many frequency bands. However, carrier aggregation technology would bring inefficiency on the implementation side and take resources away from current 4G operations to provide higher data rates to fewer users.⁸ Therefore, it is important that wide, contiguous channels be provided for 5G which will require high capacity and high performance.

Taking into account the above, therefore, global harmonization is significantly important to avoid these issues as we grow into the 5G era.

⁸ A switch in circuit for carrier aggregation might have a loss about 1 dB/1 switch and will result in lower energy efficiency in deployed base stations. Also carrier aggregation might require Multi Mode & Multi Band (MIMB) power amplifiers to implement the technology; this is inefficient in its performance and more expensive with respect to the component which is dedicated to a single band

Appendix B

Samsung Testing and Measurements in Bands Above 24 GHz

B.1 Outdoor Non Line of Sight (NLoS) channel measurement results

Outdoor radio propagation

In order to investigate feasibility of millimeter wave bands, channel measurements campaigns were conducted in various outdoor environments. This section presents measurement results in Samsung Electronics, Suwon Campus, Korea. It was expected that since building surface wall is highly reflective in these bands, a radio communication link can be provided even through multiple NLoS paths. The measurement results confirm such expectation.

Campaign 1: Research Campus (Samsung Electronics, Suwon Campus), 28 GHz¹

Measurements were performed at 28 GHz at the Samsung Complex at Suwon, Korea. Channel bandwidth is 500 MHz, transmission power is 18 dBm, and horn antenna gain 24.4 dBi for both transmitter and receiver. These measurements show that pathloss exponents are 2.39 in LOS, and 4.0 in NLoS links for the case of the best Tx and Rx beams matching.²

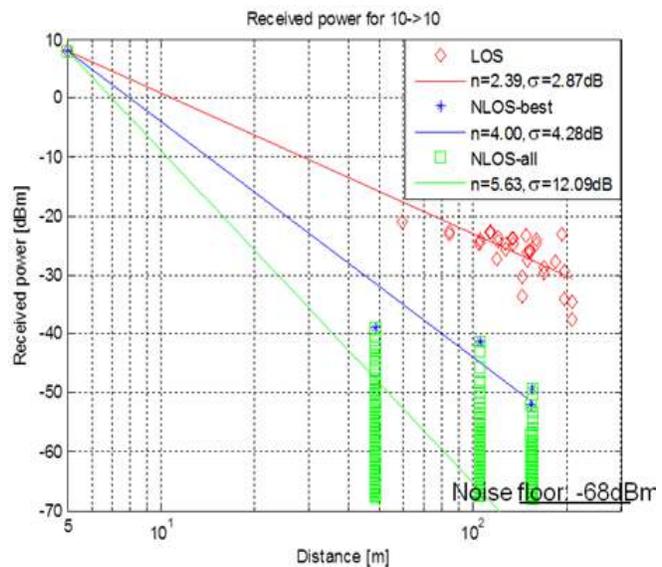


Figure B-1: Measurement Sites at Samsung Complex in Suwon, Korea (Left), Path Loss Exponent Results (Right)

B.2 Test results of prototype mobile system

Introduction

This section introduces a prototype of millimeter wave mobile communication system and provides various test results. Test results are included for 1) Line-of-Sight (LoS) environments, 2)

¹ RWS-120021, 3GPP Workshop, Jun, 2012.

² In NLoS condition, the best beam-pair at transmitter and receiver is selected in terms of received power after beam-sweeping on all combinations of beam directions.

Non-Line-of-Sight (NLoS) environments. Finally, two case studies for outdoor to indoor penetration are investigated.

Overview of a millimetric wave prototype mobile system

The millimeter wave prototype mobile system was developed for mobile communications by using FPGA and analog RF components for transmitter and receiver equipment to perform the real time processing.

The system operates at the center frequency of 27.925 GHz with the bandwidth of 500 MHz. Pencil beamforming technique is applied to both base station (BS) and mobile station (MS) transceiver to provide electronically steerable beams. Figure B-2 shows the overall system configurations which are composed of BS, MS and diagnostic monitor (DM). DM provides the status of receiver (RX) signal processing, and selected beams at BS and MS are visualized in real time.

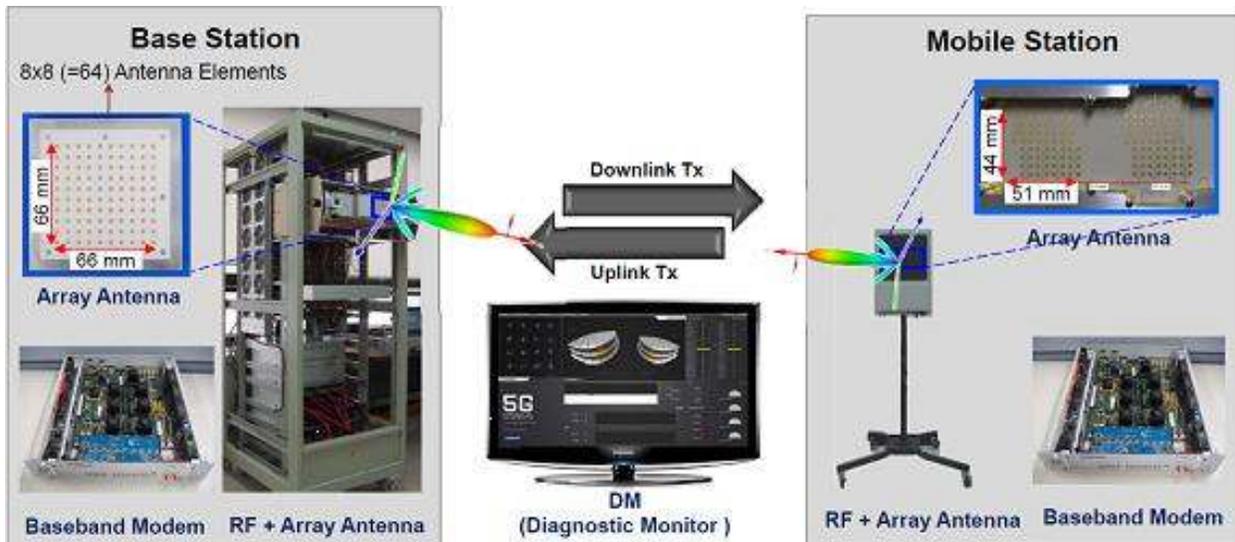


Figure B-2: Overview of the Prototype Mobile System at 28 GHz Band

Figure B-3 shows the key system parameters. Half power beam-width (HPBW) is 10 degree and total 64 or 32 antenna elements are used to generate a beam. As for transmit (TX) output power, 36 dBm is the maximum power after considering peak-to-average power ratio (PAPR) backoff. The system is OFDM using QPSK or 16-QAM modulation with the channel coding of low-density parity-check (LDPC) was used. For system operation, fundamental functions like synchronization, beam searching, and channel estimation have been implemented and data transmission is performed using the remained resources.

PARAMETER	VALUE
Carrier Frequency	27.925 GHz
Bandwidth	500 MHz
Duplexing	TDD
Array Antenna Size	8x8 (64 elements) 8x4 (32 elements)
Beam-width (Half Power)	10°
Channel Coding	LDPC
Modulation	QPSK / 16QAM

PARAMETER	VALUE	REMARKS
Supported Data Rates	1,056Mbps	
	528Mbps	
	264Mbps	
Max Tx Range	Up to 2Km @ LoS	>10 dB Tx power headroom

Figure B-3: Key System Parameters and Values

LoS range test results

The first question regarding millimeter wave signal transmission in outdoor environments would be “How far the signal can be transmitted in millimeter wave frequencies?” In order to investigate this question, range test has been performed in Samsung Campus in Suwon, Korea. The LoS environments which can be found in the Campus provide the maximum distance of 1.7 km. Figures B-4 and B-5 show the scene of LoS environments in Suwon Campus from the satellite view and ground view.

Please note that the BS is located on the rooftop of a 4-story building and the MS is located on the road.



Figure B-4: Ground View of LoS Range Test in Suwon Campus

For the given 1.7 km distance, a communication link between BS and MS was verified. We found that a 10 dB TX power margin existed with the link under these conditions. The data rate of 264 Mbps using QPSK shows no block errors and the data rate of 528 Mbps using 16-QAM shows 10^{-6} block error rate. Considering these results, we expect the maximum range to be more than 2 km in LoS environments for the given system configurations.



Figure B-5: Satellite View of LoS Range Test in Suwon Campus

NLoS mobility test results

NLoS transmission has been investigated combined with mobility test. For these test the BS is located on the 4th floor rooftop of the building indicated by R2 in Figure B-6 and the MS is located on the road indicated by the yellow box. This location provides no LoS between the BS and MS. BS transmits signal toward the building indicated as R3, and signal may reflect on the R3 building and then arrive at the MS receiver. The distance in total from BS to MS is approximately 160 m. At the receiver side, MS is moving with the speed of approximately 8 km/h.

In the conditions mentioned above, the data rate of 528 Mbps (16-QAM) was verified with the block error rate of no more than 0.5%. The data rate of 256 Mbps (QPSK) did not show any block errors. The system is configured to automatically select the best TX beam and RX beam and that selection is tracked contiguously during movement, and the necessary information was feedback to BS.

This TX-RX beam tracking make it possible for MS to move without disconnect of transmission as long as MS dwells in the BS service coverage. The mobility speed that is allowed in

beamforming systems is tightly related to beamforming configurations and beam tracking period. For example, if beamwidth is getting narrower, allowable speed to be supported would be getting slower if beam tracking period is retained. On the contrary, for the given beamwidth, making beam tracking period shorter would support the higher speed of mobility.

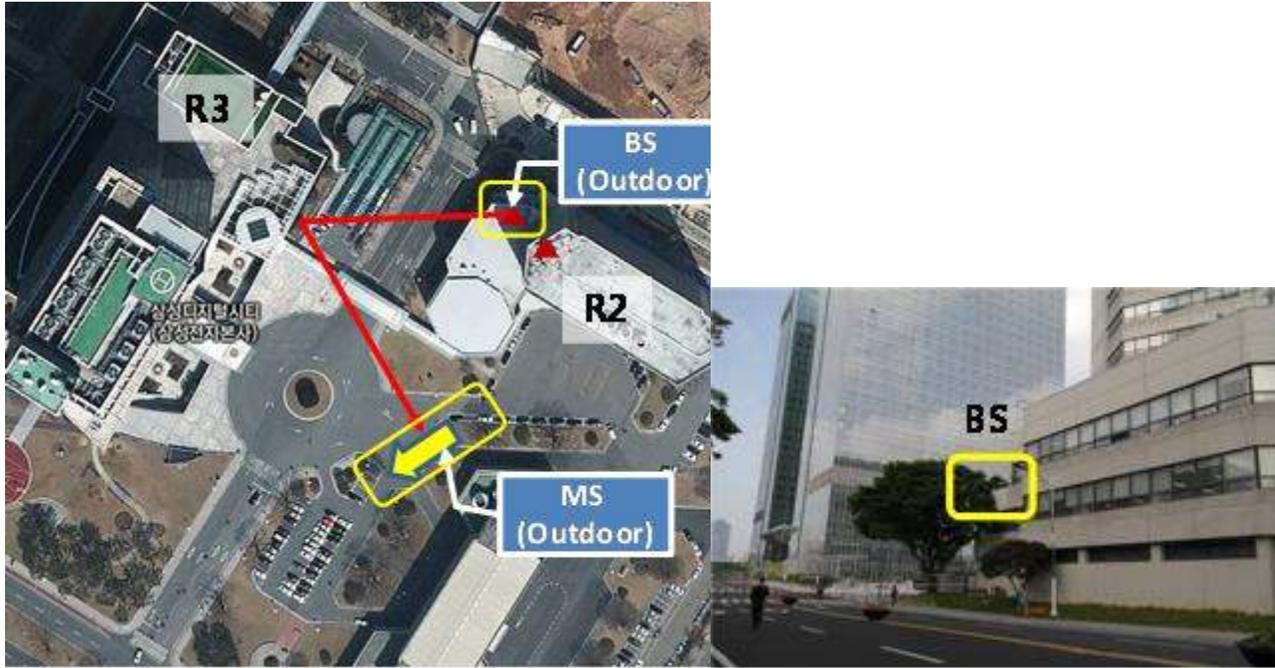


Figure B-6: View of NLos Environments for Mobility Test in Suwon Campus

Outdoor-to-indoor penetration test results

The final test was to investigate the system performance in outdoor-to-indoor penetration environments. Two case tests were conducted and the environments for the tests are shown in Figure B-7 and Figure B-8 respectively.

In the first case, the BS is located on the rooftop of the 2nd floor of the building R1 and MS is located on the 7th floor office inside the building R2 (Figure B-7). The distance between BS and MS is approximately 65 m. For the data rate of 256 Mbps (QPSK), the block error rate up to 0.6 % was obtained.

In the second case, the BS is located on the rooftop of the 4th floor of the building R2 and the MS is located on the 1st floor lobby inside the building R4 (Figure B-8). The distance between the BS and MS is approximately 150 m. For the data rate of 256 Mbps (QPSK), the block error rate up to 0.3 % was obtained.

Please note that the BS had more than 10 dB TX power margin for both cases and MS was located inside the building up to 15 m away from the window for both cases. The propagation environments inside the building were not necessarily LoS.

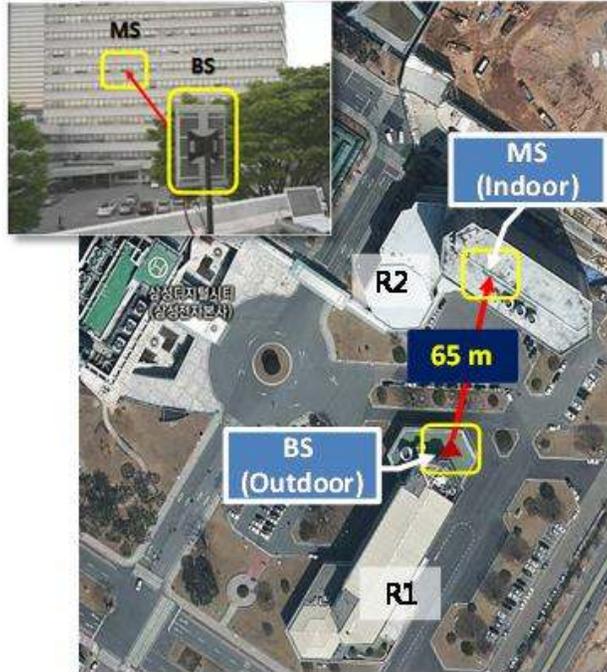


Figure B-7: View of Building Penetration Environments - Case 1



Figure B-8: View of Building Penetration Environments - Case 2

Summary

The prototype millimeter wave system using pencil beamforming has been developed and various tests were conducted with real time processing. The maximum range tested in LoS

environments was 1.7 km but it is evident that using higher power will result in the lengthened distance more than 2 km.

Mobility test results were also provided in NLoS environments. At a MS speed of approximately 8 km/h speed, it was verified that stable communication link was maintained due to fast beam tracking algorithm. Final results show that signal is received at strong signal levels and some coverage for communication links can be retained even inside the building by penetration through the window.

All test results point out the possibility of millimeter wave frequency bands for IMT systems.

B.3 Coverage test results

In this section, we provide coverage test results based on the prototype IMT system to demonstrate the service availability in typical IMT environments including LoS, NLoS and window penetration links.

The prototype IMT system used to carry out coverage tests included the following key system features:

- Operating frequency: 27.925 GHz
- Bandwidth: 500 MHz
- Tx power: 31 dBm for case 1, 24 dBm for case 2
- Half power beam width: 10 deg.
- Duplexing: TDD
- Channel coding: LDPC, 1/2
- Modulation: QPSK
- Supported data rates: 264 Mbps.

Note that the Tx power used for tests is as more than ten times smaller as the conventional BS Tx power in urban environments, while the system bandwidth is more than 25 times wider. We believe that the same level of Tx power as conventional IMT systems will result in enlarged service coverage.

Coverage test results

1) Case 1: Outdoor environments

Coverage test results in outdoor environments are provided to demonstrate the service availability in the area indicted by Figure B-9, which covers a typical urban outdoor environment including both LoS and NLoS links. The BS is located at the 4th floor rooftop and the MS is located on the roads along various streets. More specifically, the tests were performed at various sites surrounded by tall buildings where different channel propagation effects such as reflection, diffraction, or penetration are expected to occur, as shown in Figure B-9.

Figures B-10 through B-13 provide views from the BS transmitter and the MS receiver located at site 4, 6 and 12. As can be seen by the figures both LoS and NLoS conditions are captured in this study.



Figure B-9: Coverage Area Map



Figure B-10: A View From the Transmitter Side

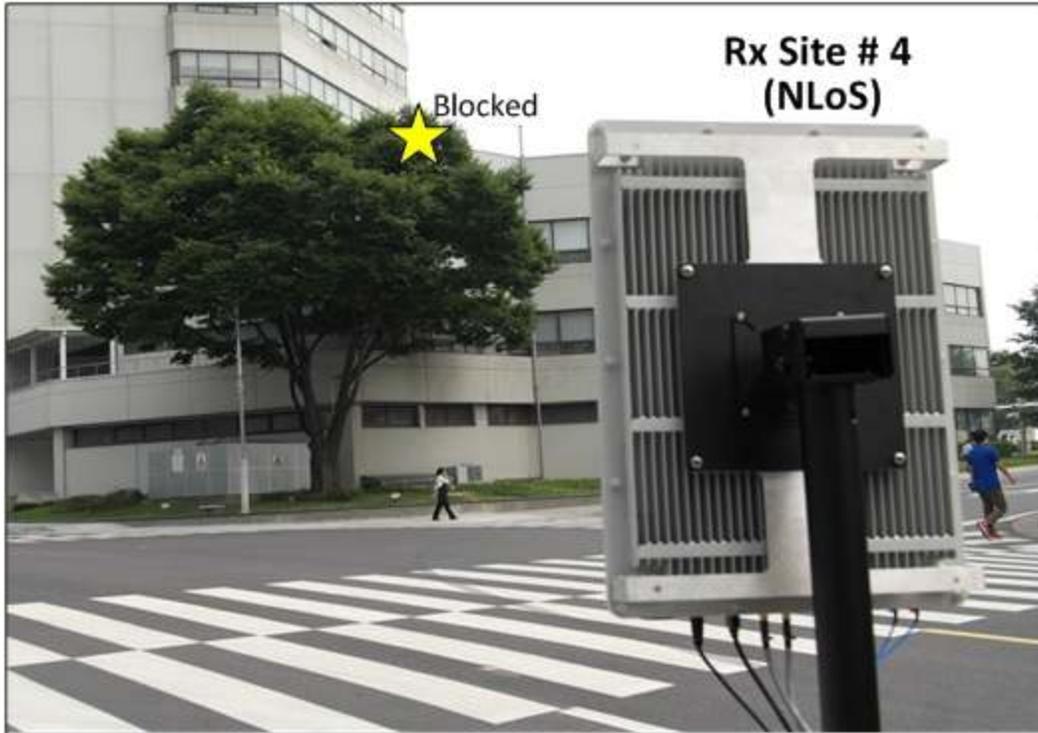


Figure B-11: A View From the Receiver Side Toward the Transmitter at Location 4



Figure B-12: A View From the Receiver Side Toward the Transmitter at Location 6

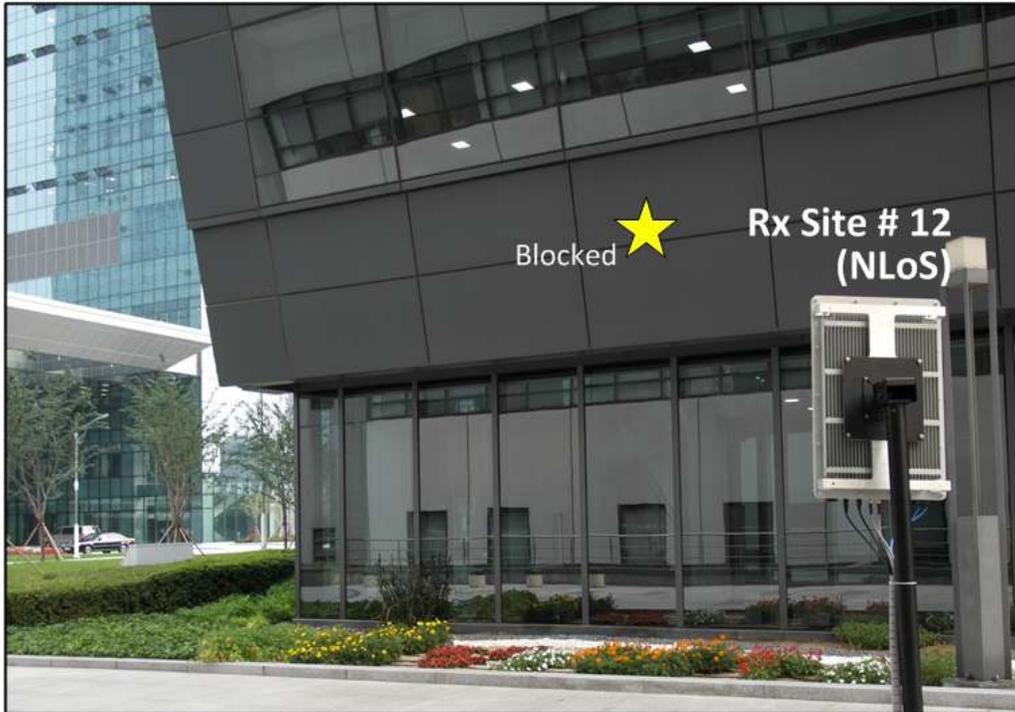


Figure B-13: A View From the Receiver Side Toward the Transmitter at Location 12

As can be seen from the test results in Figure B-14, satisfactory communications links are discovered even in NLoS sites more than 200 meters away, which is mostly due to reflections off neighboring buildings (Locations 2, 4, 5, and 12).

On the other hand, there are NLoS locations where a proper link could not be established, i.e., coverage holes (Locations 1 and 13). These locations are expected to be covered if the transmission power is increased to match conventional BS TX power levels. There are also other solutions for coverage improvement techniques such as optimized cell deployment, inter-cell coordination, relays, or repeaters.

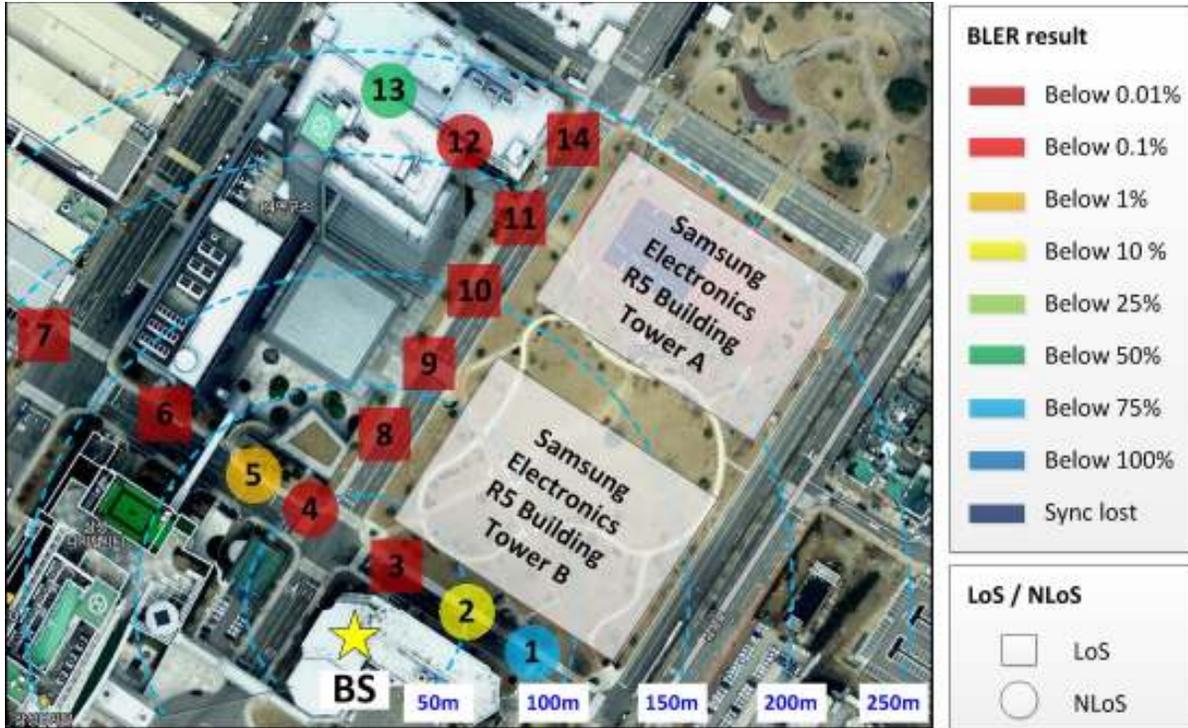


Figure B-14: Outdoor Coverage Test Results of 28 GHz Beamforming Prototype

2) **Case 2: Window penetration environments**

One of the important operation scenarios in practical cellular networks is communication between an outdoor BS and an indoor MS. The test scenario is shown in Figure B-15 where the BS is located outdoors on the 4th rooftop of a building and the MS is located on the 1st floor lobby of another modern office building which is 150 meters apart from BS. Please note that the building windows surrounding MS has heavily tinted glasses. These types of building windows are representative of presenting highly unfavorable propagation (penetration) conditions even for current cellular frequency bands below 6 GHz.

Figure B-16 provides the indoor map of coverage throughout the building. Considering the relatively low Tx power (24 dBm) surprisingly amicable in-building coverage results were obtained. Only the totally obstructed, farthest side of the building resulting in lost connections. The locations showing block error rates around 10-50% can be easily improved by BS equipped with the conventional Tx power. Furthermore there are many link quality enhancement techniques such as hybrid automatic repeat request (HARQ) and adaptive modulation/coding (AMC) that will also improve coverage. Additionally alternative ways can be considered to overcome coverage holes such as repeaters and indoor femto cells which are widely used in traditional cellular systems.

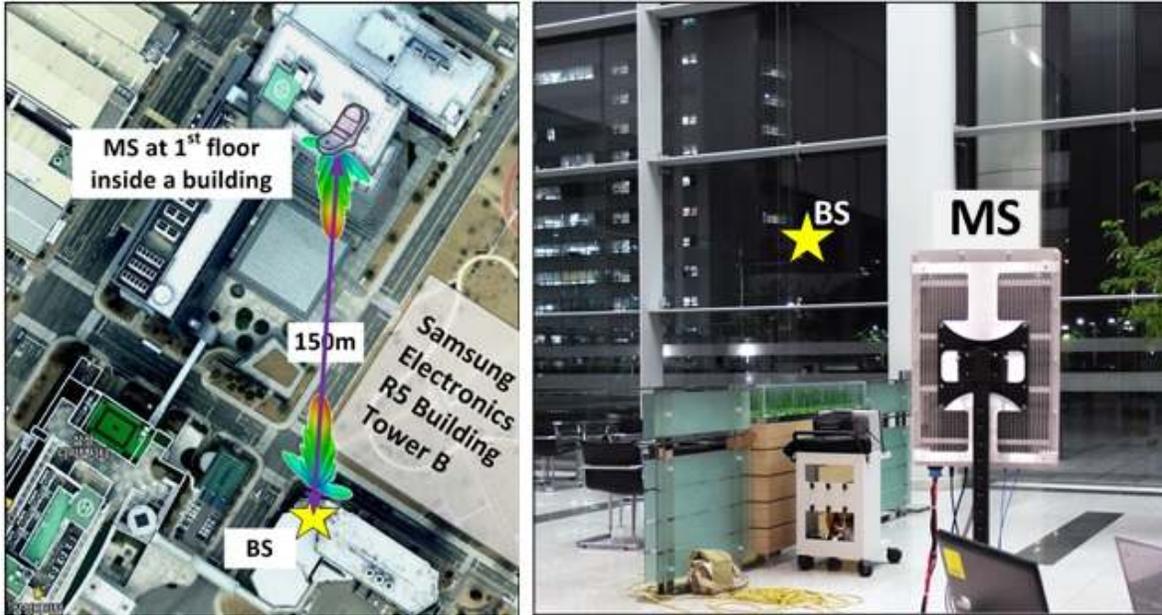


Figure B-15: A Satellite View for Outdoor to Indoor Penetration Test (left) and a View From the Receiver Side Toward the Transmitter (right)

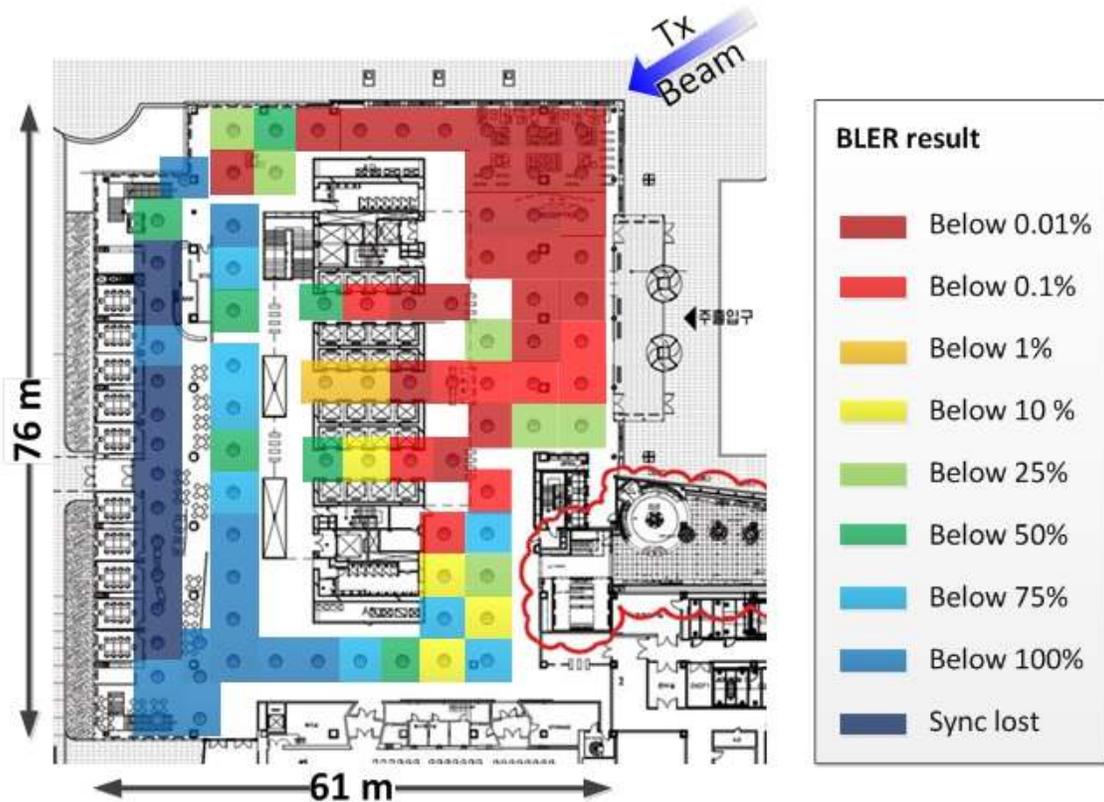


Figure B-16: Outdoor to Indoor Penetration Test Results of 28 GHz Beamforming Prototype

Summary

Coverage test results are provided by using the millimeter wave prototype IMT systems with channel bandwidth of 500 MHz operating at 28 GHz. The system incorporates a real-time

baseband modem, full millimeter wave RF circuitry, and relevant software. With this system, it was successfully demonstrated that the millimeter wave frequency band is capable of supporting a few hundred meter radius in a typical urban environments.

Appendix C

Sharing and Compatibility Studies into Fixed Systems from Mobile Broadband System

This appendix provides a preliminary assessment of interference into a fixed system operating in the 39 GHz LMDS bands. The FCC ULS database indicates that there are currently 253 common carrier fixed point-to-point (CF) active licenses and leases, the map of those licenses is shown below.¹

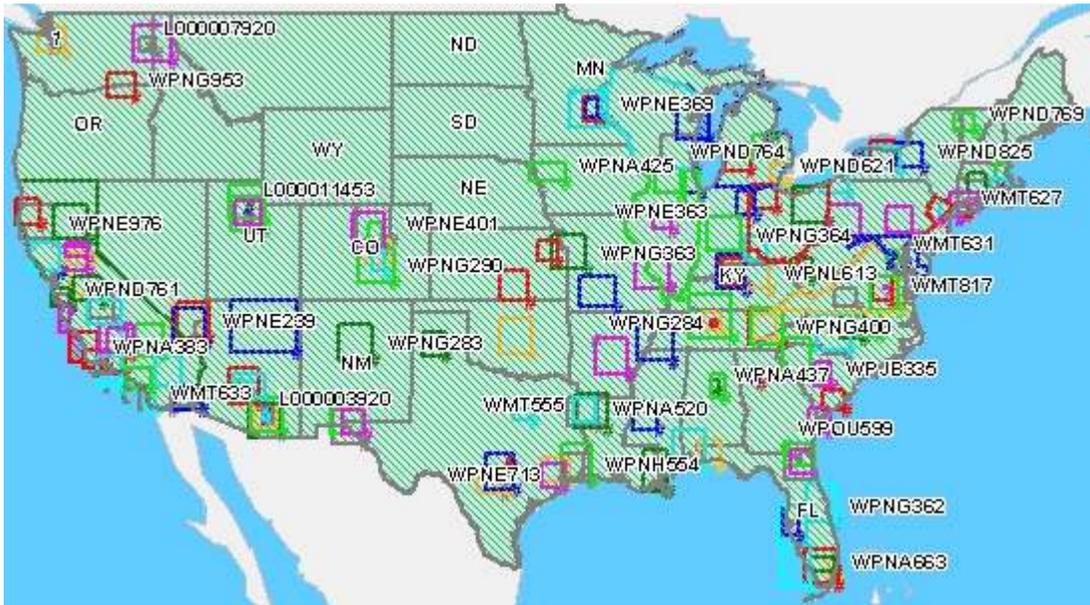


Figure C-1: Common Carrier Fixed Point-to-Point Licenses/Leases

C.1 Interference scenarios

There are four interference scenarios considered in this contribution as shown in Figure C-2.

- **Scenario A:** Co-channel interference from the mobile user equipment (UE) to Fixed Service station (FS) in geographically separated areas.
- **Scenario B:** Adjacent channel interference from the mobile UE to FS in the same geographically area.
- **Scenario C:** Co-channel interference from the mobile Base Station (BS) to FS in geographically separate areas.
- **Scenario D:** Adjacent channel interference from the mobile BS to FS in the same geographically area.

¹ See FCC ULS system, www.fcc.gov/uls (visited 12 January 2015).

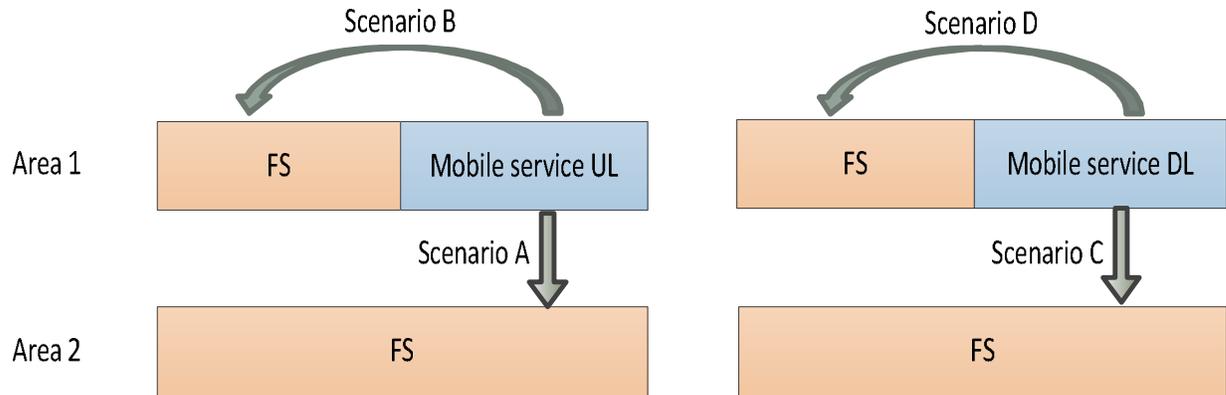


Figure C-2: Interference Scenarios

Due to the characteristic of each scenario it was decided to apply either a deterministic analysis or statistical analysis through the Monte Carlo simulation. The statistical analysis is applied to Scenarios A and B due to random locations of mobile UEs and the deterministic analysis to Scenarios C and D due to fixed locations of mobile BSs and FSs.

C.2 System characteristics of FS and MS

C.2.1 FS system characteristics

The FS deployment assumed is shown below in Figure C-3. A Sub-Central Station (Sub-CS) provides service to multiple FS receivers within the coverage area of the Sub-CS. A cluster is defined as the area covered by one Sub-CS. The parameters selected are representative of the FCC license WMN337 which has a minimum link distance of ~14 km with a maximum link distance of ~56 km.

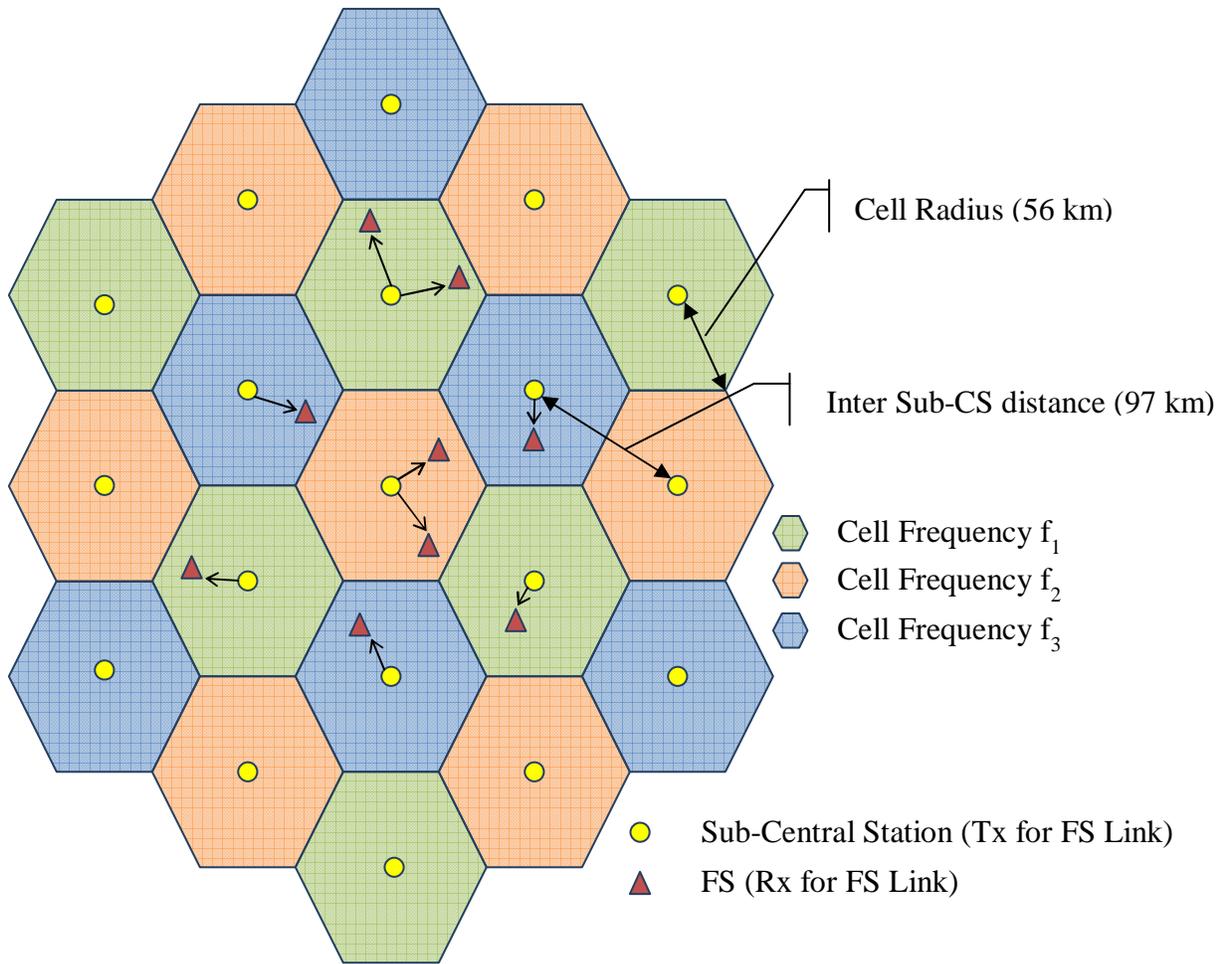


Figure C-3: Assumed FS Deployment

System parameters for the FS in this band are summarized in Table C-1.

Table C-1: System Characteristics of FS Systems

Parameters	FS system value	Note
Transmitter power (EIRP)	47 dBm	FCC Part §101.113(a)
Sub-CS antenna height	50 m	
BS antenna height	30 m	
Cell radius	56 km	
Carrier frequency	39 GHz	FCC Part §101.101
Channel spacing	50 MHz	FCC Part 101.109(c)
Inter Sub-CS distance	97 km	Deployment case in US
Min. FS link distance	14 km	Deployment case in US

FS layout	Hexagonal cluster	2-tier wrap around
Transmit antenna gain	38 dBi	FCC Part §101.115(b)(2)
Transmit antenna radiation pattern	Figure C-4	FCC Part §101.115(b)(2)
Thermal noise	-107.7 dBm/MHz	Recommendation ITU-R F.758
Normalized Rx input level for 1×10^{-6} BER	-84.2 dBm/MHz	Recommendation ITU-R F.758
I/N	-10 dB	Recommendation ITU-R F.758
FS Receiver noise figure	6.3dB	Recommendation ITU-R F.758
Nominal long-term interference power density	-107.7 + I/N dBm/MHz	Recommendation ITU-R F.758
Spectral emission mask	Figure C-5	FCC Part §101.111(a)(2)

Radiation pattern of the FS system is given by FCC Part 101.115 according to the azimuth between Tx and Rx antenna as shown in Table C-2 and Figure C-4.

Table C-2: Radiation pattern of FS systems given by FCC §101.115

Frequency (MHz)	Cat.	Maximum beamwidth to 3 dB points ¹ (included angle in degrees)	Min. antenna gain (dBi)	Minimum radiation suppression to angle in degrees from centerline of main beam in decibels						
				5° to 10°	10° to 15°	15° to 20°	20° to 30°	30° to 100°	100° to 140°	140° to 180°
38,600 to 40,000 ⁴	A	n/a	38	25	29	33	36	42	55	55
	B	n/a	38	20	24	28	32	35	36	36

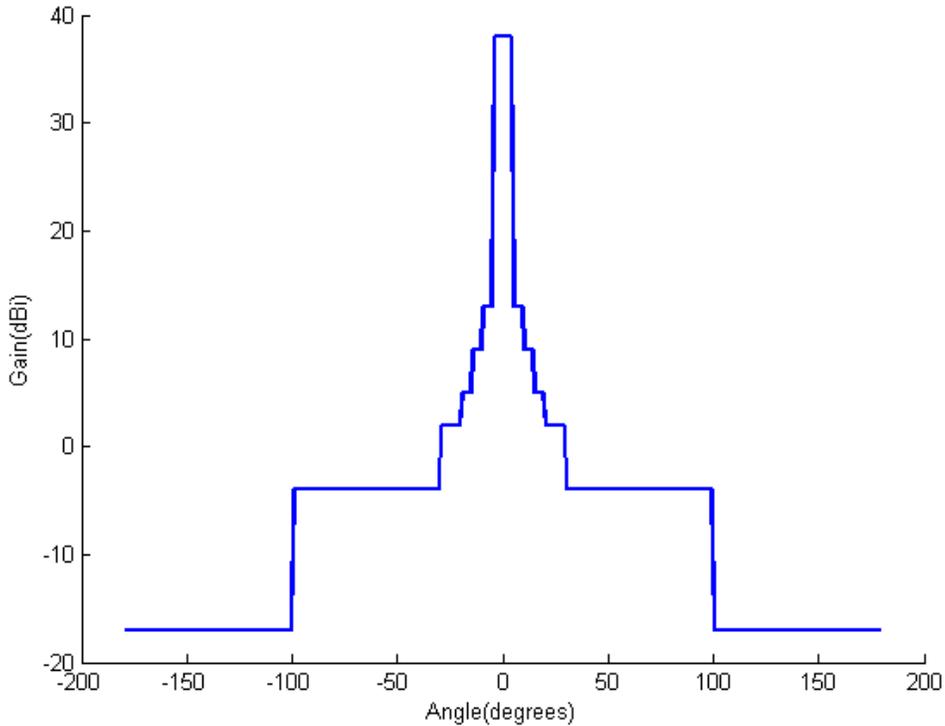


Figure C-4: Antenna radiation pattern of FS system given by FCC Part §101.115 (gain = 38 dBi)

Spectrum emission mask of FS system is given by FCC Part §101.111(a)(2) as shown in Table C-3 and Figure C-5.

Table C-3: FS Emission Mask (§101.111(a)(2))

Assigned Frequency	Attenuation in any 1 MHz band
50% to 250%	$11 + 0.4(P - 50) + 10 \log_{10}B.$ where: A = Attenuation (in decibels) below the mean output power level. P = Percent removed from the carrier frequency. B = Authorized bandwidth in MHz Attenuation greater than 56 decibels or to an absolute power of less than -13 dBm/1MHz is not required.
More than 250%	Lesser of $43 + 10 \log_{10}(\text{mean output power in Watts})$ dB or 80 dB

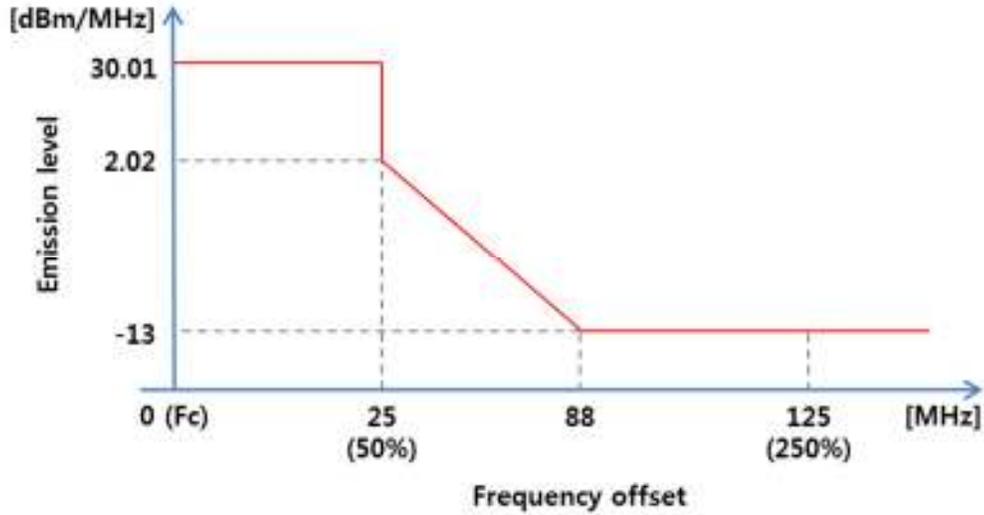


Figure C-5: Spectrum emission mask of FS system with 56 MHz

C.2.2 MS system characteristics

MS system parameters are assumed to be proposed parameters for IMT systems above 6 GHz under consideration within ITU-R WP 5D for sharing studies and summarized in Table C-4.²

Table C-4: System characteristics of MS systems

Parameters	MS system value	Note
Cell layout	Hexagonal grid	3-sectorized
Channel bandwidth	500 MHz	5D/259
Frequency reuse	1	5D/259
UE density in active mode	3510 UEs/km ²	5D/259
UE antenna height	1.5 m	5D/259
UE antenna gain	9 dBi	5D/259
UE antenna pattern	Omni directional	5D/259
Cell radius	57 m	5D/259
Duplex method	FDD	
UE max. transmit power	23 dBm	5D/259
Uplink scheduler	Round Robin	5D/259
Avg. active UEs per sector	3.28	5D/259

² ITU-R Working Party 5D Document 5D/259, “Proposed system parameters above 6 GHz for Sharing Studies”, 23 January 2013, (requires ITU Ties Account for access).

UE Spectral emission mask	Note 1	FCC Part 101.111(a)(2)
Uplink power control	Note 2	3GPP TR36.942
BS max. transmit power	37 dBm	
BS antenna gain	21 dBi	
BS Spectral emission mask	Note 1	FCC Part 101.111(a)(2)

Note 1) For operating frequencies above 15 GHz, in any 1 MHz band, the center frequency of which is removed from the assigned frequency by more than 50 percent up to and including 250 percent of the authorized bandwidth. As specified by the following equation but in no event less than 11 decibels:

$$A = 11 + 0.4(P-50) + 10 \text{ Log}_{10} B$$

(Attenuation greater than 56 decibels or to an absolute power of less than -13 dBm/1MHz is not required.)

Where:

A = Attenuation (in decibels) below the mean output power level.

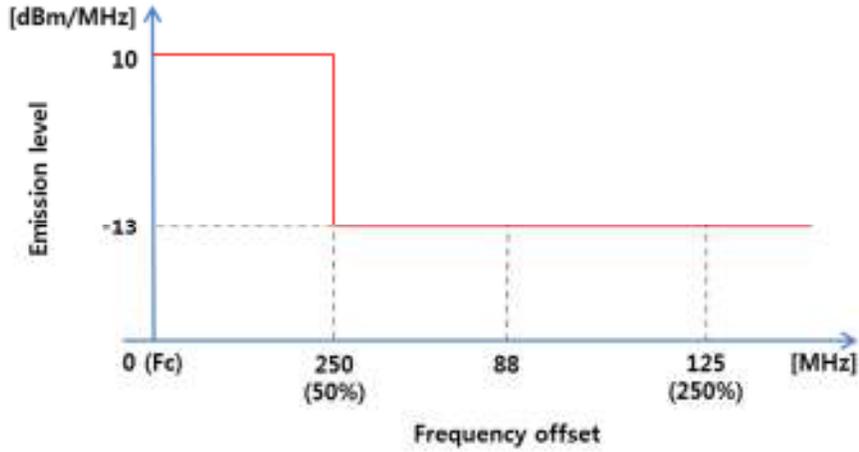
P = Percent removed from the center frequency of the transmitter bandwidth.

B = Authorized bandwidth in MHz.

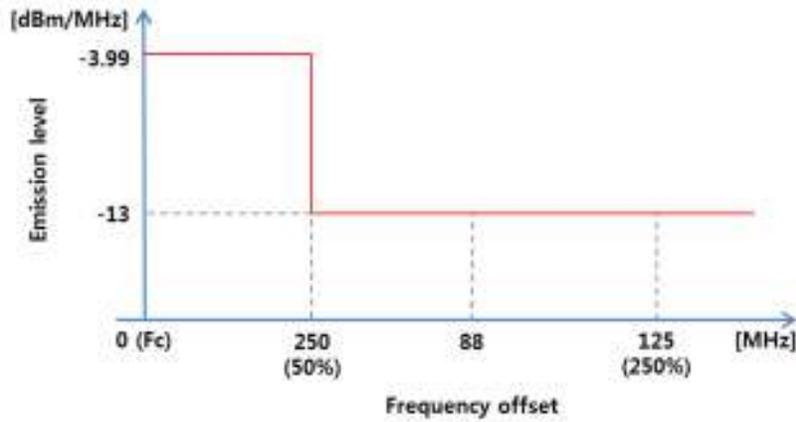
Note 2) For the MS, the resource of each mobile UE is evenly allocated to all UEs during the uplink time frame using the round-robin scheduling. The uplink power control of the mobile UE is assumed to be the same as the LTE system in 3GPP TR36.942,

$$P_t = P_{\max} \times \min \left\{ 1, \max \left[R_{\min}, \left(\frac{PL}{PL_{x-ile}} \right)^\gamma \right] \right\}$$

In the equation above, R_{\min} is -64 dB if the UE's minimum power is -40 dBm, and PL_{x-ile} is 96 dB, which is adjusted to the 28 GHz carrier frequency.



(a) Base station.



(b) UE Terminal.

Figure C-6: Spectrum emission mask of MS system

C.2.3 Path loss model

Path loss model is based on LoS situation as in Recommendation ITU-R P.1411. It is given by

$$L_{LoS,m} = L_{bp} + 6 + \begin{cases} 20 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d \leq R_{bp} \\ 40 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d > R_{bp} \end{cases}$$

where R_{bp} and L_{bp} are the break point distance and the values for the path loss at the break point, respectively. They are given by

$$R_{bp} \approx \frac{4h_b h_m}{\lambda}, \text{ and } L_{bp} = \left| 20 \log_{10} \left(\frac{\lambda^2}{8\pi h_b h_m} \right) \right|,$$

where λ , h_b and h_m are wavelength, height of the mobile BS, and height of the mobile UE, respectively.

C.3 Methodologies

C.3.1 Scenario A: Co-channel interference from the mobile UEs to FS in separate areas

The sharing study for Scenario A is a statistical analysis to account for the random location of mobile UEs. Figure C-7 shows the deployment of Scenario A. The effect of all mobile UEs are taken into account by simulating equi-spaced BSs which are uniformly located on a circle around the FS area. For every mobile BS, a constant number of UEs are randomly deployed within the mobile BS coverage. Thus, the protection distance is the result of the required separation distance that meets the interference criterion. The number of mobile UEs is assessed according to the separation distance and the mobile BS inter-site distance.

The number of mobile BSs is calculated by

$$\# \text{ of mobile BSs} = (2\pi (d_{FS_radius} + d_{protection} + d_{Mobile_radius}))/d_{Mobile_inter-site},$$

and the number of mobile UEs is calculated by (for a 3-sectorized base stations and average active UEs per sector as defined in Table 2)

$$\# \text{ of mobile UEs} = \# \text{ of mobile BSs} \times 3 \times \text{Average active UEs per sector}.$$

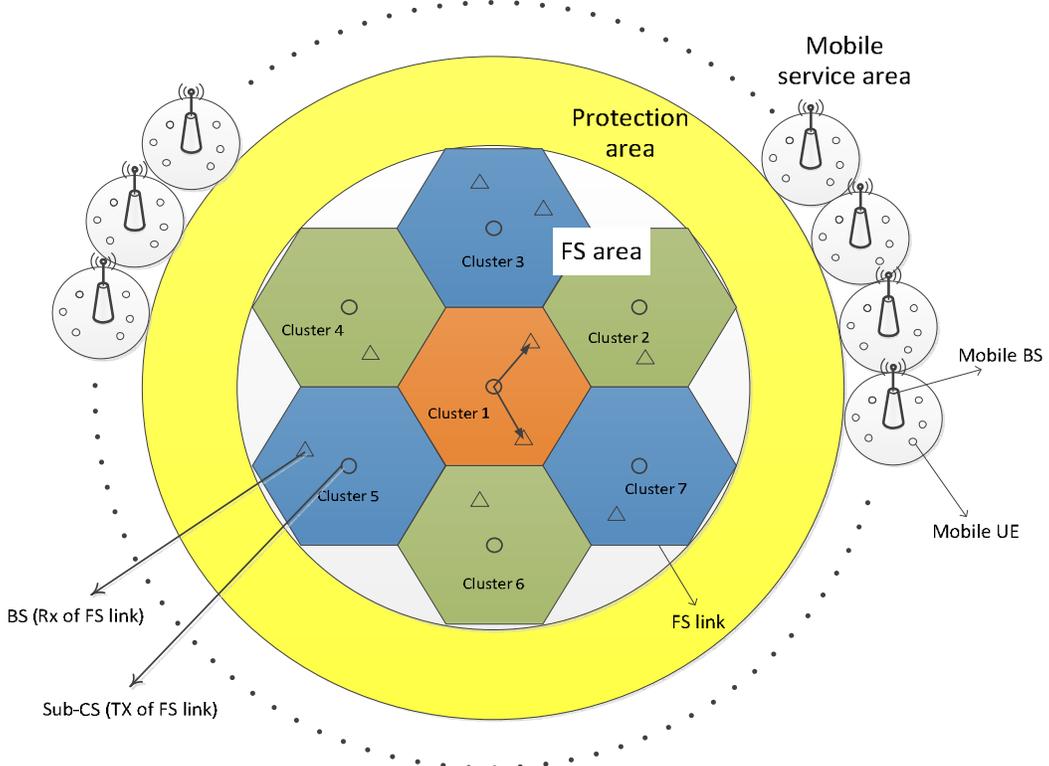


Figure C-7: Deployment of FS System in Scenario A

Two-tier hexagonal cluster is assumed for the deployment of FS. Three FS BSs per cluster are randomly located. It is assumed that all the FS BSs maintain the minimum inter-site distance (Table 1). To prevent the co-channel interference between FS links, different FS channels are used between FS links in the same cluster. The frequency reuse factor is 3 when considering to the inter-cluster interference.

Interference level is calculated by

$$I_{total} = I_{co} + I_{adj} + I_{UE},$$

where I_{co} , I_{adj} , and I_{UE} are the interference level from the co-channel FS link, adjacent channel FS link, and mobile UE, respectively. Each interference level is calculated by

$$\begin{aligned} I_{co} &= \sum_{i \in L_{co}} P_i A_{FS}(\theta_i) PL_i A_{FS}(\theta_i), \\ I_{adj} &= \sum_{j \in L_{adj}} P_j A_{FS}(\theta_j) PL_j A_{FS}(\theta_j) / ACLR_j, \\ I_{UE} &= \sum_{k \in L_{UE}} P_{UE,k} A_{UE}(\theta_k) PL_k A_{FS}(\theta_k), \end{aligned}$$

where L_{co} , L_{adj} , and L_{UE} are the sets of interfering link with FS co-channel, FS adjacent channel, and mobile UE, respectively. P_i is transmitter power of FS Sub-CS, and P_{UE} is the unwanted emission of mobile UE to FS channel. $A_{FS}(\theta)$ and $A_{UE}(\theta)$ are Tx/Rx antenna gains of the FS and mobile UE, respectively. PL is the pathloss between the victim and interferer. $ACLR_j$ is the Adjacent channel loss ratio (ACLR) of mobile UE to j -th adjacent FS channel.

C.3.2 Scenario B: Adjacent channel interference from the mobile UEs to FS in the same area

The sharing study for Scenario B is a statistical analysis to account for the random locations of mobile UE's. Deployment of mobile UEs in Scenario B is different from that in Scenario A by deploying FS and MS in the geographically same area but assuming operation on different frequencies. Mobile UEs are randomly deployed based on the given number of mobile UEs as shown in Figure C-8. The ACLR of the mobile UE to the FS channel is calculated based on the spectrum emission mask of MS UE in Figure C-6. In the case of no guard bands between the FS and MS systems, the ACLRs of the first, second, third, and fourth adjacent FS channels are 38dB, respectively. For every FS link, the aggregated interference from mobile UEs is added to the interference of FS receiver.

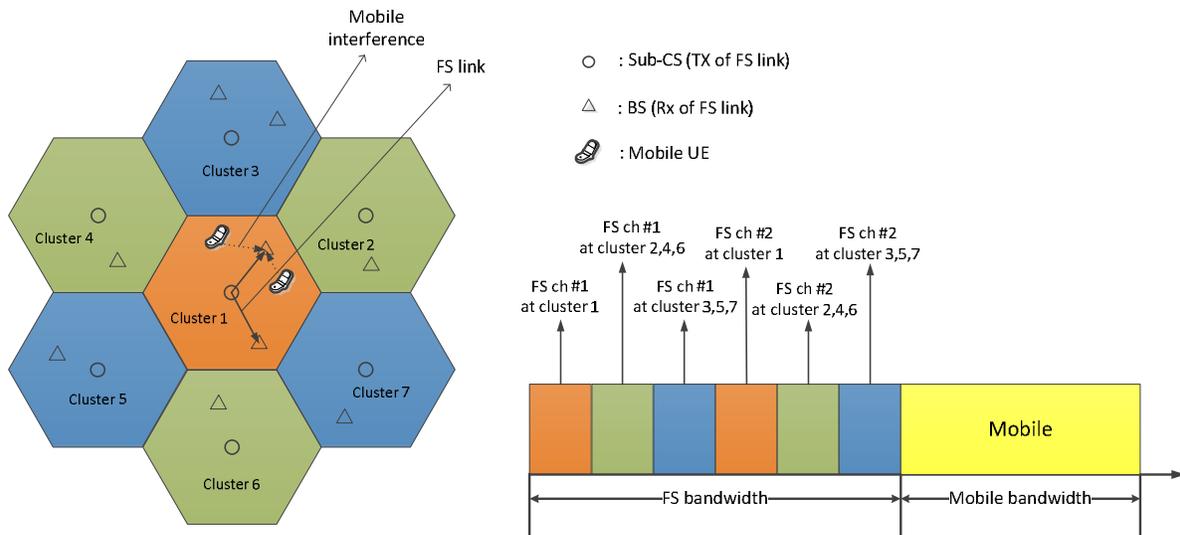


Figure C-8: Deployment of Scenario B

C.3.3 Scenario C: Co-channel interference from the mobile BS to FS in separate areas

In Scenario C, deterministic analysis is applied to derive the minimum distance between the mobile BS and FS. A single pair is considered, i.e., there is one desired FS link and one interfering mobile link. In order to consider the worst case, the azimuth between the mobile BS antenna and FS antenna is 0 degrees, and the FS receives the desired signal at the edge of the FS cluster. The distance between the FS and interfering mobile BS is defined as R (the cell radius in meter), and the angle is defined as θ (in degree). As shown in Figure C-9, when the FS is located at the edge of a cluster, the interference level from mobile BS is calculated according to R and θ between the FS and mobile BS. Finally, C/I is derived in order to analyze the impact of the interference from the mobile link to the FS link at the same region.

The C/I can be derived by

$$C/I(\text{dB}) = \text{Minimum desired signal level of FS (dBm)} - \text{Interference level (dBm)}$$

A mobile BS is separated from FS system with the protection distance and uses co-channel frequency with the FS system. It is also assumed that the minimum desired signal level and interference levels as follows.

- Minimum desired signal level is found by

Minimum desired signal level

$$\begin{aligned}
 &= \text{Tx power level of FS Sub-CS} \\
 &\quad + \text{Tx antenna gain of FS Sub-CS} \\
 &\quad + \text{path loss between FS Sub-CS and cluster-edge FS} \\
 &\quad + \text{Rx antenna gain of FS} \\
 &= 47 \text{ dBm} + 38 \text{ dB} - 159.2 \text{ dB} + 38 \text{ dB} = -36.2 \text{ dBm}.
 \end{aligned}$$

- Interference level is found by

Interference level

$$\begin{aligned}
 &= \text{Tx level of mobile BS} \\
 &\quad + \text{Tx antenna gain of mobile BS} \\
 &\quad + \text{path loss} \\
 &\quad + \text{Rx antenna gain of FS BS to the direction of mobile BS.}
 \end{aligned}$$

The Tx level of mobile BS is assumed by 37 dBm which represents a pico cell BS. The Tx antenna gain of the mobile BS is a maximum of 21 dBi in the worst case, the azimuth between mobile BS antenna and FS antenna is 0 degrees. Rx antenna gains of FS of Case 1 (sidelobe) and Case 2 (main beam) are -17 dBi and 38 dBi according to the antenna angle between the FS link and mobile link, respectively.

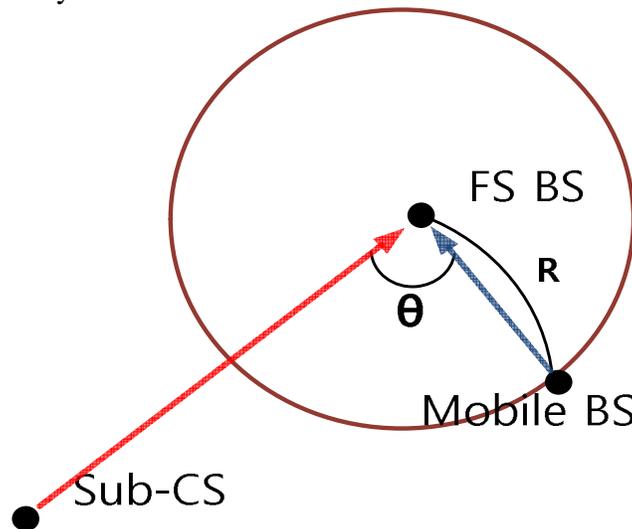


Figure C-9: Deployment Scenario C

C.3.4 Scenario D: Adjacent channel interference from the mobile BS to FS in the same area

In Scenario D, a single pair, i.e., one desired FS link and one interfering mobile link, is considered and deterministic analysis is applied to derive the minimum distance between the mobile BS and FS. The ACLR is considered as 3.5 dB which is the first adjacent FS channel ACLR. In common with Scenario C, the C/I is derived in order to analyze the impact of the interference from the mobile link to the FS link in the same region.

C.4 Results

In this sharing study we adopt the signal to noise ratio (SNR) as the performance metric to consider the impact of the interference. In practical FS, when the desired FS signal has a large link margin the FS is more robust to interference. SNR represents a more reasonable metric as for interference, and its use addressed in Recommendation ITU-R F.758. When the minimum Rx signal level to meet 10^{-6} BER is -67.21 dBm, the receiver noise level taking into account for interference is -90.71 dBm receiver noise level η . Therefore, the SNR can be derived by

$$S/N = \text{minimum Rx signal level} - \text{receiver noise level} = 23.5 \text{ dB.}$$

We also consider the carrier to interference ratio (C/I) in order to assess the effect of the additional interference caused by the MS compared to existing FS interference.

C.4.1 Scenario A: Co-channel interference from the mobile UEs to FS BS in separate areas

Figure C-10 shows the C/I distribution of FS links in the presence of the interference from mobile UEs. The cumulative distribution function (CDF) gaps between only the FS interference cases and FS plus mobile UE interference cases are small at low C/I regions. However, at high C/I region (> 40 dB), the mobile UE interference impact on an FS Rx is more significant. This trend is more serious for the low protection distance case.

From the simulation results for Scenario A, the impact of mobile UE co-channel interference depends on the protection distance. At the C/I of 23.5 dB, we compute the CDF for self-interference from FS to be 3.7%. The CDF of FS self-interference plus mobile UE interference with a 100m protection distance is 4.4%. The CDF with a 500m protection distance, 1km protection distance and 5km protection distance is 4.3%, 4.3% and 3.9% respectively. The CDF of 10km protection distance is 3.7%, which is similar to CDF of only the FS interference cases.

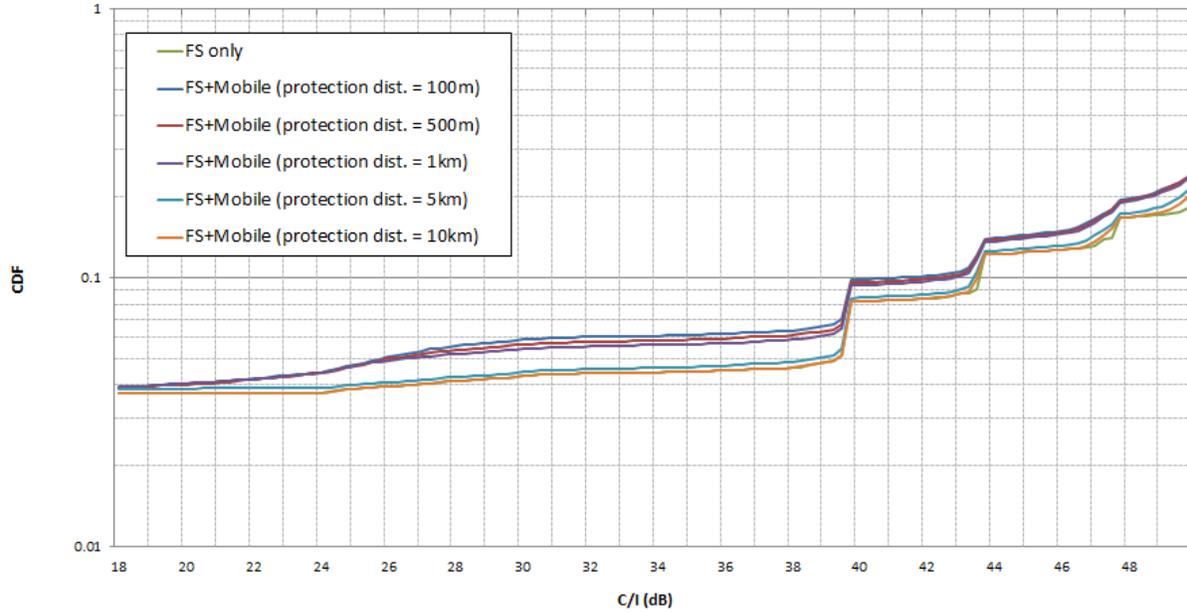


Figure C-10: Results of Scenario A

C.4.2 Scenario B: Adjacent channel interference from the mobile UEs to FS BS in the same area

Figure C-11(a) shows the C/I distribution of FS links in Scenario B. CDF gaps between only the FS interference case and FS plus mobile UE interference gradually increase as C/I to increase. Figure C-11(b) shows the desired FS signal levels, interference levels from other FS link, and interference levels from mobile UEs in Scenario B. The interference levels from other FS links are much more widely distributed than the interference from the mobile UE, and two CDF curves are crossed near -98 dBm.

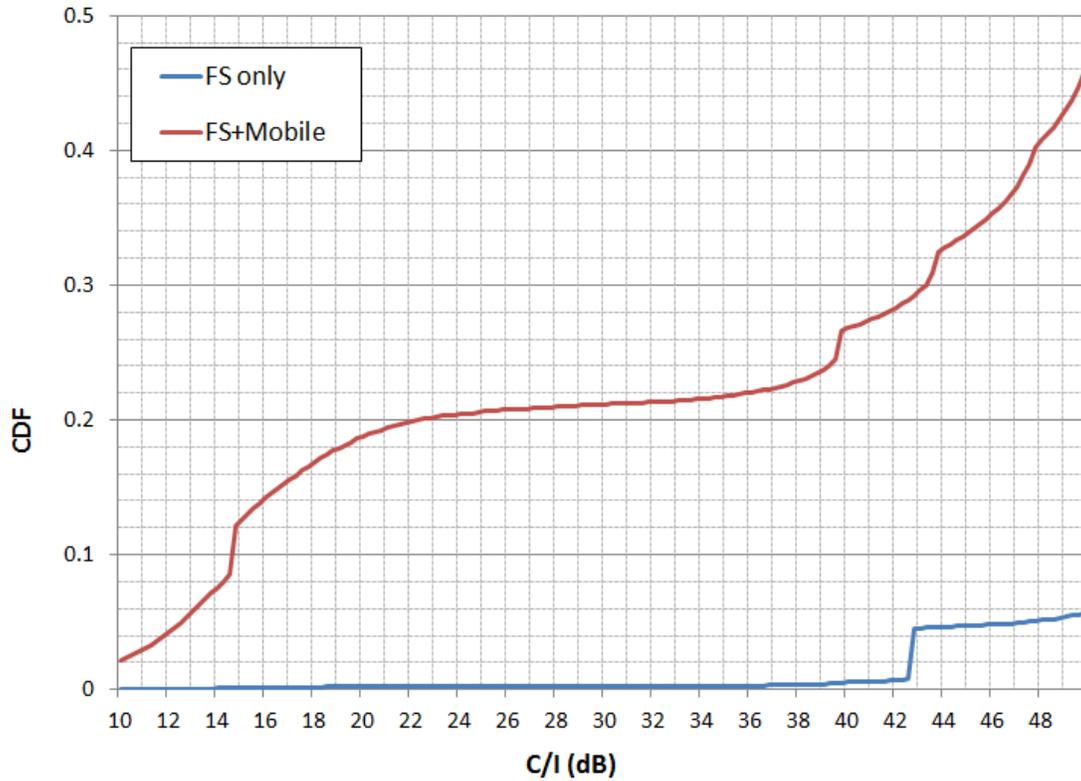


Figure C-11(a): Results of Scenario B - CDF of C/I FS links according to interference types

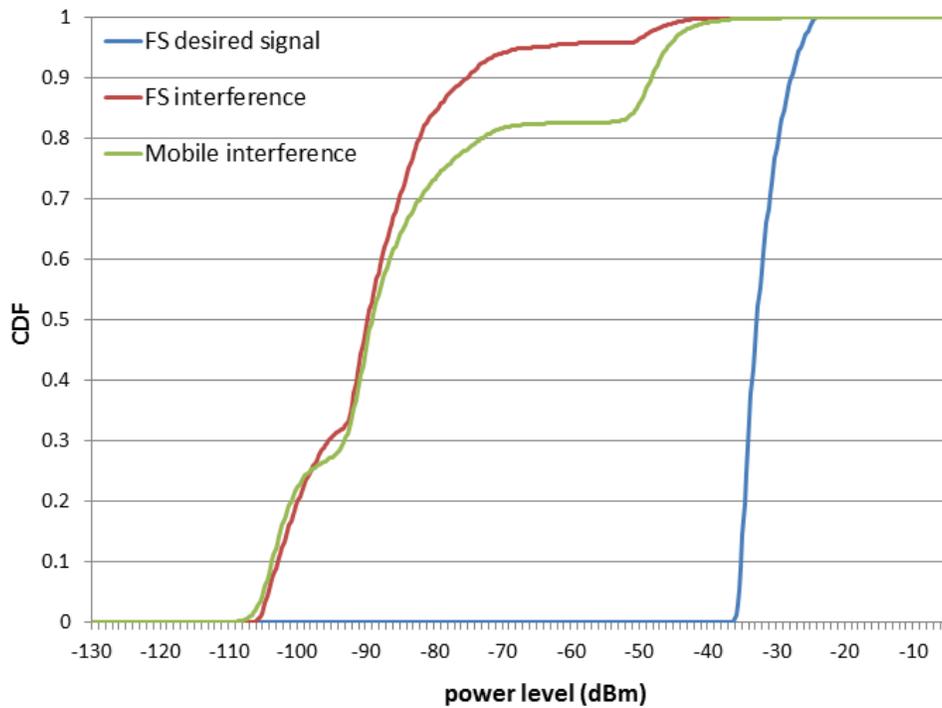


Figure C-11(b): Results of Scenario B - Signal power level for FS desired, FS interference, and mobile UE interference

C.4.3 Scenario C: Co-channel interference from the mobile BS to FS in separate areas

In Scenario C, the C/I of the FS against one mobile BS is computed by the equation addressed in section 4.3.

$$\begin{aligned}
 C/I(\text{dB}) &= \text{Minimum desired level of FS BS (dBm)} \\
 &\quad - \text{Interference level from mobile BS (dBm)} \\
 &= -36.2 \text{ dBm} \\
 &\quad - [\text{BS transmitter power} \\
 &\quad \quad - \text{path loss} \\
 &\quad \quad + \text{Tx antenna gain of mobile BS} \\
 &\quad \quad + \text{Rx antenna gain of FS}] \\
 &= -73.2 \text{ dBm} \\
 &\quad + \text{path loss} \\
 &\quad - \text{Tx antenna gain of mobile BS} \\
 &\quad - \text{Rx antenna gain of FS}
 \end{aligned}$$

The minimum receiver level of FS and mobile BS Tx power are fixed regardless of the protection distance. Path loss varies according to the protection distance. Figure C-12(a) shows the C/I of an FS link according to the location of mobile BS. If the mobile BS is located near the FS or around a line segment between the FS Sub-CS and FS, the C/I value of the FS link is very low because of the narrow beam width of the FS antenna as shown in Figure C-4. Therefore, it is recommended that the mobile BS should not be located within a protection area where the C/I is less than 23.5 dB as shown in Figure C-12(b).

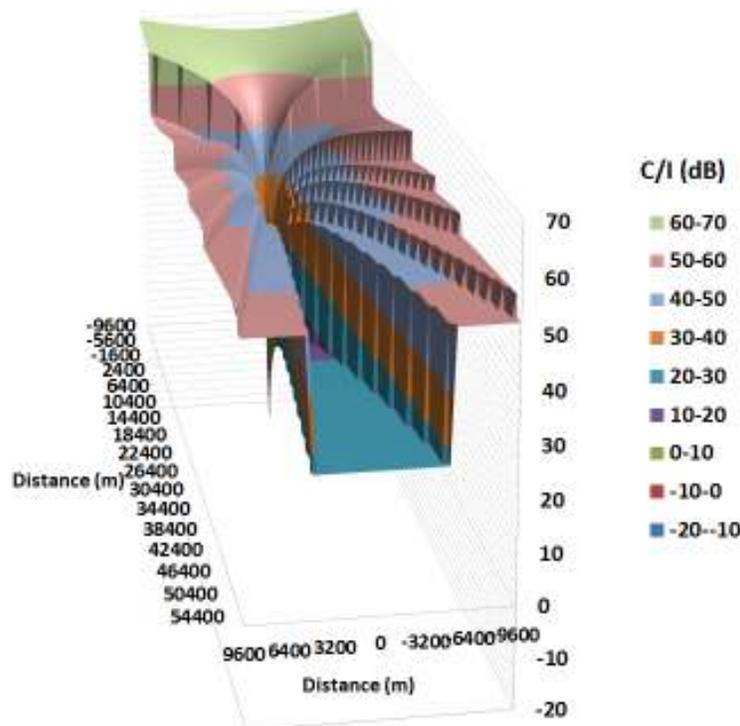


Figure C-12(a): Results of Scenario C - C/I values of FS link according to mobile BS location

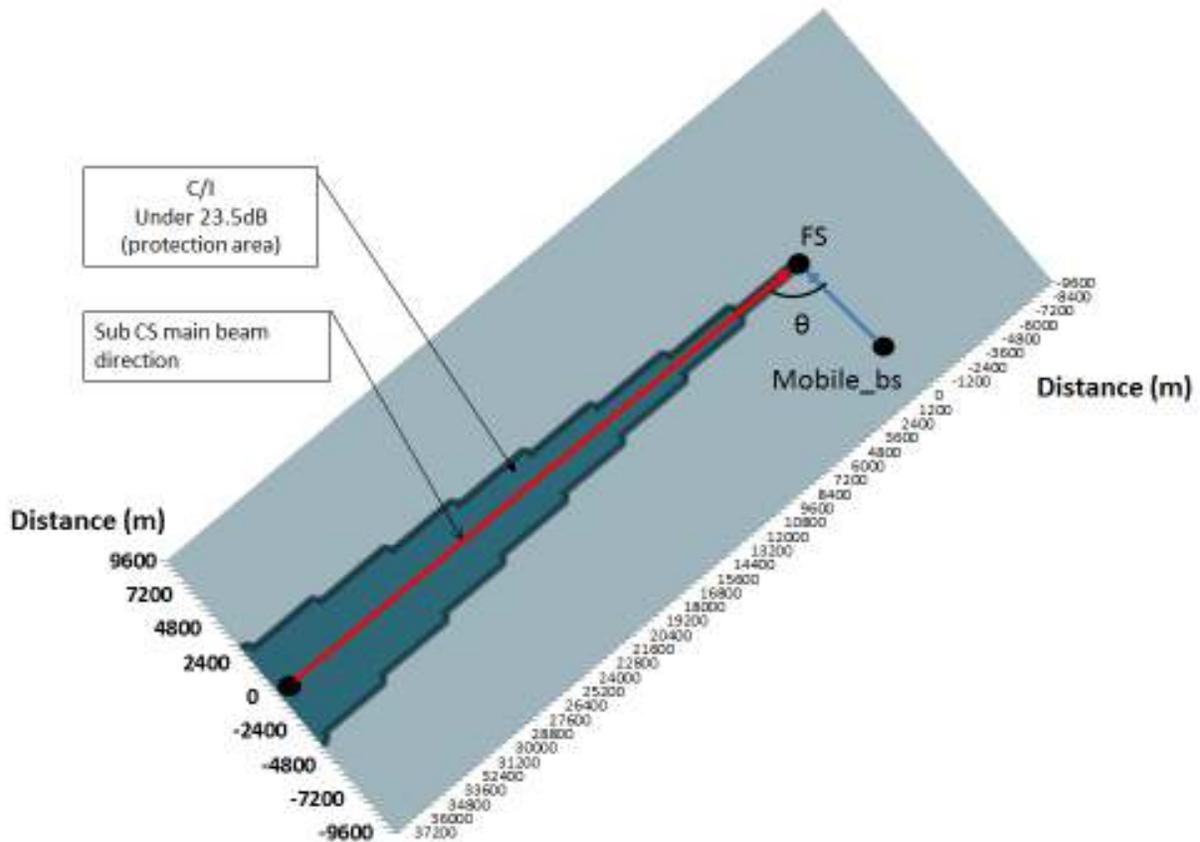


Figure C-12(b): Results of Scenario C - Protection area to prevent outage FS link ($C/I < 20.5$ dB)

C.4.4 Scenario D: Adjacent Channel interference from the mobile BS to FS in the same area

Figure C-13(a) shows the C/I of an FS link according to the locations of mobile BS. If the mobile BS is located around a line segment between the Sub-CS and FS, the C/I of the FS link is very low because of the narrow beam width of the FS antenna as shown in Figure C-4. Therefore, it is recommended that the mobile BS should not be located within a protection area where the C/I is below 23.5 dB as shown in Figure C-13(b).

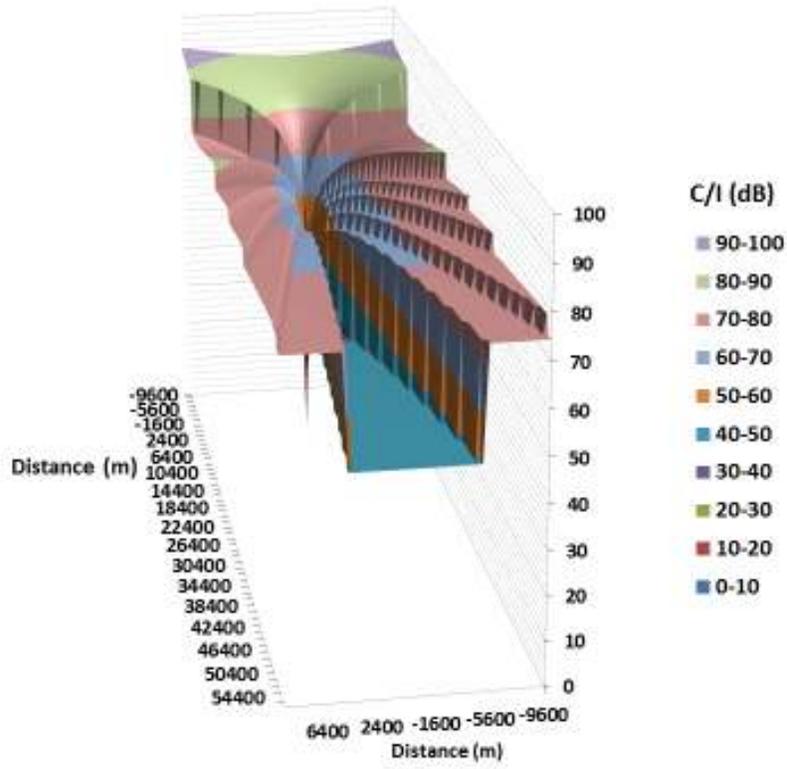


Figure C-13(a): Results of Scenario D - C/I values of FS link according to mobile BS location

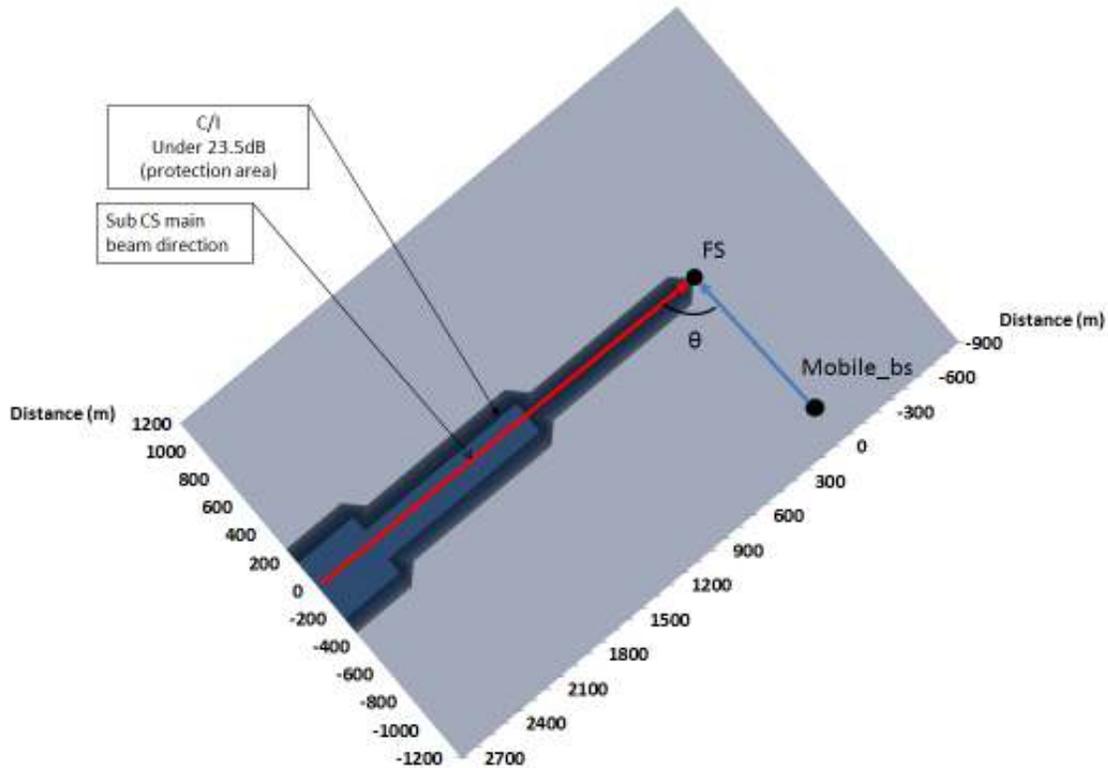


Figure C-13(b): Results of Scenario D - Protection area to prevent outage FS link ($C/I < 23.5$ dB)

C.5 Summary

We have analyzed the interference from the MS to FS in the frequency band of 38.6-40 GHz. Four interference scenarios are considered according to the frequency and geographic deployment of the two services. The outage criterion of the SNR in an FS receiver is 23.5 dB to meet 10^{-6} BER.

In Scenario A and B, the percentages for the FS SNR outage in the presence of interference from the mobile UE is increased by 0.7% for the 100m protection distance. In the protection distance less than the 1km, the percentages for the FS SNR outage increased by 0.2% or more. It is negligible to consider the 3.7 % FS SNR outage caused by the existing interference from other FS links. In Scenario C, it is shown that when the FS and MS share the same frequency, the SNR of an FS link exceeds the outage criteria, as long as the mobile BS is not in the area surrounding a line segment between the Sub-CS and FS. Similarly, in Scenario D, it is shown that when the mobile BS is not in the area surrounding a line segment between the Sub-CS and FS BS, the outage criteria of the SNR in an FS link can be met for the adjacent channel deployment.

Appendix D
Compatibility Studies Between Mobile Broadband Uses and Incumbent Services (Fixed Satellite Service) in Bands Adjacent to LMDS

This Appendix provides a preliminary assessment of the potential for interference between a mobile broadband system deployed in adjacent frequencies to a Fixed Satellite uplink service. The LMDS bands at 27.5-28.35 GHz are adjacent to GSO/FSS uplink operation in the 28.35-28.6 GHz band.

D.1. System parameters

A fixed satellite service (“FSS”) in the band 30 GHz band is used as a feeder link paired with a downlink in the 19 GHz band. The general parameters of the fixed satellite service is described in ITU-R recommendation S.1329 Annex 2. There are two kind of fixed satellite service according to type of antenna of Earth station, Very Small Aperture terminal and Large Terminal. Those technical parameters for study are shown in Table D-1.

Table D-1: Technical parameter for FSS (ITU-R Rec. F.1329)

Parameter	Very Small Aperture Terminal (VSAT)	Large terminal (LT)
Modulation	QPSK	QPSK
SNR / Minimum link $E_b / (N_0 + I_0)$	8.0	20
Typ/data rate (Mbit/s)	0.384	120
Satellite antenna peak gain (dBi)	45	51
Satellite antenna mask	Rec. ITU-R S.672	Rec. ITU-R S.465
E/S antenna (dBi)	45	60.5
Elevation angle (degree)	9.63	
Satellite altitude (km)	35,785.8 at Longitude 140 W	
E/S antenna mask	Rec. ITU-R S.672	Rec. ITU-R S.465
Noise temperature (K)	600	900
Tx power (dBW)	-10 ~ 0	Max 22
Adaptive power control	Yes	No

In this analysis it is assumed that satellite earth stations are located around New York City (latitude 40.792 N, longitude 73.96 W) and communicating with a GSO satellite located at 140 W. This represents worst case aggregate interference due to the low elevation angle from the mobile BS.

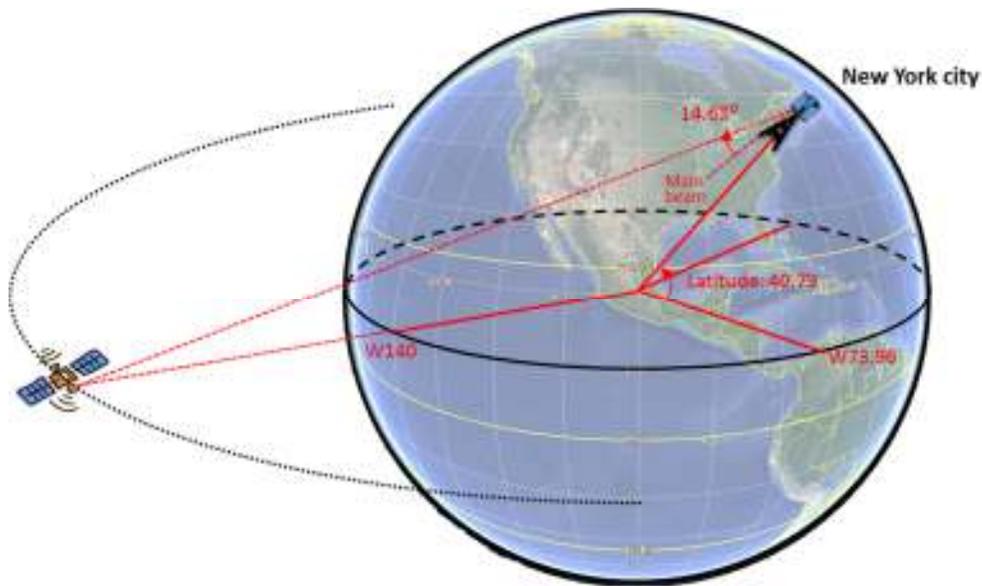
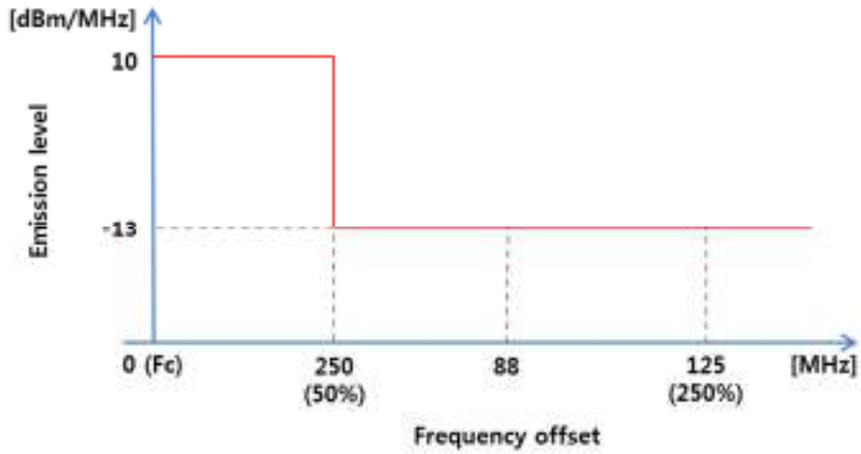


Figure D-1: Base station elevation angle to space station of FSS

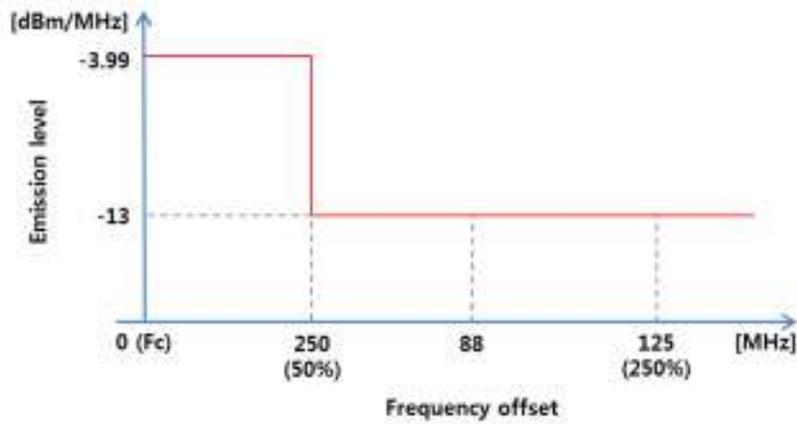
The technical parameters of mobile system and other parameters used in this study are shown below in Table D-2 and D-3.

Table D-2: Technical parameters of mobile system (General IMT parameter)

Parameter	Base station	Terminal
Tx power (dBm)	37	23
Antenna gain (dBi)	21 (main beam) -6.37 (to space station)	7
Spectrum emission mask	See figure D-2(a)	See figure D-2(b)
Adjacent channel leakage ratio (spectrum emission mask) at 40 MHz offset (dBr)	23	9.01
Antenna downtilt (degree)	5	N/A
Antenna pattern	F.1336 (15 degree for V)	Omni direction



(a) Base station



(b) Terminal

Figure D-2: Spectrum emission mask of MS system

The vertical antenna gain of mobile base station (MS BS) is referred in ITU-R F.1336 and is shown in Figure D-3.

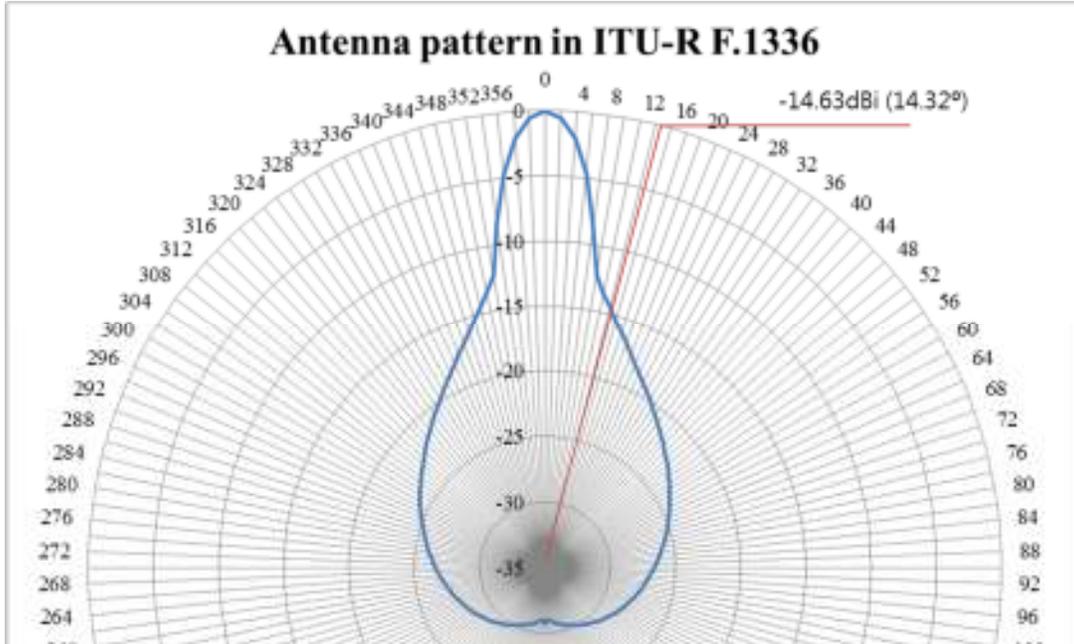


Figure D-3: The vertical antenna gain of mobile base station to space station of FSS

The antenna gain of MS BS in the direction of the space station of the FSS is 6.37 dBi (21 dBi-14.63 dB).

Table D-3: Other additional parameters

Parameter	Values
Carrier frequency	28,000 MHz (Adjacent-channel for FSS(E-S) and Mobile)
Slant range	40,658 km
Path loss model	Free space loss (32.44+20*log ₁₀ (freq (MHz)) + 20*log ₁₀ (dist. (km)))
Atmosphere loss (dB)	-1.0
Weather	Clear

D.2. Methodology

The compatibility study is conducted with deterministic analysis. The deterministic analysis is basically considered as the worst interference environment from mobile system and the fixed satellite system.

The desired received signal from earth station to space station is calculated as

$$P_{\text{space_rx}} = P_{\text{earth_station_tx}} + G_{\text{earth_station_ant}} + \text{Path loss} + \text{Atmosphere loss} + \text{Pointing/Polarization loss} + G_{\text{space_ant}}$$

Where,

- P_{space_rx} : Received power in space station
- $P_{earth_station_tx}$: Transmitting power of earth station
- $G_{earth_station_ant}$: Antenna again of earth station
- G_{space_ant} : Antenna again of space station

The received interference signal from mobile system to space station from earth station is calculated as

$$I_{space_rx} = I_{mobile_tx} - I_{mobile_ACLR} + G_{mobile_ant} + G_{mobile_ant\ pattern} + Path\ loss + Atmosphere\ loss + Pointing/Polarization\ loss + G_{space_ant}$$

Where,

- I_{space_rx} : Received interference power from the mobile station in space station
- I_{mobile_tx} : Transmitting power of mobile station
- I_{mobile_ACLR} : MS ACLR at adjacent band to FSS
- G_{mobile_ant} : Antenna again of mobile station
- $G_{mobile_ant\ pattern}$: Antenna pattern gain of mobile station for direction to space station

The ratio of the desired signal to N aggregated interference signal level including noise is calculated as

$$\frac{Desired\ signal}{Interference\ signal + Noise} = 10 \times \log_{10} \frac{P_{space_rx}}{N_0 + N \times I_{space_rx}}$$

D.3. Result of deterministic analysis.

Based on equations above, the space station of FSS when communicating with a VSAT receives a desired signal, -160.41 dBm/Hz. The interference level from a single Mobile BS is -236.1 dBm/Hz and from a single a Mobile MS is -233.57 dBm/Hz.

The space station of FSS when communicating with a LT receives desired signal, -131.86 dBm/Hz. The interference level from a single Mobile BS is -230.19 dBm/Hz and from a single Mobile MS is -230.19 dBm/Hz.

Table D-4: Calculation of interference level from MS in FSS space station receiver

Parameter	Fixed satellite		Mobile	
	VSAT	LT	BS	UE
Tx power (dBm)	20	52	37	23
Antenna gain (dBi)	45	60.5	21	9
ACLR of MS (dB)	-	-	23	9.01
Antenna elevation angle of earth station	0 (Main beam)	0 (Main beam)	14.32	-
Bandwidth (MHz)	0.384	120	500	500
Normalized tx power to the band of FSS (dBm/Hz, EIRP)	9.16	31.71	-66.62	-64.00
Path loss + Atmosphere (dB)	-214.57			
Received signal power in Space (dBm/Hz)	-205.41	-182.86	-281.19	-278.57
Pointing/Polarization in Space (dB)	-0.9	-0.9		
Receiver antenna gain in Space (dB)	45	51		
Input power in Space receiver (dBm/Hz)	-160.41	-131.86		
Normalized noise power (dBm/Hz)	-170.82	-169.06		
Interference signal from a MS BS (dBm/Hz)	-236.19	-230.19		
Interference signal from a MS UE (dBm/Hz)	-233.57	-227.57		

† The angle from the main beam of the mobile station to the space station of FSS

If the aggregated interference is considered, the SNR of the desired signal to total interference (from N simultaneous transmitters) should be 20 dB for LT or 8dB for VSAT from MS to FSS space station

$$10 \log_{10} \frac{10^{P_{space_rx}/10}}{10^{N_0/10} + N \times 10^{I_{space_rx}/10}} \geq \text{SNR of FSS (20dB for LT or 8dB for VSAT)}$$

$$N \leq \frac{10^{P_{space_{rx}}/10} - 10^{(SNR+No)/10}}{10^{(SNR+I_{space_{rx}})}}$$

As a result of these calculations, the maximum aggregated interference numbers for base and mobile stations to secure SNR of FSS uplink are summarized at Table D-5.

Table D-5: Max aggregated interference number of Mobile service to avoid interference to FSS uplink

	VSAT	LT
Maximum Number of Base Stations	2,552,459	66,747,522
Maximum Number of Mobile Station	1,396,236	36,511,960

Appendix E
Compatibility Studies Between Mobile Broadband Uses and Fixed Satellite Service in the 39.5-40 GHz

According to ITU-R Rec. F.1557, the power flux density level (pdf_↓) in the earth station receiver of FSS system must be greater than or equal -105 dB(W/(m²·MHz)) and -95 dB(W/(m²·MHz)) for the 3m gateway users (Large terminal) and for VSAT (Very small aperture terminal), respectively. It is derived parameters below Table E-1 and the equation.

$$pdf_{\downarrow} = \left(\frac{E_b}{N_0 + I_0} \right) - 10 \log \left(\frac{sps}{bps} \right) - 20 \log(D) - 10 \log(\eta) + (N_0 + I_0) + 61.05 + L_{atm/scin} + L_p + EOC + M_{fade} + M_{system}$$

where,

$$N_0 = -228.6 + 10 \log_{10}(T_{rx} + T_{rain}), \text{ thermal noise density}$$

$$T_{rx} = 10 \log(kTBF)$$

$$T_{rain} = 280(1 - 10^{-0.1(\text{Rain fade margin})})$$

$$\frac{I_0}{N_0} = 10 \log_{10}(10^{\text{degradation due to self interference}/10} - 1)$$

sps: symbol rate (Msymbols) = Bandwidth of satellite system

bps: bit rate

Table E-1: The Parameter for pdf_↓

Parameters	Value
Rain fade margin (Train)	18 dB
Earth terminal receive noise temperature(T)	800K
Pointing loss (L_p)	0.7 dB
Atmospheric and scintillation loss ($L_{atmo/scin}$)	1.2 dB
Earth station receiver noise temperature	1m for VSAT, 3m for gateway.
Degradation due to self-interference	1.5 dB
I/N by degradation due to self-interference	-3.84 dB
Edge of Coverage (EOC)	3.5 dB
Antenna efficiency (η)	70%
Center frequency	40 GHz
System margin of FSS system (M_{system})	2 dB
Required E_b/N_0	OBP ¹ : QPSK=7 dB BP ² (Transparent transponder): QPSK=10 dB

¹ OBP: On Board Processor

² BP: Bent-Pipe

With those parameters, the allowable interference level in front of antenna in FSS earth station to project FSS earth station can be calculated as follows:

$$pdf_{interference} \leq 10 \log \left(10^{0.1 * (pdf_{desired} - (\frac{E_b}{N_0 + I_0}) - 10 \log(\frac{bps}{spS}) - M_{system})} - 10^{0.1 * (N_0 - GrxE/S)} - 10^{0.1 * (I_0 - GrxE/S)} \right)$$

As the result of calculation, when the large terminal earth station receives a minimum required signal level of -105 dB(W/(m²·MHz)) the allowable receiver interference should be less than -120.2 dB(W/(m²·MHz)) or -132.5 dBm/MHz.

Similarly, when the very small aperture terminal receives a minimum requirement signal level of -95 dB(W/(m²·MHz)) the allowable receiver interference should be less than -107.0 dB(W/(m²·MHz)) or -119/3 dBm/MHz.

The technical parameters for mobile system are summarized as Table E-2.

Table E-2: Technical parameters of mobile system (General IMT parameter)

Parameter	Base station	Terminal
Tx power (dBW)	Max 7	-7
Antenna gain (dBi)	21	9
Bandwidth (MHz)	500MHz	
Antenna downtilt (degree)	5	0
Adjacent channel leakage ratio (FCC rule 101.111(a)(2))	23dB	9.01dBr
Antenna pattern	F.1336 (15 degree for V)	Omni direction

The transmit power of mobile system to adjacent FSS band is -22 dBW/MHz and -34 dBW/MHz for Base station and mobile station, respectively

Therefore, the required minimum coupling loss between mobile Base station transmitter and earth station should be more than 110.5 dB and 98.5 dB in order not to cause significant interference to the 3 m gateway user and for VSAT, respectively. Those required minimum coupling loss can be achieved with a 1 km separate distance from Mobile base station deployed in dense urban and antenna direction coordination of Mobile base station.

The required minimum coupling loss between mobile UE transmitter and earth station should be more than 98.5 dB and 85.3 dB not to cause significant interference to the 3 m gateway user and for VSAT, respectively. Those required minimum coupling loss can be achieved with a 1 km separate distance from Mobile UE.