IEEE

International Network Generations Roadmap

-2021 Edition-

Millimeter Wave and Signal Processing

IEEE Future NETWORKS

An IEEE 5G and Beyond Technology Roadmap

futurenetworks.ieee.org/roadmap

Wi-Fi® and Wi-Fi Alliance® are registered trademarks of Wi-Fi Alliance.

The IEEE emblem is a trademark owned by the IEEE.

"IEEE", the IEEE logo, and other IEEE logos and titles (IEEE 802.11™, IEEE P1785™, IEEE P287™, IEEE P1770™, IEEE P149™, IEEE 1720™, etc.) are registered trademarks or service marks of The Institute of Electrical and Electronics Engineers, Incorporated. IRDS™ is a trademark of IEEE. All other products, company names or other marks appearing on these sites are the trademarks of their respective owners. Nothing contained in these sites should be construed as granting, by implication, estoppel, or otherwise, any license or right to use any trademark displayed on these sites without prior written permission of IEEE or other trademark owners.

Ericsson is one of the registered trademarks or trademarks of Telefonaktiebolaget LM Ericsson.

"IBM", the 3 letters in text, is both a trademark of International Business Machines Corporation, and an abbreviation of its company name.

Nokia is a registered trademark and service mark of Nokia, Inc.

The “Samsung” name, the “Samsung logo” and all related names, logos, product and service names, designs and slogans are trademarks of Samsung Electronics Co., Ltd. or its affiliates or licensors.

Copyright © 2021

This edition of the INGR is dedicated to the memory of Earl McCune Jr., who left us tragically and too soon on 27 May 2020. Earl was a microwave/RF guru, brilliant technologist, major industry/IEEE contributor, global visionary, keen skeptic, and all around fantastic human being. He was a major contributor to the INGR’s early work on energy efficiency, millimeter-wave, and hardware. He worked for a technologically advanced yet more energy efficient world, and the contents of the INGR are a tribute to that vision. Rest in peace, Earl!

.

Table of Contents

1. Introduction 1
1.1. Working Group Vison 1
1.2. Scope of Working Group Effort 2
1.3. Linkages and Stakeholders 2
1.4. Cross Teams 5
1.4.1. Applications and Service WG 5
1.4.2. Satellites WG 5
1.4.3. Testbed WG 6
1.4.4. Massive MIMO WG 6
1.4.5. Standards WG 6
1.4.6. Dynamic Spectrum Sharing Community 6
1.4.7. Verticals Community 6
1.4.8. IEEE Technical Activities Operating Units 7
1.4.9. IEEE International Roadmap For Devices and Systems (IRDS) 7
2. Today's Landscape 7
2.1. Propagation Models and Frequency Bands 11
2.2. 5G Use Cases 13
2.3. Architectures for 5G Millimeter-Wave RF-Front-Ends 13
2.4. Current Development in Heterogenous Integration for 5G 16
3. Future State 19
3.1. 6G Use Cases 20
3.2. Active Device Technology for 5G and Beyond 22
4. Needs, Challenges, and Enablers and Potential Solutions 24
4.1. Key Message – High Bandwidth Channels to Support the 5G Use Cases 24
4.2. Passive Components – Filters, Diplexers, Interconnects etc. to Support Multiple Bands Through 6 GHz and mm-Waves 27
4.3. Active Components – LNA, PA, PS, Switches, Mixers 29
4.4. Design for Test 33
4.5. Design for Multiple Use Cases With Reconfigurable Hardware 34
4.6. Design for mmWave communication for the last mile 34
4.7. Design for mmwave base stations and mesh-networked terminals 38
4.8. Design for mmWave handsets 39
5. Conclusions and Recommendations 42
5.1. Summary of Conclusions 42
5.2. Working Group Recommendations 42
6. Contributors 44
7. References 45
8. Acronyms/Abbreviations 47

Tables

Table 1. Key Performance Metrics Comparison Between 4G and 5G [7]. 10
Table 2. NR Operating Bands in FR2 11
Table 3. Comparison of Substrate Materials [19].....18
Table 4. Millimeter-Wave and Signal Processing Needs, Challenges and Potential Solutions.....25
Table 5. IEEE IRDS Outside Connectivity – Difficult Challenges 26
Table 6. Passive Circuits Needs, Challenges, and Potential Solutions 27
Table 7. Active Circuits Needs, Challenges and Potential Solutions.....30
Table 8. Group III-V Compound Semiconductors Potential Solutions (IRDS) [23].....30
Table 9. Design for Test Needs, Challenges and Potential Solutions 33
Table 10. Design for Multiple Use Case Needs, Challenges and Potential Solutions.....34
Table 11. mm-wave Fixed Communication for the Last Mile: Needs, Challenges, Enablers and Possible solutions 35
Table 12. mm-wave Based Stations and Mesh-Networked Terminal: Challenges, Enablers and Possible solutions 38
Table 13. mm-wave Headsets: Challenges, Enablers and Possible solutions.....41

Figures

Figure 1. Overall 5G Architecture [1] 3
Figure 2. 3GPP Architecture for 5G Use Cases 3
Figure 3. Information Flow with Other INGR Stakeholders....5
Figure 4. 3GPP Timeline to Evolve 5G and Beyond [3]....7
Figure 5. Evolution of 5G Standards in 3GPP [2]. 8
Figure 6. Why Millimeter-Waves? [5] 9
Figure 7. 4G/5G Mobile Networks – Small Cells, Edge Servers, Wireless BackHaul and Multi-tier Architecture [9] 11
Figure 8. Atmospheric Absorption of EM Waves at Sea Level vs. Frequency [9] 12
Figure 9. 5G Spectrum Across National Borders....12
Figure 10. 5G Use Cases [10] 13
Figure 12. Challenge of Tight Integration for mm-Wave Phased Arrays [13] 15
Figure 13. Challenge of Appropriate Semiconductor Technology for Required Output Power (Asbeck) [14]..15
Figure 14. Increasing Complexity from 4G to 5G Will Drive Further FEM Integration and Packaging Challenges [15] 16
Figure 15. Advanced Substrates Technology Suitable for 5G (Yole) [16] 17
Figure 16. Advanced Packaging Industry Market Status (Yole) [17] 17
Figure 17. Comparison of Substrate Technologies for 5G/Millimeter-wave Applications (GaTech) [18] 18
Figure 18. From 5G to Beyond 5G Services – Ericsson [21]....19
Figure 19. Basic Pillars Enabling Future Smart Society (Oulu) [20] 20
Figure 20. Mega-Trend Toward 6G: Super-enhanced Mobile Broadband [2] 21
Figure 21. Mega-Trend Toward 6G: Enhanced Latency, Positioning and Connectivity [2]....21
Figure 22. “Super-Enhanced” eMBB, M2M and URLLC + Precision Positioning and AI – 6G Core Services by 2030 [2] 22
Figure 23. Link Level Performance Study Between 28-Ghz and 73-GHz LoS Channel [22] 23
Figure 24. Example of Glass Substrate for Low-Loss mmWave Filters (GaTech) [18]....28
Figure 25. High Performance BPF at 28- and 39-GHz Demonstrates How 5G RFFE Requirements Can Be Met (GaTech) [18]....28
Figure 26. Antenna in Package (AiP) development Trends (ASE) [24]....29
Figure 27. Stacked Substrate AiP Supports 28-, 39- and 60GHz with Excellent Gap Control and Alignment (ASE) [24]....29
Figure 28. GaTech PA Survey (V3) Psat vs. Frequency [25] 31
Figure 29. GaTech PA Survey (V3) – Peak PAE vs. Psat [25]....31
Figure 30. Antenna Performance Need to be Optimized for Gain, BW and Radiation Patterns (IBM) [27] 32
Figure 31. 2x64 Dual-Polarized Dual-Beam Single-Aperture 28 GHz Phased Array with High Cross-Polarization Rejection for 5G Polarization MIMO [26] 32
Figure 32. Millimeter-Wave Full Duplex IC. Note: (a) Polarization-based reconfigurable antenna cancellation concept and (b) the 60GHz SOI CMOS FD transceiver block diagram and chip photo [28]. 33

ABSTRACT

The “Millimeter-Waves and Signal-Processing” Working Group (MMW-SP WG) will examine improvements in current millimeter-wave architectures, hardware capabilities, and signal processing techniques to enable 5G systems to achieve the 3GPP Release 15 requirements for enhanced massive mobile broadband (eMBB), ultra-reliable low-latency communication (URLLC), and massive machine to machine (MM2M) use cases. The WG will translate the requirements for these drivers and describe technical challenges that should be addressed to support the growth of 5G applications within the 3-, 5-, and 10-year timeframes.

Key words:

5G, 6G, 5G and Beyond, millimeter wave (mmWave), mobile handsets, mesh-enabled radios, bandwidth, low latency, radio architecture, high-band, UE, BS, BH, user equipment, base station, bandwidth, low latency, radio architecture, spectral efficiency, energy efficiency, linearity, semiconductor technology, Si, SiGe, GaN, heterogeneous integration, packaging, antenna-in-package, antenna-on-chip, antenna arrays.

This file is a free sample of this chapter.
The full chapter is available exclusively to signed-in participants of the IEEE Future Networks Community.