

Millimeter Wave 2024



Dan McNamara



April 2024

Abstract

A complete view of 5G mmWave from end to end, including architectural details for networks, CPEs, and UEs. Key details of Massive MIMO implementation for high power/long range as well as indoor and repeater solutions are laid out. RF implementation details are illustrated for both RU and handsets, and detailed power consumption and cost analysis shows the likely choices of OEMs. Cost estimates for network and handset/hotspot implementation show the direction for operators. A forecast through 2029 includes RU deployment (macro and small cell), as well as CPEs, repeaters, mobile handsets, hotspots, tablets, and IoT devices.

5G Millimeter Wave 2024

1	EXECUTIVE SUMMARY	9
2	MARKET DRIVERS AND CHALLENGES	12
	NEW USE CASES: METRO/RAIL	13
	FWA AND DATA OFF-LOAD	13
	PRIVATE NETWORKS.....	13
	GENERAL	13
	MMWAVE MARKET STATUS BY REGION	14
3	NEW USE CASE: METRO/RAIL	17
4	SPECTRUM	20
	47-48 GHZ.....	20
	57-71 GHZ.. UNLICENSED SPECTRUM.....	20
	FR3 SPECTRUM INTEREST	21
	SPECTRUM FOR PRIVATE ENTERPRISES.....	21
	STANDARDS STATUS.....	21
5	5G MMWAVE NETWORK STRUCTURE.....	22
	STANDALONE (SA) AND NON-STANDALONE (NSA) FOR MMWAVE NETWORKS	22
	OPEN RAN	23
	BEAMFORMING ARCHITECTURES: ANALOG, HYBRID, DIGITAL.....	23
	STATUS OF 5G UPLINK	25
	... LINK BUDGET FOR FWA	25
	... SMARTPHONE MMWAVE LINK BUDGET	26
6	INFRASTRUCTURE RADIO IMPLEMENTATION	27
	OUTDOOR GNODEB.....	28
	LOW POWER GNODEB	28
	BASE STATION RADIO UNIT (RU) VENDOR COMPARISON.....	29
	MMWAVE RU: DUAL BAND.....	30
	INTEGRATED ACCESS + BACKHAUL (IAB).....	30
	REPEATERS	31
	RIS: RECONFIGURABLE INTELLIGENT SURFACES.....	32
7	CLIENT DEVICE RADIO IMPLEMENTATION	33

	FIXED BROADBAND: CPE IMPLEMENTATION.....	33
	MOBILE BROADBAND: 5G HANDSET IMPLEMENTATION.....	34
	MOBILE BROADBAND: HOTSPOT IMPLEMENTATION	36
8	MMWAVE RF COMPONENTS	37
	RF ARCHITECTURE, IMPLEMENTATION, INTEGRATION	37
	... BEAMFORMING ICs: BFIC	38
	... FILTERS.....	39
	... UP/DOWN CONVERTERS	39
	PHYSICAL INTEGRATION OF RF COMPONENTS	39
	THE COMPLETE RF PORTFOLIO.....	40
9	MILLIMETER WAVE NETWORK OUTLOOK	42
	5G MMWAVE INFRASTRUCTURE.....	43
	PUBLIC VS PRIVATE NETWORK OUTLOOK	45
	O-RAN OUTLOOK.....	45
	MMWAVE NETWORK IMPLEMENTATION OUTLOOK	46
	RF SEMICONDUCTOR FOR MMWAVE RU OUTLOOK	47
	... BEAMFORMER IC (BFIC) OUTLOOK	47
	... UP/DOWN CONVERTER IC (UDC) OUTLOOK.....	49
	5G MMWAVE RU MARKET SHARES.....	51
10	MILLIMETER WAVE REPEATER AND CPE OUTLOOK.....	52
	5G MMWAVE REPEATER OUTLOOK.....	52
	5G MMWAVE FIXED CPE OUTLOOK	53
11	MILLIMETER WAVE MOBILE DEVICE/UE OUTLOOK.....	54
	5G HANDSETS, TABLETS, AND HOTSPOT DEVICES	54
12	COMPANY PROFILES	56
	3D GLASS SOLUTIONS	56
	AIRGAIN.....	56
	AIRSPAN.....	56
	ALTIOSTAR.....	56
	ANALOG DEVICES	56
	ANOKIWAVE (QORVO).....	56
	ARCTIC SEMICONDUCTOR (FORMERLY SITUNE).....	56
	ARQANA TECHNOLOGIES	56
	ASKEY	56

BEAMMWAVE.....	57
CASA SYSTEMS.....	57
DELL.....	57
ERICSSON.....	57
FRTEK.....	57
FUJITSU.....	57
GAPWAVES.....	57
GLOBALFOUNDRIES.....	57
HUAWEI.....	57
INFINEON.....	58
INSEEGO.....	58
INTEL.....	58
MAVENIR.....	58
MICROAMP SOLUTIONS.....	58
MIXCOMM (SIVERS SEMICONDUCTOR).....	58
MOBIX LABS.....	58
MOTOROLA.....	58
MOVANDI.....	59
MURATA/PSEMI.....	59
NEC.....	59
NETGEAR.....	59
NOKIA.....	59
NUVOTRONICS.....	59
NXP.....	59
OTAVA.....	59
PERASO.....	60
PIVOTAL COMMWARE.....	60
QORVO.....	60
QUALCOMM.....	60
QULSAR.....	60
RENESAS.....	60
SAMSUNG.....	60
SIVERS SEMICONDUCTORS.....	61
TAOGLAS.....	61

	VERANA NETWORKS	61
	WISIG	61
	WISTRON	61
	XILINX (AMD)	61
	ZTE	61
13	ACRONYMS	62
14	RELATED RESEARCH BY MOBILE EXPERTS	65
15	METHODOLOGY	66

CHARTS

Chart 1: Forecasted 5G mmWave network and user device shipments through 2029	11
Chart 2: Forecasted 5G mmWave RUs, by Application	14
Chart 3: 5G mmWave RU Shipments, 2023-2029	42
Chart 4: 5G mmWave RU units shipped, by frequency range, 2023-2029	43
Chart 5: 5G mmWave RU shipments by world region, 2023-2029	44
Chart 6: 5G mmWave RU shipments, by indoor vs outdoor, 2023-2029	44
Chart 7: 5G mmWave RU shipments, Private vs Public Network, 2023-2029	45
Chart 8: 5G mmWave RU shipments, by ORAN procurement approach, 2023-2029	46
Chart 9: 5G mmWave RU shipments, hybrid vs digital beamforming, 2023-2029	47
Chart 10: BFIC shipments into Infrastructure, 2023-2029	48
Chart 11: BFIC Revenue into Infrastructure, 2023-2029	49
Chart 12: UDC Shipments into Infrastructure, 2023-2029	50
Chart 13: UDC Revenue into Infrastructure, 2023-2029	50
Chart 14: 5G mmWave RU market share for 2023	51
Chart 15: 5G mmWave Repeater Shipments, 2023-2029	52
Chart 16: 5G mmWave Fixed CPE Shipments, by frequency band, 2023-2029	53
Chart 17: 5G mmWave Mobile User Device Shipments, by UE type, 2023-2029	54
Chart 18: 5G mmWave Mobile User Device Shipments, by world region, 2023-2029	55

FIGURES

Figure 1. RU Forecast for mmWave Bands by Region, 2023-2029	16
Figure 2. mmWave AAU market in Metro Use Case	18
Figure 3. Japan and China Rail Track	19
Figure 4. mmWave Spectrum Summary	20
Figure 5. FR3 Spectrum Options.....	21
Figure 6. Options for Virtualized mmWave Network Architecture	22
Figure 7. Beamforming: Digital, Analog, Hybrid	23
Figure 8. Holographic Beamforming—Block diagram	24
Figure 9. Holographic Beamforming, product example	25
Figure 10. Link Budget Calculations for mmWave FWA uplink and downlink.....	26
Figure 11. Definitions of Base Band, Repeater, IAB, CPE, Hotspot	27
Figure 12. Mavenir mmWave AAU	28
Figure 13. Comparison of various mmWave RRH/AAS products for power, antenna configuration ..	29
Figure 14. FWA network utilizing an IAB architecture.....	30
Figure 15. mmWave FWA Implementation at MDU.....	31
Figure 16. ZTE: RIS demo at MWC24	32
Figure 17. Typical Locations for mmWave modules in Handsets	34
Figure 18. Murata mmW antenna: TxRx in two planes	35
Figure 19. Netgear MR6550, mmW hotspot	36
Figure 20. Inseego m3100, mmW (n257) hotspot	36
Figure 21. Comparison of CMOS, RF-SOI, and GaN for mmWave UE front ends	37
Figure 22. Four Primary Functions in mmWave Radio Unit.....	38
Figure 23. Comparison of Beamformer Suppliers in mmWave Radio Unit	38
Figure 24. Filter placement in mmWave RF path.....	39
Figure 25. mmWave architecture: RF integration by Murata/pSemi	40
Figure 26. Analog Devices: mmW solution line-up	40
Figure 27. Definitions of Base Band, Repeater, IAB, CPE, Hotspot	66

New in this year's report:

- Analysis of the AT&T / Ericsson deal and what it means for vRAN
- Fresh forecasts of vRAN adoption through 2032
- Operational efficiency and its role in vRAN adoption
- Life cycle cost analysis including anticipated 6G deployment

5G Millimeter Wave 2024: Radio Architecture and Outlook

**MEXP-5G MMWAVE-24
April 2024**

Cover Photos: Pexels.com

RELATED RESEARCH BY MOBILE EXPERTS

Mobile Experts conducts research covering all the aspects of licensed spectrum. Below is a list of related subject areas of research offered by Mobile Experts. An abstract and Table of Contents for each of these reports (and many others) are available at www.mobile-experts.net

- [Semiconductors for BBU/DU/CU](#)
- [RAN Revenue and CAPEX](#)
- [ORAN](#)
- [Virtual RAN](#)
- [Small Cells](#)
- [Fixed Wireless Access](#)
- [Private Network Services](#)
- [Industrial Private Cellular](#)
- [Enterprise Private Cellular](#)
- [C-IoT](#)
- [Satellite Broadband](#)

METHODOLOGY

For our 5G mmWave analysis, we balance multiple methods to arrive at the most likely scenario for future deployment. In particular, we investigated in these ways:

1. We interviewed operators and major OEMs to understand the status of trials and early commercial shipments. Both performance and business metrics are evaluated in these interviews to get an estimate of market maturity and direction.
2. We collect shipment data from key component suppliers to determine the exact number of radio units deployed so far.

We interviewed more than 25 OEMs and component suppliers to understand the tradeoffs for various semiconductor approaches, beamforming options, and other technical factors. Coupled with cost analysis and ROI calculations for the operators, we use this technical information to predict the type of products to be deployed over the next five years.

Category	Function	Description
Network	Outdoor gNodeB	Radio Unit with output power > 50dBm
	Indoor gNodeB	Radio Unit with output power ~35-43 dBm
	Repeater	Unit that extends the reach of a gNodeB (controlled by an operator)
	IAB	Radio that transmits data to end users and also provides a data link to other gNodeBs.
End User	CPE	Product that is either attached to the outside of a home/building or is in a fixed location inside. (can include consumer-controlled units that 'repeat' the mm-wave signal)
	Handset	Mobile device
	Hotspot	Mobile device, often used to distribute a cellular signal to near-by users

Figure 1. Definitions of Base Band, Repeater, IAB, CPE, Hotspot

Source: Mobile Experts