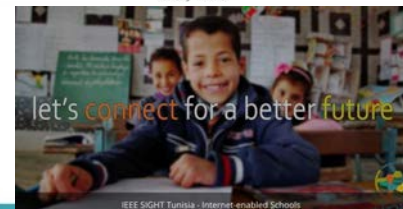


International Network Generations Roadmap (INGR)

Tim Lee (tt.lee@ieee.org)
IEEE Future Networks Initiative Co-Chair
IEEE Region 6 Director-Elect
IEEE IMS2020 General Chair
27 January 2020

IMS2020: Connectivity Matters

- IMS2020: 21-27 June 2020, LA Convention Center
- Theme: “Connectivity Matters”
 - IMS is place to be to make connections for networking, technical information exchange and Exhibition
 - MTT-s FOI: Connectivity enabled by wireless technologies
 - Connectivity for the digital economy
 - Broadband Connectivity for rural / under-served communities
- Systems Emphasis
 - 5G / 6G for eMBB, URLLC, and mM2M
 - Aerospace – SatCom, SmallSat
 - Autonomous vehicles – V2X



Please register at <https://ims-ieee.org>

2019 FUTURE DIRECTIONS Initiatives & Activities

Small Projects

Environmental
Engineering

Roadmaps Strategy
and Governance (IRSG)

Quantum Computing



iee.org/futuredirections

Graduated Initiatives



The IEEE INGR identifies new infrastructure needs for future generations (6G, 7G, etc.)

Broad vision = “IEEE International Network Generations Roadmap (INGR)”

Develop
IEEE
International
Network
Generations
Roadmap
Content

- ❖ Extends well beyond 5G
- ❖ Includes ecosystem drivers: (AI, ML, etc.)
- ❖ Identifies technology gaps and showstoppers
- ❖ Involves industry review and input

Provides forward-thinking guidance (not theoretical nor implementation-oriented)

Takes the lead for technical needs!

The INGR projects the next 10 years: 2019 – 2029, with Key Timeframe points at 3, 5, and 10 years.

<https://futurenetworks.ieee.org/roadmap>

IEEE International Network Generations Roadmap (INGR)

International Network Generations Roadmap

Reduce technical and engineering risks associated with the migration to 5G and beyond

Download the INGR today!

- Applications and Services
- Edge Automation Platform
- Hardware
- Massive MIMO
- Satellite
- Millimeter Wave for Signal Processing
- Security
- Standardization Building Blocks
- Testbeds

IEEE Future Networks

Accessing the INGR Documents

[Download the INGR Executive Summary](#) for free.

Individual chapters of the INGR are available exclusively to signed-in participants of the IEEE Future Networks Initiative (FNI). INGR membership is:

- free for all IEEE society members
- \$5 for IEEE student members
- \$10 for IEEE members who are not members of a society, and
- \$15 for non-IEEE members.

On this page:

- [About the IEEE International Network Generations Roadmap \(INGR\)](#)
- [Working Group Teams](#)
- [Reports](#)
- [News](#)
- [Upcoming Events](#)
- [Past Events](#)

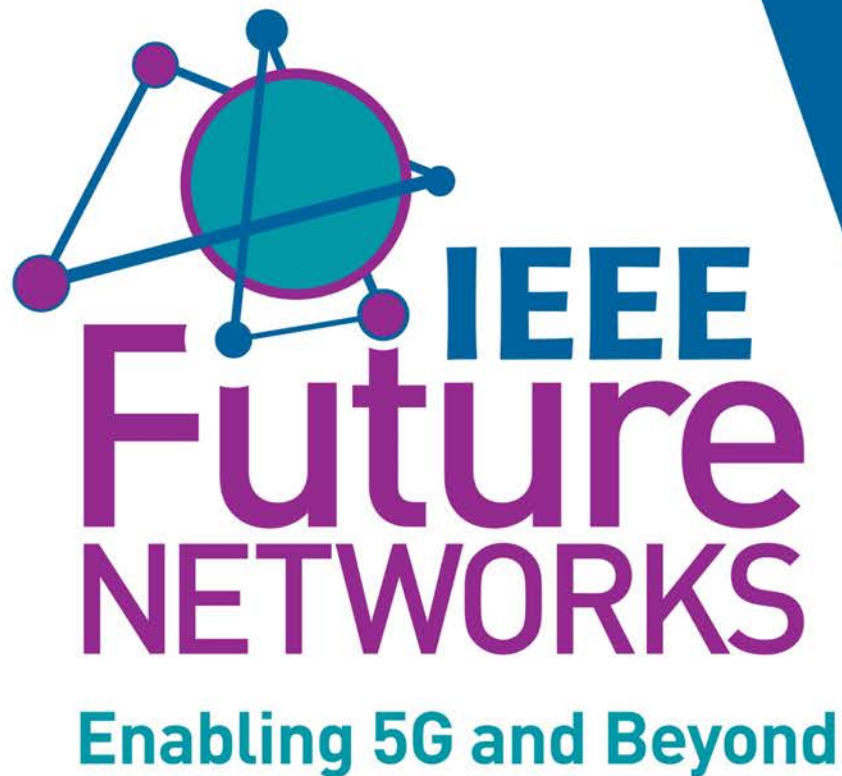
INGR Edition 1 - December 2019

- **INGR Chapters**

- Executive Summary
- Applications and Services
- Edge Automation Platform
- Hardware
- Massive MIMO
- Satellite
- Standardization Building Blocks
- **Millimeter Wave and Signal Processing**
- Security
- Testbed

- **White Papers (available 1st Quarter 2020)**

- Artificial Intelligence & Machine Learning
- Deployment
- Energy Efficiency
- Optics
- Systems Optimization



INGR 5G Technology Overview

Tim Lee
January 2020

**The
Economist**

MAY 6TH-12TH 2017

Crunch time in France

Ten years on: banking after the crisis

South Korea's unfinished revolution

Biology, but without the cells

The world's most valuable resource



**Data and the new rules
of competition**

“Data is to this century
what oil was to the last
one: a driver of growth
and change”

– The Economist

DATA GENERATION

IoT and Industry 4.0 driving an **explosion of data**

DATA STORAGE

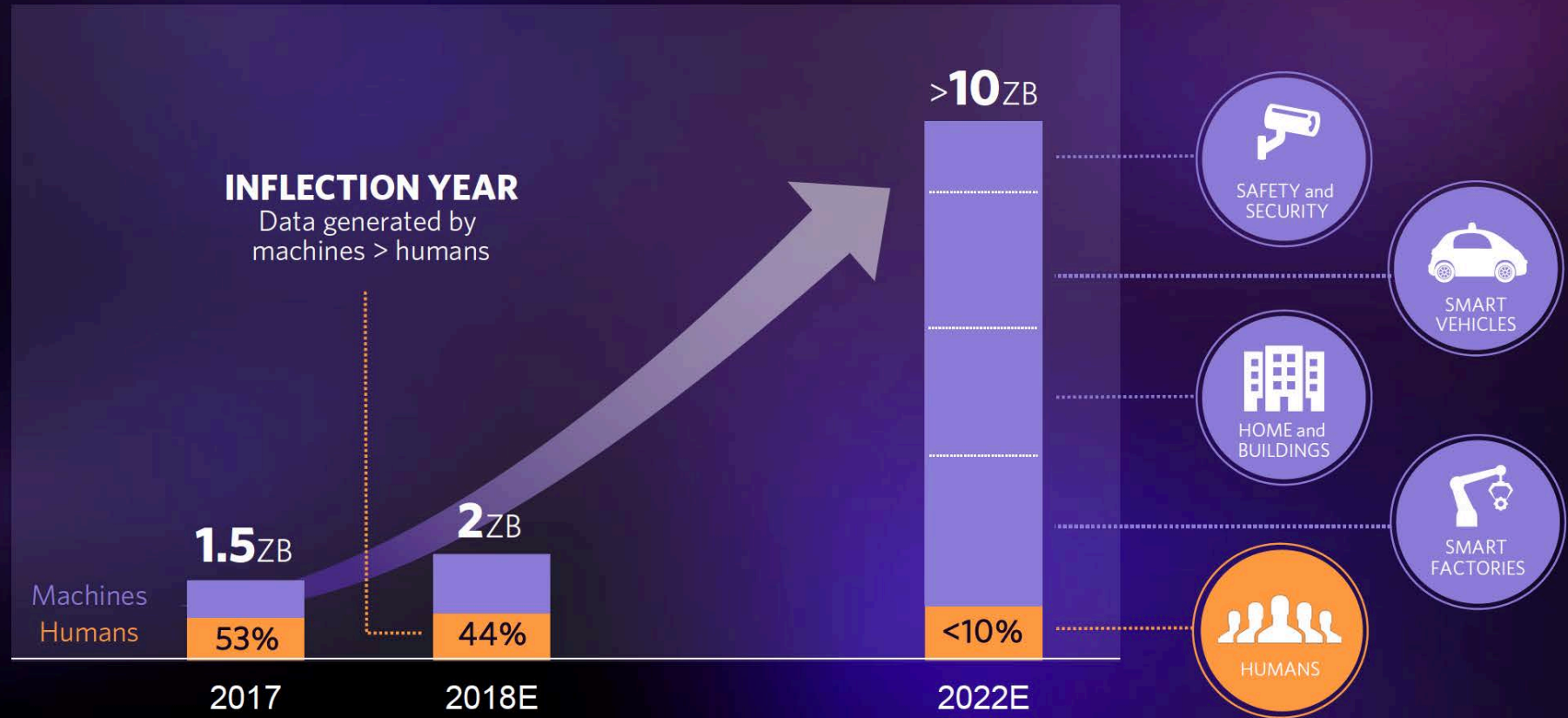
More data needs to be processed and stored –
Storage alone is not sufficient or economical

COMPUTE

New compute models to turn data into value

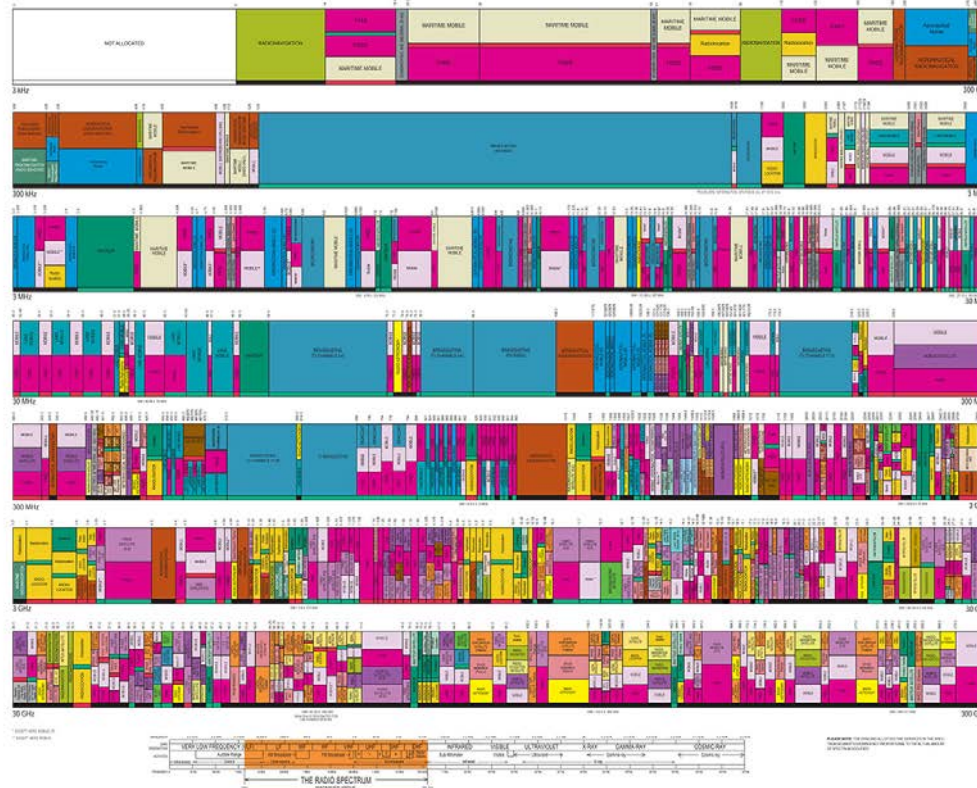
New compute architectures to process data at
edge and in cloud at right performance / watt

Explosion of Data Generation



SOURCE: Applied Materials model based on forecasts published by Cisco, Intel, Western Digital

UNITED STATES FREQUENCY ALLOCATIONS

U.S. 

- Spectrum Pipeline Act & Mobile NOW Act requires 100 MHz of spectrum be allocated for licensed use.
- 3.45-3.55 GHz band under Commerce Dept review
- This band is used by military radar systems

Other countries are making

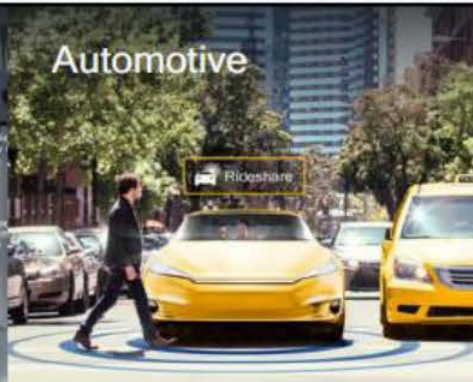
4x

more mid-band spectrum available than the U.S. by the end of 2020.

Manufacturing



Automotive



Computing



Healthcare



Energy



Industrial



Smart cities



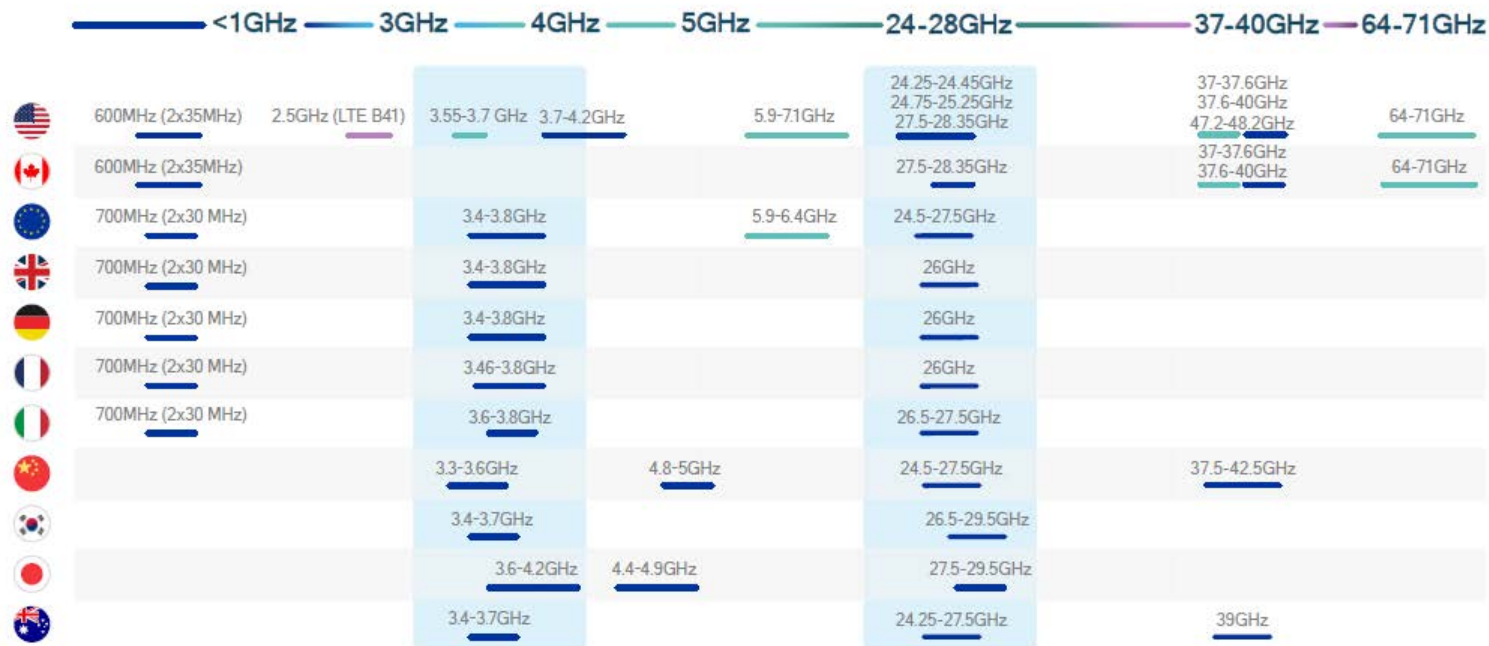
Retail



Driving transformation across industries

5G and distributed AI will provide a platform for future innovation

5G Spectrum Targeted Allocations



Global snapshot of 5G spectrum

Around the world, these bands have been allocated or targeted

New 5G band

- Licensed
- Unlicensed/shared
- Existing band

GLOBAL MARKET

Unique mobile subscribers

2017

5.0bn

68% PENETRATION RATE (% of population)

5.9bn

2025



71% CAGR 2017-25

21%

Mobile internet users

2017

3.3bn

43% PENETRATION RATE (% of population)

5.0bn

2025



61% CAGR 2017-25

5.3%

Smartphones % of connections*



57% 2017

77% 2025



% of connections*

29% 2017

53% 2025



1.2bn 2025

14% of connections*

SIM connections Excluding cellular IoT

2017

7.8bn

9.0bn

2025

103% PENETRATION RATE (% of population)

110%



1.9% CAGR 2017-25

49%

Mobile operator revenue

2017

\$1.05tn

\$1.10tn

2025



Mobile operator capex



\$479bn

2018 - Capex (cumulative) - 2020

Internet of Things



7.5bn 2017

Total connections

25.1bn

2025



Mobile industry contribution to GDP

46% 2017

\$3.6tn

5.0%

\$4.6tn

2022

Public funding

Mobile ecosystem contribution to public funding (before regulatory and spectrum fees)

\$500bn

2017



Employment



Number of jobs directly and indirectly supported by mobile ecosystem

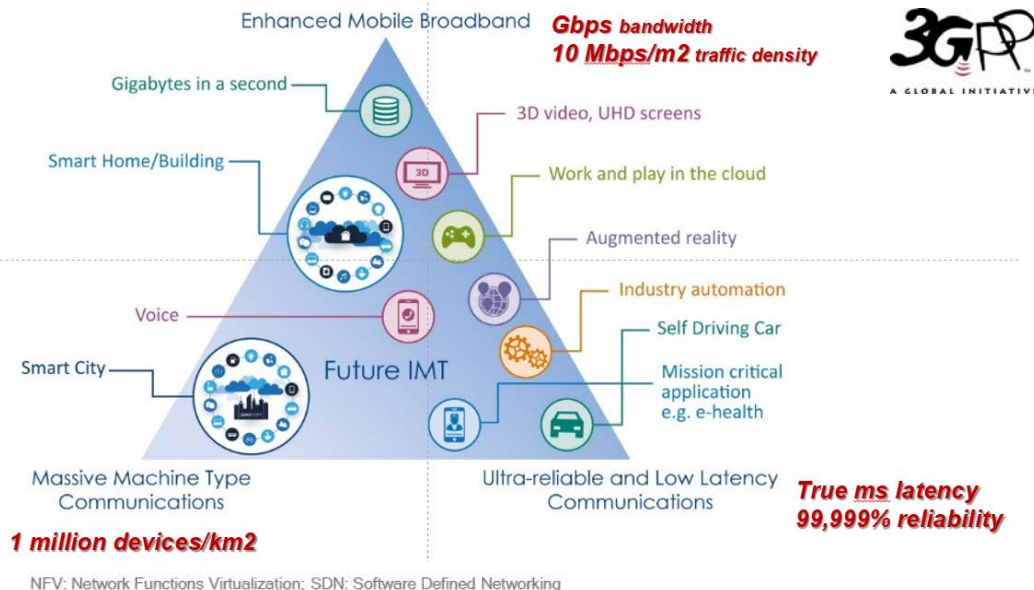
29m

2017

<https://www.gsmainelligence.com/research/2018/02/the-mobile-economy-2018/660/>

5G next Gen Core (NGC) also part of 3GPP Rel-15

Increased flexibility through NFV and SDN – essential to 5G NR expansion



Configurable end-to-end connectivity per vertical

Modular, specialized network functions per service

Flexible subscription models

Dynamic control and user planes with more functionality at the edge

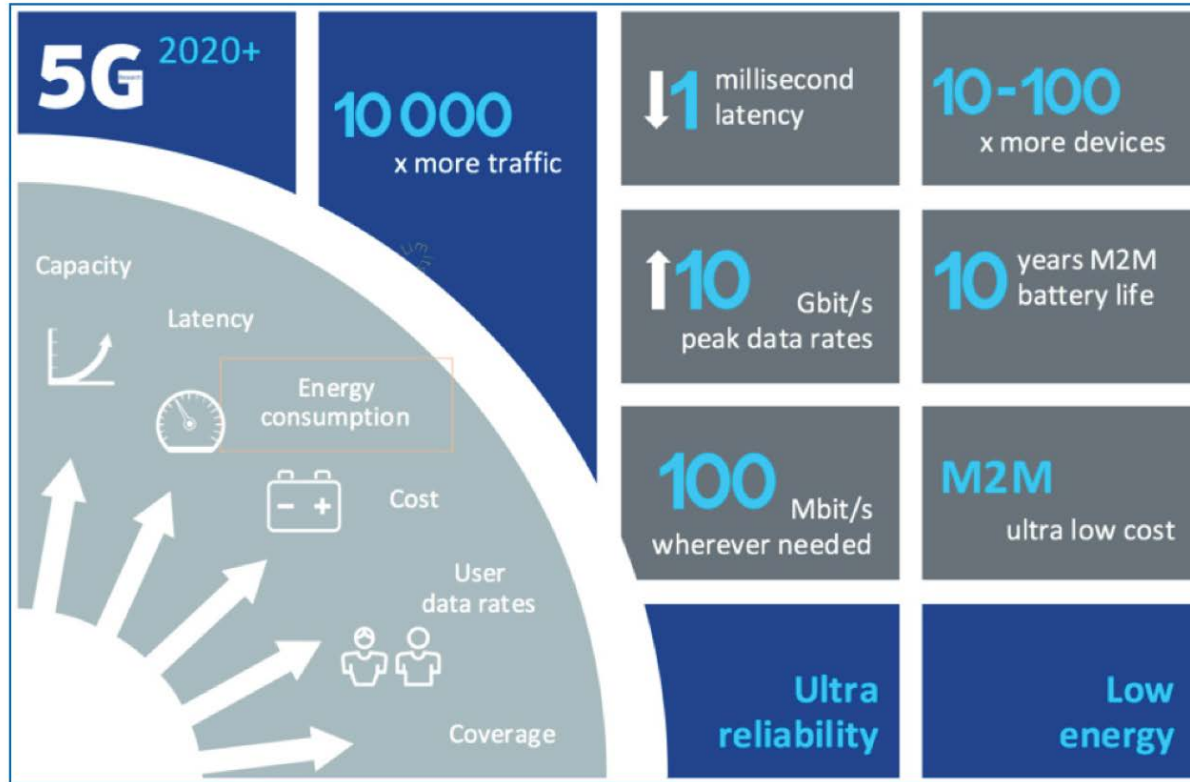
Better cost/energy efficiency

Optimized performance

Flexible biz models and deployments

Dynamic creation of services

5G Key Performance Metrics



Some Predictions on the 5G in 2020 - Spectrum Matters (Tim Lee)

- Below 6 GHz, 5G deployments will gain momentum in 2020 with many installations across the globe. Meanwhile, mmWave 5G deployments will lag due to challenges of small cell deployment issues, costs, and regulatory hurdles. American carriers like Sprint with sub-6 GHz bands (i.e., 2.5 GHz) may gain an edge since they do not have to deploy small cells so soon.
- Shared Spectrum Access will be a key technology in the US that will enable sharing of commercial licensed, unlicensed, and government bands. Once proven, this will allow sub-6 GHz spectrum for more rapid deployment, especially in rural regions.
- Second generation mmWave transceivers will be released in 2020, paving the way to improved performance and much reduced costs for user equipment (UE).
- What will be the first 5G killer app to gain attention in 2020? AR/VR? Autonomous cars? Enhanced Broadband? MM2M for IoT? Some other use case?

<https://futurenetworks.ieee.org/publications/7-experts-forecast-what-s-coming-for-5g-in-2020>

The wild-card for 5G emergence is deployment 2020 (David Witkowski)

- Until the mobile device ecosystem begins widely offering 5G support, initial deployments of 5G will focus on Fixed Broadband as a competitor to cable
- 5G Enhanced Mobile Broadband (EMBB) will ramp up in late 2020, and initially they will focus on in-building networks and downtown areas with high user densities.
- Industrial IoT (IIoT) deployments using 5G Ultra-Low Latency Communications (URLLC) and Massive Machine-Type Communications will likewise depend on availability of sensors, actuators, and, in some applications, edge computing. We expect this to begin in 2021 as IIoT device vendors release 5G-enabled products.
- Availability of 5G URLLC will enable augmented reality (AR) and virtual reality (VR) products
- Citizens Broadband Radio Service (CBRS) will enable private 4G/5G networks and will be disruptive.
- Widespread availability of CBRS support in devices will be disruptive to Wi-Fi, especially in enterprise and municipal/public deployments, then in SOHO deployments.
- The wild-card for 5G emergence is deployment. Local governments have struggled with 4G small cell deployments, and the higher density of 5G sites in millimeter wave bands presents additional challenges to application and permitting at the local level. Fears about 5G health effects will require deliberate response from industry, governments, and medical academia to counter misinformation, pseudoscience, and superstition.

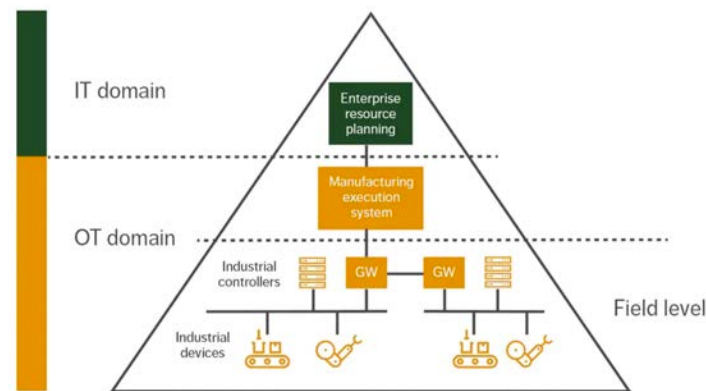
<https://futurenetworks.ieee.org/publications/7-experts-forecast-what-s-coming-for-5g-in-2020>

5G Enables Smart Factory Applications

Industry 4.0 – the fourth industrial revolution – is already transforming the manufacturing industry, with the vision of highly efficient, connected and flexible factories of the future quickly becoming a reality in many sectors. Fully connected factories will rely on cloud technologies, as well as connectivity based on Ethernet Time-Sensitive Networking (TSN) and wireless 5G radio

- Key manufacturing industry requirements

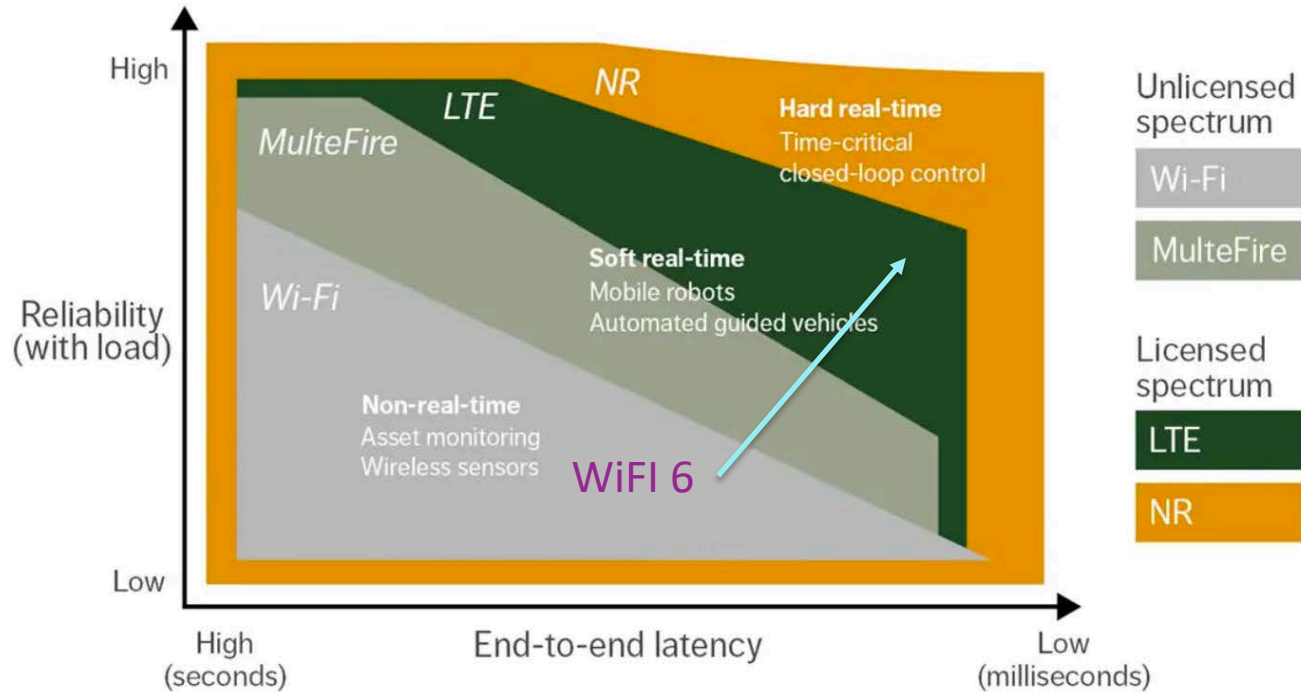
- Ultra-reliable low-latency communication for machine-type communication (MTC) in 5G – critical MTC (cMTC) – is designed to meet communication demands with stringent requirements on latency, reliability and availability
- The ability to integrate with the existing industrial Ethernet LAN and existing industrial nodes and functions is another fundamental requirement.
- Data integrity and privacy are also critical, as well as real-time performance monitoring. In addition, 5G capabilities in terms of positioning, time synchronization between devices, security and network slicing will also be essential for many manufacturing use cases.



industrial automation pyramid

<https://www.ericsson.com/49232f/assets/local/reports-papers/ericsson-technology-review/docs/2019/5g-and-smart-manufacturing.pdf>

Latency and reliability aspects of spectrum and technology choice



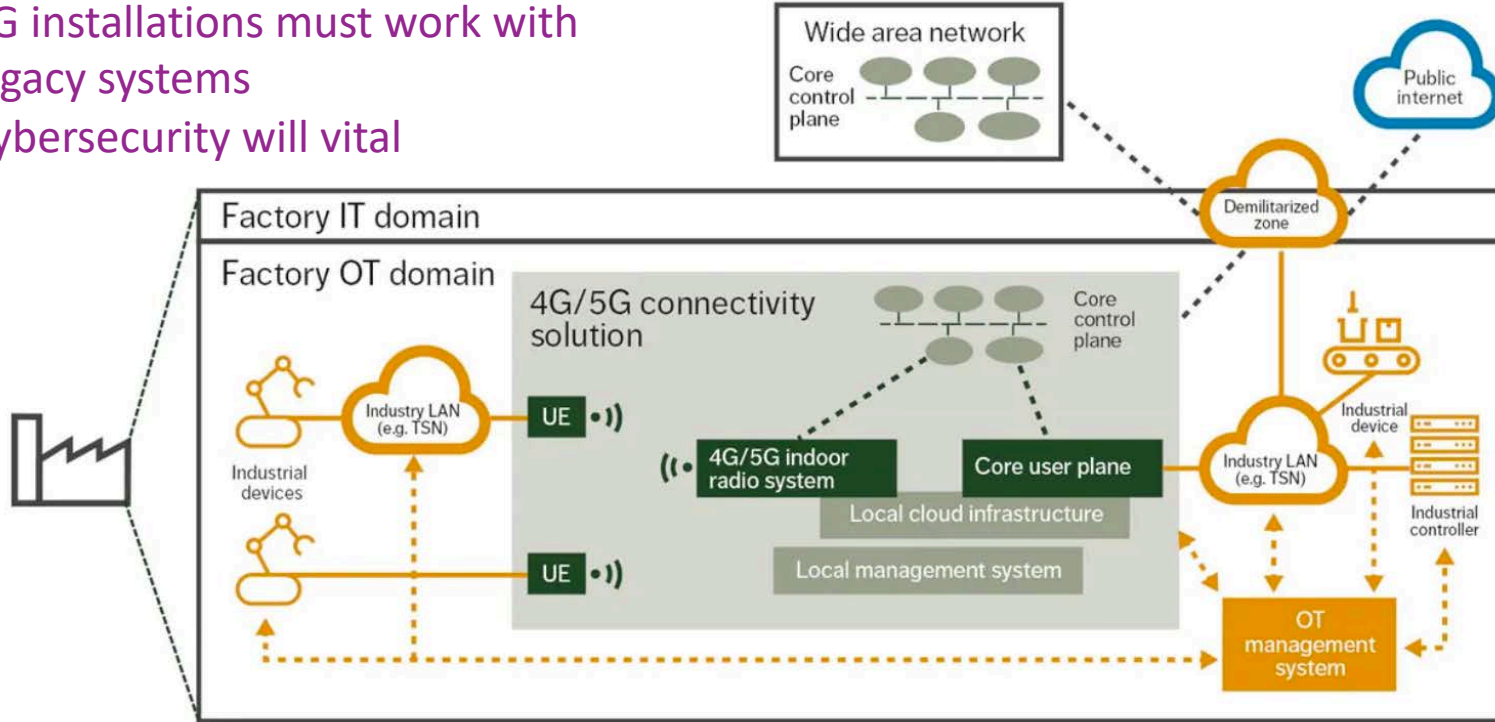
<https://www.ericsson.com/49232f/assets/local/reports-papers/ericsson-technology-review/docs/2019/5g-and-smart-manufacturing.pdf>

Which 5G is the Best for IIOT?

- Low-Band for long haul low data rate use cases (Smart Cities)
- **Mid-band spectrum is well suited for indoor deployments** since its propagation characteristics make it easy to provide good coverage with a limited set of transmission points.
- mmWave requires denser radio deployment but enables higher system capacity, and small form factor suitable for indoor deployment
 - Significantly shorter latencies (even though the spectrum is TDD), as a higher numerology with shorter transmission time intervals is used
 - Easier management of the coexistence between indoor shop floor networks and outdoor mobile networks, as mmWave radio signals are easier to confine within buildings.

Ericsson 5G Factory Automation Solution

- 5G installations must work with legacy systems
- Cybersecurity will vital



<https://www.ericsson.com/49232f/assets/local/reports-papers/ericsson-technology-review/docs/2019/5g-and-smart-manufacturing.pdf>

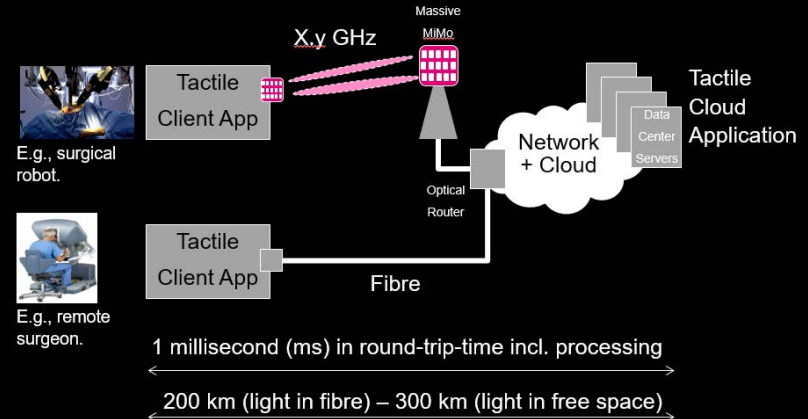
Tactile Internet

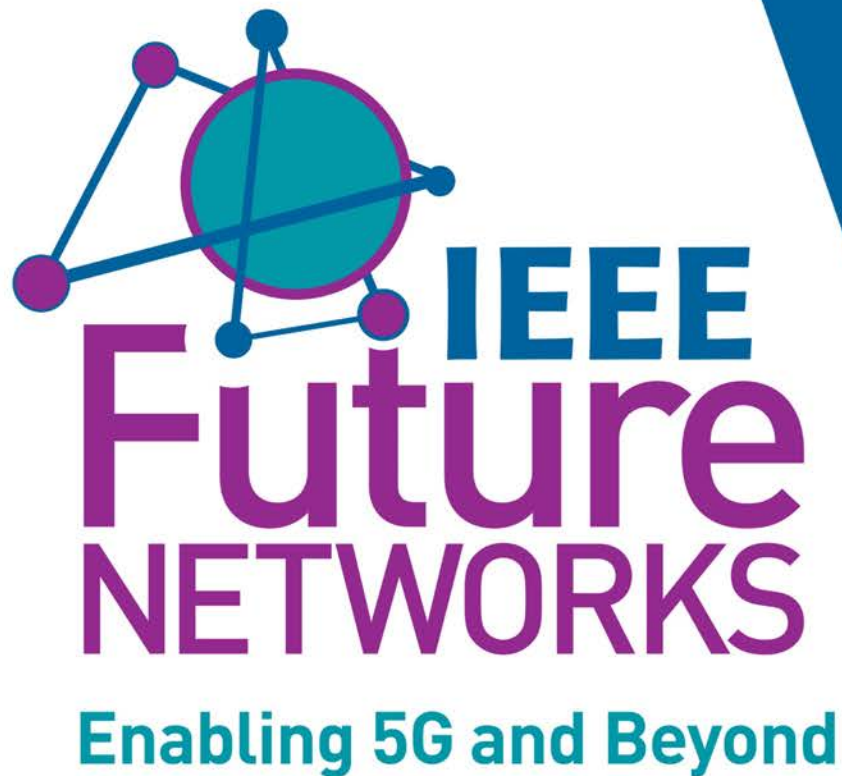
Tactile Internet will enable humans and machines to interact with their environment in real time with haptic interaction, visual feedback with ultra-low latency (1 ms).

- Industry
- Robotics and Telepresence
- Virtual Reality
- Augmented Reality
- Healthcare – tele-diagnosis & tele-surgery



The Tactile Internet. Illustration.





INGR Millimeter-Waves and Signal Processing Chapter Summary

Tim Lee
January 2020

mmWave and Signal Processing Chapter: Vision

- Working Group Roadmap Vision Statement (What does a successful landscape look like in 3 years, 5 years, 10 years?)
 - 3 years: Initial deployments of 5G hardware will, at first, grow rapidly for mid-band and more slowly in high-band (millimeter-wave).
 - 5 years: more high-band deployments as the cost of millimeter-wave infrastructure comes down
 - 10 years: defining 6G with potential use of high millimeter-wave bands (70- to 300-GHz) for another 10X improvements in data rates with low latency

mmWave and Signal Processing Chapter: Scope

- Elements that will be covered in the MMW-SP roadmap includes:
 - Millimeter-Wave Propagation models
 - RF hardware combined with optimized accelerators with programmable logic at both MAC and PHY levels to enable the performance of novel millimeter-wave algorithms
 - Use of multi-antenna (MIMO) techniques at millimeter-waves for front-haul and backhaul
 - Software-Defined Radio (SDR)
- Elements not covered in this chapter but addressed in other INGR chapters includes:
 - Satellite backhaul
 - Fiber backhaul
 - Architectures covered include:
 - Beam forming techniques to achieve large array gains
 - Analog, digital and hybrid beamforming

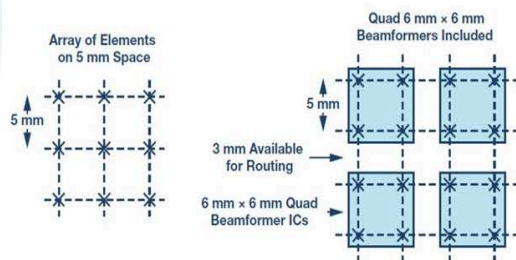
Technology/Capability Gaps and Showstoppers

Guiding questions:

- What MUST be resolved for evolution to future technologies. Identify gaps in technology sectors (infrastructure, equipment, materials, policy, research)
 - High performance low-cost 5G modems for UE which supports multiple 5G bands
 - Tight Integration for mm-wave Phased Arrays
 - Selection of Semiconductor Technology Based on Output Level
- Core competencies that are disconnected or missing?
 - Multi-physics based design tools that enable optimization of electrical, mechanical, analog, digital and antenna functions
 - Low-Loss substrates with fine-pitch geometries
- Who are the key players? (Industry sectors? Types of research needed?)
 - Silicon and GaAs/GaN foundries
 - OSAT – for advanced packaging technology

Technology/Capability Gaps and Showstoppers

Challenge 1: Tight Integration is Needed for mm-wave Phased Arrays



- ▶ At 30 GHz, $\lambda/2 = 200$ mils, or 5 mm
- ▶ Electronics Footprint a Serious Challenge
 - Worse for Dual Pole
- ▶ Front-End Function Desired in Beamformer Package
 - PAs and LNAs

Frequency	Element Spacing	Dual Pole I/O Spacing
3 GHz	50 mm, 2 inches	25 mm, 1 inch
10 GHz	15 mm, 600 mils	7.5 mm, 300 mils
30 GHz	5 mm, 200 mils	2.5 mm, 100 mils

5G Front-End architecture (number of elements, EIRP, Si vs III-V, and Packaging) need to be tailored for each use case

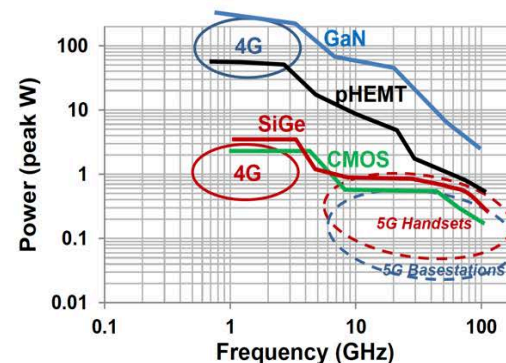
Technology/Capability Gaps and Showstoppers

Challenge 2: Selection of Semiconductor Technology Based on Output Level

5G Application Scenarios & Requirements 2018 (estimated)

	Handset	Access point	Base station	Backhaul	Last mile
EIRP (ave)	30 dBm	43dBm	60dBm	60dBm	75 dBm
Number antennas	4-6	32	256	256	256
Pave / PA	14dBm	11dBm	10dBm	10dBm	25dBm
Pmax/PA	23dBm	20dBm	19dBm	19dBm	33dBm
Efficiency (ave)	20%	20%	20%	20%	20%
DC power	0.6W	2W	12W	12W	390W

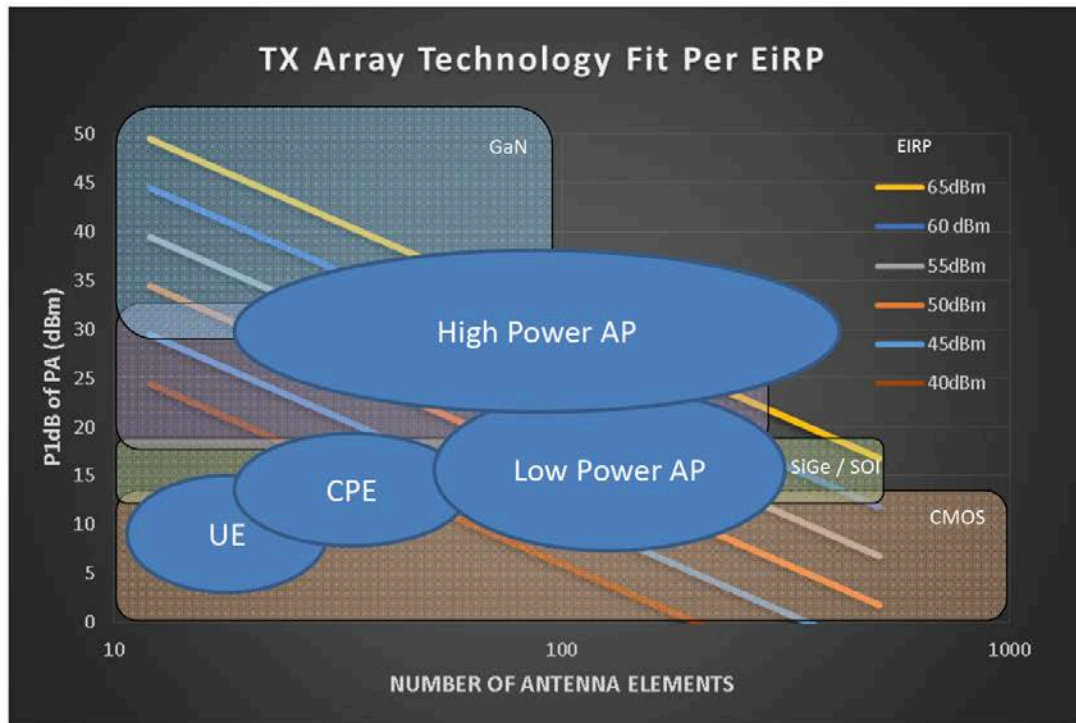
Estimated Power Ranges for 5G TX ICs & Estimated Max Power of Different Technologies



Technology Fit Per Radio Form Factor

- UE is clearly in CMOS technology domain
- CPE spans CMOS and SiGe BiCMOS
- Low power access point spans CMOS, SiGe BiCMOS and GaAs
- High power access point spans GaAs and GaN

5G Roadmap will address the system trade between Silicon and III-V



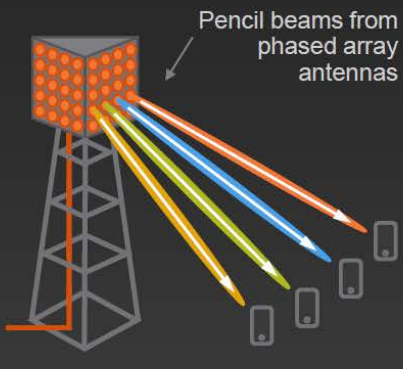
Active Circuits Needs, Challenges and Potential Solutions

Need Challenge(s) and Enablers and Potential Solutions Sets	Current State (2019) (details)	3 years (2022) (details)	5 years (2024) (details)	Future State 10-years (2029) (details)
Need: Active Components – LNA, PA, PS, Switches, Mixers	silicon RFIC + GaAs/GaN PA and SW	all silicon – analog beamformer	all silicon – analog, digital and hybrid beamformers (20 GHz to 40 GHz)	all silicon - digital beamformers (20 GHz to 40 GHz, 60 GHz, 80 to 120 GHz)
Challenge(s) for Need	High parts count/complexity to support > 40 band	Even higher complexity to add sub-6GHz and mm-waves bands	ADC/DAC data converter at every element for EDBF, Multiple RAT for each mm-wave band	Programmable RAT that can generate waveforms for multiple use cases, extremely wideband components
Possible Solution for Challenge	non-beamformer – PS not needed	Antenna in Package (AiP) integration (2.5D)	Antenna in Chip (AiC) integration (2.5D), leverage antenna gain	3D-stacked RFFE vertical integration; wafer level integration

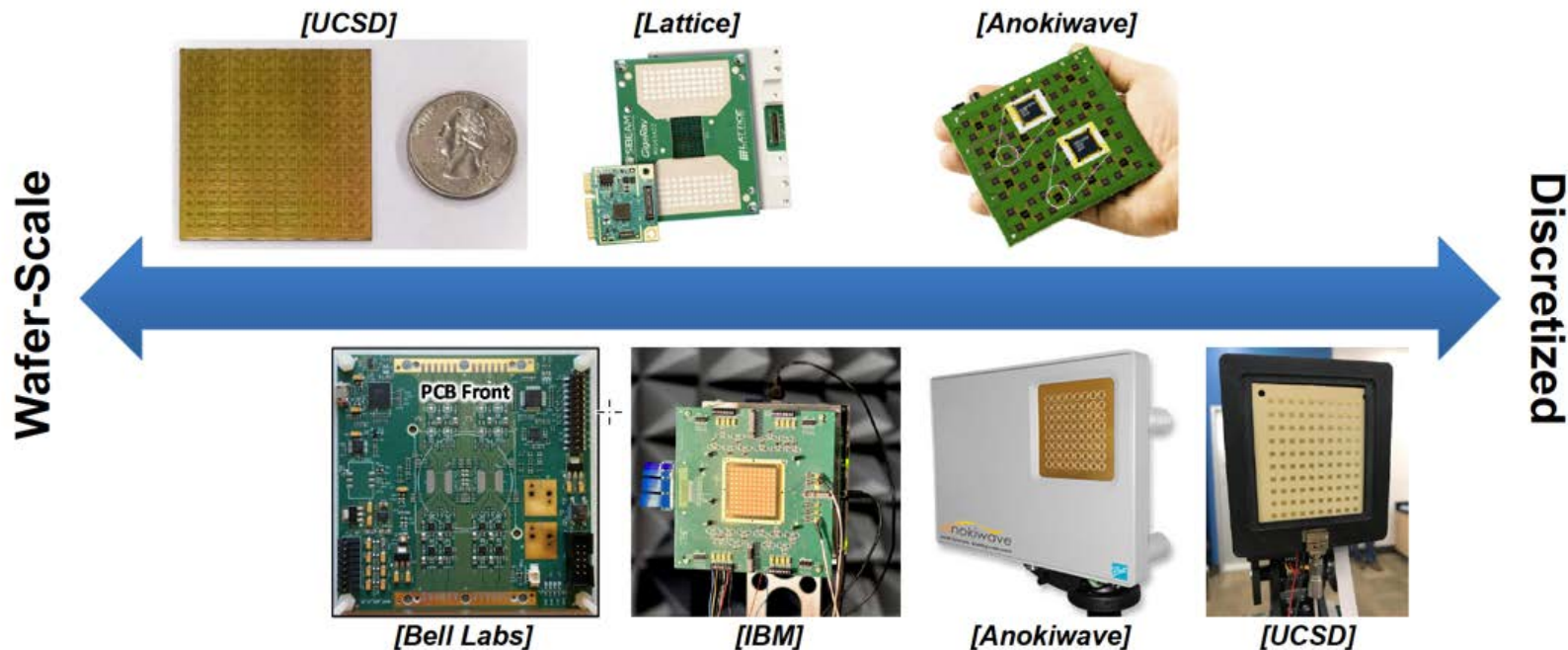
Overall Potential Solutions – for those Gaps that need solutions by a certain timeframe

- What Other Areas of opportunity? KEY QUESTION: What must happen to enable a solution?
 - Known solutions – mmWave and beamforming technologies from radar and SATCOM
 - Challenged solutions – why are these a challenge?
 - mmWave RF Front-Ends at scale (millions of units)
 - Fitting even more bands into the FEM with Advanced Packaging
 - Design for Test
 - Unknown solutions – identify gaps in knowledge
 - Accurate channel and propagation models for mmWaves (outdoors, indoors, urban, rural)
 - mmWaves signals will not penetrate buildings

Mobility: FEMs must evolve as 4G transitions to 5G

4G	5G	
Few antennas	Massive MIMO (user-specific beamforming signal)	 <p>Pencil beams from phased array antennas</p>
$F_o < 6$ GHz	$F_o > 25$ GHz (mmWave)	
Low bandwidth	High bandwidth	<ul style="list-style-type: none">• 5G will change FEM architecture, driving integration of PA, LNA, switch & phase shifter for beamformers...• Demand for legacy 4G/LTE will remain
High output power per PA (>+30 dBm)	Lower output power per PA (distributed across many PA elements: >+10 to +30 dBm)	
Discrete PA	Integrated PA (to avoid large off-chip routing losses)	

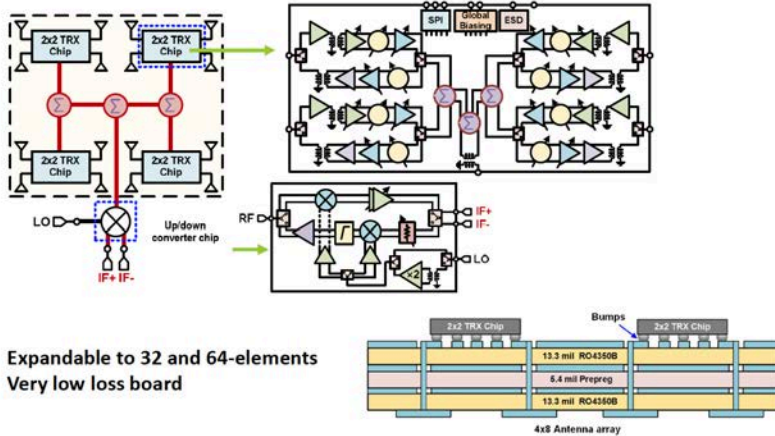
Phased Array System Architecture Considerations



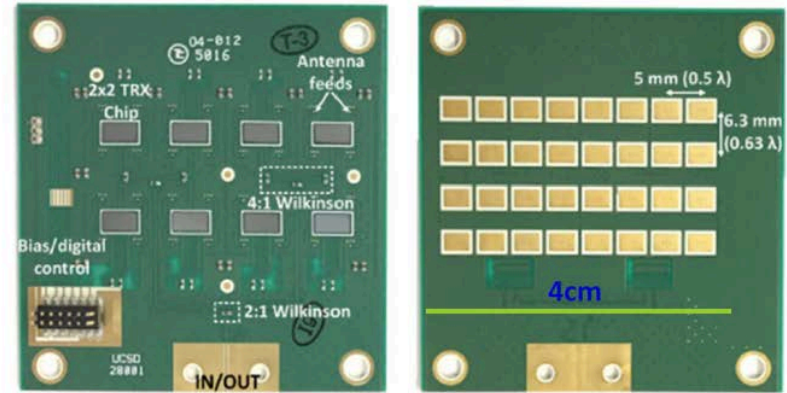
- Integration choice is influenced by operational frequency, cost and application

Highly Integrated System Where the Circuits, Antenna and Package are Functioning as One Microsystem for Small Cells

16 (4x4)-Element Phased-Array Design



- Expandable to 32 and 64-elements
- Very low loss board



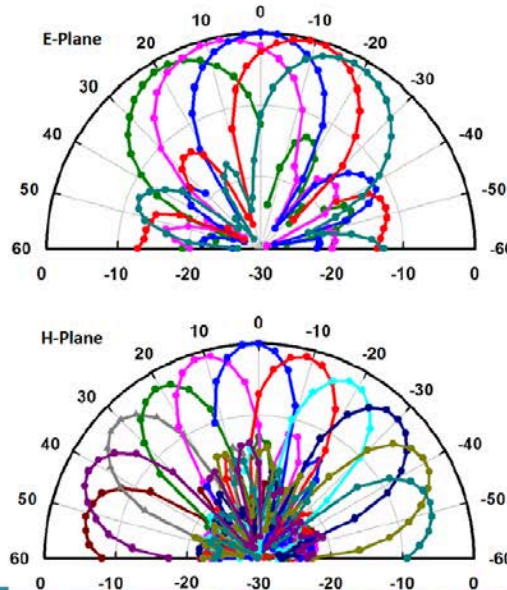
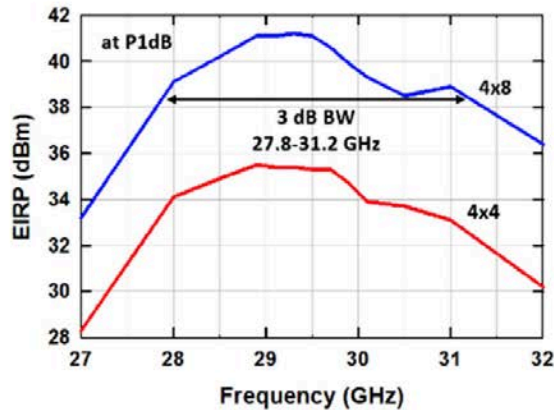
28-31 GHz Phased-Arrays

32 Elements

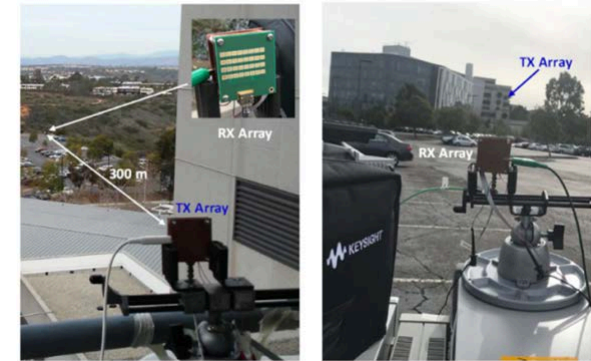
32-Element EIRP & Patterns



- **No calibration** – just load the phases and measure!!
- ± 25 degree scan in E-plane
- ± 50 degree scan in H-plane



300 Meter Link Measurement Setup



	5 m / $\pm 50^\circ$ H-plane		300 m / 0° scan	
16-QAM				
Data rate	2 Gbps	4 Gbps	400 Mbps	1.6 Gbps
EVM	3.74%	6.68%	5.9%	10.9%
Scan angle	$\pm 50^\circ$ H-plane	$\pm 50^\circ$ H-plane	$\pm 20^\circ$ E-plane	$\pm 20^\circ$ E-plane
16-QAM 300 m 1 Gbps				
EVM	12.1%	11.7%	10.3%	9.6%



<WSB-8>

HAWAII 5G Catch the Wave!



11

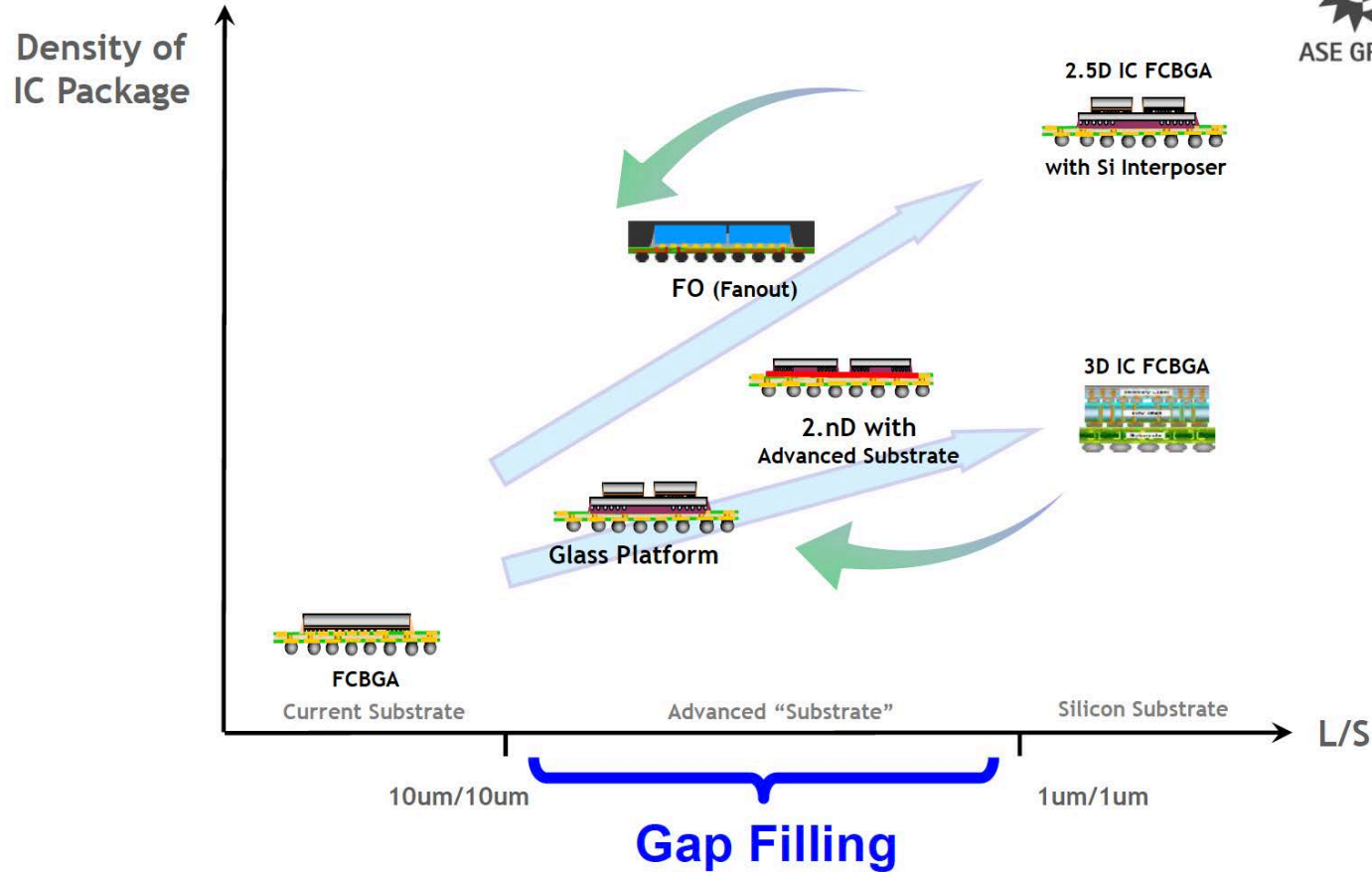
Courtesy: Gabriel Rebeiz, UCSD



2.5D / 3D IC to FO Packaging Technology



ASE GROUP



Wafer-Level Fan-Out Packaging for 5G

Scaling from 200 mm/300mm wafers to 600mm x 600mm panels for 6.5X scaling

Advantages

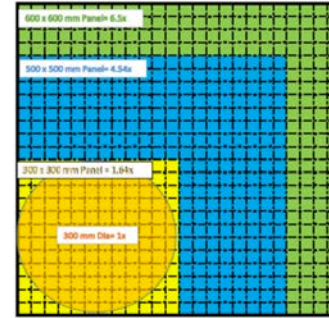
- Low-Cost for high volumes
- Size of package nearly the same as die size
- No Interposer needed

Challenges

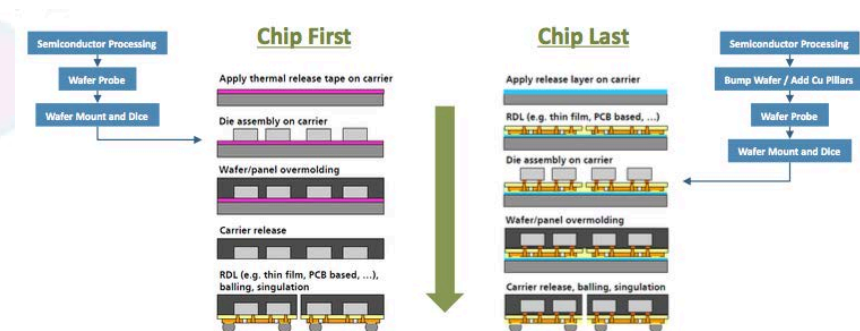
- Performance – RDL losses
- RDL trace width & pitch (# of I/O)
- Reliability - warpage
- Lack of standard panel size for tooling

Today's wafer-level fan-out is moving towards RDLs at 2-2 μ m line/space with 1-1 μ m or below in R&D. In comparison, panel fan-out is around 10 μ m line/space

<https://semiengineering.com/panel-fan-out-ramps-challenges-remain/>



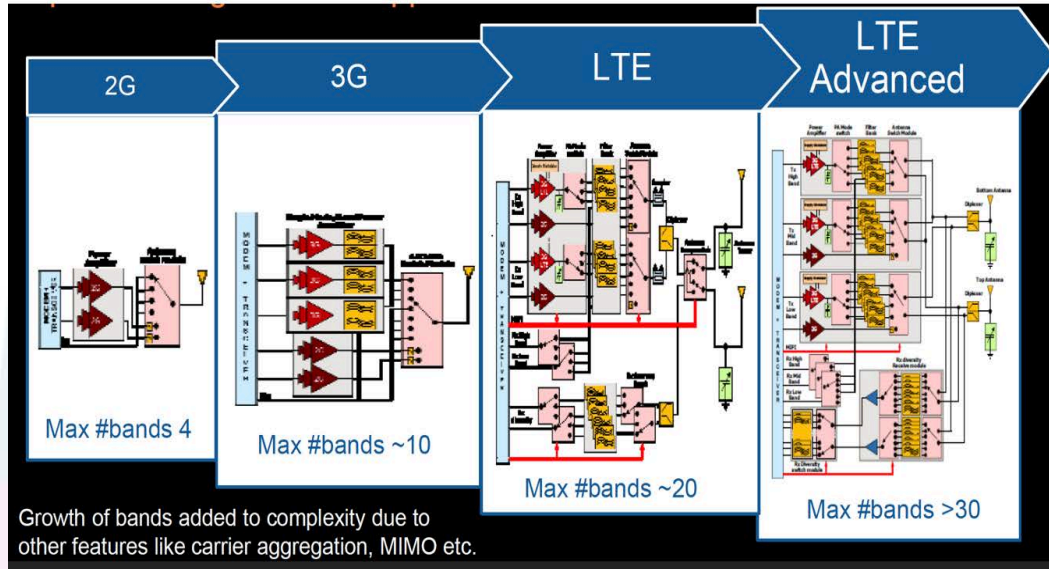
Comparison of number of die exposed on 300mm wafer to number of die on panel. Source: STATS ChipPAC, Rudolph



Chip first vs. chip last. Source: TechSearch International

Overall Potential Solutions – for those Gaps that need solutions by a certain timeframe

Challenge 3: FEM Integration and Packaging



- FEM at 3.5 / 5.9 GHz
- Mm-wave FEM at 28- and 39 GHz?

How
Many
Bands?

Introducing the Qualcomm®

QTM052 5G mmWave antenna module

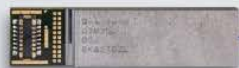
Expands portfolio of fully-integrated 5G NR mmWave modules for mobile devices



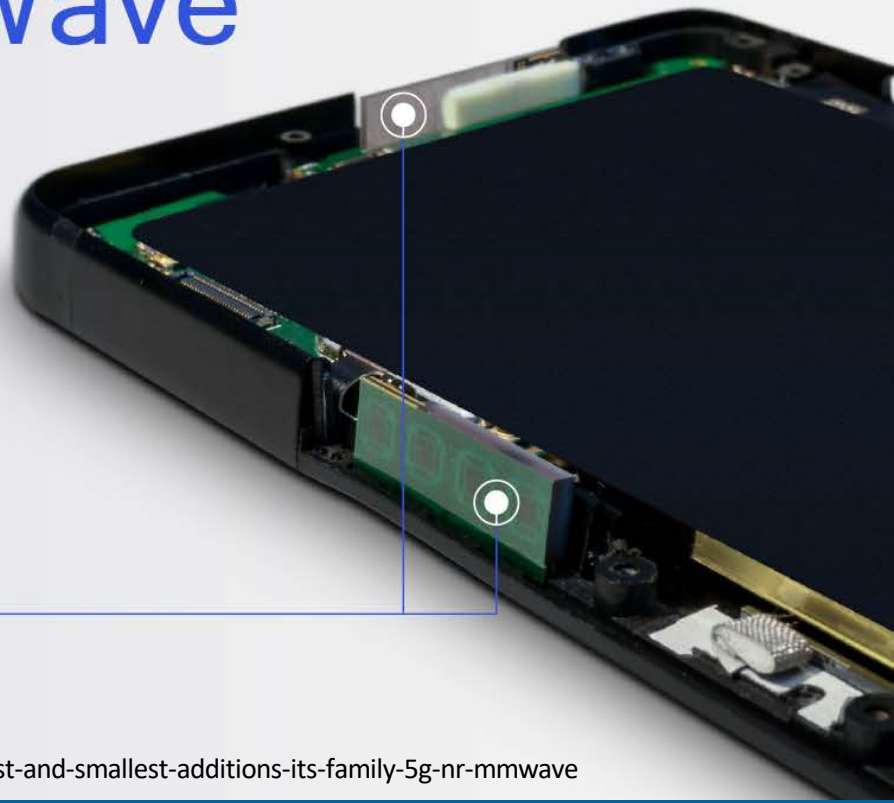
Previous



New



Size scale

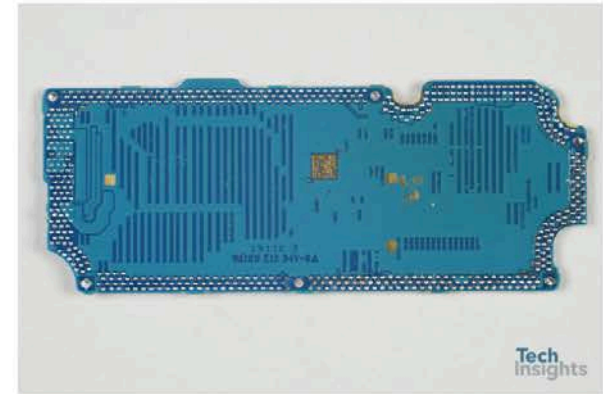
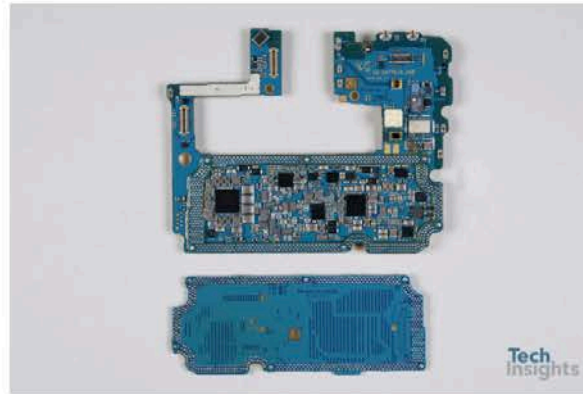


Importance of Modem-to-Antenna Design in 5G

- The 5G era opens new challenges for the core electronics supplier – Modem to antenna design
 - Qualcomm has clearly captured the first-mover advantage of this new design paradigm of a complete 5G RFFE
 - Expect the RFFE components market to heat up as incumbent component makers respond by offer more complete RFFE solutions as 5G smartphones mature.
 - Balancing act of cost verse performance.
- The first-generation designs featuring the Qualcomm X50 platform for sub-6 GHz or mmWave RFFE.
 - Complete modem-to-antenna solution saves development cost and de-risk early 5G designs (just as it has done in 4G LTE)
 - Benefits such as optimization for power consumption up and down the RF chain
- Few competitive 5G component providers driving early wins for Qualcomm's complete modem to antenna solution

<https://technology.ihs.com/616863/in-5g-smartphone-designs-rf-front-end-graduates-from-traditional-supporting-role-to-co-star-with-modem>

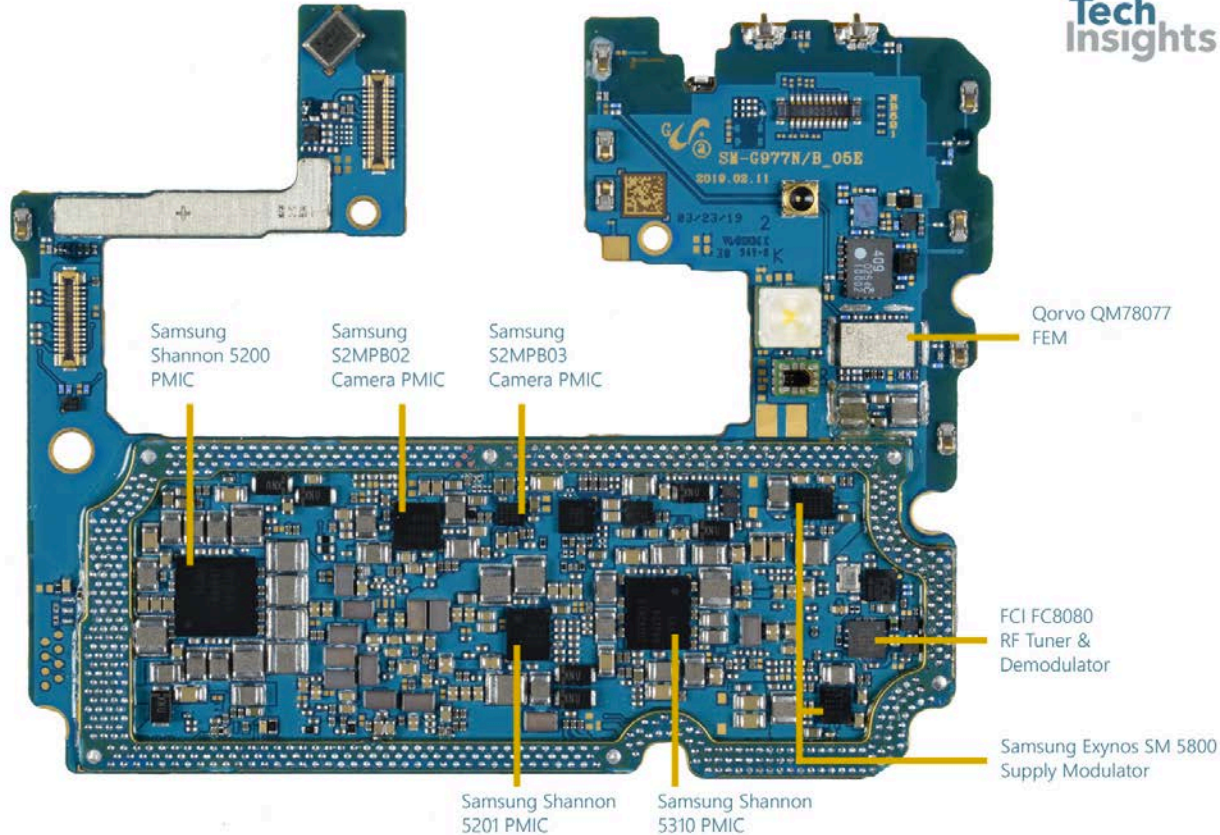
Samsung S10 5G Teardown



<https://techinsights.com/blog/samsung-galaxy-s10-5g-teardown>

Samsung S10 5G

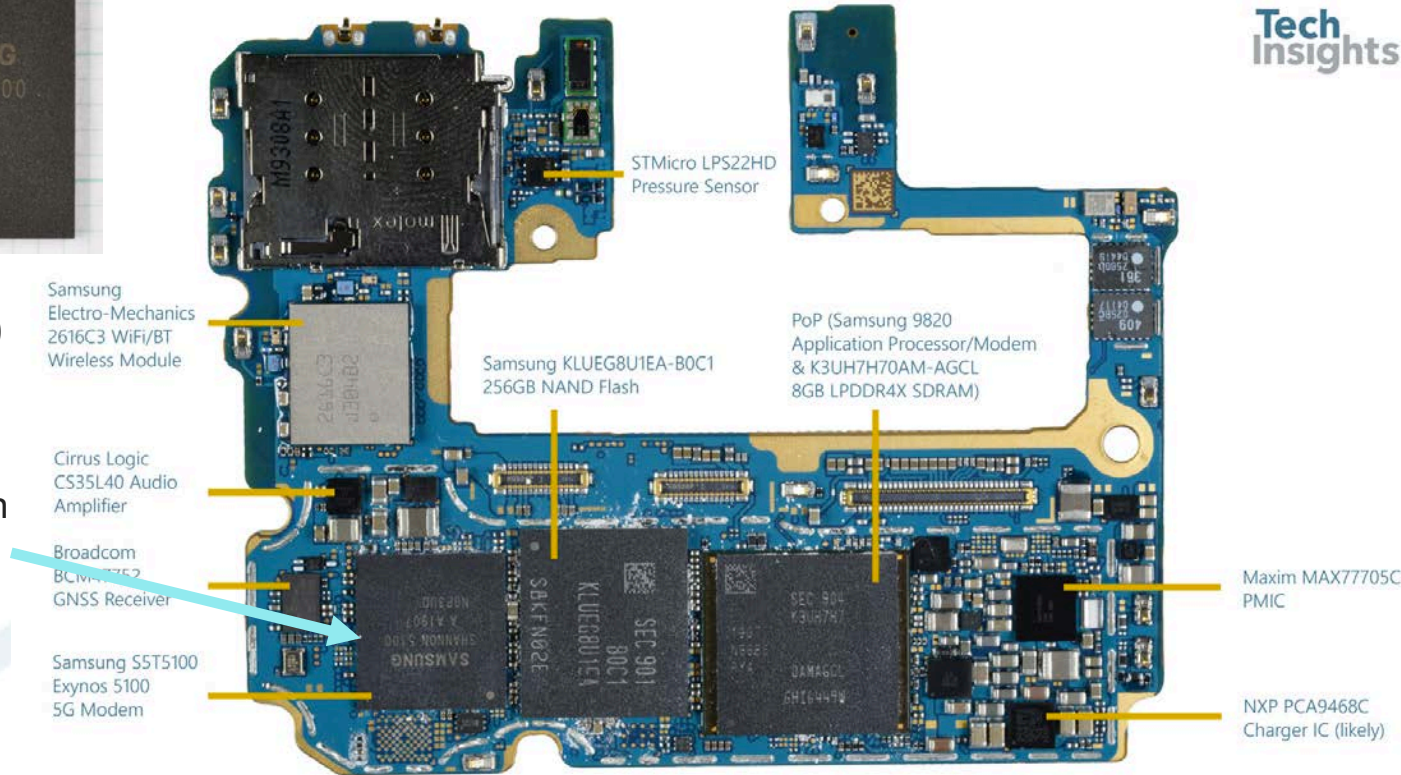
Tech
Insights



Samsung S10 5G



Galaxy S10 5G has the Exynos Modem 5100, which supports mmWave



Samsung S10 5G

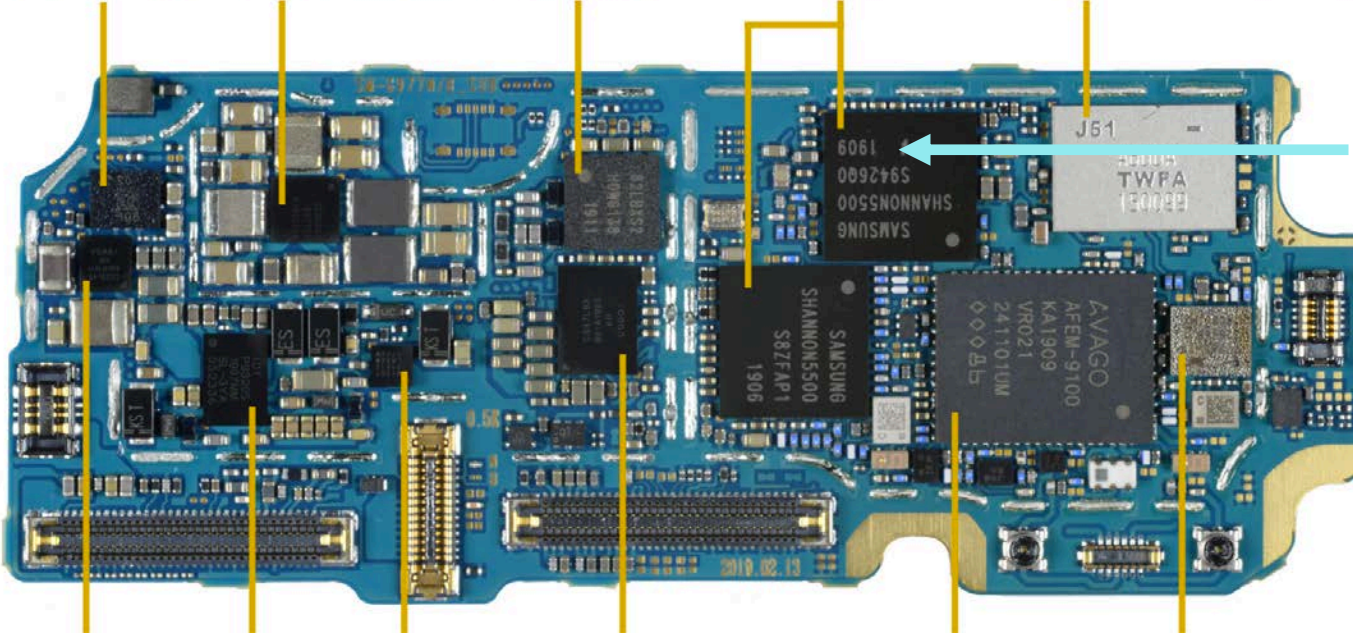
STMicro LSM6DSO
iNEMO Inertial Module

Samsung S2D0S05
Display Power Management IC

Samsung 82LBXS2
NFC Secure Controller

Samsung Shannon 5500
RF Transceiver

Murata J51
LB FEM



Exynos RF 5500 supports legacy networks and 5G-NR sub-6GHz networks in a single chip. The Exynos RF 5500 has 14 receiver paths for download, and supports 4×4 MIMO (Multiple-Input, Multiple-Output) and 256 QAM (Quadrature Amplitude Modulation).

Substrate-like PCB (SLB)

Samsung Galaxy S10 mmWave 5G

The application processor uses MCeP style PoP structure for the Qualcomm Snapdragon 855 application processor. The twin wirebond memory packages are mounted over the lower application processor, which was flip chip mounted over 3 layer Embedded Trace Substrate (ETS) 10 μm L/S. The application processor die with Cu pillar 25 μm height and 100 μm pitch is thermal compression bonded over NCF underfill.



Photo source: Prismark/Binghamton University

12.3 x 12.4mm MCeP® style PoP

- 1.3mm height, with 4 die DRAM stack
- Reduced substrate thicknesses

Samsung LPDDR4X with 8 (1GB) Die

- Gold wire bonds
- Die: 50 μm thick; FOW: 50 μm
- 120 μm EMC thickness over die

Processor Package

- 100 μm thick die; 25 μm Cu bump height
- TCB with NCP at <100 μm pitch
- 4 capacitors (0402) between bottom solder balls
- 2L "Upper substrate": 100 μm thick
- 3L Embedded Trace Substrate (ETS); 130 μm thick, 10 μm L/S, 55 μm via diameter

Samsung S10 5G Teardown

5G RFFE – Millimeter Wave Antenna Modules

Qualcomm QTM052
Antenna Modules



Substrate-like PCB (SLB)

Samsung S10 5G is first to the market with 5G mmWave. Most of the components are the same with addition of 5G baseband component, additional RF module and the antenna/tranceiver modules

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First Gen RFFE Cost Comparison (5G vs LTE)

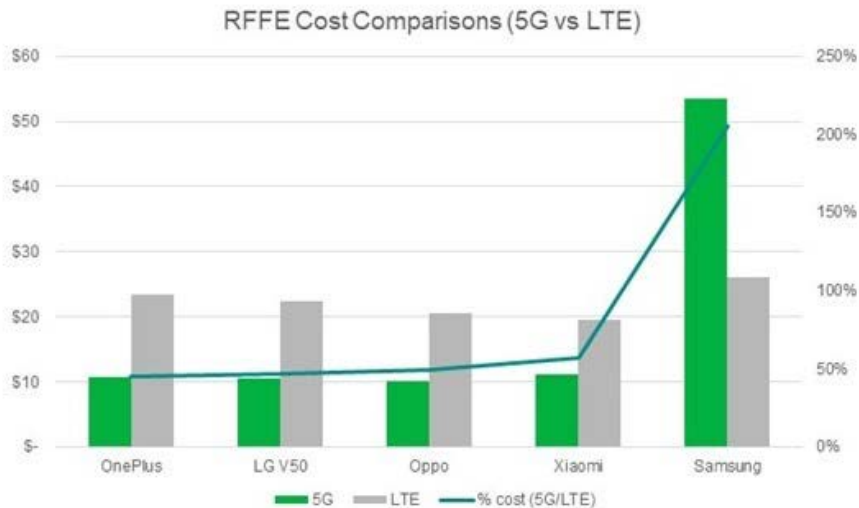


Chart 6 – Component cost comparisons of all 5 Qualcomm 5G designs

- The teardown data shows that Sub-6GHz 5G RFFE carries a cost premium of around half of the cost of existing LTE RFFE.
- While the mmWave solution (illustrated by the Samsung device) represent a staggering twice the cost of existing LTE RFFE.
- Subsequent generations of 5G phone design should lessen the 5G RFFE cost premium. In mature 5G designs, the 5G RFFE is expected to be absorbed into an integrated 5G/4G/3G RFFE design.
- This cost premium chart highlights the significance of 5G RFFE and can be used to argue the point that in terms of component cost, 5G RFFE is just as important as the modem chipset.

<https://technology.ihc.com/616863/in-5g-smartphone-designs-rf-front-end-graduates-from-traditional-supporting-role-to-co-star-with-modem>

What to Expect in 2nd Generation 5G RFFE Designs

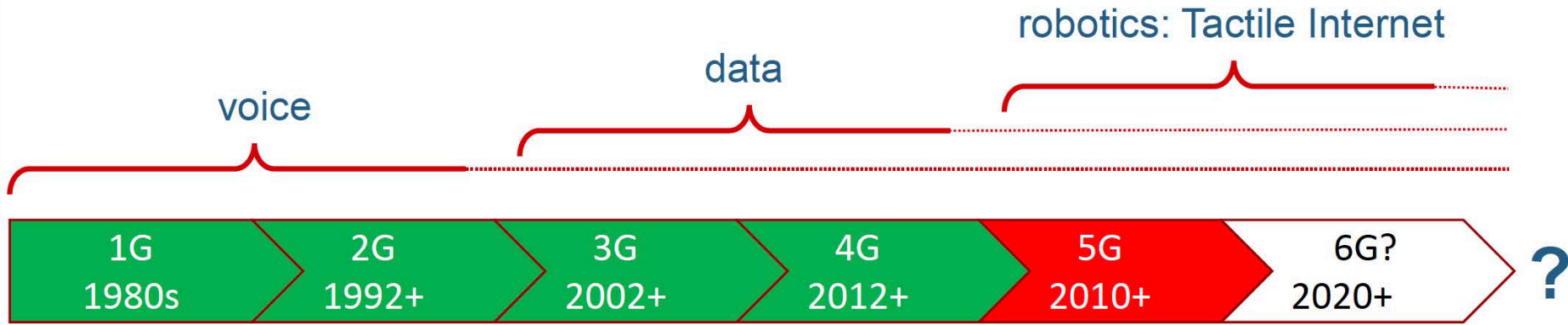
- In 2020, second-generation 5G solutions are expected to feature tighter component integration between 4G LTE and 5G NR.
- We will begin to see 5G devices that combine both Sub-6GHz and mmWave in the same RFFE.
 - These designs will allow for better chip-level integration, convergence of 4G and 5G RFFE and reduced overall cost. Second-generation 5G design are defined as multimode 5G/4G/3G/2G capable modem (single chip modem) capability and converged single RF transceiver handling both LTE and 5G as well as a converged RFFE design. Multiple
 - 5G designs based on Qualcomm's X55 second-generation 5G platform are slated to be released allowing OEMs to make bigger strides in component integration and cost optimization of the modem as well as the RFFE.
- The RF design challenges of mmWave 5G will still be present in the second-generation 5G phones.
 - Millimeter wave attenuation continues to present the problems for mobile RFFE designs.
 - Qualcomm will continue to evolve their mmWave technology for smaller antenna module designs
- As the industry moves through the 5G transition in the coming years, significant changes to the RFFE landscape are expected. Large OEMs will likely attempt to move away from a single supplier modem-to-antenna solution in order to preserve multi-source capabilities, but the benefits of a complete solution are hard to ignore, especially for competitive OEMs with ambitions of growing their market position with 5G technology.

<https://technology.ihs.com/616863/in-5g-smartphone-designs-rf-front-end-graduates-from-traditional-supporting-role-to-co-star-with-modem>

Design for Test Needs, Challenges and Potential Solutions

Need Challenge(s) and Enablers and Potential Solutions Sets	Current State (2019) (details)	3 years (2022) (details)	5 years (2024) (details)	Future State 10-years (2029) (details)
Need: Design for Test	Testing at component, cell and array levels	Low cost mfg. OTA (Over the Air) test up to 60GHz	Low cost mfg. OTA (Over the Air) test up to 120GHz	Low cost mfg. OTA (Over the Air) test up to 400GHz
Challenge(s) for Need	Cost of testing and yield loss	Isolation box, test equipment, known good units	Calibration for unit variation	Testing and calibration of array on chip
Possible Solution for Challenge	mmWave chamber, passive and active measurement Separate design, test and verification environments result in issues discovered at test	Correlated box w/ chamber, standard interface w/ golden unit Integrated design, test and verification environments reduce issues discovered at test	Build-in self calibration on package Multi-physics-based simulators enable co-design of EM, thermal and radiated patterns to enable correct by design at FEM level	Build in self-test and self-calibration on chip with self-repair. Achieve > 95% for FEM at 20 to 40 GHz

5G Today



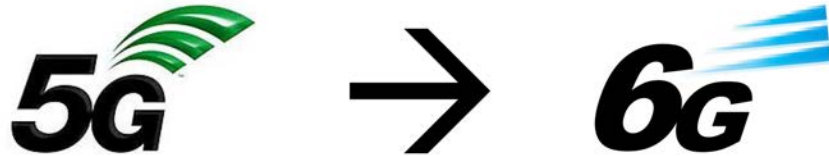
5G rushed into a standard 2 years early

Not considered: many key requirements

➔ “5G New Radio”: more like LTE + massive MIMO support

6G's Evolutionary Challenges “Stretching 5G”

- | | |
|--------------------|---|
| Reduce latency | → below 5ms end-2-end (e.g. for robotics) |
| Increase data rate | → beyond 10Gb/s (e.g. for VR) |
| Expand coverage | → connect 4B people missed-out |
| Scalable HW/SW | → enable cost-efficient applications (e.g. verticals) |
| Cleanup NFV | → entangle NFV & Openstack (e.g. “lean NFV”?) |



Issues and Topics Expected to be Addressed in 2020 2nd Edition of INGR

- More accurate technology assessment as problems are discovered during initial 5G rollout
- Beginning tracking of Rel 17 architecture, specifications, and gaps
- Design for Multiple Use Cases
- What do **YOU** think?
 - We want your feedback
 - To email us, write to **5GRM-mmWave@ieee.org**