

5G New Radio standards, Trends and Opportunities

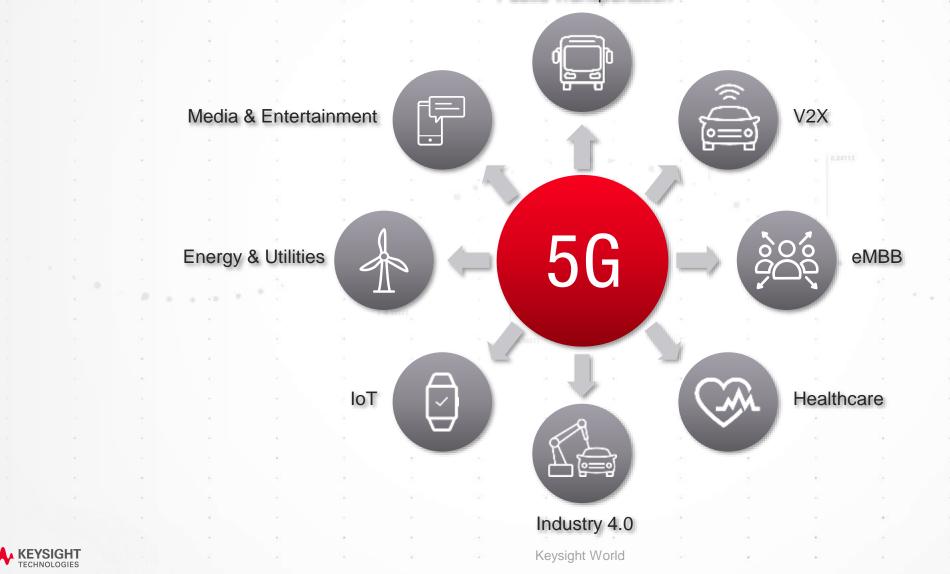
Jeffrey Chen

Keysight Technologies

Realizing the Vision of 5G

Public Transportation

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5G Trends Driving Industry Evolution

Deployments are accelerating Rollout Announcements 2019: 20 2020: More than 40 Investments 200 operators in 83 countries

Ecosystems >18 device makers using Qualcomm's 5G modem

Standards are evolving

Acceleration 5G NR NSA freeze pulled in 6 mos. to Dec '17 Maturation R15 5G NR Jun '18 freeze & Mar '19 late drop freeze Extension R16/17/18 5G NR extensions for V2X, URLLC & beyond

Technical complexity is high

Global Diversity 5G NR NSA vs. SA progressing in parallel More Bands and BW New bands: 32 FR1 & 4 FR2, with more BW options

Spatial Challenges Beamforming, tracking, and link management



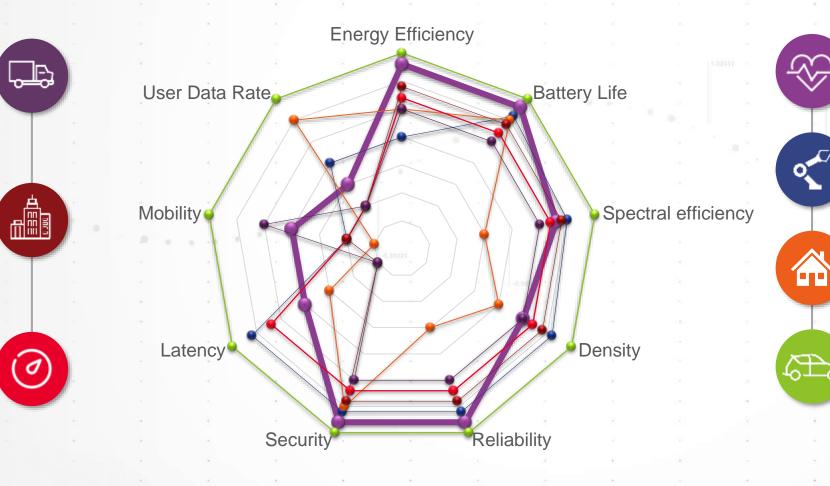
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Vertical Industry Applications Require Dedicated SLAs

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MULTI-DOMAIN KPIS DEFINE QOS AND QOE



QoS and QoE depend on the cumulative performance of the entire network:

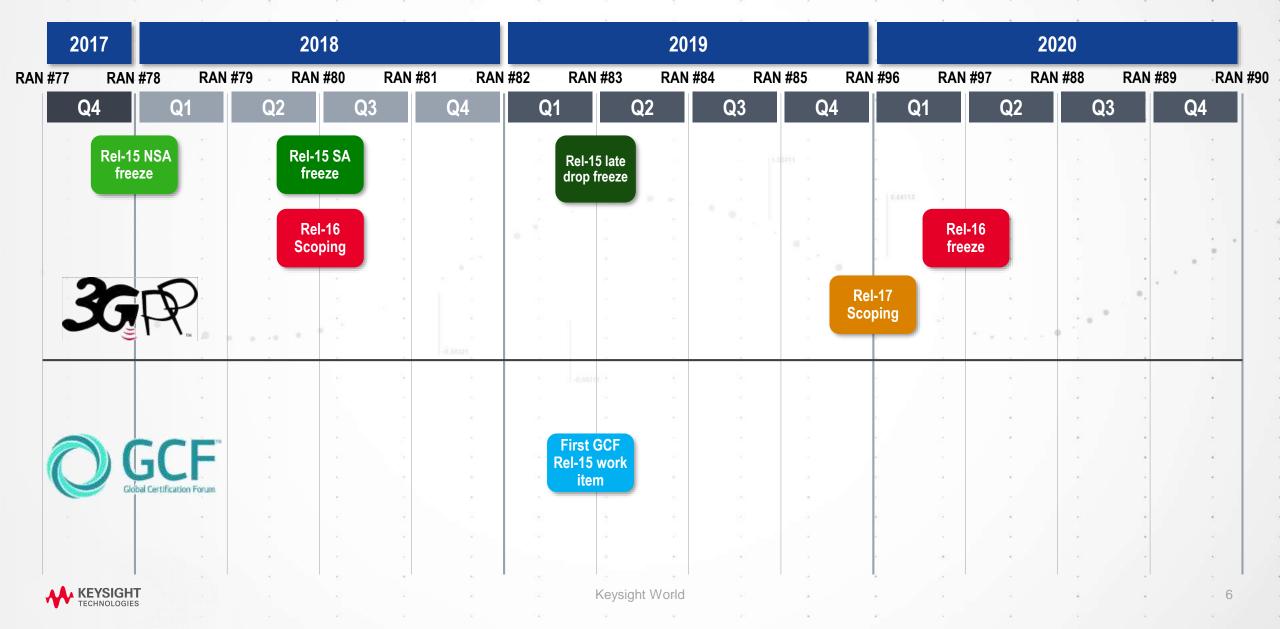
- Devices
- RAN
- Core
- Transport layer
- Cloud

SLA – Service Level Agreement
QoS – Quality of Service
QoE – Quality of Experience
KPI – Key Performance Indicator



Standards Continue to Evolve

5G NR Standards Are Evolving



Keeping Pace With 5G NR Standards

ENABLING FIRST-TO-MARKET SOLUTIONS THAT ACCELERATE INDUSTRY READINESS

- Keysight contributes more to the development of 5G **NR** than any other test vendor:
 - Authored more than 300 RAN4/5 5G NR contributions
 - Leading in GCF/PTCRB test case validation for 5G NR **RF SA and NSA device certification**
 - Simplified OTA testing with compact antenna test range (CATR) method adopted by 3GPP
- Stay ahead of the standards using Keysight's:
 - 5G Conformance Toolset
 - 5G mmWave Testbed
 - 5G NR Software Solutions



Global Certification

"Keysight's 5G test solutions are instrumental in accelerating commercial 5G development and rollout."

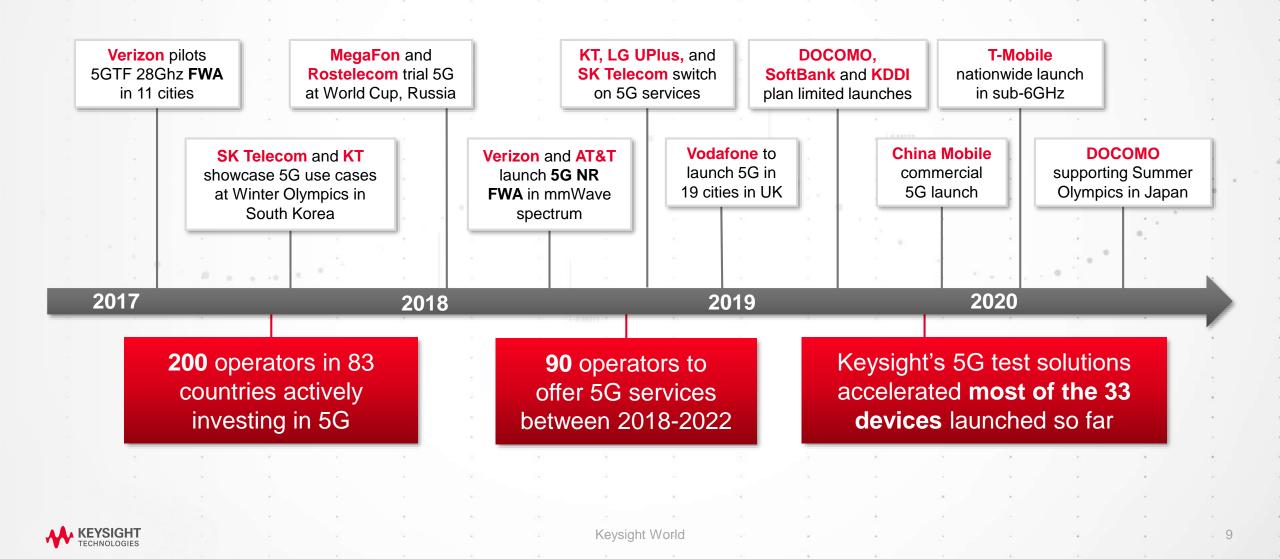
Tony Schwarz, Senior VP of Engineering, Qualcomm Technologies



Mobile Operator Deployments Accelerating Around the World

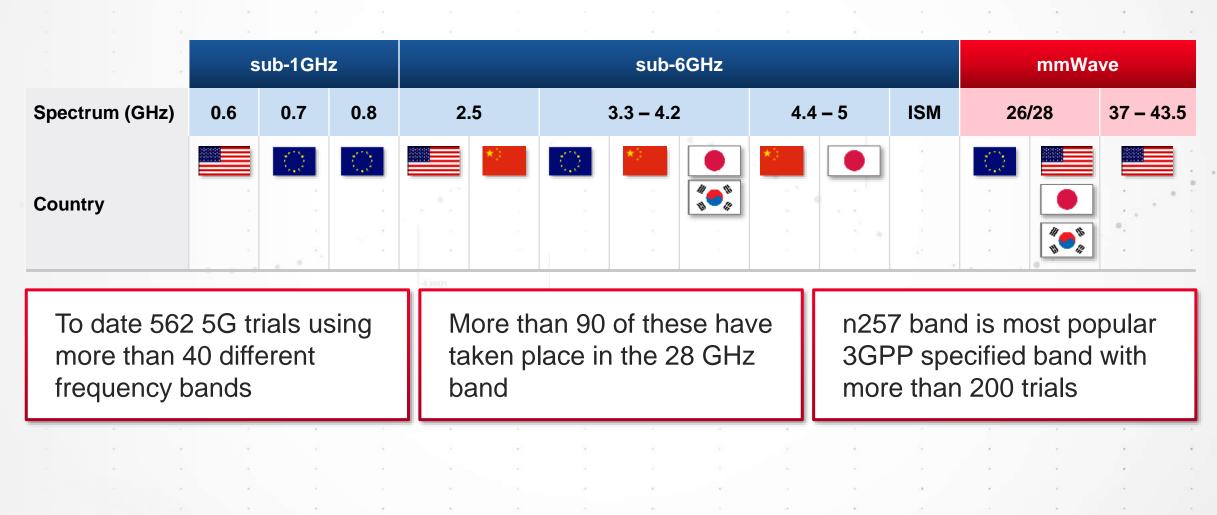
Global 5G Deployments

KEY MILESTONES



Interoperability - Key for Global Deployments

TRIALS ON VARIOUS BANDS FROM SUB-1GHZ, SUB-6GHZ & MILLIMETER WAVE



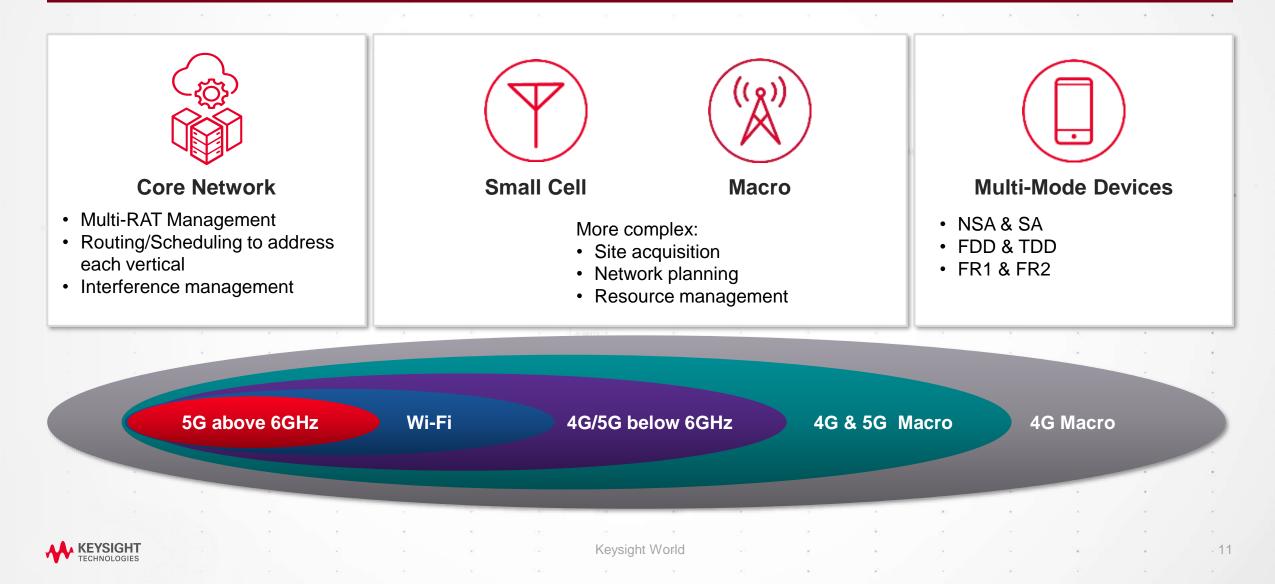


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Heterogenous Networks

INCREASING DEPLOYMENT COMPLEXITY



How does Keysight Enable the Industry? Our Role in Making 5G a Reality

Demonstrating Data Call with 5G NR Multi-Mode Modem

MEDIATEK'S 5G NR MODEM & KEYSIGHT'S 5G NETWORK EMULATION SOLUTION

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- Keysight's E7515B UXM 5G network emulation solution used with MediaTek's Helio M70 to successfully demonstrate call and support for enhanced mobile broadband applications
- M70 is a 5G modem with both LTE and 5G dual connectivity (EN-DC), supporting multi-mode for every cellular connectivity generation from 2G to 5G non-standalone (NSA) and standalone (SA) 5G network architectures.

"This demonstration with Keysight is another pivotal step forward for the rollout of 5G. With Keysight's 5G solutions, device manufacturers working with us can integrate multi-mode modems into their designs and accelerate the delivery of 5G NR mobile devices to the market."



MediaTek & Keysight Technologies Demonstrate 5G NR Data Call Using Helio M70 Multi-Mode Modem with Integrated Baseband

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Keysight's 5G network emulation solution used with MediaTek's Helio M70 to successfully demonstrate call and support for enhanced mobile broadband applications

HSINCHU, Taiwan – Feb. 21, 2019 – MediaTek, a leading fabless semiconductor company, and Keysight. Technologies, HSINCHU, Taiwan – Feb. 21, 2019 – MediaTek, a leading fabless semiconductor company, and Keysight. Technologies, nc, (NYSE: KEYS), a leading technology company that helps enterprises, service providers, and governments accelerate innovation to connect and secure the world, today announced the successful demonstration of a SG New Radio IP data transfer call using a SG multi-mode modem with integrated baseband, supporting both Non-Standalone and Standalone modes.

The demonstration used MediaTek's multi-mode 5G modern. Helio M70, which is compliant to the latest 3GPP Ref-5 standards, and Keysight's 5G network emulation solution to achieve the theoretical maximum throughput rate over DOM Iz NR bandwith. These high-level data rates are needed to deliver enhanced Mobile Broadbund for applications such as virtual reakly, augmented reality, and ultra-high-definition video streaming.

MediaTek has been active in the development of 5C technology to bring reliable, available and fast broadband to consumers everywhere. This demonstration with Reysight is another pivotal step forward for the rollout of 5C," sad IS Pan, general manager at MediaTek. "With Reysight's 5G solutions, device manufacturers working with us can ntegrate multi-mode moderns into their designs and accelerate the delivery of 5G NR mobile devices to the market."

MediaTek's Helio M20 is a SG modern with both LTE and SG dual convectivity (EN-DC), supporting multi-mode for invery cellular connectivity generation from 3G to 5G it supports initial non-standalone (NSA) and future standalone SA) SG network architectures. The Helio M70 can connect to worldwide SG NR bands and 4G LTE bands while meeting sigh Power User Equipment DHRUE support and other essential carrier features. Helio M20 is available now, and is supported to sho in the second half of 2019.

sevelabit's 5G network emulation solution leverages the company's UXM 5G Wireless Test Platform to support mobile

JS Pan *General Manager* **Mediatek**



Demonstrating Industry-Leading Data Rates for FWA

ASKEY'S 5G NR CPE & KEYSIGHT'S 5G NETWORK EMULATION SOLUTION

 High performing mmWave CPEs O VIN O NOI O THE O STOR O SHOULD HER O deliver wireless broadband services telecoms **FierceWireless** Keysight Provides NTT DoCoMo With 5G Network Emulation for 5G NR Devices to customers' homes Keysight claims first 5G device testing toolset New CPE from Askey that Keysight going strong OUR NEWS leverages Qualcomm's Snapdragon | Aug 23, 2018 7:35am X50 modem **EE**Times The U.S. firm also secured a 5G collaboration agreement with Korean carrier SK Telecom RCRWireless News Qualcomm, Keysight gies inks 5G deal with China Telecom Achieve 2-Gbps Wireless Downloads

"Keysight's 5G solutions enable us to accelerate development of 5G designs in support of emerging opportunities around the world."

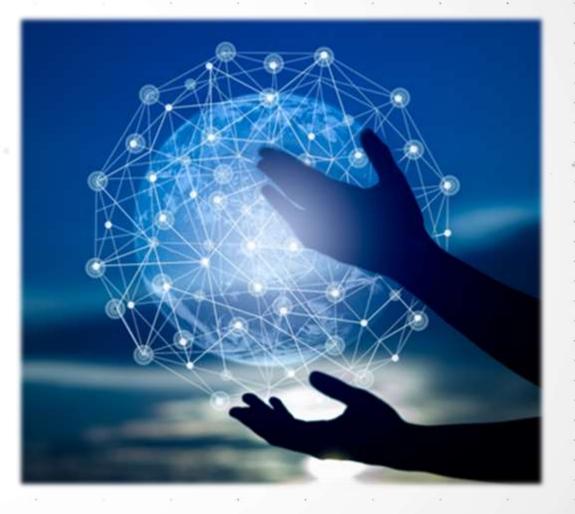
Robert Lin *Chief Executive Officer* **Askey**

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Keysight Powers China's Mobile Ecosystem

- Close collaborations with entire Chinese mobile ecosystem
 - China Mobile, China Telecom, CICT, UNISOC, CAICT, Datang, etc.
- Industry-first 5G solutions (across layer 1-7) help China launch early 5G trials
- Playing a key role in accelerating deployments by participating in industry consortia
 - 5G Device Forerunner Initiative
 - IMT-2020 (5G) Promotion Group
 - Future Forum
- Chinese mobile device makers (e.g. Xiaomi, OnePlus, Vivo, OPPO, etc.) use Keysight's 5G solutions to accelerate design, development and acceptance





5G Services in Japan by 2020

PRE-COMMERCIAL LAUNCHES IN 2019

- NTT DOCOMO & SoftBank use Keysight's 5G network emulation solutions for characterizing and validating 5G NR mobile devices
- NTT DOCOMO use Keysight's channel sounding solutions for 5G research project

"Keysight's proven expertise in 5G and end-to-end test solutions enable us to accelerate our 5G commercialization plans."

Toshiyuki Futakata Vice president and general manager Communication Device Development Department NTT DOCOMO



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30% of Korea's Mobile Users to Access 5G by 2020

ACCELERATING COMMERCIALIZATION IN KOREA WITH MARKET MAKERS

- Samsung & Keysight accomplish 5G NR IODT milestone
 - Maximum achievable 5G NR data throughput demo
 - Keysight's 5G Network Emulation Solutions (UXM 5G) used for protocol and RF development & validation
- 5G collaboration with SK Telecom covers
 - 5G network design development
 - 5G device performance validation technology
 - Test cases and processes
- 5G collaboration with **KT Corporation** to
 - Support commercial 5G NR deployment plans
 - Test 5G infrastructure and UE across sub-6GHz & mmWave



"We are pleased to collaborate with Keysight, the company with 5G expertise and solutions in this field, to help support our ambitious 5G deployment goals."

Jongkwan Park Head of Network Technology R&D Center SK Telecom



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Supporting the Entire 5G Mobile Ecosystem in the U.S.

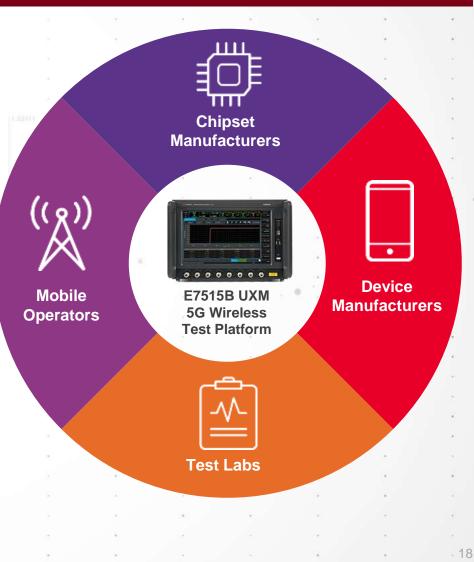
ACCELERATING DELIVERY OF FIXED WIRELESS AND EMBB SERVICES

- Keysight supports all major U.S. mobile operators in their goals to validate new mobile devices prior to deployment
- Keysight offers leading test case coverage, supporting device acceptance test plans mandated by each mobile operator
- Keysight's Nemo RAN analytics solutions automate operator's 5G NR site acceptance

"With 5G commercialization starting in the first half of 2019, Qualcomm Technologies joining forces with Keysight, helps enable the entire mobile ecosystem to make 5G a commercial reality."

Jon Detra Vice President, Engineering **Qualcomm Technologies, Inc**

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Performance Test Requirements 5G Device Testing



The 5G Race Is On...

AROUND THE WORLD

Deployments are accelerating

More mobile operators launching 5G networks to capture new business models

Standards are evolving

New use cases driving new standards evolution

Technical complexity is high

Diversity driven by multiple regional ecosystems progressing in parallel



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