The Road to 5G

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5G Vision

Future mobile technology — "5G" — is focused on *enabling a seamlessly connected society* *in the 2020 timeframe and beyond that* *brings together people along with things, data, applications, transport systems and cities in a smart networked communications environment**.*

It is expected to *enable a fully mobile and connected society* *and to* *empower socio-economic transformations* *in countless ways many of which* *are unimagined today, including those for productivity, sustainability and well-being**.*
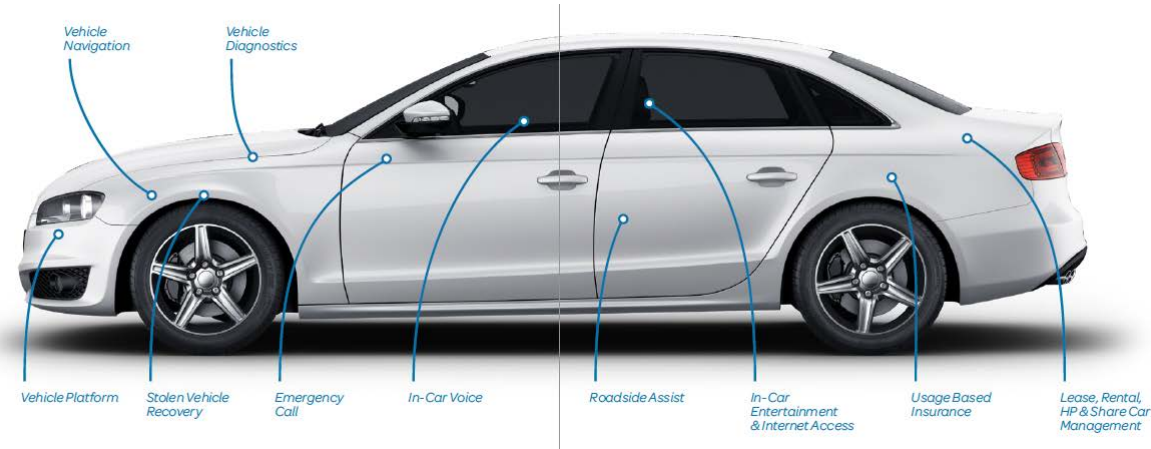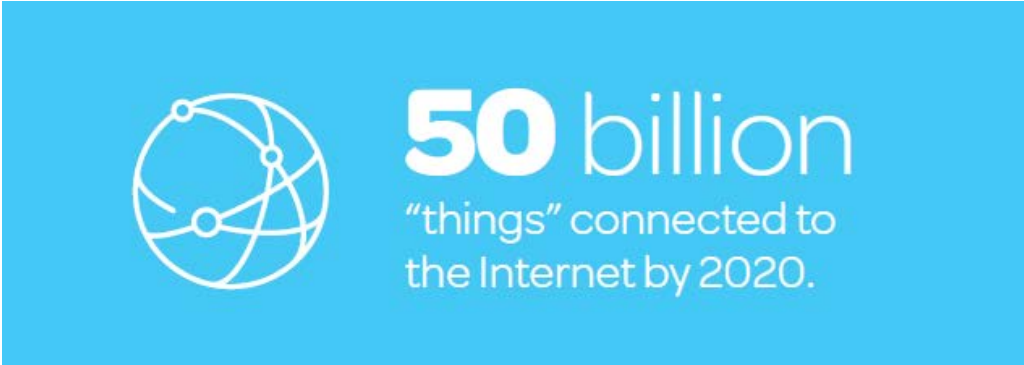
Source: ITU towards "IMT for 2020 and beyond": http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx and the NGMN 5G Whitepaper

One of the interesting things that happened in yesterday's Commission meeting was that my colleagues talked about how *we don't know exactly what 5G will become**. We can see a lot of shadows.*
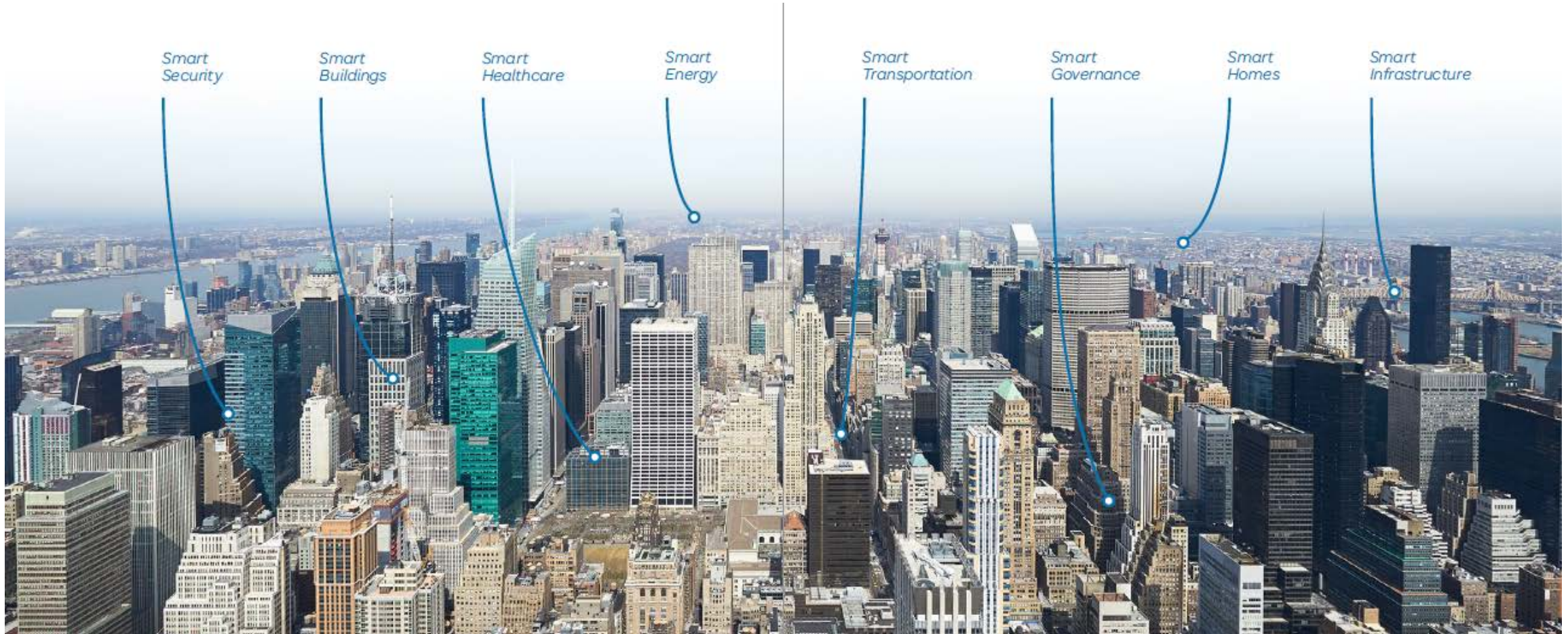
- REMARKS OF FCC CHAIRMAN TOM WHEELER AS PREPARED FOR DELIVERY ADVANCED WIRELESS RESEARCH INITIATIVE LAUNCH EVENT JULY 15, 2016

A Look to the Future – 2020 and Beyond, the rise of "Things"

50 billion "things" connected to the Internet by 2020.

Vehicle Navigation · Vehicle Diagnostics · Vehicle Platform · Stolen Vehicle Recovery · Emergency Call · In-Car Voice · Roadside Assist · In-Car Entertainment & Internet Access · Usage Based Insurance · Lease, Rental, HP & Share Car Management

Smart Transformation Synergy Cloud Structure · Networks · Automation · Application Integration Digital Cluster · Internet Services Framework Wireless Massive · Connected Data Sharing Architecture · Speed Life · Global Interface · Applications · Distributed Embedded · IOT Smart Grid Exploitation · Interconnected · Complexity Intelligence · Communication · Sensors Real Time Instantaneous Analysis · End Users Knowledge · Surveillance Development Innovation · Information Database Remote · Virtual Autonomous

1.2 billion total M2M connections in the automotive sector globally by 2024

Source: Machina Research, 2015

2020 and Beyond - Smart Cities

Smart Security
Smart Buildings
Smart Healthcare
Smart Energy
Smart Transportation
Smart Governance
Smart Homes
Smart Infrastructure

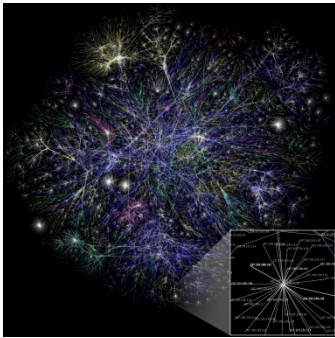# The Coming "Augmented Age" and the "Age of Things"

Industrial Age

Space Age

Digital Age

Information Age

Augmented Age / Age of Things
Artificial Intelligence
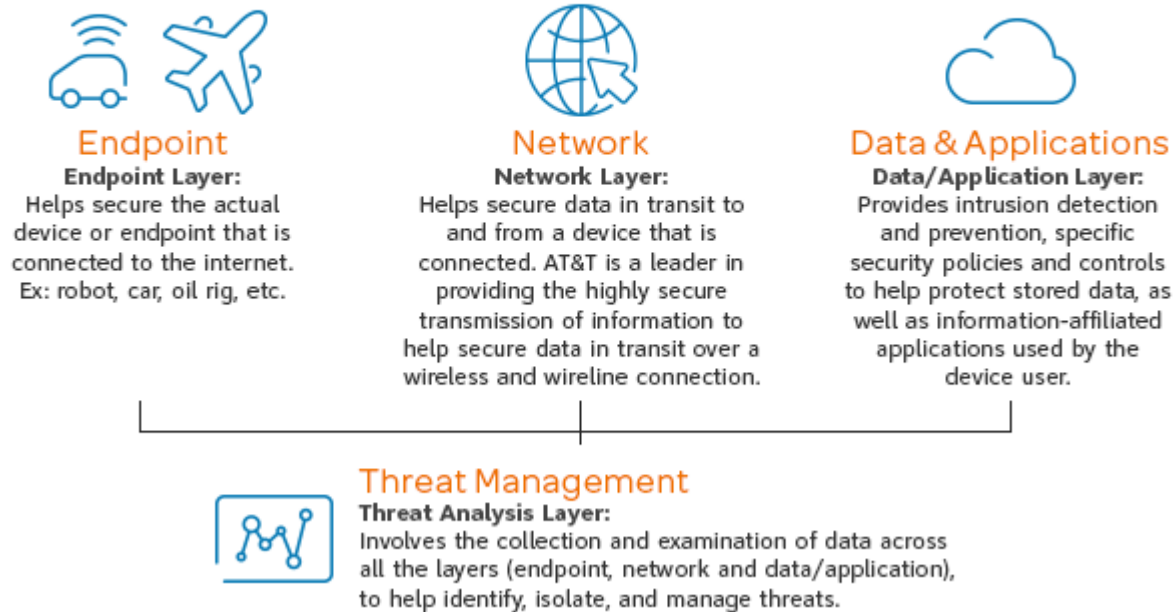"Robotification"
"Information of Everything"

Time

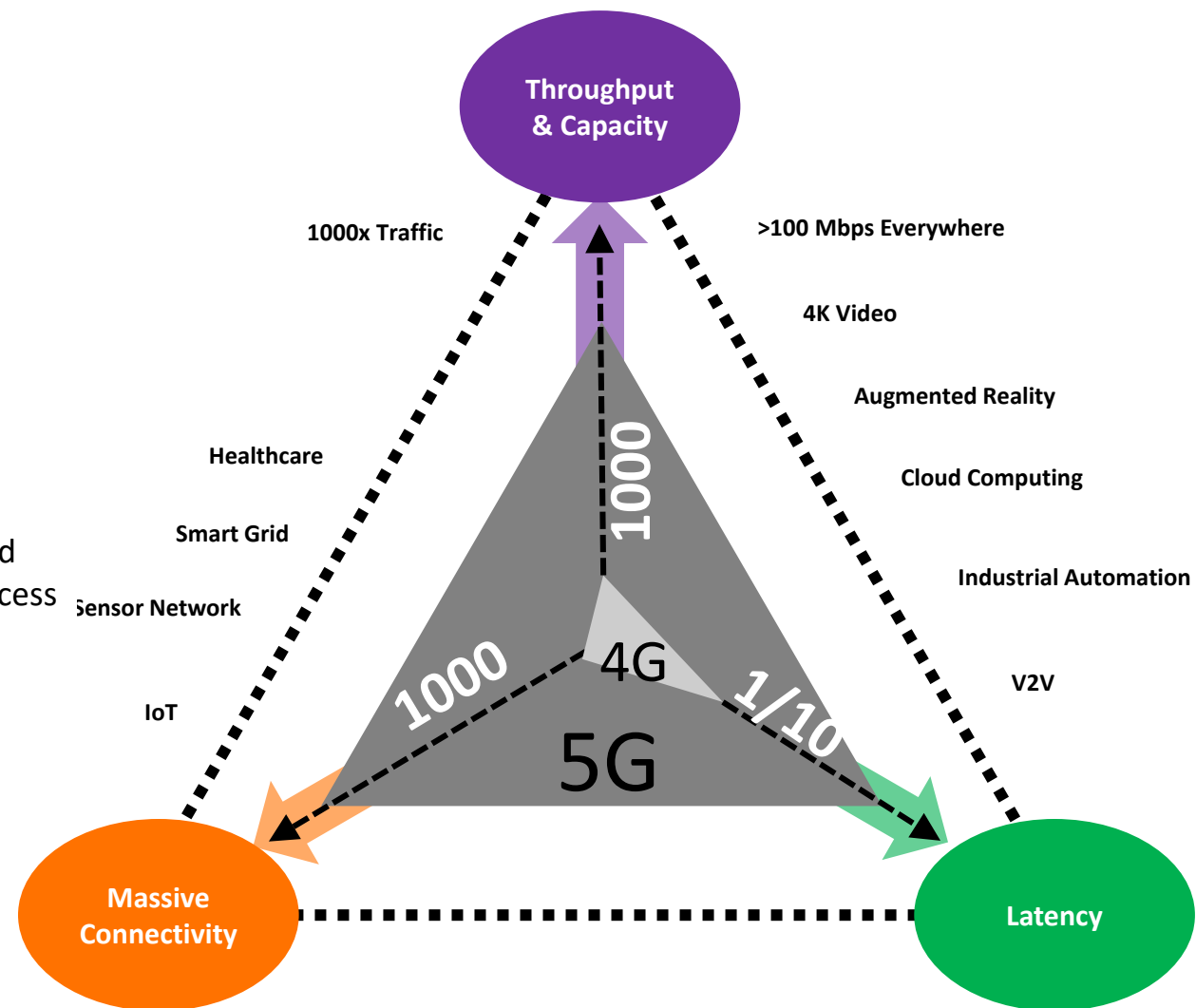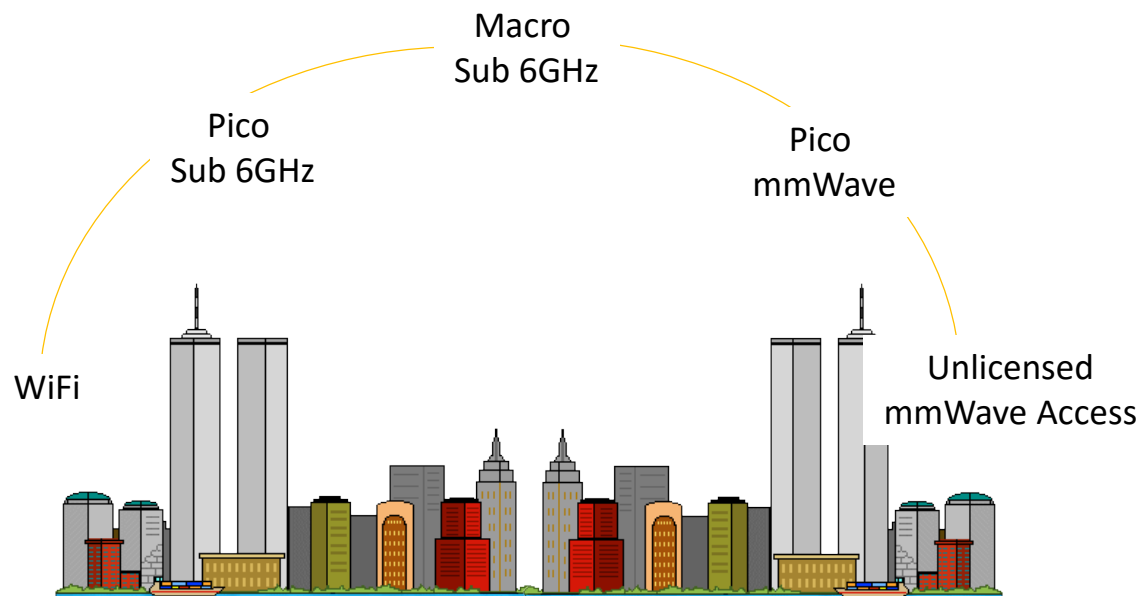# Connected "Everything" → Every Changing Cyber Risk Landscape

To adequately protect from security breaches, a multi-layered approach is recommended.

Endpoint
Endpoint Layer:
Helps secure the actual device or endpoint that is connected to the internet. Ex: robot, car, oil rig, etc.

Network
Network Layer:
Helps secure data in transit to and from a device that is connected. AT&T is a leader in providing the highly secure transmission of information to help secure data in transit over a wireless and wireline connection.

Data & Applications
Data/Application Layer:
Provides intrusion detection and prevention, specific security policies and controls to help protect stored data, as well as information-affiliated applications used by the device user.

Threat Management
Threat Analysis Layer:
Involves the collection and examination of data across all the layers (endpoint, network and data/application), to help identify, isolate, and manage threats.

We have seen a dramatic 458% increase in IoT vulnerability scans against devices.
— AT&T Cybersecurity Insights, Volume 1, October 5, 2015

5G Vocabulary – Technology Enablers

- **"Softwarization"**
  - Network Function Virtualization
  - Software Defined Network
  - Network Slicing

- **Open Source**

- **Mobile Edge Computing**

- **Mobility on Demand**

- **mmWave**

- **Massive MIMO**

- **UHRLLC**

- **Densification**

- **Cloud**

- **Big Data**

5G Requirements

A Look Back

What do we know now?

Estimated Standards Timeline

- **3GPP Phase 1: 2018**

- **3GPP Phase 2: end of 2019**

- **Expected widespread industry deployments: Phase 2 and beyond**

Use Case Opportunities

- **Enhanced mobile broadband**
  - Throughput of 5 Gbps +

- **Massive IoT**
  - Connection Density
  - Long battery life

- **High reliability / low latency**
  - Industrial control
  - Remote manipulation
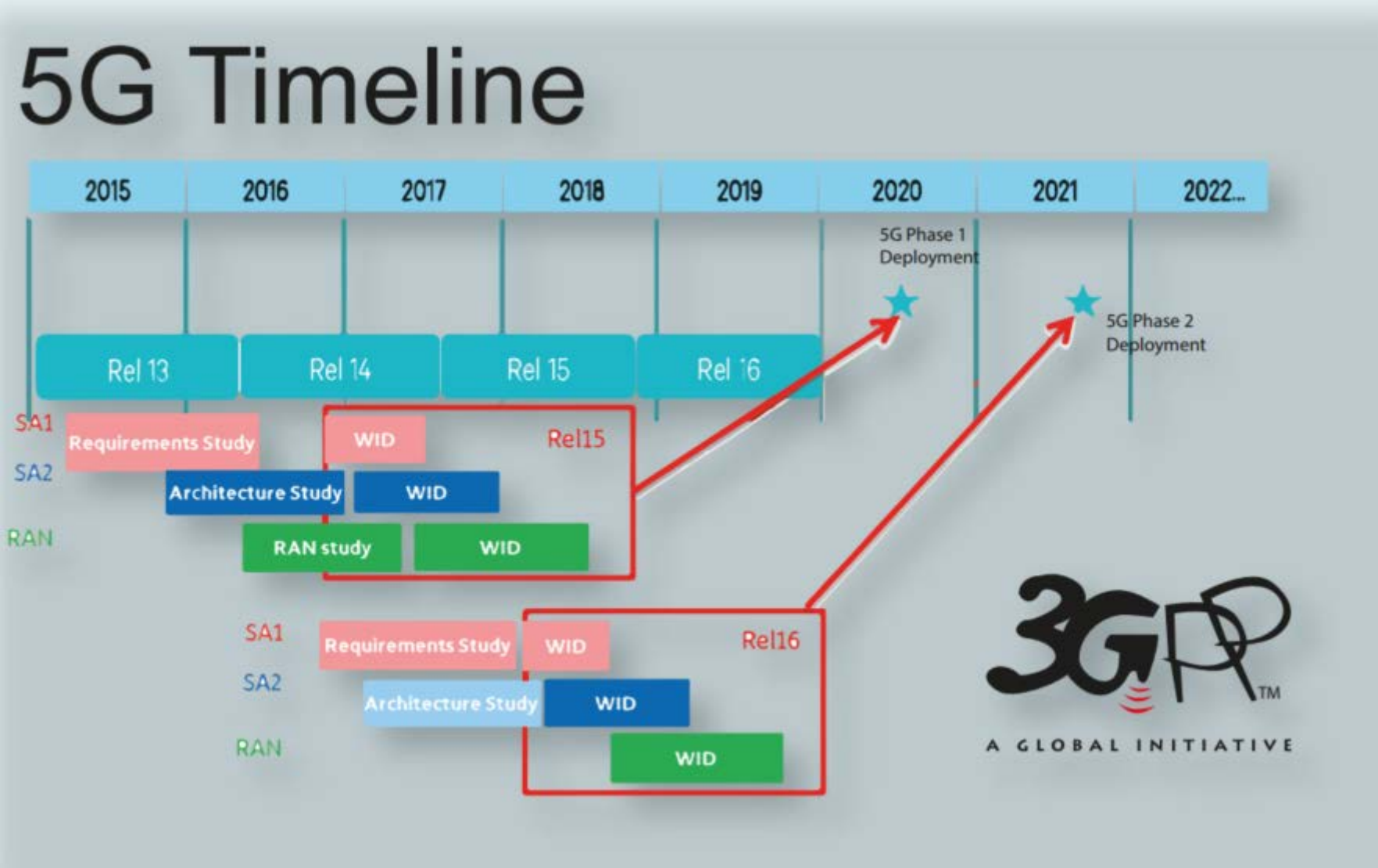
Path to 5G
(Don't Forget LTE-Adv.)

Pre-Deployment

LTE-Advanced Evolution (R13&14)

- **FD-MIMO**
- **Improved densification management**
- **Dual connectivity**
- **Improved latency**
- **Higher order modulation**
- **Virtualization**

Narrowband LTE

- Designed for low-power devices, with 10-year battery life
- Standards this summer; deployment late 2017 / early 2018

5G Industry Expectations

So much more than speed

- Multi-gigabit speeds and high capacity
- Connectionless Massive IoT
- Ultra-Low Latency and high reliability
- Sub 6 GHz for wide area coverage with improved spectral efficiency
- Flexible, lean carrier design
- Multi-RAT network using sub 6 GHz, mmWave and unlicensed bands in concert
- Massive MIMO
- Densification with self-backhaul
- SDN/NFV based architecture

"New experiences like virtual reality, self-driving cars, robotics, smart cities and more are about to test networks like never before,"

"Our approach is simple – deliver a unified experience built with 5G, software-defined networking (SDN), Big Data, security and open source software."

John Donovan
Chief Strategy Officer and Group President
AT&T Technology and Operations

Next Steps

- **Trials and Testing**
- **Standardization**
- **Key Architecture Components:**
  - NFV / SDN
  - Big Data / Analytics
- **Architecture Considerations:**
  - X-RAN
  - Transport
- **Core Network Development**

Thank You

Wireless evolution

	1G	2G	3G	4G	5G
ROAD TYPE:	Dirt road	Paved one lane road	Two lane road	Four lane highway	Ten lane superhighway
CHANNEL SIZE:	30 KHz	200 KHz	1.25 MHz	20 MHz	200 MHz
APPLICATIONS:	Voice	+ Text, Email, Limited Internet	+ Internet, low quality video	+ Social media, streaming video	+ HD video, VR, AR, High-speed data
FREQUENCY BAND:	800 MHz	800/1900 MHz	800/1700/1900 MHz 2.1 GHz	700/800/1700/1900 MHz 2.1/2.3/2.5 GHz	High Band

5G: The Next Generation of Wireless

- 5G will:
  - Have speeds at least 10x faster than 4G;
  - Support 100x more devices; and
  - Be 5x more responsive.

- **These next-generation wireless networks could add $2.7 trillion to the U.S. economy by 2030**.
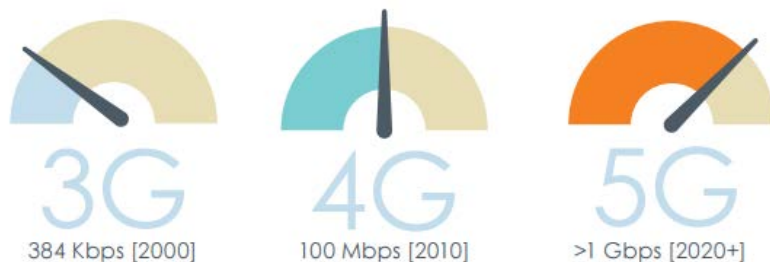
Consumer Benefits of 5G
By the Numbers

10x Faster
100x More Devices
5x More Responsive

3G 384 Kbps [2000]
4G 100 Mbps [2010]
5G >1 Gbps [2020+]

5G — 1 inch
4G — 4.6 feet
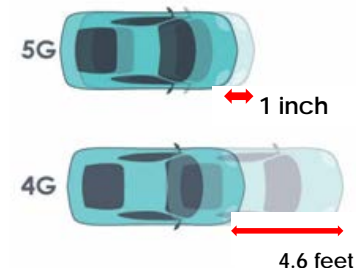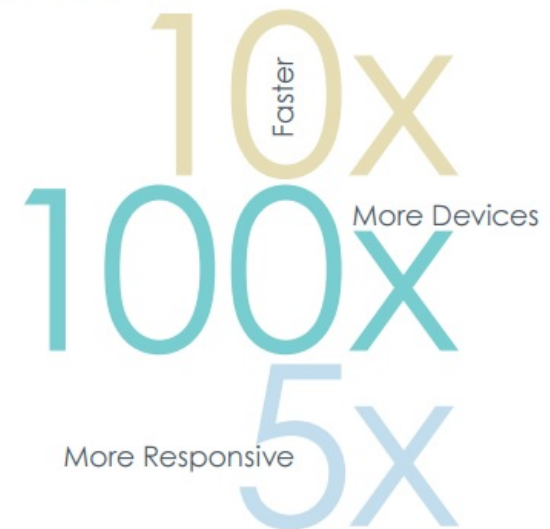
5G spectrum & infrastructure

High Band Spectrum

- Complete Spectrum Frontiers proceeding quickly

- Adopt flexible service rules

- Licensing framework that provides certainty and encourages investment

Low/Mid Band

- Low band – enable broad coverage

- Mid band – capacity and small cells

Infrastructure

- Small cell placement

- Pole attachments

Mid-Band   High-Band

700 MHz   2 GHz   3 GHz   5 GHz   6 GHz   20 GHz   40 GHz   60 GHz   80 GHz

Licensed - Available Today (Sub 6 GHz)
Unlicensed - Available Today
FCC Proposed High Band Spectrum
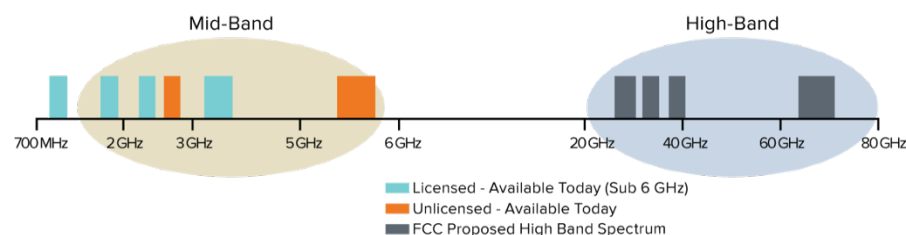
Unleashing 5G

- CTIA supports the Commission's efforts to allocate additional spectrum for mobile broadband services.

- The Commission's examination of bands above 24 GHz should be part of a holistic examination of high-, mid -, and low-band spectrum for mobile use.

  - High-band spectrum is complementary to spectrum below 3 GHz.

  - Low- and mid-band spectrum have better propagation characteristics and, for the foreseeable future, will be more advantageous for macro network coverage and capacity.

- Streamlined pole and siting policies are also necessary to support spectrum deployments.

  - Higher frequencies mean more infrastructure – carriers will need to deploy thousands of small cells to take advantage of the new spectrum to provide users with service.

High Band Spectrum is Vital to America's 5G Future

FCC News (For Immediate Release)

July 14, 2016: The rules adopted (by FCC) today creates a new Upper Microwave Flexible Use Service in the 28GHz (27.5-28.35 GHz), 37 GHz (37-38.6 GHz), and 39 GHZ (38.6-40 GHz) bands, and new unlicensed band at 64-71 GHz

425/425 MHz   200 MHz   200 MHz

5G benefits

U.S. wireless industry benefits

- > $400B in annual economic impact
- > 1.3 million jobs
- U.S. jobs – R&D, industry knowledge, universities

Markets

- Consumers
  - CTIA 5G white paper: http://tinyurl.com/jh6gemv
  - Speed – Ultra HD video, VR
  - Latency – robotics, MTC
  - IoT – wearables, tags, smart home

- Verticals
  - Industrial IoT, Connected cars, Energy, Transportation, Smart Cities, M-Health and Telemedicine

ctia Everything™ Wireless

Qualcomm's vision

Transforming our world through intelligent connected platforms

Last 30 years
Interconnecting people

Next 30 years
Interconnecting their worlds

Leveraging unparalleled systems leadership in connectivity and compute

Our 5G vision: a unifying connectivity fabric

5G

Enhanced mobile broadband

- Multi-Gbps data rates
- Extreme capacity
- Uniformity
- Deep awareness

Mobile devices   Networking

Mission-critical services

- Ultra-low latency
- High reliability
- High availability
- Strong security

Automotive   Robotics   Health

Massive Internet of Things

- Low cost
- Ultra-low energy
- Deep coverage
- High density

Wearables   Smart cities   Smart homes

Unified design for all spectrum types and bands from below 1GHz to mmWave

3

Evolving LTE to be a critical part of the 5G Platform

We are pioneering 5G technologies today

Advanced MIMO

Shared spectrum (LAA, LSA)

eLAA

256QAM

Gigabit-class LTE

Massive MIMO

Low Latency

Carrier aggregation

Narrowband IoT

Enhanced broadcast

Device-to-device

C-V2X

5G NR

Rel-15 and beyond
5G NR

5G

Rel-10/11/12
LTE Advanced

Rel-13 and beyond
LTE Advanced Pro

2015

2020+
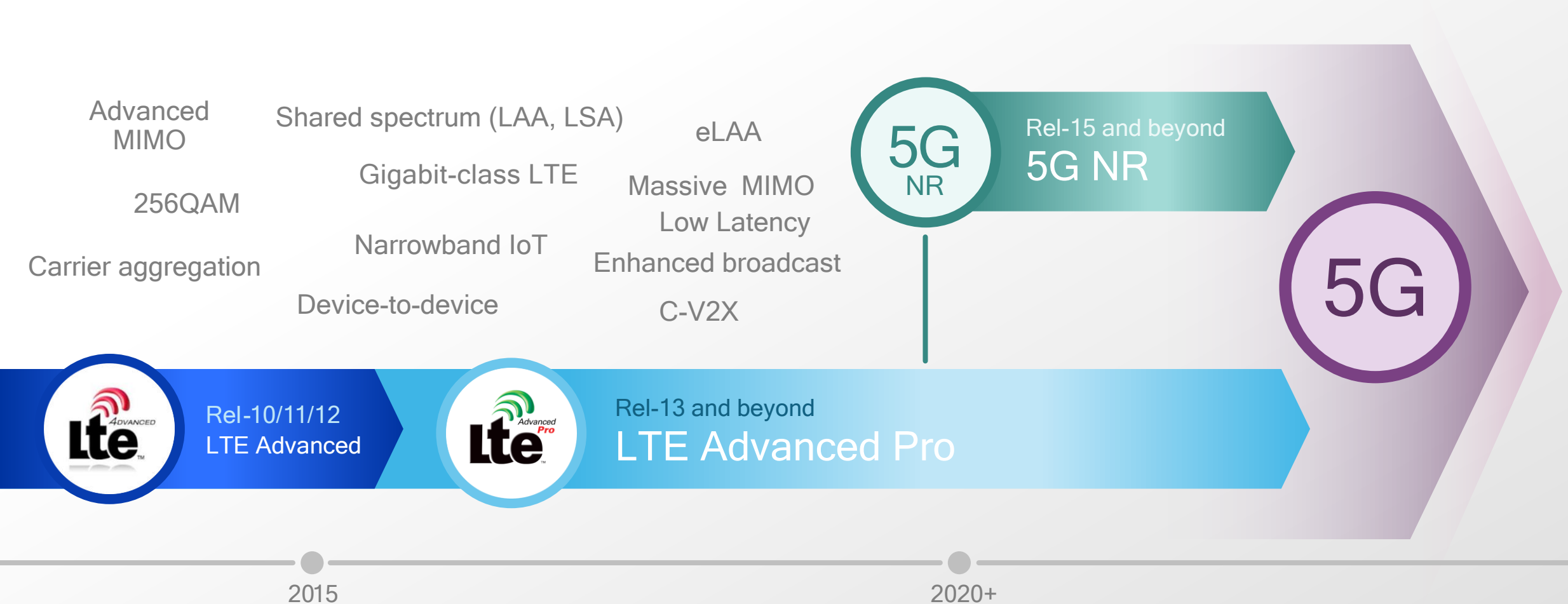
Note: Estimated commercial dates. Not all features commercialized at the same time

4

Multi-mode/multi-connectivity essential to 5G success

5G / 4G / 3G / Wi-Fi
Multi-mode device

Wi-Fi

4G LTE

5G above 6 GHz

5G NR

4G below 6 GHz

5G below 6 GHz

Simultaneous connectivity across
5G, 4G and Wi-Fi

5G NR

A unified, more capable air interface

Diverse
deployments

Diverse
spectrum

5G

Diverse services
and devices

A unified 5G design for all spectrum types/bands

Addressing a wide range of use cases and deployment scenarios

Licensed Spectrum

Cleared spectrum

EXCLUSIVE USE

Shared Licensed Spectrum

Complementary licensing

SHARED EXCLUSIVE USE

Unlicensed Spectrum

Multiple technologies

SHARED USE

Below 1 GHz: longer range for massive Internet of Things

1 GHz to 6 GHz: wider bandwidths for enhanced mobile broadband and mission critical

Above 6 GHz, e.g. mmWave: extreme bandwidths, shorter range for extreme mobile broadband

From wide area macro to local hotspot deployments

Also support diverse network topologies (e.g. D2D, mesh)

5G Enhanced mobile broadband

Extreme throughput
Ultra-low latency
Uniform experience

- Mobilizing mmWave
- Wider bandwidths
- Massive MIMO
- Shared spectrum

5G Mission critical services

High reliability
Ultra-low latency
High availability

- Low-latency TDD/FDD
- Network slicing
- Mission-critical transmissions
- Multi-connectivity

LTE roadmap the foundation for cellular IoT growth

Scaling LTE to connect the Internet of Things

Scaling down in complexity and power

LTE

LTE Cat-1
Up to 10 Mbps

eMTC (Cat-M1)
Up to 1 Mbps

NB-IoT (Cat-NB1)
10s of kbps to 100s of kbps

Energy management — Wearables — Connected healthcare — Object tracking — City infrastructure — Utility metering — Smart buildings — Environment monitoring
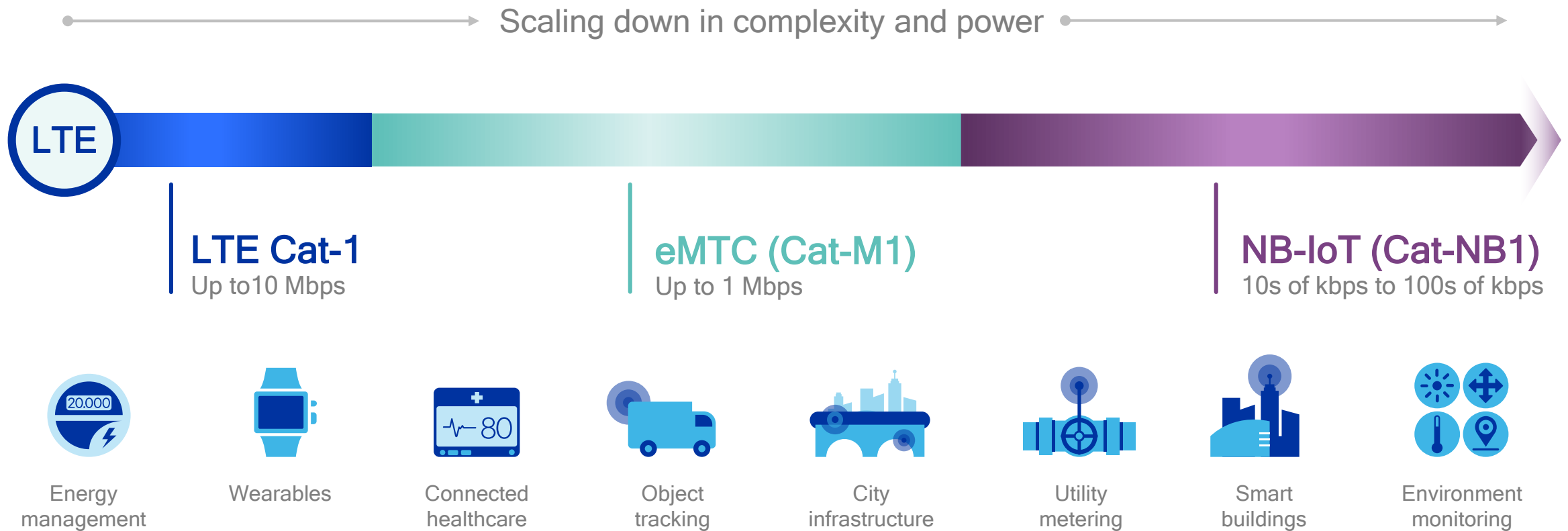
Natively incorporate advanced wireless technologies

Many technology enablers to meet 5G requirements and services

Hyper dense deployments with full self-configuration

mmWave

Massive MIMO

Low latency and ultra-reliable communication

Integrated access and backhaul

Coordinated spatial techniques

Best use of all spectrum types

Advanced receivers

Beam forming

Multicast

Multi-hop and D2D communications

Energy efficient, low cost IoT communications

V2X
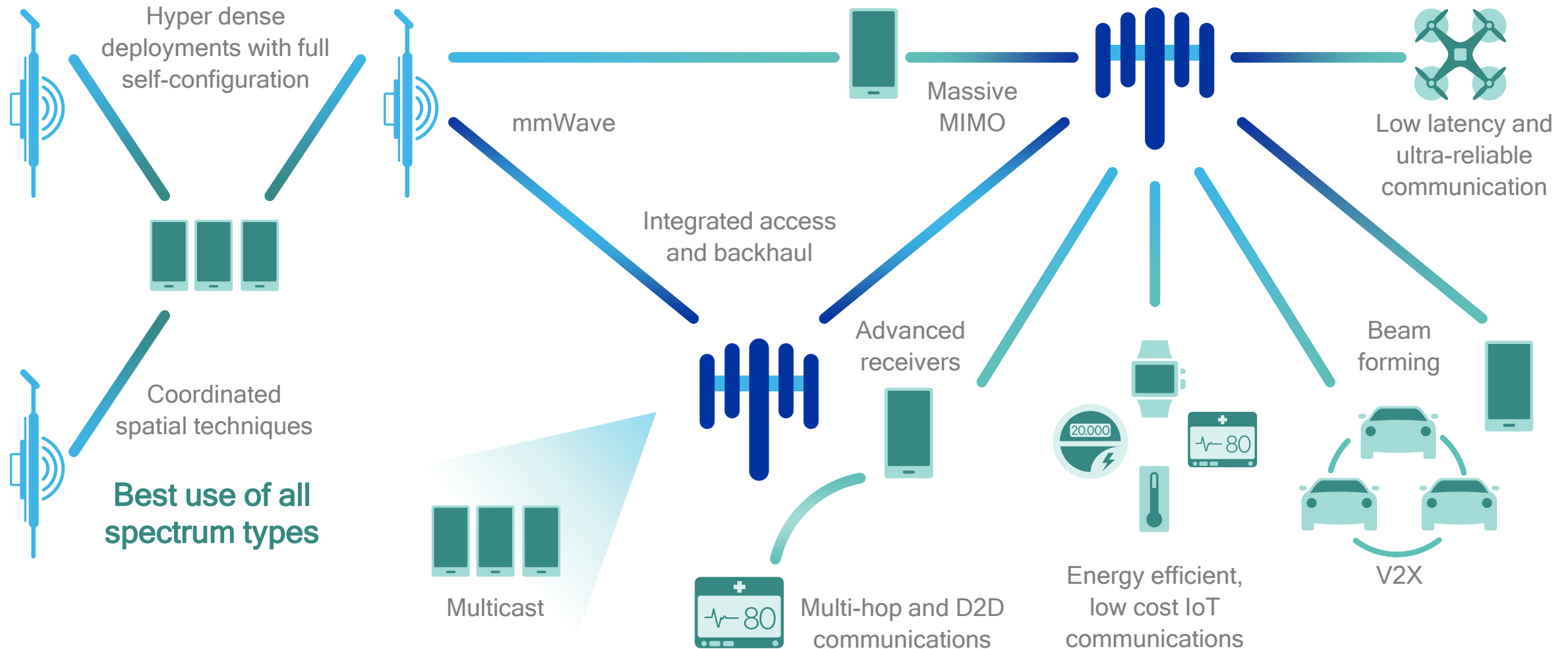
Introducing the Qualcomm Research 5G NR sub-6 GHz prototype system and trial platform

160MHz carrier bandwidth
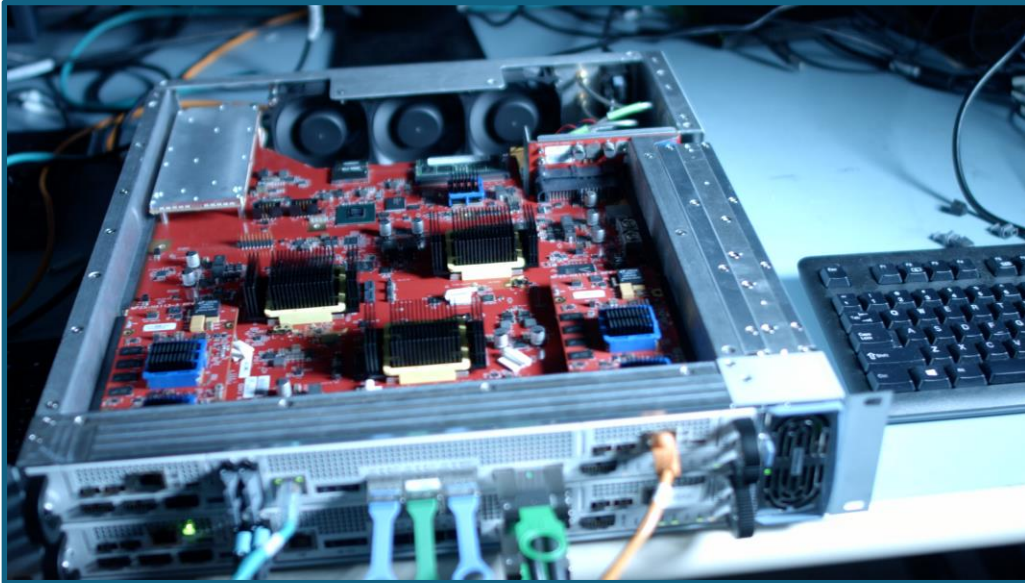
Operating in sub-6 GHz spectrum bands
Allows for flexible deployments with ubiquitous network coverage and a wide range of use cases

Achieving multi-Gbps at low latency
Showcases innovative Qualcomm 5G designs to efficiently achieve multi-gigabit per second data rates and low latency

Driving standardization on 5G NR
OFDM-based designs implemented on the prototype system are being utilized to drive 3GPP standardization

Will enable impactful 5G NR trials
Designed to flexibly track 3GPP standardization and be utilized as a trial platform for impactful and timely 5G NR trials
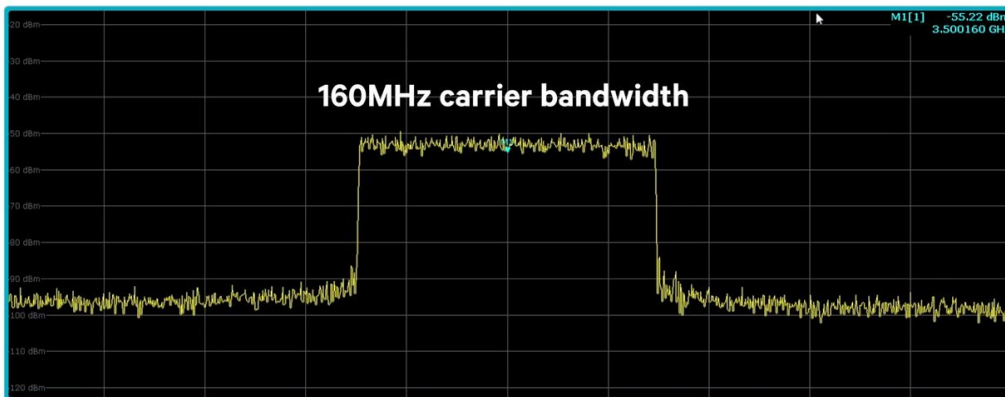
Making mmWave a reality for extreme mobile broadband

Qualcomm is driving 5G mmWave

60 GHz chipset commercial today for mobile devices

0.705 inch

0.28 inch
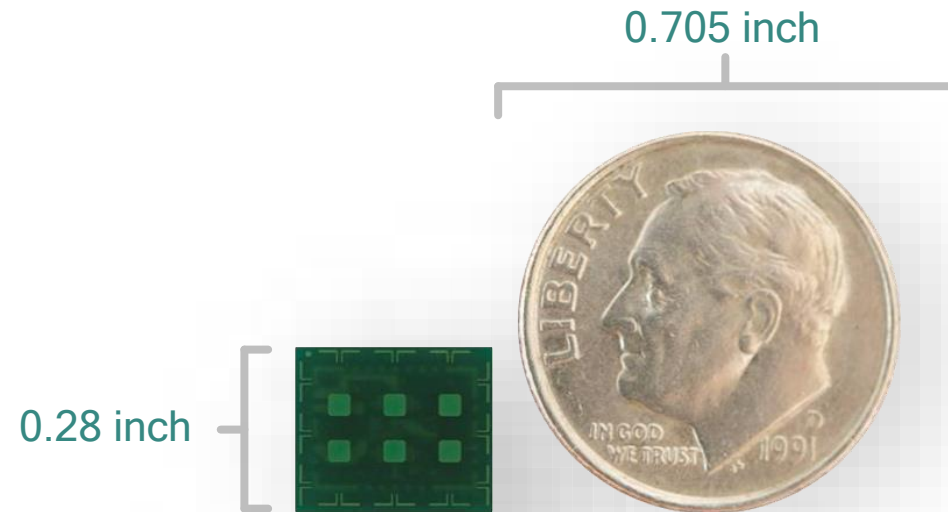
Qualcomm® VIVE™ 802.11ad technology with a 32-antenna array element

Developing robust 5G mmWave for extreme mobile broadband
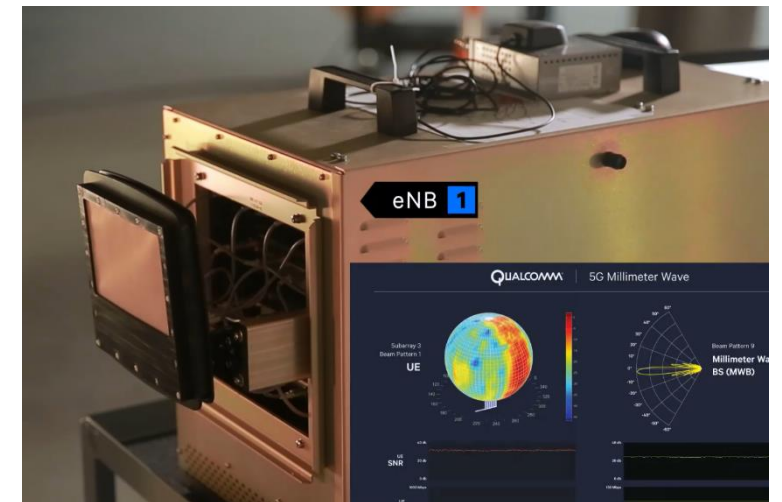
Qualcomm Research 28 GHz end-to-end prototype system demonstrates beam forming and scanning to address NLOS scenarios, improve indoor/outdoor range, and provide robust mobility

QUALCOMM®

Leading the world to 5G™

5G

Wireless technology, chipset and IoT platform leadership

End-to-end system approach from standardization to commercialization

A leader in global network experience and scale

Thank you

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