September 24, 2019



San Diego

Qualcom

## The Future of 5G

Dr. James H. Thompson

EVP, Engineering & CTO Qualcomm Technologies, Inc.







On-device Al use-cases today We can do

more with 5G

New experiences

New verticals

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Edge cloud

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Processing over 5G

## The intelligent wireless edge

**On-device Al** 

Augmented by edge cloud

**5G** 

Customized/ local value

Private/public networks

Privacy/security

Immediacy

Efficiency

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**On-device** 

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Reliability

Personalization

### Process data at the source to scale and make sense of a digitized world

Past Today **Cloud-centric Al** Partially-distributed AI Al training and Al inference Power efficient in the central cloud on-device Al inference **5G** ... ... **On-device** ... ••• ...

#### Future Fully-distributed AI

With lifelong on-device learning



Real-time assisted services like voice UI



Computer vision

Head mounted display

Handheld terminal

**Ultra-reliable** low-latency

**\_** 

Wireless edge analytics

Automated guided vehicle (AGV)

Industrial robot

Sensors

Massive

IoT

#### RSU with Al-based camera 👬

#### Traffic hazard warning

Al-based camera detects hazards and alerts

#### Road safety

V2V/V2I: Intersection assist, non-line of sight warning

V2V

12-17

RSU with AI-based camera

NEW

IN ITSI

#### Pedestrian alert

Traffic light detects crossing and alert cars via I2V

C-V2X direct communication

I2V V2P

On-device intelligence Key for cars to act with immediacy

### **Evolving 5G for smart transportation**

Burger spot

### Virtual telepresence collaboration



**5**G 

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Edge cloud-but not necessarily on-premise

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Augmenting on-device processing over 5G

## Mobile has made a leap every ~10 years



## The 5G foundation started long ago





#### **1993:** Wireless Internet

First demo over CDMA While other were adding data to 2G, we realized that

A fundamentally new design was needed for TCP/IP over wireless



#### 1998: EV-DO Over-the-air demo The foundation to mobile broadband

Data optimized OFDM for channel broadcast OFDM(A) for wider spectrum

Adaptive modulation/ coding

lation/ g Carrier aggregation

Opportunistic scheduling

RX diversity More antennae-MIMO

Mobile VolP

with QoS





#### 2013: MWC **Device-to-Device** communication

LTE-Direct proximity services over-the-air demos

#### Took longer than anticipated, but led to many new use cases

C-V2X for basic safety

Integrated access and backhaul

D2D for public safety, relays

use-cases

5G: framework with D2D/side-link

5G NR C-V2X adv. mesh, V2P

Offload, IoT relays,



#### 2013: MWC Cellular in unlicensed spectrum

LTE-U coexistence with Wi-Fi over-the-air demo

## Commercialized in LTE and integral to 5G design

LTE-LAA

Synchronized NR-U

NR-U LAA NR-U standalone Spectrum sharing paradigms

Massive number of things

Missioncritical services

Enhanced mobile broadband

**5G** 

### 2014 Industry aligns

But we envisioned a unified solution



A unified design for efficient implementation with fundamental inventions

Supporting the 5G vision and future expansion



2016: MWC First non-line-ofsight mobility OTA mmWave demo

Overcome an 'impossible' challenge to mobilize mmWave

Robust mobilityNon-line-of-sightCoverage with co-sitingRFIC, thermal, size



2017: MWC World's first NRbased connection using the flexible framework and new spatial design

## Foundation to efficient MIMO, 5G expansion, new verticals

Reciprocity based massive MIMO

Unlicensed spectrum

eURLLC with CoMP

New spatial sharing paradigms 2019

## Qualcom Making 5GNR a reality

www.qualcomm.com/5G-timeline

#### Sets the vision. Proves the path. First to arrive. Delivering on the Early visions A unified future-5G vision foundational to 5G proof platform Standard comes after vision and research First non-line of sight World's first 5G NR based World's first IoDT mmWave World's first products mmWave mobility demo MWC 2016 connection MWC 2017 launched in 2019 and sub-6 GHz end 2017 X50 4K 🚺 Qualcom

Early end-to-end system prototypes

Industry-first demos and proof-of-concepts Industry-first Interop testing and field trials

Industry-first launches

## An innovation platform for today's and future services



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# Delivering on the 5G vision

Dr. John Smee

VP, Engineering and 5G R&D lead

Qualcomm Technologies, Inc.

## First to demo



Nov 17

World's first interoperable

5G NR sub-6 GHz data

Feb 19

Announced our next generation end-to-end

over-the-air test beds to drive evolution for

R16/R17+ and early prototyping

#### End-to-end prototyping, early interoperability with partners, accelerate commercialization

## Demonstrating the future of 5G today



Sub-7 GHz testbed



mmWave testbed



Industrial IoT and spectrum testbed

> Automotive testbed



E2E system: antenna range



5G Industrial IoT



Outdoor mmWave



Synchronized NR-U



Indoor mmWave



Wide-area augmented reality



5G NR C-V2X



System RF front-end



5G standardization





2019

Early end-to end prototyping, drive evolution, drive and reflect standards, accelerate commercialization

## Driving the 5G roadmap and ecosystem expansion



Continuous research, early vision and prototyping, drive and reflect standards

						1
2018	2019	2020	2021	2022	2023+	

1. 3GPP start date indicates approval of study package (study item->work item->specifications), previous release continues beyond start of next release with functional freezes and ASN.1

## Continued evolution to deliver on the 5G vision



Initial focus: eMBB – enhanced mobile broadband services



5G core

network

5G NR IIoT with eURLLC



5G NR Cellular V2X



5G NR in unlicensed spectrum





**Enhancements** to 5G NR IIoT



Expand sidelink e.g.,

V2X reliability,

P2V, IoT relay



Unlicensed spectrum across all uses cases



Advanced channel coding

Sub-6 GHz with massive MIMO

 $\dots$ 

ITE integration



broadcast1

eMBB

evolution<sup>3</sup>



massive IoT<sup>2</sup>



Positioning across use cases

New spectrum above 52.6 GHz

NR-Light e.g., wearables. industrial sensors

Centimeter accuracy e.g., IIoT with mmWave

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Mobile mmWave



Flexible framework





IAB – integrated access/backhaul



Continuation of Rel-15

projects, others<sup>4</sup>

Continued eMBB enhancements<sup>5</sup>



Rel-15 deployment learning, XR, drones. others6

**Rel-15** Established 5G NR technology foundation



Expanding to new use cases and industries



flexible IAB



1. Enhancing Rel-14 LTE enTV to meet 5G requirements; 2. eMTC/NB-IOT in-band 5G NR and connected to 5G core; 3. MIMO, power consumption, mobility, MR DC/CA, interference management and more; 4. Non-terrestrial networks, non-public networks (private networks), NR SON/MDT and more; 5. further improvements to capacity, coverage, mobility, power consumption, spectral efficiency; 6. mixed-mode multicast, small data transmission, multi-SIM, satellite, multimedia

## Expanding 5G with the flexible framework

Early vision A unified futureproof platform

5GNR

Delivering on the 5G vision and expansion

A flexible framework with forward compatibility

Efficiently multiplex today's and unforeseen services on same frequency

Flexible slot-based framework

Scalable OFDM-based air interface

Blank su



## Expanding 5G with the flexible slot-based framework



## 5G massive IoT builds on the flexible framework



1. End-to-end system design based on CDMA20001x for low data rate, delay-tolerant applications; 2. Relays can be either network (Uu) or sidelink (PC5) based; 3. NB-IoT to support higher-order modulation such as 64-QAM and carrier aggregation; 2. Unlicensed spectrum is supported in ReI-17+

## A system approach for efficient implementation

### Can't approach fundamental components like waveform on single use case basis



Need a system approach to address all use cases and

efficient implementation-common framework

Slides from 2015 Qualcomm industry analyst day

## Expanding mmWave spectrum with the common framework



1 Rel-15 supported 450 MHz to 6 GHz and mmWave 24.25GHz 52.6 GHz.2 To support global unlicensed 60 GHz bands, SCS scaling from 24.25-52.6 GHz band with same characteristics (e.g., waveforms)

## Vision and persistence brought unlicensed spectrum to 5G



Continuous research, industry first over-the-air LAA, eLAA, MulteFire demos, interoperability with Wi-Fi

## A spectrum sharing vision exploiting the spatial domain



## Exploiting the spatial domain with CoMP for new verticals



#### Capacity from spatial multiplexing

Multiple transmissions at the same time to multiple location without interfering





#### Capacity vs. reliability tradeoff

Small-cells with few antennas create many distributed antennas for spatial domain



Reliability from spatial diversity CoMP<sup>1</sup> is key to ultra reliability for eURLLC by overcoming radio shadowing

> CoMP for IIoT reliability at MWC 2019

## EV-DO is the foundation to mobile broadband



Multi Gbps

Continuous research and innovations, early prototyping, industry first demos and trials

1. Assign all resources to a user, fast hybrid ARQ and power control 2 Higher order modulation for users with good signal quality 3 Multi-user diversity to prioritize users with better radio signal-with fairness

## Continue to enhance the eMBB foundation

#### **R15** lessons learned

Optimizations and new features to R16 and R17+



#### Foundational

Coverage, capacity, latency, power saving, mobility



Enhanced DL/UL MIMO and multiple transmission points



Device power saving with C-DRX and 2-step RACH



More robust mobility with minimal interruption during handover

**Rel**-15

#### Deployment

New spectrum, topologies, integrated backhaul...



Further improved MIMO

for e.g., higher mobility



Latency, reliability, positioning,

Enhanced IAB with full duplex and spatial multiplexing



Further power saving for idle and small data

Supporting even higher bands, up to 114.25 GHz



Further enhanced mobility for mixed topologies

Others such as, >4 Rx, 1024-QAM, multi-SIM





New services



Enhanced low/mid-band and mmWave CA and async DC

Integrated access/backhaul for

easier mmWave deployments

Unlicensed

Unlicensed spectrum including

standalone and license assisted



## 5G enabled capabilities not possible when 4G was defined

				Efficien Flexibility, lov MIMO, new f	nt TDD spa wer latency, recip eedback/pilot/mea DL D DL Data	ntial desig rocity based mas asurements Data	n Sc ssive Low depl	alable nume to mid to high mmW oyment types	Ave bands,	5GNR	Ha Sud Ove	ardware en ch as faster baseba obile mmW ercoming an 'impos	ablers and processing /ave ssible challenge'		
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					V				V			V			
2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	

## 5G is the innovation platform for the next decade



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## Expansion of 5G

**Dr. Durga Malladi** SVP & GM, 4G/5G Qualcomm Technologies, Inc.

## Driving the 5G expansion



2018	2019	2020	2021	2022	2023+	

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## 30+ launched in 6 months-faster than 4G

2019 is the year of 5G. 2020 is the year of expansion

#### 5G smartphones





Lenovo Z6 Pro 5G



Samsung Galaxy Fold



11:35

Motorola

moto  $z^4/z^3$ 

+ 5G moto mod

Samsung Galaxv Note10+5G

LG

V50 ThinQ



5G Edition

Vivo **NEX 3 5G** 

NEVER ETTLE

OnePlus

7 Pro 5G

nuole 5G

Nubia

Mini 5G

56

Vivo

iQOO







Galaxy S10 5G



ZTE

Axon 10 Pro

5G

Xiaomi Mi MIX 5G





Askey Inseego HTC Netcomm Netgear Nokia **WNC** ZTE

#### 5G modules



Compal Fibocom Longsung Quectel Sierra Wireless SIMcom Telit

## **150+** 5G devices launched or in development







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## Comprehensive 5G modem-RF solutions

#### Qualcomm snapdragon

#### X50 5G modem-RF system

#### 1<sup>st</sup> gen

- Sub-6 and mmWave
- NSA, TDD, Multi-SIM
- Qualcomm® 5G PowerSave
- Qualcomm® Smart Transmit
- Qualcomm® Signal Boost

#### Early 2019 First wave of devices



2<sup>nd</sup> gen

#### Added features

- Integrated 5G to 2G
- Standalone (SA), FDD
- Dynamic Spectrum Sharing
- Qualcomm® Wideband Envelope Tracking
- Platforms for PC, fixed wireless access, automotive, and more

#### Late 2019 Second wave

#### Snapdragon 8,7,6 Series Mobile Platforms



1st half 2020 Broader, faster adoption

#### System-level integration delivers best-in-class power-efficiency and performance



### System-level integration delivers best performance

Qualcomm QTM525 is a product of Qualcomm Technologies, Inc. and/or its subsidiaries.



## Optimization through co-design of hardware and software

Qualcomm 5G PowerSave, Qualcomm Wideband Envelope Tracking and Qualcomm Signal Boost are products of Qualcomm Technologies, Inc. and/or its subsidiaries



## Optimization through co-design of hardware and software

#### Fastest speeds

5G downloads up to 7 Gbps 4G downloads up to 2.5 Gbps

#### Sleek form factors

Tightly coupled modem-to-antenna 5G to 2G multimode solution

#### Quick availability

Turnkey solution including modules allows for quick, cost-optimized commercialization at global scale

#### Longer battery life

Including Qualcomm<sup>®</sup> 5G PowerSave and wideband envelope tracking

#### Better 5G coverage

Including Qualcomm<sup>®</sup> Signal Boost and Smart Transmit

#### Enhanced 5G roaming

Any key major band and region along with multi-SIM



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#### End-to-end Modem-RF system

## Our solution delivers best-in-class performance

## We overcome the 'impossible' mobile mmWave challenge



#### Limited coverage and too costly

Limited to just a few hundred feet, thus requiring many small cells



#### Significant coverage with co-siting

Analog beamforming w/ narrow beam to overcome path loss. Leverage lower bands for full coverage



#### Works only line-of-sight (LOS)

Blockage from hand, body, walls, foliage, rain severely limits signal propagation



#### Line-of-sight and non-line-of-sight

Pioneered advanced beamforming, beam tracking leveraging path diversity and reflections

#### Only viable for fixed use

Only commercially proven for wireless backhauls and satellites



#### Robust mobility

Robustness with adaptive beam steering and switching to overcome blockage from hand, head, body, foliage



#### Immature RFIC technology

Power hungry due to wider bandwidth with thermal challenges in small formfactor



#### Commercialized smartphone

Launched modem, RF, and antenna products to meet formfactor, thermal constraints and regulatory compliance





Expand 5G coverage and performance



Expand fixed wireless access, integrated with Wi-Fi



Expand mobile gaming including cloud gaming



Expand eMBB to vehicles - initially with Rel-14 C-V2X



Expand reach with our small cell solution



Expand device classes to always connected PC/Laptop



Expand experiences, like XR tethered to smartphones



Expand 5G eMBB modules to more verticals



## Accelerating the expansion of 5G network with small cells

Powered by Qualcomm<sup>®</sup> FSM<sup>™</sup> small cell platforms

Capable of being developed to utilize mmWave and sub-6 GHz

Supporting uniform 5G speeds and experiences, indoors and outdoors

Expected to begin sampling in 2020

Qualcomm FSM is a product of Qualcomm Technologies, Inc. and/or its subsidiaries



### Fueling fixed wireless broadband

Customer premise equipment (CPE) powered by Snapdragon X55 5G Modem-RF System for flexible, cost-effective deployments



#### First integrated extended range mmWave solution

mmWave QTM527 modules expand Snapdragon X55 5G Modem-RF System for fixed wireless access

- More antennas–up to 64 dual polarization elements
- For power class 1 devices
- Global mmWave bands<sup>1</sup>





## Accelerated 5G to 2019 with non-standalone mode

NSA UE



Dual connectivity

FP

. . .

Lower band LTE

## Expand coverage with lower bands

#### Expand 5G coverage

- Dynamic Spectrum Sharing (DSS) 5G FDD in low bands



## Direct migration to standalone core network with DSS

Higher band

#### 5G core network

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...

Option 2 to introduce 5G core services like QoS, security, slicing Higher band 5G



SA

UE

Lower 5G/4G FDD band

5G

## Increase 5G performance with carrier aggregation



### Indoor enterprises

Offices, meeting rooms, auditoriums

### Indoor/outdoor venues

Conventions, concerts, stadiums

### Transportation hubs

Airports, train terminals, subway stations

## Expanding mmWave indoors, public/private networks



Multi-Gigabit speeds with virtually unlimited capacity



Beyond smartphones, laptops, tablets, extended reality, ...



Leveraging existing Wi-Fi or cellular by co-siting





The untethered mobile office of the future

Complemented with outdoor 5G connectivity



Create with real-time collaboration



Multi-Gigabit mmWave speeds with virtually unlimited capacity, collocated with Wi-Fi

Re sp ne

Reuse operators mmWave spectrum, in/out isolation, new business models opportunity

## Enterprise networks

For 5G PCs, enterprise XR and more



Instant access to cloud compute and storage



Immersive virtual telepresence with wireless flexibility



Beyond laptops: Augmented and virtual reality (XR)



Private indoor network with cellular grade security, managed by enterprise or 3<sup>rd</sup> party

## Emerging dedicated private networks for targeted needs



## Multiple spectrum options For private 5G networks



## Licensed spectrum by mobile operators

Operators can allocate spectrum in a specific area



Unlicensed spectrum with async sharing

NR-U with asynchronous sharing work for many applications



## Dedicated regional spectrum

Regional spectrum such as 3.7GHz in Germany for IIoT



## Unlicensed spectrum with synch sharing

Synchronized sharing can provide reliability and eURLLC for IIoT



## Enhanced network communication

Faster access to cloud for in-vehicle experiences, car OEM services and telematics

## New direct communication

V2V, V2I, and V2P communications for latencysensitive use-cases, e.g. collision avoidance



#### Massive Internet of Things



Deeper coverage to connect road infrastructure (e.g. sensors and traffic cameras)



Evolution to 5G NR supports smart transportation use cases



Smarter transportation infrastructure

## Delivering on the 5G vision

Factor

Smart transportation

Where virtually everyone and everything is intelligently connected

Indoor enterprise

Extreme

Broadband

Private network

Massive lot

**5G** 

Public networks

Fixed wireless access

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## Thank you

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