The Road to 5G:
Providing The Connectivity Fabric for Everything

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Evolution of the Internet

Yesterday

Today

Tomorrow
Providing the connectivity fabric for everything

- Human communication: Scaling to connect virtually anything, anywhere
- Devices as end-points: New and intelligent ways to connect & interact
- Best effort data services: Also, new kinds of control & discovery services
- Disparate networks: Convergence of access, spectrum types, services

Requires a new connectivity paradigm
Mobile has made a leap every ~10 years
Qualcomm has played an increasing role in fueling these leaps

- **2G**
  - Digital voice

- **3G**
  - Mobile broadband

- **4G**
  - Faster and better
5G

Connecting new industries and devices

Empowering new user experiences

Enabling new services

Scalable

Edgeless

Unified
5G will be scalable across an extreme variation

- Deep coverage
- Strong security
- Ultra-high reliability
- Ultra-low latency
- Ultra-low energy
- Ultra-low complexity
- Ultra high density
- Extreme capacity
- Extreme peak rates
- Mission critical services
- Enhanced mobile broadband
- Massive number of things
- Deep awareness
- Flawless mobility
- Extreme peak rates
- Extreme capacity
- Ultra high density
- Ultra-low latency
- Ultra-high reliability
- Strong security
- Ultra-low energy
- Ultra-low complexity
- Deep coverage

Enhanced mobile broadband

Mission critical services

Massive number of things

Deep awareness

Ultra-low latency

Ultra-high reliability

Strong security

Ultra-low energy

Ultra-low complexity

Deep coverage

5G will be scalable across an extreme variation
New ultra-reliable, low-latency, mission critical services

- **High Reliability**: Extremely low loss rate
- **Low Latency**: Down to 1ms e2e latency
- **High Resilience**: Multiple links for failure tolerance and mobility

- Medical
- Industrial Automation
- Energy / Smart Grid
- Aviation and Robotics
- Automotive

5G
Scaling down to connect low cost ‘things’

- Power Efficient: Multi-year battery life
- Low Complexity: Low device and network cost
- Long Range: Deep coverage

- Wearables & fitness
- Remote sensors/actuators
- Smart cities/buildings
- Smart energy management
- Smart homes
- Object tracking

5G

Smart cities / buildings
Smart homes
Remote sensors/actuators
Smart energy management
Object tracking

Wearables & fitness
Scaling up to extreme mobile broadband

- **Extreme Throughput**: Multi-Gbps
- **Low Latency**: Down to 1ms e2e latency
- **Uniform Capacity**: Regardless of proximity to tower

Applications:
- UHD video streaming
- 3D/UHD telepresence
- Tactile Internet
- Virtual reality
- Venues
Multiple enablers toward edgeless connectivity

Uniform experiences—coverage, mobility, capacity—with no perception of ‘cell edges’

- Multi-hop to extend coverage
- Integrated access and backhaul, relays
- Device-to-device discovery and communications
- Coordinated spatial techniques
- Beam forming
- Massive MIMO
A unified, more capable 5G platform for the next decade
Configurable for specific services, verticals, deployment scenarios or phased rollout

**Unified Air Interface—a common framework**
- Wide area IoT
- Mobile Broadband
- Ultra-reliable Control

**Multi-connectivity—including 4G and Wi-Fi**

**Scalable, multi-access core network**
Flexible deployment, services, security and subscription models
- Residential
- Venue / neutral hosts
- IoT Vertical
- Traditional operator; mobile broadband, multiple IoT verticals, mission critical services
5G will build on the OFDM family foundation

Unified Air Interface

- FDD and TDD
- Synchronous and asynchronous
- Orthogonal and Non-orthogonal
- Scheduled, and opportunistic
- Licensed/shared/unlicensed spectrum

OFDM family excellent for mobile broadband and other use cases, e.g. ultra-reliable services

Other non-orthogonal methods may be proposed for specific use cases, e.g. IoT uplink
Unified 5G design across spectrum types and bands

- **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, massive number of things

**Below 6 GHz**: mobile broadband, mission critical, and possibly backhaul

**Above 6 GHz including mmWave**: for both access and backhaul, shorter range
Multi-dimensional multi-connectivity

Across technologies

Wi-Fi

4G RAN

5G access

Across any access node

Across devices
In parallel: driving 4G and 5G to their fullest potential

- Fully leverage 4G investments
- Improve cost and energy efficiency
- Enable a wide range of new services
- A unified, much more capable platform

- Further backwards-compatible 4G enhancements

Timeline:
- 2010
- ~2020
- 2030
Scaling LTE for the Internet of Things

High performance
- Fast peak rates
- More capacity
- Enhanced coverage

Ultra-efficient
- Reduced complexity
- Long battery life

LTE Advanced CA

LTE Cat-0, LTE-M, C-IOT
LTE Broadcast

Virtually unlimited number of users can receive same content
LTE Broadcast
Virtually unlimited number of users can receive same content

Simulation results

*Throughput gain vs. unicast

Avg. users per site consuming same content

Source: Qualcomm Technologies, Inc. Research. 2GHz carrier frequency, site-to-site distance = 500 meter, cluster eMBMS deployment (19 sites in single frequency network), comparison with unicast is based on the same amount of resource allocation.
LTE Direct

- Scalable
- Universal
- Always-on
- Global

Yoga classes
Social event
Book signing
Free live show
Used bike for sale
Room for rent
V2V
Aggregating licensed and unlicensed spectrum to deliver greater performance in 4G

**LTE in unlicensed spectrum**  
(for new small cells using 5GHz)

- **Carrier aggregation**
- **Gain** Median throughput

Operator A  
Wi-Fi

Operator B  
LTE in unlicensed

≥1x

>2x

Coexists well with Wi-Fi

Unlicensed spectrum
Licensed spectrum

Assumptions: Two operators. 48 Pico+108 Femto cells per operator. 300 users per operator with 70% indoor. 3GPP Bursty model. 12x40MHz @ 5GHz for unlicensed spectrum. LTE 10 MHz channel at 2 GHz; 2x2 MIMO, Rank 1 transmission, eICIC enabled; LTE-U - Phase II, 2x2 MIMO (no MU-MIMO); Wi-Fi - 802.11ac 2x2 MIMO (no MU-MIMO), LDPC codes and 256QAM.)
LTE-U is a good neighbor – not adversely affecting Wi-Fi

Using adaptive duty cycle (CSAT) for fair coexistence

Wi-Fi Average throughput

Wi-Fi performance improved

Increasing LTE-U penetration

CSAT - Carrier Sensing Adaptive Transmission
MuLTEfire™

4G LTE-like performance
Enhanced capacity and range
Improved mobility, quality of experience

Wi-Fi-like deployment simplicity
Operates in unlicensed spectrum
Leaner, self-contained¹ network architecture

¹ Does not require a traditional core network
Making the best use of licensed and unlicensed spectrum

Licensed spectrum
With opportunistic use of unlicensed

Unlicensed spectrum
LTE-based technology

Unlicensed spectrum
802.11 technology

LTE/LTE Advanced
(Including LTE-U/LAA, LTE/Wi-Fi agg.)

MuLTEfire™

Wi-Fi 802.11ac/ad/ax
The expanding role of LTE Advanced—a new paradigm

**Scale to connect the Internet of Things**
- Carrier Aggregation
  - High performance
- Ultra efficient
  - Cat-0, LTE-M

**Bring new ways to connect & interact**
- Evolving the LTE Direct Platform
  - Device-to-Device
- Multi-hop
- Vehicle-to-Vehicle / Infrastructure

**Empower new classes of services**
- Mission-critical control
  - LTE ULL
- Discovery
  - LTE Direct Proximity
- Public Safety
  - LTE Direct MCPTT

**Create a converged connectivity platform**
- Link aggregation
  - Converged LTE + Wi-Fi
- Converged spectrum solutions
- Converged deployment models
- LTE-U and LSA
- MuLTEfire™
Qualcomm fuels major technology shifts in the industry
Anticipating the big challenges and investing early on to solve them

$36B Cumulative R&D*

Digitized mobile communications
From analog to digital

Redefined computing
From desktop to smartphones

*As of Apr. '16, Qualcomm Technologies, Inc. data
Thank you

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