5G Design Across Services

May 2015
This presentation addresses potential use cases and views on characteristics of 5G technology and is not intended to reflect a commitment to the characteristics or commercialization of any product or service of Qualcomm Technologies, Inc. or its affiliates.
5G targets a range of services and devices

- Mobile broadband
- Increased indoor/outdoor hotspot capacity
- Enhanced mobile broadband
- Sensing what's around, autonomous vehicles
- Smart homes/buildings
- Health & fitness, medical response
- Smart city, smart grid and infrastructure
- Remote control, process automation
- Smart homes/buildings
- High reliability services
- Smart city, smart grid and infrastructure

© 2015 QUALCOMM Technologies, Inc. and/or its affiliates.
**Technology enablers for improved system designs**

<table>
<thead>
<tr>
<th>Technology</th>
<th>Air Interface Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improved RF/antenna capabilities</td>
<td>New mmWave bands, and Massive MIMO with new PHY/MAC design across bands</td>
</tr>
<tr>
<td>Improved radio processing</td>
<td>Faster narrow/wide bandwidth switching and TDD switching</td>
</tr>
<tr>
<td>Improved baseband processing</td>
<td>Lower latency and faster turn around, new PHY/MAC algorithms</td>
</tr>
<tr>
<td>Virtualized Network Elements</td>
<td>Dynamically move processing between cloud and edge</td>
</tr>
</tbody>
</table>

- Drive fundamental improvements in user experience, coverage, and cost efficiency
  - Deliver high quality of experience and new services across topologies and cell sizes
  - New designs below 6 GHz and above 6 GHz including mmWave

© 2015 QUALCOMM Technologies, Inc. and/or its affiliates.
Unified 5G design across spectrum types and bands
From narrowband to wideband, licensed & unlicensed, TDD & FDD

<table>
<thead>
<tr>
<th>Band</th>
<th>Single component carrier channel Bandwidth examples</th>
<th>Target Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDD/TDD</td>
<td>&lt;3 GHz</td>
<td>Deep coverage, mobility, high spectral efficiency, High reliability, wide area IoE</td>
</tr>
<tr>
<td>TDD</td>
<td>≥3GHz (e.g. 3.8-4.2, 4.4-4.9)</td>
<td>Outdoor &amp; indoor, mesh, Peak rates up to 10gbps</td>
</tr>
<tr>
<td>TDD</td>
<td>5GHz</td>
<td>Unlicensed</td>
</tr>
<tr>
<td>TDD</td>
<td>mmWave</td>
<td>Indoor &amp; outdoor small cell, access &amp; backhaul</td>
</tr>
</tbody>
</table>
5G design across services

Enabling phased feature rollout based on spectrum and applications

5G Enhanced Broadband

- Lower latency scalable numerology across bands and bandwidths, e.g. 160 MHz
- Integrated TDD subframe for licensed, unlicensed
- TDD fast SRS design for e.g. 4GHz massive MIMO
- Device centric MAC with minimized broadcast

Wide area IoE

- Low energy waveform
- Optimized link budget
- Decreased overheads
- Managed mesh

mmWave

- Sub6 GHz & mmWave
- Integrated MAC
- Access and backhaul
- mmWave beam tracking

High reliability

- Low latency bounded delay
- Optimized PHY/pilot/HARQ
- Efficient multiplexing of low latency with nominal

© 2015 QUALCOMM Technologies, Inc. and/or its affiliates.
Designing Forward Compatibility into 5G
Enabling flexible feature phasing

- Blank subframes and blank frequency resources
  - Minimized broadcast
  - Enable future features to be deployed on the same frequency in a synchronous and asynchronous manner

- Vertical service multiplexing on the same carrier

- Compatible frame structure design for multiple modes (5Gsub6, high reliability, D2D, mmW, etc.)
  - Enable future features to be deployed on a different frequency in a tightly integrated manner, e.g. 5Gsub6 control for mmW
5G targeting enhanced mobile broadband requirements

### Key requirements
- Uniform user experience
- Increased network capacity
- Higher peak rates
- Improved cost & energy efficiency

### Technical considerations
- Scalable numerology and TTI to support various spectrum and QoS requirements
- Massive MIMO to achieve high capacity, better coverage, and low network power consumption
- Self-contained TDD subframes to enable massive MIMO and other deployment scenarios
- Device centric MAC to reduce network energy consumption & improve mobility management
5G scalable numerology to meet varied deployment/application/complexity requirements

- **Normal CP** (e.g. outdoor picocell)
  - Sub-carrier spacing = 2N
  - 80MHz bandwidth

- **Indoor Wideband** (e.g. unlicensed)
  - Sub-carrier spacing = 8N
  - 160MHz bandwidth

- **mmWave**
  - Sub-carrier spacing = 16N
  - 500MHz bandwidth

Note: not drawn to scale

- Numerology Multiplexing

- 5G mmW synchronized to 5Gsub6 at e.g. 125us TTI level for common MAC, along with scaled subcarrier spacing, and timing alignment with 1ms LTE subframes

© 2015 QUALCOMM Technologies, Inc. and/or its affiliates.
Driving down air-interface latency & enabling service multiplexing

- Order of magnitude lower HARQ RTT
  - Faster processing time and shorter TTI
  - Driving down HARQ latency and storage
- Self-contained TDD subframes
  - Integrated approach to licensed spectrum, Massive MIMO, unlicensed spectrum, D2D
  - Decoupling UL/DL data ratio from latency
  - Very low application layer latency
- Provides various levels of QoS, hence bundled TTI design for latency/efficiency tradeoff
  - Short TTI traffic with low latency and high reliability
  - Long TTI for low latency and higher spectral efficiency
- Service aware TTI multiplexing
Self-contained TDD subframes
Decouple HARQ processing timeline from uplink/downlink configuration

Cellular DL or mesh/D2D transmission scheduled subframe

- To transmit control, data and pilots
- To receive ACK and other uplink control channels

Enhanced subframe
Additional headers/trailers for advanced deployment scenarios

- To support massive MIMO/ unlicensed/D2D/mesh/COMP
- E.g. headers associated with Clear Channel Assessment (CCA), hidden node discovery protocol for 5G unlicensed spectrum access

Note: Multiple users are typically multiplexed over each control/data region in FDM/TDM/SDM manner
5G modulation and access techniques

- **OFDM for enhanced mobile broadband access**
  - 5G broadband access requires the following
    - Low latency
    - Wide channel bandwidth and high data rate
    - Low complexity per bit
  - OFDM is well suited to meet these requirements due to the following characteristics
    - Scalable symbol duration and subcarrier spacing
    - Low complexity receiver for wide bandwidth
    - Efficiently supports MIMO spatial multiplexing and multiuser SDMA
    - OFDM implementations allow for additional transmit/receiver filtering based on link and adjacent channel requirements

- **In addition, resource spread multiple access (RSMA) waveforms have advantages for uplink short data bursts such as low power IoE**
  - Supports asynchronous, non-orthogonal, contention based access
  - Reduces IoE device power overhead

© 2015 QUALCOMM Technologies, Inc. and/or its affiliates.
5G coverage layer improvements (1.7km intra-site distance) with 4GHz massive MIMO & new TDD SF design

- Gains of 4 GHz Massive MIMO with 80MHz compared to 2GHz with 2Tx DL over 20 MHz
- Leverage same cell tower locations and same transmit power as legacy systems (no new cell planning)
- Cell-edge user @ 1km cell radius still able to scale up throughput with bandwidth (for ~80 Mbps)

Assumptions: 46 dBm Tx power
mmW deployment scenarios

- Stand alone mmW access
- Collocated mmW + 5Gsub6 access
- Non-collocated mmW + 5Gsub6 access
- mmW integrated access & backhaul relay
Advanced multicell scheduling algorithms improve mmWave user experience

Coordinated scheduling techniques reduce interference and improve user experience

Non-trivial interference from neighboring cell transmissions in mmW bands for small cell radii of ~100m
5G device centric MAC
Control plane improvements for energy efficiency and mobility

- **Device side: light weight mobility**
  - Transparent mobility within a device centric zone
  - Coordinated control plane processing for tightly coupled cluster

- **Network energy saving with less broadcast**
  - On-demand system info. transmission
  - When no devices are around, base station only provides a low periodicity beacon for initial discovery
  - When a few devices enter coverage, base station provides system information via on demand unicast
  - When many devices are present (or SI changes), base station can revert to broadcast
5G targeting high reliability service requirements

Key requirements

• High reliability and availability
• Low end-to-end latency
• Minimal impacts to nominal traffic while meeting reliability and latency requirements

Technical considerations

• Integrated nominal/high-reliability system design
  - New PHY coding, New FEC, and link-adaptation framework for efficient traffic multiplexing
• Low latency design
  - Efficient HARQ structure for fast turn-around
  - Scalable TTI for latency, reliability & efficiency tradeoff
• High reliability design
  - Large diversity orders to support bursty high-reliability traffic
  - New link adaptation paradigm for lower error rates
Hard latency bound and PHY/MAC design

- **Causes of packet drop**
  1. Last transmission fails at Rx
  2. Delay exceeds deadline at Tx queues
Increased reliability benefits from wideband multiplexing

Reliability, Capacity, Latency, Bandwidth Tradeoff

Wider bandwidth provides significant capacity benefits
• FDM of high-reliability/nominal traffic is sub-optimal

At lower bandwidth, achieving very low latency bound requires drop in reliability

Notes: e.g. 256 bit control every 10ms: 40 machines is 1 Mbps.
Packet Error Rate (PER) results based on -3dB cell edge worse case scenario.
5G targeting wide area IOE requirements

Key requirements

- Superior coverage for supporting remote and deep indoor nodes
- Low power consumption to enable longer battery life
- Better support low rate bursty communications from multiple device types including smartphone bursty traffic
- Scalability to enable massive number of connections

Technical Approaches

Non-orthogonal RSMA
- Resource spread multiple access
- Avoids energy cost of establishing synchronism
- Distributed scheduling

Uplink mesh downlink direct
- Leverage DL sync
- Coverage extension

Uplink IOE
- Non-Orthogonal
- Distributed Scheduling

Downlink IOE
- Orthogonal
- Centralized Scheduling

© 2015 QUALCOMM Technologies, Inc. and/or its affiliates.
5G design across services

Enabling phased feature rollout based on spectrum and applications

5G Enhanced Broadband

- Lower latency scalable numerology across bands and bandwidths, e.g. 160 MHz
- Integrated TDD subframe for licensed, unlicensed
- TDD fast SRS design for e.g. 4GHz massive MIMO
- Device centric MAC with minimized broadcast

Wide area IoE

- Low energy waveform
- Optimized link budget
- Decreased overheads
- Managed mesh

mmWave

- Sub6 GHz & mmWave
- Integrated MAC
- Access and backhaul
- mmWave beam tracking

High reliability

- Low latency bounded delay
- Optimized PHY/pilot/HARQ
- Efficient multiplexing of low latency with nominal

© 2015 QUALCOMM Technologies, Inc. and/or its affiliates.