The Future Radio Access Technologies

IEEE WCNC 2017
19-22 March 2017// San Francisco; CA

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Huawei Technologies Co. Ltd.
The 3rd Paradigm Shift of Mobile Industry is Going to Happen

198x
Voice Era (1G)

2000
MBB Era (3G)
Connectivity as a Service

2020 and Beyond
Super Connected World (5G)
eMBB + uRLLC + mMTC
Network Slice as a Service
Gigantic Gap in Services & Network Requirements

Huge Difference of Service Experience

- Autonomous car
- Tactile internet
- VR
- AR
- Multi-person video call
- Real-time gaming
- Disaster alert
- Automotive ecall
- Device remote control
- Bidirectional remote control
- Mobile video
- Office in cloud
- Personal cloud
- Sensors

Source: GSMA & Huawei Wireless X Labs

Huge Difference of Network Requirements

- MOBILE DATA VOLUME
  - 1,000x 10Tb/s/km²

- PEAK DATA RATE
  - 100x 10Gbps

- E2E LATENCY
  - 1/5x 1~5ms

- RELIABILITY
  - 99.999%

- MOBILITY
  - 1.4x 500km/h

- SERVICE DEPLOY. TIME
  - 1/1,000x 90 min.

- NUMBER OF DEVICES
  - 1,000x 1M/km²

- ENERGY EFFICIENCY
  - 1/10x

- 4G
- 4.5G
- 5G

- Latency: <1ms, 10ms, 100ms, >1s
- Data rate: <1Mbps, 10Mbps, 100Mbps, >1Gbps

Source: GSMA & Huawei Wireless X Labs
Service Oriented Radio and Cloud-Native Architecture

Service Oriented Radio (SOR)

Cloud-Native Architecture for E2E slicing
On demand Core for Low Latency

5G Core Network

- Core network user plane on-demand deployment support ultra reliable and low latency business

**CP**: Control Plane
**UP**: User Plane

- VR/AR
- Smart Meter
- Connected Car

- Local Site
- CO Site
- Local DC
- Regional DC

- RAN-RT
- RAN-NRT
- D-GW

Tradeoff
Better Experience
Higher Efficiency

On-demand Deployment for Network Slicing

>50ms
<20ms
1~5ms
Rethink Evaluation Metric of “Spectrum Efficiency”

From “Spectrum Efficiency” to “User Perceived Throughput”
- User experience need be prioritized
- Resource Utilization less than 20% for LTE networks

From UPT to Service Capacity
- Service capacity conditioned on user experience is ensured
  - UPT of 95% user 95% no less than X
  - Reasonable network utilization ratio is hinted
AR/VR will be Killer Application in 5G Era

AR/VR market has huge potential by 2025

- Game Console: $14bn
- Desktop: $62bn
- Tablet: $63bn
- TV: $99bn
- AR/VR: $110bn

Source: Goldman Sachs, AR&VR Report

More speed/capacity required for AR/VR

**Normal Experience**
- 3960(pix) X 2160(pix)
- 60fps
- 48.94 Mbps

**Excellent Experience**
- 12000(pix) X 7800(pix)
- 120fps
- 1.29 Gbps

Source: Huawei wireless X Labs
Last-mile Fiber in the Air for Households Access

Household with Internet

- >10Mbps: 0.3bn
- <10Mbps: 0.4bn
- No Access: 1bn

Source: ITU 2015 ICT Facts

Wireless Home Access

- USA
- Australia
- New Zealand
- Greece
- China

Recommended by regulator for NBN

5G Early Deployment

- 2017 5G WTTx Trial in Canada & US
- Fiber-like experience
- Fast TTM & ROI
- 5G Home Access in NA

Source: Public information

Great Needs of Internet Worldwide

Fast TTM & ROI

5G Home Access in NA
Connected Car is Strategic Focus by Leading Countries

- China: automated driving ecosystem ready by 2025
- USA: release law to force V2V installation for new car in 2020
- EU: mass production of driverless car in 2025
- Korea: 2021~2025, v2X penetration target 50%
- Japan: late 2020 realize full auto-driving

- Reduce 14% heating emission annually
  - Source: USA Environmental Protection Agency (EPA) 2014
- Save 1.2M People annually
  - Source: Global Status Report on Road Safety, World Health Organization, 2015
- Make 1000bn economic value annually
  - Source: Rocky Mountain Institute 2016
- Save 3.1bn gallon oil annually
  - Source: Texas Transportation Institute Urban Mobility Report, 2015
5G Standardization Accelerated

Previous Timeline

Accelerating Decision

March

5G Phase 1
Non-Standalone NR

5G Phase 2
Standalone NR
Full IMT-2020 NR

First stage accelerated to meet early demands

Use Case
Standard
Spectrum
Enabler

2014
Rel-13

2015
Rel-14

2016
Rel-15

2017
Rel-16

2018

2019

2020

Global Launch

NGMN
Operators

2017Q4
Verizon Trial
5G WTTx
Pre-Standard

2018Q2
Basic Function Verification

2018Q1/Q2
Korea: Winter Olympic
Megafon: World Cup
5G eMBB
Pre-Standard

2019Q3
IOT Test

2020Q2
Commercial

2020
UAE Expo
Tokyo Olympic
China
5G E2E
3GPP Compliant
5G Support Full Spectrum Access

- Rich Bandwidth
- Coverage Limited
- Performance & Cost Balance

- 5G NR Refarming
- Multiple Antenna Technology
- Low Latency & Ubiquitous Coverage

- All Spectrum available
- **C-band** Suitable for 5G as global harmonized spectrum.
- **mmWave**: Seeking for global harmonized spectrum on Group 30 & 40.

<table>
<thead>
<tr>
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<th>Standard</th>
<th>Spectrum</th>
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- **C-Band** (~100MHz)
- **mmWave** (~1GHz/Band) Group 30 Group 40 ...
C-Band & Group 30/40 to be Global Harmonized Bands

C-band will be the **only choice** that can **globally** provide at least 200M in Sub6GHz in nearly 10 years.

### Sub6G

| Frequencies (MHz) | Region 1 | | Region 2 | | Region 3 |
|------------------|----------| |----------| |----------|
|                  | EU | Africa | Arab | C.I.S | N.A | L.A | Asia |
| 3400-3600        | Y | Y | Y | Y | Y | Y | Y |

**Group 30/40 Supported by Europe/U.S./Japan/Korea**

### mmWave

<table>
<thead>
<tr>
<th>Group</th>
<th>Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 30</td>
<td>Support 26GHz</td>
</tr>
<tr>
<td>Group 40</td>
<td>Support 28/37/39/66GHz</td>
</tr>
<tr>
<td>Group 50</td>
<td>Support 28/38GHz</td>
</tr>
<tr>
<td>Group 80</td>
<td>Support 30~50GHz</td>
</tr>
</tbody>
</table>

- **Candidates of WRC-19**
- **Non-candidates of WRC-19**
eMBB for 5G: 3X UPT with same Tx/Rx antennas

Native MIMO
Beam Space MIMO, Interference Measurement, NC-JT,…

Native Clean Carrier
CRS free, on-demand transmission,…

Native Low Latency
Self-contained SF, LDPC/Polar, 2-Stage DCI,…

1.4X

1.4X

1.5X
Native MIMO

**Interference Measurement (HL, LL)**
- Subframe \( n \): measurement
- Subframe \( n+L \): data transmission

**Beam Space MIMO (HL)**
- Baseline LTE Codebook (1 DFT ray)
- Full Beam Space (N DFT rays)
- Reduced Beam Space (M<<N DFT rays)

**Partial CSI and Condensed Sounding (HL)**

**Non-coherent JT for low load**
- User Plane Protocol Stack \( \tau = 0 \):
  - PDCP
  - RLC
  - MAC
  - PHY
- User Plane Protocol Stack \( \tau > 0 \):
  - PDCP
  - RLC
  - MAC
  - PHY
## Evaluation on 5G MIMO and LTE MIMO

### Low load (FTP Model 1 lamda=1.5)

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<tr>
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<td>4T4R NR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4T2R NR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4T2R LTE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2T2R LTE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Avg. UPT**

- 4T4R NR: 3.36
- 4T2R NR: 2.01
- 4T2R LTE: 1.14
- 2T2R LTE: 1

**5% UPT**

- 4T4R NR: 2.92
- 4T2R NR: 1.17
- 4T2R LTE: 1
- 2T2R LTE: 1

### High load (FTP Model 1 lamda=4.5)

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<tr>
<td>2T2R LTE</td>
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**Avg. UPT**

- 4T4R NR: 7.02
- 4T2R NR: 2.92
- 4T2R LTE: 1.17
- 2T2R LTE: 1

**5% UPT**

- 4T4R NR: 2.92
- 4T2R NR: 1.17
- 4T2R LTE: 1
- 2T2R LTE: 1

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Note Beam Space MIMO, pre-scheduled IM and CRS-free are assumed in 5G MIMO evaluations.
Native Low Latency

Self-contained SF

LDPC (for eMBB data)
- Much Lower Complexity and parallel decoding suitable for low latency

Polar (for eMBB control)
- PC-Polar
- CA-Polar

Super Short RTT
eMBB for 5G: C-band M-MIMO Boosts Capacity

C-Band + M-MIMO Boosts DL Capacity

- **1.8GHz (20M)**: 2T2R
- **3.5GHz (100M)**: 64T64R

Support M-MIMO with Affordable Complexity

- **1.8GHz Massive MIMO**
  - ~24x
  - 1367Mbps

- **2.6GHz Massive MIMO**
  - 140cm
  - 100cm

- **3.5GHz Massive MIMO**
  - 70cm
  - 50cm
  - >65kg
  - 45kg
  - 40kg

Probability (%):

- 0.10%
- 3.10%
- 12.20%
- 28.40%
- 48.60%
- 65.70%
- 81.00%
- 90.30%
- 96.00%
- 99.00%
- 99.80%
- 100.00%
eMBB for 5G: Beam Based Access for mmWave

- **Beam Adaptation**: (on/off and periodicity control)
- **SIB1-2 on/off and periodicity can be configured**
- **Inner loop (e.g. 5ms)**
- **Outer loop**

### Use Case
- **Standard**:
  - **Spectrum**:
    - **Enabler**:
      - Beam 1
      - Beam N
      - ALL Beams ON
      - Beam Adaptation (on/off and periodicity control)
# Site Division Duplex for Macro

- Separate downlink and uplink “cell” association on unpaired spectrum
- Relaxed cancellation requirement at gNB
  - Known interference signal (CRAN)
  - Site separation

## Demo throughput on FDD

<table>
<thead>
<tr>
<th></th>
<th>FDD</th>
<th>Full Duplex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(20M DL+20M UL) Mb/s</td>
<td>(20M) Mb/s</td>
</tr>
<tr>
<td>DL</td>
<td>150.72 (peak rate)</td>
<td>147.93 (test rate)</td>
</tr>
<tr>
<td>UL</td>
<td>71.11 (peak rate)</td>
<td>65.32 (test rate)</td>
</tr>
</tbody>
</table>

## Demo throughput on TDD

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<th>TDD</th>
<th>Full Duplex</th>
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<tr>
<td></td>
<td>(20M,SA2,SSP7) Mb/s</td>
<td>(20M) Mb/s</td>
</tr>
<tr>
<td>DL</td>
<td>112.47 (peak rate)</td>
<td>147.93 (test rate)</td>
</tr>
<tr>
<td>UL</td>
<td>37.53 (peak rate)</td>
<td>65.32 (test rate)</td>
</tr>
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</table>
LTE & 5G NR Co-Existing

Traditional Refarming

LTE + NR by Coexisting

3GPP NR WI includes Co-existing support

LTE UL and NR UL within the bandwidth of an LTE component carrier

Identify and specify at least one NR band/LTE-NR band combination

NR Band

LTE Band
WTTx: Advanced Techniques

Adaptive LOS MIMO for throughput boosting @ LOS channel

Orthogonal Time-Frequency
SC waveform for good PAPR @ NLOS channel
Video for 5G: Service Awareness and Frame Recovery

Application layer triggered frame recovery

L1/L2 triggered frame recovery

1. Detect I-Frame loss
2. I-Frame retrieval request
3. I-Frame retransmission

Use Case | Standard | Spectrum | Enabler

1. L1 NACK
2. L1/2 ReTx
**Sub6G Multi-User Field Trial**

World’s First Large Scale Trial

- **SCMA**
- **F-OFDM**
- **MU-MIMO**
- **Polar Code**

**UL 3X connections**

- **Saving guard band**
- **Asynchronous transmission**

- **24 TUE**
- **Sub6GHz**
- **100MHz**

0.5~2dB gain compared with LTE Turbo Code

24 layers 3.6Gbps Peak Rate

HUawei Technologies CO., LTD.
Sub6G Multi-User Field Trial – P2
Higher Spectral Efficiency on 5G NR

5G NR Massive MIMO

>11 Gbps

Cell Average Rate

- 12 UEs of both static and mobile types, 24 Layers

Ultra U-Plane Latency

<0.5ms

U-plane Delay

- new frame structure and numerology

Tokyo • Japan

23 TUE  4.5GHz  200MHz

NTT DOCOMO
HUAWEI TECHNOLOGIES CO., LTD.
mmWave Multi-User Field Trial
Set New 5G Record

70 Gbps

2 streams per user
Up to 24Gbps per user

Each stream supports
LOS & NLOS

advanced user acquisition and
beam tracking algorithms

2GHz BW @ E-band

HUAWEI TECHNOLOGIES CO., LTD.
Mobility Test of mmWave
First Ever

**Coverage**
- 5+Gbps @ 1GHz BW at 300m distance
- 3Gbps @ 1GHz BW at 2km distance
- Inter-site Handover

**Mobility**
- **Stable Throughput** at different near LOS points) during mobility with beam tracking
High & Low Band Hybrid Networking

C-band MU-MIMO
- 10+Gbps@200MHz BW
- 3D Beamforming
- 26 Layers

28GHz MU-MIMO
- 40+Gbps@1GHz BW
- 8 Users
- 16 Layers

C-band & 28GHz Dual Connectivity
- 5Gbps+15Gbps
- 8 + 8 Layers

Compact Design for Verification in Commercial Environment
Unified platform for low & high band
THANKS