Lessons from the 5G trials in China

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5G Program Coordinator, GTI
Introduction of GTI 1.0

Kicked off GTI in 2011

- **01** Successfully built global end-to-end TD-LTE ecosystem
- **02** Successful global commercialization of TD-LTE
- **03** Successful convergence of TDD/FDD and initiation of joint operation

- **122** TD-LTE commercial networks in **61** countries, and **152** TD-LTE commercial networks in **77** countries in progress
- **2.96 million** TD-LTE base stations (Q4, 2017)
- **1.4 billion** TD-LTE subscribers
- **8014 TD-LTE** terminals, **66.8%** supporting TDD/FDD

Source: GTI, TDIA and GSA
As of Q1, 2018
Opportunities from 5G

Higher Performance

Access latency in milliseconds
Experienced data rate of 100Mbps

Higher connection density 1 million connections/km²
Energy efficiency as much as 100+

More Scenarios

Enhanced Mobile Broadband (eMBB)
massive Machine Type Communications (mMTC)
Ultra-Reliable and Low latency Communications (URLLC)

Brand-New Ecosystem

a cross-industry and shared ecosystem
Challenges for 5G Development (1)

It spent us more than 4 years for 4G


5G

New Radio (NR) SI R15 NR WI R16 NR WI

2008 2009 2010 2011 2012 2013

4G

R8 LTE R9 LTE FDD launch TDD launch

2 years left for 5G

R15 NR NSA R15 NR SA Commercial

2008 2009 2010 2011 2012 2013
### Challenges for 5G Development (2)

#### DIVERSE SPECTRUM: SUB 6GHZ VS. MM-WAVE

- **3.5GHz** seems a global band with better coverage, above 6GHz (focus in 26GHz&40GHz) provides larger bandwidth
- US/Korea/Japan are interested in 28GHz, while other operators focus on C band first, e.g. 3.5GHz

<table>
<thead>
<tr>
<th>Region</th>
<th>6GHz</th>
<th>Group 30GHz</th>
<th>Group 40GHz</th>
<th>Group 50GHz</th>
<th>Group 70/80GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>24.25</td>
<td>27.5</td>
<td>31.8</td>
<td>33.4</td>
<td>40.5</td>
</tr>
<tr>
<td>US</td>
<td>24.25/24.45</td>
<td>27.5</td>
<td>28.35</td>
<td>37</td>
<td>47.2</td>
</tr>
<tr>
<td>Japan</td>
<td>24.25</td>
<td>27.5</td>
<td>29.5</td>
<td></td>
<td>64</td>
</tr>
<tr>
<td>Korea</td>
<td>24.25</td>
<td>27.5</td>
<td>29.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>24.25</td>
<td>27.5</td>
<td>37</td>
<td>42.5</td>
<td></td>
</tr>
</tbody>
</table>

- **Sub 6GHz**
- **WRC-19 1.13 candidate bands**
- **Bands beyond WRC-19 1.13**

**Release 3.5GHz, 4GHz and 28GHz for 5G**

**3.5GHz and 28GHz for 5G**

**3.3-3.6GHz, 4.8-5GHz for 5G, 26GHz and 39GHz for 5G trial**
Challenges for 5G Development

DIVERSE PATHS FOR EARLY 5G DEPLOYMENT

**NSA system architecture**

- Step 1: EPC -> LTE, NR
- Step 2: EPC -> eLTE, NR

**SA system architecture**

- Step 1: EPC -> New Core
- Step 2: EPC -> New Core, eLTE, NR
With SA, network slicing enables MEC to be supported and provides **customized superior user experience** for enterprise and vertical industries.
GTI 2.0 kicked off in 2016: sub 6GHz 5G industrialization

**Program**

5G eMBB

**Objective**

Defining 5G eMBB requirements/use case, validating system solution, defining product requirement and promoting commercial deployment among GTI partners and with wider industry partners

**Projects**

Sub 6GHz New Device Architecture

Test Equipment

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### Work Scope

<table>
<thead>
<tr>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
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<tr>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
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<td></td>
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</tr>
</tbody>
</table>

- Prototype Lab & Field Trials
  1. 5G technologies Test
  2. Performance Test
  3. Deliver Test Reports

- Proof of Concept
  1. Define Proof Points
  2. Define Use Case & Requirements
  3. Hardware Spec/ Device Promotion
  4. PoC Test Results

- Pre-Commercial Trials
  1. Trial Planning & Test Environment
  2. Set-up trial network Deployment
  3. Large Scale Trials Test Results

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- Prototype Test
- Technologies Test
- Performance Test
- Test Reports
- Proof Points Defined
- Use Case & Requirements
- Hardware Spec/Device
- PoC Completed
- 5G RAN WP
- Trial Planning
- Scenario & requirement
- Deployment & Trial
- Industry Promotion
- Trial Result
- Pre-commercial WP
GTI Released Groups of 5G White Papers and Technical Reports to drive the 5G industrial maturity

13 White Papers and Technical Reports

- RAN
  - Sub-6GHz 5G Spectrum Whitepaper
  - Proof of Concept of 5G System Whitepaper

- Core Network
  - Sub-6GHz 5G Core Network Whitepaper
  - 5G Network Slicing Whitepaper

- Device
  - Sub-6GHz 5G Device Whitepaper
  - 5G Device RF Component Research Report

- Sub-6GHz 5G Deployment Whitepaper
- Sub-6GHz 5G Radio Access Network Whitepaper
- 5G Network Architecture Whitepaper
- 5G New Device Type Research Report
5G eMBB Progress: Products and Prototypes

Base Station: 192 antenna elements
- Baseline: 64Tx/Rx for coverage and capacity
- Alternative: 16Tx/Rx base stations

Base Station KPIs
- **Current Prototype**
  - 200 W
  - 77.5 dBm
  - –114 dBm
  - 0.32 m²
  - 45 Kg
  - 15%

- **Pre-commercial product**
  - 200 W
  - 78.5 dBm
  - –115.5 dBm
  - 0.5 m²
  - 45 Kg
  - 20%
**5G eMBB Progress: 5G PoC Trial**

### Lab Test

**Hardware/OTA Test, functions and performance**

<table>
<thead>
<tr>
<th>5G BS prototype</th>
<th>test UE/CPE/instruments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>3.4-3.6GHz</td>
</tr>
<tr>
<td>BW</td>
<td>100MHz</td>
</tr>
<tr>
<td>Power</td>
<td>200 w</td>
</tr>
<tr>
<td>Antenna elements</td>
<td>192/128</td>
</tr>
<tr>
<td>Path</td>
<td>64TR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Antennas</th>
<th>4T8R/2T4R*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>23 dBm@1Tx/26dBm@2Tx</td>
</tr>
</tbody>
</table>

* in different scenarios

### Field Test

- **key performance of 5G:**
  - 4G/5G coverage, latency, data rate, capacity...
  - in Beijing, Shanghai, Guangzhou, Ningbo, Suzhou

![Beijing, 5 sites/vendor](Beijing.png)  
![Shanghai, 7 sites](Shanghai.png)  
![Guangzhou, 7 sites](Guangzhou.png)  
![Suzhou](Suzhou.png)  

**Achievements:**

- Basic coverage and system performance has been verified
- Hardware architecture has achieved pre-commercial capabilities
- Valuable experiences has been accumulated for 5G pre-commercial trial
Findings from 5G PoC trial: Coupling loss of different bands

Questions to be answered for PoC coverage trials

- **Propagation discrepancies** between 3.5/4.8GHz and 1.9 GHz/2.6 GHz (current TD-LTE bands)?
- With **5G coverage enhancement schemes**, whether NR can achieve similar coverage with current TD-LTE network?

<table>
<thead>
<tr>
<th>Scenario</th>
<th>1.9 GHz TD-LTE</th>
<th>2.6 GHz TD-LTE</th>
<th>3.5 GHz NR</th>
<th>4.8GHz NR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outdoor</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical</td>
<td>0</td>
<td>-4.3</td>
<td>-6.38</td>
<td>-10.71</td>
</tr>
<tr>
<td>Test</td>
<td>0</td>
<td>-4.3</td>
<td>-7.3</td>
<td>-9.76</td>
</tr>
<tr>
<td><strong>Low Penetration</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical</td>
<td>0</td>
<td>-6.3</td>
<td>-10.38</td>
<td>-16.71</td>
</tr>
<tr>
<td>Test</td>
<td>0</td>
<td>-6.5</td>
<td>-10 ~ -10.5</td>
<td>-17.7~18.2</td>
</tr>
<tr>
<td><strong>O2I</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>High Penetration</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical</td>
<td>0</td>
<td>-</td>
<td>-13.5~15.5</td>
<td>-24.2~27.2</td>
</tr>
<tr>
<td>Test</td>
<td>0</td>
<td>-9</td>
<td>-13.5~15.5</td>
<td>-24.2~27.2</td>
</tr>
</tbody>
</table>

(*can reach -34.1 in some scenarios*)

Note 1: The discrepancies above is composed of the differences of antenna gain, propagation and penetration loss of each system/band

Note 2: No 5G NR coverage enhancement scheme is considered above
Findings from 5G PoC trial: Coverage enhancement in 5G

- **Beam Sweeping** (Up to 8 beams for DL Broadcast/Control)
  - Theoretical/predicted gain: 9/5 dB

- **HPUE**
  - (23 dBm + 23 dBm)
  - Theoretical/predicted gain: 3/3 dB

- **3D-MIMO (128/192 antenna elements)**
  - Beamforming gain
  - Theoretical/predicted gain: 3/2 dB

- **Power Boost**
  - Theoretical/predicted gain: 3/3 dB

- **2T4R UE**
  - 2R->4R
  - Theoretical/predicted gain: 3/2 dB

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<table>
<thead>
<tr>
<th>Predicted Gain (dB)</th>
<th>1T2R 23 dBm</th>
<th>2T4R 26 dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>DL Control</td>
<td>10.5</td>
<td>12.5</td>
</tr>
<tr>
<td>PRACH</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>
Findings from 5G PoC trial: Control coverage in 5G

- **Coverage of control channel:**
  - 3.5GHz is better than 2.6GHz (8TRX) and close to 1.9GHz (8TRX) at outdoor or O2I with one/two wall penetration
  - 3.5GHz can achieve the 2.6GHz (8Tx) at OI2 with deep penetration
  - 4.8GHz is hard to achieve the control channel coverage compared to 1.9GHz/2.6GHz (8TRX)
Findings from 5G PoC trial: Downlink coverage in 5G

- Coverage of downlink data channel:
  - Due to the large bandwidth and the 3D-MIMO beamforming of 3.5GHz 5G NR, DL THP for 3.5GHz 5G NR can achieve obvious gain more than 5X vs. 2.6GHz TD-LTE (8TX)

2.6 GHz (8TRX) and 3.5 GHz 5G NR downlink throughput

[Graph showing downlink throughput (Mbps) vs. RSRP]

[Graph showing (1/5)∗5G and LTE downlink throughput (Mbps) vs. time]
Findings from 5G PoC trial: Uplink coverage in 5G

1.8 GHz (FDD, 4TRx), 2.6 GHz (8TRX) and 3.5 GHz 5G NR Uplink throughput

- **1.8 GHz FDD (4TRx) Vs. 3.5 GHz 3D-MIMO**

- **2.6 GHz TDD (8TRX, 20MHz) Vs. 3.5 GHz 3D-MIMO**

- **Observation for coverage of uplink data channel:**
  - Coverage of 3.5GHz 5G NR is limited at PUSCH with the 5G NR control channel enhancements.
  - O2I, UL THP at cell edge for 3.5GHz is about 2~4X vs. 2.6GHz TD-LTE with one/two wall penetration, and is close to 2.6GHz TD-LTE with deep penetration.
  - O2I: UL THP at cell edge for 1.8GHz (4TRx, FDD LTE) is 2~3x vs. 3.5GHz (64TRx) at low load case with one/two wall penetration.
## Findings from 5G PoC trial: Throughput

### Single UE peak throughput for downlink

<table>
<thead>
<tr>
<th>Test case</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>test data rate</td>
<td>3.203Gbps</td>
<td>2.3Gbps</td>
</tr>
<tr>
<td>theoretical data rate</td>
<td>3.29Gbps</td>
<td>2.33Gbps</td>
</tr>
<tr>
<td>layers (8Rx/4Tx)</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Modulation</td>
<td>256QAM</td>
<td>64QAM</td>
</tr>
</tbody>
</table>

### Single UE peak throughput for uplink

<table>
<thead>
<tr>
<th>Test case</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>test data rate</td>
<td>558Mbps</td>
<td>388Mbps</td>
</tr>
<tr>
<td>theoretical data rate</td>
<td>558Mbps</td>
<td>390Mbps</td>
</tr>
<tr>
<td>layers (8Rx/4Tx)</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Modulation</td>
<td>256QAM</td>
<td>64QAM</td>
</tr>
</tbody>
</table>

### Cell peak throughput for downlink

<table>
<thead>
<tr>
<th>Test case</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>test data rate</td>
<td>6.03 Gbps</td>
<td>11 Gbps</td>
</tr>
<tr>
<td>theoretical data rate</td>
<td>6.98 Gbps</td>
<td>12.41 Gbps</td>
</tr>
<tr>
<td>total UEs</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>total layers</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>layers /ue</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

### Cell peak throughput for uplink

<table>
<thead>
<tr>
<th>Test case</th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>test data rate</td>
<td>0.79 Gbps</td>
<td>1 Gbps</td>
</tr>
<tr>
<td>theoretical data rate</td>
<td>0.8 Gbps</td>
<td>1.16 Gbps</td>
</tr>
<tr>
<td>total UEs</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>total layers</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>layers /ue</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

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**Note 1:** TDD DL/UL configuration is assumed as 3:1 or 70% DL

**Note 2:** 8Rx/4Tx were configured for 5G UE prototypes

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**Observation for throughput:**

- 3.5GHz 5G NR can achieve peak data rate close to theoretical value, which depends on the configuration and test environments.
- Though peak data rate is high for 8Rx/4Tx UE prototype, **4Rx/2Tx are the available config.** for pre-commercial TUE (SA)
Findings from 5G PoC trial: Latency

**Observation for latency:**
- **UP latency:** < 4ms (eMBB), **0.4-0.54ms** (uRLLC 32Byte with short TTI and Grant-free transmission)
- **CP latency:** ~20ms from "inactive" state -> "connected" state with 5G NR enhancements
- **Latency is still to be optimized**, since U-Plane latency is only a minor part of end-to-end latency (~X*10ms)
Findings from 5G trial: Against the ITU-R requirements

- **Observation against the ITU-R requirements:**
  - ITU-R requirements can be achieved at multiple scenarios by different numerology configuration.
Next step: Pre-commercial trial

GTI 5G eMBB Objective

Experience on 5G Key Solutions, Networking & Deployment
- Construction
- Network planning
- Operation & optimization

Commercial Industrialization
- Promoting maturity of 5G networks, terminals, chips and instruments
  - 3.5GHz Commercial Product
  - 5G Chipset and Terminals
  - >6GHz RF Components

Innovative services and applications
- Cultivate the new service, application and new business model for personal, enterprise and vertical industry

Pre-commercial Trial
- Promote the end-to-end products compliant with 3GPP specs and accelerate 5G pre-commercial phase as soon as possible, targeting the commercial launch of 5G in 2020
- Experience Sharing on 5G networking, deployment scenarios and key solutions
- Sharing on 5G+vertical industry requirements, use cases and solutions
Jointly Creating a Bright 5G Future!