5G Overview

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5G Views

• View 1 – *The hyper-connected generation*: A blend of technologies (pre-existing) covering 2G, 3G, 4G, Wi-fi, Wimax, etc.
  • higher coverage and availability
  • higher network density in terms of cells and devices
  • greater connectivity for M2M services and IoT
  • New D2D connections
  • New radio technology to enable low power, low throughput field devices

• View 2 – *Next-generation radio access technology*: traditional new generation defining view, with specific indicators targets, e.g., data rates, latency, coverage
  • new radio interfaces can be assessed against such criteria
  • Demarcation between technologies that meet the criteria and the ones that do not

• View 3 – *Mix of view 1 and 2*?
  • Ref: GSMA
ITU’s requirements on 5G (IMT-2020)

Enhancement of key capabilities from IMT-Advanced to IMT-2020

- Peak Data Rate (Gbit/s)
- User Experienced Data Rate (Mbit/s)
- Area Traffic Capacity (Mbit/s/m²)
- Network Energy Efficiency
- Connection Density (devices/km²)
- Latency (ms)
- Spectrum Efficiency
- Mobility (km/h)

The importance of key capabilities in different usage scenarios

- Enhanced Mobile Broadband
- Medium
- Low

Vertical Industries

Source: Document 5D/TEMP/625-E, ITU 22nd Meeting of Working Party 5D, San Diego, USA, 10-18 June 2015
Who needs the new targets?
Key Enabling Technologies

• Densification
  • Access Points (Network Topology, HetNets)
  • Large-Scale/Massive MIMO (multiple Inputs multiple outputs antennas)

• Spectral vs. Energy Efficiency Trade-Off
  • Shorter Transmission Distance (Relaying, small cells, D2D)
  • Power Dissipation (MIMO, Antenna Muting)
  • RF Energy Harvesting, Wireless Power Transfer, Full-Duplex

• Spectrum Scarcity
  • Cognitive Radio, Opportunistic Communications
  • mmWave (30-300 Ghz) Cellular Communications

• Software-Defined Network & Virtualization
  • SDN, NFV, SON, Network Resource Virtualization (NRV)

• Novel management & automation
## 5G Indicators

<table>
<thead>
<tr>
<th>Performance Indicators</th>
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<tbody>
<tr>
<td>User experienced data rate (bps)</td>
<td>Minimum achievable data rate for a user in real network environment</td>
</tr>
<tr>
<td>Connection density</td>
<td>Total number of connected devices per unit area</td>
</tr>
<tr>
<td>Traffic volume density (bps/km2)</td>
<td>Total data rate of all users per unit area</td>
</tr>
<tr>
<td>Mobility (km/h)</td>
<td>Relative speed between receiver and transmitter under certain performance requirement</td>
</tr>
<tr>
<td>Peak data rate (bps)</td>
<td>Maximum achievable data rate per user</td>
</tr>
<tr>
<td>Latency</td>
<td>Delay from the time a packet is sent from transmitter until it is received at the receiver (several definitions exit)</td>
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<table>
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<tr>
<th>Efficiency Indicators</th>
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<tbody>
<tr>
<td>Spectrum efficiency (bps/Hz/km2)</td>
<td>Data throughput per unit of spectrum resource per area unit</td>
</tr>
<tr>
<td>Cost efficiency (bit/$)</td>
<td>Number of bits that can be transmitted per unit cost</td>
</tr>
<tr>
<td>Energy efficiency (bit/J)</td>
<td>Number of bits that can be transmitted per joule of energy</td>
</tr>
<tr>
<td>Growth Indicators</td>
<td>Description</td>
</tr>
<tr>
<td>-----------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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<tr>
<td>Number of 5G subscriptions</td>
<td>Total subscriptions to 5G networks (including pre-paid active SIM cards, H2H (voice, data), M2M and M2H communications) 1 Subscription $\rightarrow$ several devices</td>
</tr>
<tr>
<td>Number of 5G connected devices</td>
<td>Total number of 5G connected devices incl. H2H, M2M, D2D 1 device $\rightarrow$ subscriptions</td>
</tr>
<tr>
<td>5G population coverage</td>
<td>Total population within range of 5G signal (whether or not they are subscribers) divided by the total population.</td>
</tr>
<tr>
<td>5G network coverage</td>
<td>Total land area covered by 5G signal divided by total land area</td>
</tr>
<tr>
<td>5G device ownership</td>
<td>Total connected devices (human &amp; machines communications) within range of 5G signal divided by the total population (average #devices/person)</td>
</tr>
<tr>
<td>5G device/connectivity density</td>
<td>Total connected devices (human &amp; machines communications) within range of 5G signal divided by the total land (average #devices/Km2)</td>
</tr>
<tr>
<td>5G data traffic</td>
<td>Total data traffic over 5G network (H2H, M2M, H2H, M2H, D2D, etc.)</td>
</tr>
</tbody>
</table>
Measuring 5G Growth Indicators

• Identify 5G networks
  • View 1 – A blend of tech. 2G, 3G, 4G, Wi-Fi, Wimax, etc.: all networks from the blend → 5G nets
  • View 2 – Traditional generation: net satisfying specific indicators targets (rates, latency) → 5G nets

• Traditional ways of measuring the indicators, e.g., for 3G, 4G
  • Including M2M, M2H and D2D
  • Measure the indicator for each 5G network (including M2M). Total measure estimate:
    • (Indicator net1 + Indicator net2 + ...+ Indicator net. N )
      • This measure does not exclude multiple subscriptions
      • Overestimates the indicator → provides the maximum possible value
      • Accurate when indicator measures are not overlapping for different networks
  • Max (Indicator net. 1, Indicator net. 1, ..., Indicator net. N )
    • Excludes multiple subscriptions and excludes non overlapping measures
    • Underestimate indicator → Min possible value
    • Accurate when subscriptions/network are overlapping
  • (Indicator net.1 U Indicator net. 1 U ...U Indicator net. N )
    • More precise measure that excludes multiple subscriptions but need precision data
  • Measures can include accuracy & different methods of measurements for different indicators
Examples of 5G Growth Indicators

• Example 1 Network coverage could be estimated as
  • \( \frac{(\text{Land Area 1} \cup \text{Land Area 2} \cup \ldots \cup \text{Land Area N})}{\text{Total Land Area}} \)
  • \( \max(\text{Land Area 1}, \text{Land Area 2}, \ldots, \text{Land Area N})/\text{Total Land Area} \) (underestimate)
  • \( (\text{Land Area 1} + \text{Land Area 2} + \ldots + \text{Land Area N})/\text{Total Land Area} \) (overestimate)

• Example 2 Number of subscriptions could be estimated as:
  • \( \sum \text{# subscriptions net 1} + \sum \text{# subscriptions net 2} + \ldots + \sum \text{# subscriptions net N} \)
  • \( \max(\text{# subscriptions net 1}, \text{# subscriptions net 2}, \ldots, \text{# subscriptions net N}) \)
  • \( \text{Subscriptions net 1} \cup \text{subscriptions net 2} \cup \ldots \cup \text{subscriptions net N} \)

• Example 3: Number of connected devices (>> # of subscriptions) could be measured as
  • Sum of # devices by network (incl. M2M, D2D)
    • Measure may include or exclude overlapping
    • Registered devices or connected devices, e.g., keeping database of device ID in different 5G networks
  • 5G Subscriptions \( X \) (number of devices/subscription)
  • Number of sold capable devices for each “5G” technology

• Example 4: Traffic growth
  • Sum of traffic for each network (including M2M)
    • Take into account offloading methods e.g., D2D, WiFi, etc.
Conclusions & Recommendations

• **5G is in the early phase of design**
  - No clear definition yet, different views → measuring the indicators depends on the adopted 5G view
  - Novel services & applications, new QoS requirements, more differentiation, M2M, D2D, H2H, H2M, etc.
  - Prepaid more challenging than postpaid for measuring the indicators → SIM is not locked to a device
  - Latency goal (1 ms) and high data rate expected
    - Cost: Who wants to pay?
    - Spectrum efficiency vs Energy efficiency, Interference with critical services

• **Recommendations**
  - Put in place data/information protection policy
  - Recommend precise data collection from service providers & precise data compilation from regulators
  - Put in place open data policy to promote innovation and economy
    - Taking into account security and privacy
  - Promote IoT through IoT policy, technologies and applications
    - Applications, projects and policies could be on regional or subregional levels
  - Leapfrog to data communication technologies (4G, 5G) to accommodate IoT