5G: Why Do You Care?

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Mobile Drives Global Subscriptions

source: ITU
Mobile Drives Revenue Globally

STL Partners forecasts less than 1% per annum growth in both fixed and mobile telecoms services to 2022.

Source: Company accounts, STL Partners analysis and forecasts

Source: STL Partners
Mobile Drives Revenue in Asia, Pacific

[Chart showing revenue distribution across different regions: Europe, Asia-Pacific, North America, Latin America, and Middle-East Africa.]

- **Europe, 298 billion EUR**
  - Mobile revenues: 53%
  - Data transmission/internet: 24%
  - Fixed voice revenues: 23%

- **Asia-Pacific, 346 billion EUR**
  - Mobile revenues: 64%
  - Data transmission/internet: 23%
  - Fixed voice revenues: 13%

- **North America, 266 billion EUR**
  - Mobile revenues: 59%
  - Data transmission/internet: 16%
  - Fixed voice revenues: 25%

- **Latin America, 121 billion EUR**
  - Mobile revenues: 76%
  - Data transmission/internet: 10%
  - Fixed voice revenues: 14%

- **Middle-East Africa, 84 billion EUR**
  - Mobile revenues: 76%
  - Data transmission/internet: 10%
  - Fixed voice revenues: 14%
Mobile Data Drives Subscription Growth

source: ITU
Capacity Demand Grows 50% Per Year

source: Nielsen Norman Group
4G Capacity Growth Cannot Keep Up

source: Nokia
All Products Have a Life Cycle
Mobile Products have Life Cycles

source: Chetan Sharma
Mobile Generations Have Life Cycles

Service Revenue by Generation

Source: Wireless Operator Strategies (WOS)
Higher Average Revenue Per User?

source: Strategy Analytics
Evolution or Revolution?

Evolution: Most of the value is simply adding capacity 4G cannot supply

source: 451 Research
4G Congestion

World 4G speeds vary tremendously across the day showing the impact of congestion on daytime speeds.

Chart 1

3am: few users awake, fastest 4G speed of 22.1 Mbps experienced

At 9pm, 4G speeds experienced are slowest at 11.9 Mbps

source: Opensignal
5G is Coming, on Schedule

**EVOLUTION OF CELLULAR NETWORKS**

- **1G**: 1981
- **2G**: 1993
- **3G**: 2001
- **4G**: 2013
- **5G**: 2025
4G Revenue Upside Limited

Annual growth in mobile operator revenues is tending to 1% in Asia Pacific, North America and Western Europe

<table>
<thead>
<tr>
<th>Region</th>
<th>8 year (2009-17)</th>
<th>4 year (2013-17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia Pacific</td>
<td>5%</td>
<td>1%</td>
</tr>
<tr>
<td>North America</td>
<td>4%</td>
<td>3%</td>
</tr>
<tr>
<td>Western Europe</td>
<td>0%</td>
<td>-2%</td>
</tr>
</tbody>
</table>

Source: STL Partners
Performance Demands Keep Increasing

2G - 5G Speed

- 2.5G speed is based on the maximum offered by EDGE
- 3G speed is based on the maximum offered by HSDPA

Source: www.thetech.in Nov 2018

What is 5G?

- 2G: 1991
- 3G: 1998
- 4G: 2008
- 5G: 2020?

Texting

Source: Signal Booster
5G Builds on 4G

source: Test and Verification

source: Ericsson
So 5G is Evolutionary

● Lower cost per bit
● Capacity 4G cannot supply
● Builds on 4G
  ○ dynamic spectrum sharing
  ○ 5G air interface with 4G evolved packet core
  ○ macrocell sites reused
  ○ 4G small cell sites reused
● Builds on Wi-Fi offload
● Millimeter wave for capacity reinforcement in urban areas
● Uses 4G packet core before transition to 5G core (virtualized)
5G Also is Revolutionary

- Computers talking to computers
- Enterprise drives revenue growth
- Millimeter wave
- Fixed network substitution
- Network slicing
- Internet of Things
- Edge computing for latency, transport cost use cases
- Virtual and customized networks
Growth from “Non-Human” Users...

source: Ericsson
From Scarcity to Abundance

[source: Anokiwave] orange FCC release, red/green already license to other uses. Blue shows potential mobile spectrum
## Capacity Scarcity Has Been the Norm

![CTIA Logo](image)

<table>
<thead>
<tr>
<th>Country</th>
<th>Subscribers</th>
<th>Average Minutes per Month</th>
<th>Average Revenue per Minute</th>
<th>Efficient Use of Spectrum</th>
<th>Spectrum Assigned for Commercial Wireless Use</th>
<th>Potentially Usable Spectrum/In the Pipeline</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>302.9M</td>
<td>793</td>
<td>$0.04</td>
<td>739,579</td>
<td>409.5 MHz*</td>
<td>50 MHz</td>
</tr>
<tr>
<td>Japan</td>
<td>117.1M</td>
<td>141</td>
<td>$0.23</td>
<td>337,351</td>
<td>347 MHz</td>
<td>400 MHz</td>
</tr>
<tr>
<td>Germany</td>
<td>107.4M</td>
<td>133</td>
<td>$0.11</td>
<td>174,634</td>
<td>615 MHz</td>
<td>Recently auctioned 350 MHz</td>
</tr>
<tr>
<td>U.K.</td>
<td>79.9M</td>
<td>204</td>
<td>$0.10</td>
<td>213,067</td>
<td>375 MHz</td>
<td>310 MHz</td>
</tr>
<tr>
<td>France</td>
<td>63.2M</td>
<td>231</td>
<td>$0.13</td>
<td>168,461</td>
<td>375 MHz</td>
<td>250 MHz, up to 200 MHz</td>
</tr>
<tr>
<td>Italy</td>
<td>90.0M</td>
<td>153</td>
<td>$0.11</td>
<td>240,000</td>
<td>375 MHz</td>
<td>250 MHz, up to 200 MHz</td>
</tr>
<tr>
<td>Canada</td>
<td>24.6M</td>
<td>373</td>
<td>$0.16</td>
<td>90,992</td>
<td>270 MHz</td>
<td>270 MHz</td>
</tr>
<tr>
<td>Spain</td>
<td>56.0M</td>
<td>150</td>
<td>$0.08</td>
<td>134,940</td>
<td>415 MHz</td>
<td>120 MHz</td>
</tr>
<tr>
<td>S. Korea</td>
<td>50.8M</td>
<td>303</td>
<td>$0.05</td>
<td>188,030</td>
<td>270 MHz</td>
<td>150 MHz</td>
</tr>
<tr>
<td>Mexico</td>
<td>91.0M</td>
<td>191</td>
<td></td>
<td>350,000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Figure includes AWS-1, 700 MHz spectrum not yet in use and 55.5 MHz of spectrum at 2.5 GHz. #Regulatory and company websites.

Millimeter Wave Frequencies are the Future

Cellular frequencies, 1980-2040 (logarithmic scale)

1 MHz 10 MHz 100 MHz 1 GHz 10 GHz 100 GHz 1 THz 10 THz


1G 2G 3G 4G 5G 6G

source: FutureTimeline.net
Orders of Magnitude Difference

- 3.5G/DC-HSPA+: 42.2 Mbps
- 4G/LTE: 100 Mbps
- 4G/LTE Cat. 4: 150 Mbps
- 4G/LTE Advanced: 1,000 Mbps
- 5G*: 10,000 Mbps

source: gsmaintelligence.com
Latency Advantages Drive Most New Use Cases
Low Latency Means Edge

From edge sensors to the centralized cloud

The edge computing ecosystem is comprised of four primary areas:

Centralized Cloud
Centralized data centers are farthest from the network edge. However, they offer a much greater density of compute, storage, and networking resources.

Edge Infrastructure
Small, distributed data centers that provide a resource dense midpoint between edge devices and the centralized cloud. Low roundtrip latencies of 5 – 10ms.

Edge Devices
Real-time data processing within devices based on application needs. Processing limitations present.

Edge Sensors & Chips
Data collection & origination.

Source: WinSystems

source: CB Insights
5G and Mobile Edge Computing

Both latency and bandwidth cost are use cases for mobile edge computing.
5G Shift to Enterprise

Where will new operator revenues in 5G come from?

- Enterprises (e.g. B2B, B2B2C): 69% Most Important, 20% Important, 3% Medium Importance, 6% Low Importance, 3% Least Important
- Consumers (e.g. B2C): 23% Most Important, 31% Important, 34% Medium Importance, 9% Low Importance, 3% Least Important
- Online (e.g. A2P): 17% Most Important, 17% Important, 40% Medium Importance, 17% Low Importance, 9% Least Important
- Governments (e.g. B2G, B2G2C): 14% Most Important, 26% Important, 40% Medium Importance, 17% Low Importance, 3% Least Important
- Others (please specify): 9% Most Important, 9% Important, 23% Medium Importance, 6% Low Importance, 54% Least Important

Source: Survey of 750 operator CEOs (GSMA, Oct 2016)

Figure 1: New incremental revenue opportunities in 5G to come from the enterprise segment

source: GSMA
Why 5G Fixed?

<table>
<thead>
<tr>
<th>MAIN TECHNOLOGY</th>
<th>HOMES AND BUSINESSES PASSED (MILLION)</th>
<th>FIXED BROADBAND CUSTOMERS (MILLION)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comcast</td>
<td>Cable</td>
<td>57.2</td>
</tr>
<tr>
<td>Charter</td>
<td>Cable</td>
<td>49.8</td>
</tr>
<tr>
<td>AT&amp;T</td>
<td>FTTH/xDSL</td>
<td>&gt;60</td>
</tr>
<tr>
<td>Verizon</td>
<td>FTTH/xDSL</td>
<td>14.6</td>
</tr>
</tbody>
</table>

* Includes business customers (the vast majority of customers are residential though). Q4 2017 figures. Source: company data and GSMA Intelligence

source: GSMA Intelligence

source: Mobile Experts

source: Siklu
Share of Value in 5G Era?

Figure 10. Payment and retention of customer spend
(wireless industry total in $ billion)

2000

2006

2013

Sources: 2000 annual reports for AT&T, Verizon, Sprint, T-Mobile, USCC; 2006 annual reports for AT&T, Verizon, Sprint, T-Mobile, Alltel, USCC, Motorola, Apple, Google, Microsoft, Nokia, Research in Motion; 2013 annual reports for AT&T, Verizon, Sprint, T-Mobile, USCC, Apple, Google, Microsoft, Nokia, Research in Motion; Deloitte analysis.

source: Deloitte University Press

Graphic: Deloitte University Press | DUPress.com
Network Slicing

Network slicing creates end-to-end virtualized networks differentiated by speed, reliability, latency, energy consumption, security, geography, edge or cloud computing, charging, identity.
# One Size Fits All

<table>
<thead>
<tr>
<th>Wholesale</th>
<th>Retail</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVNO: pay for what you use</td>
<td>Best effort access only</td>
<td>Shared access</td>
</tr>
</tbody>
</table>
### New Things You Can Do

<table>
<thead>
<tr>
<th>Wholesale</th>
<th>Retail</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>End to end:</strong></td>
<td><strong>End to end:</strong></td>
<td><strong>On-demand</strong></td>
</tr>
<tr>
<td>Quality of service</td>
<td>QoS</td>
<td>Geography</td>
</tr>
<tr>
<td>Class of service</td>
<td>CoS</td>
<td>Speed</td>
</tr>
<tr>
<td>MVNO capacity</td>
<td>Substitution</td>
<td>Latency</td>
</tr>
<tr>
<td>Access VNO</td>
<td>On-demand</td>
<td>Reliability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Security</td>
</tr>
</tbody>
</table>
Business Model Impact

<table>
<thead>
<tr>
<th>Wholesale</th>
<th>Retail</th>
<th>Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customized product with higher revenue and value</td>
<td>Product differentiation</td>
<td>Customized networks</td>
</tr>
<tr>
<td></td>
<td>Speed tiers</td>
<td>IoT</td>
</tr>
<tr>
<td></td>
<td>QoS tiers</td>
<td>Ultra-low latency</td>
</tr>
<tr>
<td></td>
<td>CoS tiers</td>
<td>Video, gaming</td>
</tr>
</tbody>
</table>

Edge Computing Value: Latency, Bandwidth Cost

4G link latency 50 ms to 70 ms
5G link latency 1 ms to 2 ms

source: DataBank
Replace Half of Revenue Every 10 Years

source: Turk Telecom
“Access” CAGR Drops 50% in 5 Years

Internet value chain size and growth by segment

<table>
<thead>
<tr>
<th>$ billion, %</th>
<th>2008</th>
<th>2015</th>
<th>2020f</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content rights</td>
<td>35 (3%)</td>
<td>577 (17%)</td>
<td>577 (10%)</td>
</tr>
<tr>
<td>Online services</td>
<td>509 (41%)</td>
<td>1,537 (47%)</td>
<td>816 (14%)</td>
</tr>
<tr>
<td>Enabling technology and services</td>
<td>159 (13%)</td>
<td>373 (11%)</td>
<td>816 (14%)</td>
</tr>
<tr>
<td>Connectivity (Internet related)</td>
<td>226 (18%)</td>
<td>813 (23%)</td>
<td>1,289 (22%)</td>
</tr>
<tr>
<td>User interface</td>
<td>309 (25%)</td>
<td>1,289 (22%)</td>
<td>1,289 (22%)</td>
</tr>
</tbody>
</table>

CAGR 2008-2015: +16%

CAGR 2015-2020f: 10%

Note: Includes restatements of 2008 data to 2015 structure to enable comparability.
Source: A.T. Kearney analysis

source: AT Kearney
Many Related Advances...

Virtualized Core (NFV, SDN)
Virtualized Edge (Slicing)
Small Cells (Backhaul dominates cost)
Use “any spectrum” (below 2 GHz, Millimeter)
Aggregate licensed and unlicensed spectrum
Millimeter wave capacity
Substitute for fixed network
Designed for new use cases (IoT)
Key Attributes

● 1-10Gbps connections
● 1 millisecond end-to-end delay (latency)
● 1000x bandwidth per unit area
● 10-100x number of connected devices
● 99.999% availability
● 90% reduction in network energy usage
● Up to 10-year battery life
● M2M device support
Battery Life, Cost are Key for Many IoT Apps

- unattended operation
- low device cost
- low access cost
- long battery life
- low bandwidth
- low latency

**LPWA Solution**

<table>
<thead>
<tr>
<th></th>
<th>SIGFOX</th>
<th>LoRa</th>
<th>NB-LTE</th>
<th>LTE-M</th>
<th>EC-GSM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (outdoor)</td>
<td>&lt;13km</td>
<td>&lt;11km</td>
<td>&lt;15km</td>
<td>&lt;11km</td>
<td>&lt;15km</td>
</tr>
<tr>
<td>MCL</td>
<td>106dB</td>
<td>157dB</td>
<td>164dB</td>
<td>166dB</td>
<td>164dB</td>
</tr>
<tr>
<td>Spectrum</td>
<td>Unlicensed</td>
<td>Unlicensed</td>
<td>Licensed</td>
<td>Licensed</td>
<td>Licensed</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>100Hz</td>
<td>&lt;500Hz</td>
<td>180kHz</td>
<td>1.4MHz</td>
<td>200kHz</td>
</tr>
<tr>
<td>Data Rate</td>
<td>&lt;100bps</td>
<td>&lt;10kbps</td>
<td>&lt;150kbps</td>
<td>&lt;1Mbps</td>
<td>10kbps</td>
</tr>
<tr>
<td>Battery Life</td>
<td>&gt;10 yrs</td>
<td>&gt;10 yrs</td>
<td>&gt;10 yrs</td>
<td>&gt;10 yrs</td>
<td>&gt;10 yrs</td>
</tr>
<tr>
<td>Cost of Device</td>
<td>~2 USD</td>
<td>~2 USD</td>
<td>&lt;5 USD</td>
<td>&lt;5 USD</td>
<td>&lt;5 USD</td>
</tr>
<tr>
<td>Timeline</td>
<td>Today</td>
<td>Today</td>
<td>2016-17</td>
<td>2016-17</td>
<td>2016-17</td>
</tr>
</tbody>
</table>

**Table 1. Network Behavior of Three Examples of IoT Services and Smartphone Users**

- Smart Meters: Massive (millions) and Low (2–10 t/h); Mobility: None; Latency: High Tolerance
- Non Consumer Video: Moderate (10+ thousands) and High (2–10 t/hr); Mobility: None; Latency: Low Tolerance
- Connected Car: High (millions) and High (500–1000 t/hr); Mobility: Frequent; Latency: Moderate Tolerance
- Smartphone Users: High (millions) and Moderate (200–500 t/hr); Mobility: Frequent; Latency: Moderate Tolerance
Spectrum Sharing

- Citizens Broadband Radio Service
- TV White Spaces
- Licensed Assisted Access
- Licensed Shared Access
Most of the Upside is Apps

Figure 23: M2M/IoT Value Chain – Projected Revenues

<table>
<thead>
<tr>
<th>Value Chain</th>
<th>Hardware*</th>
<th>Connectivity**</th>
<th>Value-Added Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>$1.4 BN</td>
<td>$0.3 BN</td>
<td>$30 - $50 BN</td>
</tr>
<tr>
<td></td>
<td>Worldwide</td>
<td>Worldwide</td>
<td>Worldwide</td>
</tr>
<tr>
<td></td>
<td>North America</td>
<td>North America</td>
<td>North America</td>
</tr>
<tr>
<td>2018</td>
<td>$4 BN</td>
<td>$1.3 BN</td>
<td>$80 - $120 BN</td>
</tr>
<tr>
<td></td>
<td>Worldwide</td>
<td>Worldwide</td>
<td>Worldwide</td>
</tr>
<tr>
<td></td>
<td>North America</td>
<td>North America</td>
<td>North America</td>
</tr>
</tbody>
</table>

Source: ABI Research
THANK YOU