5G and the Wireless Ecosystem: toward a disruption? (an economist’s perspective)

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Advanced Network Architecture
Digital Economy is the future!
- Global transformation: all economies, all sectors (at different rates)
- ICTs accelerate, amplify, and augment changes. Disrupt.
- Digital & “analog” elements of society/economy (laws, institutions, processes, skills, behavior, ....) must co-evolve

Everything, everywhere, always connect(able) to computing and networked resources

- 5G is the networking infrastructure to enable
- Clouds, IoT, BigData, AI, robots, Autonomous vehicles, Augmented Reality....”everything as a Service” (XaaS)
- Smart-X smart highways & vehicles; greener energy grids; healthcare; supply chains; natural resource mgmt.; finance & payments, etc.
- Real and Virtual World Convergence

5G is (vision of) the networking infrastructure to enable!
5G vision: Order magnitude performance improvement

.. We realize the future as we move toward the horizon


Figure 2: 5G Network Improvements

- **eMBB**
- **mMTC**
- **URLLC**

Future IMT

- 3D video, UHD screens
- Work and play in the cloud
- Augmented reality
- Industry automation
- Mission critical application
- Self driving car

Massive machine type communications

Ultra-reliable and low latency communications

5G Needs Spectrum Across All Bands

- Reliable Low-Latency Comms
  - Localized, reliable high capacity service
- Enhanced Mobile Broadband
  - Consistent capacity and speed experience
- Massive IoT
  - Nationwide coverage reliability
**Exhibit 8:**

**5G: global CAPEX $872B.** (1.7 x 4G CAPEX 2019-2030)

Master 5G comparison table for the four markets

<table>
<thead>
<tr>
<th>Country</th>
<th>Spectrum</th>
<th>Spectrum allocation timing</th>
<th>Spectrum cost (US$bn)</th>
<th>5G capex (US$bn)</th>
<th>Expected service launch</th>
<th>Focused application in early stage</th>
<th>Potential market structure changes</th>
<th>Infrastructure plays</th>
<th>Potential incremental revenue (US$ bn)</th>
<th>as % telecom service revenue</th>
<th>as % mobile service revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Mid band</td>
<td>3.3-3.6 &amp; 4.8-5.0GHz; maybe 2.6GHz</td>
<td>Late 2018</td>
<td>NA</td>
<td>421</td>
<td>2020</td>
<td>Network sharing: CU and CT</td>
<td>Tower, Data Centers, Construction Vendor</td>
<td>60.2</td>
<td>32%</td>
<td>45%</td>
</tr>
<tr>
<td>USA</td>
<td>mmWave</td>
<td>24.75-27.5; 37-42.5GHz</td>
<td>mmWave in 4Q18 and 19; Mid band will be later</td>
<td>26.0</td>
<td>239</td>
<td>1Q19</td>
<td>Merge: T-Mobile and Sprint</td>
<td>Tower, Data Centers, Fiber, Spectrum Holders</td>
<td>76.3</td>
<td>23%</td>
<td>42%</td>
</tr>
<tr>
<td>Korea</td>
<td>3.42-3.7GHz</td>
<td>Jun-18</td>
<td>7.4</td>
<td>50</td>
<td>4Q19</td>
<td>IoT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan</td>
<td>3.6-4.2, 4.4-4.9GHz</td>
<td>1Q19</td>
<td>NA</td>
<td>129</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Source: Morgan Stanley Research

**“$9B 5G Fund for Rural Broadband” (FCC announced, Dec2019)**
IHS (2017) study:

“5G will enable $12.3 trillion in sales, generating $3.5 trillion in additional global output that will support 22 million jobs by 2035”

“Annual global investment of $200B per year”
Meeting the 5G challenge

- **Small cells: CAPEX increases, backhaul challenge**
  - Enable Spectrum reuse, MEC, Energy efficiency, mmW spectrum
  - When cells smaller, spectrum more fungible (e.g. mid-band, high-band, etc.)
  - Spectrum smaller share of per-cell cost (site, power, backhaul, etc.)

- **Intelligent Core Network: Softwarization & Virtualization**
  - Expanded flexibility, customizability, scalability ("network-as-a-service"). Accessibility of cloud services.
  - Delocalization control ➔ realize scale/scope economies.
  - via alphabet soup of tech: NFV, SDN, MEC, Slicing

- **Shared Spectrum: everyone wants more so have to share**
  - DSA: dynamic, granular shared RF in all dimensions (time, space, context, ...)
  - Heterogeneous users/uses/networks co-exist. Active/passive uses.
  - 5G is NOT just 3GPP (LTE) but also WiFi (802.11x), satellite, etc.
  - Regulatory ➔ markets: continuum from licensed to unlicensed (e.g., CBRS)
Future BB Competition: intensifying competition

- **Specialized and Local Facilities-based Entry** *(new)*
  - Venues: Stadiums, Campuses, Shared-tenant-networks
  - Small cells (access/site control bigger issue)
  - Shared costs, virtualize infrastructure/functionality (delocalized, network-as-a-service)
  - End-user deployed ⇔ new vector for competition (e.g., WiFi, Muni-nets, etc.)

- **MVNO competition intensified** *(seen this before, but new flavor)*
  - 3 MNOs with excess capacity ⇒ robust wholesale market.
  - Edge providers integrate forward for enhanced control of user experience. Rise CDNs.
  - 5G vertical niches as SmartX drives need to vertically-integrate. New specialized MVNOs

- **Fixed-Mobile Convergence** *(been coming for a while)*
  - Intensified intermodal competition. Mobile closer substitute to fixed.
  - Revenue drivers: Cord-cutting, OTT rise. Falling prices mobile.
  - Rise WiFi (Google *Project Fi*, Comcast *Xfinity*). 5G traffic more nomadic, less fast-mobile.
  - Smaller cells ⇔ CAPEX looks more similar for fixed/mobile
  - Converged Landscape: MNOs are smaller part of overall picture
Will the Internet survive Covid-19? (press coverage March 2020....)

“Despite massive traffic increases — particularly across consumer last-mile networks — we have not seen a significant corresponding spike in Internet outages.”

Ookla Speedtest Data: relatively stable performance (as of 3/30/2020)
5G & Platforms in a (post) Covid World

Internet and Broadband rise to the challenge (mostly)
- Network traffic increase 30-40% during peak
  - Broadband, IXPs, Clouds, Applications, etc.
  - Increased video-conferencing, video-streaming, gaming
  - Drop in business traffic as work shifted to home helped
  - Cloud shift for VPNs helped
  - WiFi replaced cellular
- Congestion some, outages few
  - Local bottlenecks, Configuration errors, Older equipment
  - Applications (e.g., Zoom, Microsoft Teams) and Websites (e.g., employment sites) saw unanticipatable short-term growth.
- Cyberattacks increase, Privacy & Surveillance

Long-term effects (??)
- Accelerate traffic trends already under way: virtual life a step closer...
  - Shift to Clouds and CDNs, Private replace public networks, flatter topology
- More Telemedicine, FinTech (ePayments), Remote Collaboration, ....
- Demand shock & Supply Response – Government must lead
  - Digital Divide ➔ 5G should be for everyone. Push for Universal Service public subsidies
  - Supply response ➔ Economic recovery (??) and scarcity private capital. Revenue pressure.
- More (or less) regulation?
  - Digital platform antitrust, Network Neutrality, Privacy, etc.
Summing Up: 5G & Wireless Ecosystem....

Autonomy = Real/Virtual world convergence

5G = platform for Pervasive Computing
- Everything connectable does not mean everything should/will be connected
- Like the Internet, control & ownership will be distributed/decentralized

$Trillions of future Smart-X potential
- Transformation will be disruptive. Adjustment costs will be significant
- Realization depends on co-evolution of digital & analog elements

Covid-19, Climate Change, Globalization, .... might not be threats in world without computers
but our ability to respond surely depends on continued advances

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Additional Material --- not used
Convergence of WLAN (802.11x) and Cellular (3GPP)

- Data rates
- Cell size
- Support for multi-APs and standalone deployment

Spectrum sharing

Citizen Band Radio Service (CBRS) 3.5GHz

- High-value mid-band spectrum for 5G
- History:
  - FCC (2015) CBRS rules announced
  - September 2019, GAA commercial begins; June 2020 PAL auction

Figure 1. CBRS 3-Tier Shared Spectrum Licensing Structure
Citizen Band Radio Service (CBRS) 3.5GHz

Business models
1. MNO capacity augmentation, e.g., using carrier aggregation
2. New CBRS MSO entrant (e.g., Cable, new) to build out new LTE network
3. Neutral Host RAN: manage interconnection, shared resources, multiple networks
4. Enterprise Private LTE: improvement over DAS, Wi-Fi
What should 6G be?

Shuping Dang, Osama Amin, Basem Shihada and Mohamed-Slim Alouini

5G v. 6G (one perspective...)
- Service: 3D VR/AR v. Tactile
- Max data: 35Gbps v. 100Gbps
- Max spectrum: 90GHz v. 10THz
- Massive MIMO v. Intelligent surface

Table 2 | Detailed comparisons of 1G to 6G communications

<table>
<thead>
<tr>
<th>Features</th>
<th>1G</th>
<th>2G</th>
<th>3G</th>
<th>4G</th>
<th>5G</th>
<th>6G (supposed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum rate</td>
<td>2.4 kb s⁻¹</td>
<td>144 kb s⁻¹</td>
<td>2 Mb s⁻¹</td>
<td>1 Gb s⁻¹</td>
<td>35.46 Gb s⁻¹</td>
<td>100 Gb s⁻¹</td>
</tr>
<tr>
<td>Maximum frequency</td>
<td>894 MHz</td>
<td>1,900 MHz</td>
<td>2,100 MHz</td>
<td>6 GHz</td>
<td>90 GHz</td>
<td>10 THz</td>
</tr>
<tr>
<td>Service level</td>
<td>Voice</td>
<td>Text</td>
<td>Picture</td>
<td>Video</td>
<td>3D VR/AR</td>
<td>Tactile</td>
</tr>
<tr>
<td>Standards</td>
<td>MTS, AMPS, IMTS, PTT</td>
<td>GSM, IS-95, CDMA, EDGE</td>
<td>UMTS, WCDMA, IMT2000, CDMA2000, TD-SCDMA</td>
<td>WiMAX, LTE, LTE-A</td>
<td>5G NR, WWWWW</td>
<td>-</td>
</tr>
<tr>
<td>Multiplexing</td>
<td>FDMA</td>
<td>FDMA, TDMA</td>
<td>CDMA</td>
<td>OFDMA</td>
<td>OFDMA</td>
<td>Smart OFDMA plus IM</td>
</tr>
<tr>
<td>Architecture</td>
<td>SISO</td>
<td>SISO</td>
<td>SISO</td>
<td>MIMO</td>
<td>Massive MIMO</td>
<td>Intelligent surface</td>
</tr>
<tr>
<td>Core network</td>
<td>PSTN</td>
<td>PSTN</td>
<td>Packet N/W</td>
<td>Internet</td>
<td>Internet, Internet of Things</td>
<td>Internet of Everything</td>
</tr>
<tr>
<td>Highlight</td>
<td>Mobility</td>
<td>Digitization</td>
<td>Internet</td>
<td>Real-time streaming</td>
<td>Extremely high rate</td>
<td>Security, secrecy, privacy</td>
</tr>
</tbody>
</table>

VR, virtual reality; AR, augmented reality; MTS, Mobile Telephone Service; IMTS, Improved Mobile Telephone Service; PTT, push to talk; GSM, Global System for Mobile Communications; IS-95, Interim Standard 95; CDMA, code-division multiple access; EDGE, Enhanced Data rates for GSM Evolution; UMTS, Universal Mobile Telecommunications Service; IMT2000, International Mobile Telecommunications-2000; LTE-A, Long-Term Evolution Advanced; 5G NR, Fifth-Generation New Radio; WWWWW, World Wide Wireless Web; FDMA, frequency-division multiple access; TDMA, time-division multiple access; OFDMA, orthogonal frequency-division multiple access; IM, index modulation; SISO, single-input single-output; PSTN, public switched telephone network; Packet N/W, packet-switched network.
What is 5G?
5G is not a single technical innovation, but rather a set of advances with spectrum

Network Architecture: 4G LTE vs. 5G

<table>
<thead>
<tr>
<th>Core Network</th>
<th>Transport</th>
<th>Tower / Access Point</th>
<th>Antenna</th>
<th>Air Interface Technology</th>
<th>Spectrum</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>4G</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Most computing resources located in core</td>
<td>Legacy copper, wireless, or fiber backhaul</td>
<td>eNodeB macro cell base stations</td>
<td>MIMO sends / receives limited # of signals simultaneously</td>
<td>One size fits all waveform with OFDM</td>
<td>Carrier aggregation maximum of five component carriers (100 MHz bw)</td>
<td>Standard LTE chipsets and battery life</td>
</tr>
<tr>
<td><strong>5G</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NFV and SDN technologies, NSA, SA slicing</td>
<td>Fiber Fronthaul</td>
<td>Macro-sites+ Many small cells</td>
<td>Massive MIMO and adaptive beamforming</td>
<td>Rel 15 OFDMA with improved flexibility</td>
<td>Higher freq (mmWave) and wider bandwidths carrier aggregation</td>
<td>Multi-mode, low power 5G chipsets</td>
</tr>
</tbody>
</table>

Greater Capacity
Faster Download Speeds
Lower Latency

Source: A&Co. Research & Analysis
What is 5G?
5G is not a single innovation, but rather a set of advancements in spectrum usage.

Networks are Evolving to Address Capacity Needs
Ongoing 4G activity includes new wrinkles on equipment configurations.

Typical 3G Deployment
- SISO Antennas - only antennas deployed on the tower

4G Deployment
- MIMO Antennas
- LTE Remote Radio Heads (RRHs) and Multi-RAT antennas
- Fiber running down the tower (rather than coax)

The Trend Has Been More Equipment Being Placed on Towers

Ongoing Evolution of Wireless Networks
Heterogeneous Networks (Hetnets) and unlicensed LAA will continue to play an important role in urban deployments, as they will share spectrum for neutral host indoor installations.

Network deployments are expected to consist of multiple layers—traditional macro cell towers provide a blanket of coverage, while underneath this umbrella, a combination of other technologies are deployed to increase network capacity, particularly in dense urban areas.

- Macro sites expected to continue providing wide area coverage for high mobility users and be the core of wireless networks.
- Multiple solutions including DAS, Rooftops, Wi-Fi and Small Cell networks expected to complement the coverage provided by towers in urban locations.

5G IoT Capabilities
The Internet of Things (IoT) is expected to experience rapid growth as 5G is deployed.

Multitude of IoT use cases
- Healthcare
- Education
- Transportation
- Home automation
- Industrial IoT

Huge IoT Volumes
Total IoT devices: 4.5X growth
Total IoT traffic: 11X growth (65% CAGR)
Widely varying IoT scales and requirements,

Summary: 5G is not a single innovation, but rather a set of advancements in spectrum usage.

American Tower
M2M connections dominate

Figure 3: Connections of Places Versus People Versus Things

5G connections grow fast, small share still by 2023

Figure 4: Mobile Subscriptions by Technology (Billions)

$/GB falling steeply

Figure 12: Reduced Cost per GB of 5G Compared to 4G

Similarly, an analyst firm predicts that the cost of delivering a gigabyte of data will drop from $1.25 with 4G to $0.16 with 5G.