5G and Next Generation Wireless

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Introduction: 5G and Next Generation Wireless

5G is a unique opportunity design a new wireless network incorporating recent technological advancements to radically extend wireless capacity and adaptability.

5G will move beyond mobile broadband, toward systems that connect far more different types of devices.

Presentation focuses on three key use-cases driving 5G, three key enabling technologies, and implications.

The "Gs"

Mobile technology has been characterized by the generations of standards.

- 1G – analog voice service; 1980s.
- 2G – digital voice (GSM and CDMA); 1990s.
- 3G – introduced data services and functionalities beyond voice, e.g. multimedia, texting (UMTS, EDGE); 2000s.
- 4G – designed to support mobile broadband (LTE, WiMax); 2010s.
- 5G – ???; estimated 2020, with earlier trials.

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Challenges, Use Cases, and Goals

5G development is driven by challenges and opportunities that cannot be met by current networks.

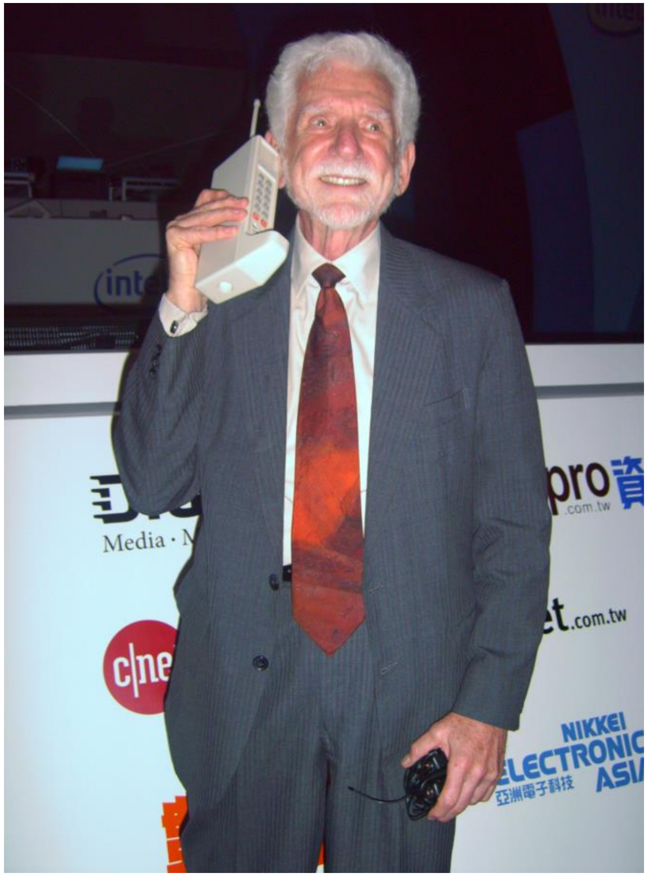
Three categories:

- Enhanced Mobile Broadband
- Massive Internet of Things (IoT)
- Critical Communications and Control

Enhanced Mobile Broadband

Use-case we are most familiar with as consumers.

- Improved consumer experience of mobile broadband; faster, more responsive network.
- 100 Mbps reliably; >10 Gbps peak download capacity.
- Currently constrained by relative spectrum scarcity and cost of smaller cell sizes.



Martin Cooper, inventor of the cell phone

Attribution: Rico Shen

Massive Internet of Things

IoT at a much larger scale requires changes throughout the network.

- 5.5 million "things" connected every day of 2016; total of 20.8 billion IoT devices connected by 2020 (Gartner estimates).
- 3G and 4G not designed for IoT.
- Must support simplified signaling, cost-efficient devices, and long battery life (goal is 10 year battery life).
- But adaptability is key. Not all "IoT" devices are low-bandwidth; some mobile, some stationary.
- Competing with solutions based on unlicensed spectrum.

Critical Communications and Control

Extremely reliable, low-latency, low error-rate connections will enable real-time control.

- High-value industrial automation.
- Autonomous or connected cars and other safety applications.
- Very low latency needed for "Tactile Internet," and applications like shared augmented/virtual reality.

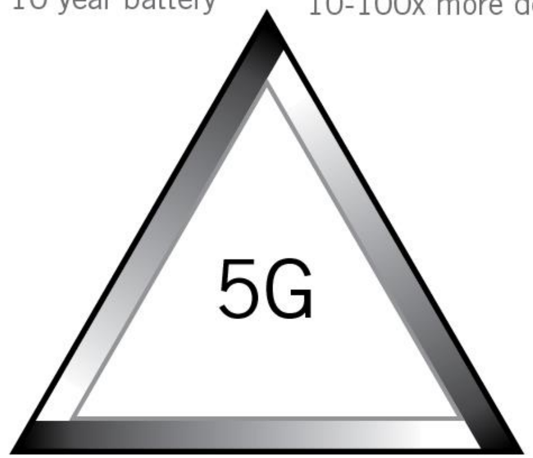
5G Triangle

Massive IoT

Large Number of Connections
with Low Power, Low Cost

10 year battery

10-100x more devices



Enhanced Broadband

Throughput Capacity

100 Mbps reliably

>10 Gbps peak

Critical Communications

Low-Latency, High-Reliability

<1 ms radio latency

10^{-9} error rate

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Technology behind 5G

5G not simply a new standard, but a collection of diverse technologies, many still under development.

Three key technologies:

- High-band or “mmWave” spectrum
- Advanced antenna technology
- Software-based networking

Spectrum Crash Course

"Spectrum" is a conceptual tool used to organize a set of physical phenomena.

- Electric and magnetic fields oscillate, producing electromagnetic waves.
- Electromagnetic waves vary in frequency (and wavelength), with different properties.
- Radio spectrum is managed by the government through a licensing system to prevent interference.
- 5G looking at higher frequency spectrum than used for mobile today.

U.S. Spectrum Allocations

High-band Spectrum

Extremely high-frequency spectrum is one key component of anticipated 5G networks.

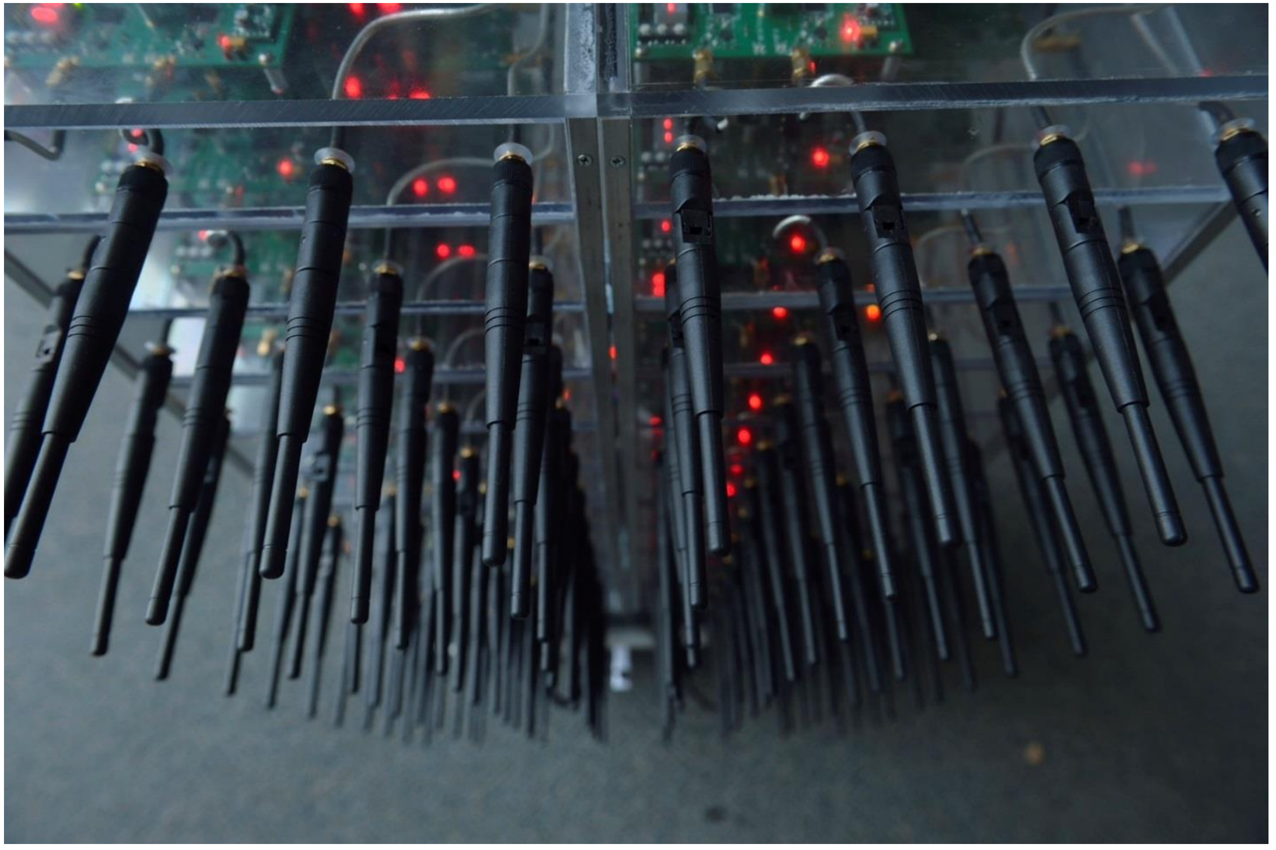
- Existing mobile (e.g. 700 MHz, 800 MHz, 2.5 GHz) will be complimented with new spectrum.
- FCC has moved forward with rules for a series of bands between 28 and 71 GHz.
- Much, much larger bandwidth means greater capacity.
- But comes with a trade-off. Higher frequencies do not propagate as far; can't penetrate buildings, foliage.
- Denser networks of smaller cells.

Advanced Antennas

High-band spectrum really shines when combined with advanced antenna technologies.

- Can use multiple antennas to transmit a single stream of information; called Multiple Input Multiple Output (MIMO).
- mmWave spectrum enables "massive MIMO," using over 100 antennas.
- Narrow beams can steer signals directly to users, allowing spectrum to be re-used.

Massive MIMO



Rice University researchers will use many-antenna base stations with more than 100 antennas apiece in a 5G wireless test network in Houston on the university's campus. Photo credit: Jeff Fitlow/Rice University

Software-Based Networking

New developments in networking allow for more flexible, dynamic allocation of network resources.

- Software-defined networking (SDN) and network functions virtualization (NFV) are transformational.
- Can move many functions from individually configured equipment to centrally-controlled software running on generic hardware.
- Foundation for "network slicing"—dedicated portion of network capacity adapted for specific use cases.
- Net neutrality may affect development.

Numerous other Technologies

Other tech in various levels of development.

- Full duplex; simultaneous transmission and reception on same frequency.
- Aggregation of heterogeneous networks.
- Cloud-RAN; move baseband processing to centralized location for a cluster of small-cells.
- Mobile edge computing; network predicts desired content, cache closer to user.
- "New Radio"—standardization of new air interface.
- Wireless backhaul, higher-order modulation, virtual cells etc.

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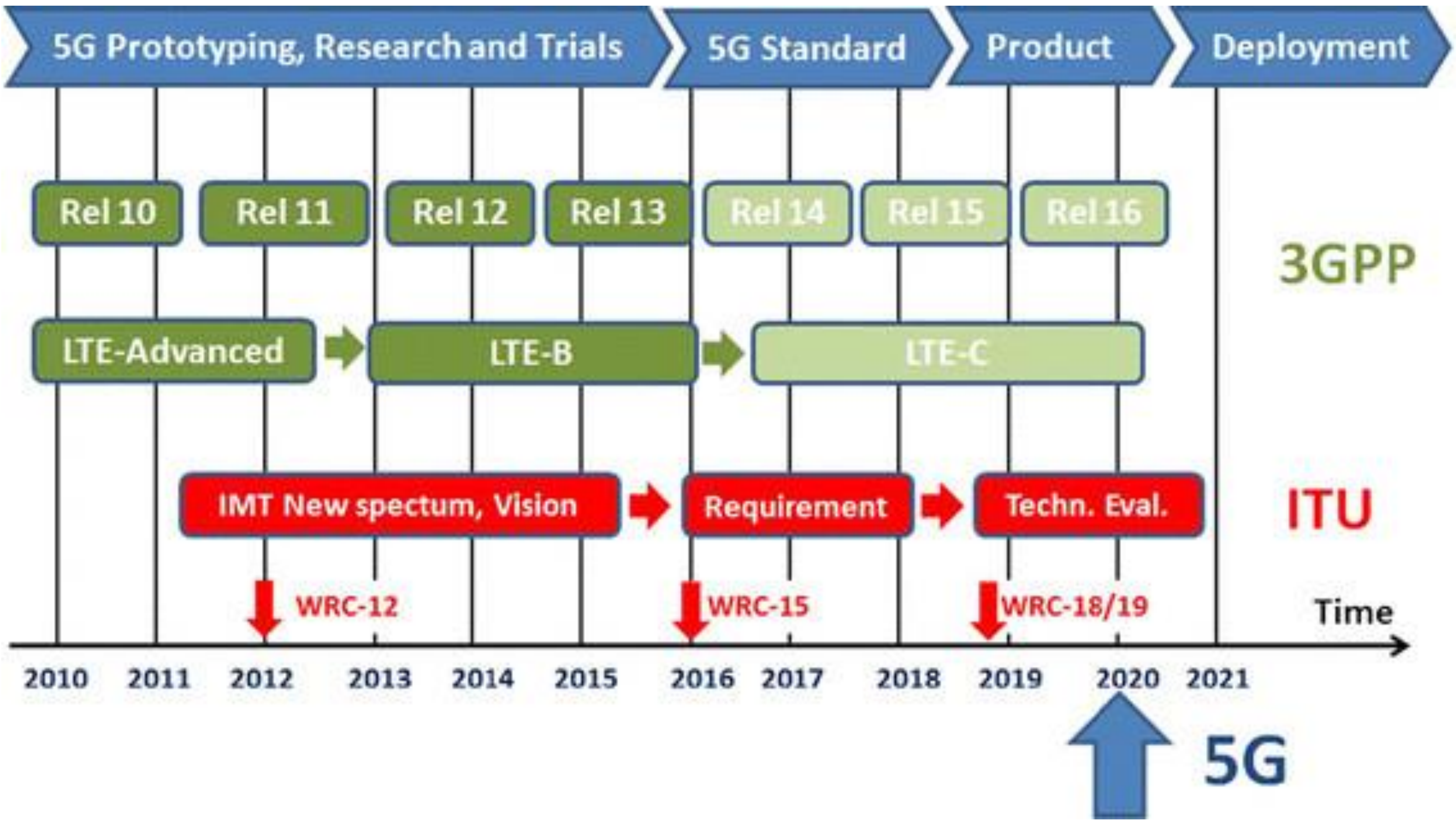
Standardization Process

Standardization is key for interoperability, with several bodies involved.

- International Telecommunications Union (ITU) solicits proposals for "IMT-2020."
- 3GPP is main standards body for the mobile industry. Will submit a strong candidate technology for IMT-2020.
- IEEE standardizing 802.11ad "WiGig" that uses mmWave unlicensed spectrum.
- EU Commission formed the 5G Infrastructure Public Private Partnership (5G PPP) with €1.4 billion.

Standardization Timeline



Long Runway of LTE

Today's dominant 4G standard, LTE, still has a long shelf-life.

- LTE still actively developed in 3GPP.
- Numerous functionalities in LTE specification yet to be fully utilized by operators.
- Equipment vendors looking to meet opportunities with existing networks.
- Will be an evolutionary transition to "5G" with "pre-standards" deployments.

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Competition

5G opens new avenues of competition.

- Mobile performance closes on fiber means increasing competition between wired and wireless. First "5G" deployments will be fixed wireless.
- Land-grab in IoT market.
- Some advancements dramatically lower cost, others still expensive. Backhaul may be key differentiator.
- SDN/NFV sees shake-up in networking equipment market, with value shifting to operations management and orchestration.
- International competitiveness is a consideration.

Cooperation

Different forms of cooperation will be important for flourishing of 5G.

- Standardization requires large-scale agreement on most important benchmarks.
- Extent of infrastructure sharing is a key question.
- Cooperation from local governments on both antenna siting and backhaul will greatly assist deployment.

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Policy Considerations

Stage setting rather than full industrial policy.

- Continued R&D
- Allocate spectrum
- Streamline infrastructure deployment.

R&D

Continuing role for government support of academic and industry development of new technology.

- Many constituent technologies developed in academic research setting.
- NSF recently launched a $400 million Advanced Wireless Research Initiative.
- Some wireless technologies carry expensive, high-risk development.

Spectrum Allocation

FCC recently moved on allocating large portion of mmWave spectrum for 5G uses.

- Licensed use in the 28 GHz, 37 GHz and 39 GHz bands; Unlicensed use in the 64-71 GHz band; Shared access in the 37-37.6 GHz band.
- Huge bandwidth: 4x existing licensed spectrum; 15x existing unlicensed spectrum.
- Strategic move on part of United States to advance its mobile ecosystem.
- Requires sharing with existing federal and satellite operations.

Infrastructure Deployment

Again, backhaul and siting will be key economic constraint. Cities play a key role.

- Streamlining of permitting and access to rights-of-way. Consolidated paperwork.
- Dig-once policies for streets and sewers; install conduit when already digging.
- Utility poles and streetlights will be key assets.
- States should ensure non-discriminatory access, mandatory timelines, just and reasonable rates, and an efficient complaint process.

Thank You!

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