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Ani Gevorkian

Covington & Burling LLP
One CityCenter
850 Tenth Street, NW
Washington, DC 20001-4956
T +1 202 662 5143
agevorkian@cov.com

By ECFS

January 13, 2016

Ms. Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

Dear Ms. Dortch:

Re: Written *ex parte* presentation in GN Docket No. 14-177

On January 13, 2016, Reed Hundt met with Robert Nelson of the International Bureau, Michael Ha and Julius Knapp of the Office of Engineering and Technology, and Brian Regan, Matthew Pearl, Roger Sherman, and Chris Helzer of the Wireless Telecommunications Bureau. The parties discussed the attached slide deck.

Please direct any questions to the undersigned.

Sincerely yours,

/s/ Ani Gevorkian

Ani Gevorkian

Attachment

cc: Robert Nelson
Michael Ha
Julius Knapp
Brian Regan
Matthew Pearl
Roger Sherman
Chris Helzer

The Future of Wireless Broadband: 5G

A Presentation for the Federal Communications Commission

Reed Hundt

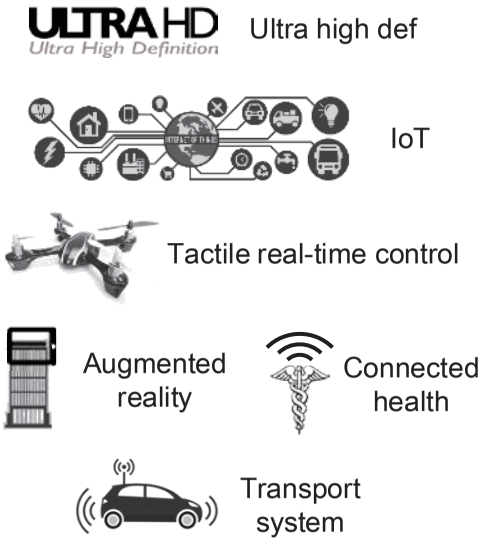
January 2016

Drivers

Industry **trends** putting **pressure on today's networks***…

- Data traffic explosion → Radical Capacity Enhancement
- System ROI pressure → Lower cost/bit
- Massive connections → 50-200B devices
- Mature markets seeking New Revenue Growth

…coupled with demand for critical/radical **new use cases** that are not being met today…



eMBB mMTC uMTC

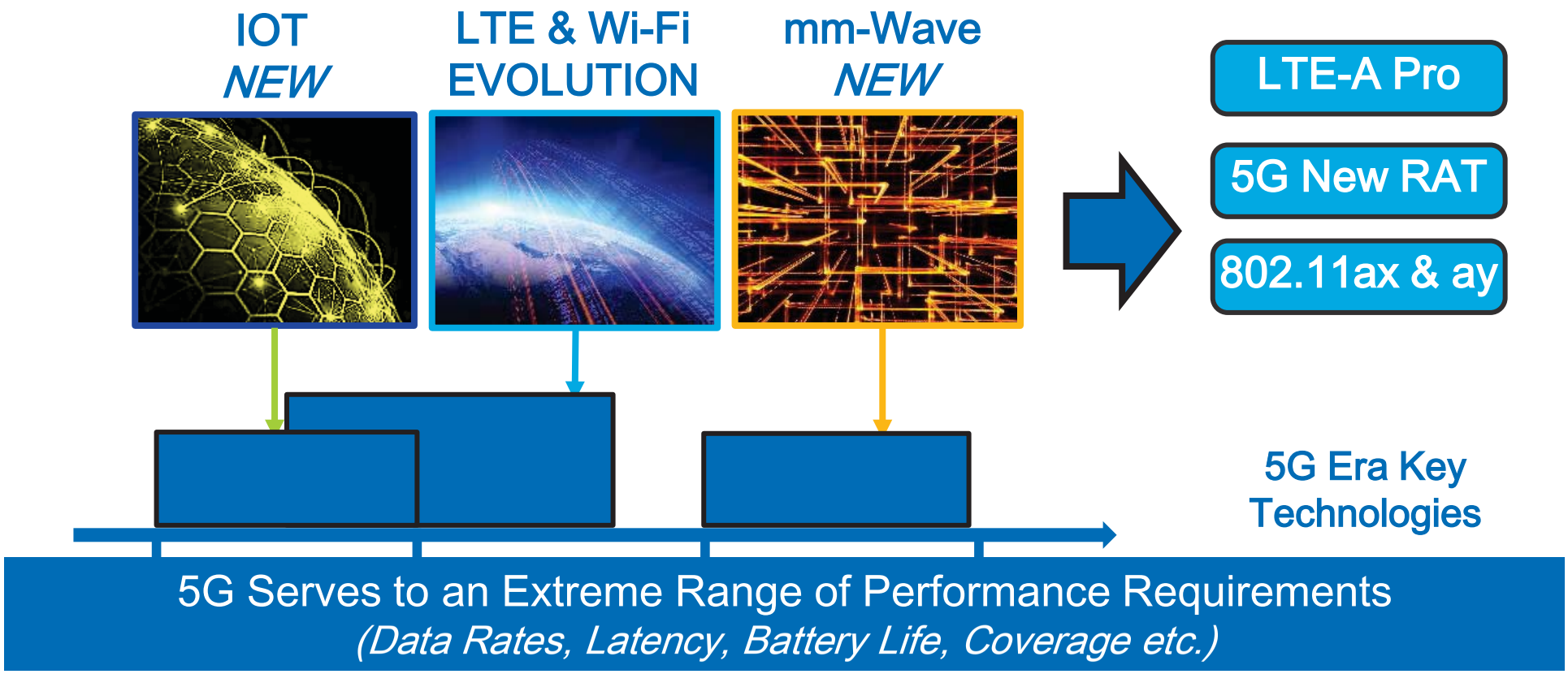
…are driving **new requirements** and **fresh wave of investments**

- **User throughput**
  Up to 20Gbps
- **Edge latency**
  Less than 1ms
- **System Bandwidth**
  At least 100MHz
- **Duplex**
  FDD and TDD
- **Spectrum**
  Up to 100GHz
- **Time Scale**
  2020-2030 and *Beyond*

eMBB – Enhanced Mobile Broadband, uMTC – Ultra-reliable and Low-latency Communications, mMTC – Massive Machine Type Communications

Intel Confidential – Internal Use Only

5G Era –Technology Tracks



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5G Core Technologies

5G Key Technologies

Evolved Multi-Antenna Processing Very Large or Massive MIMO Systems	**New Modulation and Coding** Non-Orthogonal Multiple Access	**New Access to Spectrum** Unlicensed, Licensed Shared Access, cmW, mmW	**Low Energy Systems** Devices and Infrastructure
Coordinated Systems C-RAN Topologies and Silicon Photonics	**Network Virtualization** Software Defined Network	**Multi-RAT Operation** Intelligence Traffic Routing	**Device-Device Communications** MTC and V2V Applications

5G Key Radio Bands

m-Wave Sub-10GHz ~100-200MHz BW SU/MU-MIMO	**cm-Wave (cmW) 10-30GHz** 100-500MHz+ BW SU/MU-MIMO	**mm-Wave (mmW) 30-90GHz** 500MHz+ BW Hybrid MU-MIMO-BF

5G eMBB and MTC Prototypes and Trials

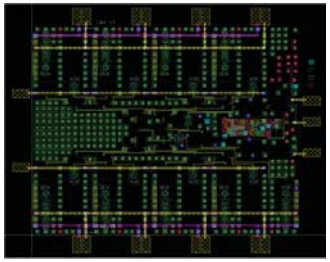
Enterprise

Field Trials

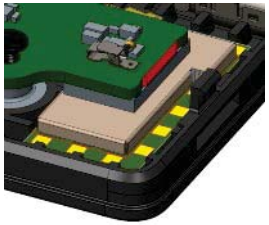
Campus and Backhaul

5G Devices

5G Baseband Engine

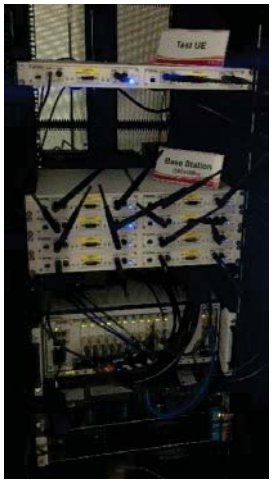


5G cmW RFIC



5G Form Factor Devices

5G Networks



Massive MIMO

LTE-mmW Dual Connectivity

Future of Wireless – Realizing the 5G Vision

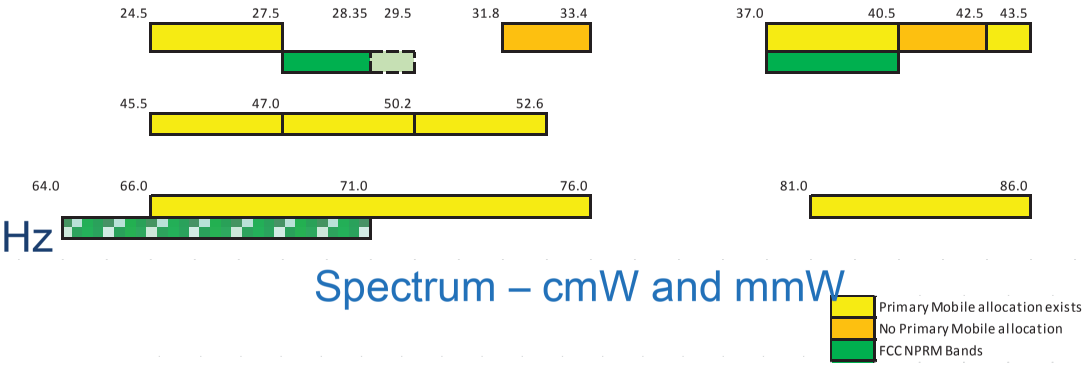
- 5G Outlook
  - **Technical Specifications**
    - » 3GPP & IEEE Radio and Network Standards Proceeding
  - **Technical Viability**
    - » Air Interface Specifications, Silicon Process Nodes and Architectures Emerging
  - **Channel**
    - » Models Emerging for 6-100GHz for Multiple Deployment Modes
  - **Spectrum**
    - » New Sub-6GHz and cmW/mmW Spectrum Between 2017-2020
  - **Timeline**
    - » Standards, Spectrum, Silicon and Use Cases Aligning

LTE-A Pro | 5G New RAT | 802.11ax | 802.11ay

Broad and Diverse Set of 5G Systems Operational by 2020

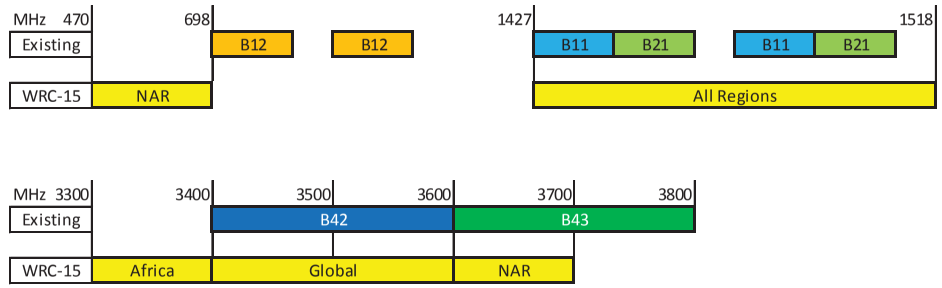
5G Spectrum Outlook after WRC-15

- WRC-15 – cmW and mmW
  - Multiple Mobile Primary Bands
  - Outstanding Example: U.S.
    - 28GHz, 37-40GHz, 64-71GHz



Spectrum – cmW and mmW

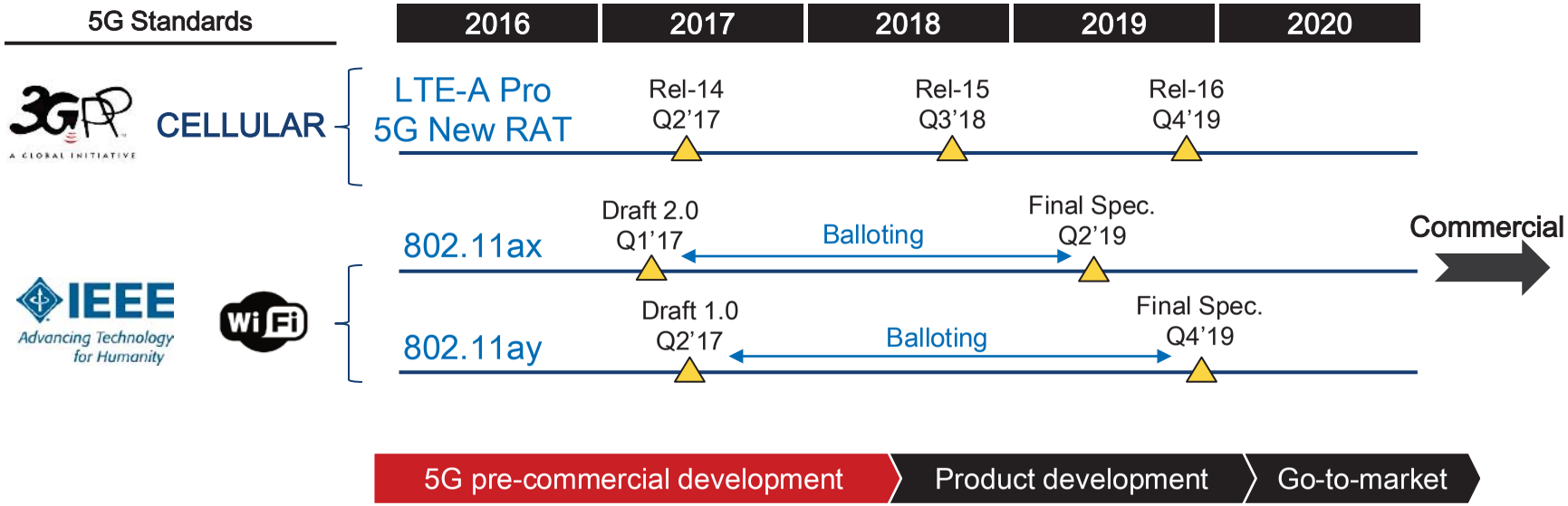
- WRC-15 – Sub-6GHz
  - Sub-700MHz in North America
  - Global L-Band Emerging - SDL
  - Limited 3GHz and 4GHz Outlook
  - National Leadership Required



Spectrum – Sub-6GHz

5G Spectrum Emerging – Especially at cmW/mmW

Technical Specifications – 5G Era Timelines



Diverse Set of Competitive 5G Specifications Targeting 2019-2020

3GPP 5G New Radio Access Technology (RAT)

3GPP Release 14/15

5G Phase 1

- Flexible OFDM Numerology Delivering Peak Rates of 20Gbps+
- Common Support for Sub-6GHz to ~40GHz
- Unified support for eMBB, Looking Forward to mMTC and uMTC
- Dynamic TDD/FDD, Flexible Frame Structure Supporting Beamforming
- Cell Virtualization, Massive Multi-Site MIMO
- Tight Interworking with LTE using New 5G Core Network

3GPP Release 16

5G Phase 2

- Extend up to 100GHz Spectrum Within same Unified Flexible Framework
- New Waveform for mmW Spectrum
- In-Band Full Duplex

Technical Viability – Silicon Performance

Manufacturing

14 nm

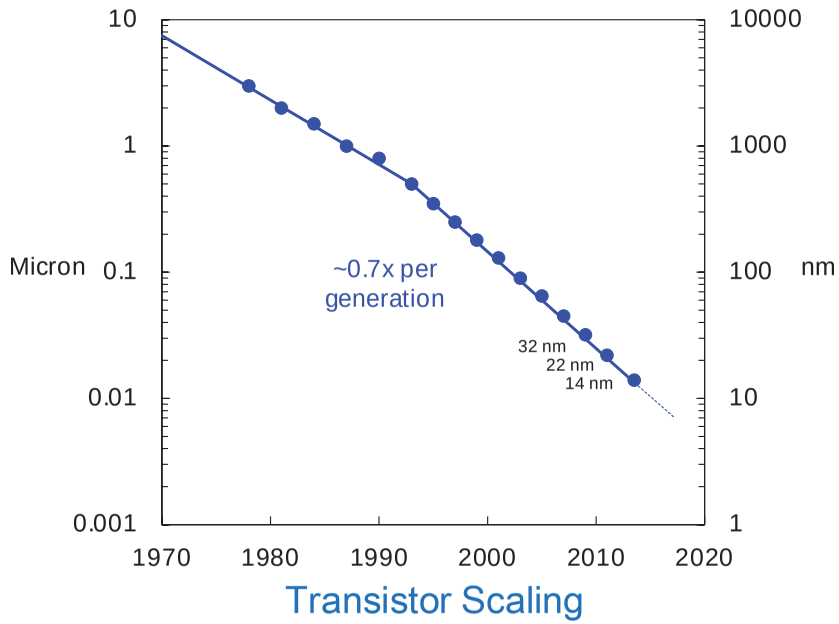
Development

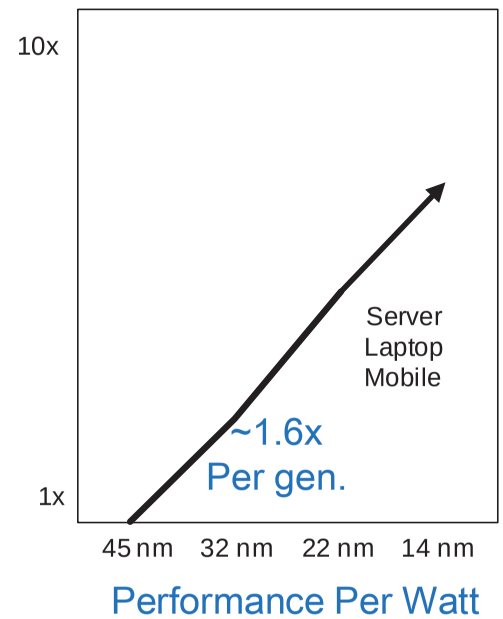
10 nm

Research

7 nm

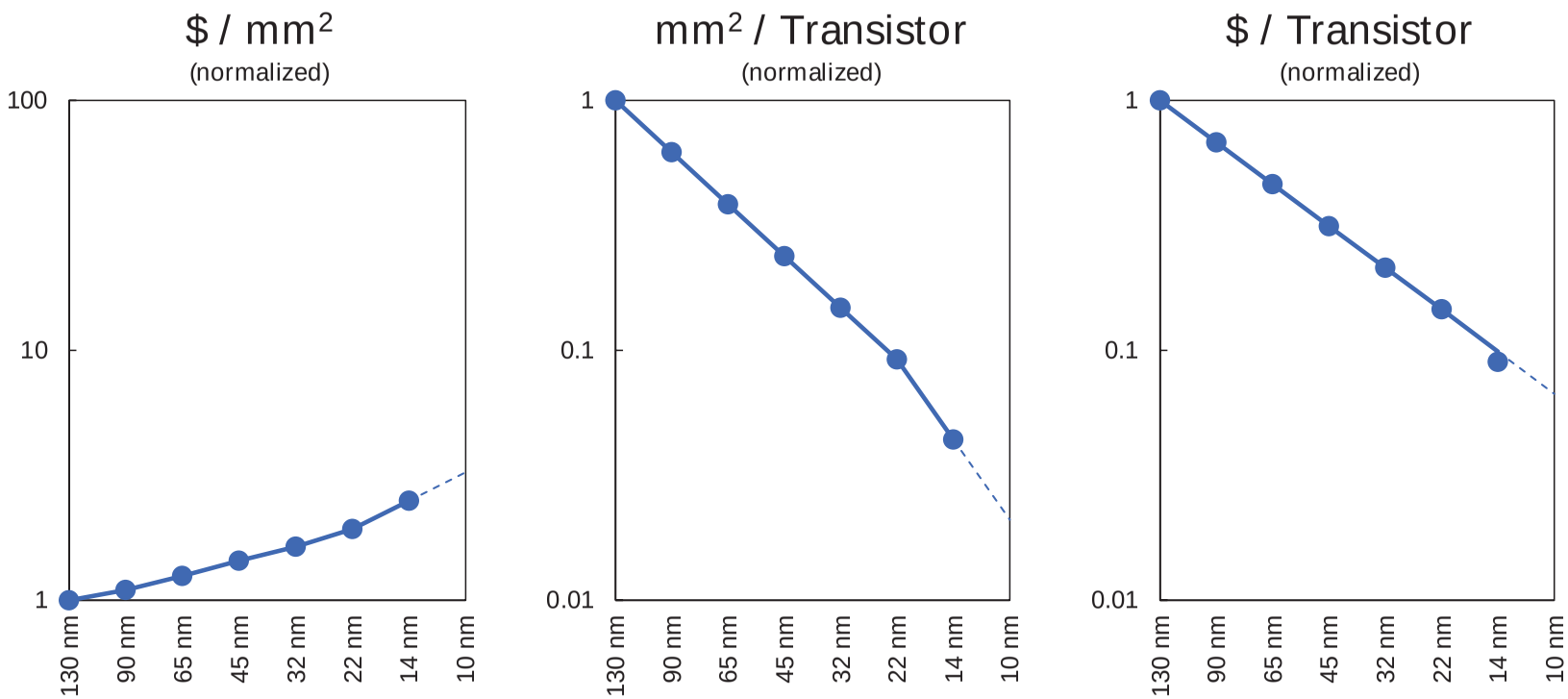
Process Node Maturity





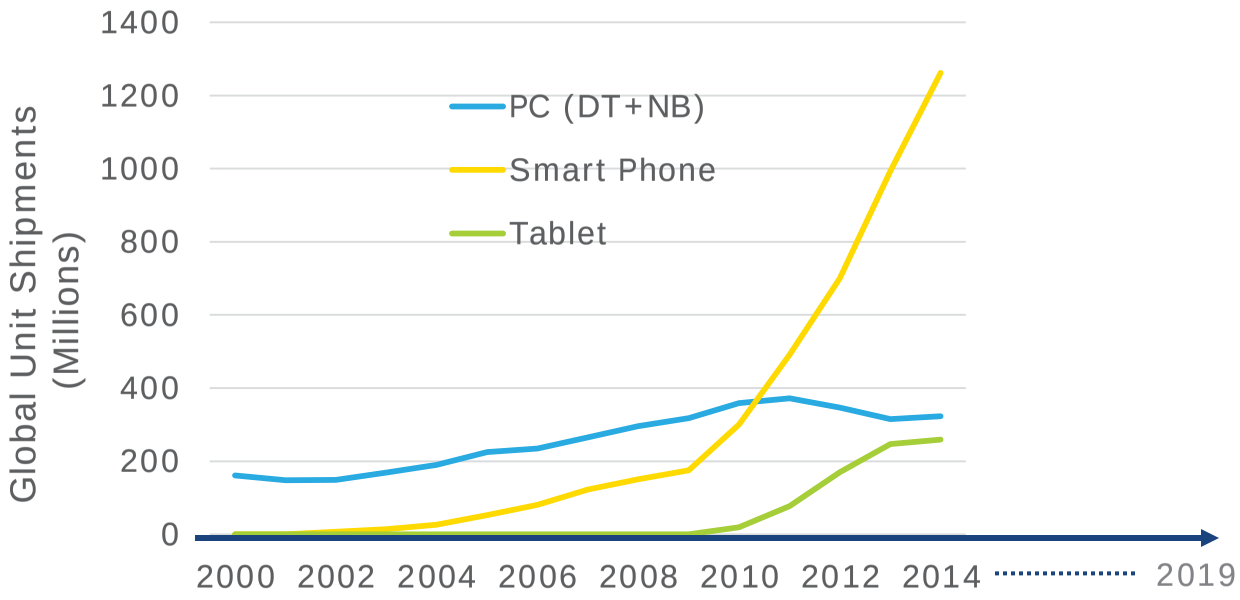
Advances in Process Technology Point to 5G Era Performance

Economic Viability – Silicon Cost per Transistor

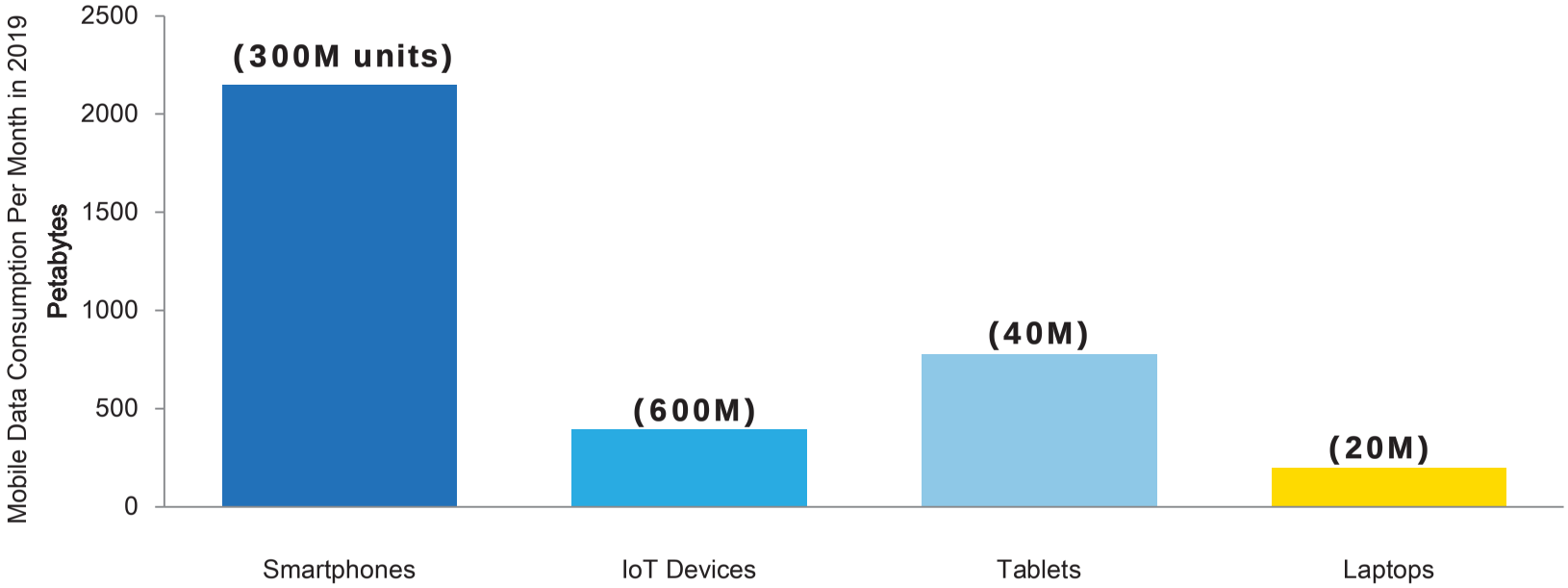


Advances in Process Technology Point to Viable 5G Era Economics

Where We Are Now?



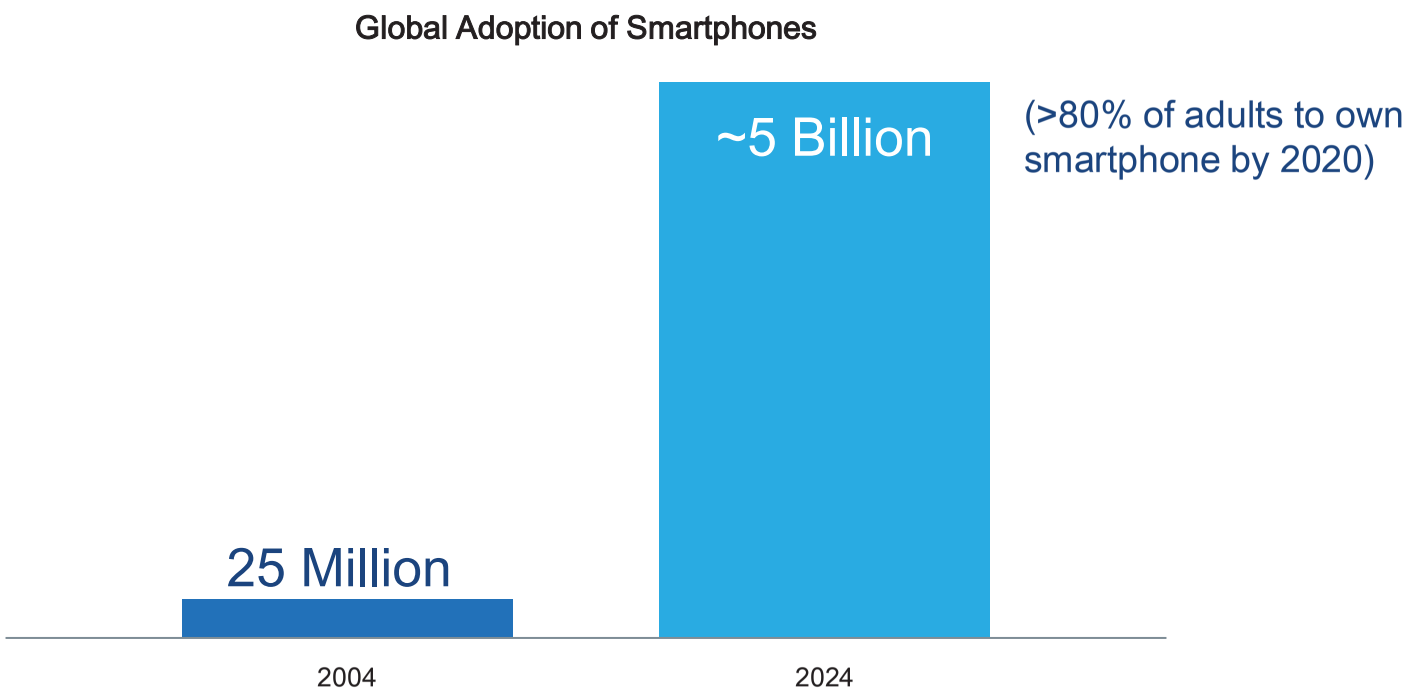
Total U.S. Mobile Data Growth Doubling Every 18 Months!



Doubling Like Moore's Law

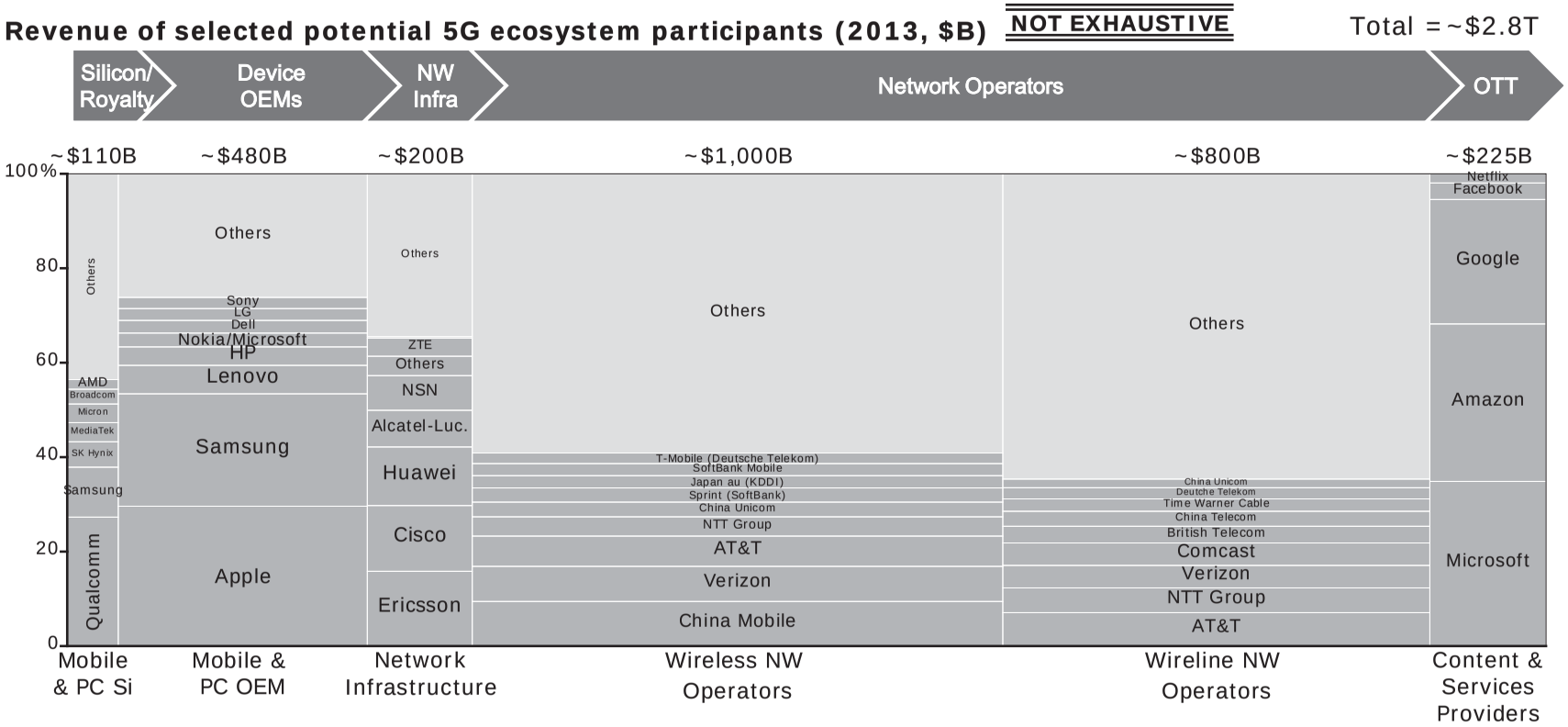
Source: Cisco Visual Networking Index (VNI) Forecast Mobile Data Traffic Update, 2014–2019

5G Will Reach Everywhere, Everyone

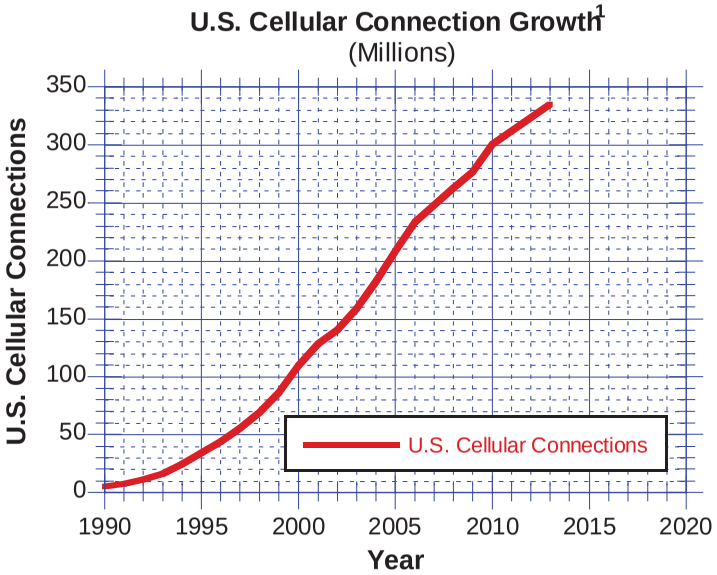


Source: IDC

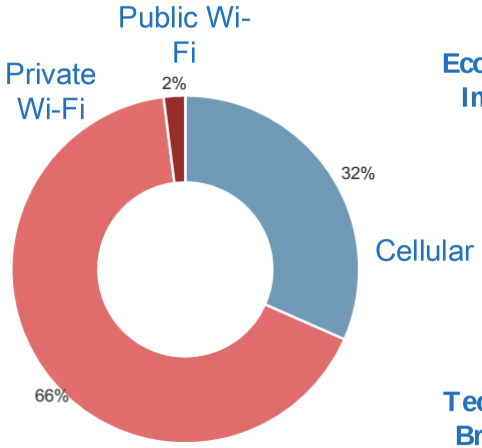
~$3T Wireless Ecosystem



Mobile Communications – Engine for Growth



U.S. Cellular Subscriber Growth



Fraction of Traffic by Network – USA[5]

Global Scale

Global SIM Connections (2014): 7.3Bn
World Population (2014): 7.2Bn

Economic Impact

Mobile Industry Value (2014): $3.0Tn[2]

Country	GDP ($Tn)[3]
USA	16.8
China	9.2
Japan	4.9
Germany	3.6
France	2.7
UK	2.5
Brazil	2.2
Russia	2.1

Technical Breadth

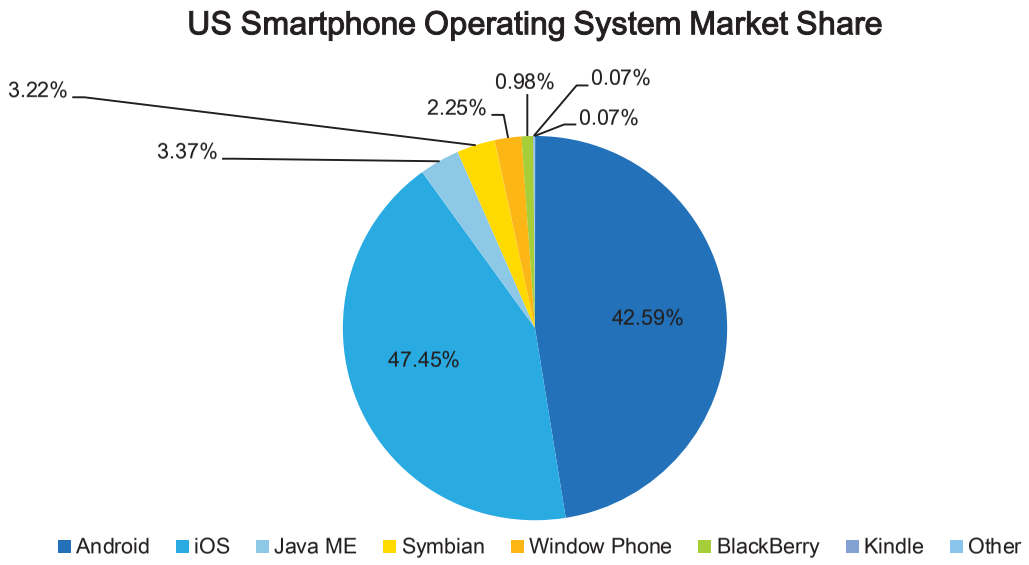
Device Shipments (2014)[4]
Wi-Fi Enabled: 2.3Bn
Global Public Wi-Fi Hotspots (2014): 47.1M
Global Public Wi-Fi Hotspots (2020): 340.0M[6]

5G Era – How to Create the Best Engine For Growth?

1. Source: CTIA, Chetan Sharma Consulting
2. Source: GSM Association
3. Source: International Monetary Fund
4. ABI Research
5. Coleago Consulting for GSMA, 2014
6. Projection – source ABI.

Handful Of Firms With Global Reach

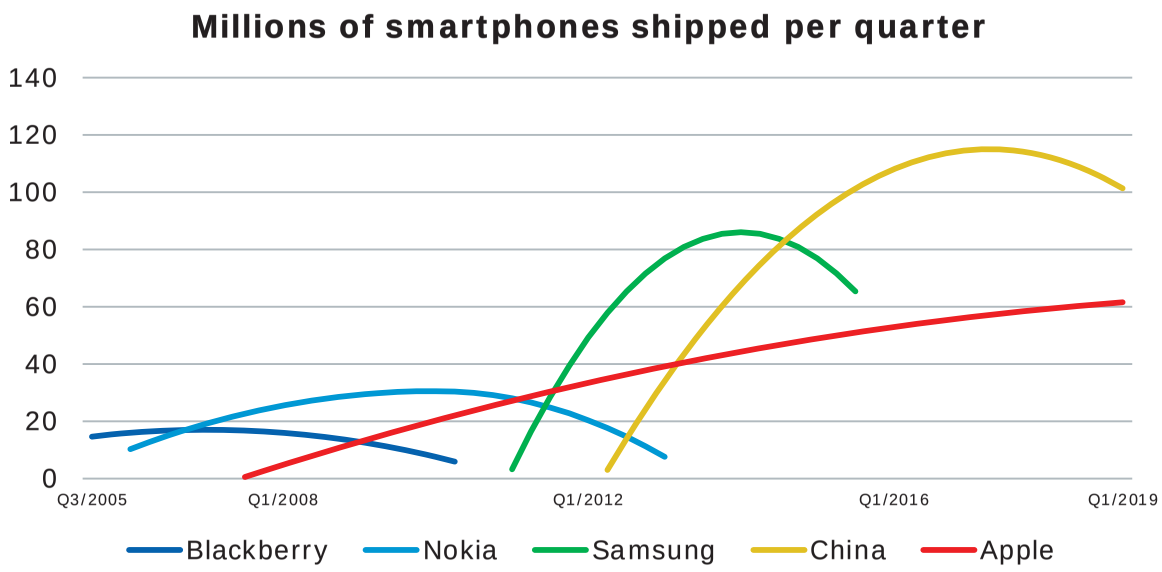
Apple and Samsung Currently Winning US Smartphone Market



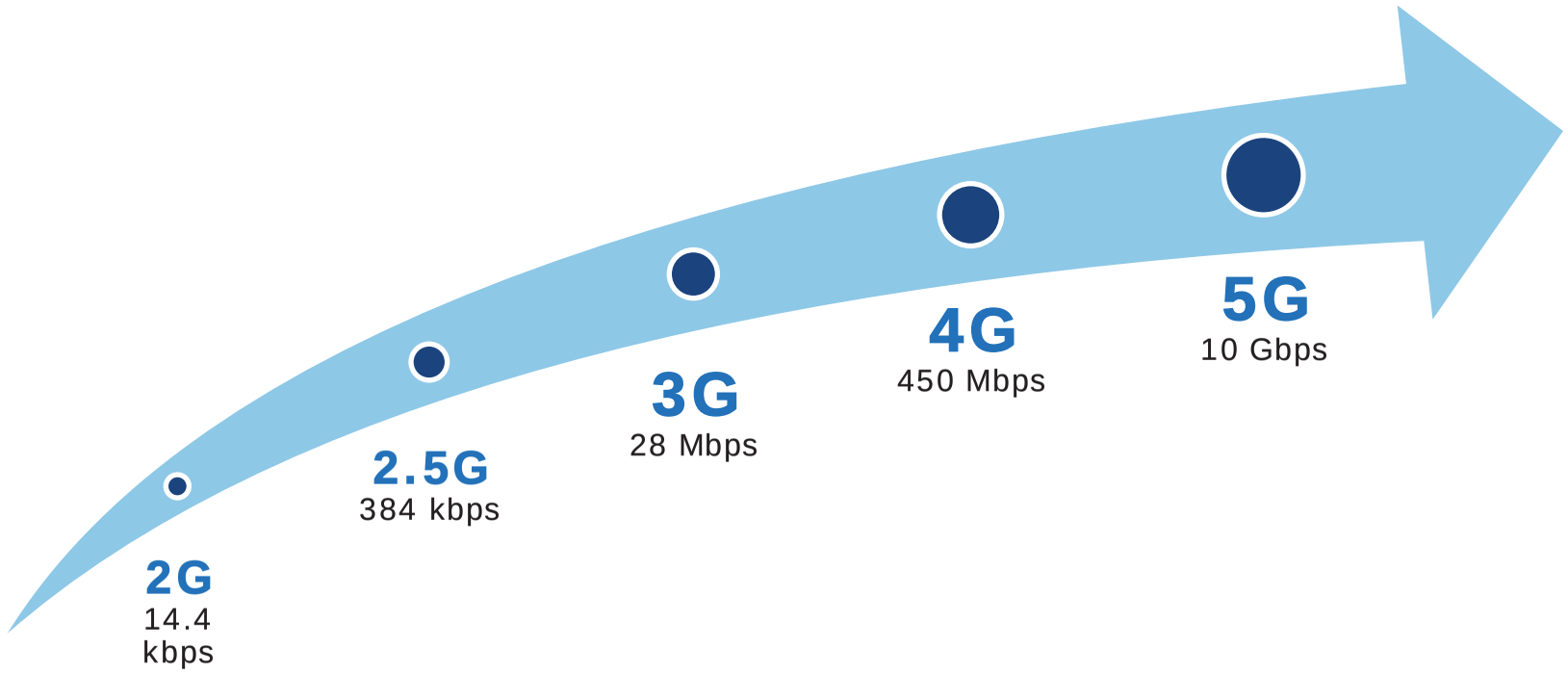
Apple Has Three Quarters of Handset Profits; Samsung, One Quarter; Rest Lose Money

Source: Net MarketShare, as of Jan. 2015

But Wireless Epochs Rise and Fall at Great Speed



Each Generation Brings Faster Communications

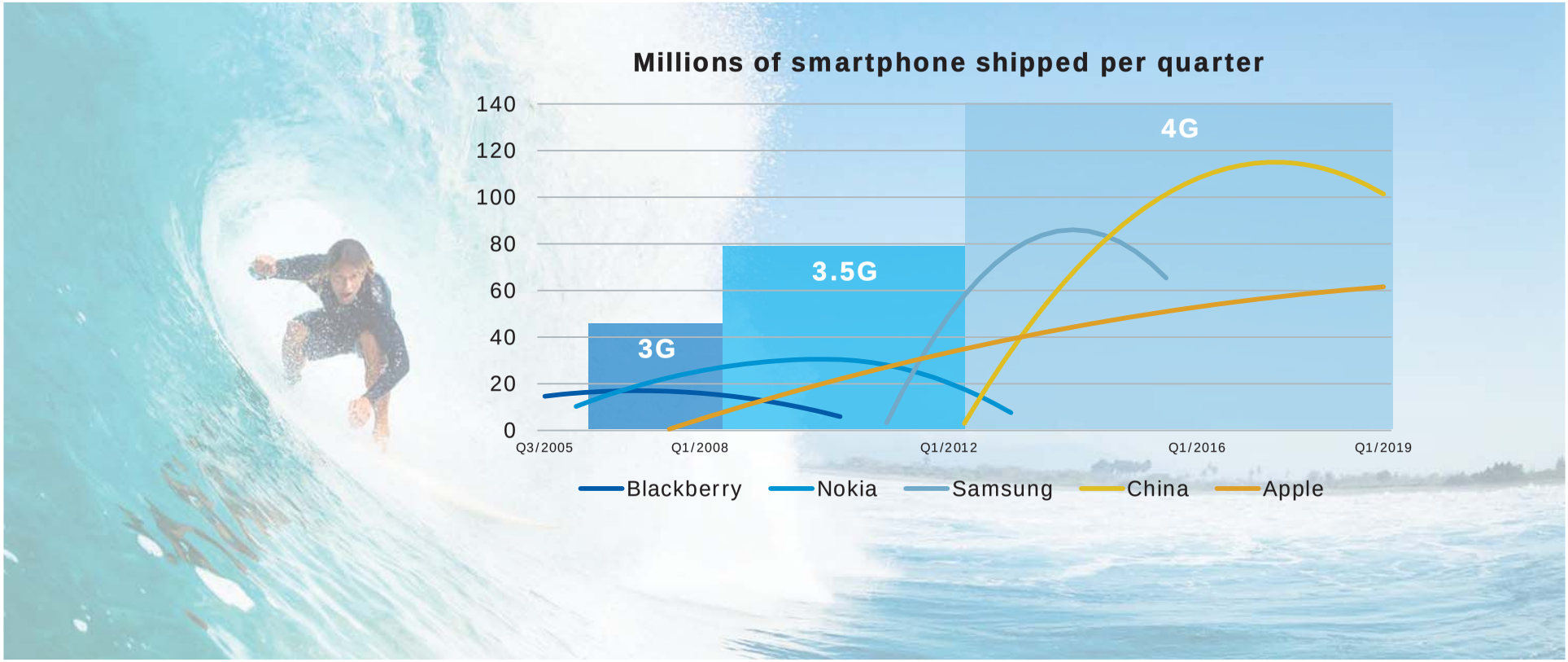


3G reference point: HSPA Rel-7
4G reference point: LTE Rel-10

Every Generational Shift In Wireless:

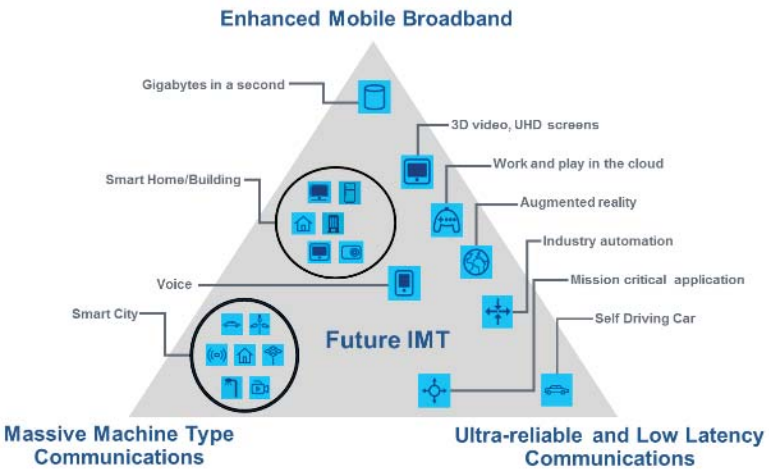
- Produces much more value creation
- Restructures market structure
- Radically changes industry conduct
- Produces more change than the previous generational shift
- Wraps the world more tightly in a common medium of communication and information

Winners Catch the Generational Wave



Role of Spectrum in Arriving at 5G

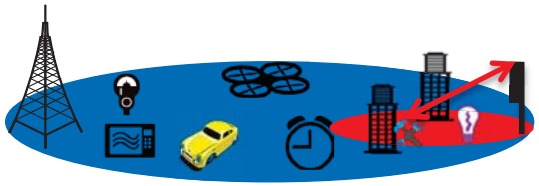
- Continuous flow of sufficient, adequate, new spectrum is key to:
  - expansion of wireless market to 5G and beyond, and
  - building a strong and healthy eco-system
- Economies of scale achieved through availability of globally harmonized bands is essential to growth of the wireless market
- Consequently, a variety of spectrum bands/ranges are needed
- < 1 GHz – for wide area applications, e.g. sensor networks, etc.
- < 6 GHz – for coverage/capacity trade-off, e.g. massive MIMO, outdoor-to-indoor
- Higher – for apps needing ultra-wide channels, e.g. 4k/8k video, VR, etc.



Source: Recommendation ITU-R M.2083, "IMT Vision - Framework and overall objectives of the future development of IMT for 2020 and beyond"

IOT Requires 5G; 5G Requires New Radio Access Network on Greenfield Spectrum

5G Requires New Radio Access Network

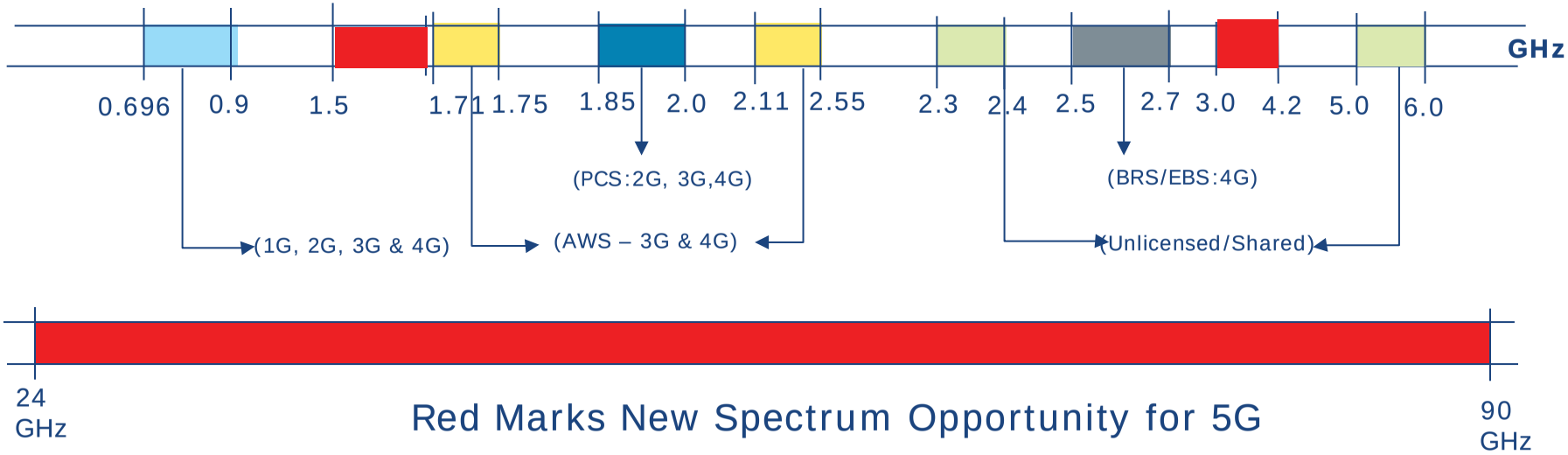


Localized hot spots suitable for higher frequency, unlicensed, sharing

- IOT requires high device density and very low latency: 5G
- Green field midband spectrum ideal for 5G IOT
- IOT and Wireless Broadband will call for densified hot spots in high frequency, coupling with unlicensed bands

5G: 40 Times More Spectrum

Spectrum Used for 2G, 3G and 4G Mobile Communications



Red Marks New Spectrum Opportunity for 5G

So where will 5G Green Field Build Occur?

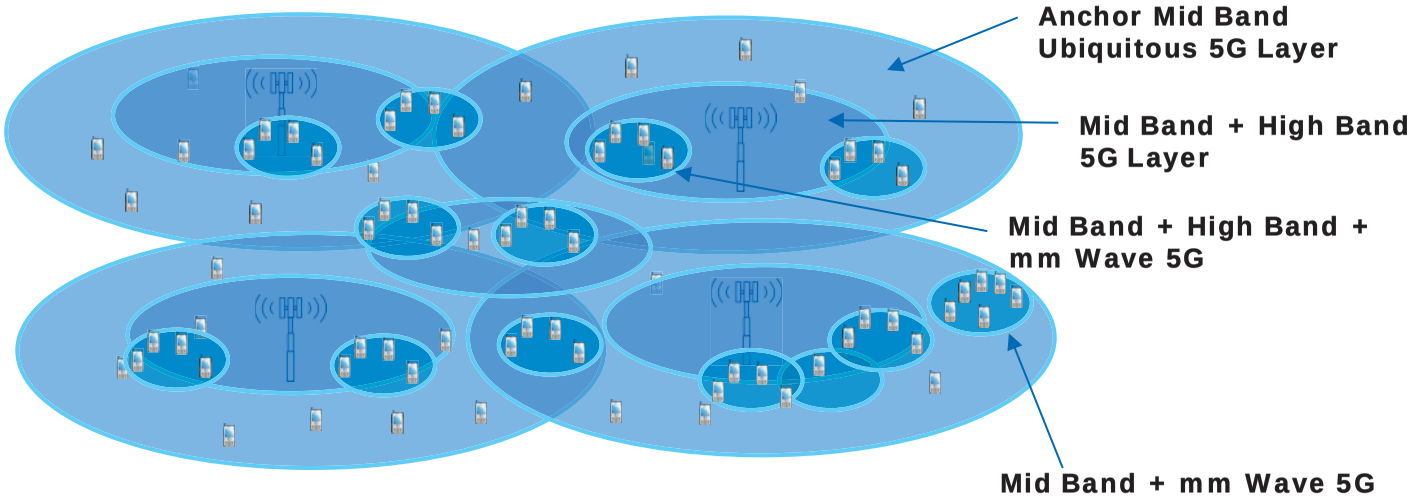
- Too little spectrum available below 2GHz. Large bandwidths available at high frequency spectrum such as millimeter wave. High frequency is appropriate for densification but not for wide area deployment.
- 5G green field build needs to be anchored in mid band

DRIVERS	< 2GHz	2 GHz - 6 GHz	> 6 GHz	COMMENTS
COVERAGE RANGE	HIGH	MED	LOW	Below 2 GHz, or mid band, have low propagation loss. 2 GHz and above show increasing penetration loss, attenuation, and depend on smaller cell radius/higher cost per geographic coverage
MOBILITY	HIGH	MED	LOW	Mobility at higher frequencies limited
AVAILABLE SPECTRUM	LOW	MED	HIGH	Really high frequencies suitable for densification networks, producing very high bandwidth for portable use cases

5G Requires Green Field Spectrum at Various Frequencies

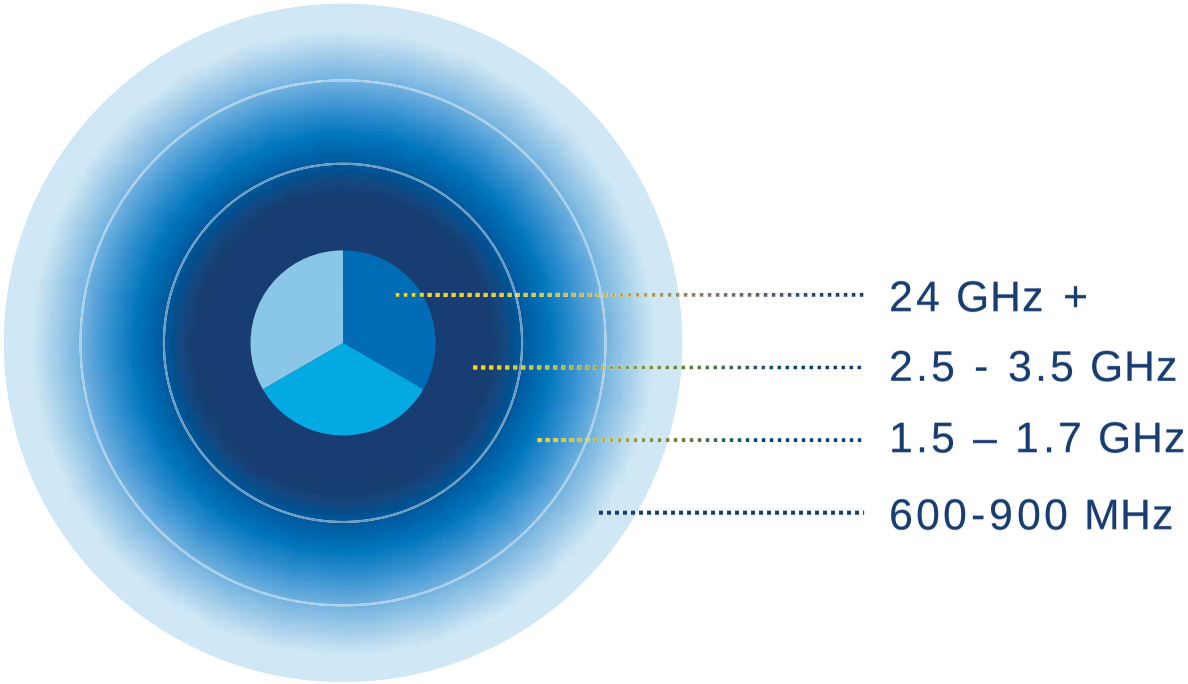
Mid Band (Below 2 GHz), High Band (3.5- 6 GHz), and Very High MM Wave (24 GHz and Above)

- 5G on mid band spectrum (Below 2 GHz) anchors use cases to provide seamless experience



Top Down Look at Spectrum

- Licensed
- Shared
- Unlicensed



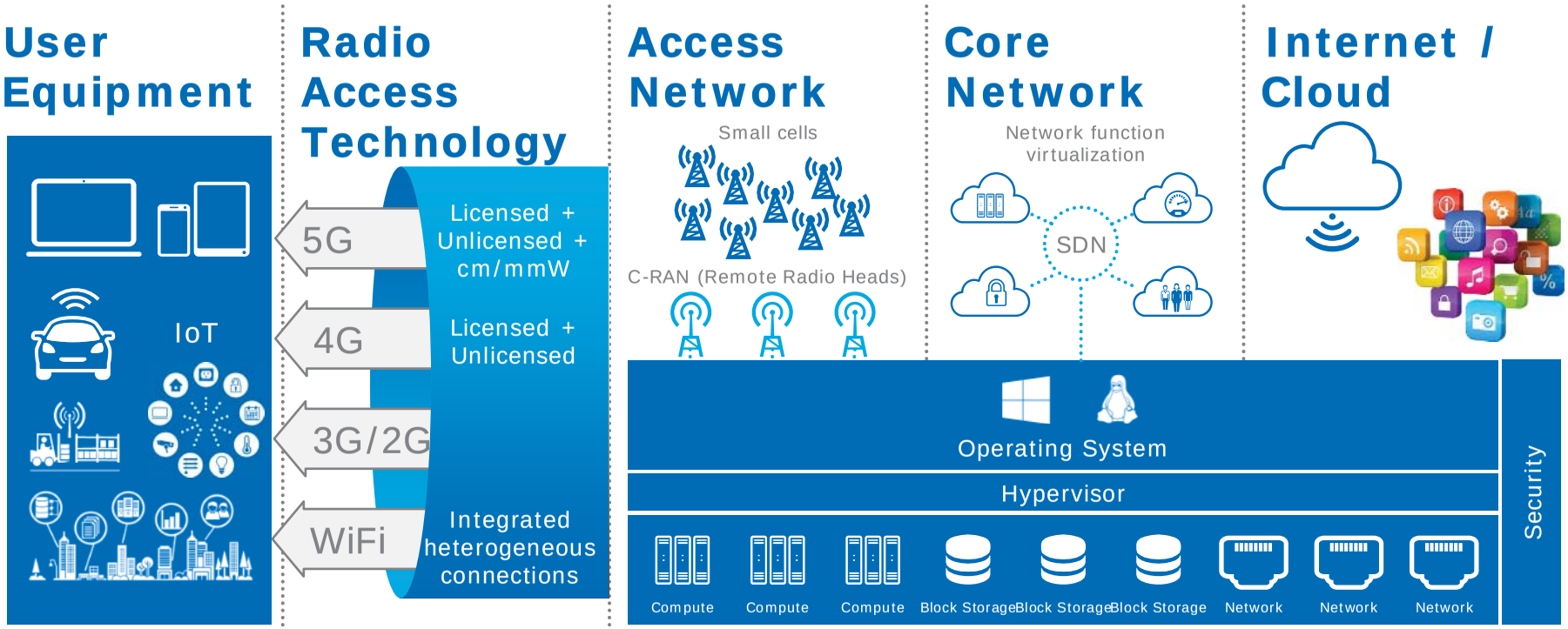
5G vision: Computing + Communications

- <u>What 5G solves</u>

- Breaks physical limitation of IoT & Wearable platforms
- Higher capacity & lower latency to enable new applications and services
- Scalability through virtualization
- Energy Efficiency through workload distribution and more efficient silicon technology

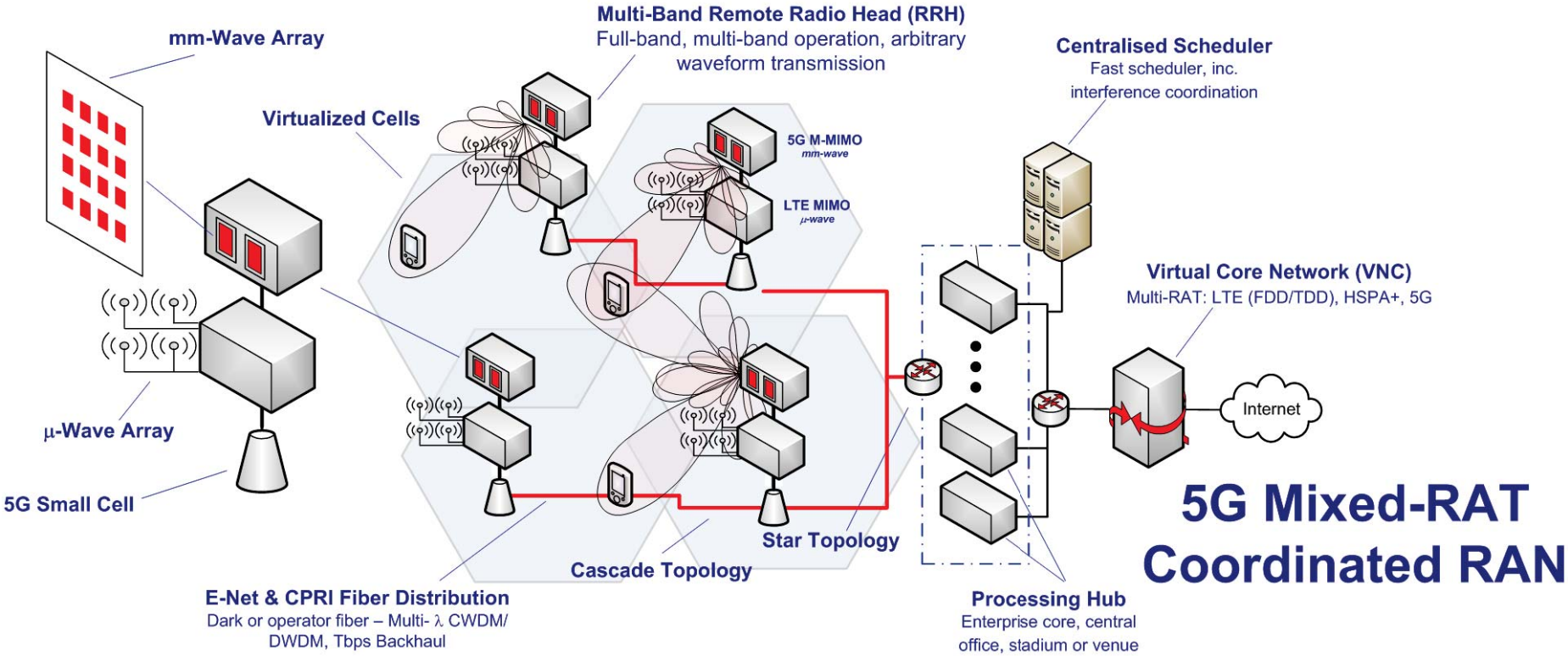
5G marks the point of computing and communication

5G: Network Transformation



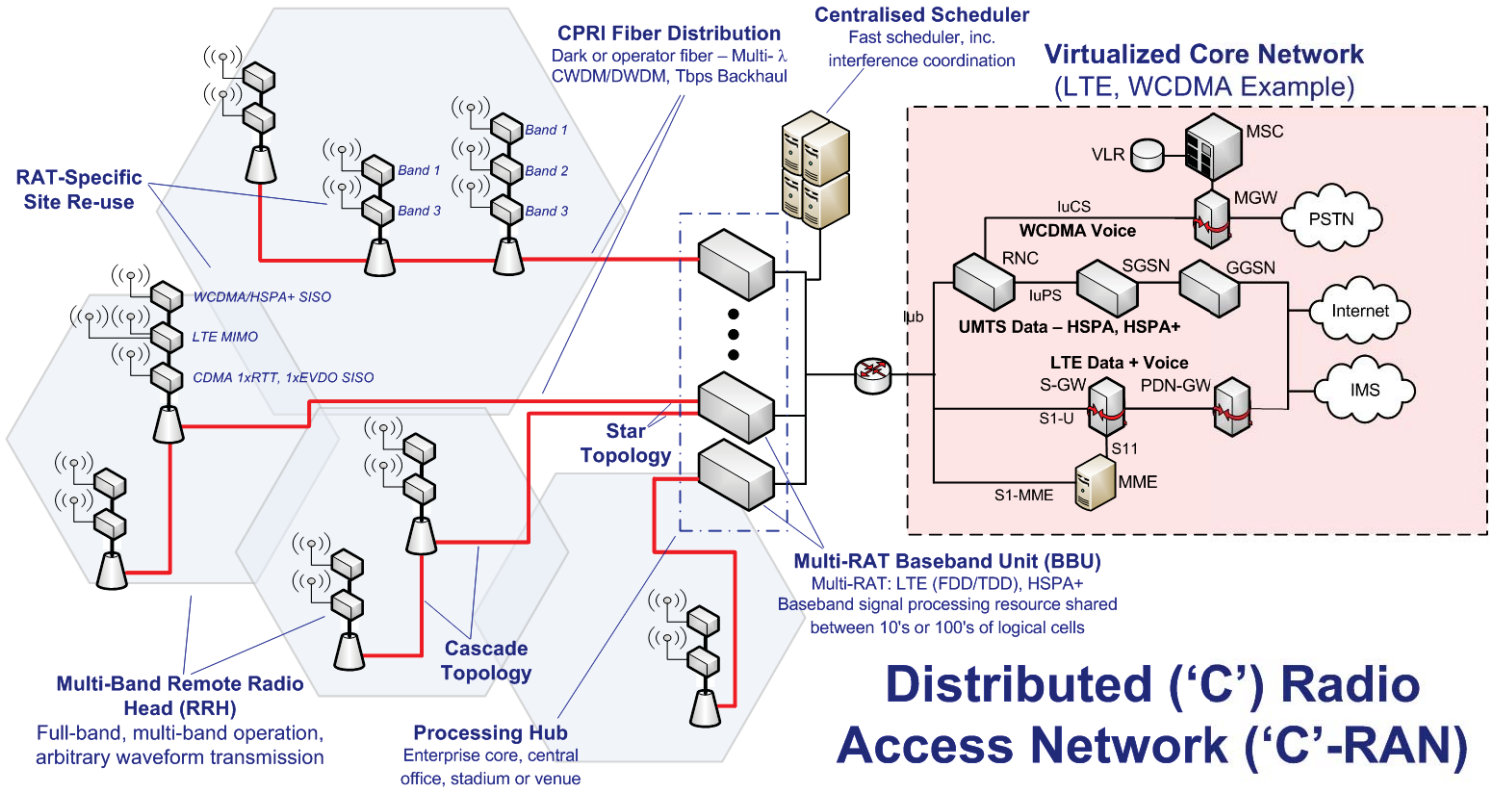
5G Radio Access – Example Topology

Mixed LTE and mm-wave Small Cells

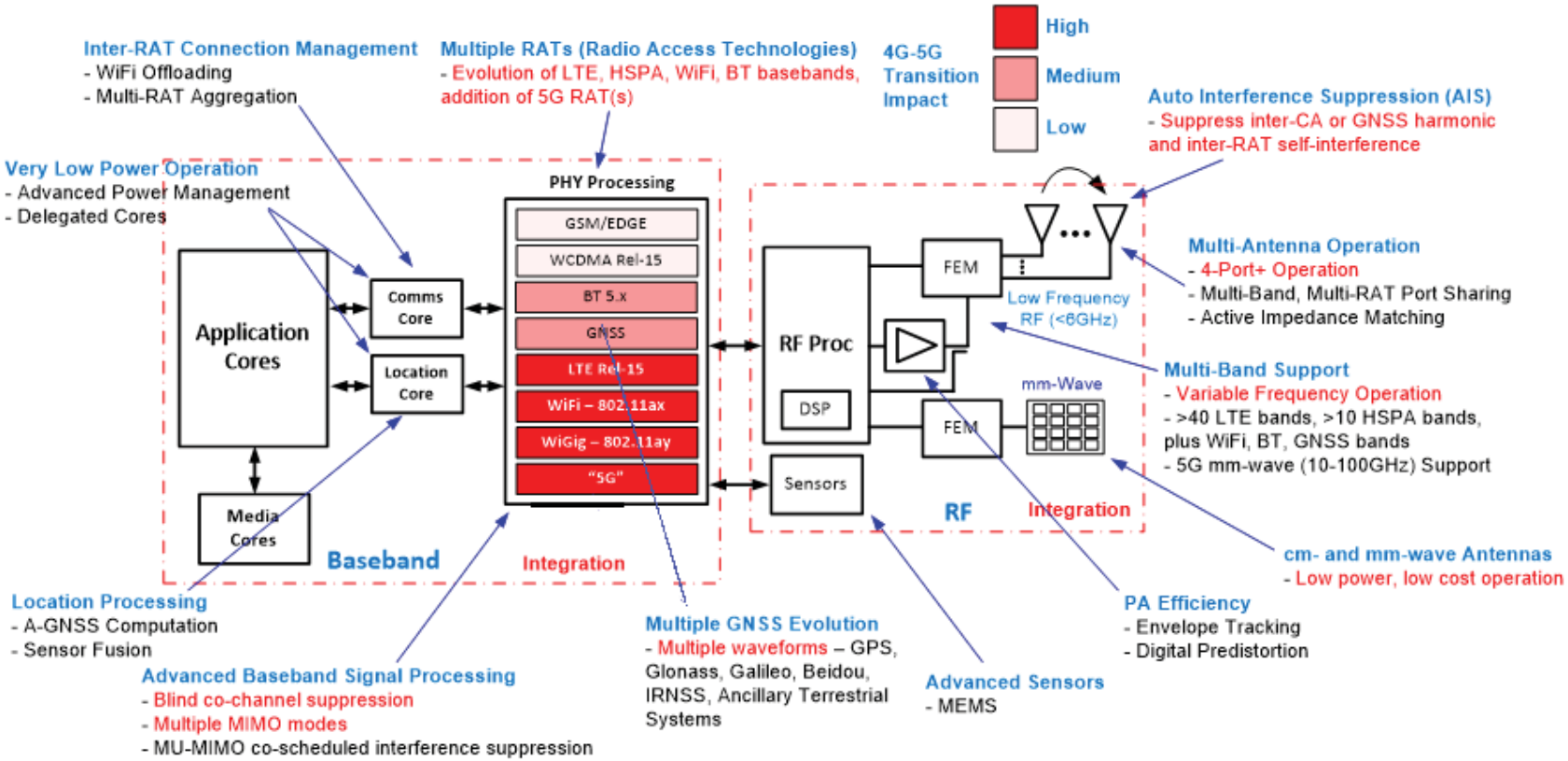


Network Evolution

Virtualization and Coordinated or Distributed RAN

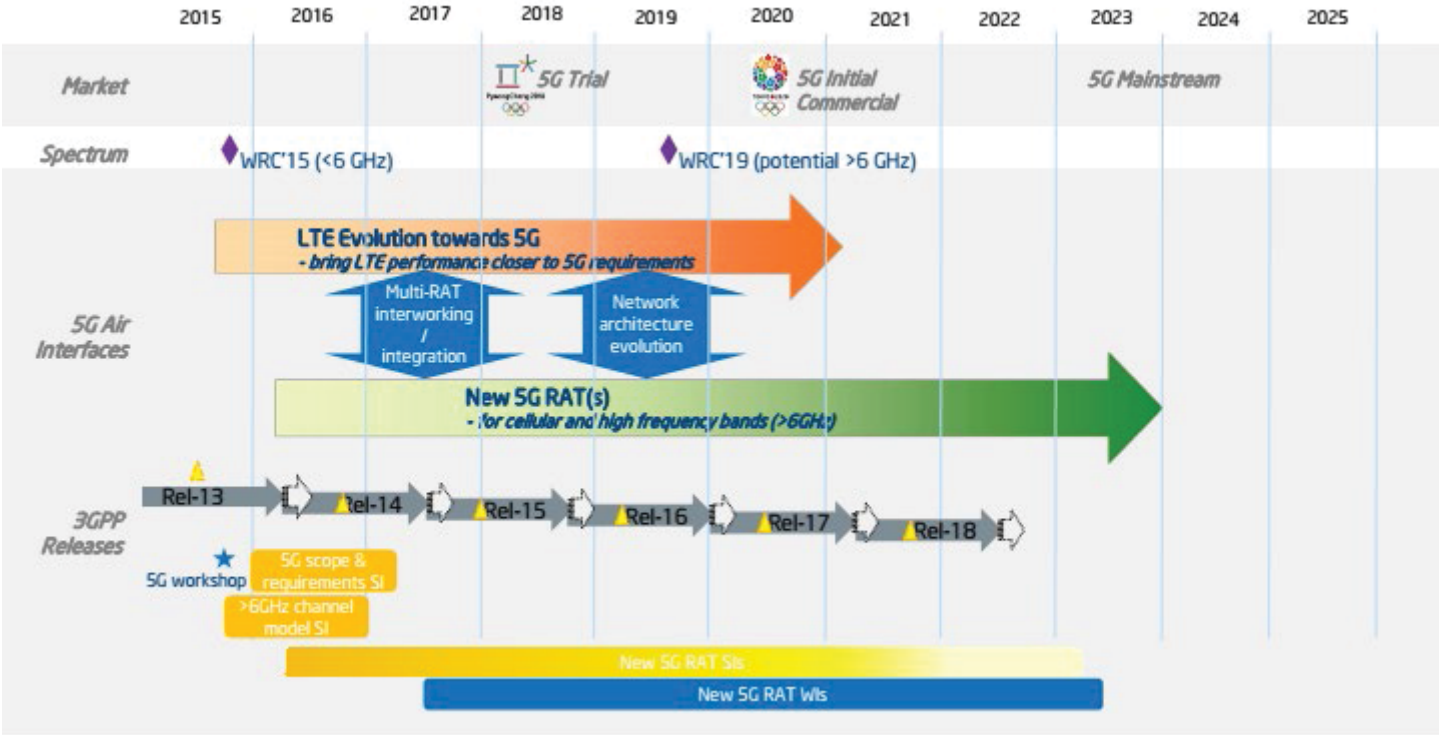


5G Innovation – Device



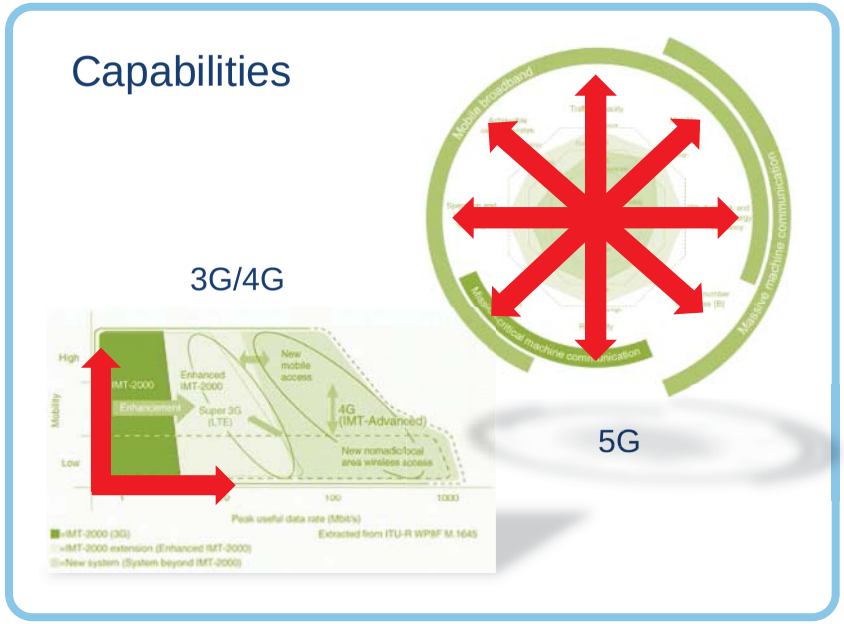
Note: Critical technologies indicated in red.

5G Radio Access Development



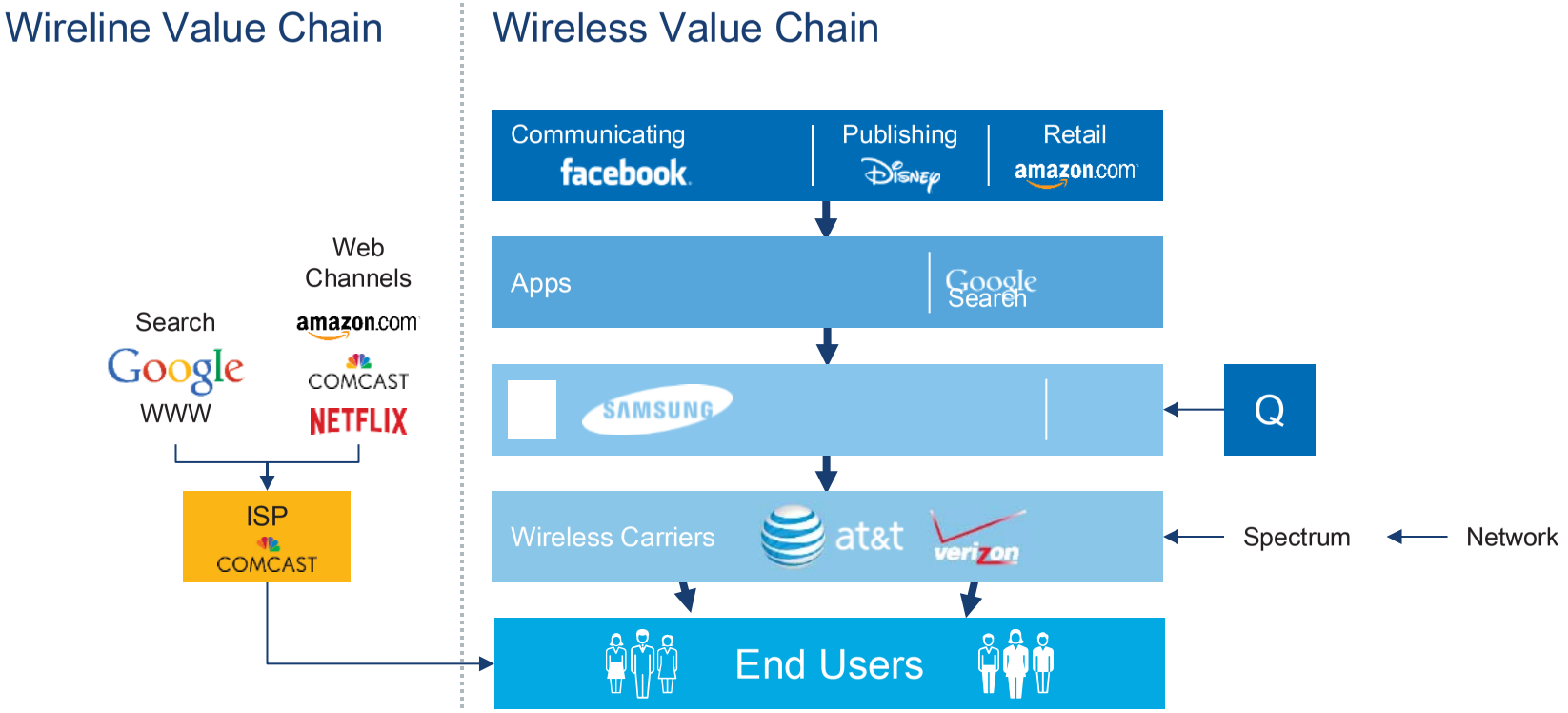
- 5G trial in 2018 based on Rel-14 SI and initial Rel-15 WI
- 5G initial commercial deployment in 2020 based on Rel-15 spec
- IMT 2020 submission based on Rel-16 spec

5G: What Can Be Done Will Be Done



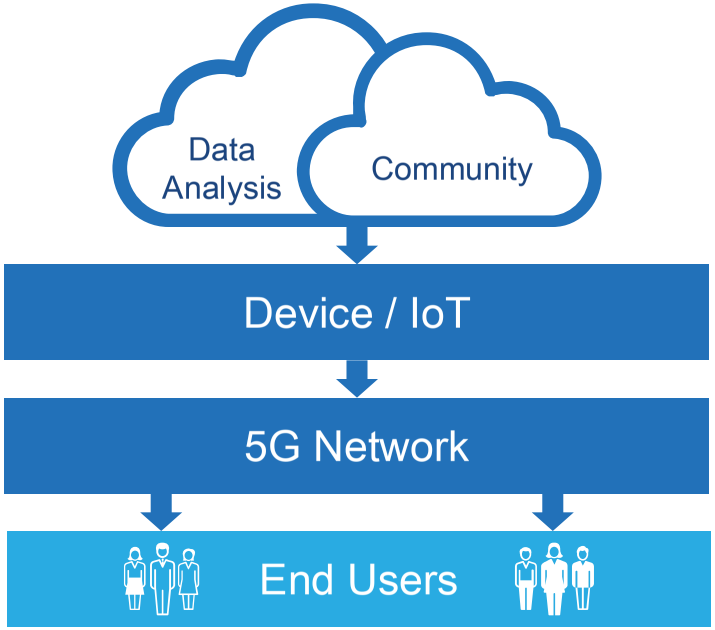
5G dynamically integrates compute and communication for future generations of applications and services

Existing Value Chain

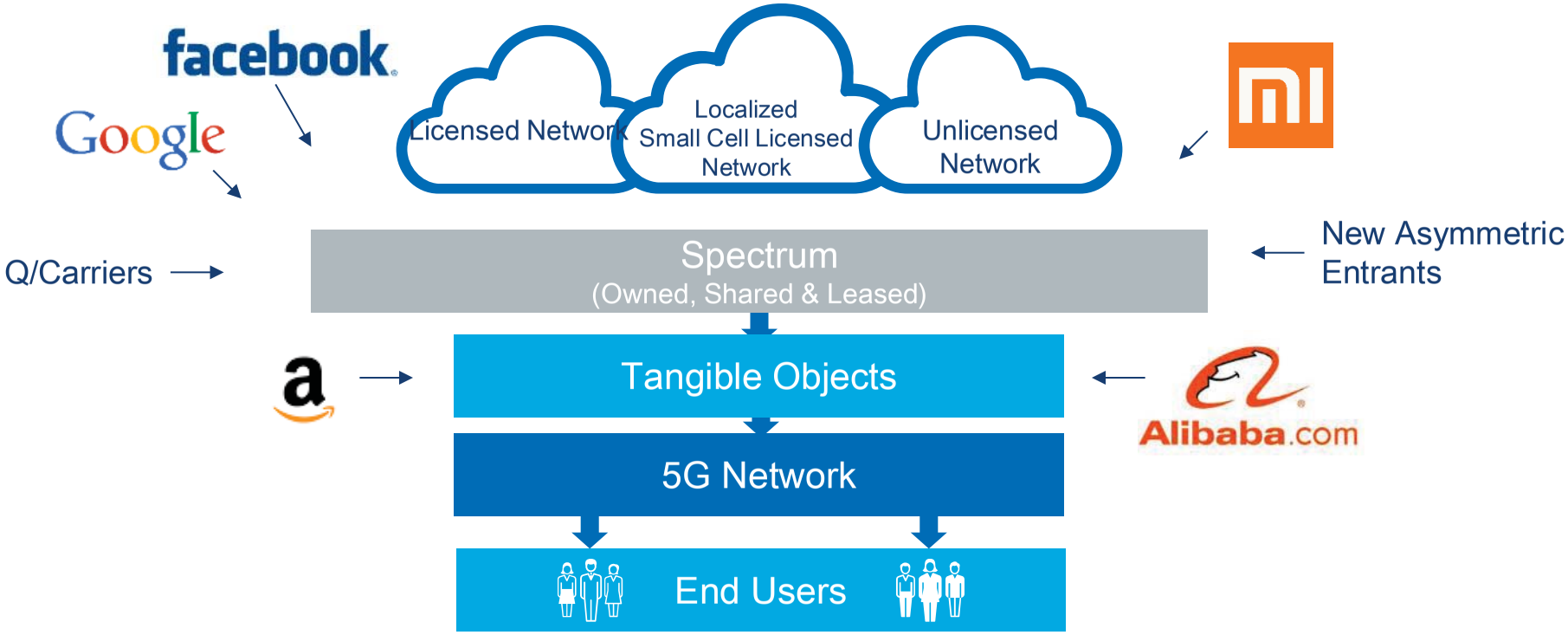


*other names and brands may be claimed as the property of others

Possible New Value Chain – Part I



Possible New Value Chain – Part II



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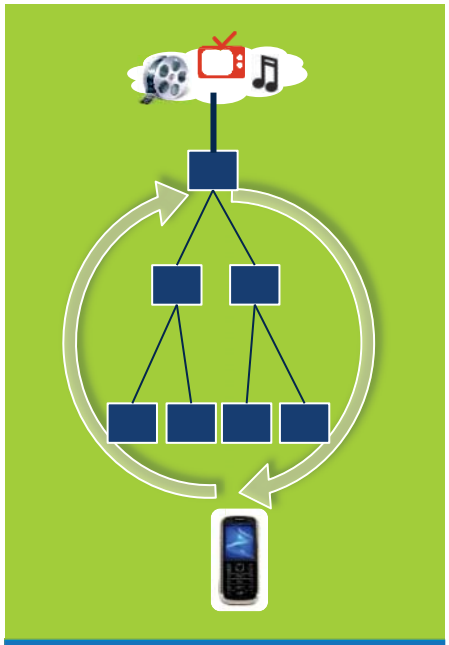
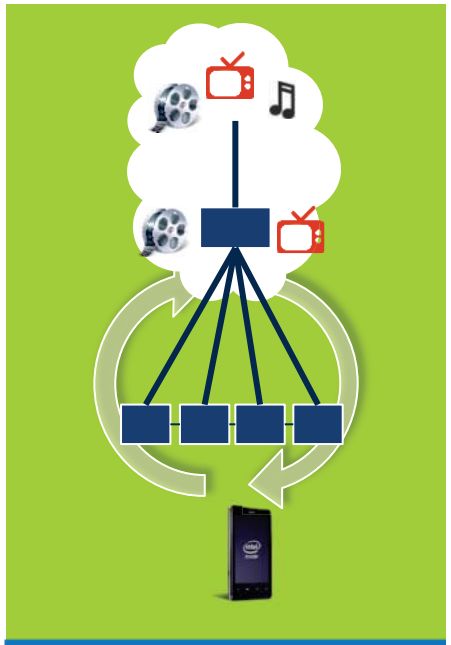
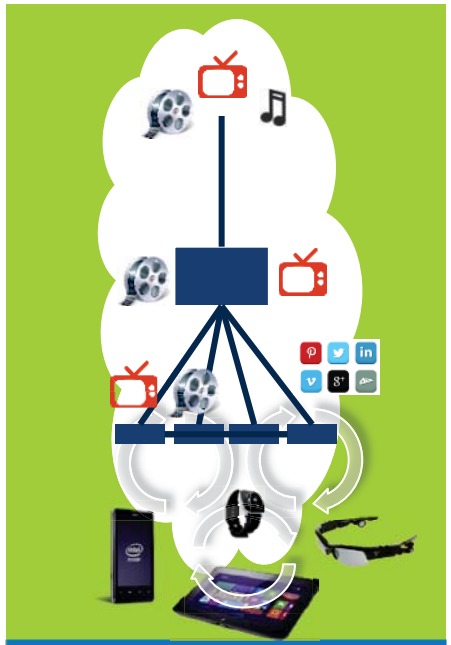
Possible New Value Chain 3.0: Storage, Networking, Computing, Community Move to Edge



Remote Cloud / Basic Terminal



CDN / Cooperative Radio



Edge Cloud / Underlay Net Clusters

Logos shown represent categories of common Internet content and are used for conceptual illustration only.

Focus on User

MMI[1] Communications

- Virtual Remote Communications
- Telepresence

Transportation Systems

- Navigation and Infotainment
- Autonomous Vehicles

Connected Health

- Remote Healthcare
- Continuous Diagnostics

Tactile Real-Time Control

- Remote Tactile Experience
- Critical Real-Time Machine Type Communications (MTC)

Augmented Reality

- Perception at a Distance
- Embedded Multi-view

Ultra High Definition

- Video and Audio
- Multi-Angle Viewing

The Coolest Uses for 5G…Not Yet Invented.

1. MMI – Man-Machine Interface

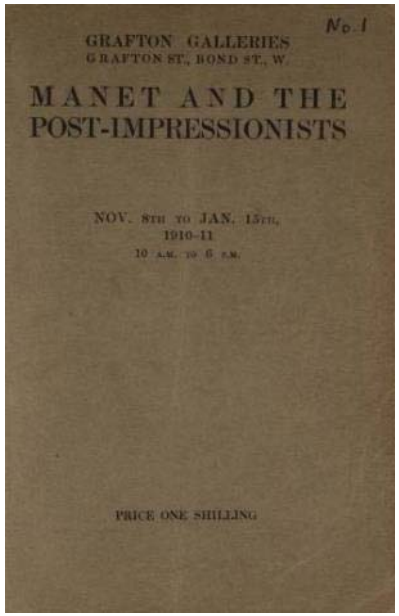
AI & Entertainment

(intelligence separates from consciousness)

- Tell us “What to do,” “When to do it,” “How to do it.”
- New medium uses old medium as its content… only at first
- And Maybe Machines Pay Less Attention to Us

“On or About December 1910, Human Character Changed.“

– Virginia Woolf



Roger Fry

Van Gogh

On or about December 2020, Human Character m*ay* Change

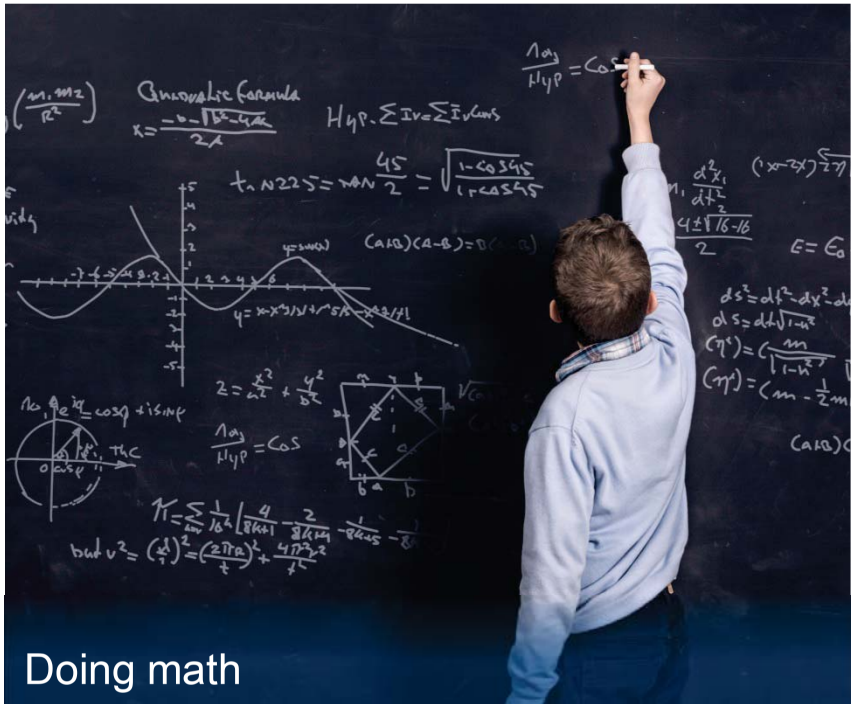
1910

- Movies
- Radio to a ship
- Motor car
- Long distance phone
- Elevator/tall steel buildings
- Mass movement/individualism

2020

- Lifestream
- Radio/thing integration
- Carriage
- End of distance
- Brain/computer interface
- From healing to improving
- Communities/personal worth?

Intelligence Separates from Consciousness


Doing math

Lying on the beach

Intelligence Separates from Consciousness

Thank You