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September 30, 2015

Mr. Julius Knapp
Chief
Office of Engineering & Technology
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: GN Docket No. 14-177

Dear Mr. Knapp:

Please find attached a presentation that Reed Hundt has prepared entitled, "The Future of Wireless Broadband: 5G." Mr. Hundt will discuss the presentation later this week with Congressional staff and also has presented it to a class at the Harvard Business School, among others. We thought that you would find it of interest as the Commission explores new technologies that could unlock mid-band and higher band frequency spectrum for 5G and the next generation of mobile wireless services that it offers.

Thank you for your consideration.

Respectfully submitted,

Gerard J. Waldron

Gerard J. Waldron

Attachment

cc: Mr. Reed Hundt

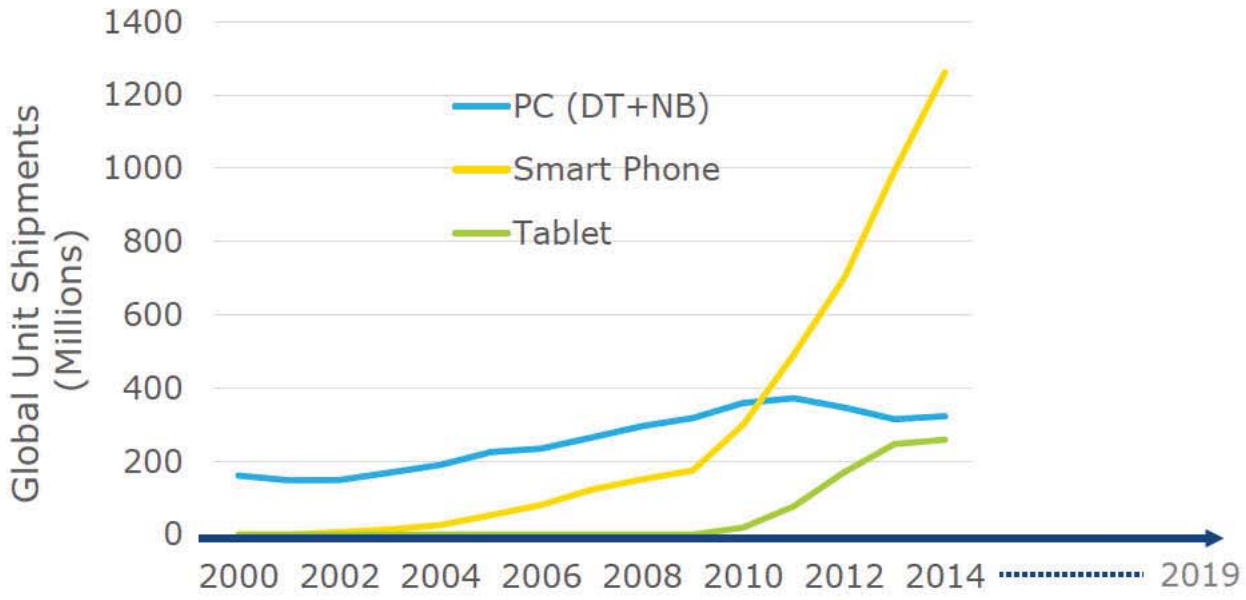
The Future of Wireless Broadband: 5G

A Presentation for the Senate Commerce Committee

Reed Hundt

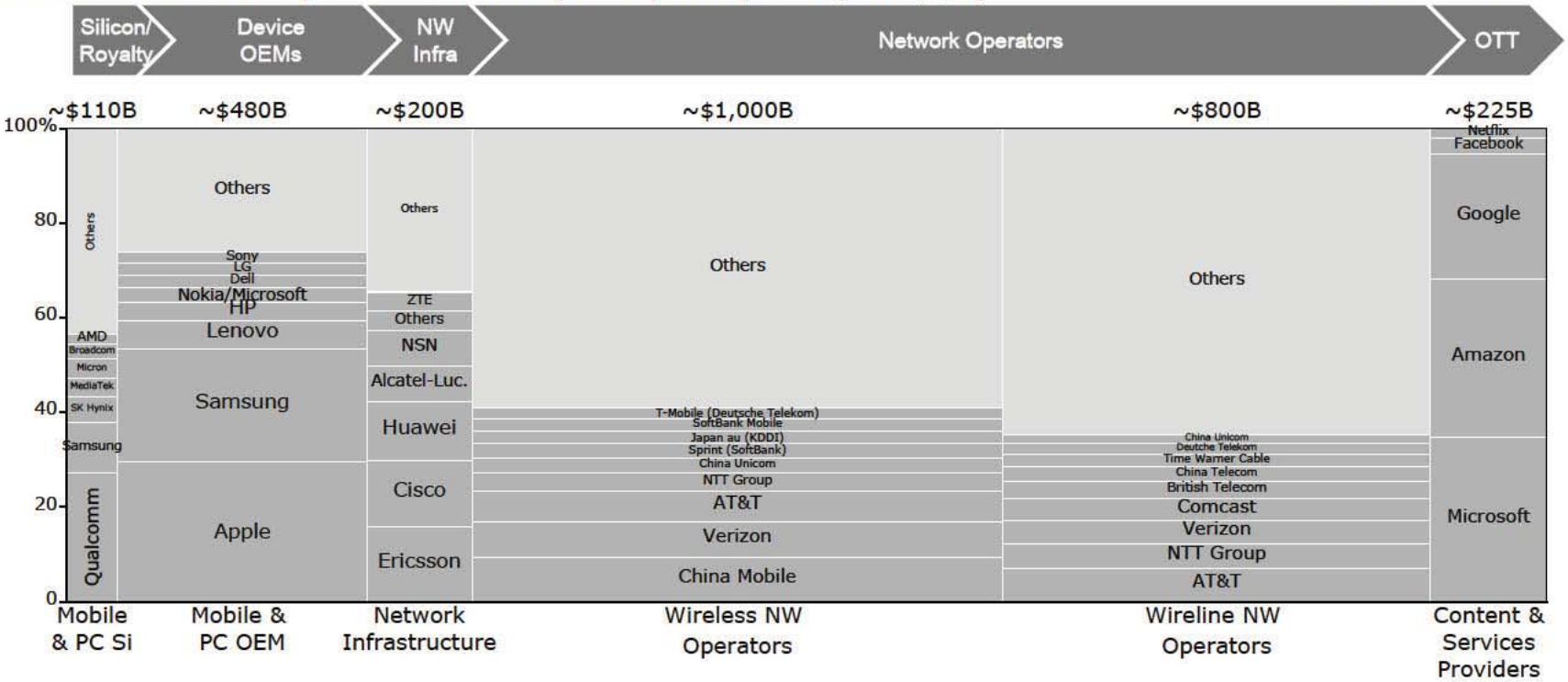
October 2, 2015

Where We Are Now?



~$3T Wireless Ecosystem

Revenue of selected potential 5G ecosystem participants (2013, $B) **NOT EXHAUSTIVE** Total =~$2.8T



In The Beginning…

March 1983: Motorola DynaTAC 8000x*

Motorola DynaTAC 8000X

DynaTAC 'Dynamic Adaptive Total Area Coverage'

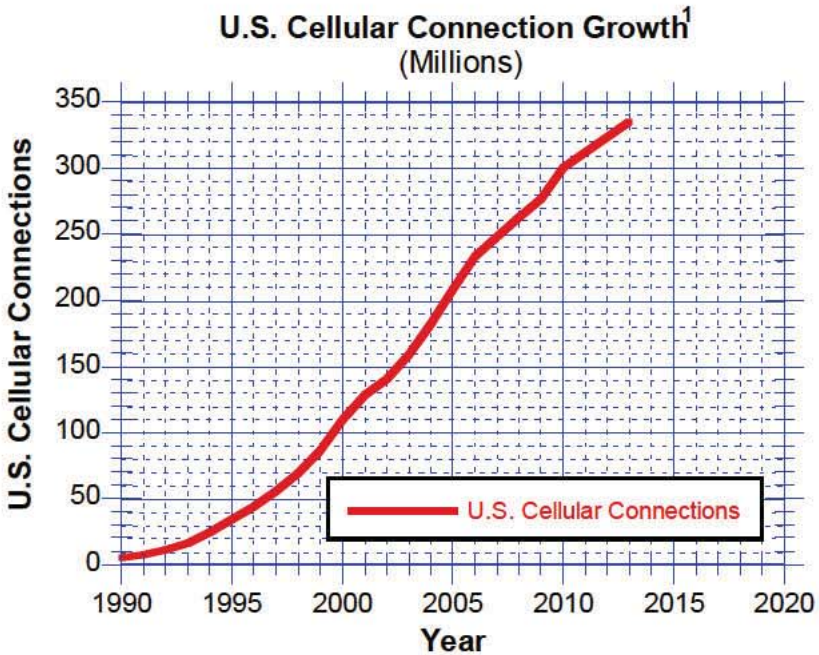
Introduced: March 1983
Talk Time: 30 minutes
Stand By Time: 8 hours
Recharge Time: 10 hours
Dimensions: 33 x 4.5 x 8.9cm
Volume: ~1300cc
Display: LED
Memory: 30 Number, <1MB (256B Pages)
Air Interface: AMPS (30kHz FM)
Price: $3,995 (~$9,400 2014 $'s)

Motorola DynaTAC 8000X*

VW Beetle* 1966

1300cc Engine

Mobile Communications Economic Impact
1990-2013



Example – U.S. Subscriber Growth

Global Scale

Global Mobile Subscriptions (2014): 7.5Bn
World Population (2014): 7.2Bn

Economic Impact

Mobile Industry Value (2013): $2.3Tn[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

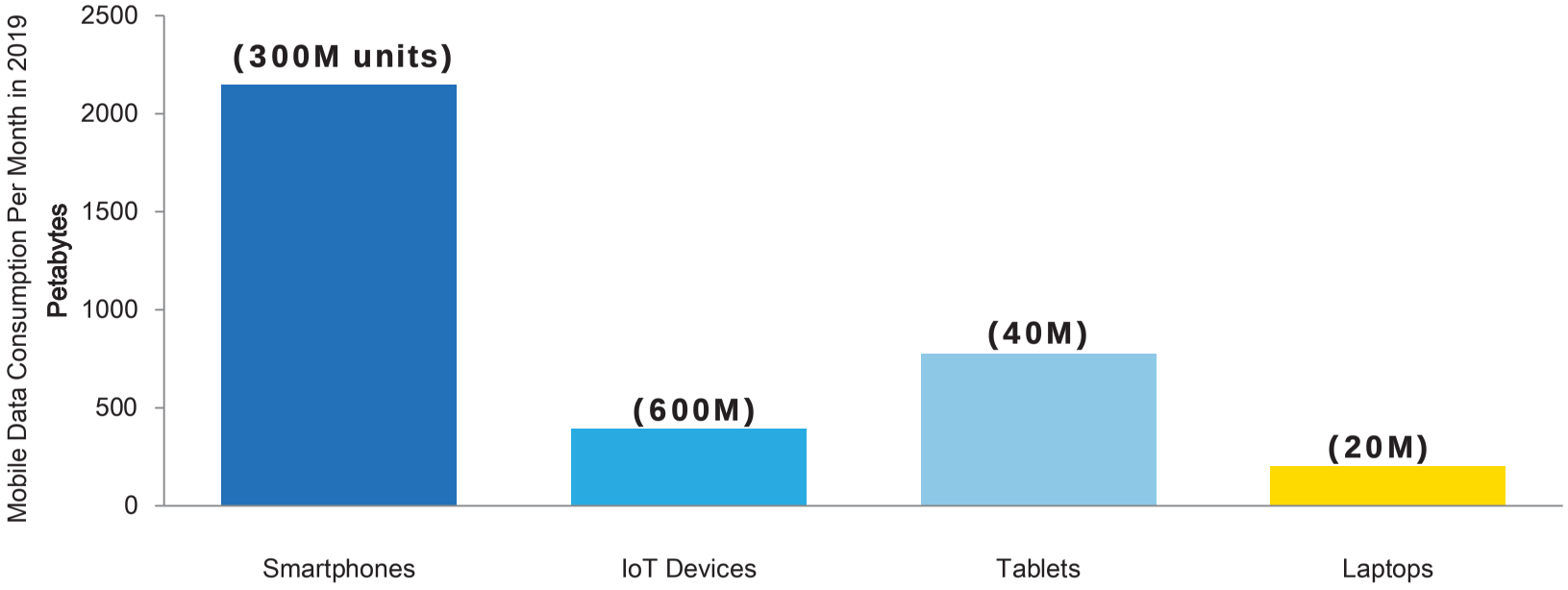
Device Shipments (2013)[4]
WiFi Enabled: 1.2Bn
Bluetooth Enabled: 1.5Bn
Global WiFi Hotspots (2013): 4.2M

Economic Indicators

1. Source: CTIA, Chetan Sharma Consulting
2. Source: GSM Association
3. Source: International Monetary Fund
4. ABI Research

Handful Of Firms With Global Reach

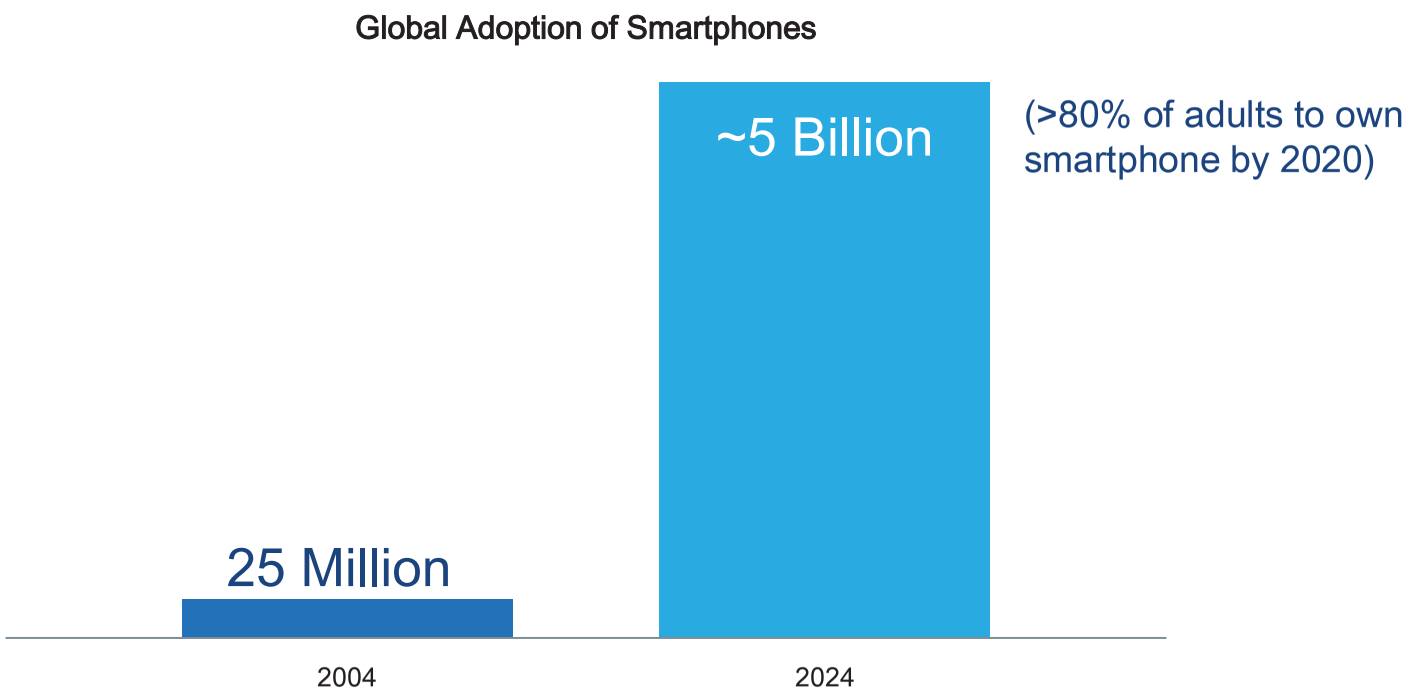
Total U.S. Mobile Data Growth Doubling Every 18 Months!



Doubling Like Moore's Law

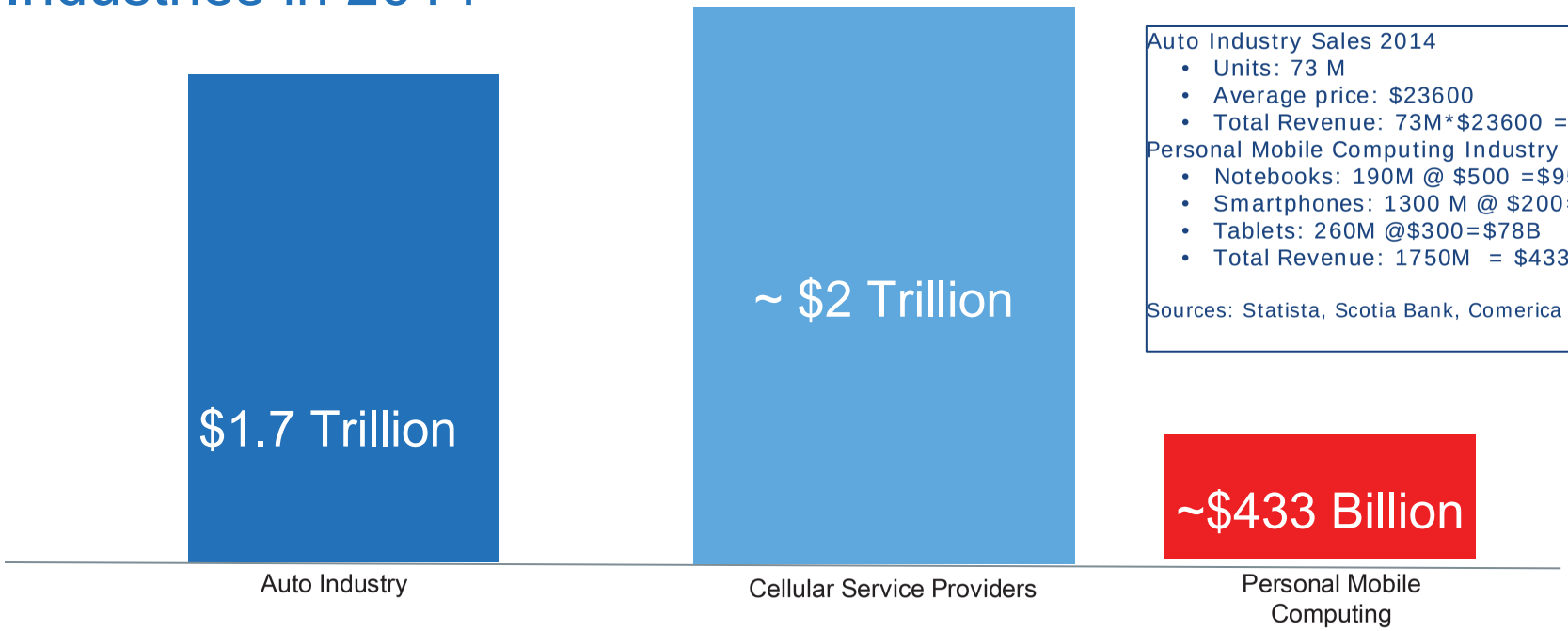
Source: Cisco Visual Networking Index (VNI) Forecast Mobile Data Traffic Update, 2014–2019

5G Will Reach Everywhere, Everyone



Source: IDC

Compare Revenue for Auto and Personal Mobile Computing Industries in 2014



Auto Industry Sales 2014
- Units: 73 M
- Average price: $23600
- Total Revenue: 73M*$23600 = $1.7T

Personal Mobile Computing Industry Sales 2014
- Notebooks: 190M @ $500 =$95B
- Smartphones: 1300 M @ $200=$260B
- Tablets: 260M @$300=$78B
- Total Revenue: 1750M = $433B

Sources: Statista, Scotia Bank, Comerica Bank, IDC

Compare Physical Transport with Virtual Transport

Auto

1. Easier to design and build a Ferrari than a Ford
2. Production (capacity utilization) rules
3. No drivetrain innovation since 1886
4. China is the new United States
5. Cross-ownership preserves rule 2
6. The purpose is transportation; roads matter more than cars
7. Easier to go fast than far

Phone

1. Easier to innovate from top than bottom
2. Production rules; scale matters; utilization is life/death
3. Does processing innovation matter much?
4. China is the new United States
5. Cross relationships impact rule 2
6. The purpose is getting information; comms matters more than compute
7. Easier fast than last long

“But in Autos no Successful Attack on Incumbents for 50 Years… No Drive Train Innovation For 100 Years…until Now?”

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

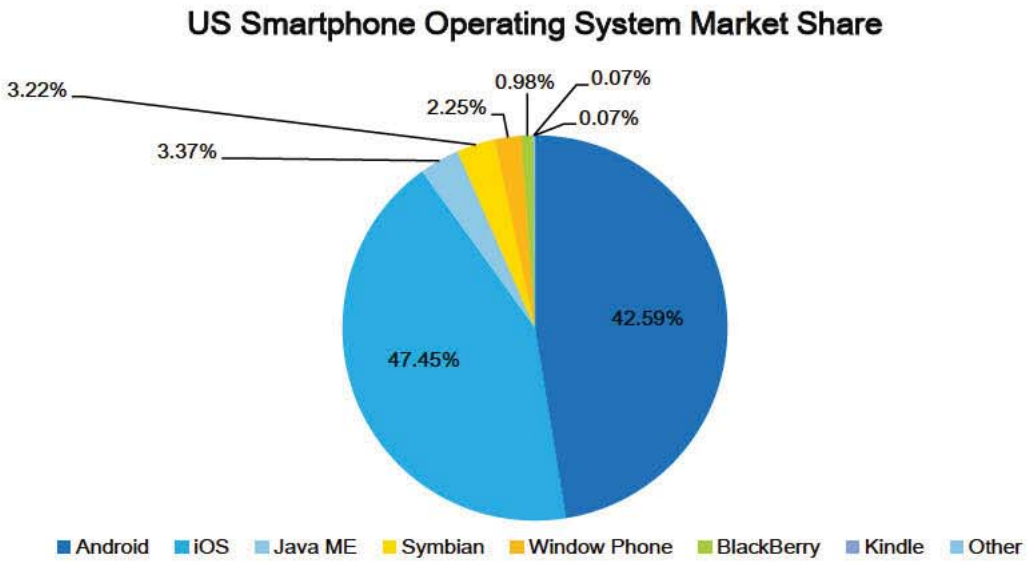
Whereas in Wireless Each Generation Brings New Leader…

Blackberry

Apple Watch

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

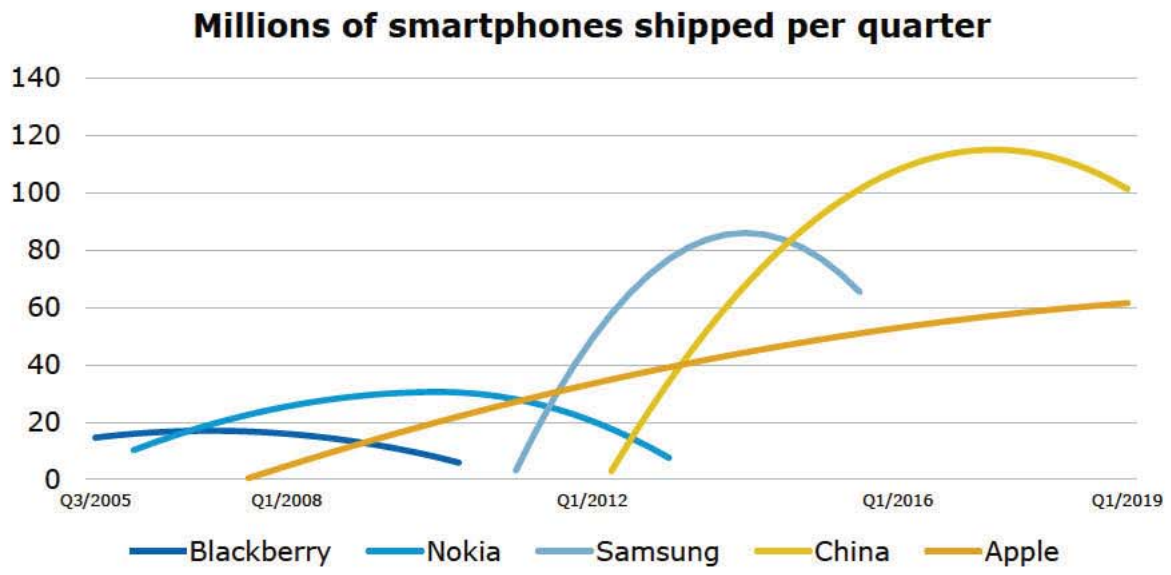
Apple and Samsung Currently Winning US Smartphone Market



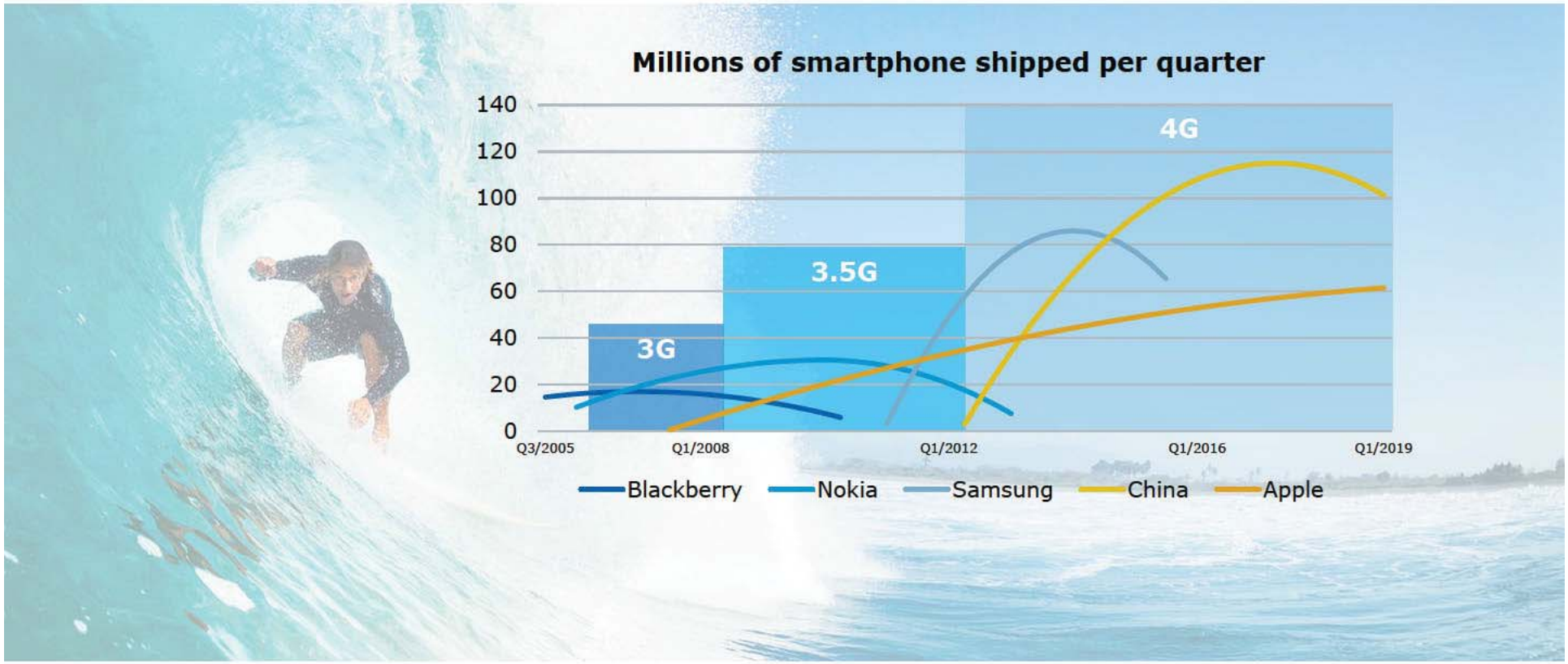
Apple Has Three Quarters of Handset Profits; Samsung, One Quarter; Rest Lose Money

Source: Net MarketShare, as of Jan. 2015

But Wireless Epochs Rise and Fall at Great Speed



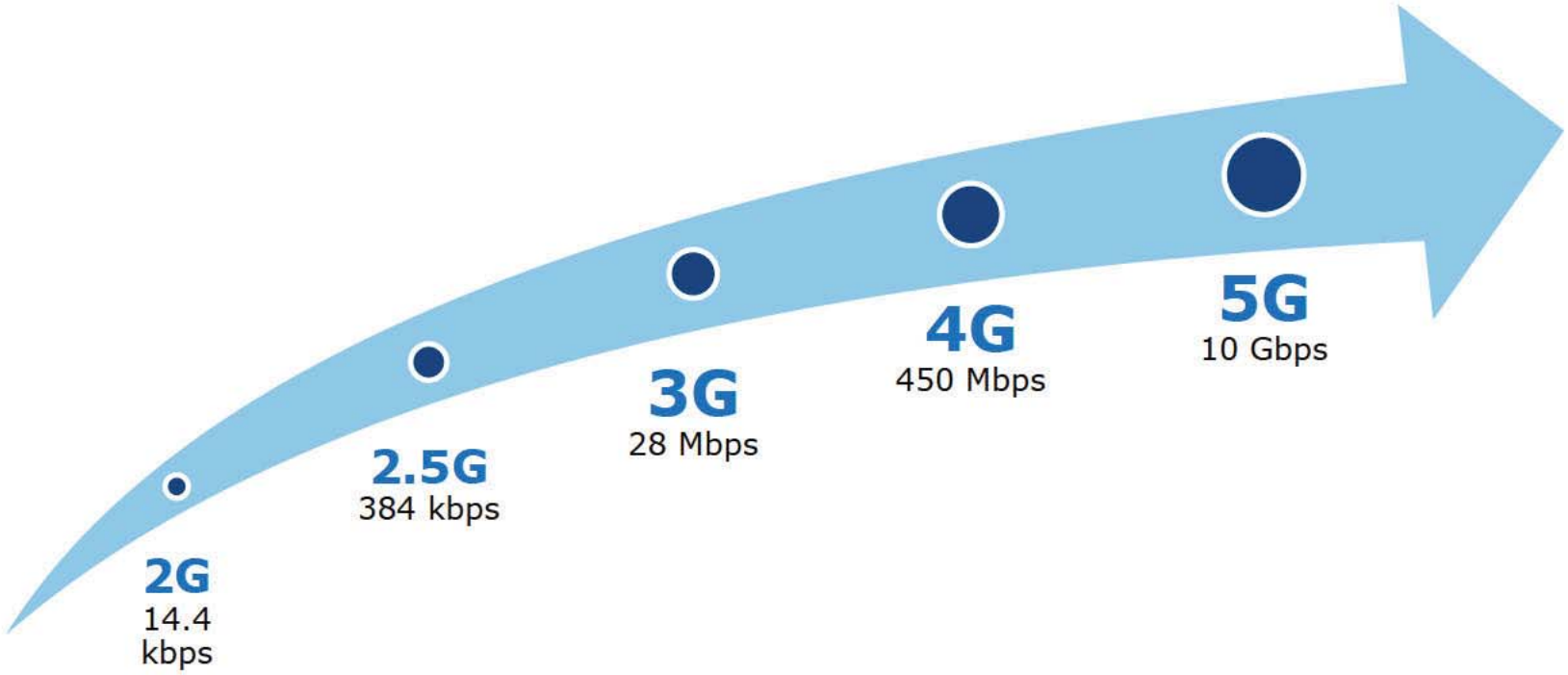
Winners Catch the Generational Wave



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

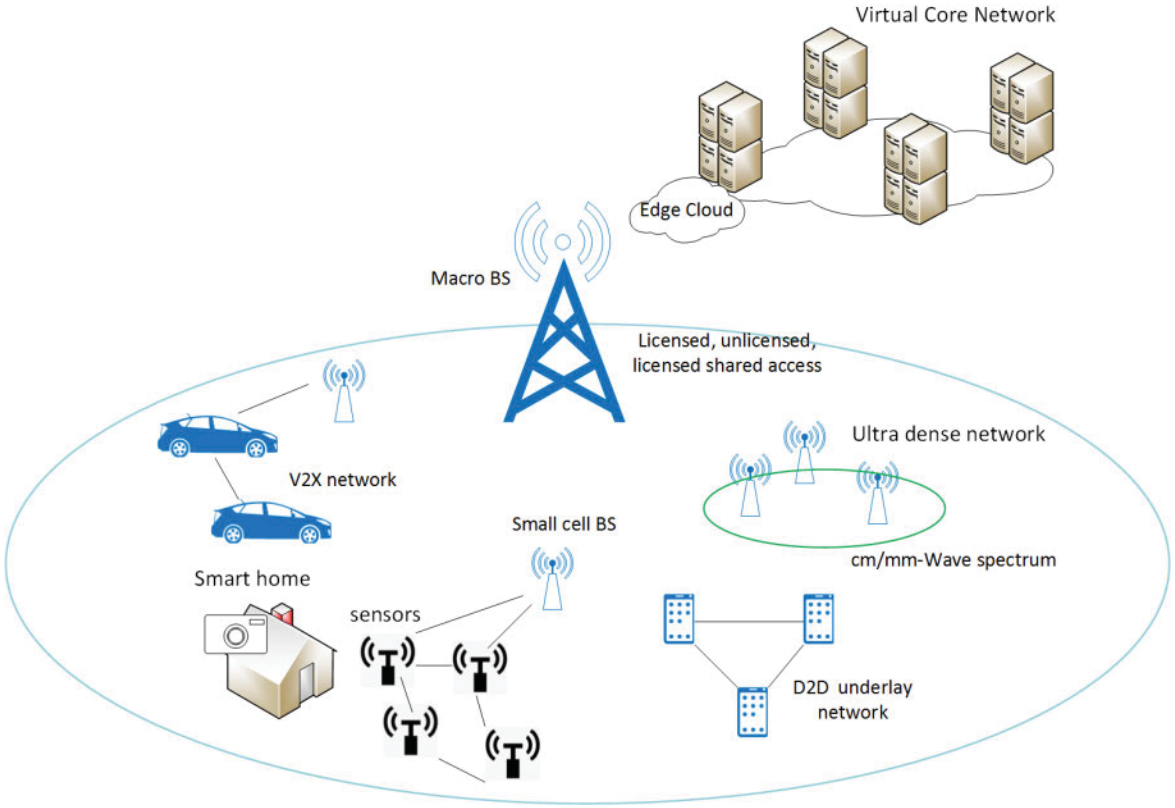
Unlike Autos, Each Generation Brings Faster Communications



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

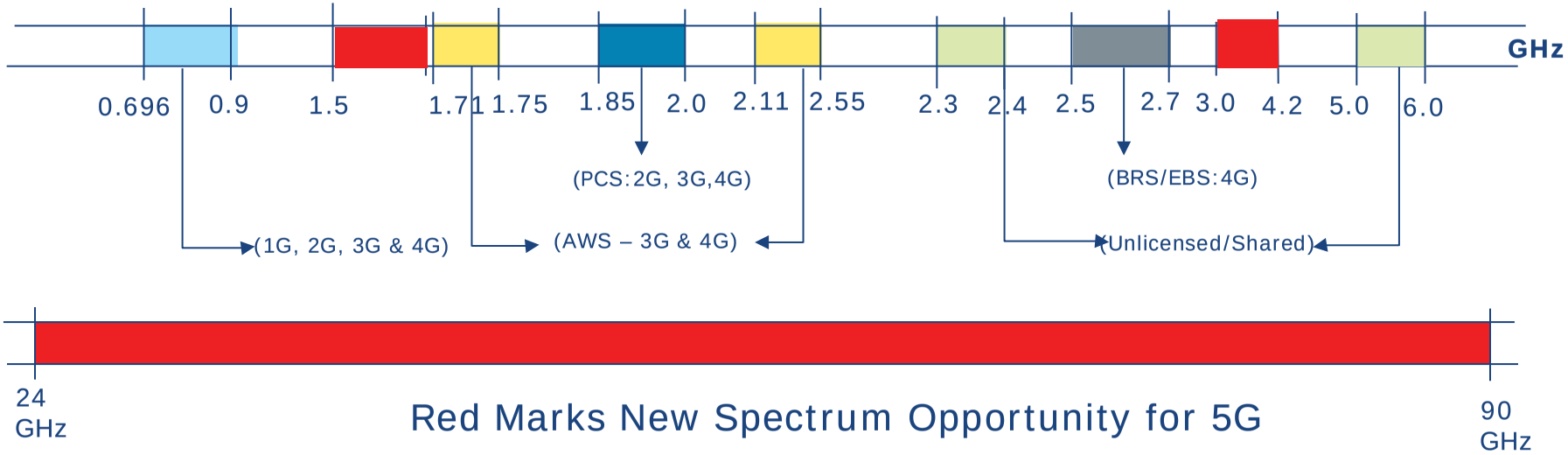
Unlike Cars, Each Generation Changes in Many Dimensions

- Licensed spectrum sharing
- Efficient use of licensed and unlicensed spectrum
- Dense small cells with high frequency reuse
- Mobile underlay network connecting wearable devices and things
- New radio access technology
- Evolving applications
- Ubiquitous sensors
- Edge computing, edge cloud and mobile proxy



5G: 40 Times More Spectrum

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



Red Marks New Spectrum Opportunity for 5G

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

So where will 5G Green Field Build Occur?

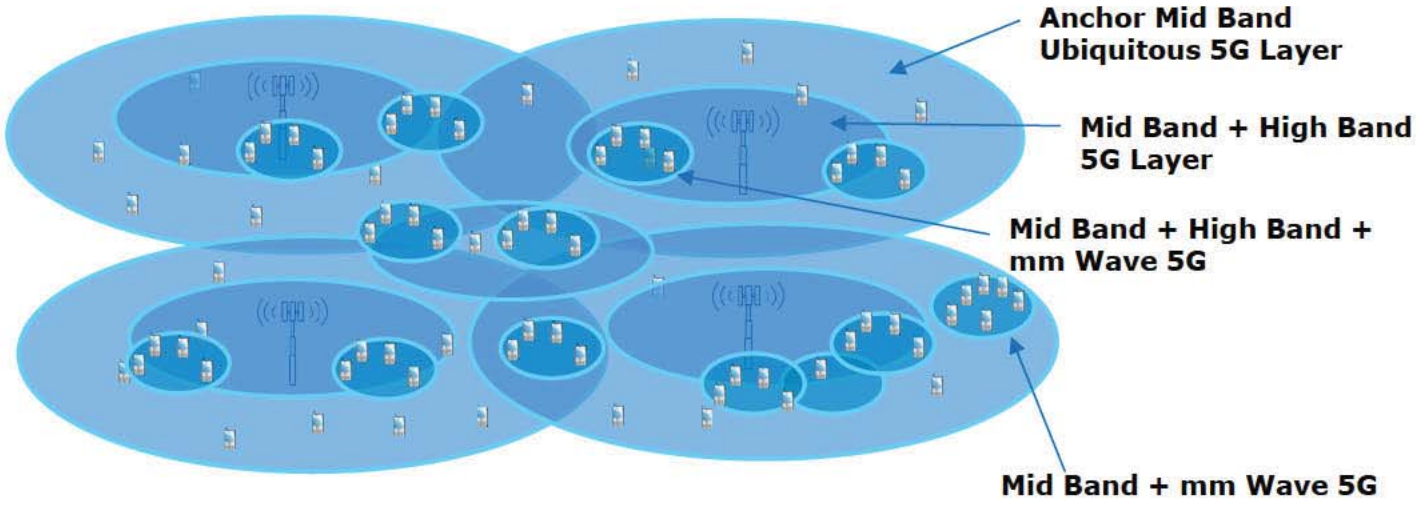
- Too little spectrum available below 2GHz. Large bandwidths available at high frequency spectrum such as millimeter wave. High frequency is appropriate for densification but not for wide area deployment.
- 5G green field build needs to be anchored in mid band

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

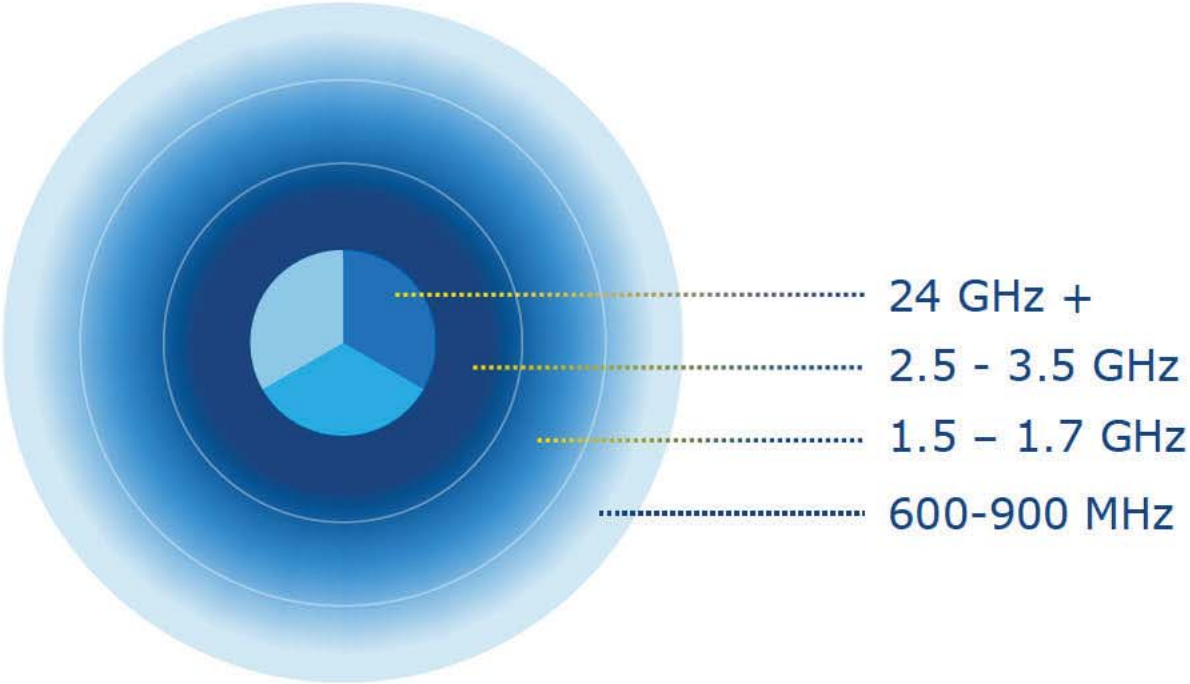
Mid Band (Below 2 GHz), High Band (3.5- 6 GHz), and Very High MM Wave (24 GHz and Above)

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

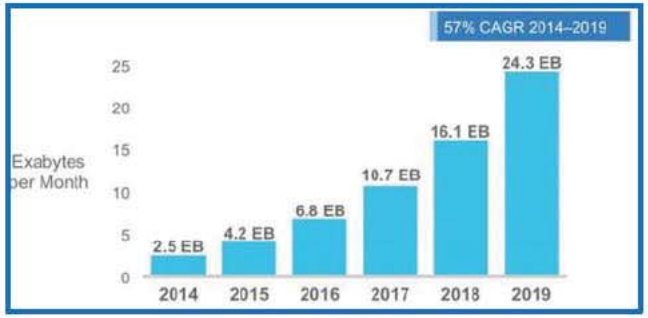


Top Down Look at Spectrum

- Licensed
- Shared
- Unlicensed

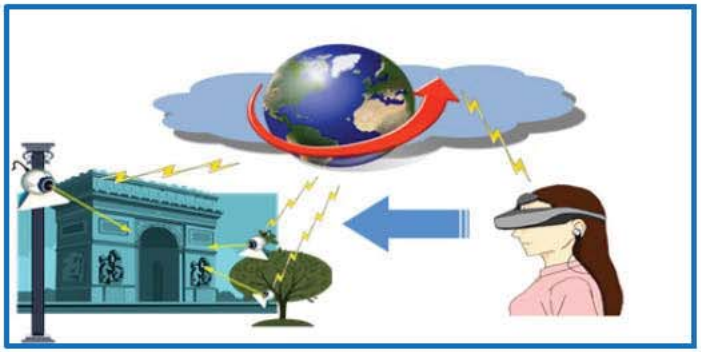


Why do we need 5G?



Constantly increasing mobile traffic demand

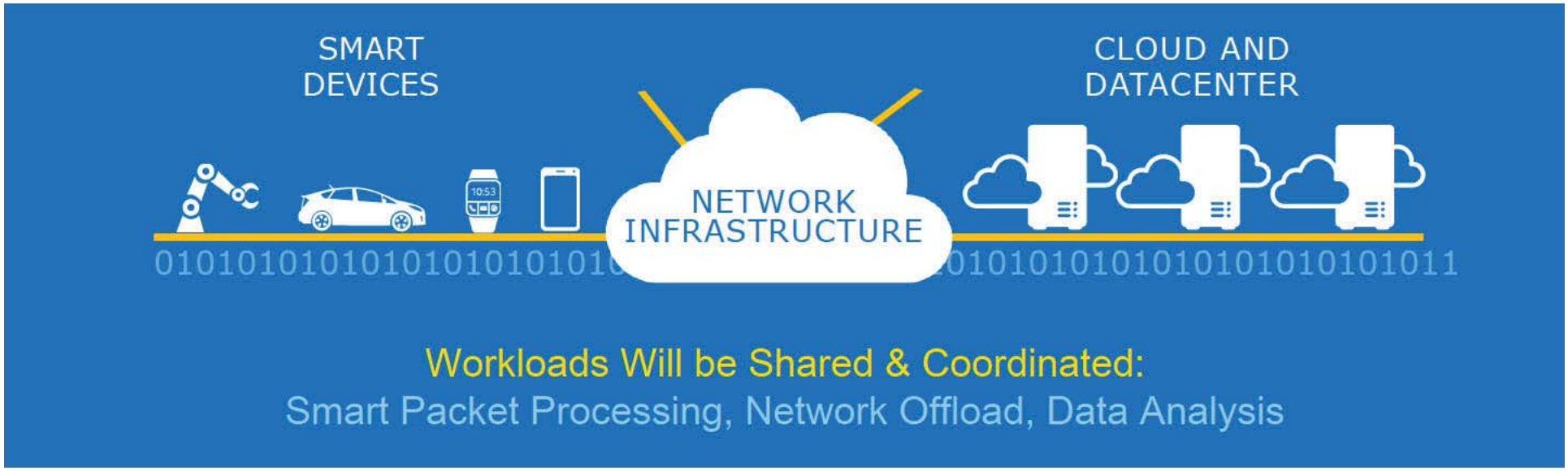
The rise of new devices and smart things (IoT)



New user experiences and applications

Further advance Information and Communication Technology (ICT) to meet market demand for 2020 and beyond

The Next Mobile Era: Computing + Connectivity



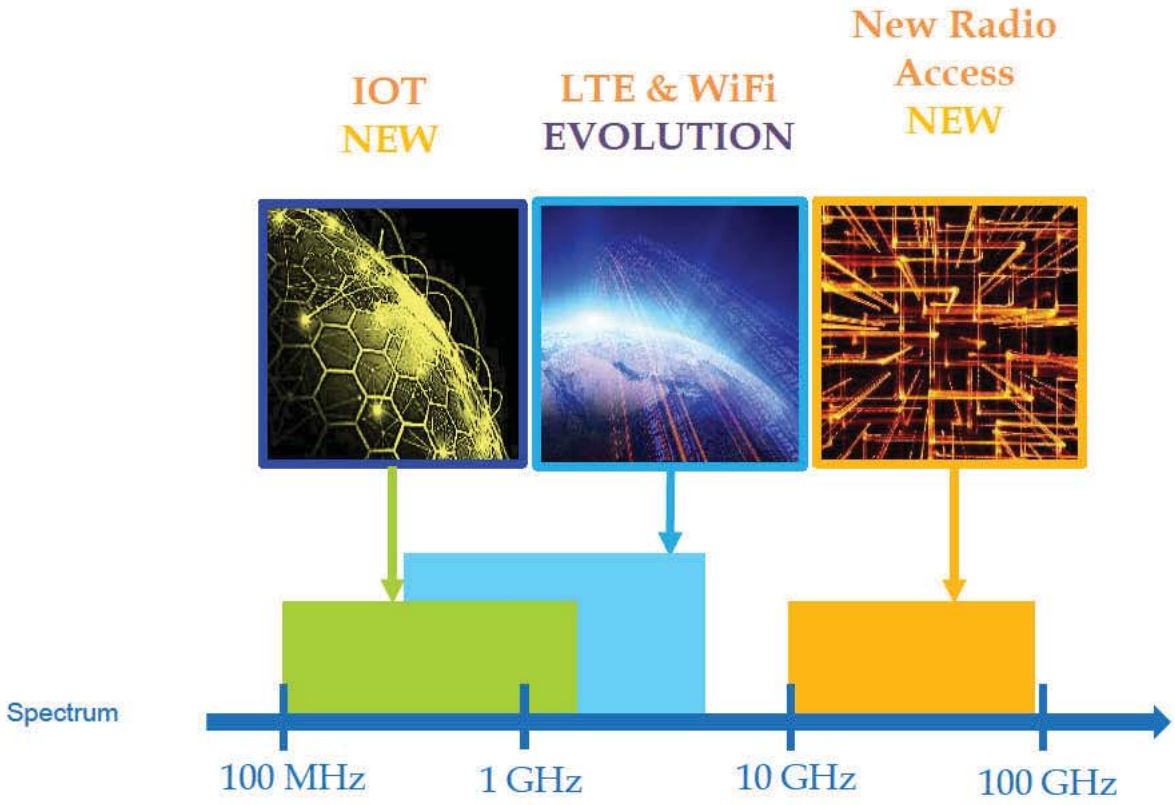
5G vision: Computing + Communications

- <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

Three Technology Tracks of 5G Era

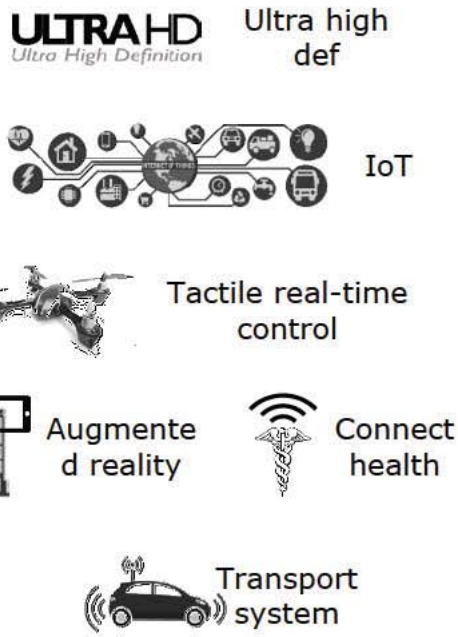


Forces Driving 5G

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

- Data traffic explosion → **1000x** capacity
- Massive connections → **50-200B** devices
- Carrier ROI pressure → **Lower cost/bit**
- Mature markets seeking **new revenue growth**

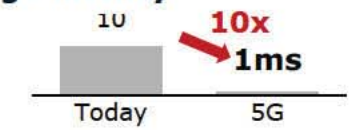
...coupled with demand for critical/radical **new use cases** that are not being met today...



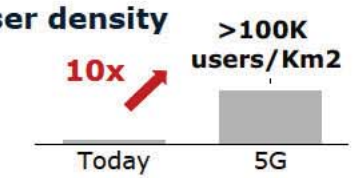
...are driving **new requirements** and **fresh wave of investments**

- **User throughput**

- **Edge latency**



- **User density**



- **>500 km/hr** mobility
- **>100x** energy efficiency
- **5-15x** spectrum efficiency

*includes wired and wireless networks (e.g. MNOs), OTT (over the top) providers (e.g. Google, Netflix) and verticals (e.g. GE)

5G Core Technologies

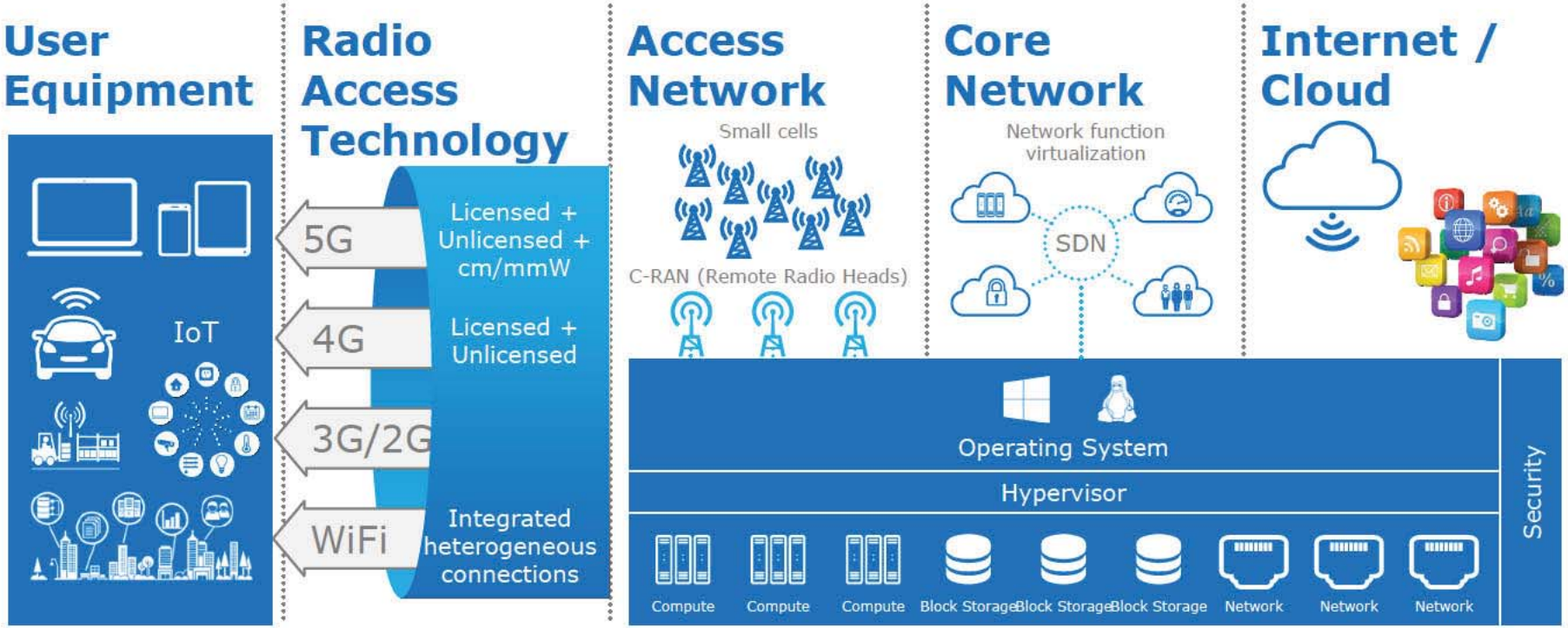
5G Key Technologies

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

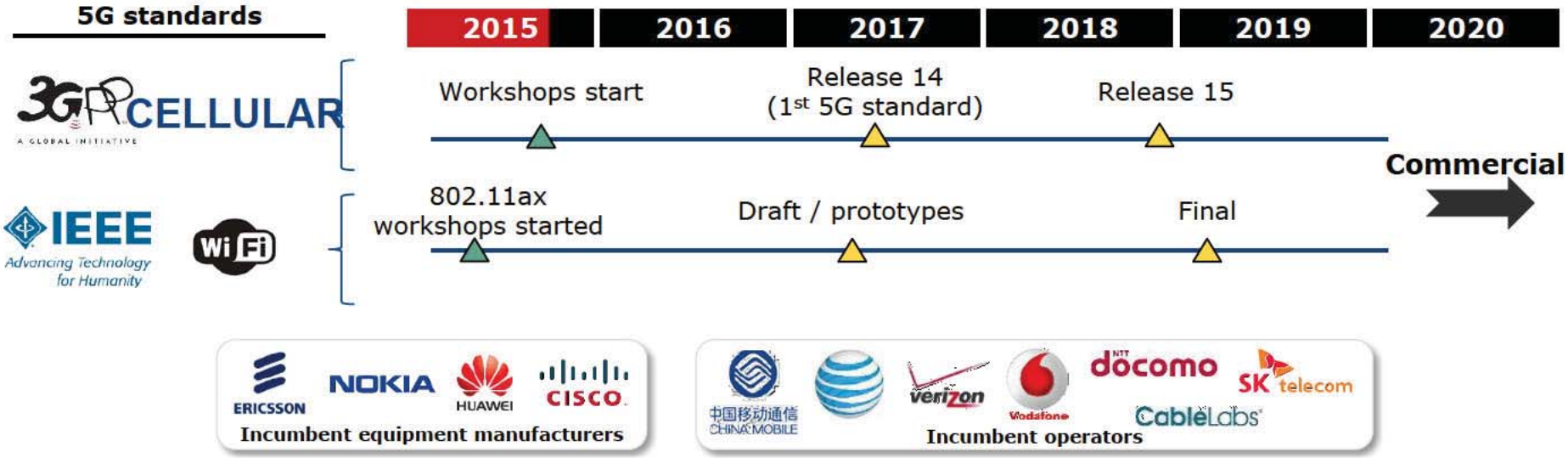
5G Key Radio Bands

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: Network Transformation

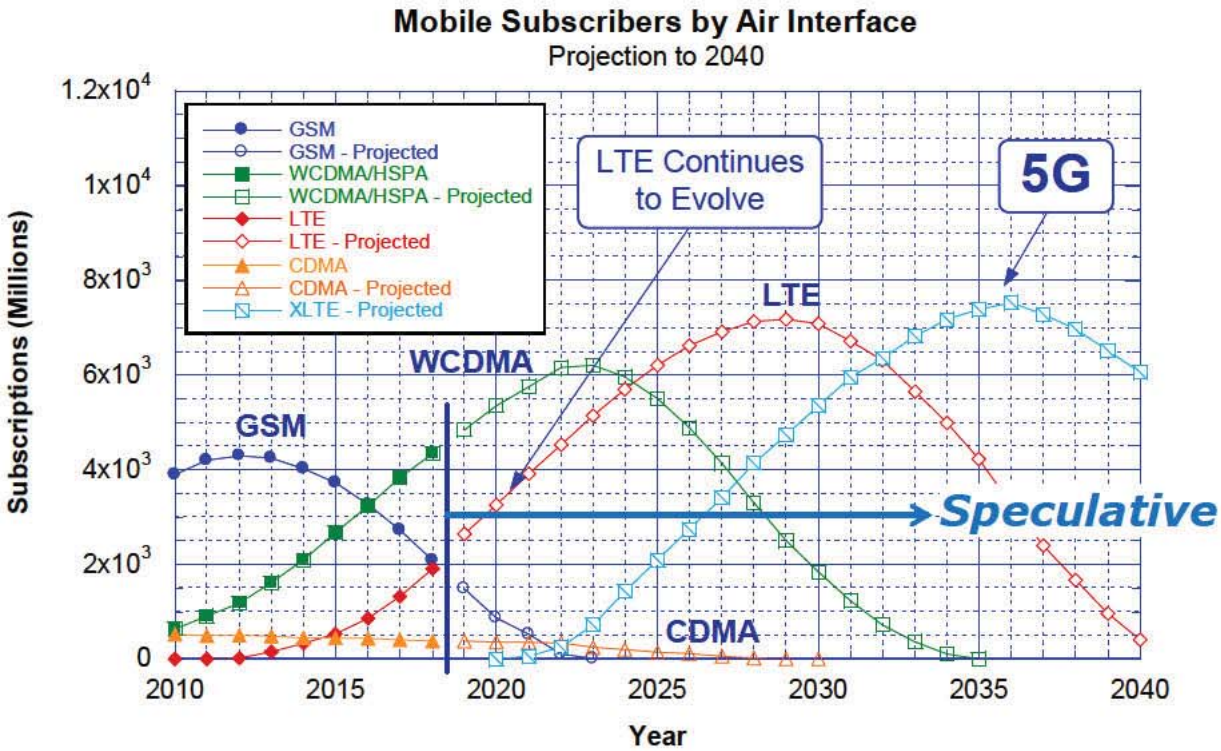


5G Timelines



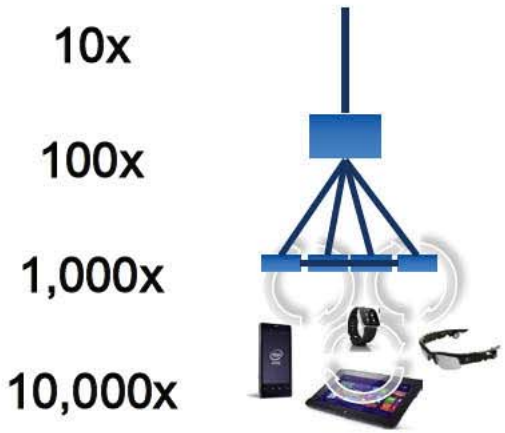
4G Systems Remain Significant in a 5G World

Low Cost Markets and Legacy Infrastructure



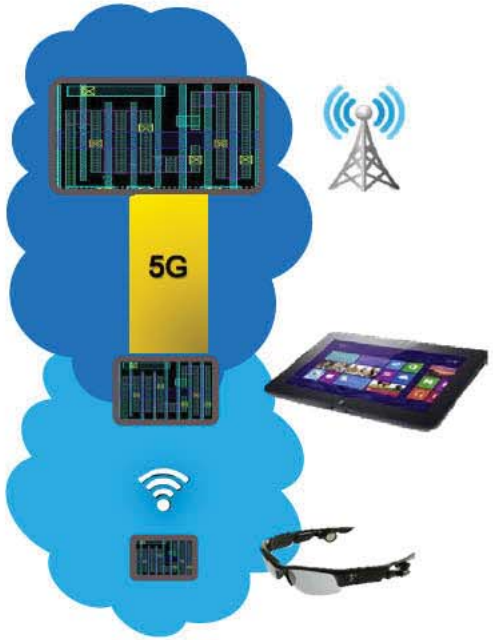
[1] *"Self-Organizing Networks (SON): Self-Planning, Self-Optimization and Self-Healing for GSM, UMTS and LTE"*, Hamied et. Al, 2012; [2] Strategy Analytics; [3] Ericsson and Cisco

5G network and device platforms



5G network capacity scaling

Edge cloud shortens distance between user and content/services, matches 5G air interface capability



5G high data rate + low latency radio links enable mobile device + access virtualization across the air interface

Leading in 5G

Core Technologies for 5G

- 7nm Process and Beyond
- Network Virtualization
- RF including mm-Wave
- Research and Standards

Research for 5G

- Core Concept Development
- Partnerships and Prototyping
- Spectrum Policy
- Intellectual Property
- User Experiences

LTE Evolution
Key Feature Summary

1
Category Evolution
Categories 9-12
4 & 5 DL-CA, DL 4x4, 256QAM, UL-MIMO, UL-64QAM

2
Interference Suppression & Control
FeICIC, NAICS, CoMP, NOMA

3
Unlicensed and Shared Spectrum
License Assisted Access, Licensed Share Access

4
LTE-WiFi Interworking & Aggregation
S2b, Radio Interworking, VoWiFi, Aggregation

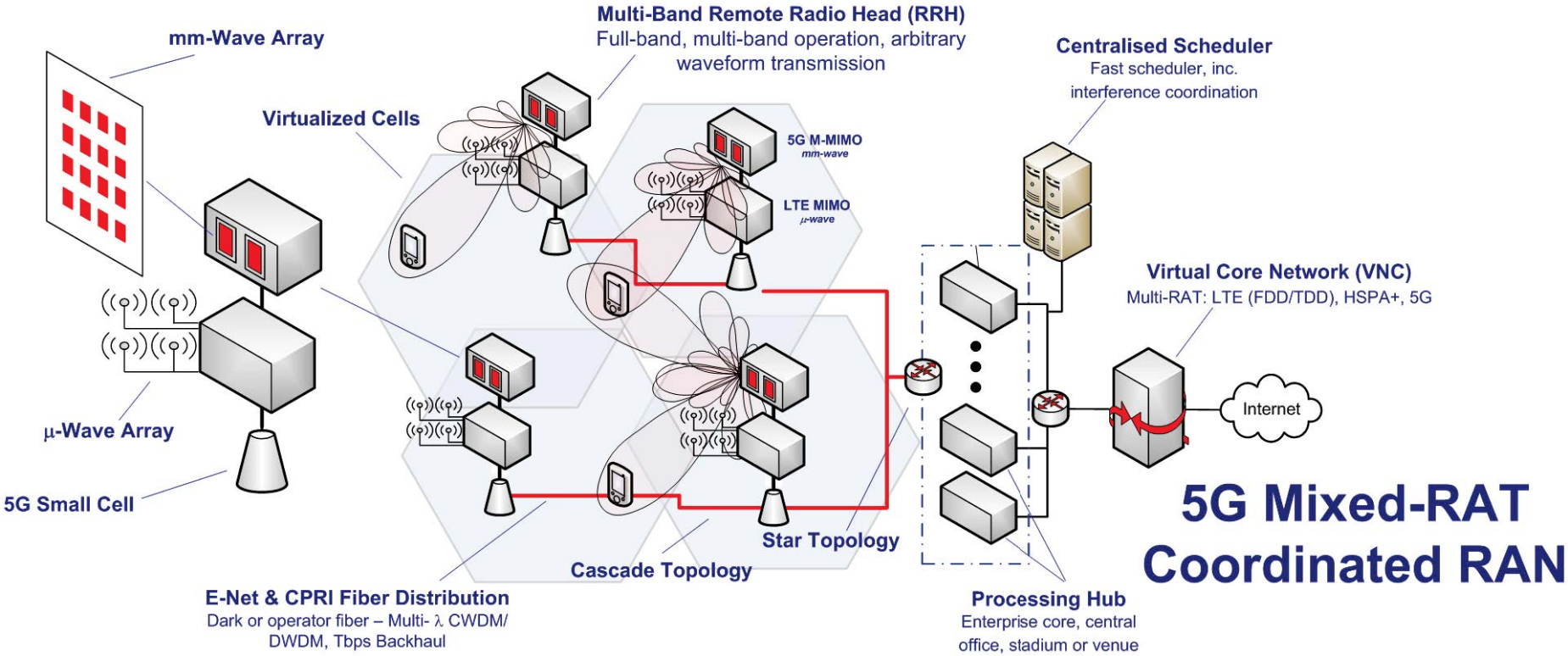
5
3D or Full Dimension MIMO
3D and Massive MIMO

6
Dual Connectivity & Small Cell
Control Plane Anchoring, Energy Enhancements

Key Components of LTE Evolution

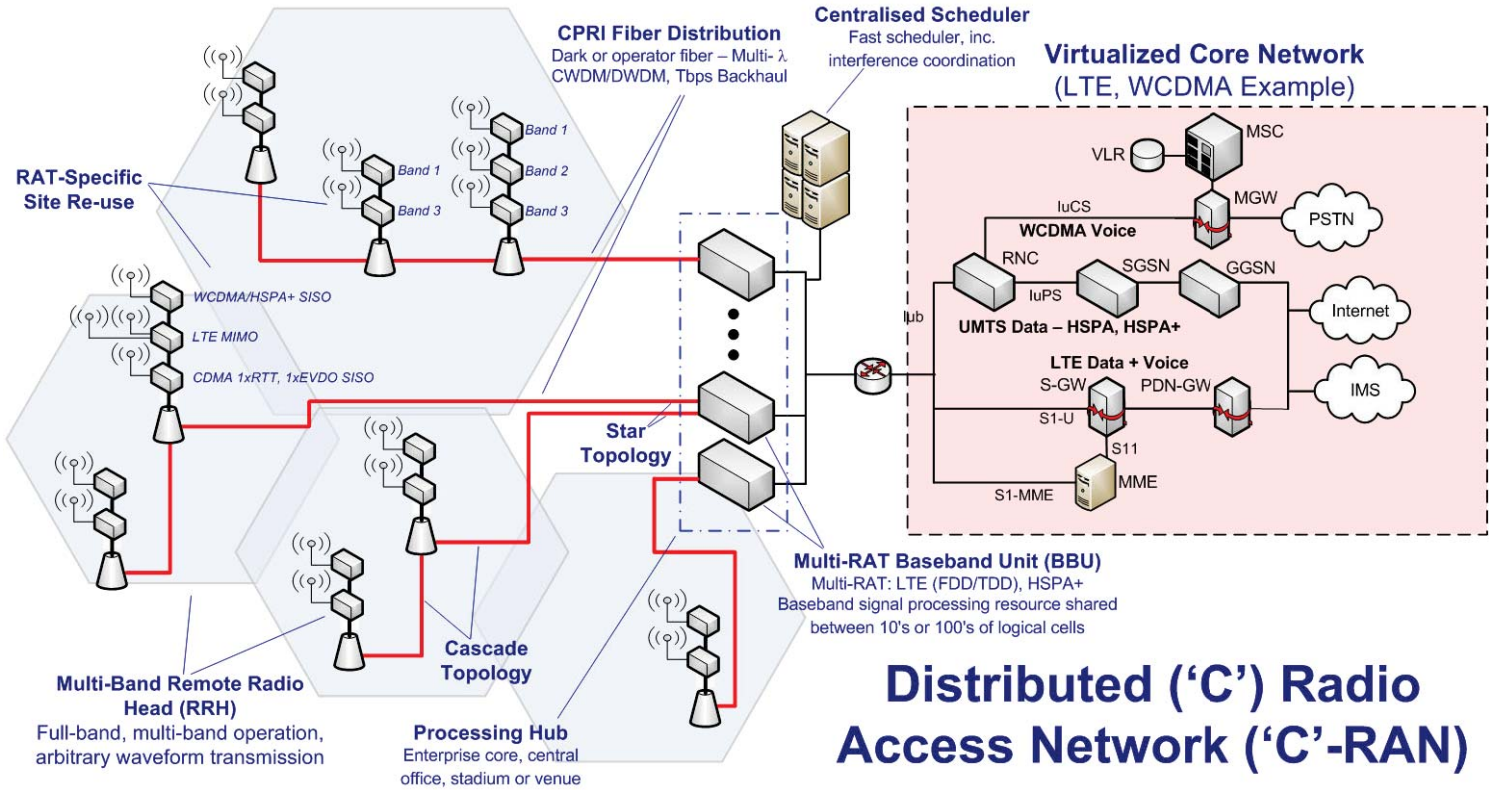
5G Radio Access – Example Topology

Mixed LTE and mm-wave Small Cells

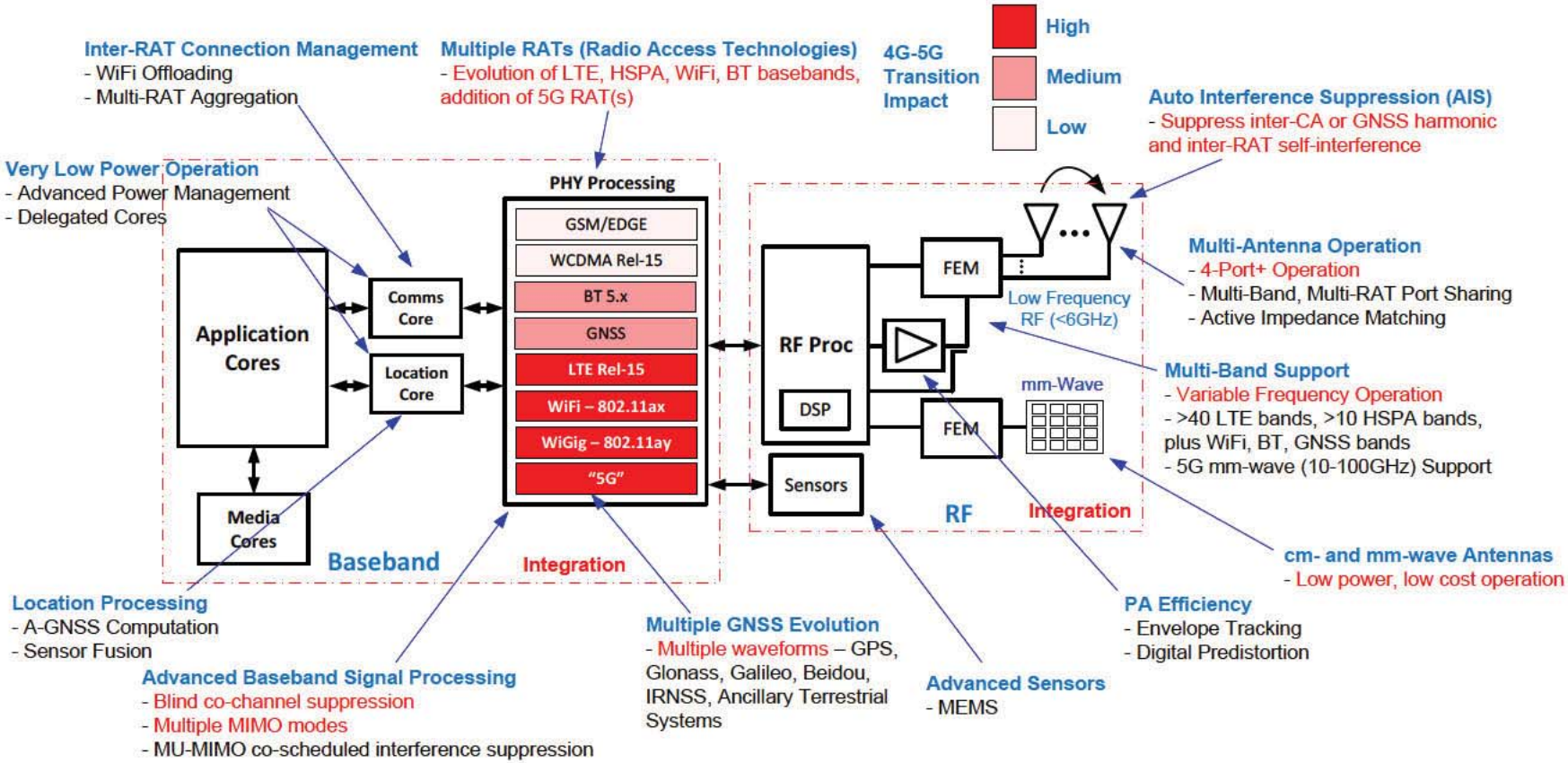


Network Evolution

Virtualization and Coordinated or Distributed RAN

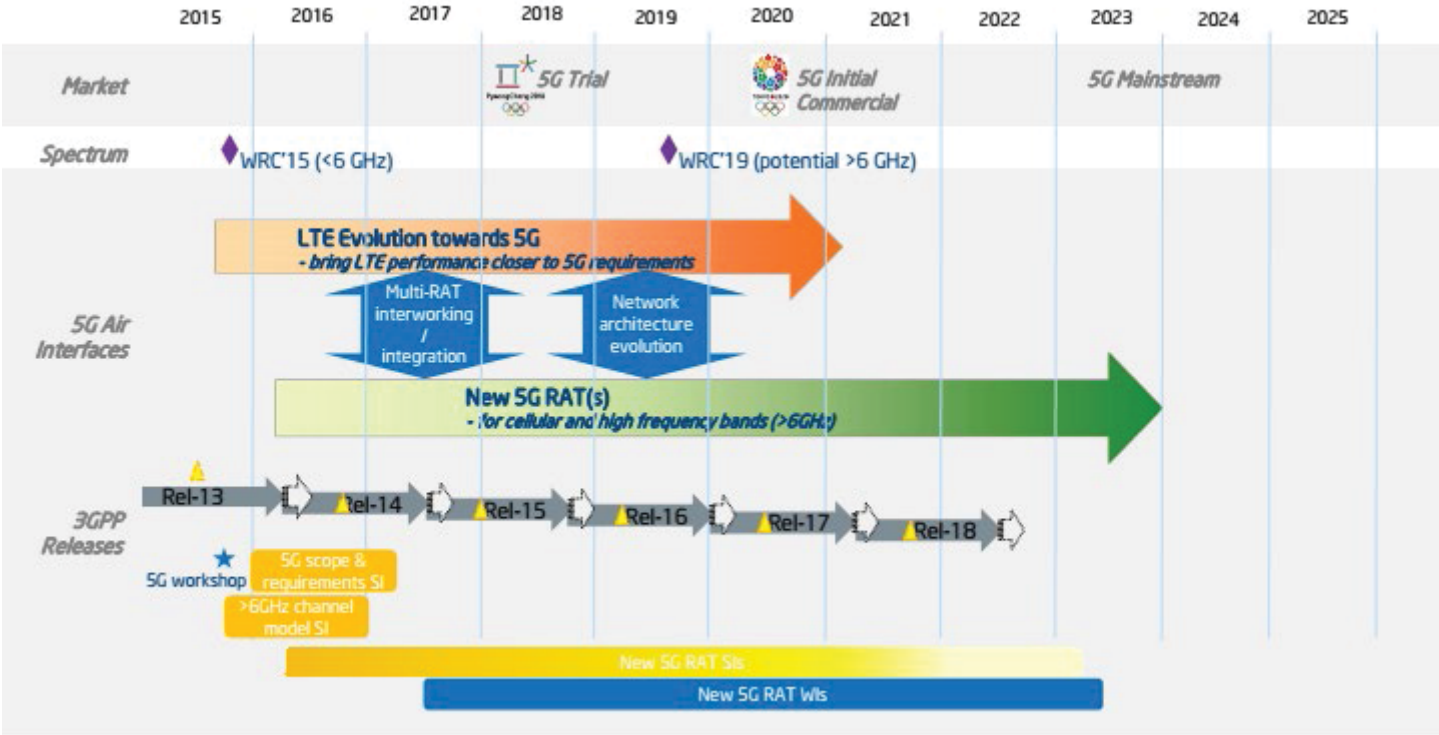


5G Innovation – Device



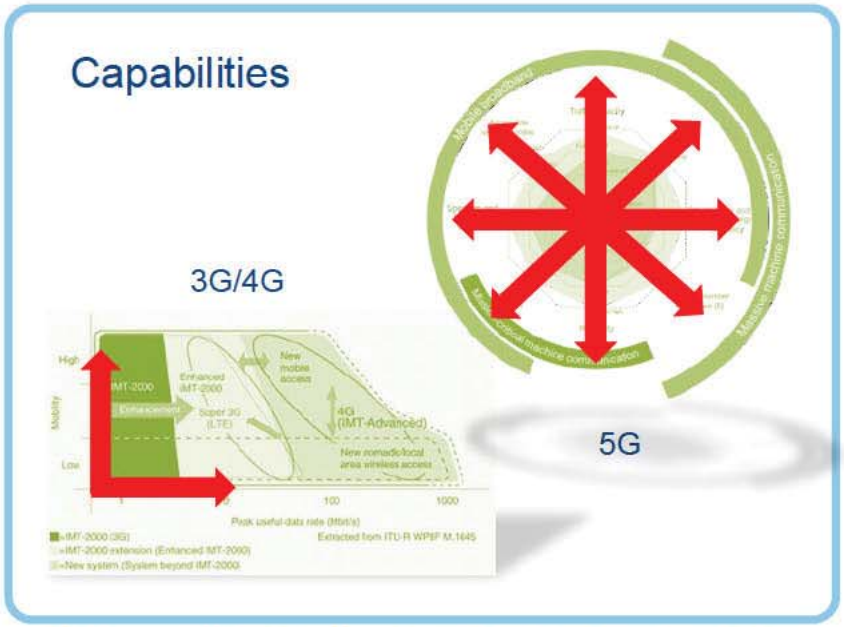
Note: Critical technologies indicated in red.

5G Radio Access Development



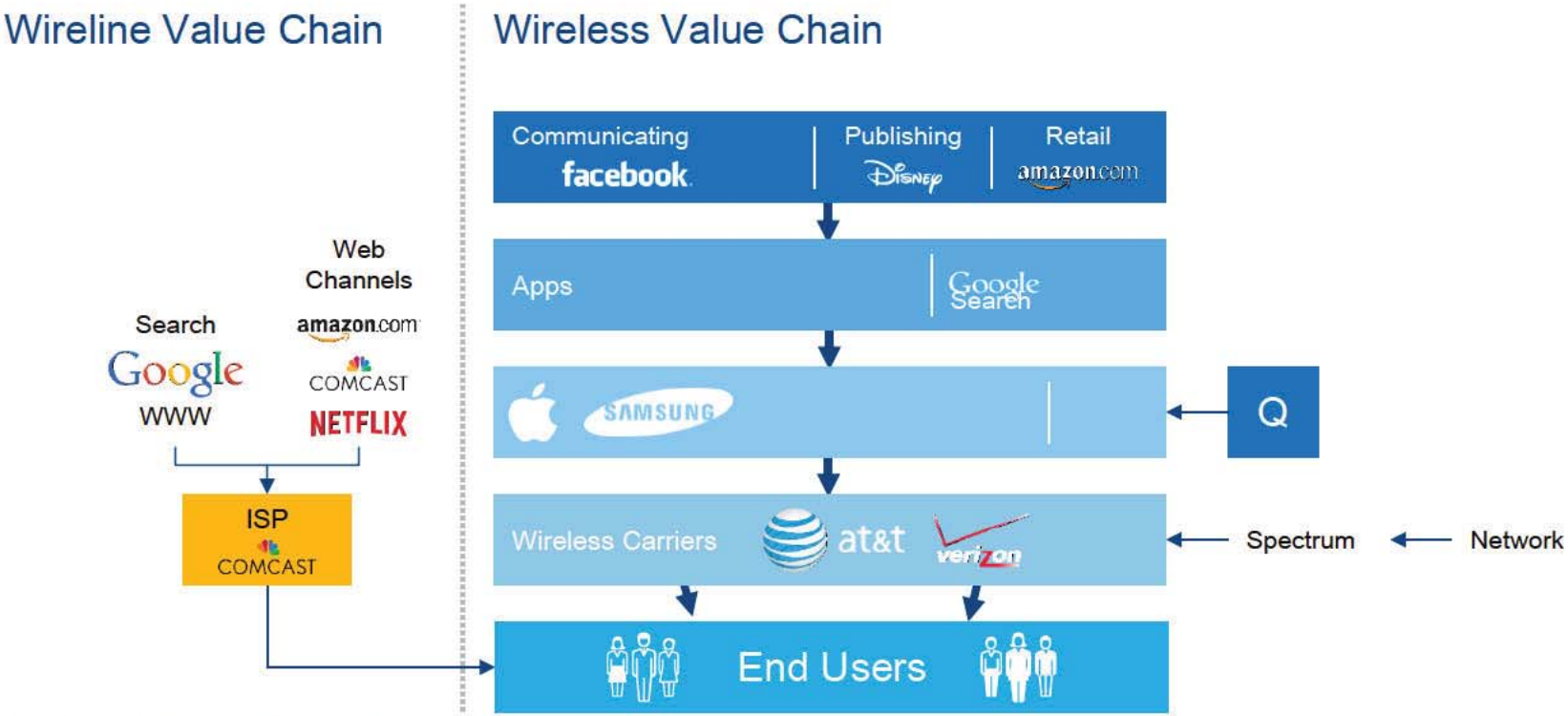
- 5G trial in 2018 based on Rel-14 SI and initial Rel-15 WI
- 5G initial commercial deployment in 2020 based on Rel-15 spec
- IMT 2020 submission based on Rel-16 spec

5G: What Can Be Done Will Be Done



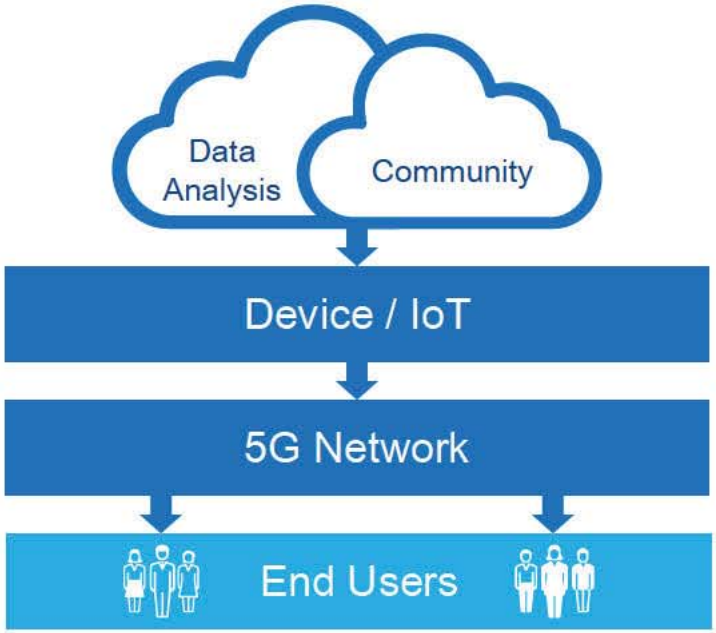
5G dynamically integrates compute and communication for future generations of applications and services

Existing Value Chain

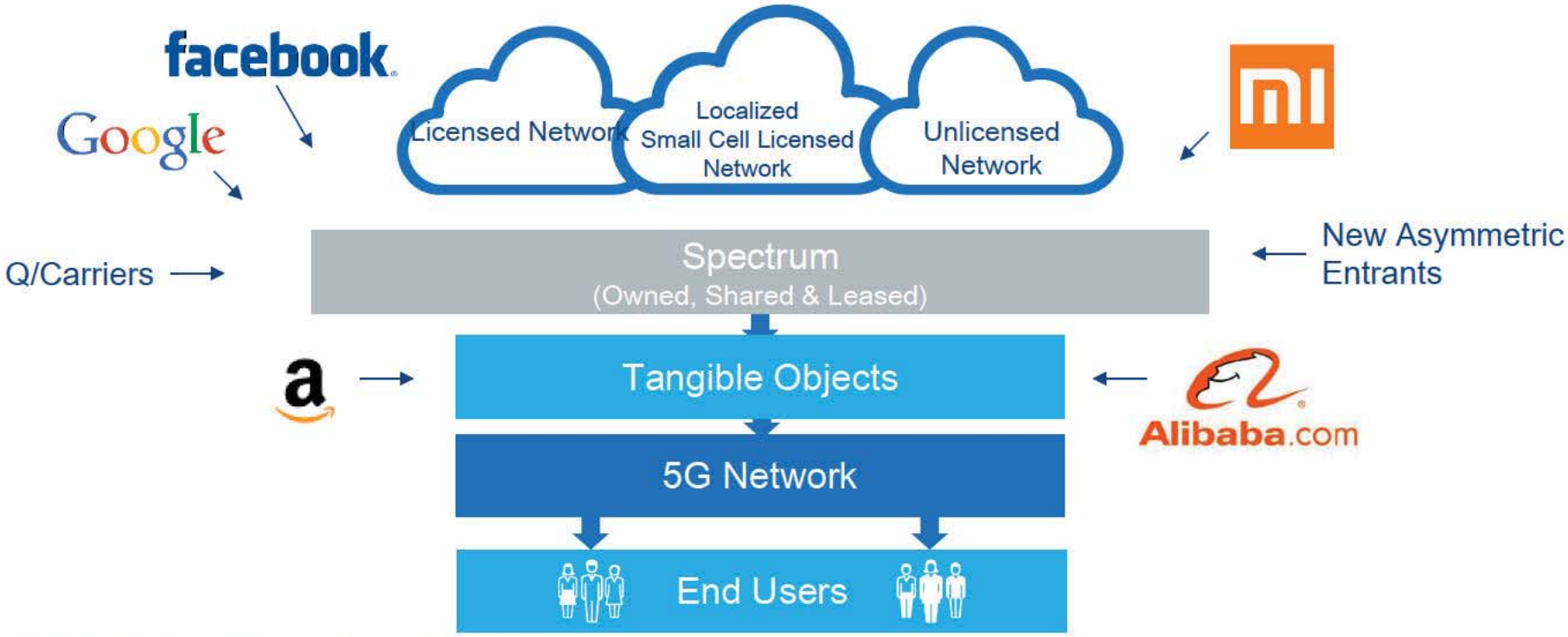


*other names and brands may be claimed as the property of others

Possible New Value Chain – Part I

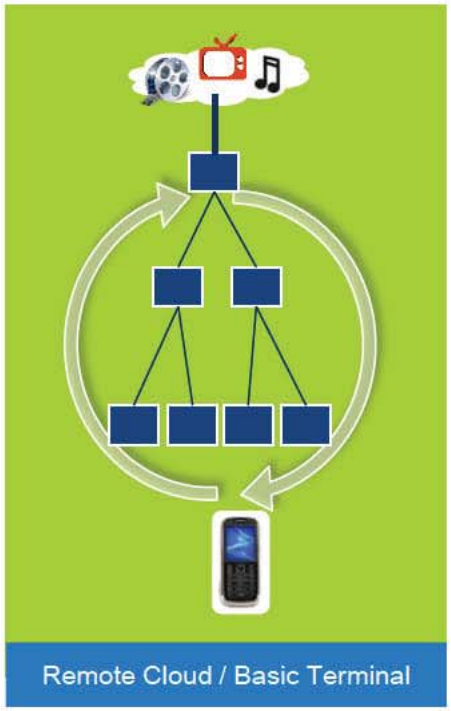


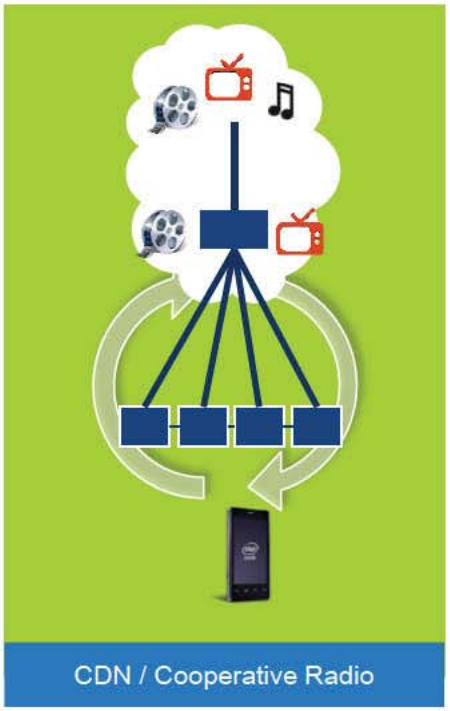
Possible New Value Chain – Part II



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

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





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

Early 5G Services and Applications

MMI[1] Communications

- Virtual Remote Communications
- Telepresence

[1]MMI – Man-Machine Interface

Transportation Systems

- Navigation and Infotainment
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• The Coolest Uses for 5G … Not Yet

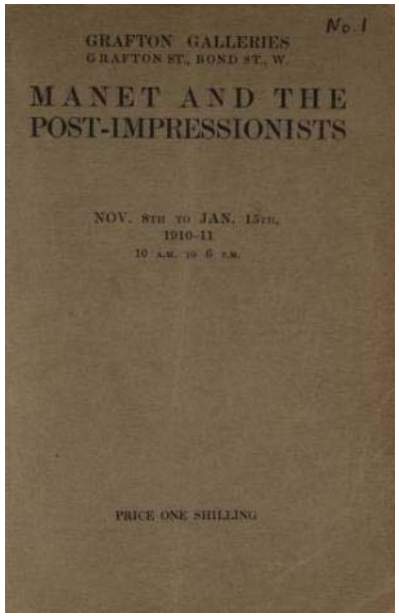
AI & Entertainment

(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

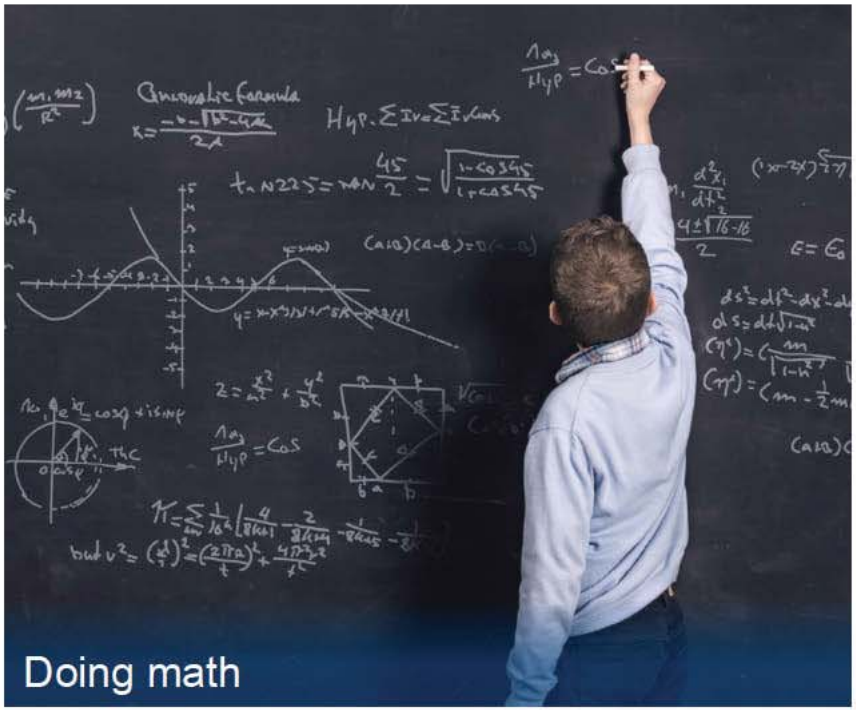
1910

- 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



Intelligence Separates from Consciousness

Specific Measures

- Permit satellite licensees to sell terrestrial secondary uses
- Move to sharing and unlicensed as two complementary means of allocating and using spectrum.
- FCC to issue NOI re similar usage rules, with the same interference rules for all spectrum
- Commercialize much more spectrum!
- Create industry standard setting body for receiver standards (including foreign satellite issues)
- USG to develop plan for accelerating 5G standard setting and deployment
  - NTIA to commence a process for achieving international agreement on use case in 3700-4200 MHz.
    - Urge Wireless Innovation Forum to promulgate sharing rules for satellite and terrestrial use of the spectrum
    - FCC to extend sharing rules for 3.5 MHz to 3.7-4.2 MHz
    - FCC to define exclusion zones for satellite dishes so as to facilitate shared terrestrial use of spectrum
    - Industry fund CRADA test (all agencies to use Boulder) of data base dynamically maximizing terrestrial use around exclusion zones.
  - Issue experimental licenses for 5G demonstrating IOT use case
  - Commence rulemaking for 28 and 39 GHz bands ahead of WRC-15, turning these bands into “de facto mm-wave 5G bands.”
  - Allow 5G experimental licenses for densification networks
  - USG to push for international harmonization of all steps above at WRC-19
  - USG to develop trade policy protecting intellectual property for all 5G technologies, and opening all global markets to non tariffed trade of same.

Thank You