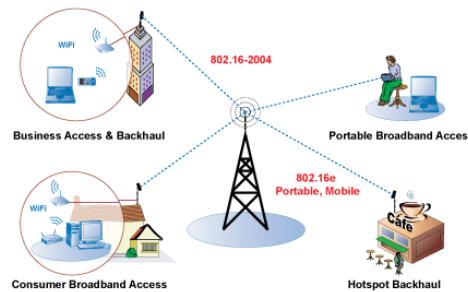


Wireless and Mobile Networking: Facts, Statistics, and Trends



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Audio/Video recordings of this lecture are available at:

<http://www.cse.wustl.edu/~jain/cse574-16/>



1. Wireless: History
2. Wireless Infrastructure Hype Cycle
3. Wireless Speed Trends (Moore's Law)
4. Global Mobile Data Forecast [Cisco]
5. Trends

Billion Dollar Question

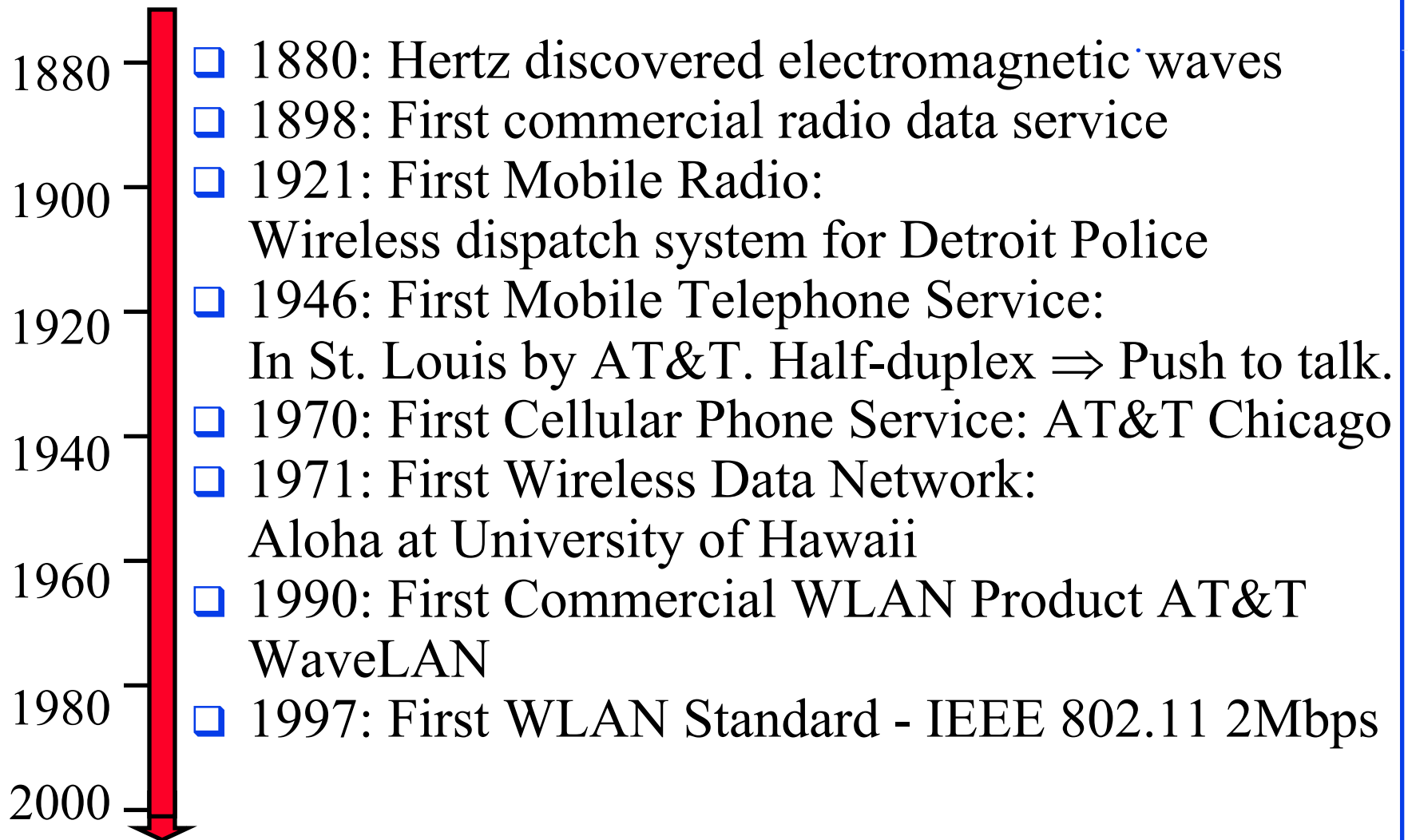
Joan
Quigley



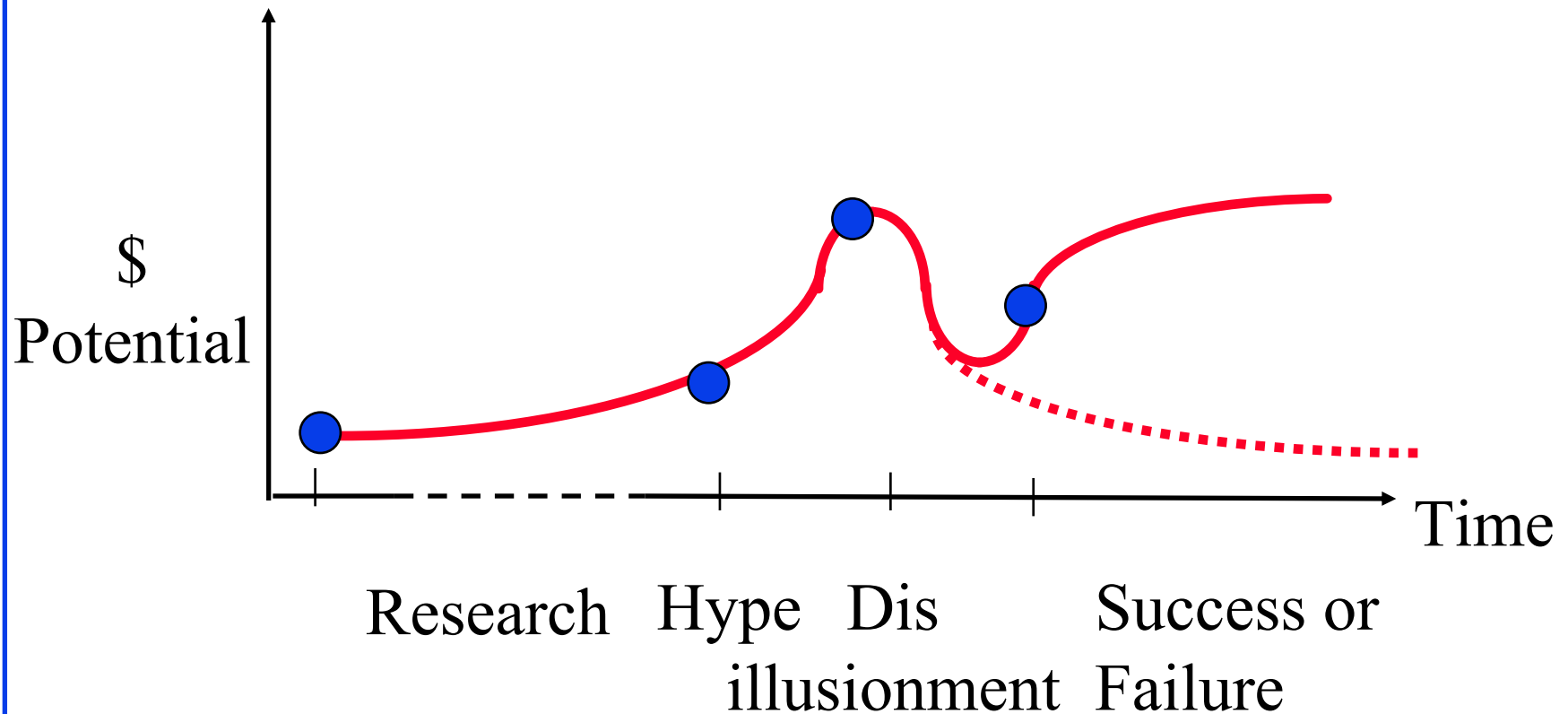
White
House
Astrologer

All I want you to tell me is what will be the
hot networking technology in the year 2016

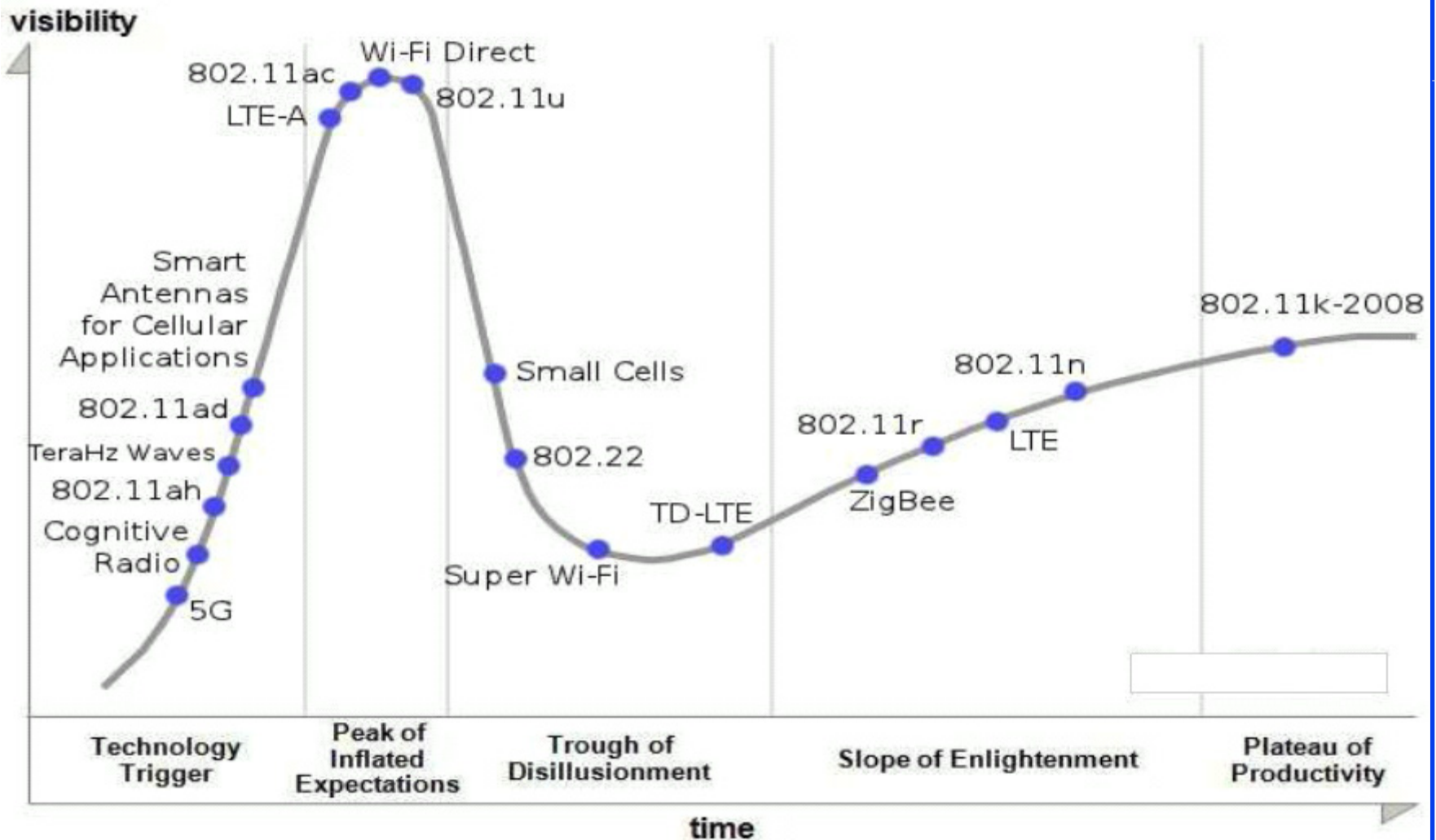
Wireless: History



Life Cycle of Technologies



Wireless Networking Infrastructure Hype Cycle 2013



Ref: A. Chokalingam, "Gigabit Access in Wireless," Second Annual NKN Workshop, Bangalore
 18 October 2013, http://nkn.in/nkn-workshop2013/images/presentation/2nd_annual_nkn_workshop_ac_d4.pdf

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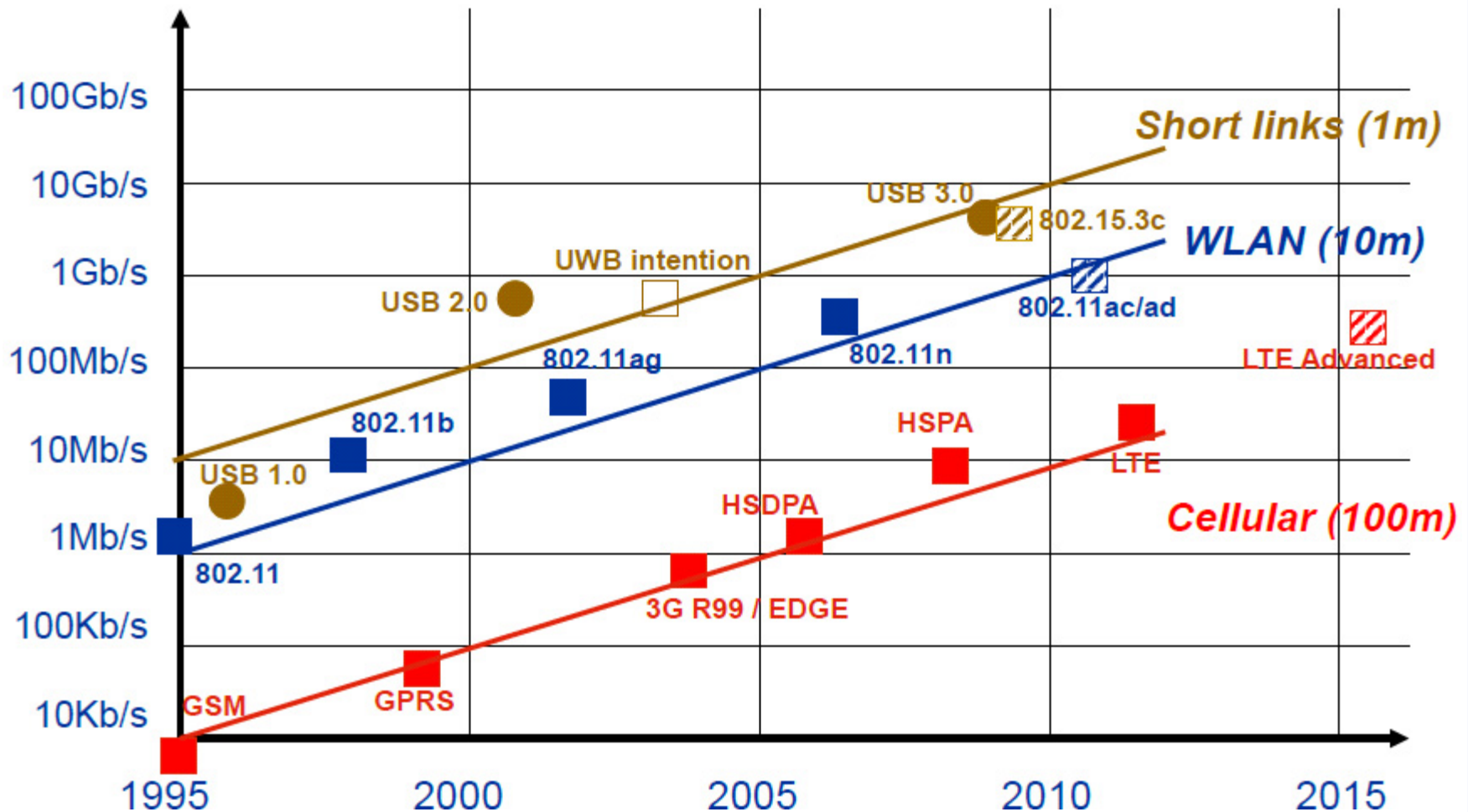
Wireless Innovations

- ❑ **5G**: Beyond 4G. Expected in 2020. 100X LTE
- ❑ **Cognitive Radio**: Find unused channels and use them
- ❑ **802.11ah**: Low-speed coordinated communication for M2M
- ❑ **TeraHz Waves**: Sub-millimeter waves. 1 mm to 0.1mm wavelength. 0.3 to 3THz. Between Radio and light
- ❑ **802.11ad**: WiGig. Gigabit Wireless
- ❑ **Smart Antennas**: Antenna arrays that can orient towards direction of arrival
- ❑ **LTE-Advanced**: Next generation of LTE. Real 4G. 1 Gbps
- ❑ **802.11ac**: 500Mbps-1 Gbps WiFi
- ❑ **WiFi Direct**: Point-to-Point WiFi without access point
- ❑ **802.11u**: Authentication for 802.11 hotspots

Wireless Innovations (Cont)

- ❑ **Small Cells**: 10m to 2km. Includes Micro cells, Pico cells, Femto cells
- ❑ **802.22**: Wireless regional area network using white spaces in TV channels
- ❑ **Super WiFi**: Long-distance internet access using TV white spaces
- ❑ **TD-LTE**: LTE using time-division duplexing rather than frequency division duplexing
- ❑ **ZigBee**: Trade name for 802.15.4 personal area networks. Like WiFi for 802.11
- ❑ **802.11r**: Fast Base Station transition
- ❑ **LTE**: Long-Term Evolution. 3.9G

Wireless Speed Trends



□ Doubling every 18 months \Rightarrow Moore's Law

Ref: G. Fettweis, "The limits of 4G and how to design a new 5G Phy," <http://www.ieee-ctw.org/2013/slides/Fettweis.pdf>

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Global Mobile Data Forecast [Cisco]

1. Global IP Traffic: 5X in last 5 years, 3X in next 5 years
=> 23% Compound Annual Growth Rate (CAGR)
2. Busy hour traffic growing faster: 3.4X in next years
3. Mobile data traffic will increase 10X in 5 years
4. Business traffic will increase by 2X in 5 years
5. Metro traffic (2/3) and long haul (1/3)
Metro traffic will grow faster than long-haul traffic
Due to Content Delivery Networks (CDNs)
6. CDNs will carry a higher fraction of total traffic (63% in 2019 vs. 39% in 2014)
7. Over half-of all IP traffic will originate from non-PC devices

Ref: Cisco Visual Networking Index: Forecast and Methodology, 2014-2019 White Paper,

http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html

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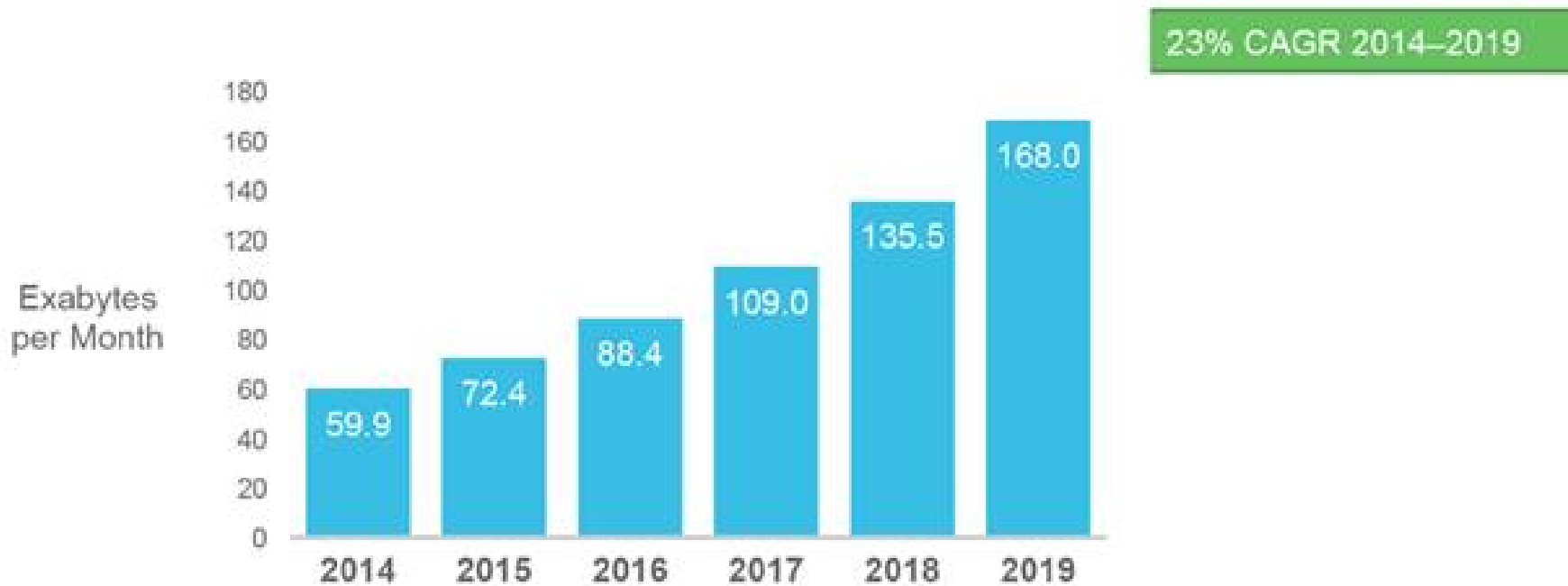
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Global Mobile Data Forecast (Cont)

8. Traffic from wireless devices will exceed those from wired
9. Number of devices will be 3X the population size
10. Video traffic will be 80% of consumer traffic
11. Million minutes of video will cross Internet per second
12. IP Traffic: fastest growth **rate** in the Middle East and Africa followed by Asia Pacific

Note: The next 12 slides are all from Cisco VNI

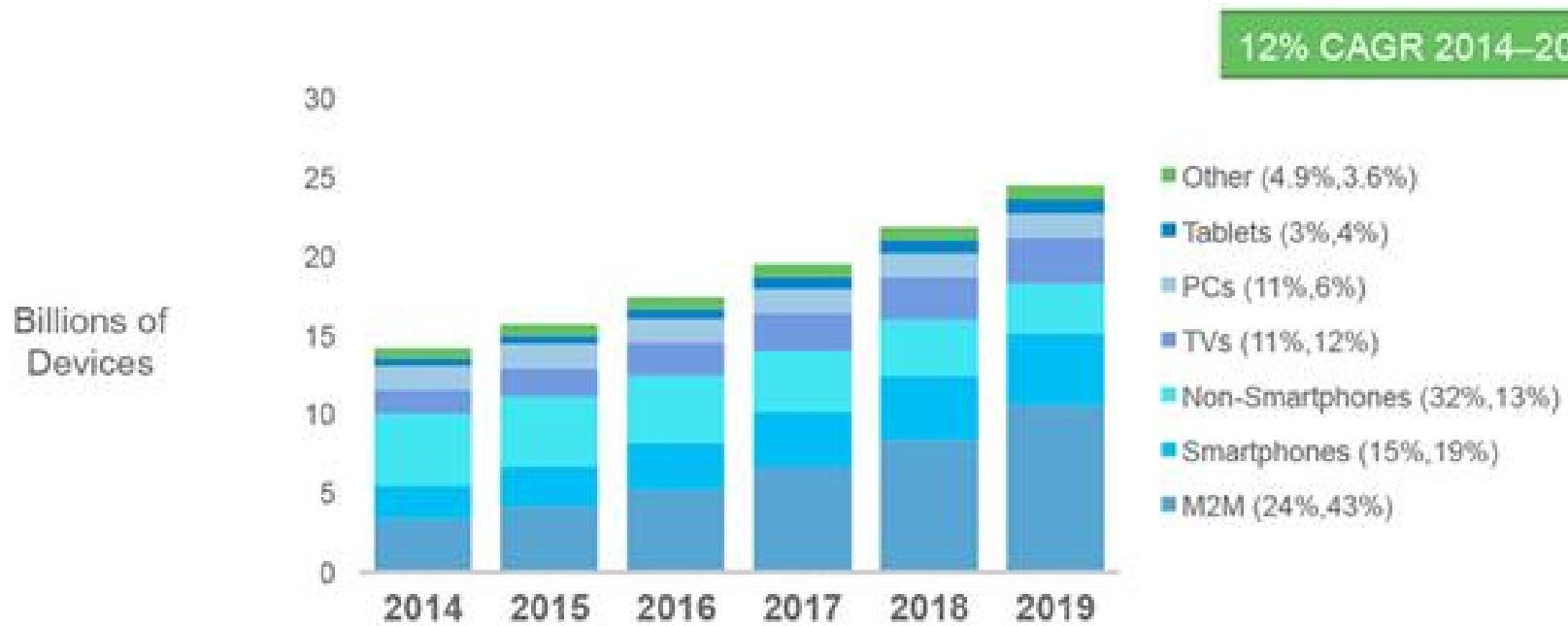
Growth in IP Traffic



[Source: Cisco VNI]

□ 3X in 5 years

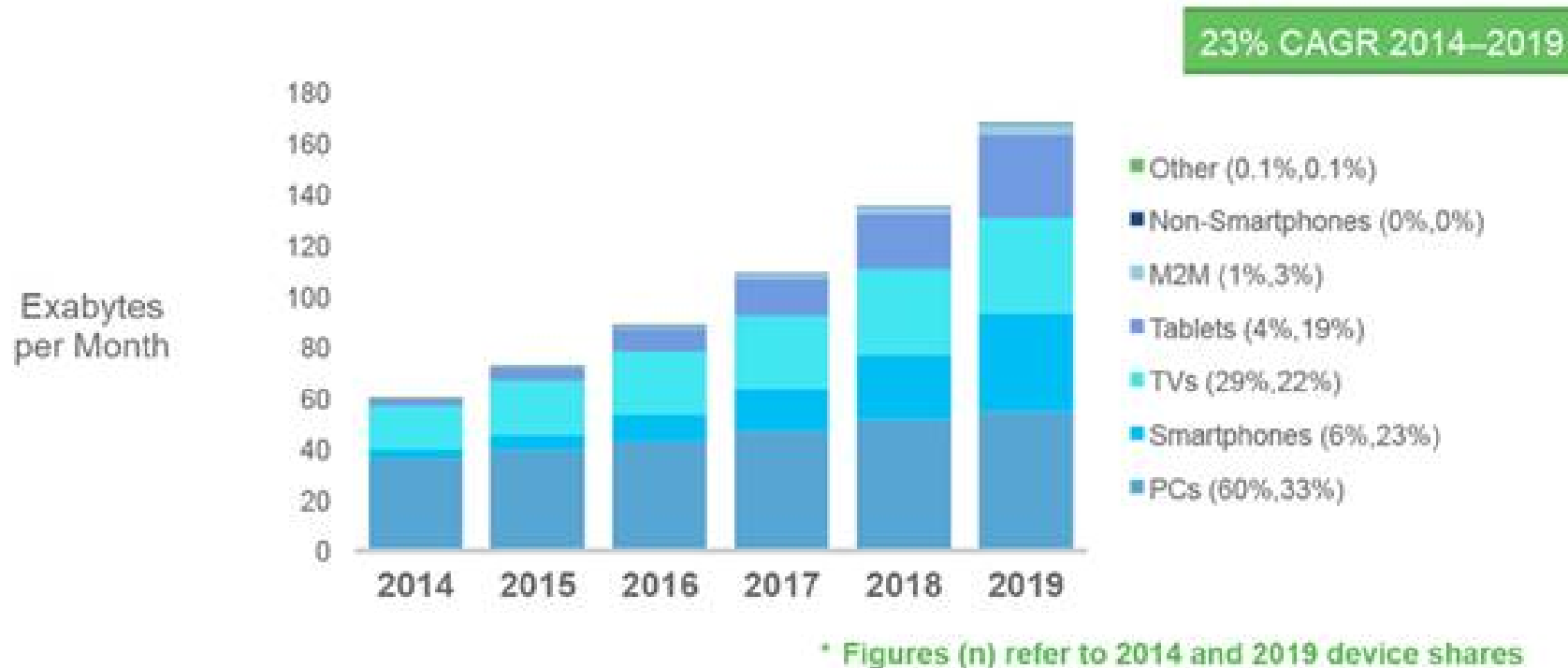
Number of Devices



* Figures (n) refer to 2014 and 2019 device shares

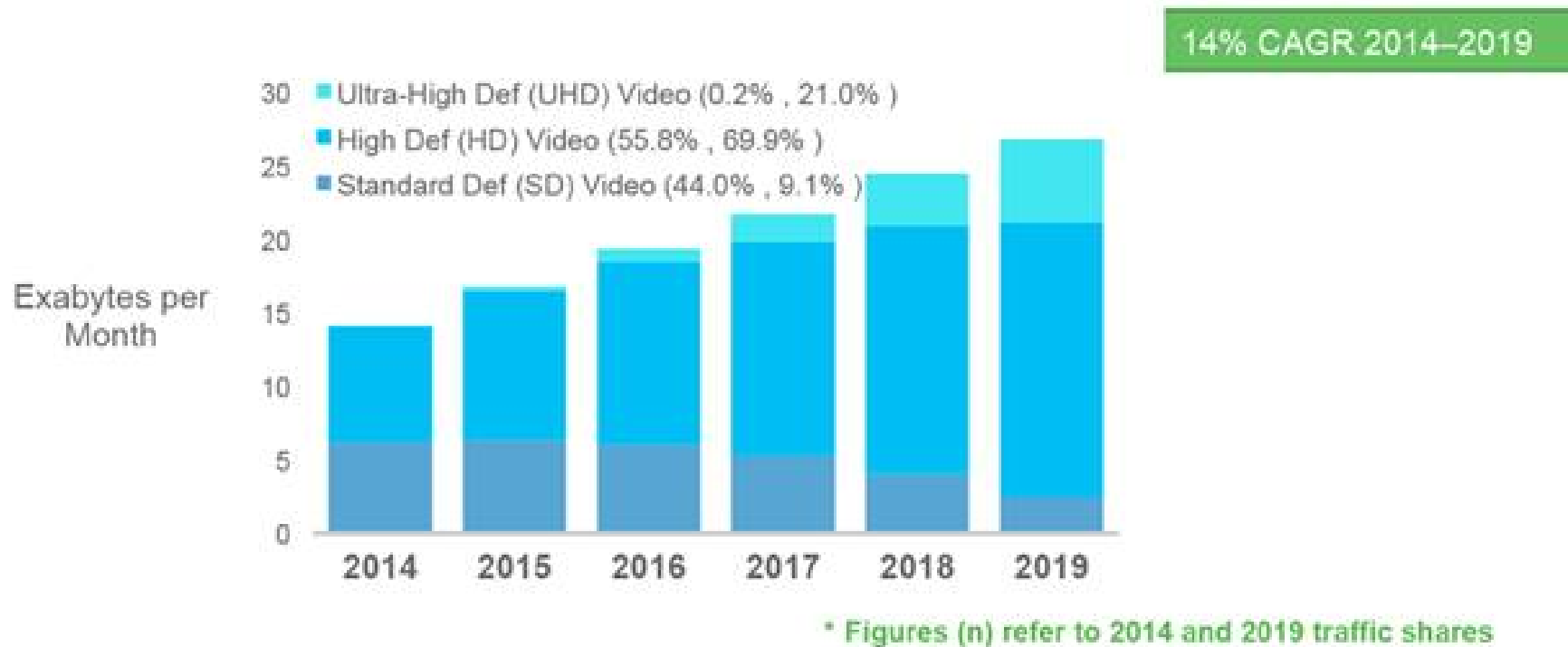
- ❑ Devices = 3X population
- ❑ Large # of M2M connections

Total IP Traffic



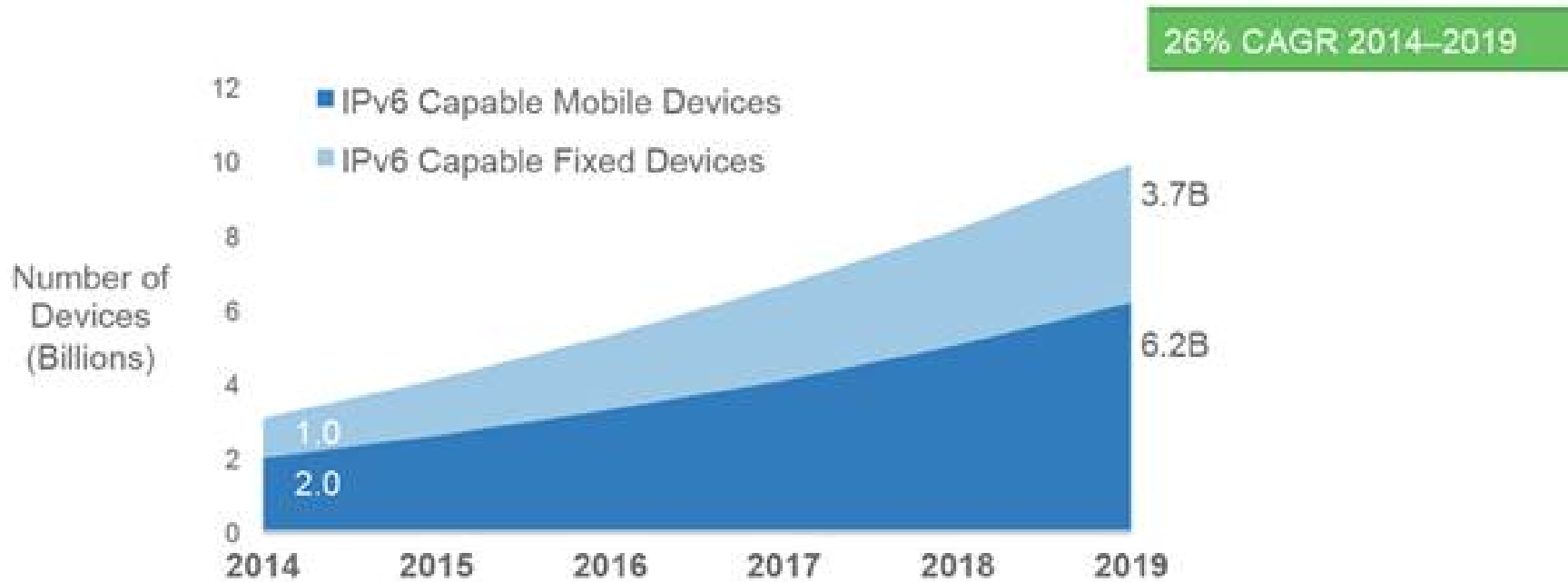
- 2/3 of all traffic will originate from non-PC sources

Video on Demand Traffic



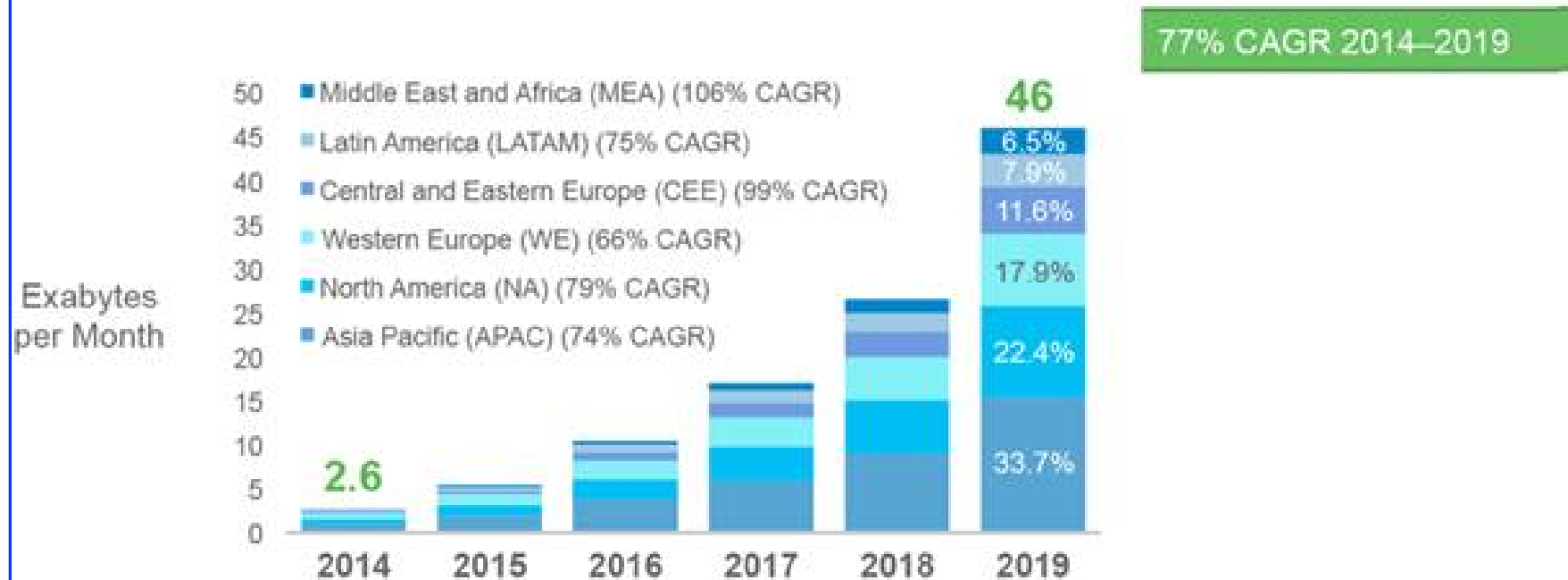
- 4K and HD traffic increasing

IPv6 Devices



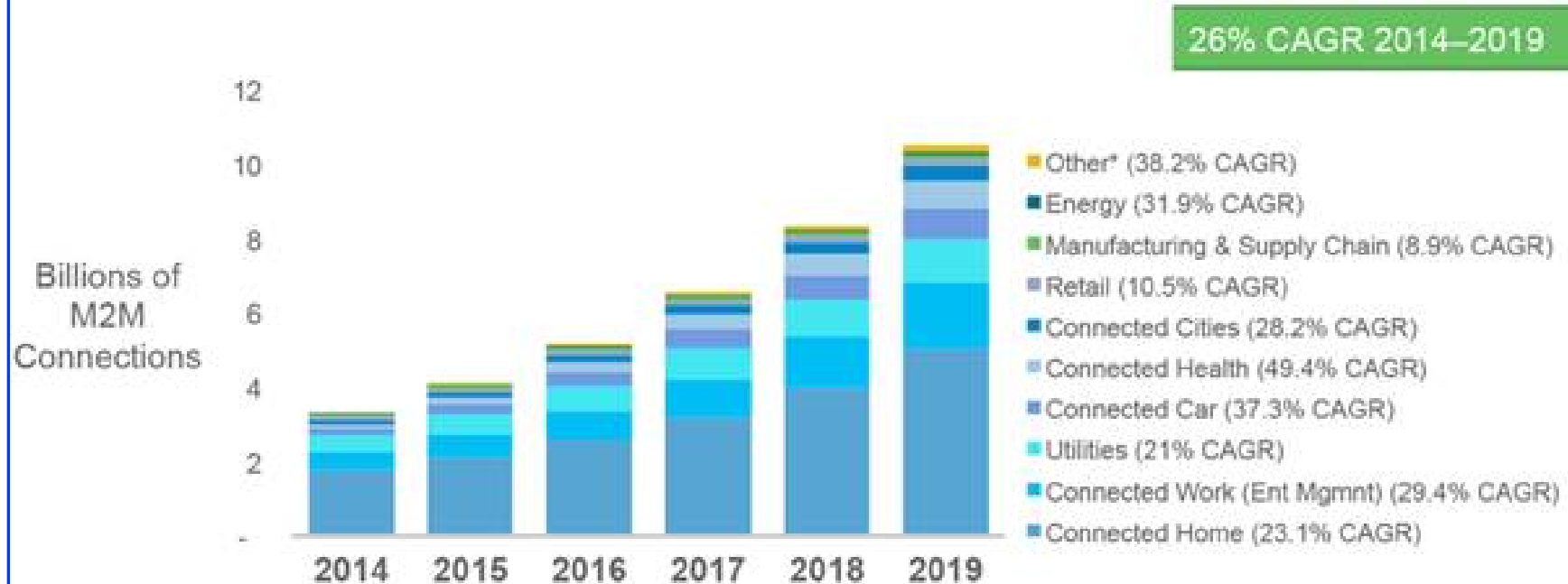
□ 3X IPv6 in 5 years

Geographic Distribution



- Highest growth in Middle East and Africa (MEA)

IoT Growth Areas



*Other includes Agriculture, Construction, & Emergency Services

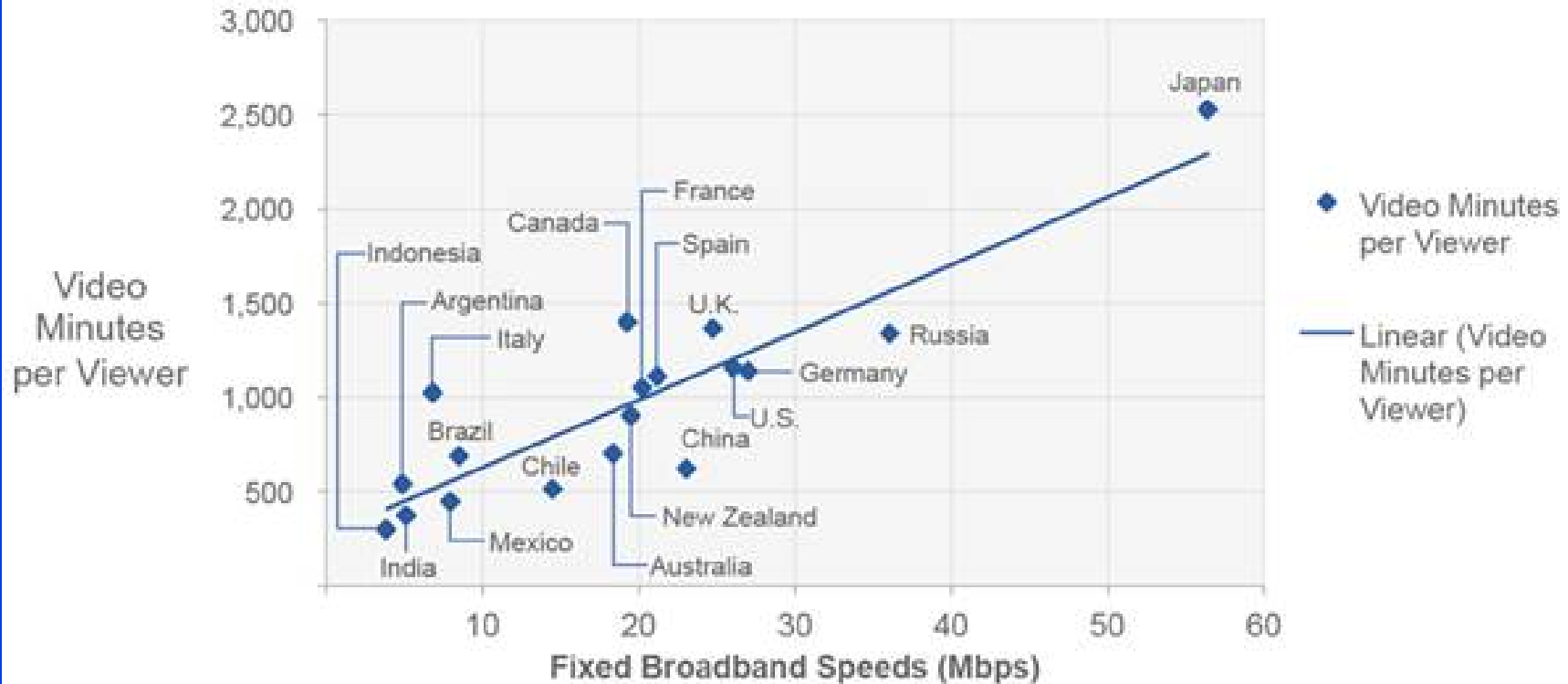
□ Highest growth in connected homes

Application Traffic



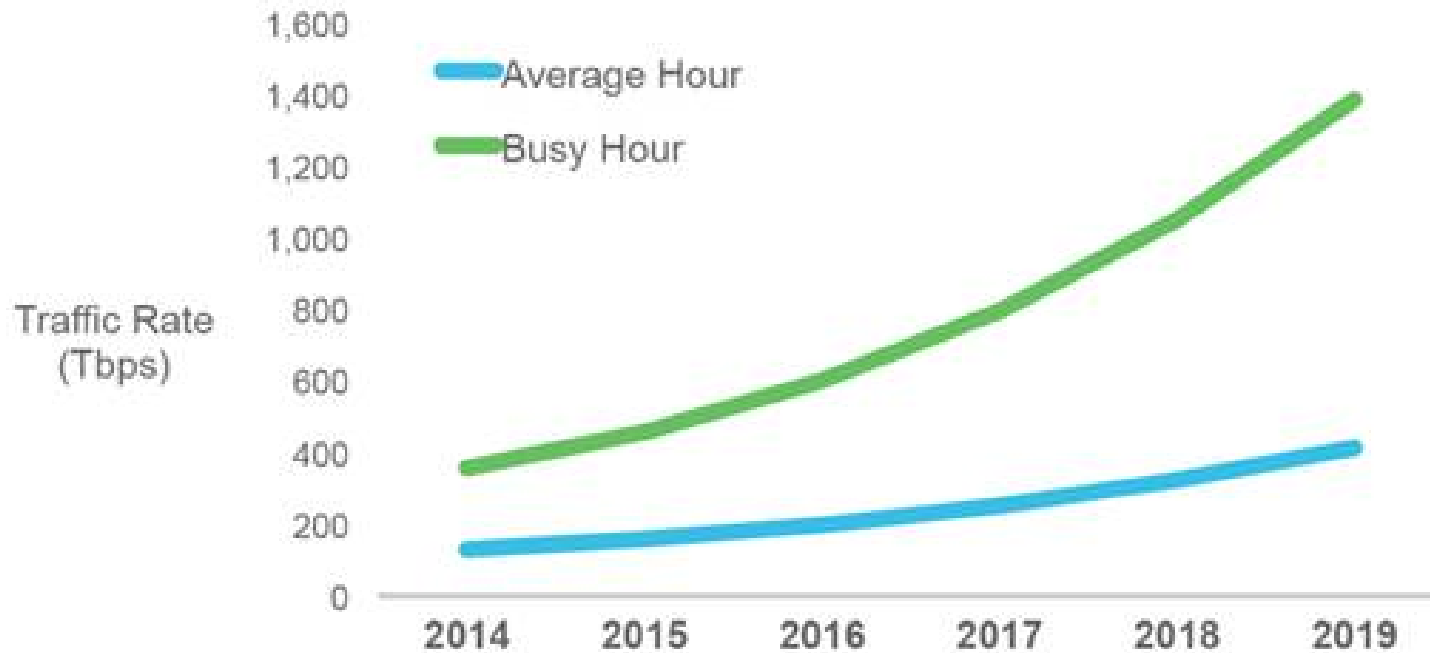
- 80% traffic is video => Highly asymmetric => Time Critical
- P2P distribution could make it symmetric

Broadband Speeds



- ❑ Strong correlation between network speed and minutes of video viewed

Average vs. Busy Hour



□ Prime time video => Busy hour

2015 Info & Comm Tech Figures

1. 7X users in 15 years
6% to 43% of global population
4B people are offline => Significant opportunities ahead
2. 12X increase in mobile broadband in 8 years
69% of global population has access to 3G
89% of urban population, 29% of rural population
3. Fixed broadband increasing very slow: only 7% per year
1.7X more expensive than mobile broadband

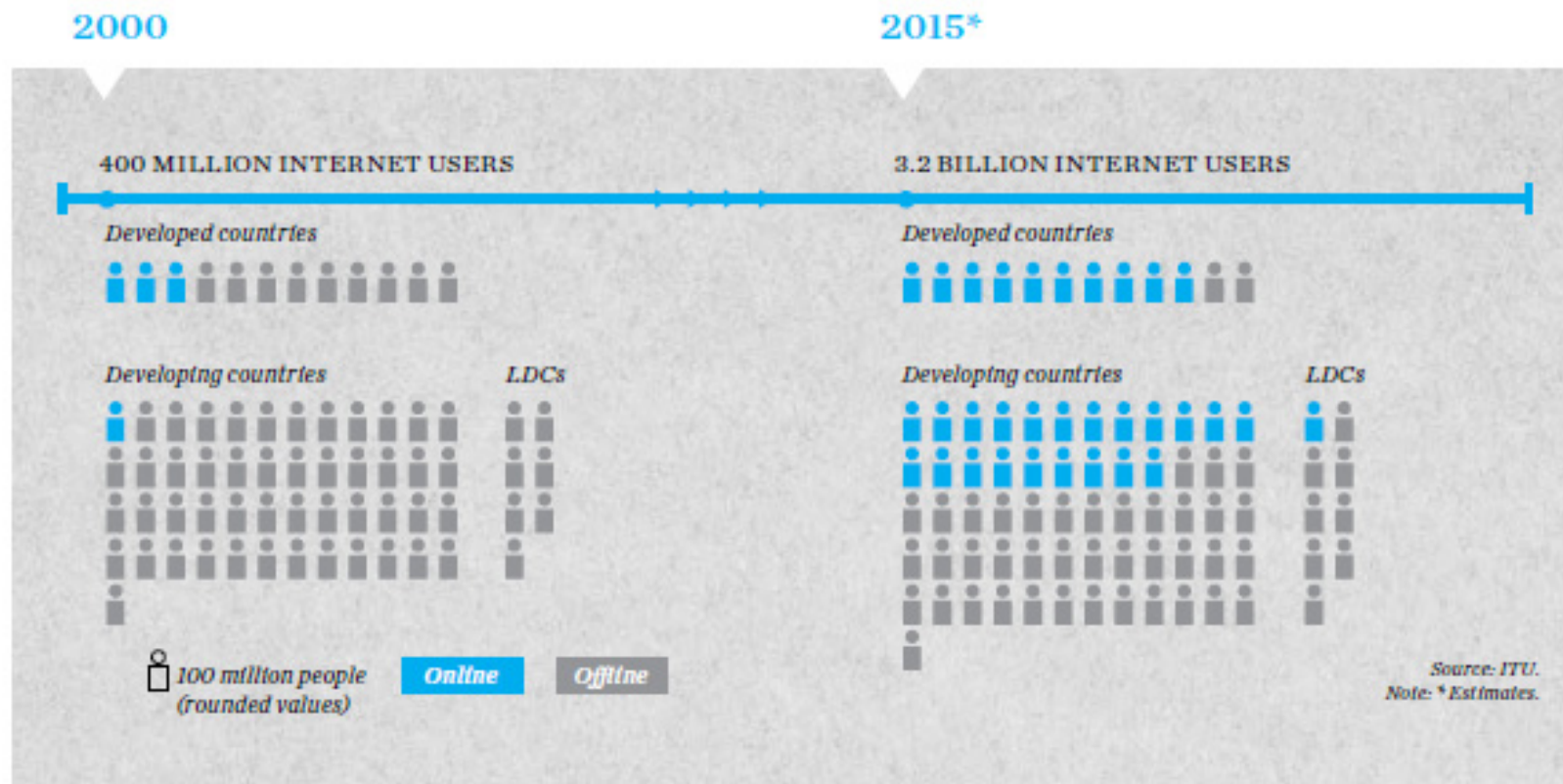
Ref: ITU, "ICT Facts and Figures: The world in 2015," <http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>

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Internet Users: Digital Divide



❑ Least developing countries (LDCs)

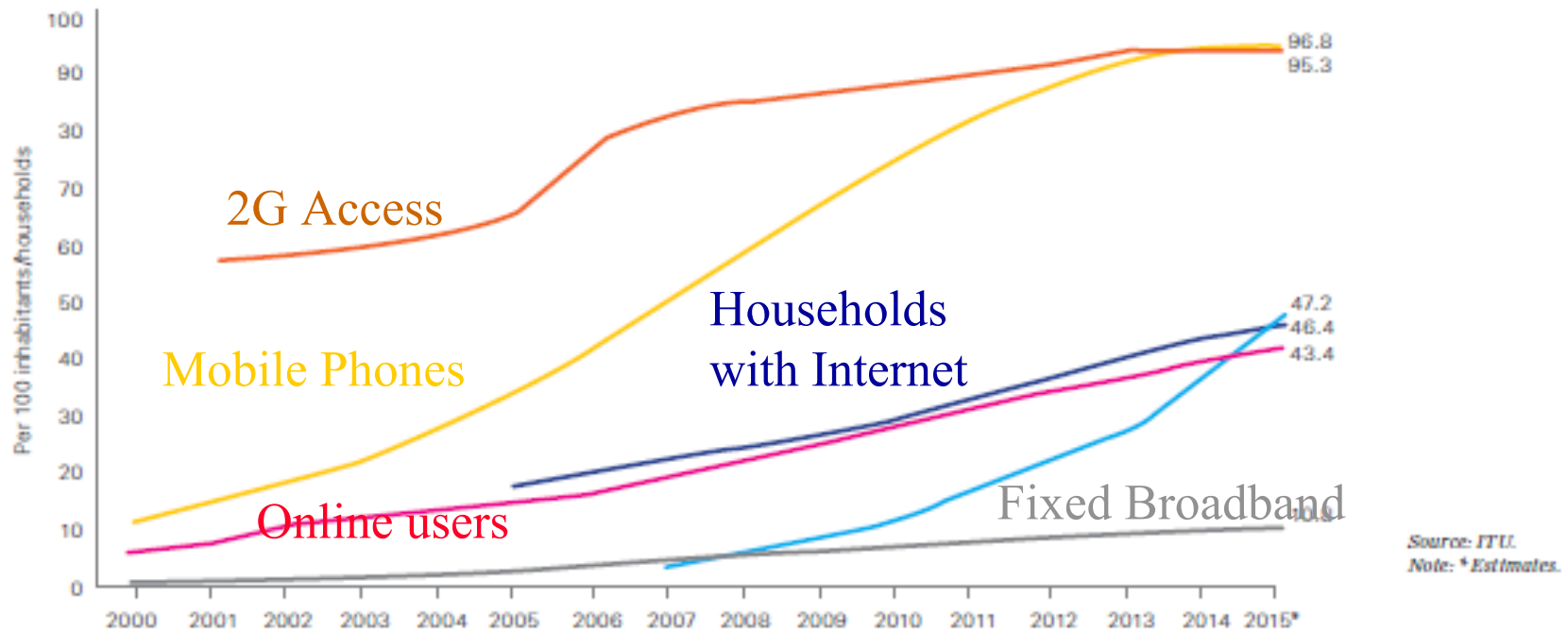
Ref: ITU, "ICT Facts and Figures: The world in 2015," <http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>

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Mobile vs. Fixed



- ❑ Mobile phones rather than fixed broadband is the future for internet access

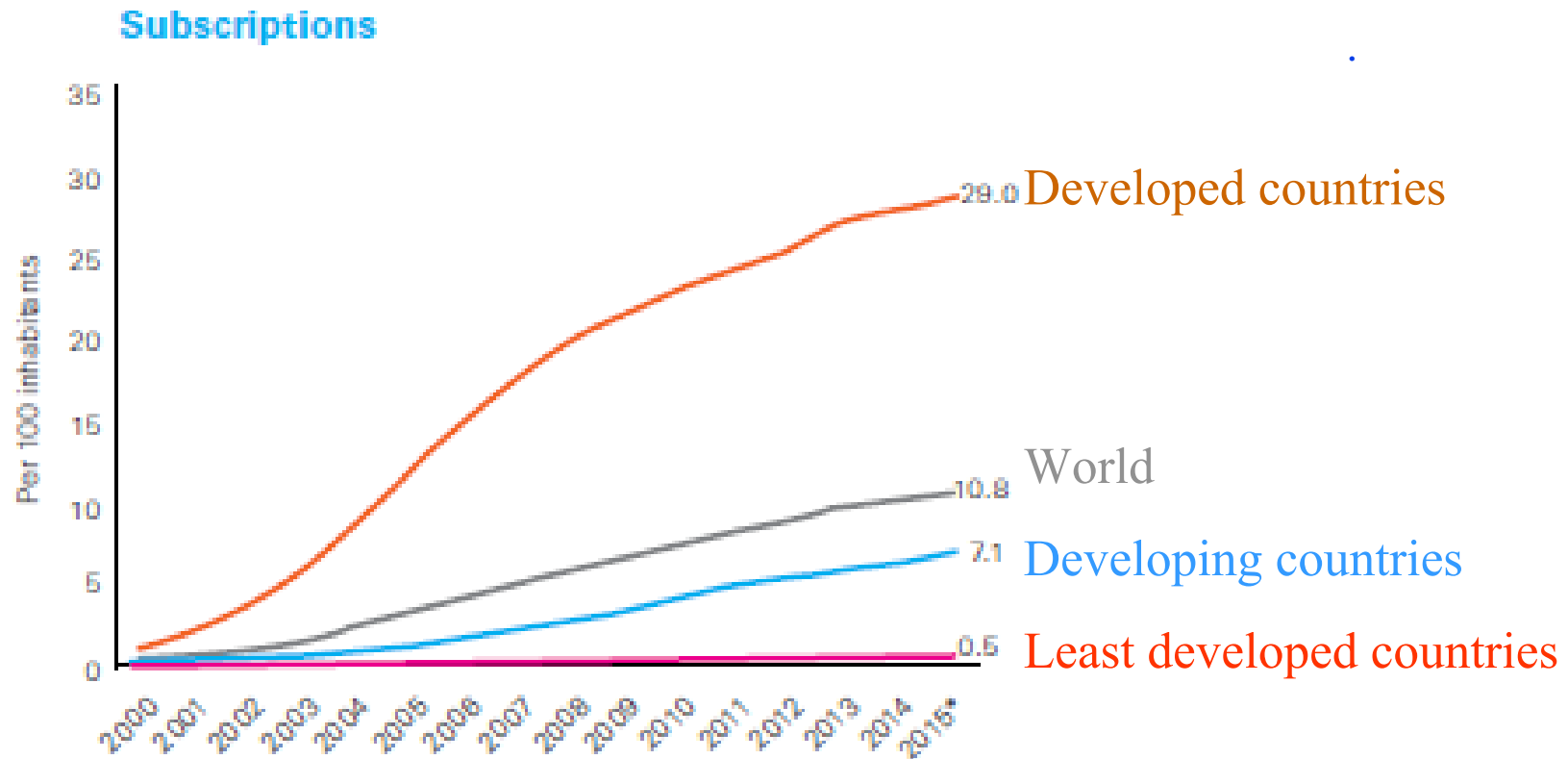
Ref: ITU, "ICT Facts and Figures: The world in 2015," <http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>

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Internet Users



- ❑ Significant work to be done in least developing countries (LDCs)

Ref: ITU, "ICT Facts and Figures: The world in 2015," <http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>

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Internet of Things

- ❑ Only 1% of things around us is connected.
Refrigerator, car, washing machine, heater, a/c, garage door, should all be connected but are not.
- ❑ From 10 Billion today to 50 Billion in 2020
Should include processes, data, things, and people.
- ❑ \$14 Trillion over 10 years
⇒ Third in the list of top 10 strategic technologies by Gartner (After Mobile devices, Mobile Apps, but before Clouds, ...)
- ❑ a.k.a. **Internet of Everything** by Cisco
Smarter Planet by IBM
Industrial Internet by GE
Cyber-Physical Systems (CPS)
Internet of European Things (more popular in Europe)

Ref: "Gartner Identifies Top 10 Strategic Technologies,"

<http://www.cioinsight.com/it-news-trends/gartner-identifies-top-10-strategic-technologies.html>

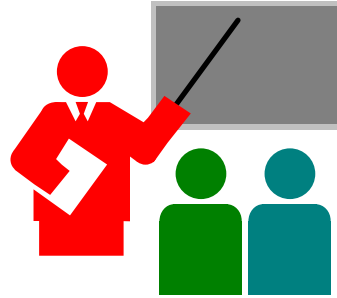
Ref: J. Bradley, "The Internet of Everything: Creating Better Experiences in Unimaginable Ways," Nov 21, 2013,

<http://blogs.cisco.com/ioe/the-internet-of-everything-creating-better-experiences-in-unimaginable-ways/#more-131793>

Cavemen of 2020



Summary: Wireless and Mobile Trends



1. WiFi has grown worldwide in just 15 years
2. 5G, Cognitive radio, M2M, TeraHz, Smart Antennas, LTE Advanced are topics for active research.
3. Wireless speed growth is following Moore's Law
4. Mobile subscriptions are approaching world population
5. Most of the traffic is video

Acronyms

- ❑ AP Access Point
- ❑ CIO Chief Information Officer
- ❑ CIS Commonwealth of Independent
- ❑ CMO Chief Marketing Officer
- ❑ CPS Cyber-Physical Systems
- ❑ DDoS Distributed Denial of Service
- ❑ DSL Digital Subscriber Line
- ❑ GB Giga Byte
- ❑ GE General Electric
- ❑ GHz Giga Hertz
- ❑ Hz Hertz
- ❑ ICT Information and Communications Technologies
- ❑ IEEE Institution of Electrical and Electronic Engineers
- ❑ iOS iPhone Operating System
- ❑ IPTS Institute for Prospective Technological Studies
- ❑ IPv6 Internet Protocol Version 6

Acronyms (Cont)

- ❑ ITU International Telecommunications Union
- ❑ KISDI Korea Information Society Development Institute
- ❑ LTE Long-Term Evolution
- ❑ MIMO Multiple Input Multiple Output
- ❑ MMSE Minimum Mean Squared Error
- ❑ NFC Near Field Communications
- ❑ NGO Non-Governmental Organization
- ❑ OFDM Orthogonal Frequency Division Multiplexing
- ❑ RAN Regional Area Networks
- ❑ RFID Radio Frequency Identification
- ❑ SDN Software-defined networks
- ❑ SSD Solid-state Storage Drive
- ❑ TD-LTE Time-Division Duplexing Long-Term Evolution
- ❑ TeraHz 10^{12} Hertz
- ❑ THz Tera Hertz
- ❑ TV Television

Acronyms (Cont)

- ❑ US United States
- ❑ USB Universal Serial Bus
- ❑ VNI Visual Networking Index
- ❑ WiFi Wireless Fidelity
- ❑ WiGig Gigabit Wireless
- ❑ WLAN Wireless Local Area Network
- ❑ WPAN Wireless Personal Area Network
- ❑ ZigBee Trade name for 802.15.4

Reading List

- ❑ Cisco, “Cisco Visual Networking Index: Forecast and Methodology,” 2014-2019 White Paper,
http://www.cisco.com/c/en/us/solutions/collateral/service-provider/ip-ngn-ip-next-generation-network/white_paper_c11-481360.html
- ❑ ITU, “ICT Facts and Figures: The world in 2015,”
<http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>
- ❑ Gartner, “Gartner Identifies Top 10 Strategic Technologies,”
<http://www.cioinsight.com/it-news-trends/gartner-identifies-top-10-strategic-technologies.html>
- ❑ CTIA, “Wireless Quick Facts,” <http://www.ctia.org/your-wireless-life/how-wireless-works/wireless-quick-facts>

Wikipedia Links

- ❑ http://en.wikipedia.org/wiki/White_spaces
- ❑ http://en.wikipedia.org/wiki/IEEE_802.11ah
- ❑ <http://spectrum.ieee.org/aerospace/military/the-truth-about-terahertz>
- ❑ <http://en.wikipedia.org/wiki/802.11ad>
- ❑ http://en.wikipedia.org/wiki/Smart_antenna
- ❑ http://en.wikipedia.org/wiki/LTE_Advanced
- ❑ http://en.wikipedia.org/wiki/IEEE_802.11ac
- ❑ http://en.wikipedia.org/wiki/Multi-user_MIMO
- ❑ http://en.wikipedia.org/wiki/Wi-Fi_Direct
- ❑ <http://en.wikipedia.org/wiki/802.11u>

Wikipedia Links (Cont)

- ❑ http://en.wikipedia.org/wiki/Small_cell
- ❑ http://en.wikipedia.org/wiki/IEEE_802.22
- ❑ http://en.wikipedia.org/wiki/Super_Wi-Fi
- ❑ http://en.wikipedia.org/wiki/Time-Division_Long-Term_Evolution
- ❑ <http://en.wikipedia.org/wiki/ZigBee>
- ❑ http://en.wikipedia.org/wiki/IEEE_802.11r-2008
- ❑ [http://en.wikipedia.org/wiki/LTE_\(telecommunication\)](http://en.wikipedia.org/wiki/LTE_(telecommunication))
- ❑ http://en.wikipedia.org/wiki/IEEE_802.11n-2009
- ❑ http://en.wikipedia.org/wiki/IEEE_802.11k-2008

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Related Modules



Introduction to 5G,

http://www.cse.wustl.edu/~jain/cse574-16/j_195g.htm

Low Power WAN Protocols for IoT,

http://www.cse.wustl.edu/~jain/cse574-16/j_14ahl.htm



Introduction to Vehicular Wireless Networks,

http://www.cse.wustl.edu/~jain/cse574-16/j_08vwn.htm

Internet of Things,

http://www.cse.wustl.edu/~jain/cse574-16/j_10iot.htm



Audio/Video Recordings and Podcasts of
Professor Raj Jain's Lectures,

<https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw>