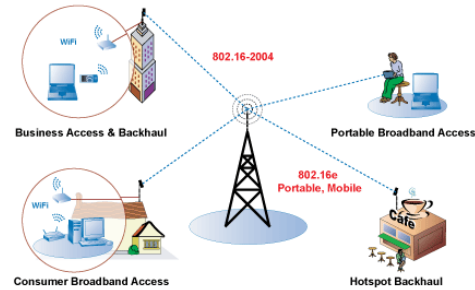


Wireless and Mobile Networking: Facts, Statistics, and Trends



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Audio/Video recordings of this lecture are available at:

<http://www.cse.wustl.edu/~jain/cse574-22/>

Student Questions



1. Wireless: History
2. Life Cycle of Technologies
3. Recent Wireless Innovations
4. Wireless Trends
5. Internet of Things

Student Questions

Billion Dollar Question

Joan
Quigley




White
House
Astrologer

Student Questions

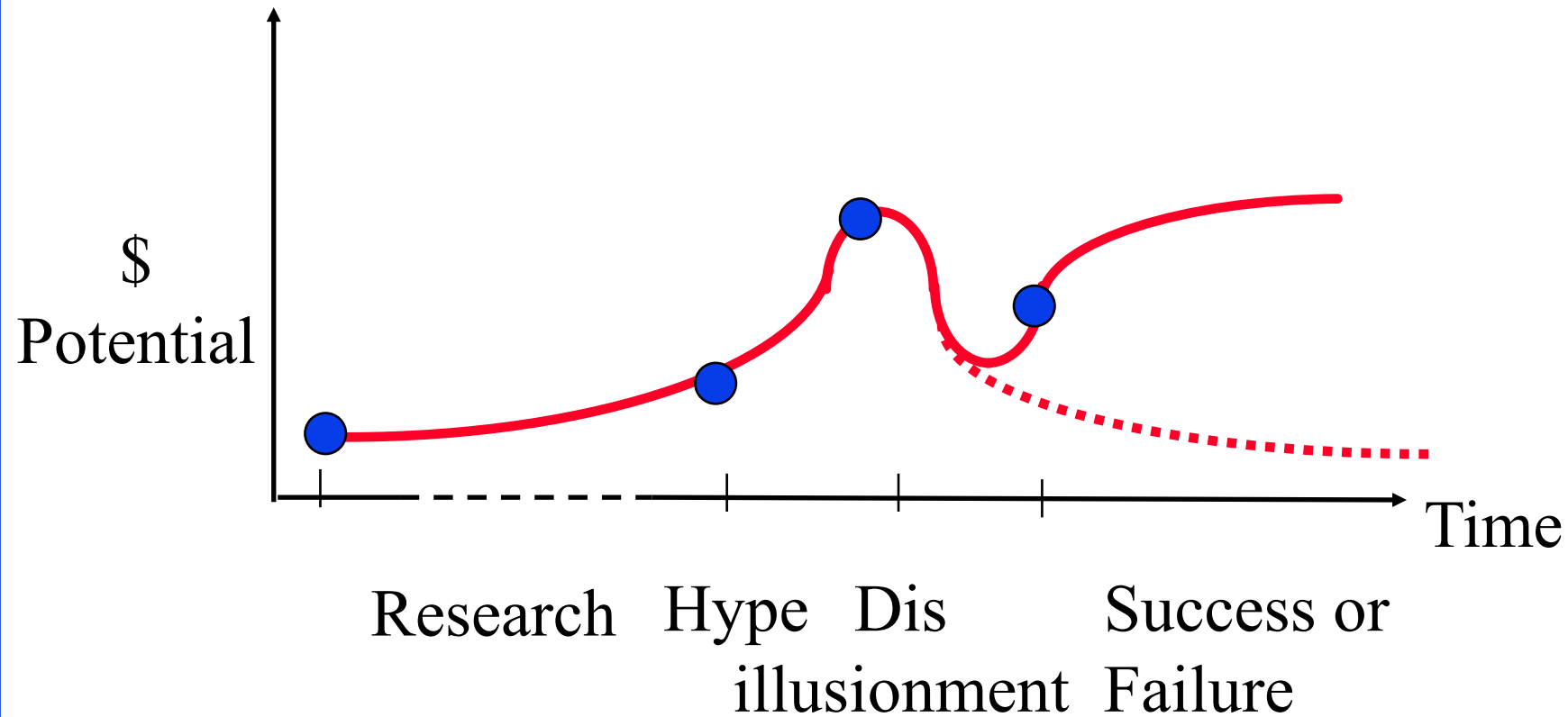
- ❑ All I want you to tell me is what will be the hot networking technology in the year 2020

Wireless: History

- 
- 1880 — 1880: Hertz discovered electromagnetic waves
 - 1898: First commercial radio data service
 - 1900 — 1921: First Mobile Radio:
Wireless dispatch system for Detroit Police
 - 1920 — 1946: First Mobile Telephone Service:
In St. Louis by AT&T. Half-duplex \Rightarrow Push to talk.
 - 1940 — 1970: First Cellular Phone Service: AT&T Chicago
 - 1971: First Wireless Data Network:
Aloha at University of Hawaii
 - 1960 — 1990: First Commercial WLAN Product AT&T
WaveLAN
 - 1980 — 1997: First WLAN Standard - IEEE 802.11 2Mbps
 - 2000 —

Student Questions

Life Cycle of Technologies



Student Questions

Recent Wireless Innovations

- ❑ **5G**: Beyond 4G. 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 Wi-Fi
- ❑ **Wi-Fi Direct**: Point-to-Point Wi-Fi without access point
- ❑ **802.11u**: Authentication for 802.11 hotspots

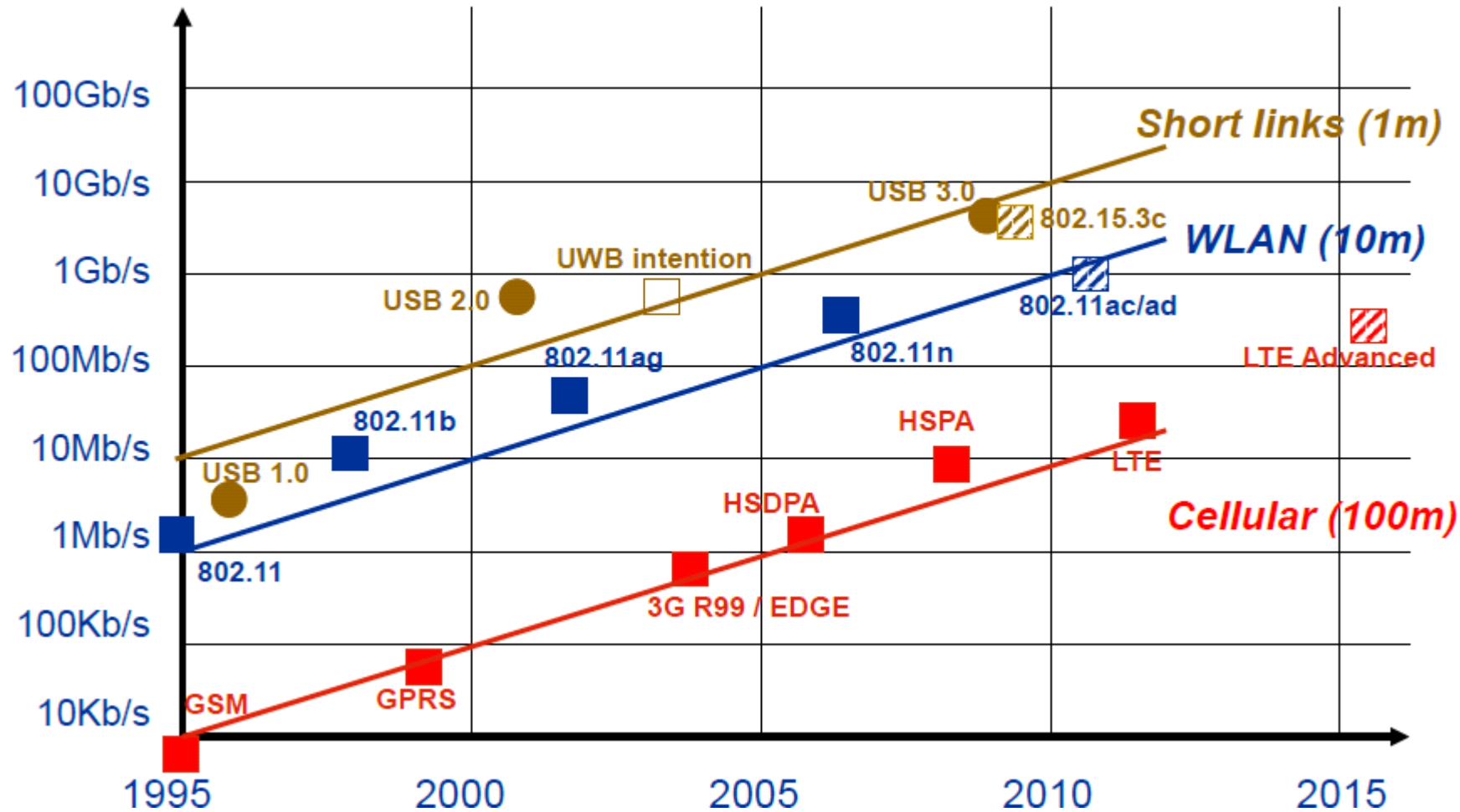
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Wireless Innovations (Cont)

- ❑ **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 Wi-Fi**: 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 Wi-Fi for 802.11
- ❑ **802.11r**: Fast Base Station transition
- ❑ **LTE**: Long-Term Evolution. 3.9G

Student Questions

Wireless Speed Trends



Student Questions

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: 3X in 5 years (2016-2021)
⇒ 24% Compound Annual Growth Rate (CAGR)
2. Busy hour traffic growing faster: 3.2X in 5 years
3. Fixed/Wi-Fi will be 46% of total IP traffic
4. Fixed/wired will be 37%
5. Mobile will be 17% = 46% CAGR
6. IP Video will be 82% of all IP traffic
7. 27.1 billion devices in 2021 ⇒ 3.5 devices per person
8. 43% of devices will be mobile
9. 51% of devices will be M2M (PCs 5%, Tablets 3%)
10. Average broadband speed 53 Mbps

Ref: Cisco, "Cisco Visual Networking Index: Forecast and Methodology, 2016-2021" June 6, 2017, 17 pp.

<https://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.pdf>

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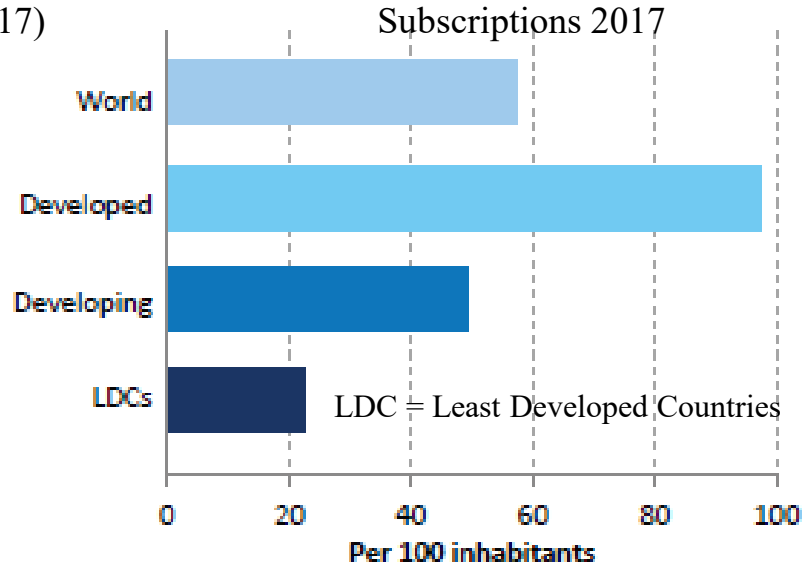
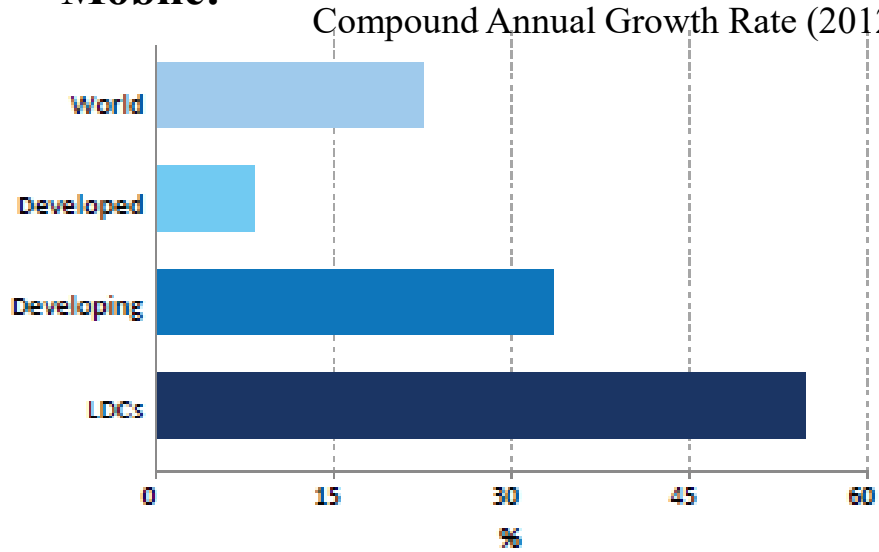
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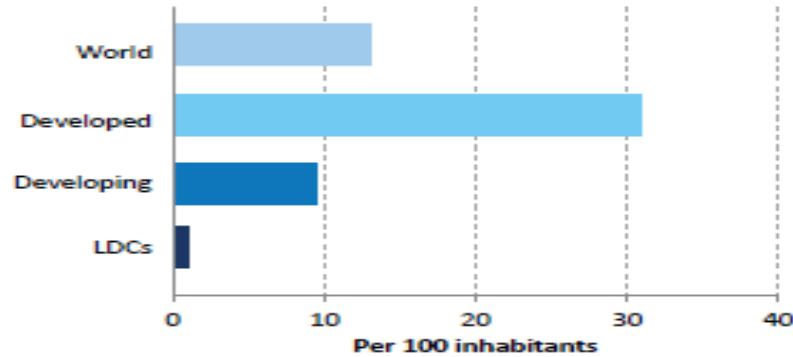
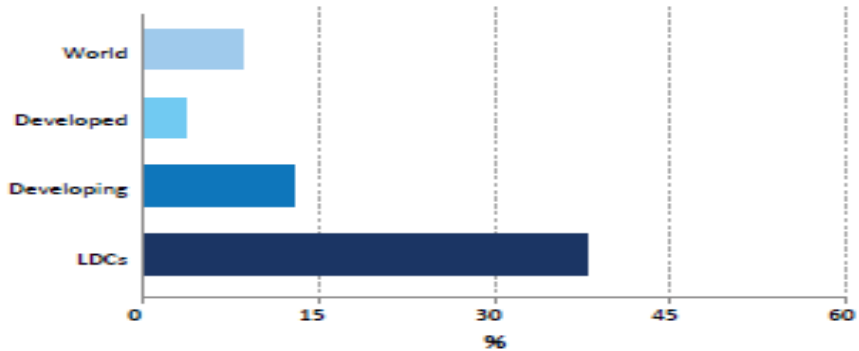
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Broadband Subscriptions

Mobile:



Fixed:



Student Questions

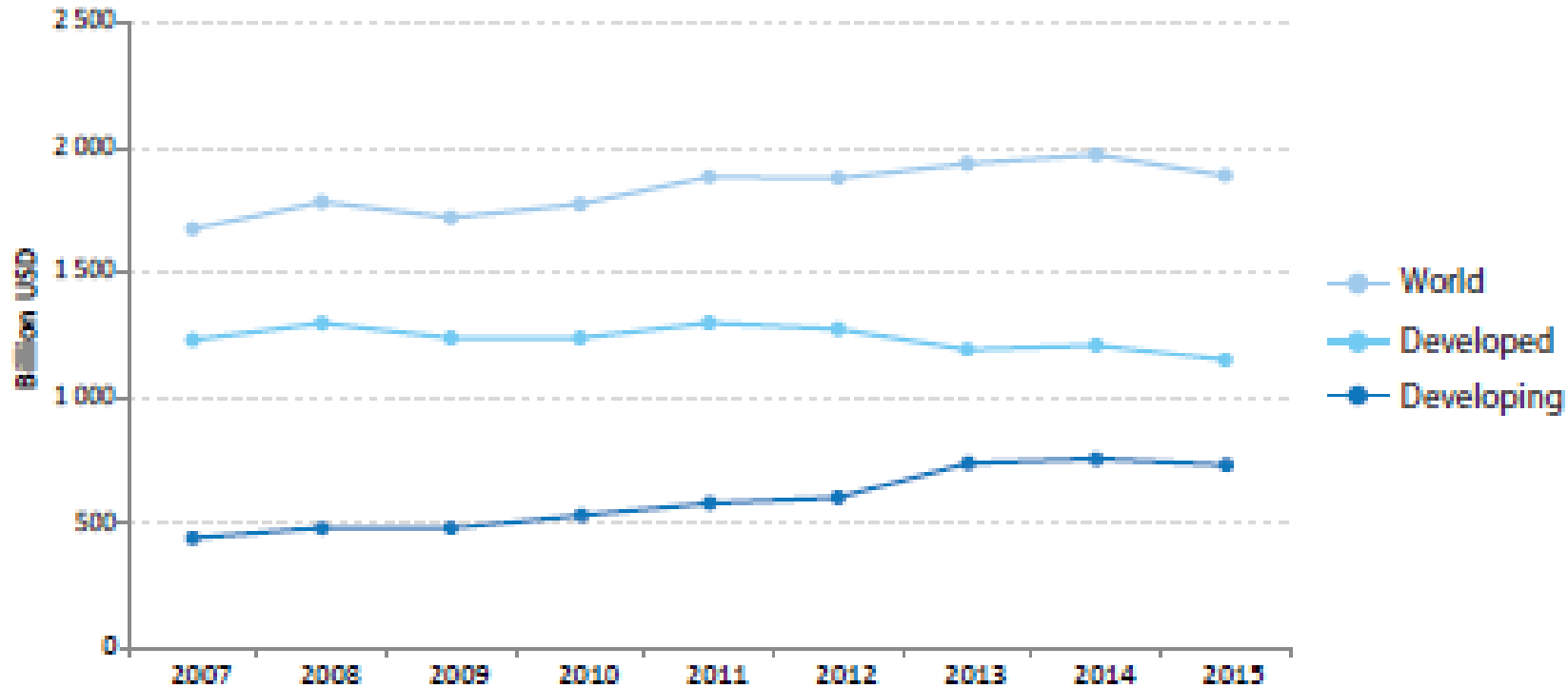
Ref: ITU, "ICT Facts and Figures 2017," 8 pp., <https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf>

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Telecom Revenues



Student Questions

- Revenues declined by 4% between 2014 and 2015.

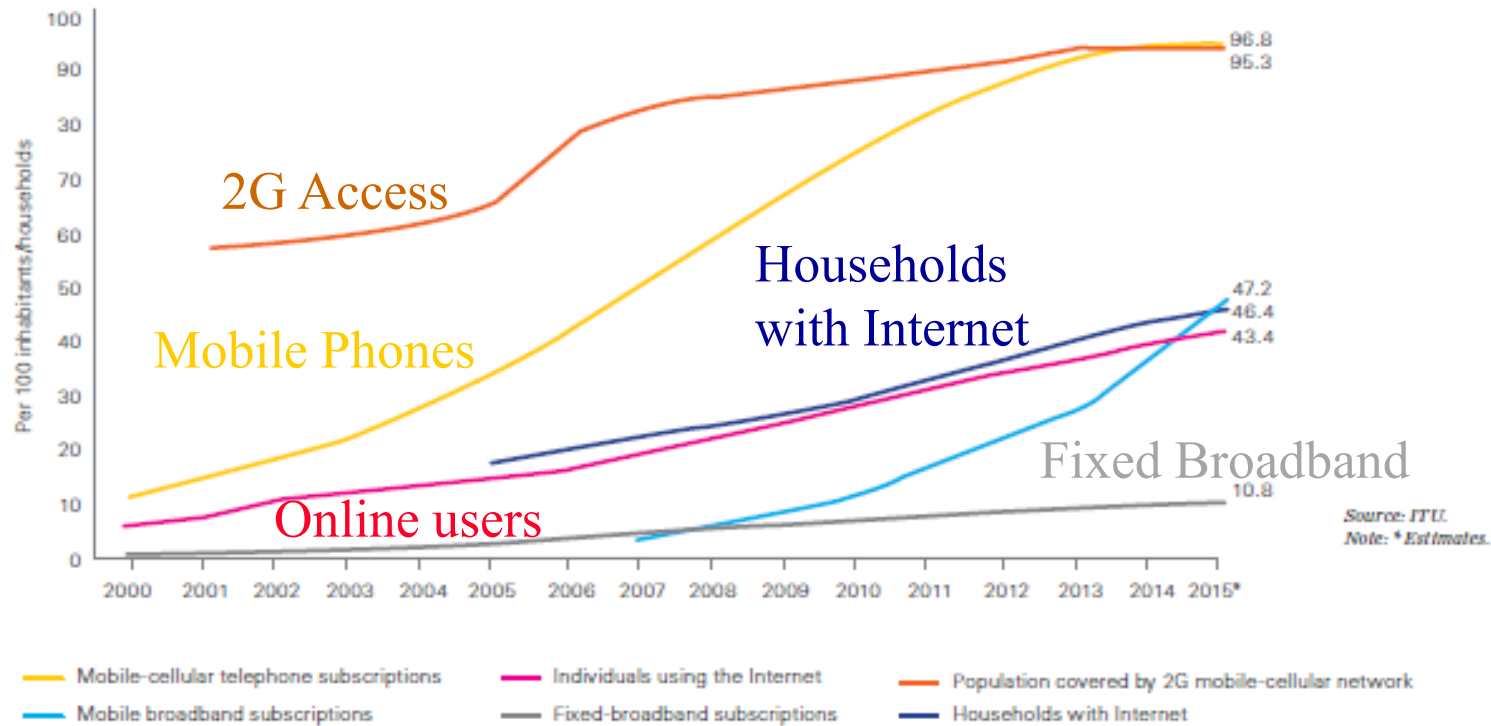
Ref: ITU, "ICT Facts and Figures 2017," 8 pp., <https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFactsFigures2017.pdf>

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Mobile vs. Fixed



Student Questions

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

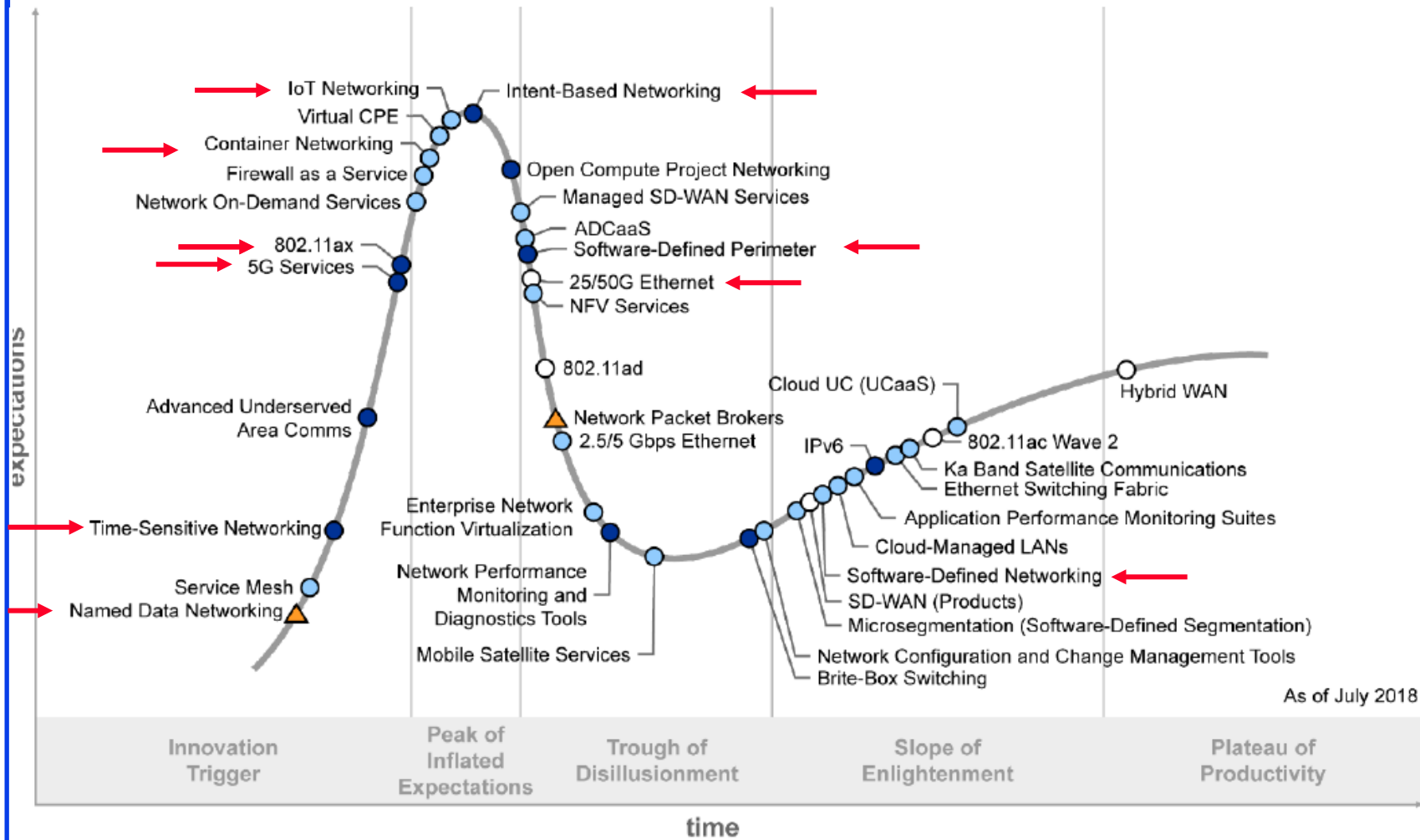
Ref: ITU, "ICT Facts and Figures: The world in 2015," <http://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>

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Hype Cycle for Enterprise Networking and Communications, 2018



Student Questions

Ref: D. Young, M. Toussaint, "Hype Cycle for Enterprise Networking and Communications, 2018," Gartner Report ID G00338722, 13 July 2018, 69 pp.

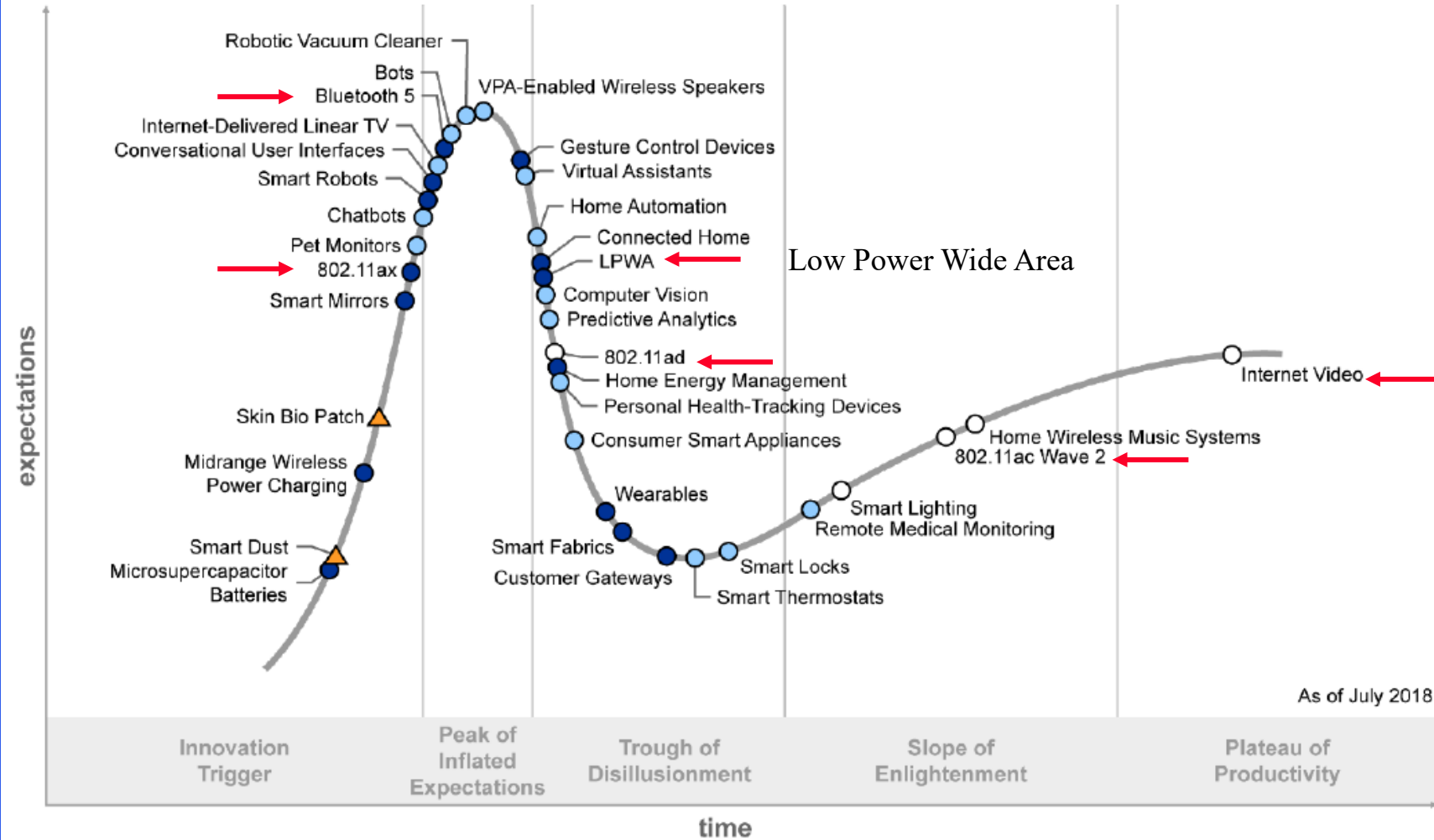
New Networking Tech

- ❑ Service Mesh: μ Service-to- μ service communication
- ❑ Time Sensitive Networking: IEEE standards for real-time
- ❑ Container Networking: IP address management and service registration for containers using embedded switches and routers
- ❑ Virtual Customer Premise Equipment: CPEs using standard equipment and Virtual network functions for routers, firewalls, ...
- ❑ Software Defined Perimeter: Logical separation of network-connected nodes in to a secure computing enclave
- ❑ Micro segmentation: Software defined segmentation to isolate applications in a cloud or datacenter using firewalls or crypto
- ❑ 2.5G/5G and 25G/50G Ethernet

Ref: D. Young, M. Toussaint, "Hype Cycle for Enterprise Networking and Communications, 2018," Gartner Report ID G00338722, 13 July 2018, 69 pp.

Student Questions

Hype Cycle of Connected Homes 2018



Student Questions

Ref: F. Elizalde, "Hype Cycle for the Connected Home, 2018," Gartner Report ID G00340387, 30 July 2018, 68 pp.

New Wireless Technologies

- ❑ **802.11ac Wave 2**: Peak rate of 6 Gbps vs. 1.3 Gbps for Wave 1 using 2.4 and 5.8 GHz
- ❑ **802.11ad**: 7 Gbps using 60 GHz (millimeter wave)
- ❑ **802.11ax**: user throughput 4x 801.11ac
- ❑ **Bluetooth 5**: Longer range than Bluetooth 4.2, higher speeds, mesh networking (Approved Dec 2016)
- ❑ **Low Powered Wide Area (LPWA)**: For IoT. LTE Cat-M1, EC-GSM-IoT, LTE Cat-NB1, LoRa, Sigfox, RPMA, FlexNet, WiSUN, Synergize
- ❑ **Mobile Satellite Services**: 500 kbps and **up**

Student Questions

Ref: F. Elizalde, "Hype Cycle for the Connected Home, 2018," Gartner Report ID G00340387, 30 July 2018, 68 pp.

Internet of Things

- ❑ More IoT devices than mobile phones in 2018
- ❑ 70% of wide-area IoT devices will use cellular
- ❑ Cisco predicts \$457B by 2020 with a CAGR of 28%
- ❑ Statista predicts \$8.9T in 2020
- ❑ Accenture estimates IIoT \$14.2T by 2020
- ❑ Manufacturing dominates IoT connections

Student Questions

Ref: L. Columbus, "2017 Roundup of Internet of Things Forecasts," December 10, 2017,

<https://www.forbes.com/sites/louiscolumbus/2017/12/10/2017-roundup-of-internet-of-things-forecasts/>

Postscapes, "IoT Market Forecasts," August 20, 2018,

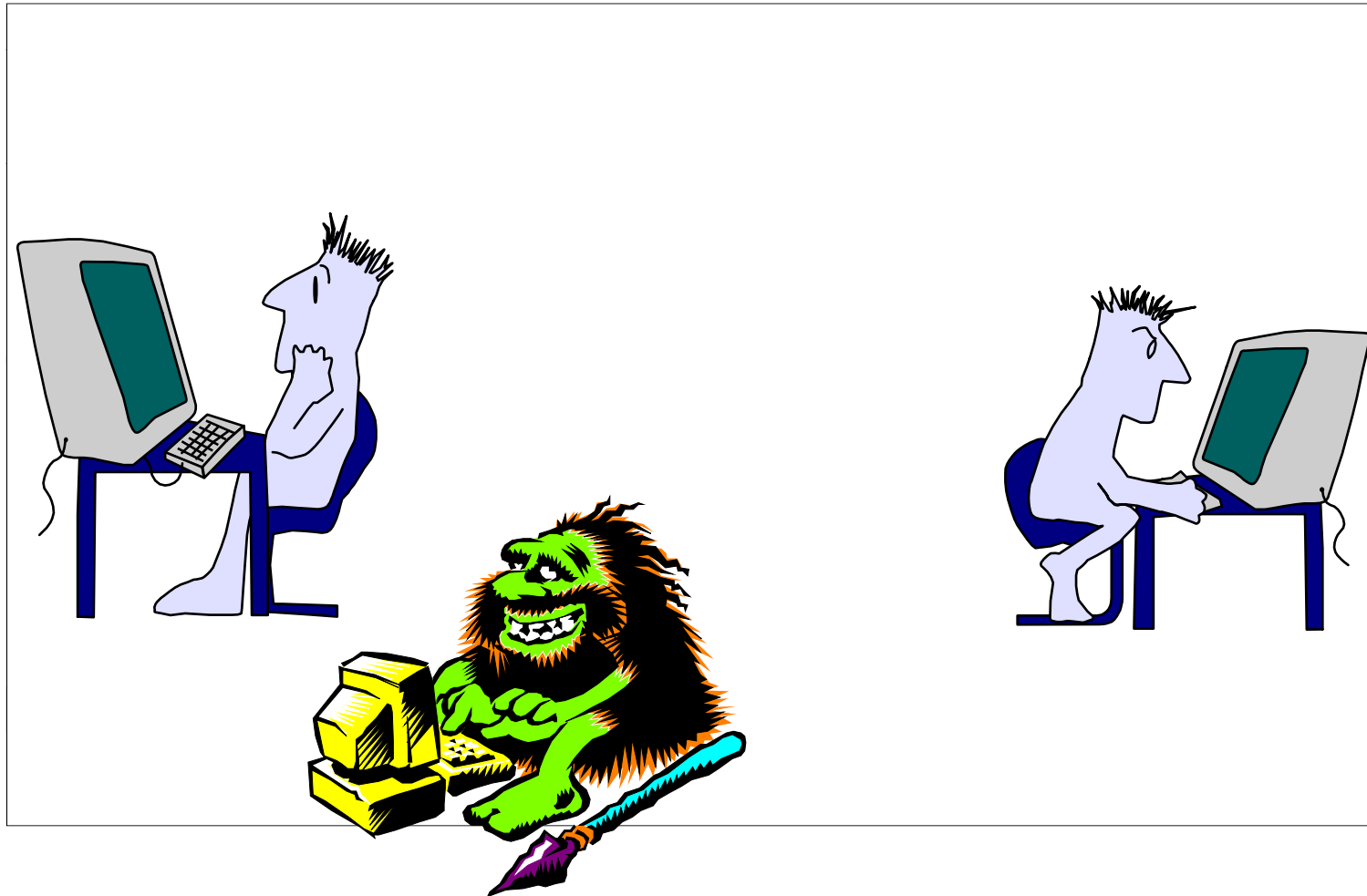
<https://www.forbes.com/sites/louiscolumbus/2017/12/10/2017-roundup-of-internet-of-things-forecasts/>

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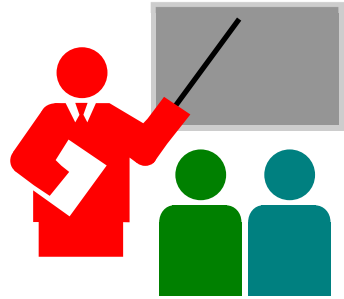
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Cavemen of 2020



Student Questions

Summary: Wireless and Mobile Trends



1. Wi-Fi 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

Student Questions

Reading List

- ❑ K. Takiishi, "Hype Cycle for CSP Networks Infrastructure, 2022," Gartner Report ID G00763254, 20 July 2022, 124 pp., Available to WUSTL Students via <https://one.wustl.edu/task/all/gartner>
- ❑ Cisco, "Cisco Annual Internet Report (2018–2023) White Paper," White Paper, March 9, 2020, 35 pp., <https://www.cisco.com/c/en/us/solutions/collateral/executive-perspectives/annual-internet-report/white-paper-c11-741490.html>
- ❑ ITU, "Measuring digital development: Facts and figures 2021," 2021, 31 pp., <https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2021.pdf>

Student Questions

Homework 2

Based on the latest Cisco and ITU reports in the reading list, answer the following:

1. Number of IP devices will be _____X population
2. In 2021, fixed telephony declined to _____% of the population
3. Over _____% of the population will have mobile connectivity.
_____ % in North America (NA)
4. In 2021, Mobile cellular subscriptions rose to _____%
5. Connected home appliances will form the _____ share of Machine-to-machine communications
6. Connected Cars will be the _____ growing application
7. In 2021, in half of the countries more than _____% own a mobile phone.
8. Mobile Cellular speeds will triple from 13.2 Mbps to 43.9 Mbps
9. Average 5G connection speeds will reach _____ Mbps
10. In 2021, there was _____X growth in attacks

Student Questions

References

- ❑ D. Young, M. Toussaint, "Hype Cycle for Enterprise Networking and Communications, 2018," Gartner Report ID G00338722, 13 July 2018, 69 pp.
- ❑ F. Elizalde, "Hype Cycle for the Connected Home, 2018," Gartner Report ID G00340387, 30 July 2018, 68 pp.
- ❑ L. Columbus, "2017 Roundup of Internet of Things Forecasts," December 10, 2017, <https://www.forbes.com/sites/louiscolumbus/2017/12/10/2017-roundup-of-internet-of-things-forecasts/>
- ❑ Postscapes, "IoT Market Forecasts," August 20, 2018, <https://www.forbes.com/sites/louiscolumbus/2017/12/10/2017-roundup-of-internet-of-things-forecasts/>

Student Questions

Acronyms

- ❑ AT&T American Telephone and Telegraph
- ❑ CAGR Cumulative Annual Growth Rate
- ❑ CIO Chief Information Officer
- ❑ CIS Commonwealth of Independent States
- ❑ CMO Chief Marketing Officer
- ❑ CPE Customer Premises Equipment
- ❑ 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
- ❑ ITU International Telecommunications Union
- ❑ KISDI Korea Information Society Development Institute
- ❑ LDC Least Developed Countries

Student Questions

Acronyms (Cont)

- ❑ LTE Long-Term Evolution
- ❑ MIMO Multiple Input Multiple Output
- ❑ NFC Near Field Communications
- ❑ NGO Non-Governmental Organization
- ❑ OFDM Orthogonal Frequency Division Multiplexing
- ❑ RFID Radio Frequency Identification
- ❑ SSD Solid-state Storage Drive
- ❑ TD-LTE Time-Division Duplexing Long-Term Evolution
- ❑ TeraHz 10^{12} Hertz
- ❑ THz Tera Hertz
- ❑ TV Television
- ❑ US United States
- ❑ USB Universal Serial Bus
- ❑ Wi-Fi Wireless Fidelity
- ❑ WiGig Gigabit Wireless
- ❑ WLAN Wireless Local Area Network
- ❑ ZigBee Trade name for 802.15.4

Student Questions

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Raj Jain

<http://rajjain.com>

Student Questions

http://www.cse.wustl.edu/~jain/cse574-22/j_02trn.htm

Related Modules



CSE567M: Computer Systems Analysis (Spring 2013),
https://www.youtube.com/playlist?list=PLjGG94etKypJEKjNAa1n_1X0bWWNyZcof

CSE473S: Introduction to Computer Networks (Fall 2011),
https://www.youtube.com/playlist?list=PLjGG94etKypJWOSPMh8Azcg5e_10TiDw



Recent Advances in Networking (Spring 2013),
<https://www.youtube.com/playlist?list=PLjGG94etKypLHyBN8mOgwJLHD2FFIMGq5>

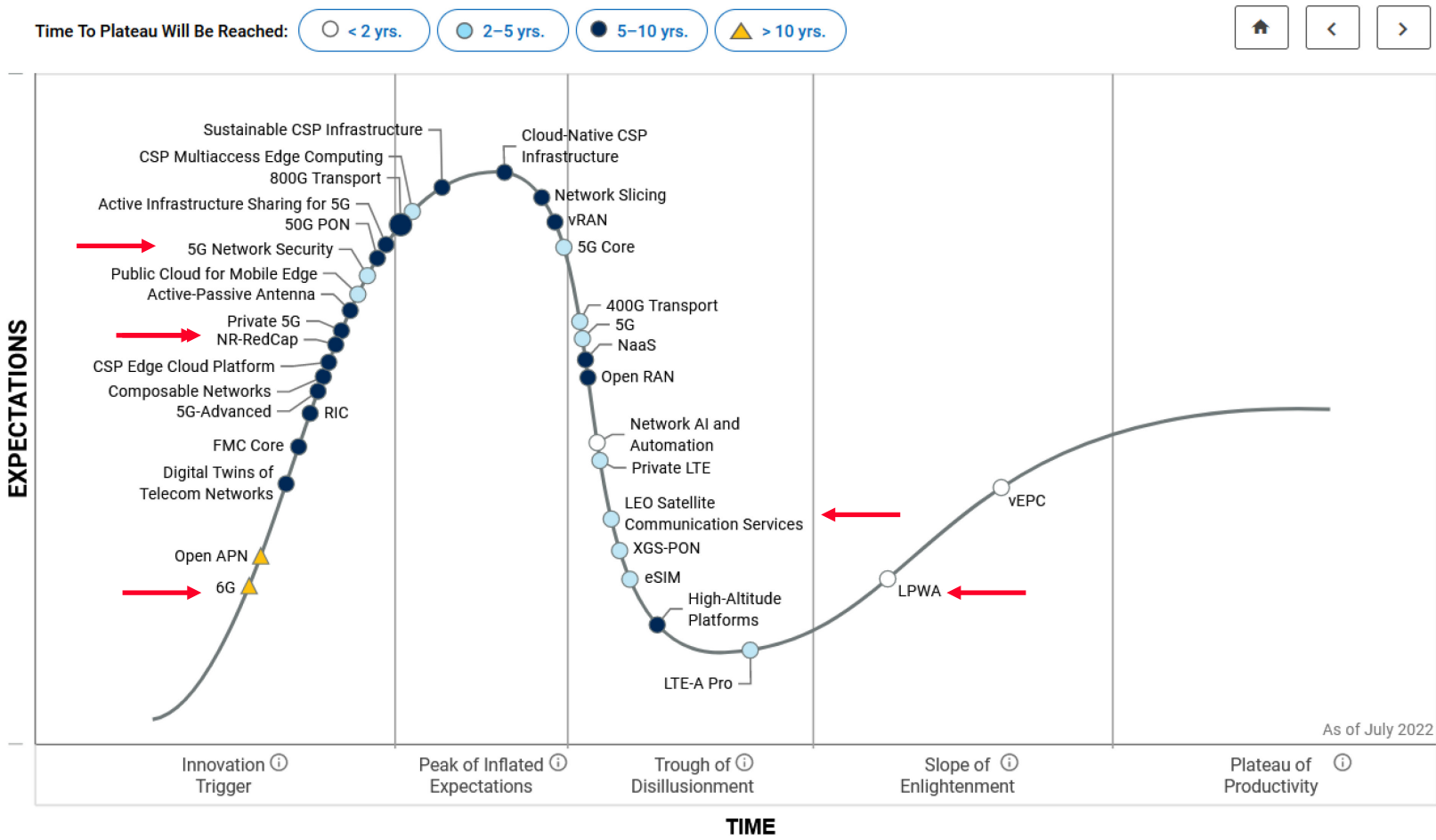
CSE571S: Network Security (Fall 2011),
<https://www.youtube.com/playlist?list=PLjGG94etKypKvzfVtutHcPFJXumyyg93u>



Video Podcasts of Prof. Raj Jain's Lectures,
<https://www.youtube.com/channel/UCN4-5wzNP9-ruOzQMs-8NUw>

Student Questions

Hype Cycle for CSP Networks Infrastructure, 2022



Student Questions

❑ CSP=Communications Service Provider aka Carriers

Ref: K. Takiishi, "Hype Cycle for CSP Networks Infrastructure, 2022," Gartner Report ID G00763254, 20 July 2022, 124 pp., Available to WUSTL Students via <https://one.wustl.edu/task/all/gartner>

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New Wireless Technologies

- ❑ Low Powered Wide Area Network (LPWA): Meter reading
- ❑ High-Altitude Platforms: Balloons or Planes
- ❑ LEO Satellite Communications: SpaceX and Amazon
- ❑ Private 5G: 5G for in-company use
- ❑ 5G Advanced: Soon
- ❑ 6G: in 2030
- ❑ Reduced Capability New Radio (NR-RedCap): 5G for IoT

Student Questions

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