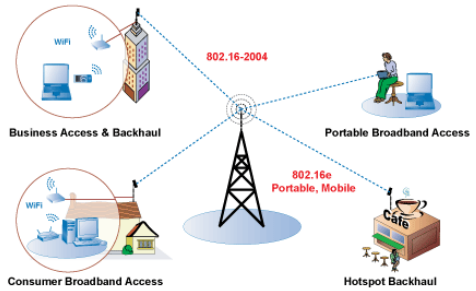
Wireless and Mobile Networking: Facts, Statistics, and Trends



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Audio/Video recordings of this lecture are available at:

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

Student Questions

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Q on 4,9b,16, 21

Overview

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

Student Questions

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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 2020

Student Questions

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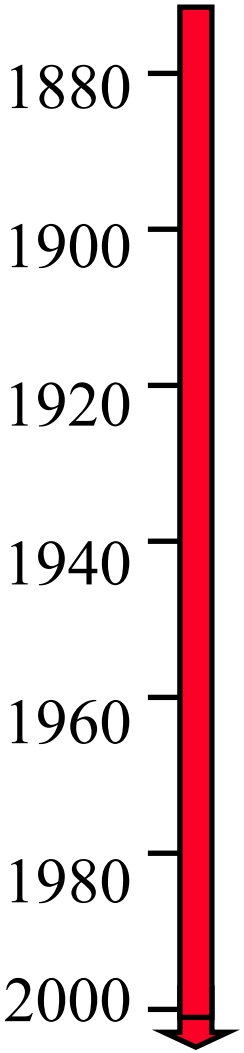
Wireless: History



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

Student Questions

- What exactly is WaveLAN, and how is it different from a WLAN?

WLAN= Wireless LAN
WaveLAN = Wireless service by AT&T

- How did mobile phones work between 1946 and 1970 without cellular? Is cellular just a way to organize the network?

Point to Point. Walkie-talkie.

- How do we communicate to those people in other "cells"? I mean in different frequency?

Cell to cell is generally wired between the cell offices/towers.

- Is this included in the exam?

Yes, years are not important.

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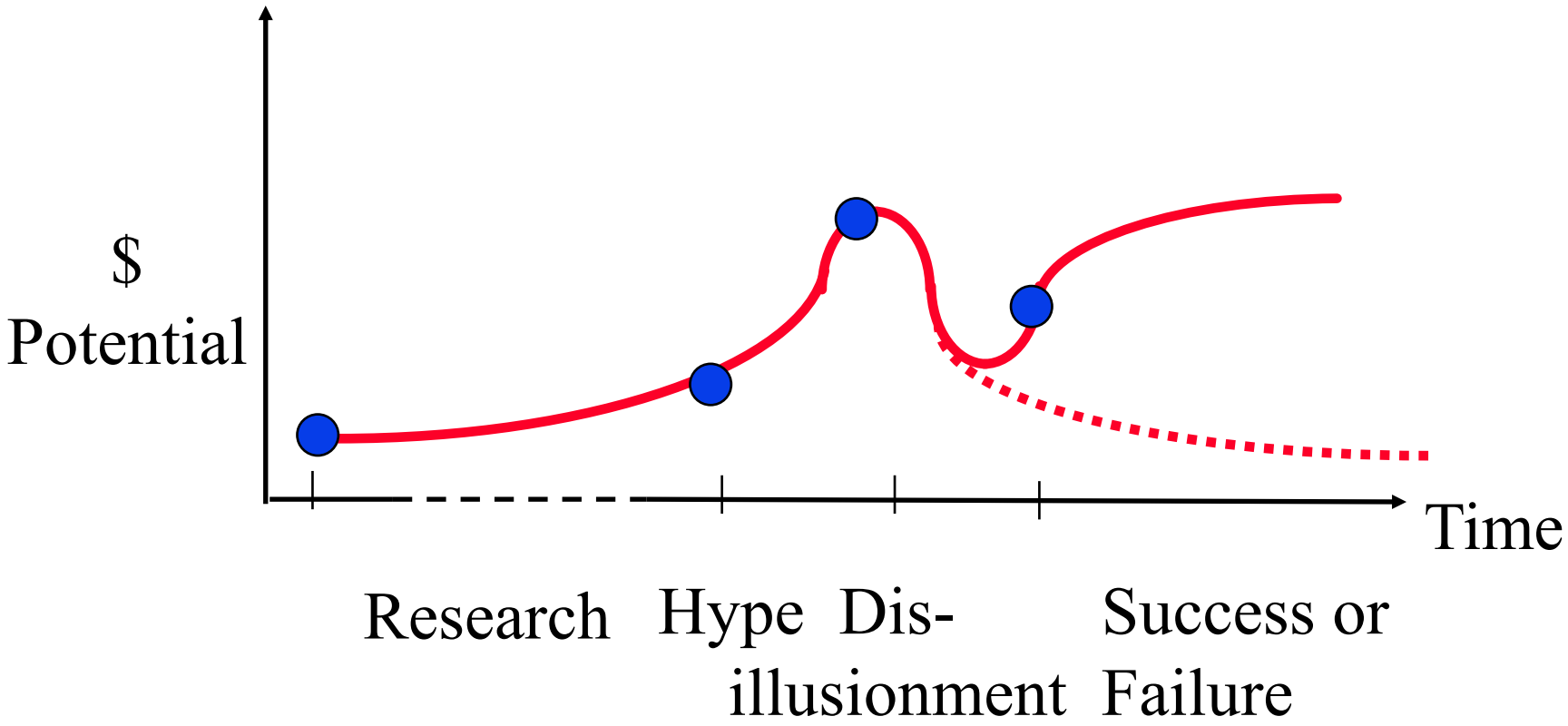
Life Cycle of Technologies



Student Questions

- What do "hype" and "dis" mean in this figure?

Hype = What the world believes. It May or may not be valid.
Disillusionment = Finding that some belief isn't true.

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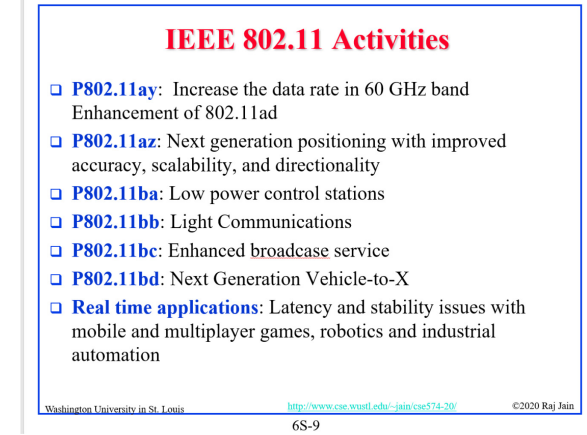
Recent Wireless Innovations

- **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

Student Questions

- Since 802.11ad exists now -- what is the "next" thing for wireless?

See Slide 6S-9 in the "Supplement to Wireless LANs Part II: 802.11a/b/g/n/ac"



- Can you please explain how smart antennas work?

It will be explained briefly in Modules 3 and 4.

Recent Wireless Innovations

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Student Questions

- For Wi-Fi direct, will the point-to-point direct links between buildings be a form of ad hoc wireless?

Wi-Fi Direct = Access point built-in, e.g., in printers and other server devices, including smartphones (for screen sharing).

- What frequency range can cognitive radios operate in so far?

Television frequencies are where they are most required.

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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

- I had never heard of the smaller cells before. Do they boost the cell tower's signal, or are they connected to the service another way?

Small cells are now everywhere. Particularly inside shopping malls. Work with a wireless or wired connection to the core network.

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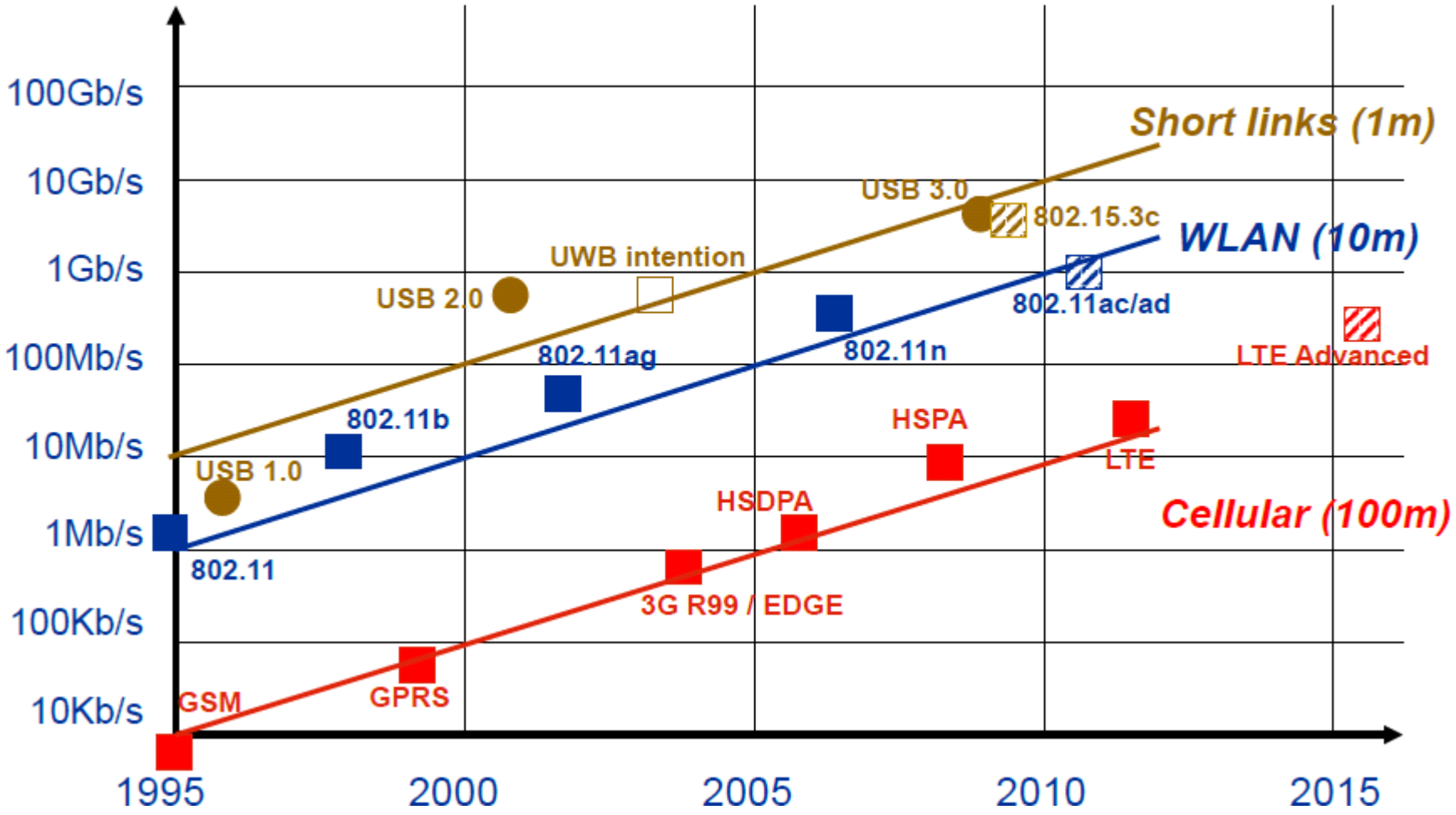
Wireless Speed Trends



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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Student Questions

- Where would 5G be on this graph? Will it be close to (or above?) the WLAN line since it is 100X more powerful than LTE?

5G is on the red line. It is the next generation of LTE advanced.

- By cellular links (100m), do you mean microwave links?

Cellular = Cellular topology for towers
Microwave = Wavelength or Frequency
You can have either or both.

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

Student Questions

- 51% of devices will be M2M, the Internet of things, non-computer. Does that mean 49% of devices will be a computer?

51% M2M = IoT
49% Non-IoT

- To clarify: a mobile phone within the Internet of Things?

Thing = Not a computer.
Smartphones are now computers.
No longer IoT.

- The prediction was made that in 2021 there would be 27.1 billion devices (3.5 per person). Do we know how close that prediction was now that it is 2022?

See homework 2.

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Global Mobile Data Forecast [Cisco]

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

Student Questions

- ❑ Why is 17% mobile IP traffic equal to 46% CAGR?

CAGR = Cumulative annual growth rate = Slope

- ❑ Is data like this required in the exam?

Not specific numbers but directions, yes.

- ❑ M2M doesn't precisely equal IoT?

M2M = A machine serving another machine

IoT = "Things" connected to the Internet

- ❖ Is there any device that could be IoT but not M2M?

Digital devices controlled via the Internet are IoT, e.g., modern thermostats. M2M is the subset that serves another machine, e.g., Industrial controllers.

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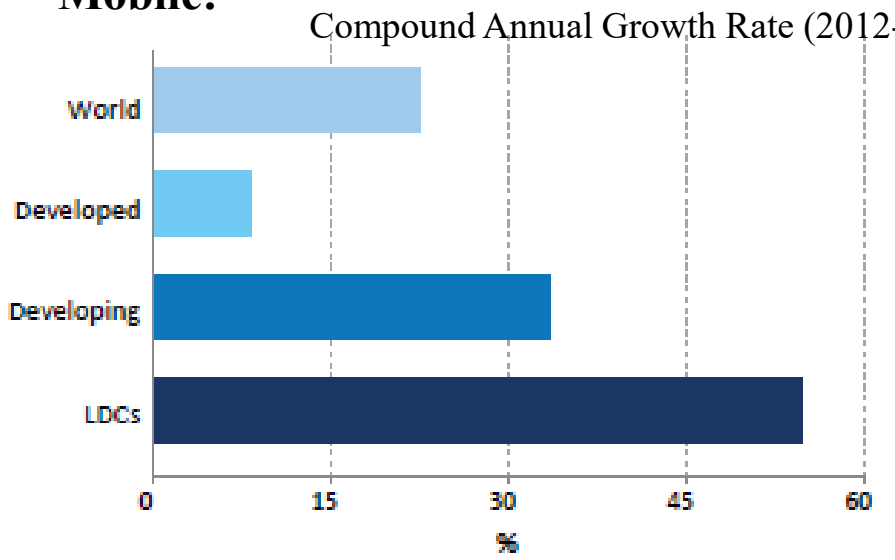
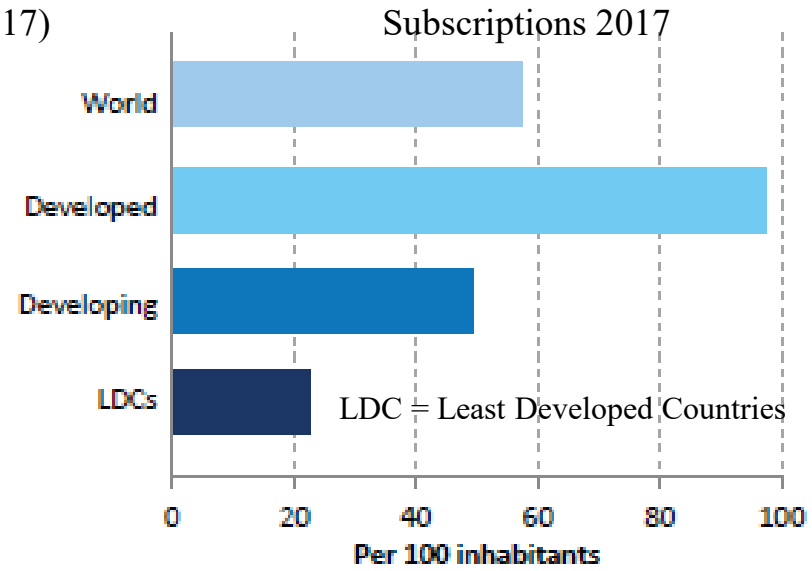
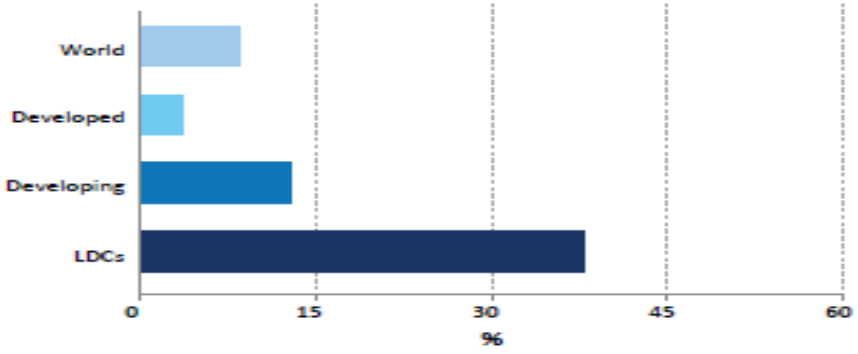
Broadband Subscriptions

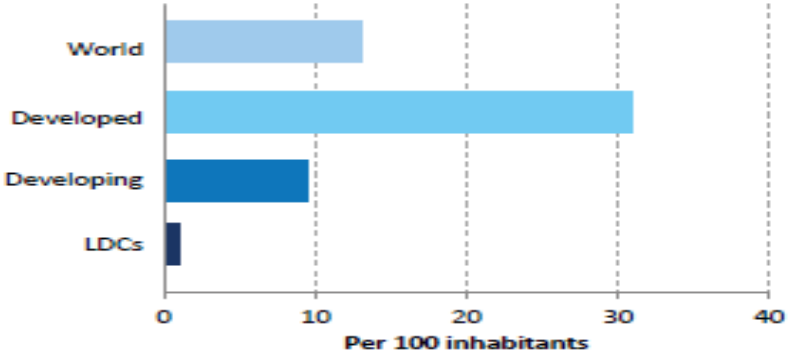
Mobile:





Fixed:





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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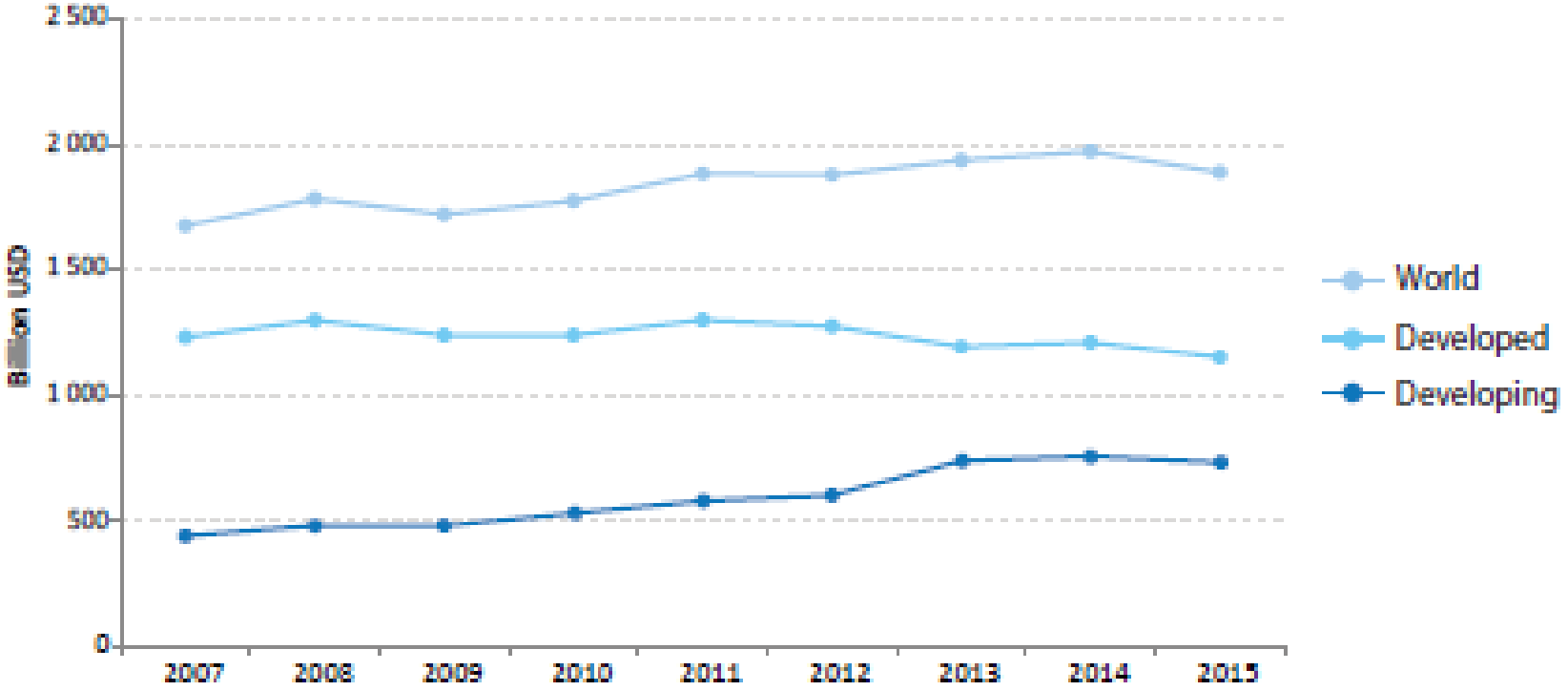
Student Questions

- With fixed traffic decreasing, are there any technology that leverages the existing fixed telephone infrastructure like White-Fi?

Yes, core part of fixed telephone infrastructure was fiber. It is being used for Internet and Video delivery. The edge's were copper that are being used to provided DSL internet but are being replaced by fiber to provide high speed Internet and Video. Telephone ⇒ Telecommunications

Telecom Revenues



- Revenues declined by 4% between 2014 and 2015.

Student Questions

- Are telecom revenues still declining in 2020? I would think the opposite due to most work being moved online

Lower price and higher cost is continuing. I have 200 Mbps for $50/month. Used to get 110 bps on modem for $50/month in 1974.

- I wonder why the world's revenue is higher than that of developed and developing countries. What is the trend in the least developed countries?

World = Developed + Developing + Least developed

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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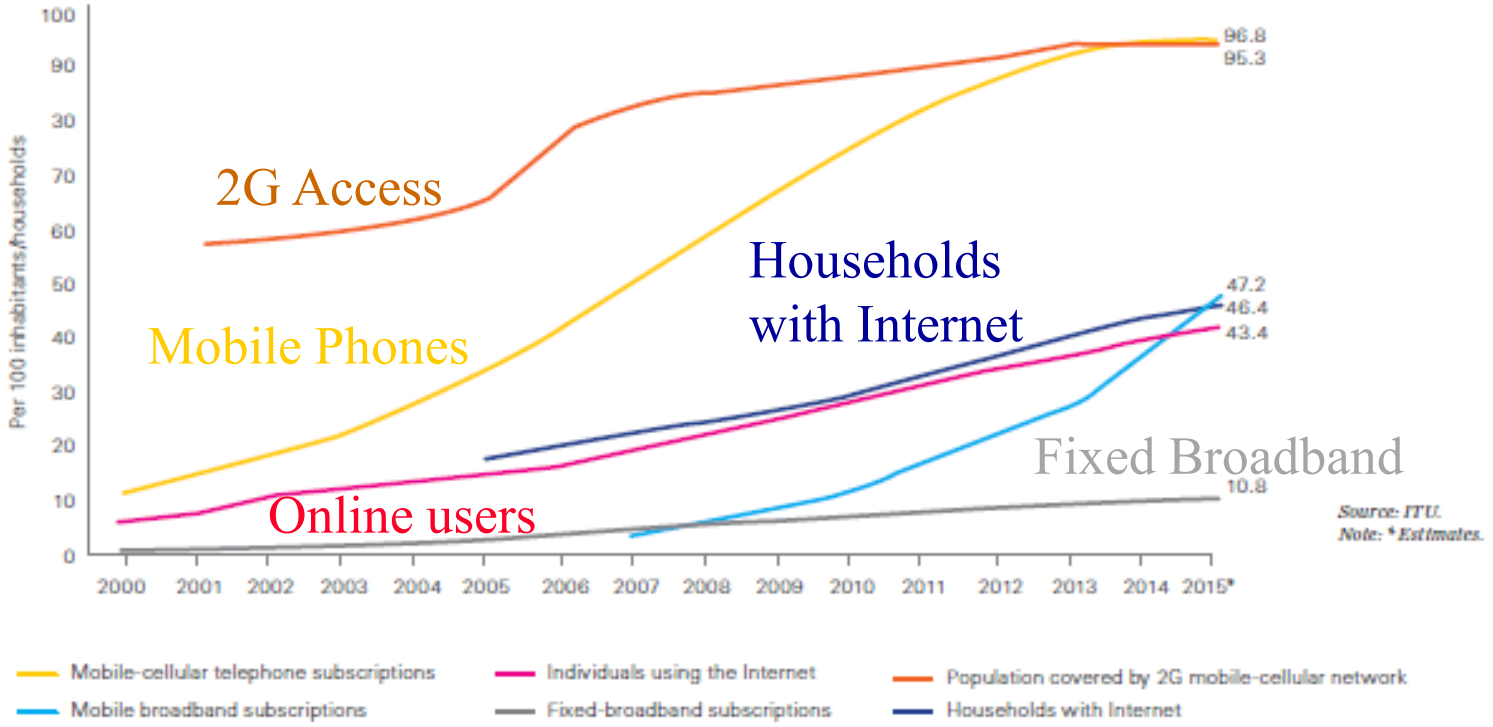
Mobile vs. Fixed



- 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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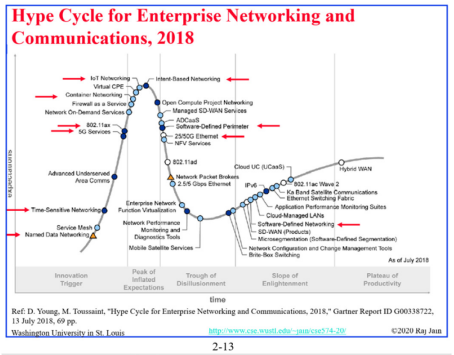
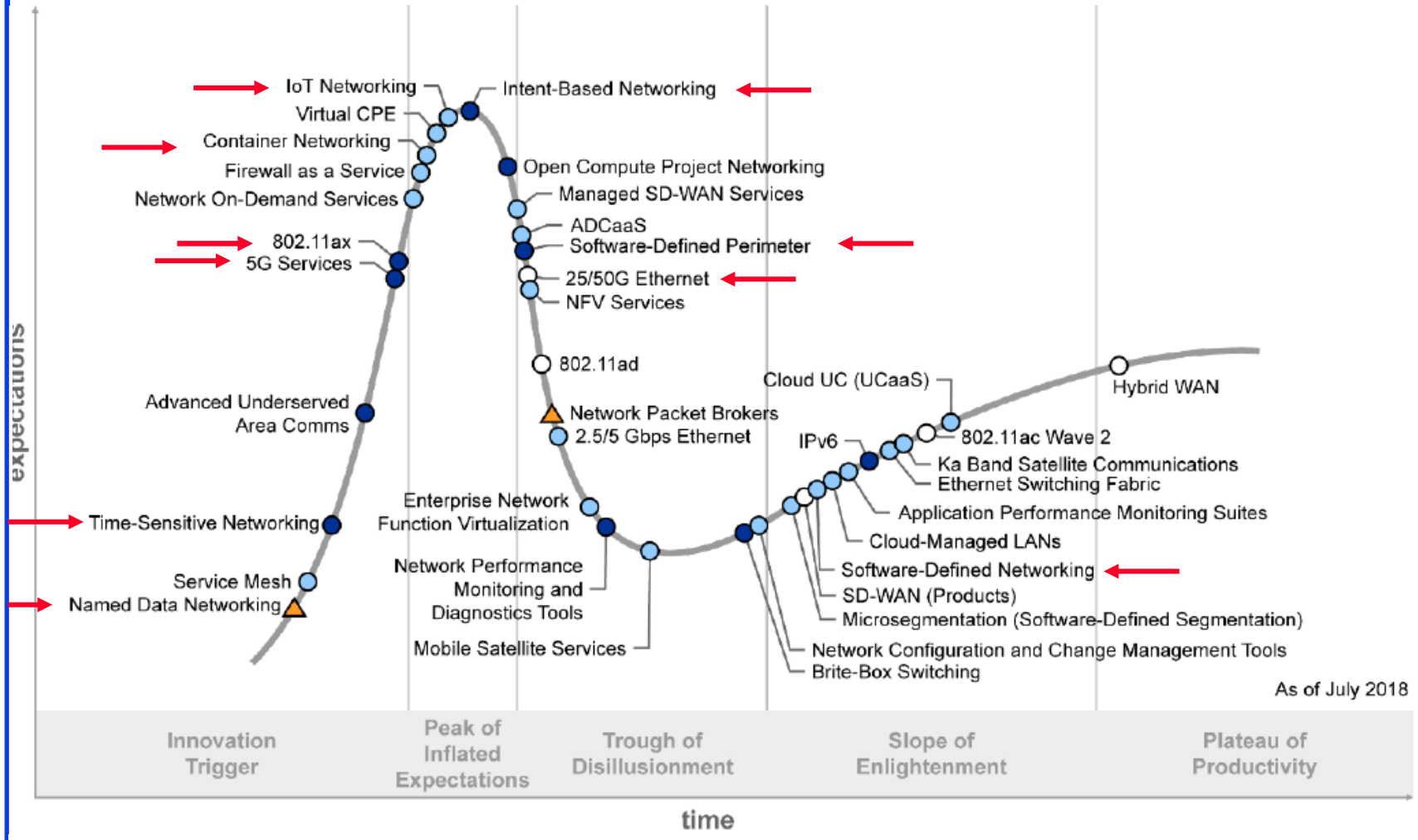
Student Questions

- Why is 802.11ad in the trough of disillusionment if it is being widely deployed in current routers?

Trough does not mean death. It means not enough profit. Profits are high when the hype is high. During wide deployment, profit is from low-cost manufacturing. Inventors move on to the next thing that is high on the hype.



Hype Cycle for Enterprise Networking and Communications, 2018



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

Student Questions

- When does the Hype Cycle get updated and released?

Yearly as selected by Gartner, depending upon the industry interest.

- You said "we" want to stay on the top-right side of this cycle. Could you please define "we"? I assume that as researchers, we should focus on the research phase.

B.E. = Right
M.E. = Middle
Ph.D. = Left
Startups = Middle
VCs = Top Left
In this graduate course:
We = You + me
In my lab: We = Ph.D. students

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New Networking Tech

- Service Mesh: µService-to-µservice 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

- The service mesh is within a company, correct?

The extent of the mesh is not limited to the company. It could be a single system with many services, e.g., a computer with many services or a data center with many servers.

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New Networking Tech

- Service Mesh: µService-to-µservice communication
- Time Sensitive Networking: IEEE standards for real-time
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Ref: D. Young, M. Toussaint, "Hype Cycle for Enterprise Networking and Communications, 2018," Gartner Report ID G00338722, 13 July 2018, 69 pp.

Student Questions

- Could you please explain software-defined networking (SDN) and network function virtualization (VNF) a little bit and the difference between the two? Are they related to Software Defined Perimeter?

There are five classes on SDN in CSE 473.
https://www.cse.wustl.edu/~jain/cse473-22/i_4nld.htm
VNF is covered in two lectures in CSE 570 (Recent Advances in Networking)
https://www.cse.wustl.edu/~jain/cse570-21/m_16nfv.htm
Software-defined perimeter is related to network security (CSE 571).
SDN = Central control of all network policies vs. going to program each device
NFV = Software implementation of network functions, e.g., routing, web service, etc. ⇒ Can share hardware.

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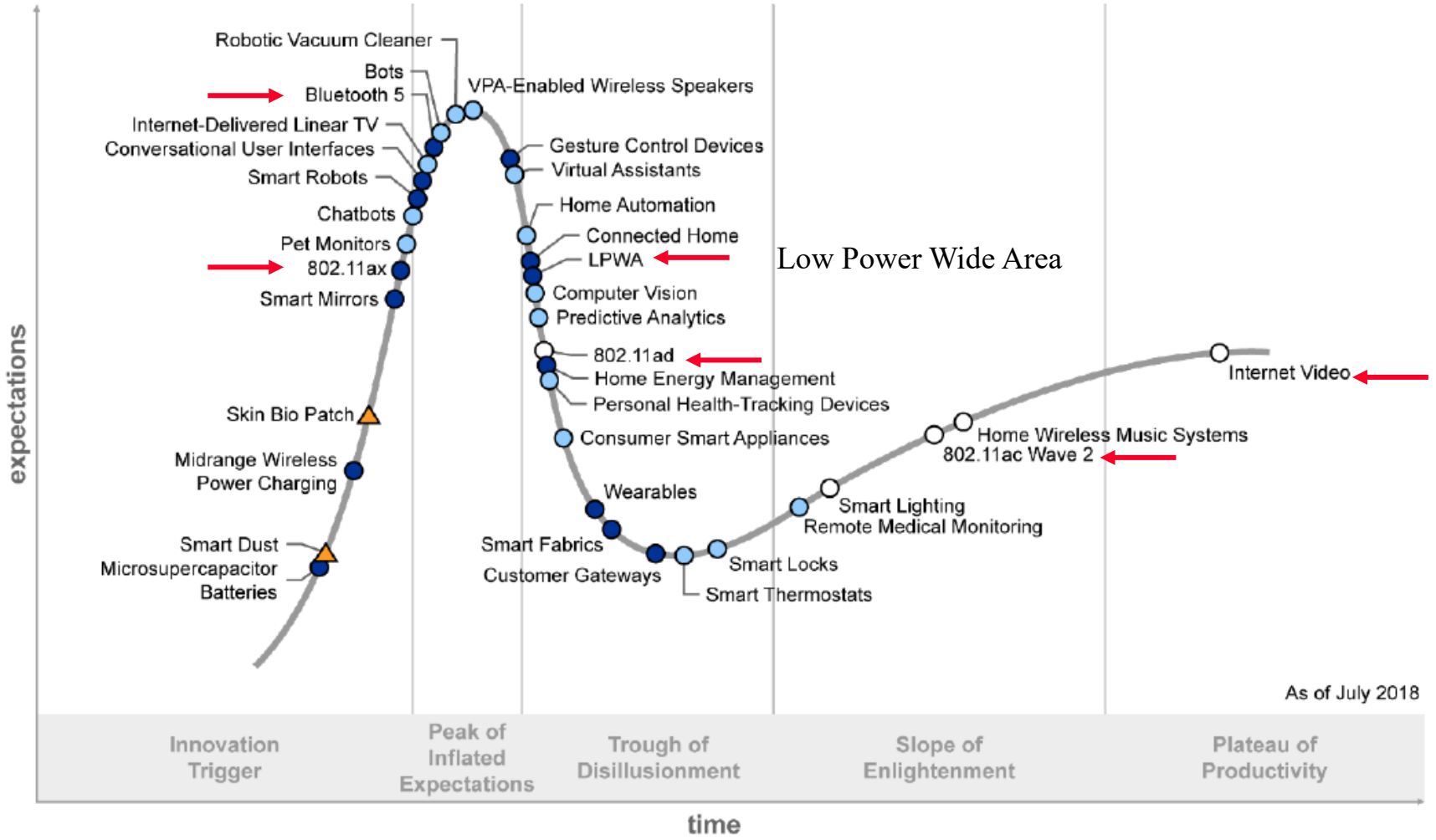
Hype Cycle of Connected Homes 2018



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

Student Questions

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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**

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

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Student Questions

- Of these new wireless technologies you listed, what exists now, and what is still being developed?

Bolded ones are still not here.

- Mobile Satellite Service seems so slow. What would be its potential application in the real world?

In the middle of a desert. In the open sea. Non-inhabited areas.

- Could mobile satellite services (such as Starlink) replace cellular data 4G/5G services?

They complement each other. Use Starlink if there is no 4G/5G, e.g., 10 miles from the main highway.

- Do we need to remember details in this slide?

Yes, when they are covered in detail later. E.g., Wi-Fi 6.

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

- Can you explain what you mean by "Manufacturing dominates IoT connections"?
- More IoT (sensors) are used in manufacturing plants than in home.

- Do many wide-area IoT devices today use cellular as phone companies predicted? What percentage of devices are wide-area?

Very few because of tariffs.

- What is the main characteristic(s) of IoT networking? Low power consumption?

Limited compute + Limited power + Large #
Discussed in detail in the IoT module of this course. Also, in CSE 473 and CSE 570.

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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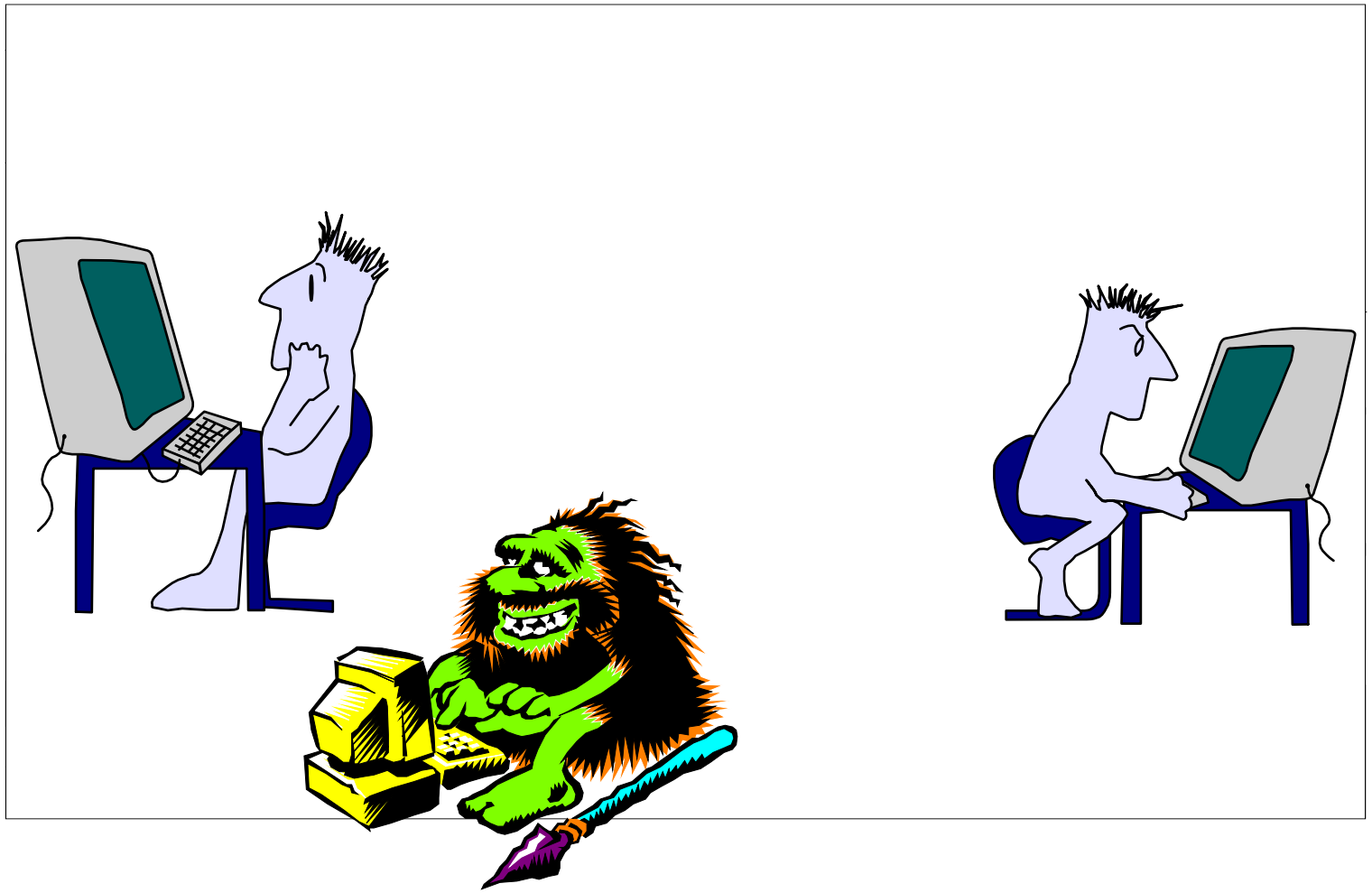
Cavemen of 2022



Student Questions

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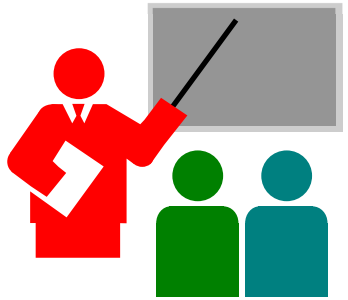
Summary: Wireless and Mobile Trends



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

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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

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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 _____.
9. Average 5G connection speeds will reach _____ Mbps
10. In 2021, there was _____X growth in DDoS attacks

Student Questions

- ❑ Year missing in some questions?

In all questions, where the date is missing, the default is 2023.

- ❑ *What does "X growth" mean?*

A factor of X growth.

- ❖ Will the questions about the details in the trends will be in the exam?

Yes. Not specific numbers but trends.

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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

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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 Duplixing 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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http://rajjain.com

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

Student Questions

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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=PLjGG94etKypJWOSPMh8Azcgy5e_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

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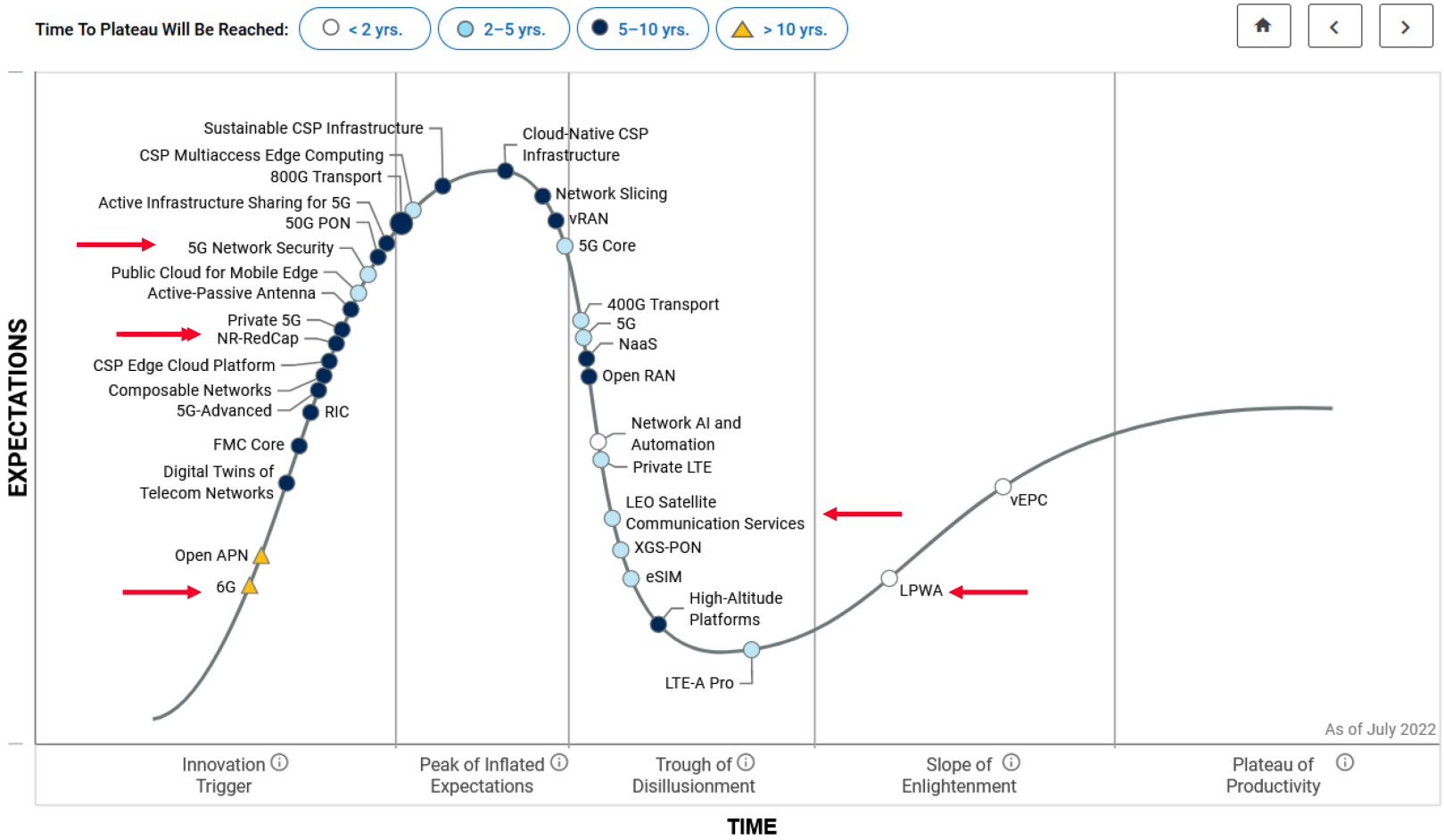
Hype Cycle for CSP Networks Infrastructure, 2022



- 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

Student Questions

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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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