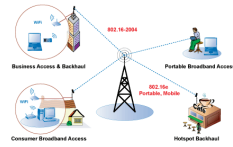# Wireless and Mobile Networking:
Facts, Statistics, and Trends

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Audio/Video recordings of this lecture are available at:

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

Overview

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

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	

Life Cycle of Technologies

$ Potential vs Time

Research | Hype | Dis illusionment | Success or Failure
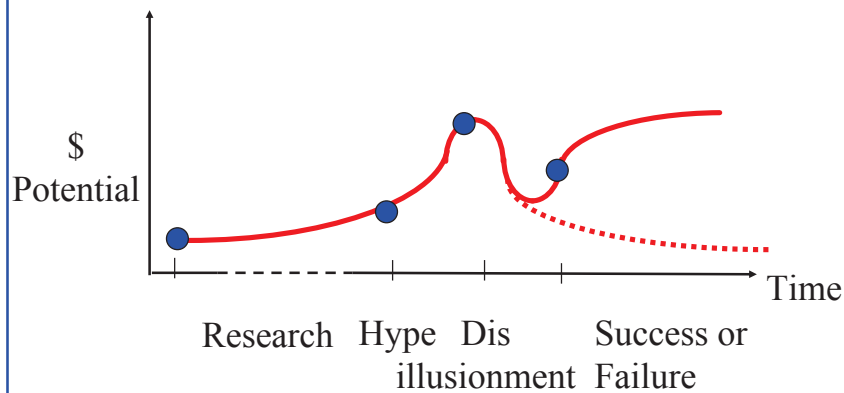
Wireless Networking Infrastructure Hype Cycle 2013
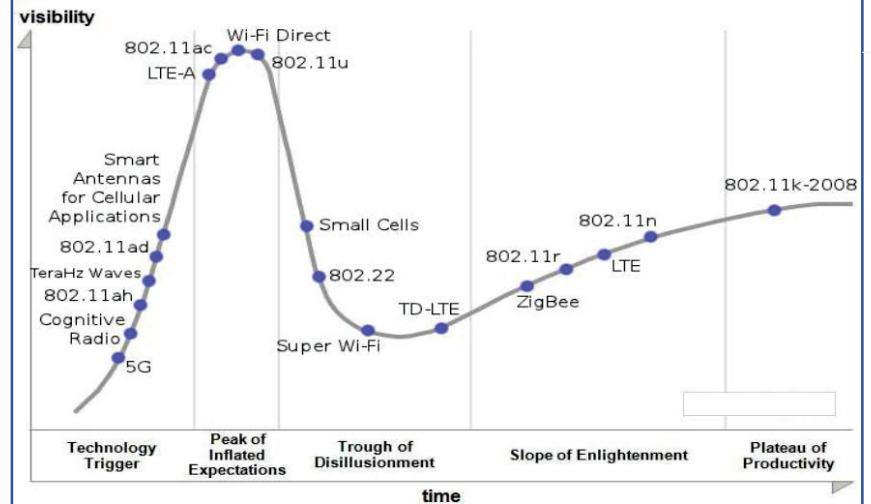
Ref: A. Chokalingam, "Gigabit Access in Wireless," Second Annual NKN Workshop, Bangalore 18 October 2013, http://nkn.in/nkn-workshop2013/images/presentation/2nd_annual_nkn_workshop_ac_d4.pdf

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
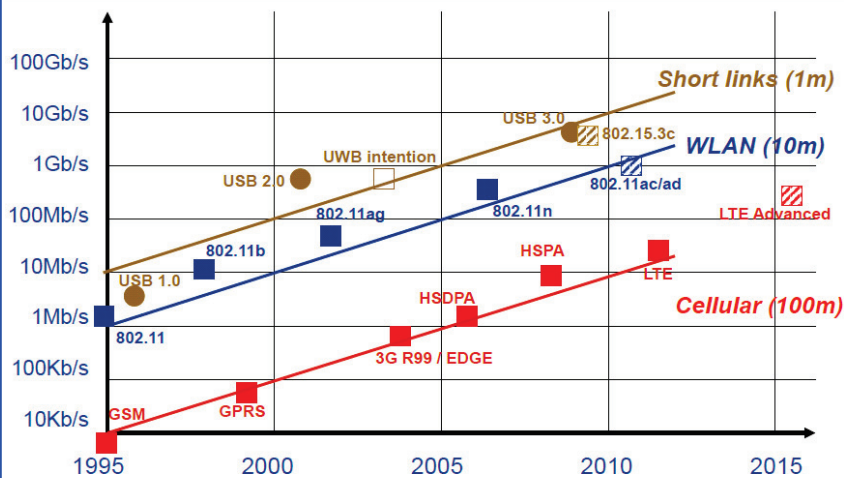
❑ Doubling every 18 months ⇒ Moore's Law

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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## 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
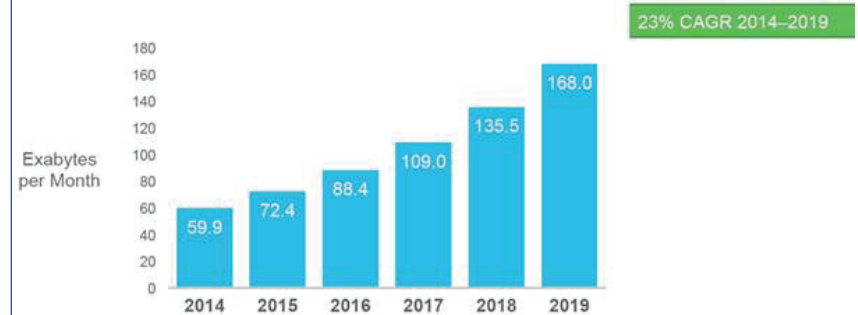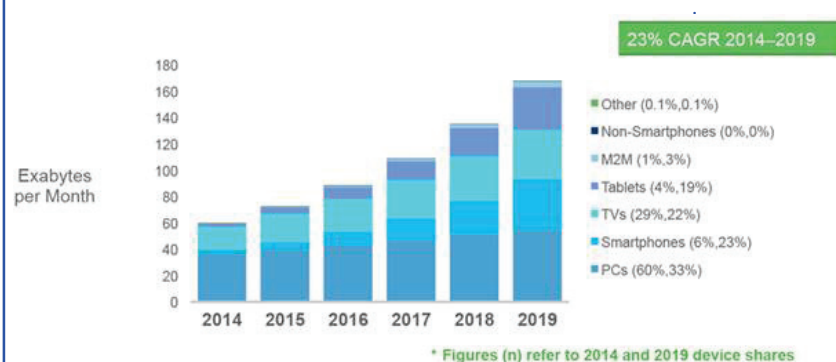

[Source: Cisco VNI]

❑ 3X in 5 years
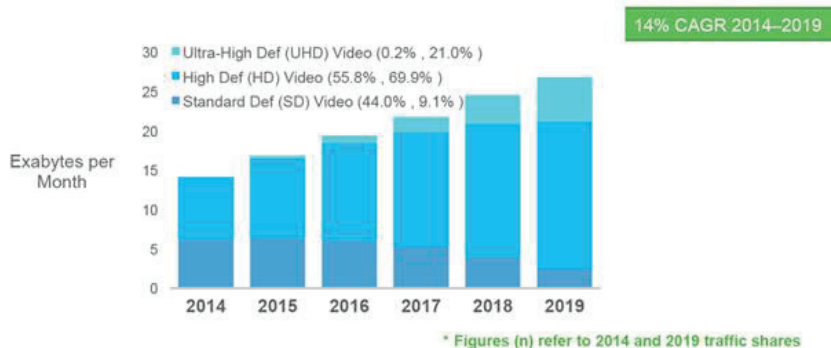
Number of Devices
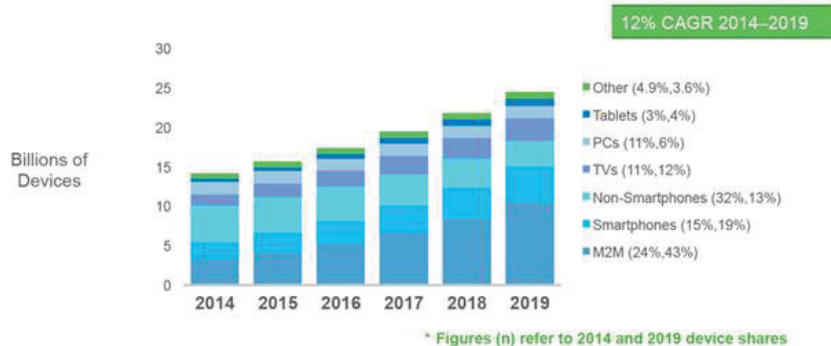
- Devices = 3X population
- Large # of M2M connections

Total IP Traffic

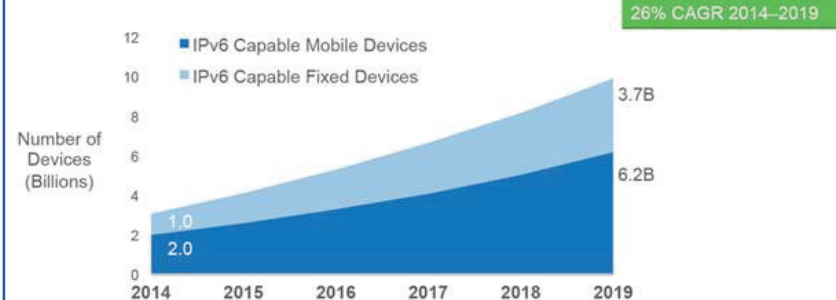
- 2/3 of all traffic will originate from non-PC sources
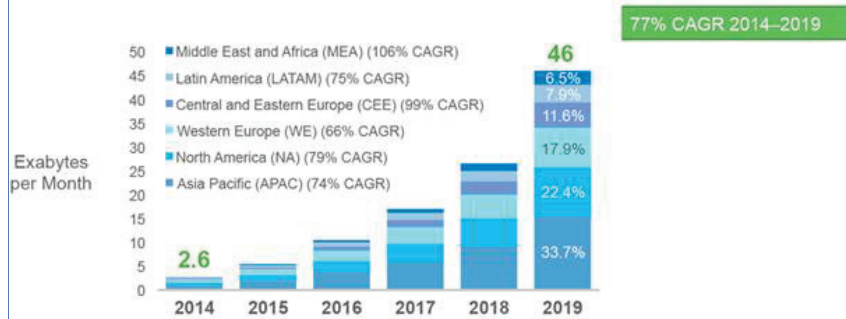
Video on Demand Traffic

- 4K and HD traffic increasing

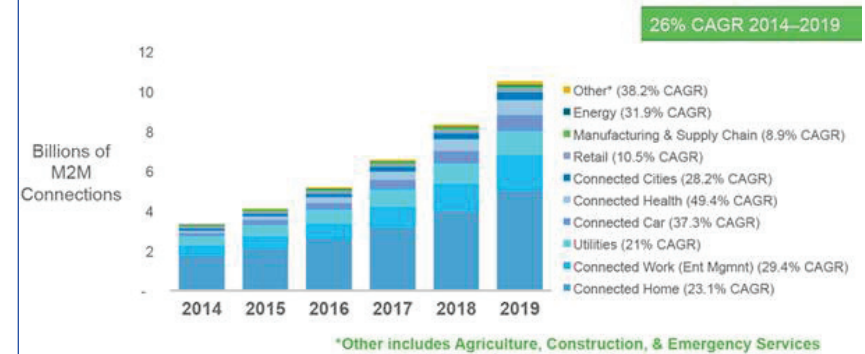# IPv6 Devices

- 3X IPv6 in 5 years
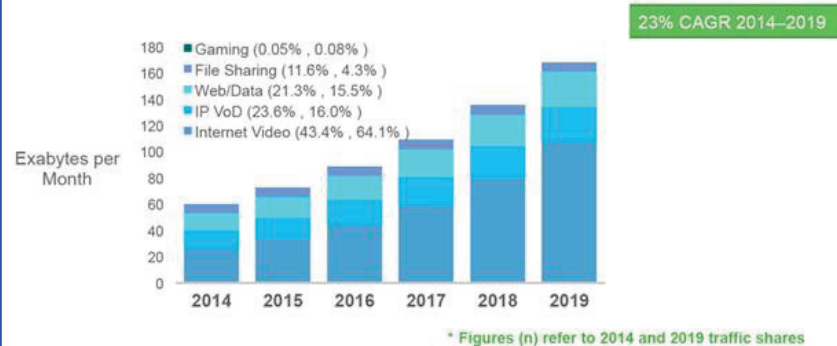
Geographic Distribution

❑ Highest growth in Middle East and Africa (MEA)
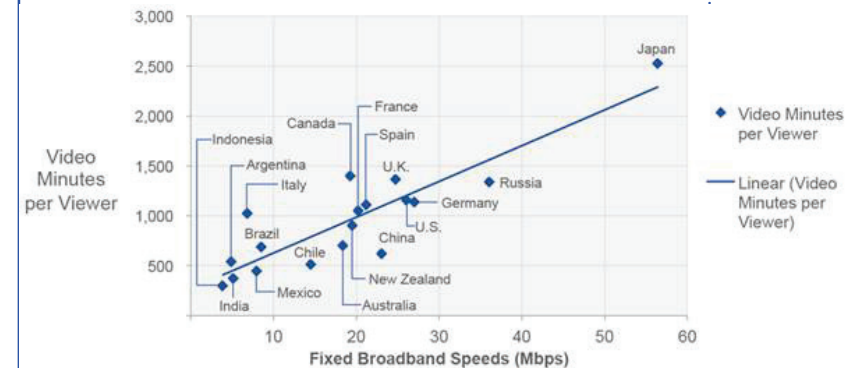
IoT Growth Areas

❑ 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 <u>access</u> 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

Internet Users: Digital Divide
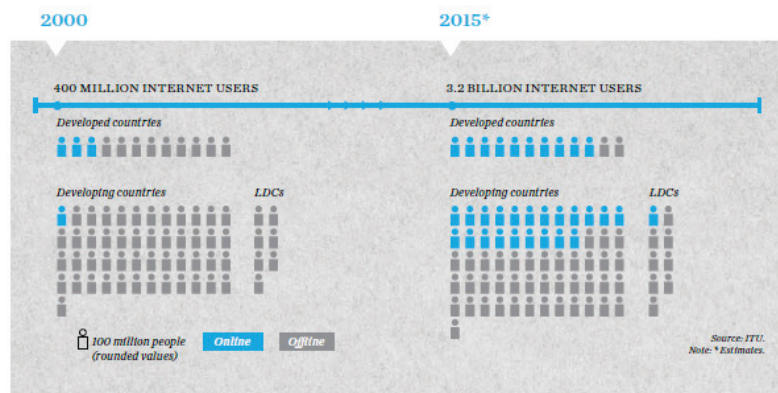
❑ Least developing countries (LDCs)

Mobile vs. Fixed
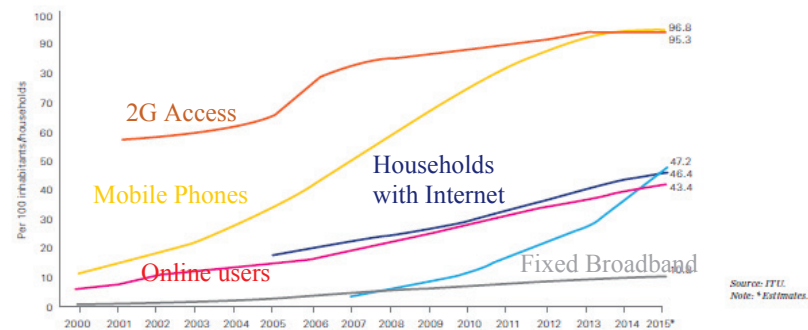
❑ Mobile phones rather than fixed broadband is the future for internet access

Internet Users

Subscriptions

- Developed countries — 29.0
- World — 10.8
- Developing countries — 7.1
- Least developed countries — 0.5

- 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

Internet of Things

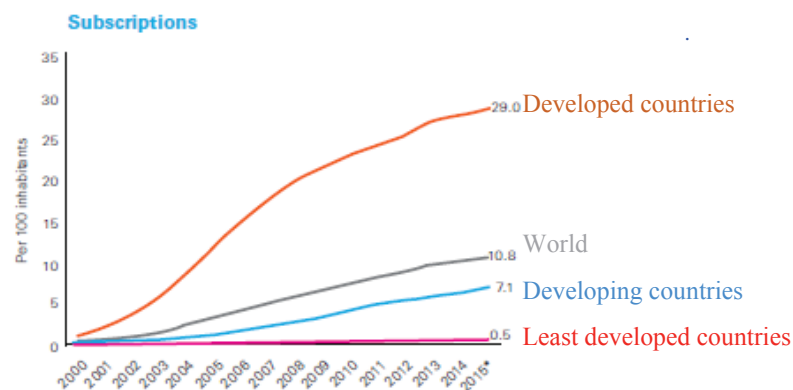- Only 1% of things around us is connected. Refrigerator, car, washing machine, heater, a/c, garage door, should all be connected but are not.
- From 10 Billion today to 50 Billion in 2020 Should include processes, data, things, and people.
- $14 Trillion over 10 years
  $\Rightarrow$ Third in the list 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 Duplixing 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/IEEE_802.11n-2009
- http://en.wikipedia.org/wiki/IEEE_802.11k-2008

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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