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/cse574-14/
1. Wireless: History
2. Wireless Infrastructure Hype Cycle 2013
3. Wireless Speed Trends (Moore’s Law)
4. Global Mobile Data Forecast [Cisco]
5. Trends
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
Life Cycle of Technologies

$\text{Potential}$

$\text{Time}$

$\text{Research}$  $\text{Hype}$  $\text{Disillusionment}$  $\text{Success or Failure}$
Wireless Networking Infrastructure Hype Cycle 2013

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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
- **802.11n**: WiFi with multiple antennas
- **802.11k**: Discover the best AP before transition
Wireless Speed Trends

- Doubling every 18 months ⇒ Moore’s Law

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Global Mobile Data Forecast [Cisco]

- Global Mobile data grew 70% in 2012.
- 885 Peta bytes per month in 2012 from 75 Peta bytes per month in 2000.
- Mobile video traffic is more than 50% of the mobile traffic.
- Connection speeds doubled:
  - 526 kbps in 2012 up from 248 kbps in 2011.
- 4G

Note: The next 12 slides are all from Cisco VNI.

Ref: Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update
Exponential Growth in Mobile Data
Highest Growth in Asia Pacific

Exabytes per Month

66% CAGR 2012–2017

Latin America (LATAM)
Central and Eastern Europe (CEE)
Middle East and Africa (MEA)
Western Europe (WE)
North America (NA)
Asia Pacific (APAC)

Source: Cisco VNI Mobile Forecast, 2013
Most Traffic due to Smart Phones

Exabytes per Month

2012 | 2013 | 2014 | 2015 | 2016 | 2017

0 | 6 | 12

66% CAGR 2012–2017

- Other Portable Devices (0.2%)
- Non-Smartphones (1.4%)
- M2M (5.1%)
- Tablets (11.7%)
- Laptops (14.0%)
- Smartphones (67.5%)

Figures in legend refer to traffic share in 2017.
Source: Cisco VNI Mobile Forecast, 2013
Majority of Traffic due to Mobile Video

Exabytes per Month

2012 | 2013 | 2014 | 2015 | 2016 | 2017

66% CAGR 2012-2017

- Mobile File Sharing (3.5%)
- Mobile M2M (5.1%)
- Mobile Web/Data (24.9%)
- Mobile Video (66.5%)

Figures in legend refer to traffic share in 2017.
Source: Cisco VNI Mobile Forecast, 2013
Offload from Cellular to Fixed

Exabytes per Month

- Offload Traffic from Mobile Devices
- Cellular Traffic from Mobile Devices

Source: Cisco VNI Mobile Forecast, 2013

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3G and 4G on the Rise

Source: Cisco VNI Mobile Forecast, 2013
2G vs. 3G vs. 4G Traffic Volume

Source: Cisco VNI Mobile Forecast, 2013
In January 2010, top 1% users generated 52% of traffic.
Cellular vs. WiFi

- 4 times more WiFi
Machine to Machine Modules

- Security, health, Sensors ⇒ Internet of things
Machine to Machine Traffic

Source: Cisco VNI Mobile Forecast, 2013
Mobile Devices with IPv6

Number of Devices (B)

Source: Cisco VNI, 2013

33% CAGR 2012-2017

2012 2013 2014 2015 2016 2017

1B

2.5

5.0

4.2B
100% Mobile Cellular Penetration

- 96% globally, 128% in developed countries, 89% in developing countries

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Mobile Penetration

- CIS = Commonwealth of Independent States


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Growth of Mobile Broadband

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Trend: Access is All Wireless

- Wireless, in the form of WiFi, started in 1999.
  - First it was an option.
  - Now it is standard in all computing devices
- Most of the access (end user connectivity) is wireless
- Mobile phones, tablets have multiple wireless technologies: 2G, 3G, 4G, WiFi, Bluetooth, NFC but no wired connectivity
Trend: End-user Computing is all Mobile

- 2007: Apple introduced iPhone
- 68-83% of people in the United States have smart phones. 56% worldwide.
- Internet is now available to masses
- A large fraction of population uses smart phones and tablets as their sole computing, communication, entertainment device
- Operating systems: Android, iOS, and Windows

All about mobiles

Trend: Most Revenue in Wireless

- US Wireless industry is valued at $195.5 billion ≥ publishing, agriculture, hotels and lodging, air transportation, and motion picture and recording.
- Wireless industry directly/indirectly provides more than 2.6% of all US employment.
- Wireless revenue is expanding.

Mobile Advertising Revenue

<table>
<thead>
<tr>
<th>Year</th>
<th>North America</th>
<th>Western Europe</th>
<th>Asia Pacific and Japan</th>
<th>Rest of World</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>3181.5</td>
<td>1600.5</td>
<td>4333</td>
<td>641.1</td>
</tr>
<tr>
<td>2013</td>
<td>3825.7</td>
<td>1941.4</td>
<td>4864.9</td>
<td>788</td>
</tr>
<tr>
<td>2014</td>
<td>4694.9</td>
<td>2367.8</td>
<td>5506.7</td>
<td>960.5</td>
</tr>
</tbody>
</table>

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Trend: Distributed App Development

- Desktop Era: Large software packages – office, Photoshop, …, each costing $100-$1000 per seat
- Mobile Era: $0.99 apps or free apps for desktop publishing, image manipulation, …
- Millions of App developers versus a large software company
- Personal Apps to Enterprise Apps
- 2 Billion Apps with 50 billion downloads
- 70 Apps stores
- Mobile presence critical - Apps for Facebook, New York Times, …

Ref: http://www.mobilestatistics.com/mobile-statistics
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Trend: Cloud Computing and Storage

- High-Speed Wireless
  - Remote computing and storage
  - Ideal for mobile devices
- Cloud storage:
  - Google Drive, iCloud, Sky Drive, Drop Box
- Cloud Computing:
  - Google Docs, Office 360, …
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,”
Ref: J. Bradley, “The Internet of Everything: Creating Better Experiences in Unimaginable Ways,” Nov 21, 2013,
IEEE Communications Society Digital Library: Top 10 Downloads (Nov 2013)

1. Performance Analysis of Macrodiversity MIMO Systems with MMSE and ZF Receivers in Flat Rayleigh Fading
2. Are we ready for SDN? Implementation challenges for software-defined networks
3. A survey on sensor networks
4. A simple transmit diversity technique for wireless communications
5. Performance analysis of the IEEE 802.11 distributed coordination function
7. A Survey of Defense Mechanisms Against Distributed Denial of Service (DDoS) Flooding Attacks
8. Improving network management with software defined networking
9. A survey of spectrum sensing algorithms for cognitive radio applications
10. Network virtualization and software defined networking for cloud computing: a survey

Observation: 7 wireless, 2 SDN, 1 Security.

Ref: http://www.comsoc.org/topten
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Time Spent on Mobiles

- **Web Browser**: 18%
- **Games**: 32%
- **Facebook**: 18%
- **Entertainment**: 8%
- **Utility**: 8%
- **Social Networking**: 6%
- **News**: 2%
- **Productivity**: 2%
- **Other**: 6%

Time to Reach 50M Users

- Draw Something App: 50 days
- Facebook: 3.5 years
- Internet: 4 years
- TV: 13 years
- Radio: 38 years

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, growth in Asia Pacific
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
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITU</td>
<td>International Telecommunications Union</td>
</tr>
<tr>
<td>KISDI</td>
<td>Korea Information Society Development Institute</td>
</tr>
<tr>
<td>LTE</td>
<td>Long-Term Evolution</td>
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<tr>
<td>MIMO</td>
<td>Multiple Input Multiple Output</td>
</tr>
<tr>
<td>MMSE</td>
<td>Minimum Mean Squared Error</td>
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<tr>
<td>NFC</td>
<td>Near Field Communications</td>
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<tr>
<td>NGO</td>
<td>Non-Governmental Organization</td>
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<tr>
<td>OFDM</td>
<td>Orthogonal Frequency Division Multiplexing</td>
</tr>
<tr>
<td>RAN</td>
<td>Regional Area Networks</td>
</tr>
<tr>
<td>RFID</td>
<td>Radio Frequency Identification</td>
</tr>
<tr>
<td>SDN</td>
<td>Software-defined networks</td>
</tr>
<tr>
<td>SSD</td>
<td>Solid-state Storage Drive</td>
</tr>
<tr>
<td>TD-LTE</td>
<td>Time-Division Duplexing Long-Term Evolution</td>
</tr>
<tr>
<td>TeraHz</td>
<td>$10^{12}$ Hertz</td>
</tr>
<tr>
<td>THz</td>
<td>Tera Hertz</td>
</tr>
<tr>
<td>TV</td>
<td>Television</td>
</tr>
</tbody>
</table>
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


- Gartner, “Gartner Identifies Top 10 Strategic Technologies,"

- Super Monitoring, “State of the Mobile 2013 (infographic),”

- G. Fettweis, "The limits of 4G and how to design a new 5G Phy,"
Reading List (Cont)


Wikipedia Links

- [http://en.wikipedia.org/wiki/802.11ad](http://en.wikipedia.org/wiki/802.11ad)
- [http://en.wikipedia.org/wiki/Multi-user_MIMO](http://en.wikipedia.org/wiki/Multi-user_MIMO)
Wikipedia Links (Cont)

References

References (Cont)


References (Cont)