CSMC 417

Computer Networks
Prof. Ashok K Agrawala

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General

• Instructor - Ashok K. Agrawala
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  – 4149 AVW

• TA – Andrew Pachulski
  – Office Hours –

• Class Meets – Tu Th 12:30 – 1:45 CSIC 3117
Prerequisite

• Required Background
  – must have 351 and 330 (412 or 430 would be helpful)

• Expectations
  – Understand the basics of Computer Architecture
  – Experience in implementing non-trivial systems-type projects
  – Should know
    • Processor
    • Memory
    • Kernel vs. user process
  – Familiar with basic probability
Expectations – After the course

- Understand the fundamentals of networking protocols, including protocol layering, basic medium access including wireless protocols, routing, addressing, congestion control
- Understand the principles behind the Internet protocols and some application layer protocols such as http, ftp, and DNS, and a few peer-to-peer systems/protocols such as Gnutella and Chord.
- Understand some of the limitations of the current Internet and its service model
- Understand the causes behind network congestion, and explain the basic methods for alleviating congestion
- Design, implement, and test substantial parts of network protocols
Announcements

- **Required Work**
  - will require about the same amount of effort as 412
    - 412 a (slightly) harder project to debug
    - 417 project is (by design) more ambiguous

- **Required Texts**
Other Material

• Recommended Texts

• RFCs
Grading

• Final 25%
• In-Term Exam(s) 25%
• Programming Assignments 35%
• Class Participation 15%
  – Learning Reports
  – Pop Quizzes
  – ...
Learning Reports

- Usually once a week
  - At the end of the class
  - When I ask you to
- One page
  - Your name and date
  - What you learned this week/this class as asked
  - What concept you found difficult
  - Any comments for me.
What is this course all about?

- Computer Networking
  - ???

![Diagram](image)
Block Diagram of Typical Laptop/desktop

Motherboard (~1998)

Backplane (~1998)

Some CPU chips

GLOBAL DIGITAL SNAPSHOT
A SNAPSHOT OF THE WORLD'S KEY DIGITAL STATISTICAL INDICATORS

TOTAL POPULATION
7.395 BILLION
URBANISATION: 54%

INTERNET USERS
3.419 BILLION
PENETRATION: 46%

ACTIVE SOCIAL MEDIA USERS
2.307 BILLION
PENETRATION: 31%

UNIQUE MOBILE USERS
3.790 BILLION
PENETRATION: 51%

ACTIVE MOBILE SOCIAL USERS
1.968 BILLION
PENETRATION: 27%

United States of America
A snapshot of the country's key digital statistical indicators

- Total Population: 322.9 million
- Active Internet Users: 282.1 million
- Active Social Media Users: 192.0 million
- Mobile Connections: 342.4 million
- Active Mobile Social Users: 169.0 million

Urbanisation: 82%
Penetration: 87%
Penetration: 59%
Penetration: 106%
Penetration: 52%

Sources: UN, US Census Bureau, ITU; Facebook; GSMA Intelligence.
JAN 2016 DIGITAL DEVICE OWNERSHIP
PERCENTAGE OF THE ADULT POPULATION* THAT OWNS EACH KIND OF DEVICE

- MOBILE PHONE (ALL TYPES): 86%
- SMART PHONE: 51%
- LAPTOP OR DESKTOP COMPUTER: 50%
- TABLET DEVICE: 7%
- TV STREAMING DEVICE: 2%
- HANDHELD GAMING CONSOLE: [N/A]
- E-READER DEVICE: [N/A]
- WEARABLE TECH DEVICE: [N/A]

*Please see notes at the end of the report for definitions.
Global Internet Users = 3B @ 42% Penetration... +9% vs. +9% Y/Y...+7% (Excluding India)
Internet Statistics 2016

- There are **3.26 billion internet users** as at December 2015; that’s over 40% of the world population.
- **Asia, as a continent, has the most internet users.** It accounts for 48.4% of global internet users.
- China, as a country, has the most internet users; with an estimated 640 million internet users, the **number of internet users in China is twice the number of the entire U.S population.**
- **China has the highest percentage of internet users (21.97%),** followed by the U.S. (9.58%) and India (8.33%).
- **Bermuda has the highest internet penetration at 97.75%;** a whopping 63,987 of Bermuda’s 65,461 population uses the internet.
- In contrast, while a whopping 86.75% of the U.S. population uses the internet, the U.S. is only ranked #25 in terms of internet penetration. The U.K. ranks #15 in terms of internet penetration with an estimated 89.90% of U.K. citizens using the internet.
- Digital interactions influenced retail sales to the tune of $2.2 trillion in 2015.
- By 2017, there will be more internet traffic than all prior internet years combined
- Wi-Fi and mobile-connected devices will generate 68% of all internet traffic by 2017.
- In 2015, 64% of all in-store sales, or sales to the tune of $2.2 trillion, were influenced by the internet.
- **Facebook now has 1.55 billion active users.**
- 2.9 billion Google searches are made every day.
- 2.7 million blog posts are published every day.
Domain Name Statistics 2016

• **There are currently 123.78 million registered .com domain names**, making the .com TLD the top domain name extension. This is followed by the .tk TLD with 27.7 million registered domain names.

• The .com TLD accounts for 50% of all registered TLDs.

• As of November 2015, there are a total of 1096 TLDs.

• **The most expensive domain name ever sold is Insurance.com, for $35.6 million in 2010.**
Web Hosting and Website 2016

• There are currently 966 million websites in the world today.
Web Hosting and Website 2016

• The highest number of websites connected to internet was 1 billion; this happened in September 2014, but the number eventually declined and is expected to be achievable again by mid 2016.
• The world’s first website was published on August 6, 1991 by British physicists Tim Berners-Lee.
• Only 44% of web traffic is from humans; a massive 56% of web traffic is from bots, impersonators, hacking tools, scrapers and spammers.
• 39% of web servers are hosted on Apache.
• Google is the #1 most popular website in the world, followed by Facebook and YouTube.
• The average e-commerce site takes 7.12 seconds to load in Internet Explorer 9, an average of 7.15 seconds to load in Firefox 7 and an average of 7.5 seconds to load in Google Chrome.
• Google uses site speed as a ranking factor.
• The most popular CMS is WordPress, powering 25.4% of all websites in the world and responsible for over 76.5 million blogs.
• An estimated 37,000 websites are hacked every day.
E-commerce and Conversion Statistics 2016

• 40% of global internet users, or more than 1 billion people, have bought products or goods online.
• The U.S. e-commerce economy is worth $349 billion while China’s e-commerce economy is worth $562.66 billion.
• A single second delay in your website loading time can result in a 7% loss in conversion, and 40% of web users will abandon a website if it takes longer than 3 seconds to load.
• Slow loading websites cost the U.S. e-commerce market more than $500 billion annually.
• Online retail sales in the U.K. reached an estimated £52.25 billion in 2015, with the average shopper spending £1,174.
• Worldwide B2C e-commerce sales reached $1.7 trillion in 2015, and it is estimated to reach $2.35 trillion by 2018.
• 8 out of 10 consumers will shop online if offered free shipping.
E-commerce and Conversion Statistics 2016

- Personalized recommendations can increase conversion rates by up to 5.5 times.
- 51% of U.S. online shoppers cite slow site loading times as the top reason they abandon a purchase.
- 34% of British consumers cite a store’s reputable brand name for being their reason for shopping with a brand, while 38% cite social media interaction as their reason for visiting a retailer’s website.
- 40% of shoppers consult 3 or more channels, often in the process of shopping, before making a purchase; that’s a massive increase from 10% in 2002, and it goes to show the increasing importance of having an online presence in as many places as possible.
- While mobile internet usage is high, desktop and tablet internet usage still leads for conversions; an estimated 8.52% of desktop users add to cart and an estimated 2.78% convert to sales. This is much higher than Smartphone conversion rates with an estimated 4.70% add to cart rate and an estimated 0.80% sales conversion rate. The number is much higher when you consider conversion rates from tablets and other mobile devices, but desktop still leads when it comes to actual sales.
- An increase in site speed from 8 to 2 seconds can boost your conversion rate by 74% (this is based on data monitoring real user activity from 33 major retailers).
E-commerce and Conversion Statistics 2016

• Increasingly shrinking attention span keeps influencing e-commerce; in 2010, a page that took 6 seconds to load suffered a 40% loss in conversion. Today, a page that takes 6 seconds to load will experience a 50% loss in conversion.

• The abandonment rate for mobile shopping cart is higher (at 97%) than that of desktop shopping carts (at 70 – 75%).

• E-commerce sales from social media grew by 202% in 2014, and is expected to further increase.

• The average human attention span has declined from 12 seconds in the year 2000 to 8 seconds now. This is much shorter than the attention span of a goldfish (at 9 seconds). This was revealed by a recent study by Microsoft Corp. that surveyed 2,000 people and monitored brain activity of 112 others using electroencephalograms (EEGs).
Mobile Internet 2016

• There are more mobile internet users than desktop internet users; 52.7% of global internet users access the internet via mobile, and 75.1% of U.S. internet users access the internet via mobile.

• Mobile media time in the U.S. has exceeded desktop, with mobile media time estimated to be 51% while desktop media time is estimated to be 42%.

• While there are more mobile users than desktop users, mobile advertising spend is still slightly lower than desktop advertising spend; mobile advertising spend currently represents 49% of digital advertising spend, compared to desktop at 51%.

• Mobile advertising spend is projected to account for 60.4% of all digital advertising spend by 2016 and 72.2% of all digital advertising spend by 2019.

• In 2015, mobile influenced retail sales to the tune of over $1 trillion.

• Search engines are the starting point for mobile research, with an estimated 48% of mobile internet users starting their search on search engines.

• Consequently, the #1 search engine, Google started to significantly use mobile compatibility as a factor when ranking websites.

• B2C mobile commerce sales in the U.S. is valued at an estimated $83.93 billion.

• 4 out of 5 consumers use a Smartphone to shop.

• 70% of mobile searches result in an online action within an hour of the search being conducted.

• 50% of mobile users will abandon of web page if it takes more than 10 seconds to load, and 60% won’t return to the site.
TIME SPENT ON THE INTERNET
AVERAGE NUMBER OF HOURS SPENT USING THE INTERNET PER DAY, SPLIT BY PC USE AND MOBILE PHONE USE

ACCESS THROUGH LAPTOP / DESKTOP
ACCESS THROUGH MOBILE DEVICE

Source: GlobalWebindex, Q4 2015. Based on a survey of internet users aged 16-64.
2016 What happens in an INTERNET MINUTE?

- 701,389 Facebook logins
- 69,444 Hours watched
- 20.8 MILLION+ Messages
- 2.78 MILLION Video Views
- 2.4 MILLION Search Queries
- 38,052 Hours of Music
- 1.04 MILLION Vine Loops
- 38,194 Posts to Instagram
- 150 MILLION Emails Sent
- 150 MILLION Photos Shared
- 120+ New Linkedin Accounts
- 527,760 App Downloads from Apple
- 51,000 App Downloads from Google
- 1389 Uber Rides
- $203,596 In sales
- 347,222 New Tweets
- 972,222 Swipes
- Available on the App Store

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GROWTH IN THE INTERNET OF THINGS
THE NUMBER OF CONNECTED DEVICES WILL EXCEED 50 BILLION BY 2020

BILLIONS OF DEVICES

Source: Cisco
Social Issues

- Network neutrality – no network restrictions
- Content ownership, e.g., DMCA takedowns
- Anonymity and censorship
- Privacy, e.g., Web tracking and profiling
- Theft, e.g., botnets and phishing
Network Types

Networks can be classified by their scale:

<table>
<thead>
<tr>
<th>Scale</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vicinity</td>
<td>PAN (Personal Area Network) »</td>
</tr>
<tr>
<td>Building</td>
<td>LAN (Local Area Network) »</td>
</tr>
<tr>
<td>City</td>
<td>MAN (Metropolitan Area Network) »</td>
</tr>
<tr>
<td>Country</td>
<td>WAN (Wide Area Network) »</td>
</tr>
<tr>
<td>Planet</td>
<td>The Internet (network of all networks)</td>
</tr>
</tbody>
</table>
Personal Area Network

Connect devices over the range of a person

Example of a Bluetooth (wireless) PAN:
Local Area Networks

• Connect devices in a home or office building
• Called enterprise network in a company

Wireless LAN with 802.11

Wired LAN with switched Ethernet
Local Area Networks

- Two broadcast networks
  - (a) Bus
  - (b) Ring
Metropolitan Area Networks

Connect devices over a metropolitan area

Example MAN based on cable TV:
Wide Area Networks

• Relation between hosts on LANs and the subnet.
Wide Area Networks (2)

- A stream of packets from sender to receiver.
Broadcast Networks

• Types of transmission technology
• Broadcast links
• Point-to-point links
Broadcast Networks (2)

- Classification of interconnected processors by scale.

<table>
<thead>
<tr>
<th>Interprocessor distance</th>
<th>Processors located in same</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>Square meter</td>
<td>Personal area network</td>
</tr>
<tr>
<td>10 m</td>
<td>Room</td>
<td>Local area network</td>
</tr>
<tr>
<td>100 m</td>
<td>Building</td>
<td>Metropolitan area network</td>
</tr>
<tr>
<td>1 km</td>
<td>Campus</td>
<td>Wide area network</td>
</tr>
<tr>
<td>10 km</td>
<td>City</td>
<td>The Internet</td>
</tr>
<tr>
<td>100 km</td>
<td>Country</td>
<td></td>
</tr>
<tr>
<td>1000 km</td>
<td>Continent</td>
<td></td>
</tr>
<tr>
<td>10,000 km</td>
<td>Planet</td>
<td></td>
</tr>
</tbody>
</table>
Wireless Networks

• Categories of wireless networks:
  • System interconnection
  • Wireless LANs
  • Wireless WANs
Wireless Networks (2)

- (a) Bluetooth configuration
- (b) Wireless LAN
Wireless Networks (3)

- (a) Individual mobile computers
- (b) A flying LAN
Home Network Categories

- Computers (desktop PC, PDA, shared peripherals)
- Entertainment (TV, DVD, VCR, camera, stereo, MP3)
- Telecomm (telephone, cell phone, intercom, fax)
- Appliances (microwave, fridge, clock, furnace, airco)
- Telemetry (utility meter, burglar alarm, babycam).
Network Software

- Protocol layers
- Design issues for the layers
- Connection-oriented vs. connectionless service
- Service primitives
- Relationship of services to protocols
Protocol Layers (1)

Protocol layering is the main structuring method used to divide up network functionality.

- Each protocol instance talks virtually to its **peer**
- Each layer communicates only by using the one below
- Lower layer **services** are accessed by an **interface**
- At bottom, messages are carried by the medium
Protocol Layers (2)

- Example: the philosopher-translator-secretary architect
- Each protocol at different layers serves a different purpose
Protocol Layers (3)

- Each lower layer adds its own **header** (with control information) to the message to transmit and removes it on receipt.

- Layers may also split and join messages, etc.

![Diagram of protocol layers with message flow]
Design Issues for the Layers

Each layer solves a particular problem but must include mechanisms to address a set of recurring design issues

<table>
<thead>
<tr>
<th>Issue</th>
<th>Example mechanisms at different layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability despite failures</td>
<td>Codes for error detection/correction (§3.2, 3.3)</td>
</tr>
<tr>
<td></td>
<td>Routing around failures (§5.2)</td>
</tr>
<tr>
<td>Network growth and evolution</td>
<td>Addressing (§5.6) and naming (§7.1)</td>
</tr>
<tr>
<td></td>
<td>Protocol layering (§1.3)</td>
</tr>
<tr>
<td>Allocation of resources like bandwidth</td>
<td>Multiple access (§4.2)</td>
</tr>
<tr>
<td></td>
<td>Congestion control (§5.3, 6.3)</td>
</tr>
<tr>
<td>Security against various threats</td>
<td>Confidentiality of messages (§8.2, 8.6)</td>
</tr>
<tr>
<td></td>
<td>Authentication of communicating parties (§8.7)</td>
</tr>
</tbody>
</table>
Connection-Oriented vs. Connectionless

- Service provided by a layer may be kinds of either:
  - Connection-oriented, must be set up for ongoing use (and torn down after use), e.g., phone call
  - Connectionless, messages are handled separately, e.g., postal delivery

<table>
<thead>
<tr>
<th>Service</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable message stream</td>
<td>Sequence of pages</td>
</tr>
<tr>
<td>Reliable byte stream</td>
<td>Movie download</td>
</tr>
<tr>
<td>Unreliable connection</td>
<td>Voice over IP</td>
</tr>
<tr>
<td>Unreliable datagram</td>
<td>Electronic junk mail</td>
</tr>
<tr>
<td>Acknowledged datagram</td>
<td>Text messaging</td>
</tr>
<tr>
<td>Request-reply</td>
<td>Database query</td>
</tr>
</tbody>
</table>
Service Primitives (1)

- A service is provided to the layer above as primitives
- Hypothetical example of service primitives that may provide a reliably byte stream (connection-oriented) service:

<table>
<thead>
<tr>
<th>Primitive</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>LISTEN</td>
<td>Block waiting for an incoming connection</td>
</tr>
<tr>
<td>CONNECT</td>
<td>Establish a connection with a waiting peer</td>
</tr>
<tr>
<td>ACCEPT</td>
<td>Accept an incoming connection from a peer</td>
</tr>
<tr>
<td>RECEIVE</td>
<td>Block waiting for an incoming message</td>
</tr>
<tr>
<td>SEND</td>
<td>Send a message to the peer</td>
</tr>
<tr>
<td>DISCONNECT</td>
<td>Terminate a connection</td>
</tr>
</tbody>
</table>
Service Primitives (2)

- Hypothetical example of how these primitives may be used for a client-server interaction

**Client**
- CONNECT (1)
- SEND
- RECEIVE (3)
- DISCONNECT (5)

**Server**
- LISTEN (0)
- ACCEPT RECEIVED (2)
- SEND (4)
- DISCONNECT (6)

Events:
- Connect request
- Accept response
- Request for data
- Reply
- Disconnect
• Packets sent in a simple client-server interaction on a connection-oriented network.
Relationship of Services to Protocols

Recap:

- A layer provides a **service** to the one above
  [vertical]
- A layer talks to its peer using a **protocol**
  [horizontal]
Reference Models

Reference models describe the layers in a network architecture

- OSI reference model
- TCP/IP reference model
- Model used for this text
- Critique of OSI and TCP/IP
Reference Models

The OSI reference model.
OSI Reference Model

- A principled, international standard, seven layer model to connect different systems

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Data link</td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
</tr>
</tbody>
</table>
The TCP/IP Reference Model Layers

- Link layer
- Internet layer
- Transport layer
- Application layer
TCP/IP Reference Model

- A four layer model derived from experimentation; omits some OSI layers and uses the IP as the network

Protocols are shown in their respective layers

- IP is the “narrow waist” of the Internet
Reference Models (2)

- The 7

<table>
<thead>
<tr>
<th>OSI</th>
<th>TCP/IP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Application</td>
</tr>
<tr>
<td>6 Presentation</td>
<td>Transport</td>
</tr>
<tr>
<td>5 Session</td>
<td>Internet</td>
</tr>
<tr>
<td>4 Transport</td>
<td>Host-to-network</td>
</tr>
<tr>
<td>3 Network</td>
<td></td>
</tr>
<tr>
<td>2 Data link</td>
<td></td>
</tr>
<tr>
<td>1 Physical</td>
<td></td>
</tr>
</tbody>
</table>

Not present in the model
Reference Models (3)

Layer (OSI names)
Application
Transport
Network
Physical + data link

Protocols

TCP
UDP
IP

Networks

ARPANET
SATNET
Packet radio
LAN

TELNET
FTP
SMTP
DNS
Model Used in this Course

It is based on the TCP/IP model but we call out the physical layer and look beyond Internet protocols.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Application</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Link</td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
</tr>
</tbody>
</table>
Example Networks

- The Internet »
- 3G mobile phone networks »
- Wireless LANs »
- RFID and sensor networks »
The ARPANET

- (a) Structure of the telephone system.
- (b) Baran’s proposed distributed switching system.
The ARPANET (2)

- The original ARPANET design.
NSFNET

- NSF Supercomputer center
- NSF Midlevel network
- Both
Internet (1)

Before the Internet was the ARPANET, a decentralized, packet-switched network based on Baran’s ideas.

ARPANET topology in Sept 1972.

Nodes are IMPs, or early routers, linked to hosts.

56 kbps links.
The early Internet used NSFNET (1985-1995) as its backbone; universities connected to get on the Internet.
Internet (4)

Architecture of the Internet
3G Mobile Phone Networks (1)

3G network is based on spatial cells; each cell provides wireless service to mobiles within it via a base station.
Fourth-Generation Mobile Phone Networks

• Technologies
  – WiMAX
    • MAXWell Lab at UMd
  – LTE

• TDM Based

• Higher user level bandwidth
Ethernet

- Architecture of the original Ethernet.
Wireless LANs

- (a) Wireless networking with a base station.
- (b) Ad hoc networking.
Wireless LANs (2)

Signals in the 2.4GHz ISM band vary in strength due to many effects, such as multipath fading due to reflections

- requires complex transmission schemes, e.g., OFDM
Radio broadcasts interfere with each other, and radio ranges may incompletely overlap.

- CSMA (Carrier Sense Multiple Access) designs are
Wireless LANs (4)

- A multicell 802.11 network.
Ad hoc Networks

• Similar to Sensor Networks
• All nodes are equal
  – Some distinguished nodes may have servers/external connections
• Information moves from node to node
RFID and Sensor Networks (1)

Passive UHF RFID networks everyday objects:

- Tags (stickers with not even a battery) are placed on objects
- Readers send signals that the tags reflect to communicate
RFID and Sensor Networks (2)

Sensor networks spread small devices over an area:

- Devices send sensed data to collector via wireless hops
Network Standardization

• Who’s Who in the Telecommunications World
• Who’s Who in the International Standards World
• Who’s Who in the Internet Standards World
Network Standardization

Standards define what is needed for interoperability

Some of the many standards bodies:

<table>
<thead>
<tr>
<th>Body</th>
<th>Area</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITU</td>
<td>Telecommunications</td>
<td>G.992, ADSL, H.264, MPEG4</td>
</tr>
<tr>
<td>IEEE</td>
<td>Communications</td>
<td>802.3, Ethernet, 802.11, WiFi</td>
</tr>
<tr>
<td>IETF</td>
<td>Internet</td>
<td>RFC 2616, HTTP/1.1, RFC 1034/1035, DNS</td>
</tr>
<tr>
<td>W3C</td>
<td>Web</td>
<td>HTML5 standard, CSS standard</td>
</tr>
</tbody>
</table>
ITU

• Main sectors
  • Radiocommunications
  • Telecommunications Standardization
  • Development

• Classes of Members
  • National governments
  • Sector members
  • Associate members
  • Regulatory agencies
## Who’s Who in International Standards (1)

<table>
<thead>
<tr>
<th>Number</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.1</td>
<td>Overview and architecture of LANs</td>
</tr>
<tr>
<td>802.2</td>
<td>Logical link control</td>
</tr>
<tr>
<td>802.3</td>
<td>Ethernet</td>
</tr>
<tr>
<td>802.4</td>
<td>Token bus (was briefly used in manufacturing plants)</td>
</tr>
<tr>
<td>802.5</td>
<td>Token ring (IBM’s entry into the LAN world)</td>
</tr>
<tr>
<td>802.6</td>
<td>Dual queue dual bus (early metropolitan area network)</td>
</tr>
<tr>
<td>802.7</td>
<td>Technical advisory group on broadband technologies</td>
</tr>
<tr>
<td>802.8</td>
<td>Technical advisory group on fiber optic technologies</td>
</tr>
<tr>
<td>802.9</td>
<td>Isochronous LANs (for real-time applications)</td>
</tr>
<tr>
<td>802.10</td>
<td>Virtual LANs and security</td>
</tr>
<tr>
<td>802.11</td>
<td>Wireless LANs (WiFi)</td>
</tr>
<tr>
<td>802.12</td>
<td>Demand priority (Hewlett-Packard’s AnyLAN)</td>
</tr>
</tbody>
</table>

The 802 working groups. The important ones are marked with *. The ones marked with ↓ are hibernating. The one marked with † gave up and disbanded itself.
### Who’s Who in International Standards (2)

<table>
<thead>
<tr>
<th>802.13</th>
<th>Unlucky number; nobody wanted it</th>
</tr>
</thead>
<tbody>
<tr>
<td>802.14 ‡</td>
<td>Cable modems (defunct: an industry consortium got there first)</td>
</tr>
<tr>
<td>802.15 *</td>
<td>Personal area networks (Bluetooth, Zigbee)</td>
</tr>
<tr>
<td>802.16 *</td>
<td>Broadband wireless (WiMAX)</td>
</tr>
<tr>
<td>802.17</td>
<td>Resilient packet ring</td>
</tr>
<tr>
<td>802.18</td>
<td>Technical advisory group on radio regulatory issues</td>
</tr>
<tr>
<td>802.19</td>
<td>Technical advisory group on coexistence of all these standards</td>
</tr>
<tr>
<td>802.20</td>
<td>Mobile broadband wireless (similar to 802.16e)</td>
</tr>
<tr>
<td>802.21</td>
<td>Media independent handoff (for roaming over technologies)</td>
</tr>
<tr>
<td>802.22</td>
<td>Wireless regional area network</td>
</tr>
</tbody>
</table>

The 802 working groups. The important ones are marked with *. The ones marked with ‡ are hibernating. The one marked with † gave up and disbanded itself.
Metric Units

The main prefixes we use:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Exp.</th>
<th>prefix</th>
<th>exp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>K(ilo)</td>
<td>$10^3$</td>
<td>m(illi)</td>
<td>$10^{-3}$</td>
</tr>
<tr>
<td>M(ega)</td>
<td>$10^6$</td>
<td>μ(micro)</td>
<td>$10^{-6}$</td>
</tr>
<tr>
<td>G(iga)</td>
<td>$10^9$</td>
<td>n(ano)</td>
<td>$10^{-9}$</td>
</tr>
</tbody>
</table>

- Use powers of 10 for rates, powers of 2 for storage
  - E.g., 1 Mbps = 1,000,000 bps, 1 KB = 1024 bytes
- “B” is for bytes, “b” is for bits
## Metric Units

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Explicit</th>
<th>Prefix</th>
<th>Exp.</th>
<th>Explicit</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-3}$</td>
<td>0.001</td>
<td>milli</td>
<td>$10^{3}$</td>
<td>1,000</td>
<td>Kilo</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>0.000001</td>
<td>micro</td>
<td>$10^{6}$</td>
<td>1,000,000</td>
<td>Mega</td>
</tr>
<tr>
<td>$10^{-9}$</td>
<td>0.00000001</td>
<td>nano</td>
<td>$10^{9}$</td>
<td>1,000,000,000</td>
<td>Giga</td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>0.0000000001</td>
<td>pico</td>
<td>$10^{12}$</td>
<td>1,000,000,000,000</td>
<td>Tera</td>
</tr>
<tr>
<td>$10^{-15}$</td>
<td>0.00000000000001</td>
<td>femto</td>
<td>$10^{15}$</td>
<td>1,000,000,000,000,000,000</td>
<td>Peta</td>
</tr>
<tr>
<td>$10^{-18}$</td>
<td>0.00000000000000001</td>
<td>atto</td>
<td>$10^{18}$</td>
<td>1,000,000,000,000,000,000,000</td>
<td>Exa</td>
</tr>
<tr>
<td>$10^{-21}$</td>
<td>0.000000000000000000001</td>
<td>zepto</td>
<td>$10^{21}$</td>
<td>1,000,000,000,000,000,000,000,000</td>
<td>Zetta</td>
</tr>
<tr>
<td>$10^{-24}$</td>
<td>0.00000000000000000000001</td>
<td>yocto</td>
<td>$10^{24}$</td>
<td>1,000,000,000,000,000,000,000,000,000,000</td>
<td>Yotta</td>
</tr>
</tbody>
</table>

- The principal metric prefixes.
# Metric Units (1)

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Explicit</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-3}$</td>
<td>0.001</td>
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<tr>
<td>$10^{-6}$</td>
<td>0.000001</td>
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</tr>
<tr>
<td>$10^{-9}$</td>
<td>0.00000001</td>
<td>nano</td>
</tr>
<tr>
<td>$10^{-12}$</td>
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<tr>
<td>$10^{-15}$</td>
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<tr>
<td>$10^{-18}$</td>
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<tr>
<td>$10^{-21}$</td>
<td>0.000000000000000000001</td>
<td>zepto</td>
</tr>
<tr>
<td>$10^{-24}$</td>
<td>0.00000000000000000000001</td>
<td>yocto</td>
</tr>
</tbody>
</table>

The principal metric prefixes
## Metric Units (2)

<table>
<thead>
<tr>
<th>$10^n$</th>
<th>Explicit</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^3$</td>
<td>1,000</td>
<td>Kilo</td>
</tr>
<tr>
<td>$10^6$</td>
<td>1,000,000</td>
<td>Mega</td>
</tr>
<tr>
<td>$10^9$</td>
<td>1,000,000,000</td>
<td>Giga</td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>1,000,000,000,000,000</td>
<td>Tera</td>
</tr>
<tr>
<td>$10^{15}$</td>
<td>1,000,000,000,000,000,000</td>
<td>Peta</td>
</tr>
<tr>
<td>$10^{18}$</td>
<td>1,000,000,000,000,000,000,000</td>
<td>Exa</td>
</tr>
<tr>
<td>$10^{21}$</td>
<td>1,000,000,000,000,000,000,000,000</td>
<td>Zetta</td>
</tr>
<tr>
<td>$10^{24}$</td>
<td>1,000,000,000,000,000,000,000,000,000</td>
<td>Yotta</td>
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</tbody>
</table>

The principal metric prefixes