Overview

- What’s the Internet?
- What’s a protocol?
- Network edge vs. core
- Access net, physical media
- Performance: loss, delay
- Protocol layers, service models
- Backbones, NAPs, ISPs
- History & Future

What’s the Internet: “nuts and bolts” view

- Millions of connected computing devices: Hosts, End-Systems
  - PC’s, workstations, servers
  - PDA’s, phones, toasters running network applications
- Communication links
  - fiber, copper, radio
- Routers
  - forward packets (chunks) of data through network
"Cool" Internet appliances

IP picture frame
[www.ceiva.com]

World's smallest web server
[www-ccs.cs.umass.edu/~shri/iPic.html]

Web-enabled toaster and weather forecaster

What’s the Internet: “nuts and bolts” view

- protocols: control sending, receiving of messages
  - TCP, IP, HTTP, FTP, PPP
- Internet: “network of networks”
  - loosely hierarchical
  - public Internet versus private Intranet
- Internet standards
  - RFC: Request for comments
  - IETF: Internet Engineering Task Force

What’s the Internet: a service view

- communication infrastructure enables distributed applications
  - WWW, email, games, e-commerce, databases, voting, file (MP3) sharing
- communication services provided
  - connectionless
  - connection-oriented
- cyberspace [Gibson]: “a consensual hallucination experienced daily by billions of operators, in every nation, ....”

What’s a protocol?

Human protocols
- “what’s the time?”
- “I have a question”
- introductions

Network protocols
- machines rather than humans
- all communication activity in Internet governed by protocols

... specific msgs sent
... specific actions taken when msgs received, or other events
What's a protocol?

a human protocol and a computer network protocol

Do you know other human protocols?

Hi

TCP connection req.

TCP connection reply.

GET http://distcomp.ethz.ch/index.html

<file>

A closer look at network structure

• network edge
  – hosts and applications
• network core
  – routers
  – network of networks
• access networks, physical media
  – communication links

The network edge

• end systems (hosts)
  – run application programs
  – e.g. WWW, email
  – at “edge of network”
• client/server model
  – client host requests, receives service from server
  – e.g. WWW client (browser) /server; email client/server
• peer-to-peer model
  – host interaction symmetric
  – e.g. Kazaa, Emule

Network edge: connection-oriented service

Goal: data transfer between end systems

TCP [RFC 793]

• reliable, in-order byte-stream data transfer
  – loss: acknowledgements and retransmissions
• flow control
  – sender won’t overwhelm receiver
• congestion control
  – senders “slow down sending rate” when network congested
Network edge: connectionless service

Goal: data transfer between end systems
- same as before!

• UDP - User Datagram Protocol [RFC 768]
  - Internet’s connectionless service
  - unreliable data transfer
  - no flow control
  - no congestion control

App’s using TCP
- HTTP (WWW)
- FTP (file transfer)
- Telnet (remote login)
- SMTP (email)

App’s using UDP
- streaming media
- teleconferencing
- Internet telephony

The network core

• “graph” of interconnected routers
• the fundamental question: how is data transferred through net?

• Circuit switching
  - dedicated circuit per call
  - telephone network
• Packet switching
  - data sent through network in discrete “chunks”

Circuit Switching

• End-end resources reserved for “call”
• Divide link bandwidth into “pieces”
  - Frequency division
  - Time division
• dedicated resources
  - no sharing; “piece” is idle if not used by user
• circuit-like (guaranteed) performance
• call setup required

Frequency Division and Time Division Multiple Access

Example:
4 users

FDMA

frequency

time

TDMA

frequency

time
Packet Switching

- each end-end data stream divided into packets
- packets share network resources
- each packet uses full link bandwidth
- resources used as needed

Bandwidth division into “pieces”
Dedicated allocation
Resource reservation

• resource contention
  - aggregate resource demand can exceed amount available

• congestion
  - packets queue
  - wait for link use

• store-and-forward
  - packets move one hop at a time
  - router receives whole packet before sending the first bit over the next link

Circuit switching vs. Packet switching

- 1 Mbit link
  - each user
    - 100Kbps when “active”
    - active 10% of time
  - circuit-switching
    - 10 users
  - packet switching:
    - with 50 users, Pr[more than 10 users active] < 1%
    - with 100 users, Pr[more than 10 users active] ≈ 42%

- Packet switching allows more users... Really?
Circuit switching vs. Packet switching

- Is packet switching a “slam dunk winner”?
- Great for bursty data
  - resource sharing
  - no call setup
- But: Excessive congestion: packet delay and loss
  - protocols needed for reliable data transfer
  - header overhead
  - congestion control
- How to provide circuit-like behavior?
  - bandwidth guarantees needed for audio/video apps
  - still an unsolved problem

Packet-switched networks: Routing

- Goal: move packets among routers from source to destination
- We later study several path selection algorithms
- datagram network
  - destination address determines next hop
  - routes may change during session
  - analogy: driving, asking directions
- virtual circuit network
  - each packet carries tag (virtual circuit ID)
  - tag determines next hop
  - fixed path determined at call setup time, remains fixed
  - routers maintain per-call state

Delay in packet-switched networks

- packets experience delay on end-to-end path
- four sources of delay at each hop
  - Nodal processing
    - check bit errors
    - determine output link
  - Queuing
    - time waiting at output link for transmission
    - depends on congestion level of router

- Transmission delay:
  - $R=\text{link bandwidth (bps)}$
  - $L=\text{packet length (bits)}$
  - time to send bits into link = $L/R$

- Propagation delay:
  - $d=\text{length of physical link}$
  - $s=\text{propagation speed in medium (~}2\times10^8 \text{ m/sec)}$
  - propagation delay = $d/s$

Note: $s$ and $R$ are different quantities!
Queuing delay

- \( R \) = link bandwidth (bps)
- \( L \) = packet length (bits)
- \( a \) = average packet arrival rate (packets per second)

- Arrival rate \( \lambda = L a \) (bps)
- Service rate \( \mu = R \) (bps)
- Traffic intensity \( \rho = \frac{\lambda}{\mu} \)

- \( \rho \) small: average queuing delay small
- \( \rho \to 1 \): delays become large
- \( \rho \geq 1 \): more "work" arriving than can be serviced, average delay grows infinitely!

Networking Taxonomy

- Circuit Switching
  - FDM
  - TDM
- Packet Switching
  - Virtual Circuit
  - Datagram

- We concentrate on right-hand path (predominant in Internet)

“Real” Internet delays and routes: traceroute

Q: How to connect end systems to edge router?
- residential access nets
- institutional access networks (school, company)
- mobile access networks

Keep in mind
- bandwidth (bits per second) of access network?
- shared or dedicated?
Residential access: point to point access

- Dialup via modem
  - up to 56Kbps direct access to router (conceptually)

- ISDN
  - integrated services digital network
  - 128Kbps all-digital connect to router

- ADSL
  - asymmetric digital subscriber line
  - up to 1 Mbps home-to-router
  - up to 8 Mbps router-to-home
  - ADSL deployment: happening

### Residential access: cable modems

- Other forms of cable modems
  - Power line: e.g. Ascom Powerline
  - TV cable modem: e.g. CableCom, Glattnet
  - Satellite with feedback on phone line
  - Wireless local loop

### Institutional access: local area networks

- company/university local area network (LAN) connects end system to edge router

- Example: Ethernet
  - shared or dedicated cable connects end systems and router
  - 10 Mbps, 100Mbps, Gigabit Ethernet

- deployment: institutions, home LANs happening now

### Wireless access networks

- shared wireless access network connects end system to router

- wireless LANs
  - radio spectrum replaces wire
  - 802.11b with 11 Mbps
  - 802.11a with up to 54 Mbps

- wider-area wireless access
  - GSM: wireless access to ISP router via cellular network
Home networks

Typical home network components
- ADSL or cable modem
- router/firewall
- Ethernet
- wireless access point

Physical Media

- physical link
  - transmitted data bit propagates across link
- guided media
  - signals propagate in solid media: copper, fiber
- unguided media
  - signals propagate freely, e.g. radio

Physical Media: coax, fiber

- Coaxial cable:
  - wire (signal carrier) within a wire (shield)
  - variant baseband ("50Ω")
    - single channel on cable
  - variant broadband ("75Ω")
    - multiple channels on cable
  - bidirectional
  - 10Mbps Ethernet

- Fiber optic cable:
  - glass fiber carrying light pulses
  - high-speed operation: 100Mbps Ethernet
  - high-speed point-to-point transmission (>10 Gbps)
  - low error rate

Physical media: Radio

- signal carried in electromagnetic spectrum
- no physical "wire"
- bidirectional
- propagation environment effects:
  - reflection
  - obstruction by objects
  - interference

- Radio link types:
  - microwave
    - e.g. up to 45 Mbps
  - Wireless LAN (802.11)
    - 2Mbps, 11Mbps, 54Mbps
  - wide-area (e.g. cellular)
    - GSM, 10's Kbps
    - UMTS, Mbps
  - satellite
    - up to 50Mbps channel (or multiple smaller channels)
    - GEO: 270 msec end-end delay
    - geosynchronous vs. LEO's
Networks are complex!

- many “pieces”
  - hosts
  - routers
  - links of various media
  - applications
  - protocols
  - hardware
  - software

- Questions:
  - Is there any hope of organizing the structure of a network?
  - Or at least our discussion of networks?

Organization of air travel

- ticket (purchase) → ticket (complain)
- baggage (check) → baggage (claim)
- gates (load) → gates (unload)
- runway takeoff → runway landing
- airplane routing

Organization of air travel: a different view

- Layers: each layer implements a service
  - via its own internal-layer actions
  - relying on services provided by layer below

Layered air travel: services

- Counter-to-counter delivery of person+bags
- baggage-claim-to-baggage-claim delivery
- people transfer: loading gate to arrival gate
- runway-to-runway delivery of plane
- airplane routing from source to destination
Distributed implementation of layer functionality

- ticket (purchase)
- baggage (check)
- gates (load)
- runway takeoff
- airplane routing

- ticket (complain)
- baggage (claim)
- gates (unload)
- runway landing
- airplane routing

intermediate air traffic sites

- airplane routing

Why layering?

- Dealing with complex systems
- Explicit structure allows identification, relationship of complex system's pieces
  - layered reference model for discussion
- Modularization eases maintenance, updating of system
  - change of implementation of layer's service transparent to rest of system
  - e.g. change in gate procedure doesn't affect rest of system

Internet protocol stack (TCP/IP reference model)

- application:
  - ftp, SMTP, http
- transport: host-host data transfer
  - TCP, UDP
- network: routing of datagrams from source to destination
  - IP, routing protocols
- link: data transfer between neighboring network elements
  - PPP, Ethernet
- physical: bits "on the wire"
ISO/OSI Reference Model

- 7 layers instead
  - Application, Presentation, Session, Transport, Network, Data Link, Physical
  - Presentation: Syntax and semantics of information transmitted
  - Session: Long-Term transport, such as checkpointing

- 3 central concepts
  - Service: Tells what the layer does
  - Interface: Tells the process above how to access the layer
  - Protocol: How the service is performed; the layer's own business.

- In this course, we use the Internet reference model

Layering: logical communication

Each layer
- distributed
- “entities” implement layer functions at each node
- entities perform actions, exchange messages with peers

Layering: physical communication

Example: transport
- take data from app
- add addressing, reliability check info to form “datagram”
- send datagram to peer
- wait for peer to ack receipt
- Analogy: post office
Protocol layering and data

- Each layer takes data from above
  - adds header information to create new data unit
  - passes new data unit to layer below

Internet structure: network of networks

- roughly hierarchical
- national/international backbone providers (NBPs), a.k.a. “tier 1”
  - e.g. UUNet, Sprint, Abovenet, AT&T, BBN/GTE, etc.
  - interconnect (peer) with each other privately, or at public Network Access Point (NAP)
- regional ISPs
  - connect into NBPs
- local ISP, company
  - connect into regional ISPs

Network of typical backbone provider

Zur Geschichte der Kommunikation

- Tontäfelchen (3000 v.u.Z)
- Fackeltelegraphie
  - bereits im 5. Jh. v.u.Z. (Griechenland)
- Brieftauben
  - Spätestens Mittelalter
- Reiterboten
  - Ab 1860
- Trommeln, Spiegel, Flaggen, …
- Optische Telegraphen
  - Claude Chappe (Frankreich, 1791)
  - Schweiz: ab 1850

- Alphabet als 5 Gruppen zu 5 oder 4 Zeichen
- 2 Gruppen mit je 5 Fackeln
- Verbindungsaufbau
  1. Sendeabsicht: Heben von 2 Fackeln
  2. Empfangsbereitschaft: Heben von 2 Fackeln
  3. Senken der Fackeln
- Datenübertragung für jedes Zeichen
  1. Linke Fackelgruppe: Zeichengruppe anzeigen
  2. Senken der Fackeln
  3. Rechte Fackelgruppe: Zeichen anzeigen
  4. Senken der Fackeln

Protokoll bei Optischen Telegraphen

- Regeln für korrekten Nachrichtenaustausch
- Typischerweise synchrones Protokoll, d.h. sendende Station muss Symbol so lange zeigen, bis es von der empfangenden Station bestätigt wird.
- Es gab ein Fehlersignal, mit dem man wie bei "backspace" das letzte Zeichen löschen konnte.
- Dieses Protokoll erinnert stark an moderne Protokolle.

Elektrische Telegraphen

- 1774: 26 Drähte (unpraktisch)
- 1837: Elektrischer Zeigertelegraph
  – Cooke und Wheatstone
  – 5 Magnetnadeln, jeweils 2 werden abgelenkt und zeigen auf 1 von 20(!) Zeichen
- Man erreicht ca. 25 Zeichen pro Minute
- 1837: Samuel Morse
- 1851: Paris – London
- 1852: 6400km Kabel in England
- 1866: London – New York
  – 20 Wörter kosten $100
- Eigenständige Industrie

Telefon

- Reiss (1863), Bell (1876), Edison (1877), Siemens (1878)
- "This 'phone' has way to many shortcomings to consider it as a serious way of communicating. The unit is worthless to us." [Aktenvermerk Western Union, 1876]
- Ab 1880: Öffentliche Telefonnetze
  – Zuerst maximal 30km Ausdehnung
Wireless Transmission

- 1895: Guglielmo Marconi (1874 – 1937)
  - first demonstration of wireless telegraphy (digital!)
  - long wave transmission, high transmission power necessary (> 200kW)
  - Nobel Prize in Physics 1909
- 1901: First transatlantic connection
- 1906 (Xmas): First radio broadcast
- 1907: Commercial transatlantic connections
  - huge base stations (30 100m high antennas)
- 1920: Discovery of short waves by Marconi
- 1928: First TV broadcast
  - Atlantic, color TV

Internet History 1961-72: Early packet-switching principles

- 1961: [Kleinrock] queuing theory shows effectiveness of packet-switching
- 1964: [Baran] packet-switching in military nets
- 1967: ARPANet conceived by Advanced Research Projects Agency
- 1969: first ARPANet node operational, first network with 4 nodes

- 1972
  - ARPAnet demonstrated publicly
  - NCP (Network Control Protocol) first host-host protocol
  - first e-mail program
  - ARPAnet has 15 nodes

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe’s PhD thesis proposes Ethernet
- 1974: [Cerf and Kahn] architecture for interconnecting networks

1972-80: Internetworking, new and proprietary nets

- Vinton G. Cerf and Robert E. Kahn’s (Ehrendoktoren der ETH seit 1998) internetworking principles:
  - minimalism
  - autonomy
  - no internal changes required to interconnect networks
- Late 70’s:
  - proprietary architectures: DEcnet, SNA, XNS
  - switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Weitere historische Meilensteine

- 1964: Nachrichtensatelliten
- 1966: Glasfaser
  - Vergleich PTT (Swisscom) NATEL: 1978 – 1995
- 1982 : Start der GSM Standardisierung
- 1997: Wireless LAN
- …
1980-90: new protocols, a proliferation of networks

- 1983: deployment of TCP/IP
- 1982: SMTP e-mail protocol defined
- 1983: DNS defined for name-to-IP-address translation
- 1985: FTP protocol defined
- 1988: TCP congestion control
- new national networks: NSFnet, CSNET, BITnet, Minitel
- 100,000 hosts connected to confederation of networks

1990’s: Commercialization, WWW

- Early 1990’s: ARPAnet decommissioned
- early 1990s: WWW
  - hypertext [Bush 1945, Nelson 1960’s]
  - HTML, http: Berners-Lee
  - 1994: Mosaic, later Netscape
  - late 1990’s commercialization of the WWW
- Late 1990’s
  - est. 50 million computers on Internet
  - est. 100 million+ users
  - backbone links running at 1 Gbps

Number of hosts in the Internet (lower bound)

Internet Domain Survey Host Count

Source: Internet Software Consortium (www.isc.org)

Internet Providers by “size” and “region”

Copyright ©1999, US Government, all rights reserved.
The image depicts the Internet topology. It shows 535,000-odd Internet nodes and over 600,000 links. The nodes, represented by the yellow dots, are a large sample of computers from across the whole range of Internet addresses.

This graph is part of a larger graph and shows the portion of a corporate Intranet that is "leaking" with the Internet.

A topology map of a core network of a medium-sized ISP.

The SWITCH network

"The pan European KPNQwest network, when complete, will connect major cities together by six high-capacity backbone rings."
### Internet Users Worldwide

![Map of Internet Users Worldwide](image)

### Global Online Population

#### Worldwide Internet Population 2002
- 445.9 million (eMarketer)
- 533 million (Computer Industry Almanac)

#### Projection for 2004
- 709.1 million (eMarketer)
- 945 million (Computer Industry Almanac)

<table>
<thead>
<tr>
<th>Nation</th>
<th>Population</th>
<th>Internet Users (Source)</th>
<th>Active Users (Nielsen/NetRating)</th>
<th>ISPs</th>
</tr>
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<tbody>
<tr>
<td>Brazil</td>
<td>174.5 million</td>
<td>6.1 million</td>
<td>6.0 million</td>
<td>50</td>
</tr>
<tr>
<td>China</td>
<td>1.3 billion</td>
<td>33.7 million</td>
<td>N/A</td>
<td>3</td>
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<td>Germany</td>
<td>83 million</td>
<td>26 million</td>
<td>15.1 million</td>
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<td>7.3 million</td>
<td>3.4 million</td>
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<tr>
<td>Sudan</td>
<td>36 million</td>
<td>10,000</td>
<td>N/A</td>
<td>1</td>
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<tr>
<td>United States</td>
<td>278 million</td>
<td>149 million</td>
<td>102.0 million</td>
<td>7,800</td>
</tr>
</tbody>
</table>

### Internet Languages & Searches

- Percentage of searches done by US web surfers in May 2004:
  - English: 25.2%
  - Spanish: 9.5%
  - French: 4.4%
  - Portuguese: 3.1%
  - German: 2.4%
  - Japanese: 1.9%
  - Italian: 1.8%
  - Russian: 1.7%
  - Chinese: 1.1%
  - Other: 59.0%

[http://searchenginewatch.com/reports/article.php]

### Favorite Web Sites in Switzerland

- According to Jupiter Media Metrix, 2.022 million visitors used the Internet in Switzerland in February 2001 for an average of 9.5 days.
- On an average day, 680’000 visitors went online for 33 minutes and viewed 27 unique pages.
- Global sites from Microsoft, Yahoo, AOL and Lycos found under the top rankings in all three language regions. National domains are very strong. Bluewin.ch tops the list with an overall reach of 50 percent. Other national sites among the top 20 domains include Search.ch (22 percent reach), SBB.ch (15.5 percent), Sunrise.ch (11.8 percent), Swissonline.ch (10.2 percent) and UBS.com (9.9 percent).
Internet Usage in Switzerland

- Internet usage in Switzerland, 1995-2005
- Domain names ending in .ch

Domain Names ending in .ch

- Internet usage in Switzerland 2

- Domain names ending in .ch

The “Dot-Com Bubble”

- Not all Internet companies are subject to the bubble. Some major ones are doing quite well (Cisco, MS, IBM, etc.)

- Many of my fellow students work in the networking or distributed systems area (not that this is a representative subset)

- Networking still important
SPIEGEL: “Neustart im Netz”

Course overview

Introduction
Overview
Applications: Email, WWW, etc.
More Applications and Sockets
Transport Layer: UDP and TCP
Advanced Transport Layer
Network Layer: Routing Basics
Advanced Network Layer
Link Layer: Aloha, etc.
Link Layer: Ethernet, Hubs, etc.
Physical Layer, Wireless
Peer-to-Peer Computing
Distributed Systems
Mobile Systems
(Gustavo Alonso)

Literature

Course book
Andrew S. Tanenbaum
Computer Networks
Fourth Edition

German version also available

There are alternatives, for example Kurose/Ross

Other Courses, Master* in Distributed Systems

Enterprise Application Integration* – Alonso
Parallel and Distr. Databases* – Alonso
Ubiquitous Computing* – Mattern
Distributed Algorithms* – Mattern
Ad Hoc and Sensor Networks* – Wattenhofer
Principles of Distributed Computing* – Wattenhofer
Web Algorithms – Wattenhofer & Widmayer

More: See www.{dcg, tik.ee, pc.inf}.ethz.ch.