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

- Goal: get context, overview, “feeling” of networking, postpone details.

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

Local ISP

Regional ISP

Company network

Router

Workstation

Mobile
“Cool” Internet appliances

- Web-enabled toaster and weather forecaster
- World’s smallest web server
- Streaming (Video, Audio, VoIP)

Plus Web “2.0” Stuff

- e.g. “I kind of look like…”
- Plus lots of social networking sites
  - myspace, flickr, last.fm, secondlife, etc.

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 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

… specific msgs sent
… specific actions taken
when msgs received, or
other events

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

protocols define format, order of
msgs sent and received among
network entities, and actions
taken on msg transmission,
receipt

A closer look at network structure

A human protocol and a computer network protocol

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. BitTorrent, Skype
Network edge: connection-oriented service

Goal: data transfer between end systems
- handshaking: setup (prepare for) data transfer ahead of time
  - "Hello, hello back" human protocol
  - set up "state" in two communicating hosts
- TCP
  - Transmission Control Protocol
  - connection-oriented service of the Internet

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!

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- reliable, in-order byte-stream data transfer
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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

- 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

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Packet switching
- data sent through network in discrete “chunks”
### Frequency Division and Time Division Multiple Access

**FDMA**
- Frequency division into "pieces"
- Dedicated allocation
- Resource reservation

**TDMA**
- Time division into "pieces"
- Dedicated allocation
- Resource reservation

### Packet Switching
- Each end-end data stream divided into packets
- Packets share network resources
- Each packet uses full link bandwidth
- Resources used as needed

### 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, \( \Pr[\text{more than 10 users active}] < 1\% \)
  - With 100 users, \( \Pr[\text{more than 10 users active}] \approx 42\% \)

- Packet switching allows more users... Really?
Packet Switching

- Source breaks message into smaller chunks: "packets"
- Store-and-forward: switch waits until one chunk has completely arrived, then forwards/routes
- What if message was sent as a single unit?

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
Delay in packet-switched networks

- Transmission delay:
  - R = link bandwidth (bps)
  - L = packet length (bits)
  - Time to send bits into link = L/R

- Propagation delay:
  - d = length of physical link
  - s = propagation speed in medium (~2x10^8 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)
- \( \lambda = \frac{aL}{R} \) (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!

“Real” Internet delays and routes: traceroute

```
1   <10 ms <10 ms <10 ms   rou-ifw-1-inf-vs.ethz.ch [129.132.13.122]
2   <10 ms <10 ms <10 ms   rou-gw-switch-1-mega-transit-2.ethz.ch [129.132.99.213]
3   <10 ms <10 ms <10 ms   sswiez2.ethz.ch [192.33.92.11]
4   <10 ms <10 ms <10 ms   swiIX1-G2-3.switch.ch [130.59.36.250]
5   <10 ms <10 ms <10 ms   zch-b1-geth4-1.telia.net [213.248.79.189]
6   <10 ms <10 ms <10 ms   ffm-b1-pos5-3.telia.net [213.248.77.133]
7   <10 ms <10 ms <10 ms   78.213.248.68.90
8   <10 ms <10 ms <10 ms   80.81.192.226
9   <10 ms <10 ms <10 ms   so-0-1-0.cr1.fra1.de.mfnx.net [216.200.116.213]
10  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
11  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
12  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
13  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
14  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
15  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
16  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
17  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
18  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
19  <10 ms <10 ms <10 ms   so-0-1-0.mp4.sjc2.us.mfnx.net [208.184.233.133]
```

Networking Taxonomy

- Circuit Switching
  - FDM
  - TDM

- Packet Switching
  - Virtual Circuit
  - Datagram

- We concentrate on right-hand path (predominant in Internet)
Access networks and physical media

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, etc.

• 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 up to 11 Mbps
  - 802.11a/g 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

- Twisted Pair TP (UTP, STP)
  - two insulated copper wires
  - Category 3
    - traditional phone wires
    - 10 Mbps Ethernet
  - Category 5
    - 100Mbps Ethernet
  - Category 6
    - 1Gbps Ethernet
- 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)
- baggage (check)
- gates (load)
- runway takeoff
- airplane routing
- ticket (complain)
- baggage (claim)
- gates (unload)
- 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

Another example of layering

- 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

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
Layering: physical communication

- 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

- roughly hierarchical
- national/international backbone providers (NBPs), a.k.a. “tier 1”
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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. Empfangsbereitsschaft: 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

**Weitere historische Meilensteine**

- 1964: Nachrichtensatelliten
- 1966: Glasfaser
  - Vergleich PTT (Swisscom) NATEL: 1978 – 1995
- 1982: Start der GSM Standardisierung
- 1997: Wireless LAN
- …

**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
1972-80: Internetworking, new and proprietary nets

- 1970: ALOHAnet satellite network in Hawaii
- 1973: Metcalfe’s PhD thesis proposes Ethernet
- 1974: [Cerf and Kahn] architecture for interconnecting networks
- Late 70’s:
  - proprietary architectures: DECnet, SNA, XNS
  - switching fixed length packets (ATM precursor)
- 1979: ARPAnet has 200 nodes

Vinton G. Cerf and Robert E. Kahn’s (Ehrendoktoren der ETH seit 1998) internetworking principles:
- minimalism
- autonomy
- no internal changes required to interconnect networks
- best effort service model
- stateless routers
- decentralized control
  ➢ define today’s Internet architecture

• new national networks: NSFnet, CSNET, BITnet, Minitel
• 100,000 hosts connected to confederation of networks

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

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)
Domain Names ending in .ch

![Bar chart showing the growth of domain names ending in .ch from 1995 to 2004.](http://www.cybergeography.org/atlas/topology.html)

Internet Providers by “size” and “region”

![Graph depicting Internet providers by size and region.](http://www.cybergeography.org/atlas/topology.html)

Internet Topology

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. [http://www.cybergeography.org/atlas/topology.html]

More Internet Topology

This graph is part of a larger graph and shows the portion of a corporate Intranet that is 'leaking' with the Internet. [http://www.cybergeography.org/atlas/topology.html]

This graph shows the router level connectivity of the Internet. A topology map of a core network of a medium-sized ISP.
The SWITCH network

Internet Users Worldwide

Favorite Web Sites

- Switzerland
  - bluewin (world rank 498), ricardo, pctipp, bluewin, bluewin,
    bluewin, libellules, sunrise, 20min, ubs, gameswelt, sunrise...

- World
  - google.com, yahoo, google.de, google (https), google.co.uk,
    google.fr, mail.google, microsoft, bbc, bbc, foxnews, google.ca

The “Dot-Com Bubble”
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
Network Security
Distributed Systems
Network Management
Etc.

Introduction
Layer 5
Layer 4
Layer 3
Layer 2
Layer 1

Special Topics

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.

Literature

Course book
Andrew S. Tanenbaum
Computer Networks
Fourth Edition

German version also available

There are alternatives, for example Kurose/Ross