Advanced Computer Networks

cs538, Spring 2016 @ UIUC

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Lecture 2

Based on

C. Partidge, “Forty Data Communications Research Questions”, CCR, 2011
Prior 2010-2013, lecture material by Brighten Godfrey and Matt Caesar
Announcements

• Select reviews by January 28
• Form groups and select lecture as a group by January 28
• Read papers for January 28 lecture
  - A protocol for packet network intercommunication (Cerf and Kahn, 1974)
  - The Design Philosophy of the DARPA Internet Protocols (Clark, 1988)
Outline

• History of Internet

• Review of basic concepts

• Grand challenges – few examples
Visions

• Vannevar Bush, “As we may think” (1945): memex

• J. C. R. Licklider (1962): “Galactic Network”
  • Concept of a global network of computers connecting people with data and programs
  • First head of DARPA computer research, October 1962
Circuit switching

1935

International operator, New York  AT&T
Source: http://www.corp.att.com/history/nethistory/switching.html

1967
1961-64: Packet switching

<table>
<thead>
<tr>
<th>Circuit Switching</th>
<th>Packet switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical channel carrying stream of data from source to destination</td>
<td>Message broken into short packets, each handled separately</td>
</tr>
<tr>
<td>Three phase: setup, data transfer, tear-down</td>
<td>One operation: send packet</td>
</tr>
<tr>
<td>Data transfer involves no routing</td>
<td>Packets stored (queued) in each router, forwarded to appropriate neighbor</td>
</tr>
</tbody>
</table>
1961-64: Packet switching

• Key benefit: Statistical Multiplexing
  • (what else?)
1961-64: Packet switching

• Concurrent development at three groups
  • Paul Baran (RAND)
  • Donald Davies (National Physical Laboratories, UK)
Baran’s packet switching

Baran’s packet switching

There is an increasingly repeated statement made that one day we will require more capacity for data transmission than needed for voice. If this statement is correct, then it would appear prudent to broaden our planning consideration to include new concepts for future data network directions. ... New digital computer techniques using redundancy make cheap unreliable links potentially usable. ... Such a system should economically permit switching of very short blocks of data from a large number of users simultaneously with intermittent large volumes among a smaller set of points.

1965: First computer network

- Lawrence Roberts and Thomas Merrill connect a TX-2 at MIT to a Q-32 in Santa Monica, CA
- ARPA-funded project
- Connected with telephone line
  - works, but it’s inefficient and expensive
  - confirmed one motivation for packet switching
- Roberts utilized Davies’ packet switching theory late 1960’s and built into ARPANET
The ARPANET begins

- Roberts joins DARPA (1966), publishes plan for the ARPANET computer network (1967)
- December 1968: Bolt, Beranek, and Newman (BBN) win bid to build packet switch, the Interface Message Processor (IMP)
  - First generation of gateways
- September 1969: BBN delivers first IMP to Kleinrock’s lab at UCLA
ARPANET comes alive

Stanford Research Institute (SRI)

“LO”
Oct 29, 1969

UCLA
ARPANET grows

- Dec 1970: ARPANET Network Control Protocol (NCP)
- 1971: Telnet, FTP
- 1972: Email (Ray Tomlinson, BBN)
- 1979: USENET
ARPANET grows
ARPANET to Internet

• Meanwhile, other networks such as PRnet, SATNET developed

• May 1973: Vinton G. Cerf and Robert E. Kahn present first paper on interconnecting networks

• Concept of connecting diverse networks, unreliable datagrams, global addressing, ...

• Became TCP/IP
TCP/IP deployment

• TCP/IP implemented on mainframes by groups at Stanford, BBN, UCL
• David Clark guides architecture, implements it on Xerox Alto and IBM PC
  • Design by committee didn’t win
• January 1, 1983: “Flag Day” NCP to TCP/IP transition on ARPANET
Growth from Ethernet

- Ethernet: R. Metcalfe and D. Boggs, July 1976
- Spanning Tree protocol: Radia Perlman, 1985
- Made local area networking easy
Growth spurs organic change

- Early 1980s: Many new networks: CSNET, BITNET, MFENet, SPAN (NASA), ...

- Nov 1983: DNS developed by Jon Postel, Paul Mockapetris (USC/ISI), Craig Partridge (BBN)

- 1984: Hierarchical routing: EGP and IGP (later to become eBGP and iBGP)
NSFNET

• 1984: NSFNET for US higher education
  • Serve many users, not just one field
  • Encourage development of private infrastructure (e.g., backbone required to be used for Research and Education)
  • Stimulated investment in commercial long-haul networks

• 1990: ARPANET ends
• 1995: NSFNET decommissioned
Explosive growth!

In hosts

![Hobbes' Internet Timeline](http://www.zakon.org/robert/internet/timeline/)
Explosive growth!

In networks

(Colors correspond to measurements from different vantage points)

[Huston ’12]
Explosive growth!

In devices & technologies

- O(100 million) times as many devices
- Link speeds 200,000x faster
- NATs, firewalls, DPI, ...
- Wireless everywhere
- Mobile everywhere
- Tiny devices (smart phones)
- Giant devices (data centers)
- ...

In applications

- Morris Internet Worm (1988)
- World wide web (1989)
- MOSAIC browser (1992)
- Search engines
- Peer-to-peer
  - Voice
  - Radio
  - Botnets
- Social networking
- Streaming video
- Cloud computing
- Mobile apps

The results of your class projects!
Huge societal relevance

Routing instabilities and outages in Iranian prefixes following 2009 presidential election

[James Cowie, Renesys Corporation]
Huge societal relevance

Reachability to Libya

Globally Reachable Libyan Networks
July 25 - August 22, 2011

Reachable prefixes

July - August 2011

[James Cowie,
Renesys Corporation]
Top 30 inventions of the last 30 years

1. Internet/Broadband/World Wide Web
2. PC/Laptop Computers
3. Mobile Phones
4. E-Mail
5. DNA Testing and Sequencing/Human Genome Mapping
6. Magnetic Resonance Imaging (MRI)
7. Microprocessors
8. Fiber Optics
9. Office Software
10. Non-Invasive Laser/Robotic Surgery
11. Open Source Software and Services
12. Light Emitting Diodes (LEDs)
13. Liquid Crystal Displays (LCDs)
14. GPS
15. Online Shopping/E-Commerce/Auctions
16. Media File Compression
17. Microfinance
18. Photovoltaic Solar Energy
19. Large Scale Wind Turbines
20. Social Networking via Internet
21. Graphic User Interface (GUI)
22. Digital Photography/Videography
23. RFID
24. Genetically Modified Plants
25. Biofuels
26. Bar Codes and Scanners
27. ATMs
28. Stents
29. SRAM/Flash Memory
30. Anti-Retroviral Treatment for AIDS

Compiled by the Wharton School @ U Penn, 2009
So we’re done! ... right?

- Core protocols changed little, but the context has...
  - Criminals and malicious parties
  - Everyone trying to game the system
  - Incredible growth
  - Constant mobility
  - Extreme complexity

- ...and fixing the net involves fundamental challenges
  - It’s distributed
  - Components fail
  - Highly heterogeneous environments
  - Highly complex systems components and interactions
  - Must get competing parties to work together
Review of Basics before Grand Challenges
Layering

• A kind of modularity

• Functionality separated into layers
  • Layer n implements higher-level functionality by interfacing only with layer n-1
  • Hides complexity of surrounding layers: enables greater diversity and evolution of modules
Layering

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Layering

Tunnel
# Common functionality & problems

<table>
<thead>
<tr>
<th>Layer</th>
<th>Functionality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td><em>Anything you want...</em></td>
</tr>
<tr>
<td>Transport</td>
<td>Process-level communication</td>
</tr>
<tr>
<td>Network</td>
<td>Packets across domains</td>
</tr>
<tr>
<td></td>
<td>Packets across networks</td>
</tr>
<tr>
<td>Data Link</td>
<td>Packets on a ‘wire’</td>
</tr>
<tr>
<td>Physical</td>
<td>Encoding of bits</td>
</tr>
<tr>
<td></td>
<td><em>Life, the universe, and everything</em></td>
</tr>
<tr>
<td></td>
<td>Reliability, flow control, ordering, congestion, ...</td>
</tr>
<tr>
<td></td>
<td>Independent parties, scale, routing</td>
</tr>
<tr>
<td></td>
<td>Addressing, heterogeneity, routing</td>
</tr>
<tr>
<td></td>
<td>Framing, errors, addressing</td>
</tr>
<tr>
<td></td>
<td>Physics</td>
</tr>
</tbody>
</table>
Grand Challenges
Grand Challenges

• Widely recognized as among the most important unsolved problems in a field
  • P vs. NP
  • natural language understanding
  • bug-free programs
  • moving society to carbon-neutral energy
  • preventing cancer
  • ...
Grand Challenges in networking?

• Getting an A in this class?
GC’s in networking

An Informal Survey

• “What I’m working on!”
• High level objectives
  • Security & privacy
  • Reliability
  • Usability

• Different than P vs. NP: hard to even define “security”; objectives involve tradeoffs
Unreliability: One Example
Internet Routing

AS 36561
YouTube

AS 7018
AT&T

AS 698
UIUC

eBGP

iBGP

AS 11537
Internet2
Border Gateway Protocol

Route selection
Instability causes outages

- Link state changes
- Router failures
- Config. changes
- ...

Eventually, control message: \( \text{CACBD} \)

Forwarding loop

- Loops
- Detection delay
- Black holes

\( \implies \) FAIL

Loop detected!
Instability causes outages

[F. Wang, Z. M. Mao, J. Wang, L. Gao, R. Bush SIGCOMM’06]
Instability causes outages

[ F. Wang, Z. M. Mao, J. Wang, L. Gao, R. Bush SIGCOMM’06 ]

More outages

Longer outages

(...and higher latency, packet reordering, router CPU load during instability)
Many sources of unreliability

- Congestion
  - no end-to-end bandwidth reservations in the Internet
- Configuration or software bugs
- Failures or delays
  - in network, DNS servers, caches, application servers, ...
Insecurity: one example
Prefix hijacking

• Anyone can advertise routes for any IP prefix!
• How can hijacker get the advertised routes to actually be used by other ASes?
  • Announce more specific (longer) prefix than real owner
  • Now everyone’s traffic is “blackholed”
• Can protect against this (Secure BGP), but...
  • it’s not deployed today
  • and even then, can still cleverly (or accidentally) attract traffic and eavesdrop
From hijacking to MITM

- August ’08, Kapela and Pilosov
- Man in the Middle (MITM) attack
  - Traffic to a destination redirected (not blackholed) through an attacker
  - Attacker can watch everything you do without you noticing
- What’s the key problem here?

How can attacker forward traffic to destination, if attacker is pretending to be the destination?
Hijacking + eavesdropping

- A finds legitimate path ABD for 128.2.0.0/16
Hijacking + eavesdropping

- A finds legitimate path ABD for 128.2.0.0/16
- A sends semi-bogus announcement of path ABD for 128.2.0.0/17

Result:
- ASes (here B) on real path keep using real path because of loop elimination
- All other ASes use route through A (/17 beats /16)
- A forwards traffic to B
Grand Challenges in networking

An Informal Survey

• “What I’m working on!”
• Nebulous high level objectives
  • Security & privacy
  • Reliability
  • Usability
  • Complexity
• Why does networking lack a crisp Grand Challenge?
  • Infrastructure needs to support highly diverse and dynamic goals, applications, and environments
Grand Challenges in networking

Meta-challenge:

How do we make the Internet evolvable?