CS4450

Computer Networks: Architecture and Protocols

Lecture 18
Putting it ALL together

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Announcements

• Prelim 2 next Monday
  • Open book, open notes
  • If the class is between 8AM and 10:30PM in your local timezone
    • You have to take the prelim during the lecture hours
      • Unless you have gotten permission otherwise
    • If you prefer to take it from home, completely okay
    • If you prefer to take it in the lecture hall, we will be here
  • Otherwise
    • You can take the exam in a 24 hour window
      • You have the same amount of time as others
      • 7:30PM ET on Monday to 7:29PM ET on Tuesday
      • We reserve the right to invite you to an oral exam

• We will send a detailed email about the exam before Monday afternoon
  • Please plan to check your email at least once after noon Monday
Announcements

• Practice exam for Prelim 2 posted

• Problem set 4 solutions posted

• Coverage: everything we have covered so far
Goal of Today’s Lecture

• Put it ALL together

• Answer any questions you may have ....
Discovery protocols: ARP and DHCP

Suppose Host A wants to communicate with Host B
Discovery

• Suppose I am host A

• I want to communicate with B (say, www.google.com)

• I was “born” knowing only my name — my MAC address :-)

• Must discover some information before I can communicate with B
  • What is my IP address?
  • What is B’s IP address?
    • Using DNS
  • Is B within my LAN?
  • If yes, what is B’s MAC address?
  • If not, what is the address of my first-hop router to B?
  • ...
DHCP and ARP

- Link layer discovery protocols
  - DHCP — Dynamic Host Configuration Protocol
  - ARP — Address Resolution Protocol
- Configured to a single LAN
- Rely on broadcast capability
DHCP and ARP

• Link layer discovery protocols
• Serve two functions

1. Discovery of local end-hosts
   • For communication between hosts on the same LAN

2. Bootstrap communication with remote hosts
   • What’s my IP address?
   • Who/where is my local DNS server?
   • Who/where is my first hop router?
DHCP

• Dynamic Host Configuration Protocol
  • Defined in RFC 2131

• A host uses DHCP to discover
  • Its own IP address
  • Subnet masks — allows to test whether an IP address is local or not
  • IP address(es) for its local DNS name server(s)
  • IP address(es) for its first-hop “default” router(s)
DHCP: operation

1. One or more local DHCP servers maintain required information
   - IP address pool, netmask, DNS servers, etc.
   - Application that listens on UDP port 67
DHCP: operation

1. One or more local DHCP servers maintain required information

2. Client broadcasts a DHCP discovery message
   • L2 broadcast, to MAC address FF:FF:FF:FF:FF:FF
DHCP: operation

1. One or more local DHCP servers maintain required information

2. Client broadcasts a DHCP discovery message

3. One or more DHCP servers respond with a DHCP “offer” message
   • Proposed IP address for client, lease time
   • Other parameters
DHCP: operation

1. One or more local DHCP servers maintain required information

2. Client broadcasts a DHCP discovery message

3. One or more DHCP servers respond with a DHCP “offer” message

4. Client broadcasts a DHCP request message
   - Specifies which offer it wants
   - Echoes accepted parameters
   - Other DHCP servers learn they were not chosen
DHCP: operation

1. One or more local DHCP servers maintain required information
2. Client broadcasts a DHCP discovery message
3. One or more DHCP servers respond with a DHCP “offer” message
4. Client broadcasts a DHCP request message
5. Selected DHCP server responds with an ACK
Are we there yet?

What I learnt from DHCP
My IP: 1.2.3.48
Netmask: 1.2.3.0/24
Local DNS: 1.2.3.156
Router: 1.2.3.9
ARP: Address Resolution Protocol

• Every host maintains an ARP table
  • List of (IP address — MAC address) pairs
  • For IP addresses within the same LAN

• Consult the table when sending a packet
  • Map destination IP address to destination MAC address

• But: what if IP address not in the table?
  • Either its not local (detected using DHCP)
  • If its local:
    • Sender broadcasts: “Who has IP address 1.2.3.156?”
    • Caches the answer in ARP table
Key Ideas in Both ARP and DHCP

• Broadcasting: can use broadcast to make contact
  • Scalable because of limited size

• Caching: remember the past for a while
  • Store the information you learn to reduce overhead
## Taking Stock: Discovery

<table>
<thead>
<tr>
<th>Layer</th>
<th>Examples</th>
<th>Structure</th>
<th>Configuration</th>
<th>Resolution Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>App Layer</td>
<td><a href="http://www.cs.cornell.edu">www.cs.cornell.edu</a></td>
<td>Organizational hierarchy</td>
<td>~ manual</td>
<td>DNS</td>
</tr>
<tr>
<td>Network Layer</td>
<td>123.45.6.78</td>
<td>Topological hierarchy</td>
<td>DHCP</td>
<td>ARP</td>
</tr>
<tr>
<td>Link Layer</td>
<td>45-CC-4E-12-F0-97</td>
<td>Vendor(flat)</td>
<td>Hard-coded</td>
<td></td>
</tr>
</tbody>
</table>
Where are we?
What protocols have we learnt on LAN?

• Link Layer MAC names/addresses: come with the hardware

• CSMA/CD Protocol: To transmit frames on broadcast Ethernet

• Spanning Tree Protocol: To transmit frames on switched Ethernet

• Domain Name System: To map application-layer names to IP addresses

• DHCP: To learn
  • Its own IP address
  • Whether an IP address is local or not
  • IP address(es) for its local DNS name server(s)
  • IP address(es) for its first-hop “default” router(s)

• ARP: To map IP addresses to MAC names (for IP addresses on the same LAN)
What have we learnt beyond LAN?

• Link-state and Distance-vector Protocols:
  • For finding routes (and a next-hop) to an IP address within an ISP

• Border Gateway Protocol:
  • For finding routes to an IP address range

• Forwarding at routers
  • Store **routing tables** (map **destination prefixes** to outgoing port)
  • Longest prefix match for destination address lookup
How does the Internet work?

Let's first see what it actually looks like!
What is a computer network?

A set of network elements connected together, that implement a set of protocols for the purpose of sharing resources at the end hosts.
What does Internet actually look like?

• The smallest component:
  • A Network Interface Card (NIC), or a machine, or a server
  • Has a Link Layer MAC name/address

• Multiple NICs connected in a Local Area Network (LAN) via
  • Broadcast Ethernet,
  • Or, Switched Ethernet

• Switches in LAN
  • Connected to larger routers
What does Internet actually look like?
What does Internet actually look like?

"Autonomous System (AS)" or "Domain"
Region of a network under a single administrative entity
Multiple “Autonomous Systems (AS)” or “Domains” connect together using Border Routers.
This entire infrastructure is a part of the INTERNET :-)
How does the Internet work?

Are you ready?

(Count the number of protocols used for each packet)
How does Internet work — end-to-end?

- Network stack receives data from the application (roughly speaking)
- What is my IP address? (using DHCP)
- What is the destination IP address? (using DNS)
- Encapsulate data into packets (and add an IP header)
- Is destination IP address within my LAN? (using DHCP)

**If destination IP address local:**
- What is destination MAC address (using ARP)?
- Encapsulate packet into frames with source/destination address
  - And, add a Link layer header
- Convert frames into bits
- Forward the bits to the wire ...

- Each switch:
  - Forwards to destination (using STP/CSMA/CD)
End-to-End

DHCP

Source IP

Destination within my LAN?

Destination IP

DNS

ARP

Destination MAC

S

T

N

L

IP

LL

T

N

L

DD

D

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How does Internet work — end-to-end?

• Network stack receives data from the application (roughly speaking)
• What is my IP address? (using DHCP)
• What is the destination IP address? (using DNS)
• Encapsulate data into packets (and add an IP header)
• Is destination IP address within my LAN? (using DHCP)
• If destination IP address remote:
  • What is my next-hop router IP address? (using DHCP)
  • What is my next-hop router MAC address? (using ARP)
  • Encapsulate packet into frames with source/destination address
    • And, add a Link layer header
  • Convert frames into bits
  • Forward the bits to the wire ...
• Each router ....
How does Internet work — end-to-end?

A router upon receiving a packet (implicit questions)

• Is the destination in a LAN connected to me?
  • Forward the packet to the destination
  • Using STP/CSMA/CD

• Is the destination not in my LAN but in my ISP?
  • Forward the packet to the next-hop router towards the destination
  • Using next-hops computed via distance-vector routing algorithm

• Is the destination in a different ISP?
  • Forward the packet to the next-hop router towards the destination
  • Using next-hops computed via BGP routing algorithm
Are We There Yet?

• Yes!
• How can we be sure?
• Let's go back to where we started ....
Recall the end-to-end story from our third lecture :-)  

• Application opens a **socket** that allows it to connect to the **network stack**

• Maps **name** of the web site to its **address** using **DNS**

• The network stack at the source embeds the address and **port** for both the source and the destination in **packet header**

• Each **router** constructs a **routing table** using a distributed algorithm

• Each router uses destination address in the packet header to look up the **outgoing link** in the routing table
  • And when the link is free, forwards the packet

• When a packet arrives the destination:
  • The network stack at the destination uses the port to forward the packet to the right application
You now know how the Internet works!!!!

All that is remaining:

Reliability.