cs/ee/ids 143  Communication Networks

Chapter 4  Internetworking

Text: Walrand & Parekh, 2010

Steven Low
CMS, EE, Caltech
Warning

These notes are not self-contained, probably not understandable, unless you also were in the lecture

They are supplement to, not replacement for class attendance
Recap: Internet overview

Some basic mechanisms

- Packet switching
- Addressing
- Routing
  - hierarchical (AS), forwarding, shortest path routing, software defined networking
- Transport
  - congestion control, error recovery
- Medium access control
- Internetworking
Recap: Internet overview

Some basic concepts

- Performance metrics
  - Throughput, line rate (bandwidth), line capacity
  - Delay, delay jitter

- Scalability
  - location-based routing, hierarchical
  - best-effort service, end-to-end principle

- Layering
Network mechanisms implemented as protocol stack

Each layer designed separately, evolves asynchronously

- Many control mechanisms...
- Error control, congestion control (TCP)
- Routing (IP)
- Medium access control
- Coding, transmission, synchronization
Recap: Internet overview

Some basic analytic tools

- Convex optimization
  - We will use it to understand equilibrium properties of TCP congestion control

- Control and dynamical system
  - We will use it to understand stability properties of TCP congestion control

- Queueing theory
  - We will use it to understand statistical properties of wireless MAC
Recap: Routing

Covered layer 3 routing

- Autonomous systems (AS)
  - Defined by administrative domains
- Inter-AS: BGP
  - Policy based
- Intra-AS: Dijkstra, Bellman-Ford
  - Shortest-path routing

Error recovery

- Can be used in link, transport, or application layer
- Parity check, FEC, network coding
This week

Internetworking
- Routing across LANs, layer2-layer3
- DHCP
- NAT

Transport layer
- Connection setup
- Error recovery: retransmission
- Congestion control
Internetworks

Layer 2 networks

Each (layer 2) network
- **full connectivity**: every node can reach every other node
- **broadcast capable**: every node (inc. router) can broadcast to all other nodes

Layer 3 view: ignore the details of subnetworks
Internetworks

an Ethernet network (layer 2)

Ethernet switch

Layer 3 view
Addresses, Subnet mask, Gateway

Network layer on a host knows:
1. Own IP address
2. Subnet mask
3. Gateway router IP
4. DNS server IP
Network layer on a host knows:

1. Own IP address
2. Subnet mask
3. Gateway router IP
4. DNS server IP
Addresses, Subnet mask, Gateway

Network layer on a host knows:
1. Own IP address
2. Subnet mask
3. Gateway router IP
4. DNS server IP

Tells the host the range of IP addresses in the same Layer 2 subnet
Addresses, Subnet mask, Gateway

Network layer on a host knows:
1. Own IP address
2. Subnet mask
3. Gateway router IP
4. DNS server IP

Router (interface) that connects host to the rest of the internet
Network layer on a host knows:
1. Own IP address
2. Subnet mask
3. Gateway router IP
4. DNS server IP

This server returns IP addresses for a domain name
Example

Ethernet sub-network 1

Ethernet sub-network 2

Internet

Gateways
Example: H1 wants to send packet to H2

Network layer on H1 uses subset mask to determine that IP2 is within its subnet => next (layer 3) hop is IP2
Example: H1 wants to send packet to H2

Link layer on H1 needs the MAC address e2 corresponding to IP2 to deliver the packet:
ARP (Address Resolution protocol)
Example: H1 wants to send packet to H2

Link layer on H1 broadcasts a message (ARP query) on its layer 2 network asking for the MAC address corresponding to IP2
Example: H1 wants to send packet to H2

Link layer on H2 responds to the ARP query with its MAC address
Example: H1 wants to send packet to H2

Once the link layer on H1 knows e2, it can now send the original message
Example: H1 wants to send packet to H2

Link layer on H2 delivers the packet to the network layer on H2.
Example: H1 wants to send packet to H3
Example: H1 wants to send packet to H3

Network layer on H1 checks that IP3 is not in its subnet, so it routes it to its gateway IP4.
Example: H1 wants to send packet to H3

[IP1, IP3, X]  Network  Link  Send [IP1, IP3, X] to IP6
Example: H1 wants to send packet to H3
Summary

- **Network layer (Layer 3)**
  - Provides host-to-host communication service by finding a path of routers connecting any two hosts
  - Main function: routing

- **Link layer (Layer 2)**
  - Provides host-router and router-router communication by utilizing the physical communication links
  - => provides a service to the network layer
Putting it all together

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
The network addresses of nodes are given by <AS>.<Network>.0.<node>, e.g., node A has the address AS1.E1.0.A,

The bridge IDs satisfy B1 < B2 < B3 ..., 

H is not connected to AS2.E5 for part (a),

The BGP Speakers use the least-next-hop-cost policy for routing (i.e., among alternative paths to the destination AS, choose the one that has the least cost on the first hop), and

The network topology shown has been stable for a long enough time to allow all the routing algorithms to converge and all the bridges to learn where to forward each packet.

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
Putting it all together

**Figure 5.19:** Figure for Routing Problem 3. [W&P 2010]

1. How to route G → A?
2. As soon as H is added, D tries to send a packet to H. What happens?
3. If AS2.R2 goes down, what will be the routing changes?

later goes down

initially unconnected
1. compute spanning tree

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
Recap: STP routing on subnet

x → y: [ y | x | data ]
2. compute intra-AS routing

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
Recap: intra-AS routing

Send pkt X to IP3
3. compute inter-AS routing

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
Recap: inter-AS routing

Example
BGP policy at Berkeley:
1. If possible, avoid AT&T
2. Choose path with smallest #hops
3. Alphabetical

Berkeley decision:
use path Sprint-Verizon-MIT to reach MIT
3. compute inter-AS routing

1. How to route G → A?

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
3. compute inter-AS routing

1. How to route G → A?

Does A → G follow the same path?

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
4. Address resolution protocol

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]

1. How to route G → A?
2. As soon as H is added, D tries to send a packet to H. What happens?
3. If AS2.R2 goes down, what will be the routing changes?

initially unconnected
4. Address resolution protocol

- Packets from D can be delivered to subnet AS2.B1 based on IP address of H
- AS2.B1 does not know H
- AS2.B1 uses ARP to find H’s MAC address
- Use STP to forward pkts to H

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
Example: H1 wants to send packet to H2

Link layer on H1 broadcasts a message (ARP query) on its layer 2 network asking for the MAC address corresponding to IP2.
Example: H1 wants to send packet to H2

Link layer on H2 responds to the ARP query with its MAC address.
Once the link layer on H1 knows e2, it can now send the original message
Example: H1 wants to send packet to H2

Link layer on H2 delivers the packet to the network layer on H2
5. re-compute routing table

1. How to route G → A?
2. As soon as H is added, D tries to send a packet to H. What happens?
3. If AS2.R2 goes down, what will be the routing changes?

Figure 5.19: Figure for Routing Problem 3. [W&P 2010]
5. re-compute routing tables

- Failure detected by AS2.R1 and AS2.R3; update routing tables (intra-AS)
- Failure detected by border gateway in AS5
- BGP re-computes
- The path between AS2 and AS5 will be changed

**Figure 5.19:** Figure for Routing Problem 3. [W&P 2010]
DHCP

- **Motivations**
  - Allows reuse of IP addresses
  - Enhances mobility, e.g., a laptop gets a new (local) IP address whenever it connects to a different LAN

- A DHCP server maintains a pool of available IP addresses

- A host that wants to connect to LAN requests a **dynamic** IP address of the DHCP server

- Once granted, the host periodically renew its IP

- When the host leaves and the IP address expires, the DHCP server puts the IP back into the available pool

- Host using dynamic IP cannot be a server
NAT

- Most home routers implement NAT (Network Address Translation)

**Motivations**
- Reuse of IP addresses
- Security

- Devices on LAN (e.g. in home) use private IP addresses that are local in scope
- Outside world only knows the (static) IP address of the NAT box
- NAT translates to maintain end-to-end connection of a TCP flow

- How?
Protocol stack

Network mechanisms implemented as protocol stack

Each layer designed separately, evolves asynchronously

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>application</td>
<td>Many control mechanisms...</td>
</tr>
<tr>
<td>transport</td>
<td>Error control, congestion control (TCP)</td>
</tr>
<tr>
<td>network</td>
<td>Routing (IP)</td>
</tr>
<tr>
<td>link</td>
<td>Medium access control</td>
</tr>
<tr>
<td>physical</td>
<td>Coding, transmission, synchronization</td>
</tr>
</tbody>
</table>
Transport services

UDP
• Datagram service
• No congestion control
• No error/loss recovery
• Lightweight

TCP
• Connection oriented service
• Congestion control
• Error/loss recovery
• Heavyweight
NAT

Key idea

• A flow is specified by IP address + TCP port #

• NAT uses TCP port# to hide private IP
End-to-end connection between IPb & IPx without NAT

- [source IP | destination IP | source port | destination port | ... | data]
End-to-end connection between IPb & Ip with NAT

[ source IP | destination IP | source port | destination port | … | data ]
NAT translates

[ source IP | destination IP | source port | destination port | ⋯ | data ]
NAT

- Most home routers implement NAT (Network Address Translation)
- Motivations
  - Reuse of IP addresses
  - Security
- Devices on LAN (e.g. in home) use private IP addresses that are local in scope
- Outside world only knows the (static) IP address of the NAT box
- NAT translates to maintain end-to-end connection of a TCP flow
- Only home device can initiate connection to outside world (server)