IP/MAC Address Translation
Today

- Go over quiz answers
- ARP
- DHCP
- NAT
Transition from Network to Datalink

• How do we get datagrams to the right physical host?
  – Tricky part comes when a router is forwarding to a LAN with multiple hosts (which is typically the case)
• IP datagrams contain an IP address
  – Configured in OS
• NIC’s only understand addressing of their particular network
  – Ethernet’s 48 bit MAC addresses
Address Translation Problem

• We need a means for mapping IP addresses into MAC (physical) addresses
  – Destination host
  – Next hop router
  – We can then encapsulate (surprise!) IP datagrams inside a frame with link level address

• Possible mapping techniques
  – Encode physical address in host part of IP address
    • Make physical address the same as the host portion of IP address
    • Obviously not possible using IPv4 and Ethernet
  – Build a table of IP/MAC pairs
    • How is it maintained?
Address Resolution Protocol (ARP)

- ARP is part of the TCP/IP specification
- Enable each host to build table of IP to physical address bindings
  - Dynamic binding protocol – no static entries in table
  - Allows new nodes to be easily added to broadcast network
- Simple idea: broadcast request if an IP address not in table
  - Supported by link level technology
  - Determine host B’s physical address $P_B$ from it IP address $I_B$
    1. Host A broadcasts an ARP request containing $I_B$ to all hosts on LAN
    2. Host B responds with an ARP reply containing the pair $(I_B, P_B)$
ARP Implementation

• ARP Packet Details
  – HardwareType: type of physical network (e.g., Ethernet)
  – ProtocolType: type of higher layer protocol (e.g., IP)
  – HLEN & PLEN: length of physical and protocol addresses
    • Provides for flexibility to handle a variety of network technologies
  – Operation: request or response
  – Source/Target-Physical/Protocol addresses

• Notes
  – Table entries timeout in about 10 minutes (caching is important)
  – Update table with source when you are the target
  – Update table even if there is already an entry
  – Do not refresh table entries upon reference
  – IP addresses are assigned independently of a systems HW addresses
ARP Packet Format

- Ethernet II header
- Destination address
- Source address
- Type 0x8060
- ARP Request or ARP Reply
- Padding
- CRC

<table>
<thead>
<tr>
<th>Hardware type (2 bytes)</th>
<th>Protocol type (2 bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware address length (1 byte)</td>
<td>Protocol address length (1 byte)</td>
</tr>
<tr>
<td>Source hardware address*</td>
<td>Operation code (2 bytes)</td>
</tr>
<tr>
<td>Source protocol address*</td>
<td></td>
</tr>
<tr>
<td>Target hardware address*</td>
<td></td>
</tr>
<tr>
<td>Target protocol address*</td>
<td></td>
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</tbody>
</table>

The length of the address fields is determined by the corresponding address length fields.
Determining an IP Address at Startup

• How does a machine without permanent storage determine its IP address?
  – OS images with specific IP’s cannot be used on multiple machines
  – Critical for network appliances or embedded systems

• Use the network to obtain an IP from a remote server
  – System must use its physical address to communicate
  – Requests address from server which maintains table of IP’s
  – System doesn’t know the server - sends broadcast request for address
Dynamic Configuration

• BOOTP was designed for relatively static environment where each host has a permanent network connection
  – Net manager creates a BOOTP config file with parameters for each host – file is typically stable for long periods

• Wireless networking enables environments much more dynamic
  – BOOTP does not provide for dynamic address assignment

• Dynamic configuration is the primary method for IP address allocation used today
  – Not only facilitates mobility but also efficient use of IPs
Dynamic Host Configuration Protocol

• DHCP extends BOOTP
  – Still supports static allocation
  – Supports automatic configuration where addresses are permanent but assigned by DHCP
  – Supports temporary allocation

• Relies on existence of a DHCP server
  – Repository for host configuration information
  – Maintains a pool of available IP’s for use on demand
  – Considerably reduces administration overhead
    • Autoconfiguration of course depends on administrative policy
  – Uses UDP to send messages
    • Uses a relay agent to communicate with servers off LAN (same as BOOTP)
      – Relay agent is statically configured with DHCP server address
DHCP Implementation

• State machine (6 states) which determines DHCP operation
  – Host boots into INITIALIZE state
• To contact the DHCP server(s) a client sends DHCPDISCOVER message to IP broadcast address and moves to SELECT state
  – Unique header format with variable length options field
  – UDP packet sent to well known BOOTP port 67
• Server(s) respond with DHCPOFFER message
  – Client can receive 0 or more responses and responds to one
• Client moves to REQUEST state to negotiate IP lease with 1 server
  – Sends DHCPREQUEST message to server which responds with DHCPACK
• Client is then in BOUND (normal) state
• From *BOUND*, client can issue DHCPRELEASE and return to *INITIALIZE* state
  – This is simply client deciding it no longer needs the IP
• When lease reaches 50% of lease expiration time, it issues DHCPREQUEST to extend lease of current IP with server and moves to *RENEW* state
  – Receipt of DHCPACK moves client back to *BOUND* state
  – Receipt of DHCPNACK moves client back to *INITIALIZE* state
• If no response is received by 87.5% of lease expiration time, the client resends the DHCPREQUEST and moves to *REBIND* state
  – Receipt of DHCPACK moves client back to *BOUND* state
  – Receipt of DHCPNACK or timeout moves client back to *INITIALIZE* state
DHCP Details

• Without relay agent, DHCP would not scale since it would require large number of servers (one per LAN)
• Addresses which are leased over a given period of time and must be updated
  – This means that DHCP requests might have to be made multiple times by the same system (RENEW requests)
• DHCP does not interact with DNS
  – Binding between IP assigned by DHCP and host name must be made independently
    • Possible result 1: No host name given
    • Possible result 2: Host is automatically assigned a preallocated domain name with its IP
    • Possible results 3: Hosts are assigned permanent names
      – Requires additional mechanisms which do not yet exist
NAT - Network Address Translation

- Little over 4 Billion IP Addresses
  - Not enough IP Addresses to go around!
- How do you manage IP Addresses?
  - What if you’re only assigned 1?
- DHCP doesn’t know all IPs on the internet
- How do you deal with duplicates?
  - ie.) 192.168.1.100
NAT - Basic Idea

- Use one IP address for multiple devices
- Devices IP addresses are only seen in local network
- External network (ie Internet) sees one IP for all the devices
- Solves “too many devices” problem
- Allows DHCP to work without coordination
- Easy to manage
NAT - Some Details

- NAT Gateway translates internal addresses to external ones
  - External IP Address + port => Internal Address + Port
- Keeps *NAT Translation Table*
  - Cache of mappings
- Uses cache to forward incoming packets
- Saves new entries for outgoing packets
NAT - Problems

- Port numbers for processes not NAT
- Slows adoption of IPv6 (longer IP Addresses)
- Interferes with P2P
  - How to connect from outside?
  - No NAT Translation Table entry
NAT Traversal

- Establishing a P2P connection through NAT
- Easiest Way: use an intermediary with Public IP Address
  - Game servers, etc.
- UPnP (Universal Plug and Play)
  - Add ports to NAT Translation Table manually, for specific applications