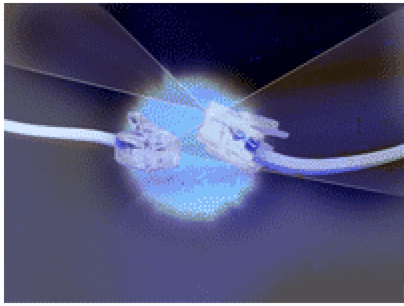
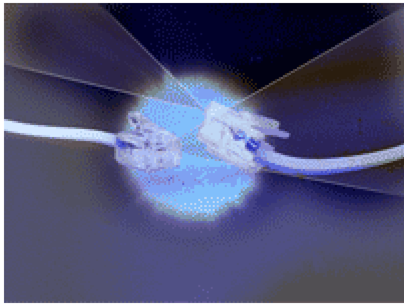


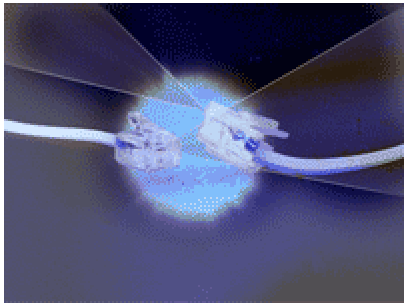
IP – Fragmentation and Reassembly

- IP datagrams can be up to 65,535 bytes – much larger than most networks can transmit in one packet
- Each network type defines *maximum transmission unit* (MTU) – maximum number of bytes that can be carried in payload of link-level frame



Fragmentation (cont.)

- Originating host chooses size for datagram – MTU of host’s network is a good choice
  - Then fragmentation is only required if an intermediate network has a smaller MTU
  - If originating host sends a datagram larger than the network MTU, source host must fragment in IP layer



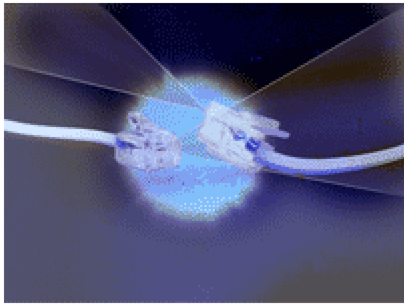
Fragmentation (cont.)

- If fragmentation required, the **ident**, **flags**, and **offset** fields in header are used
  - 16-bit **ident** the same for every fragment of datagram; chosen by source host, should be unique for each datagram sent within some reasonable time period
  - Destination host assembles all fragments with same **ident**; if some do not arrive, all others are discarded. IP does not attempt to recover missing fragments

Fragmentation (cont.)

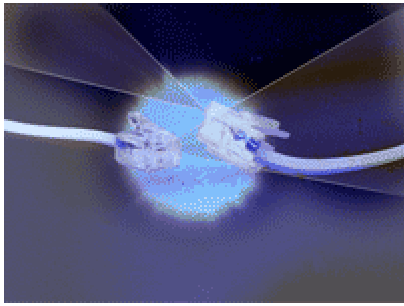
- **flags** contains an **M** bit that indicates that there are more fragments to follow
- **offset** is number of 8-byte chunks that have been sent before this fragment (fragmentation must be done on 8-byte boundaries)

• Fragments are reassembled at destination host, not each intermediate



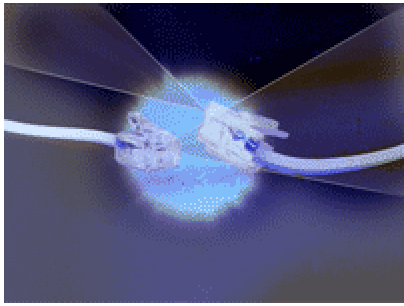
Datagram Forwarding in IP

- Datagram forwarding
  - Every packet includes dest. IP address
  - Network portion of IP address identifies a single unique network on the Internet
  - Every interface attached to a physical network must have the same network portion of its IP address
  - Every network must be connected to at least one router, which is connected to at least one other network



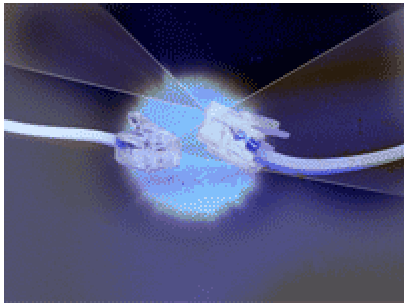
Forwarding (cont.)

- Check network part of destination address with network part of address for each interface
  - If match, deliver packet directly on that interface
  - Otherwise, need to send packet to *next hop* router
    - Forwarding table contains (network #, next router) pairs
    - Node also has default router



Address Resolution Protocol (ARP)

- Protocol used to determine a physical address given the host portion of an IP address
- Dynamically learns address mappings to build lookup table – *ARP cache* or *ARP table*
- Entries in ARP table have TTL; they are removed periodically, to handle dynamic changes to network (every 15 min)

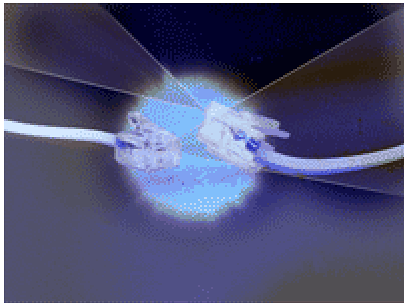


ARP (cont.)

- ARP invoked whenever no match found in table
- Broadcast ARP query with target IP addr.
- Any host with match responds
- Sender extracts link-level address from reply and adds to table
- ARP query also includes senders IP and link-level addresses, so everyone on network can update its own ARP table

ARP (cont.)

- If address is already in ARP table, just refresh entry (reset TTL)
- If receiver is target of query, always adds sender
- Other nodes that hear query don’t add new entry

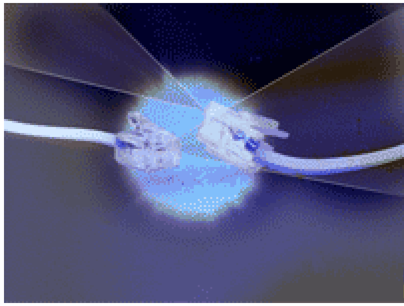


ARP Packet Format

- Mapping for IP – Ethernet

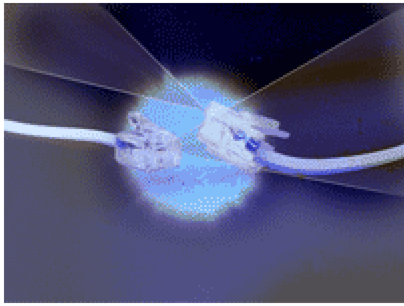
0 4 8 16 19 31

Hardware type = 1		Protocol Type = 0x0800
HLen = 48	PLen = 32	Operation
Source hardware address (bytes 0 – 3)		
Source HW Addr (bytes 4 – 5)		Source Protocol Addr (bytes 0 – 1)
Source Protocol Addr (bytes 2 – 3)		Dest HW Addr (bytes 0 – 1)
Dest HW Addr (bytes 2 – 6)		
Dest Protocol Addr (bytes 0 – 3)		



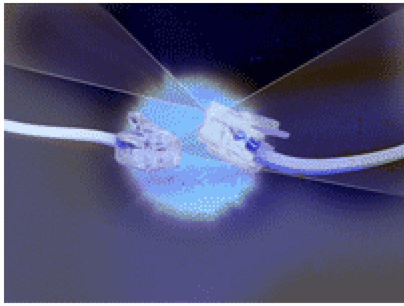
IP Addresses (cont.)

- HLen is hardware address length, PLen is protocol address length, operation indicates request vs. response
- Might add ARP info to regular forwarding table



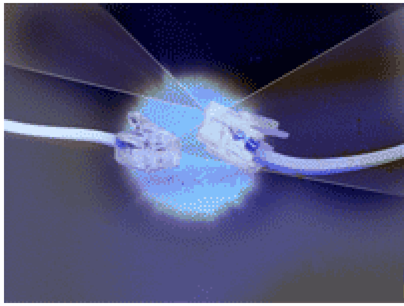
Dynamic Host Configuration Protocol (DHCP)

- Used to simplify task of configuring hosts on a network with the necessary IP address and default router
- Automatic operation based on broadcast messages
- Each network should have at least one DHCP server



DHCP (cont.)

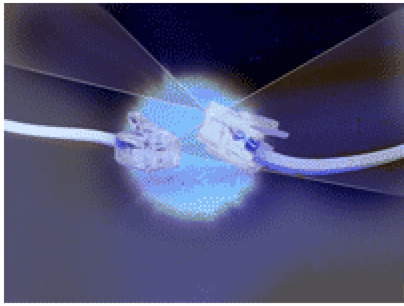
- Server has default router information, and either a pre-configured table of hosts, indexed by link-level address, or a pool of available IP addresses that are handed out on demand
  - Dynamically allocated addresses are only *leased*; host must renew lease when it expires
- Following example of *ipconfig* on Windows



DHCP (cont.)

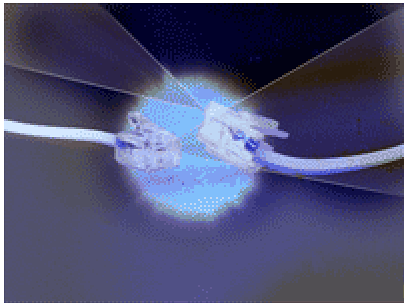
- Windows IP Configuration
  - Host Name . . . . : Odin
  - Primary Dns Suffix . . . . :
  - Node Type . . . . : Unknown
  - IP Routing Enabled. . . . . : No
  - WINS Proxy Enabled. . . . . : No

  Ethernet adapter Local Area Connection:
  - Connection-specific DNS Suffix . :
  - Description . . . . : Intel(R) PRO/1000 CT Desktop Connection
  - Physical Address. . . . . : 00-50-2C-0A-0B-EE
  - Dhcp Enabled. . . . . : Yes
  - Autoconfiguration Enabled . . . . : Yes
  - IP Address. . . . . : 192.168.0.3
  - Subnet Mask . . . . : 255.255.255.0
  - Default Gateway . . . . : 192.168.0.1
  - DHCP Server . . . . : 192.168.0.1
  - DNS Servers . . . . : 69.51.76.26
69.51.76.36
  - Lease Obtained. . . . . : Tuesday, October 25, 2005 10:46:20 PM
  - Lease Expires . . . . : Friday, October 28, 2005 10:46:20 PM



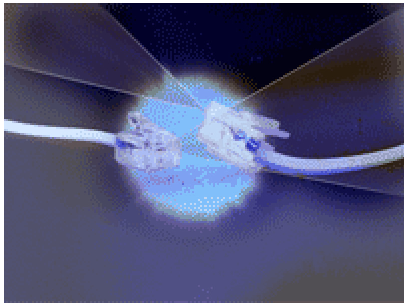
DHCP (cont.)

- Newly booted client broadcasts DHCPDISCOVER message; if DHCP server present, responds with config.
- If no DHCP server on network, one node can act as *relay agent*
  - Relay agent knows IP address of DHCP server, and just resends discovery request to server, and relays response back to original client



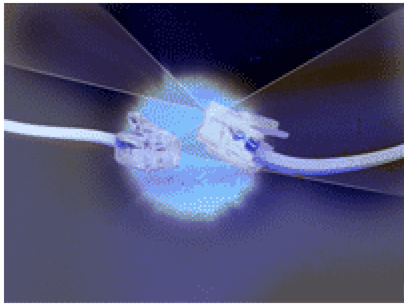
DHCP (cont.)

- Based on older BOOTP protocol (so some fields in DHCP packet no longer apply).



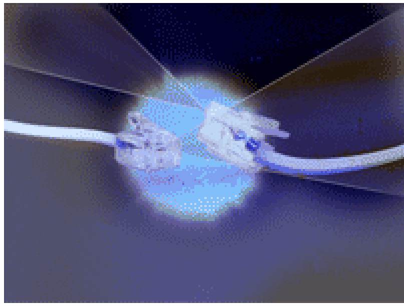
Internet Control Message Protocol (ICMP)

- Defines error messages to be returned to sender if router cannot process datagram successfully
  - Destination network or host unreachable
  - Reassembly process failed (fragment lost)
  - TTL reached 0
  - IP header checksum failed
  - *Source Quench* to control congestion
  - *Echo* to send round-trip between nodes



ICMP (cont.)

- Additional control messages
  - ICMP-Redirect tells source to update routing table
- *Ping* uses the echo message and *traceroute* uses the TTL message to measure performance through network



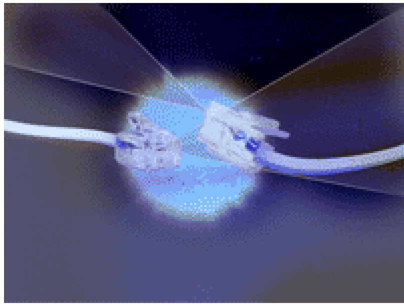
ICMP Ping

- C:\>ping www.google.com

  Pinging www.l.google.com [66.102.7.99] with 32 bytes of data:

  Reply from 66.102.7.99: bytes=32 time=184ms TTL=239
  Reply from 66.102.7.99: bytes=32 time=544ms TTL=239
  Reply from 66.102.7.99: bytes=32 time=798ms TTL=239
  Reply from 66.102.7.99: bytes=32 time=693ms TTL=239

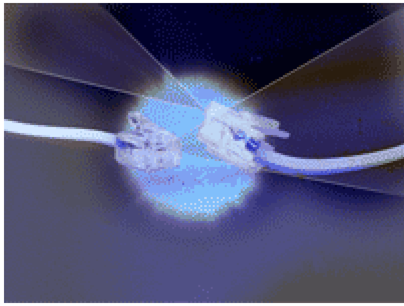
  Ping statistics for 66.102.7.99:
  Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
  Approximate round trip times in milli-seconds:
  Minimum = 184ms, Maximum = 798ms, Average = 554ms



ICMP Traceroute

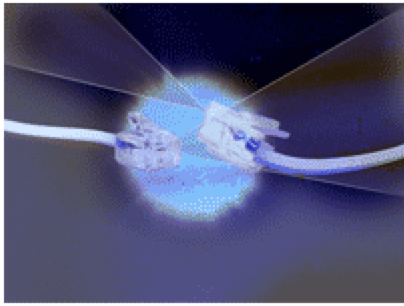
- C:\>tracert www.google.com

```
Tracing route to www.l.google.com [66.102.7.104] over a maximum of 30 hops:

  1    <1 ms    <1 ms    <1 ms  192.168.0.1
  2     2 ms     2 ms     2 ms  64.25.129.146
  3   548 ms   501 ms   359 ms  64.25.129.145
  4    14 ms    58 ms    59 ms  64.25.130.17
  5    15 ms    50 ms    74 ms  69.51.77.157
  6   505 ms   222 ms   109 ms  ge-0-1-0-fh-sea.mt.core.transaria.net [69.51.76.46]
  7    80 ms    50 ms   127 ms  ge-0-1-0-fh-sea.mt.core.transaria.net [69.51.76.46]
  8   333 ms   328 ms   760 ms  12.118.34.5
  9  1010 ms   905 ms  1034 ms  12.122.80.234
 10   326 ms   137 ms    70 ms  ggr1-p340.st6wa.ip.att.net [12.123.44.129]
 11   369 ms   569 ms   502 ms  so-3-2-0.gar1.Seattle1.Level3.net [4.68.127.109]
 12   468 ms   546 ms   255 ms  ae-1-55.mp1.Seattle1.Level3.net [4.68.105.129]
 13   167 ms   125 ms    76 ms  as-0-0.bbr2.SanJose1.Level3.net [64.159.0.218]
 14    64 ms    65 ms    59 ms  ae-22-56.car2.SanJose1.Level3.net [4.68.123.176]
 15    95 ms    95 ms   117 ms  unknown.Level3.net [209.247.202.218]
 16   216 ms   146 ms   105 ms  66.249.94.31
 17   393 ms   312 ms   472 ms  216.239.49.146
 18   512 ms   537 ms   790 ms  66.102.7.104

Trace complete.
```



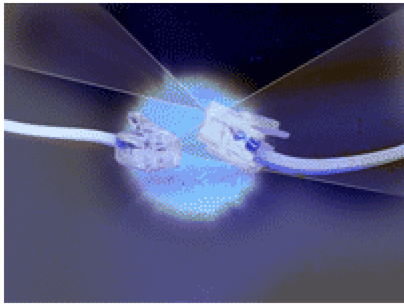
Virtual Private Network (VPN)

- Share a large public network (i.e. the Internet), but create a virtual subset of the network that is only accessible by one organization
  - – Keep data from hosts outside the VPN out
  - – Keep data from hosts inside the VPN secure
- One possibility – use virtual circuits, administratively control who can establish them



VPN (cont.)

- Create *IP tunnels* – virtual point-to-point links over a public switched network
  - Encapsulate an IP packet to a host on the destination network inside an IP packet to the router at the other end of tunnel
  - Implement virtual interface to handle adding the extra headers before sending out over physical interface
  - Can also encrypt payload to add security



VPN (cont.)

- Can encapsulate non-IP packets to send through IP network
- Can also use to redirect IP packet to a network other than the one its header indicates; used for mobile host forwarding