

2G1305 Internetworking/Internetteknik

Spring 2005, Period 4

Module 2: IP Basics: Routing, ARP, and RARP

Lecture notes of G. Q. Maguire Jr.

For use in conjunction with *TCP/IP Protocol Suite*, by
Behrouz A. Forouzan, 3rd Edition, McGraw-Hill.

For this lecture: Chapters 6 - 8



KTH Information and
Communication Technology

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IP Basics Outline

- IP Routing: Delivery and Routing of IP packets
- Address Resolution: ARP and RARP

Connection-oriented vs Connectionless

- Connection-Oriented Services
 - Network layer first establishes a connection between a source and a destination
 - Packets are sent along this connection
 - Route is decided **once** at the time the connection is established
 - Routers/switches in connection-oriented networks are **stateful**
- Connectionless Services
 - Network layer can process each packet **independently**
 - A route lookup is performed for **each** packet
 - IP is connectionless
 - IP routers are **stateless**

Of course reality is (much) more complex, to gain performance IP routers dynamically create state (in caches) as there is frequently **correlation** between packets (i.e., if you just did a route lookup for destination B, there is a non-zero probability that another packet which will arrive shortly might also be headed to destination B).

Routing

The internet protocols are based on moving packets from a source to a destination with each hop making a routing decision.

Two components to routing:

- **packet forwarding** - Routing Mechanism: search the routing table and decide which interface to send a packet out.
 - A matching host address? If no,
 - A matching network address? (using longest match) If no,
 - Default entry.
- **computing routes** - Routing Policy: rules that decide which routes should be added into the routing table.

Traditionally most of the complexity was in the later (i.e., computing routes) while packet forwarding was very straight forward -- this is no longer true due to QoS.

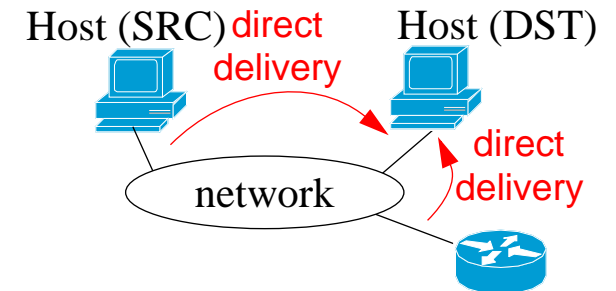
Routers vs. hosts -- a node can be both

- Routers forward IP packets
- Hosts generate or sink IP packets

Direct vs. indirect Delivery

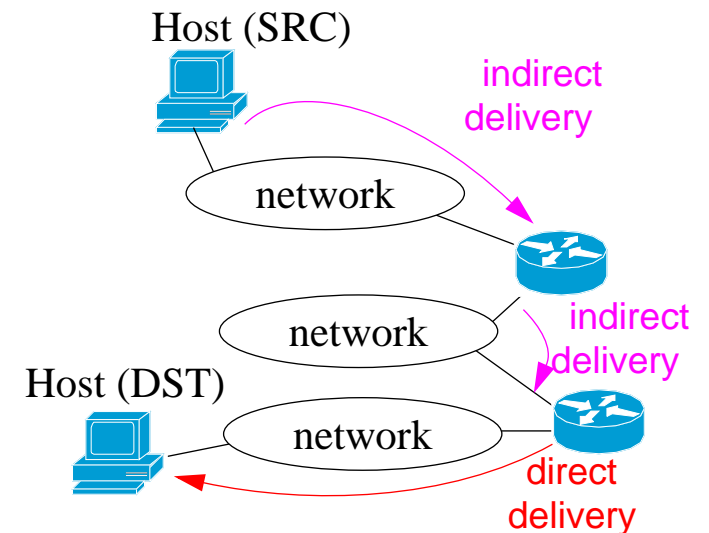
- **Direct delivery**

- The final destination is (directly) connected to the same physical network as the sender
- IP destination address and local interface have the same netmask
- Map destination IP address to destination physical address via **ARP**



- **Indirect delivery**

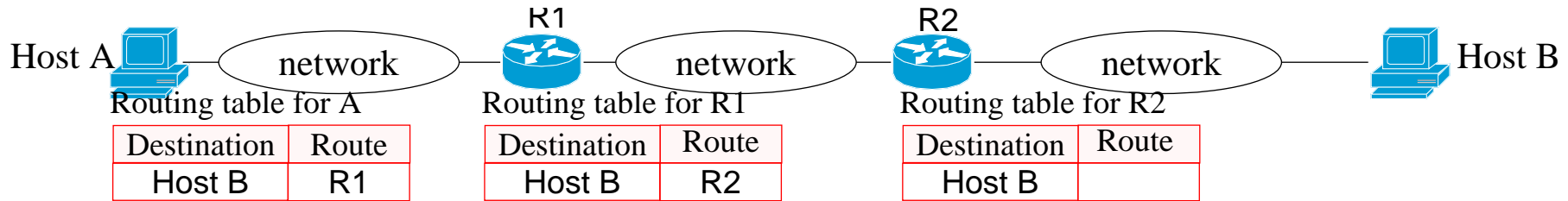
- From router to router (note: the last delivery is always direct!)
- Destination address is used for a **routing lookup** in a **routing table**: Routing



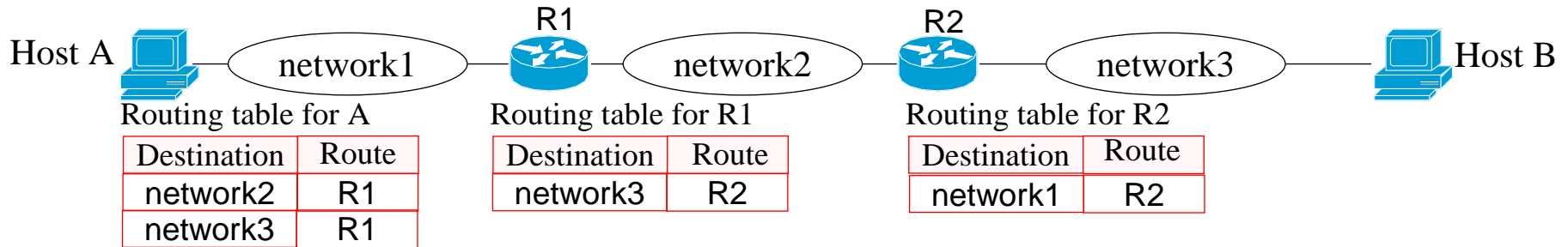
SRC=Source
DST = Destination

Forwarding

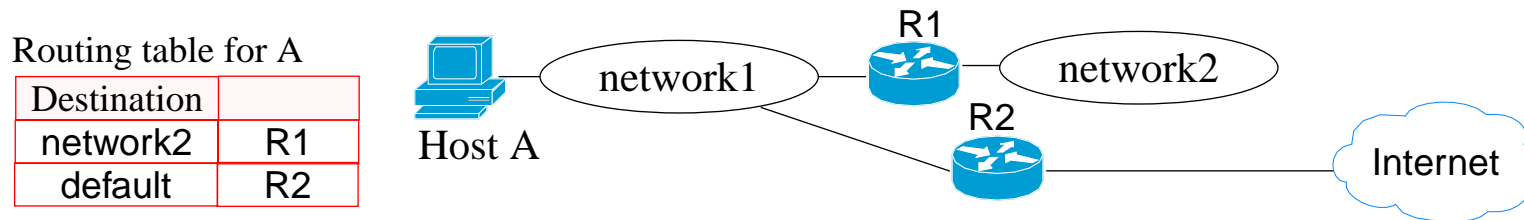
- Next-Hop method - routing table holds only the address of the next hop



- Network-specific method - routing table entries are for **networks**

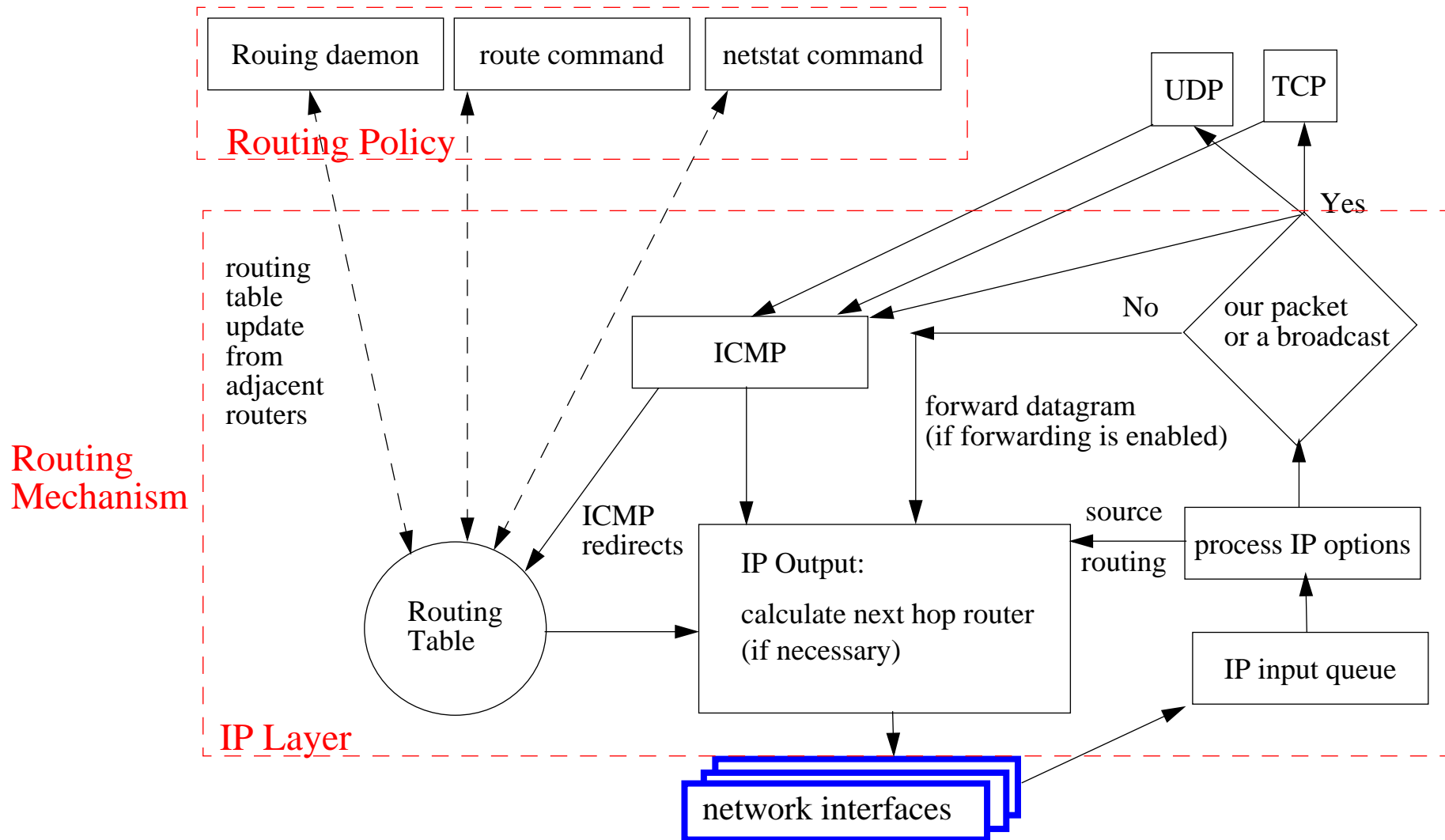


- Host-specific method - per host routes
- Default method - specifies a default route (normally network address 0.0.0.0)



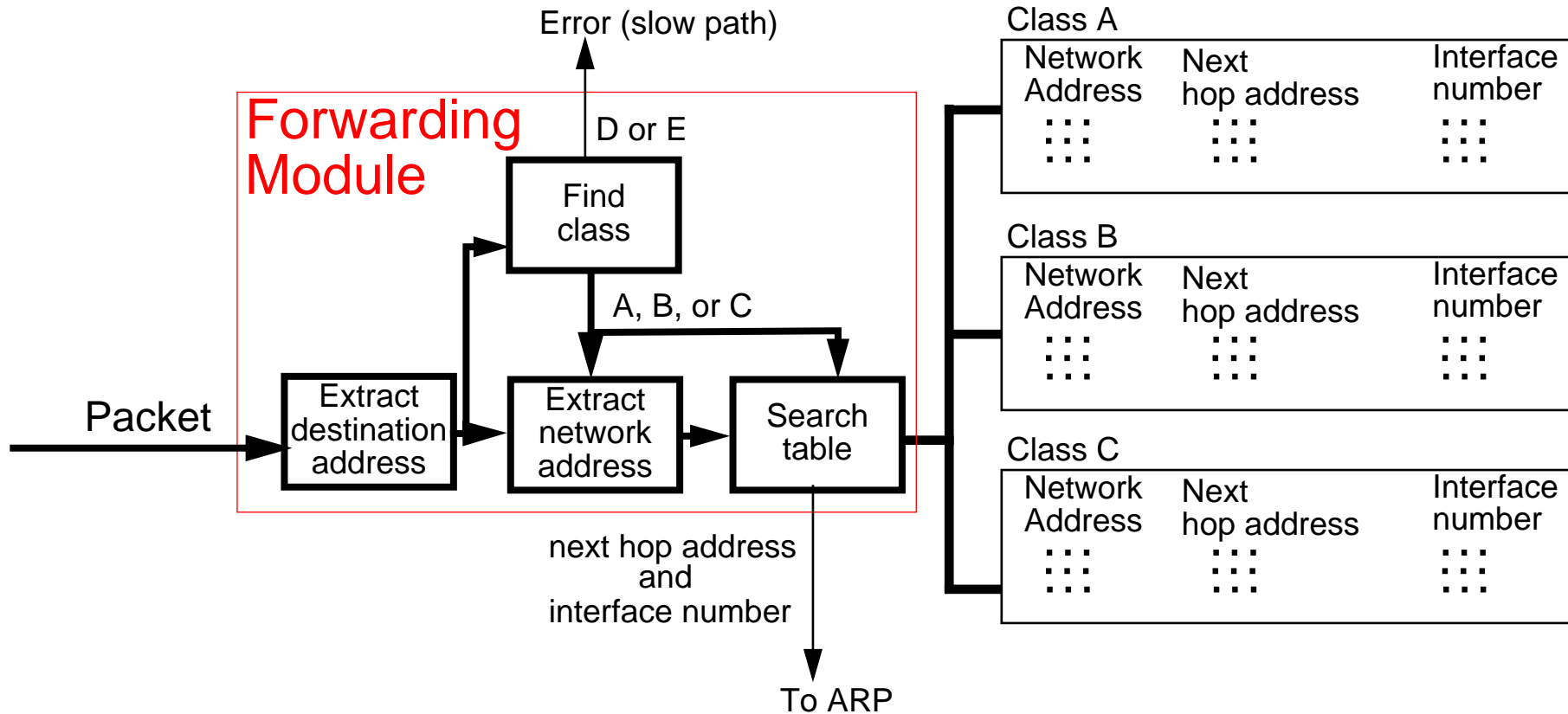
See textbook sections 6.2 for more examples.

Processing



Forwarding module

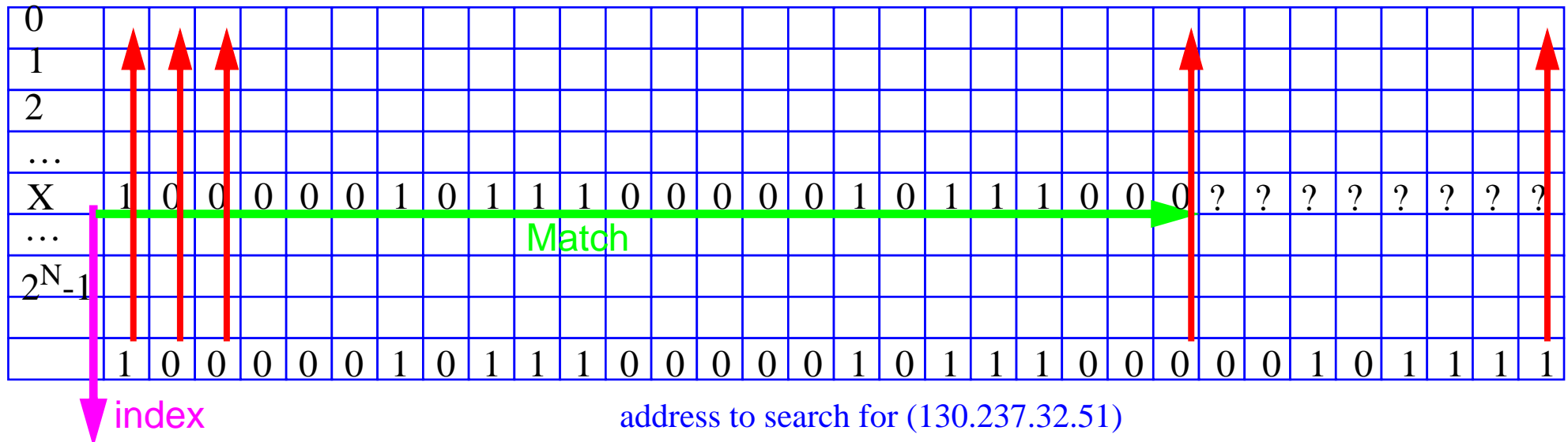
A simplified view of forwarding using classful address without subnetting:



The bulk of the forwarding effort is **searching** the tables (as most of the rest of the processing is simple logical bit operations).

Routing Table Search - Classless

- Match destination with longest prefixes first
 - Software algorithms: tree, binary trees, tries (different data structures) [12]
 - Hardware support: Content Addressable Memory
 - Ternary CAM (TCAM) - [7],[8] - for searching and pattern matching
 - Ternary because each cell has three states: 0, 1, or ? (aka "don't care")
 - Performance an associate search (i.e., in parallel), returns the index (X) of the first match
 - 4-8 ns/search (i.e., 125M - 250M lookups per second)



Note that the entries in the table have to be sorted - to achieve the longest match being at the smallest index.

Fast forwarding

Mikael Degermark, Andrej Brodnik, Svante Carlsson, Stephen Pink, “Small Forwarding Tables for Fast Routing Lookups”, in Proceedings of the ACM SIGCOMM’97. (*compressed postscript*) {basis for *Effnet AB*}

- IP routing lookups must find routing entry with longest matching prefix.

Networking community *assumed* it was impossible to do IP routing lookups in software fast enough to support gigabit speeds - but they were wrong!

Paper presents a forwarding table data struct. designed for quick routing lookups.

- Such forwarding tables are small enough to fit in the cache of a conventional general purpose processor.
- The forwarding tables are very small, a large routing table with 40,000 routing entries can be compacted to a forwarding table of 150-160 Kbytes.
- With the table in cache, a 200 MHz Pentium Pro or 333 MHz Alpha 21164 can perform >2 million lookups per second.
 - A lookup typically requires less than 100 instructions on an Alpha, using eight memory references accessing a total of 14 bytes.

∴ Full routing lookup of each IP packet at gigabit speeds without special hardware

Routing Tables

- Aggregate IP addresses (i.e., exploit CIDR)
 - more specific networks (with longer prefixes)
 - less specific networks (with shorter prefixes)
 - \Rightarrow smaller routing tables
- If each routing domain exports (i.e., tells others) only a small set of prefixes, this makes it easier for other routers to send traffic to it
 - Unfortunately this requires clever address assignments
- Some mechanisms lead to increased fragmentation
 - Due to limited availability of addresses long prefixes (particularlyly /24) are scattered geographically
 - Increasingly sites are connected to multiple ISPs (for redundancy) i.e., Multihoming - thus they have addresses from several **different** subnetworks
- Current routing tables have ~157,975 entries [13] (of which a large fraction are /24 prefixes) with a growth rate of “18,000 entries per year”[14].

There are a limited number of prefixes for Class A + B + C networks (2,113,664). If the longest prefixes which a backbone router had to deal with were /24, then a table with 16,777,216 entries would be sufficient (even without aggregation) - each entry only needs to store the outgoing port number! This would allow a **direct lookup** in a memory of ~26Mbytes - with upto 256 outgoing ports.

Routing table

Flags	Destination IP address	Next-hop Router IP address	point to local interface to use	Refcnt	Use	PMTU ...
UGH	140.252.13.65	140.252.13.35	emd0	<i>ddd</i>	<i>ddd</i>	<i>ddd</i>
U	140.252.13.32	140.252.13.34	emd0	<i>ddd</i>	<i>ddd</i>	<i>ddd</i>
UG	default	140.252.13.33	emd0			
UH	127.0.0.1	127.0.0.1	lo0			

where *ddd* is some numeric value.

display the routing table with "netstat -rn"

"r" is for routing table

"n" asks for numeric IP addresses rather than name

Flags:

U	route is Up
G	route is to a Gateway
H	route is to a Host
D	route was Discovered by a redirect
M	route was Modified by a redirect

Host vs. router - two behaviors

- Hosts generate or sink IP packets
- Routers forward IP packets

Thus it is possible for a device to be both a host **and** a router.

Unless a host is **explicitly** configured as a router is **not** supposed to forward IP datagrams. The default behavior must be **never forward**.

In linux the variable which controls this is: `/proc/sys/net/ipv4/ip_forward`

- If this variable is set to **1**, then the node **will** perform IP forwarding.
- If this variable is set to **0**, then the node **will not** perform IP forwarding.

Host routing

A host either:

- knows a route - manually **configured** [i.e., "Static routes"]
 - from the interface (for directly connected networks) or manually via the "route" command
- or **learns of a route** [i.e., "Dynamic routes"]
 - Simplest method of learning a route:
 - The host sends a packet via the default route and is told via an ICMP Redirect of a better route
 - or the host hears an ICMP router advertisement (perhaps in response to its ICMP router solicitation message)
 - routers (**almost**) periodically broadcast or multicast advertisements of their existence and desire to provide routing service
 - format of ICMP router advertisement packet shown in Forouzan figure 9.18 on page 226
 - advertisements typically every 450..600 seconds
 - advertisements have a stated lifetime (typically 30 minutes)
 - or the host learns via a dynamic routing protocol.
- or uses a **default** route.

On booting hosts send ~3 ICMP router solicitation messages (~3 seconds apart) to find a default router. This allows for dynamic discovery of the default router.

Routing

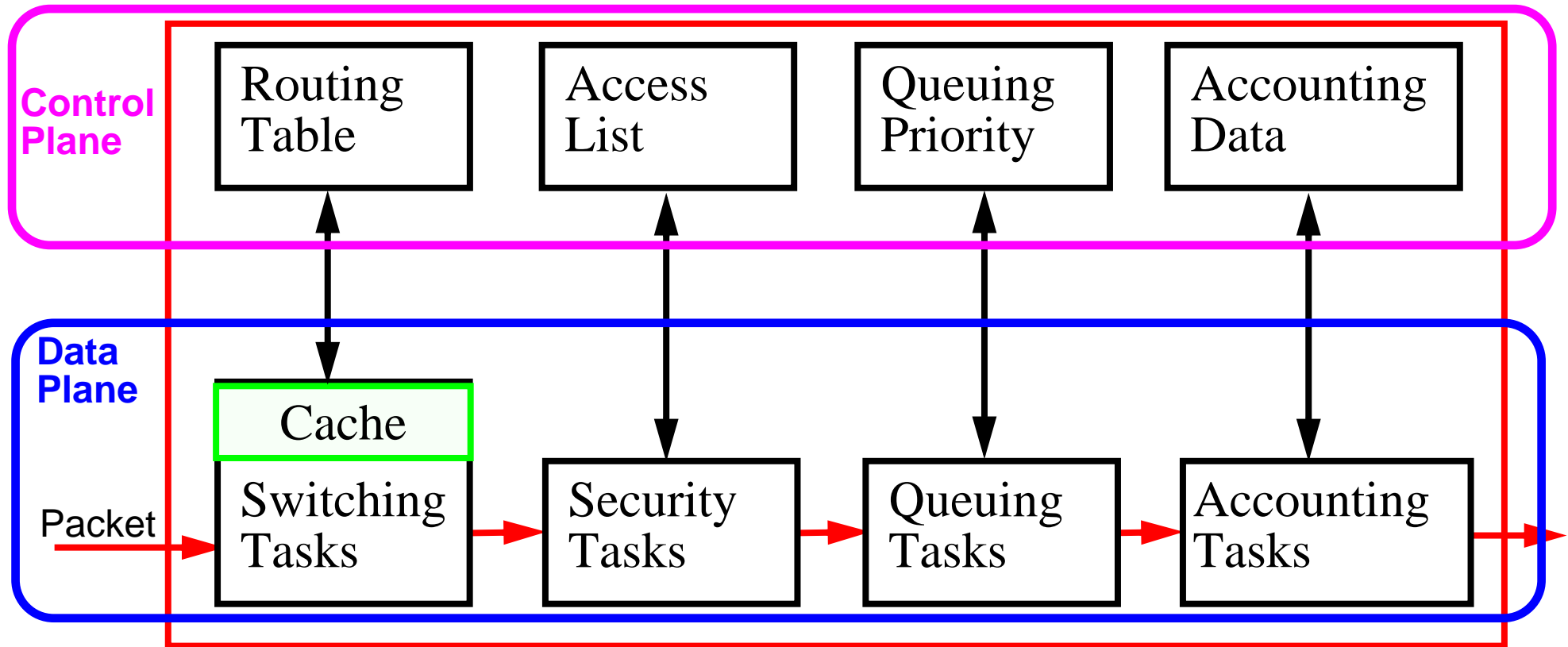


Figure 18: Basic steps in Routing

The routing table tells us which output port to use based on the destination (and possibly the source) IP address. The **data plane** has to run at packet rates (i.e., in real-time). However, a router also performs a lot of other processing

Combining layers

Many devices now combine processing of several layers:

- Switch/Routers: combine layers 2+3

Devices combining layers 3+4 are appearing - which extract “flows” based on looking at transport layer port numbers in addition to network addresses.

ARP and RARP

Address resolution (logical \Leftrightarrow physical addresses):

- Mapping IP addresses \Rightarrow link layer (MAC) addresses via Address Resolution Protocol (ARP)
- Mapping link layer (MAC) addresses \Rightarrow IP addresses via Reverse Address Resolution Protocol (RARP)

What to do with a new computer?

We will assume that the computer has an ethernet interface:

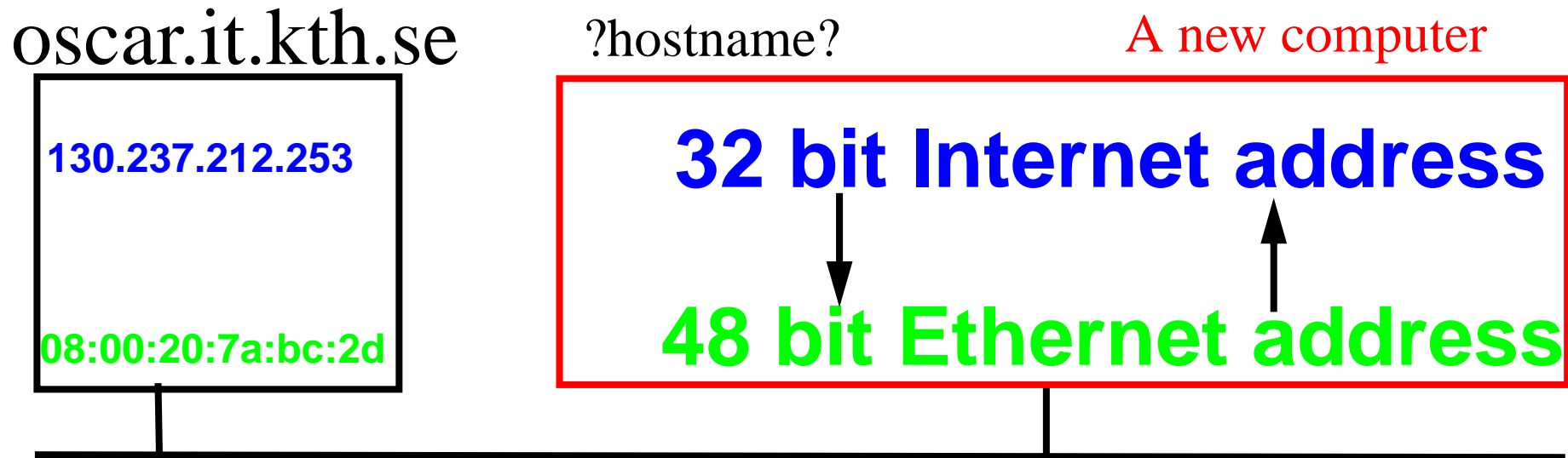


Figure 19: Name and IP Address needed!

- **Direct mapping** - requires no I/O, just a computation; hard to maintain; and requires stable storage (since you have to store the mappings somewhere) *or*
- **Dynamic Binding** - easier to maintain; but has a delay while messages are exchanged

Address Resolution: ARP, RARP

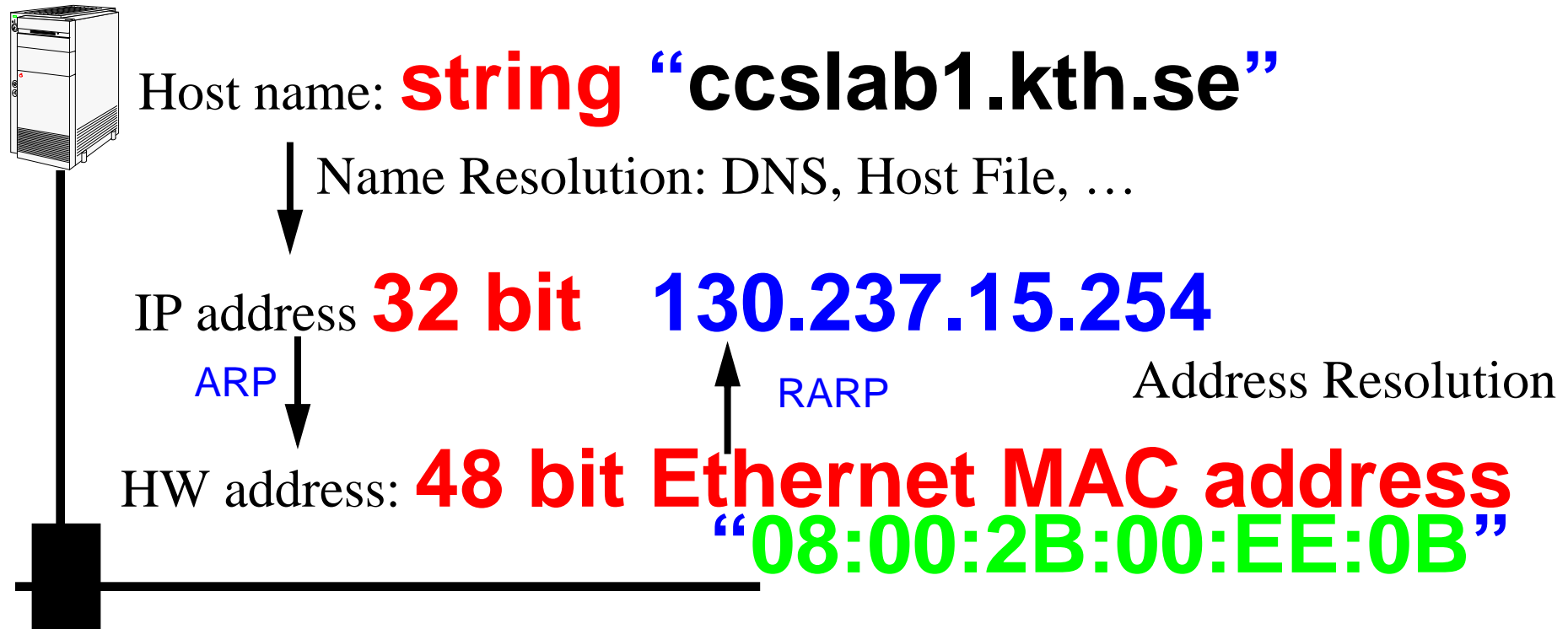


Figure 20: mapping between host names, IP address, and MAC address

ARP - Address Resolution Protocol

RARP- Reverse ARP

ARP ≡ Address Resolution Protocol (RFC826)

Address Resolution Protocol (ARP) - allows a host to find the physical address of a target host **on the same network**, given only the target's internet address.

- Sending host (source) wants to send an IP datagram, but does not know the corresponding ethernet address
- ARP request - **broadcast** to every host on the network (i.e., EtherDST=0xFFFFFFFFFFFF), TYPE=0x0806
- Destination host: "It is my address!" and sends an ARP reply
- Source host - receives the **unicast** ARP reply, and now uses it to send the IP datagram

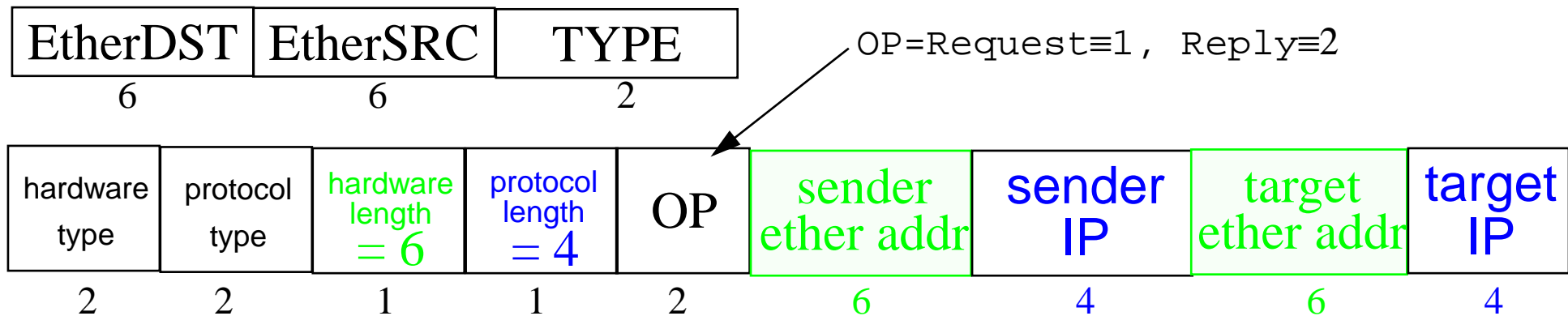


Figure 21: Format of ARP request/reply packet (see Stevens, Vol. 1, figure 4.3, pg. 56)

ARP example 1

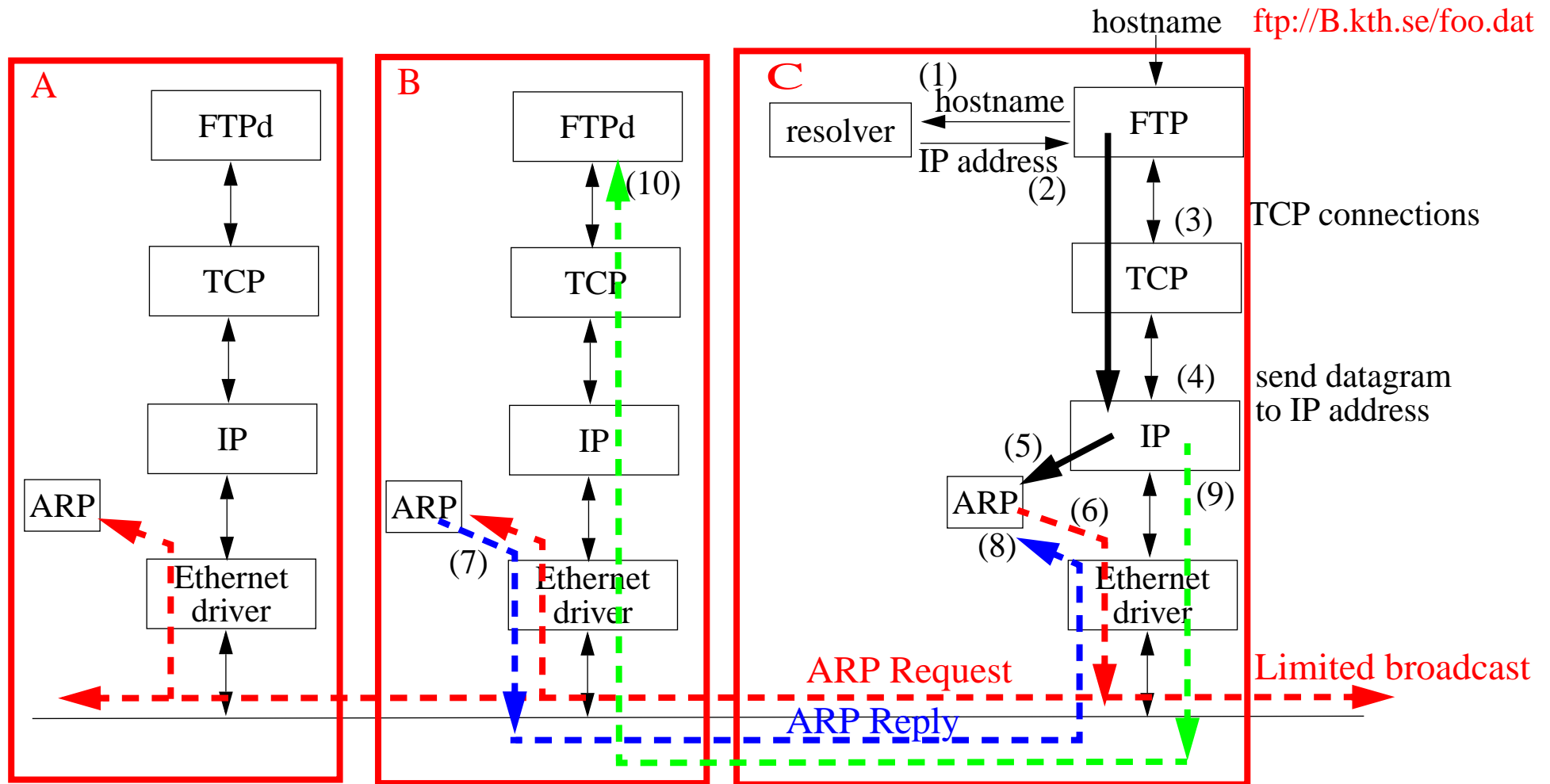


Figure 22: Using ARP on host C to determine MAC address of the interface on host B

Address Resolution Cache

Since you have just looked up the address, save (*cache*) it for reuse:

- to limit ARP traffic
- works because of *correlations* in use of addresses

You can examine the arp cache:

```
arp -a
machine-name (x.x.x.x) at xx:xx:xx:xx:xx:xx
...
```

```
arp -an
(x.x.x.x) at xx:xx:xx:xx:xx:xx
...
```

Note that the later form (with the “n” option) does *not* lookup the hostname, this is *very useful* when you don’t yet have a name resolution service working!

ARP Refinements

Since the sender’s Internet-to-Physical address binding is in every ARP broadcast; (all) receivers update their caches before processing an ARP packet

ARP Timeouts

- If there is no reply to an ARP request
 - the machine is down or not responding
 - request was lost, then retry (but not too often)
 - eventually give up (When?)
- ARP cache timeouts
 - Berkeley implementations timeout
 - completed entry in 20 minutes
 - incomplete entry in 3 minutes
 - Linux:
 - for entries to which there has been no traffic a timeout occurs at `gc_stale_time`, set to 60 seconds by default (`/proc/sys/net/ipv4/neigh/default/gc_stale_time`)
 - Microsoft Windows NT
 - Using the registry editor, see `HKEY_LOCAL_MACHINE\SYSTEM\CurrentControlSet\Services\Tcpip\Parameters` enter `ArpCacheLife` default value is set to 2 minutes
 - Cisco IOS v10.0 and above
 - select interface then “arp timeout xxxx”, default value is set to 240 minutes (14400 sec.) and can be changed on a per-interface basis
 - RFC 1533: DHCP Options and BOOTP Vendor Extensions, defines:
 - ARP Cache Timeout Option (code for this option is 35).
 - Host Requirements RFC - says entries should be timed out **even if in use**

ARP example 2

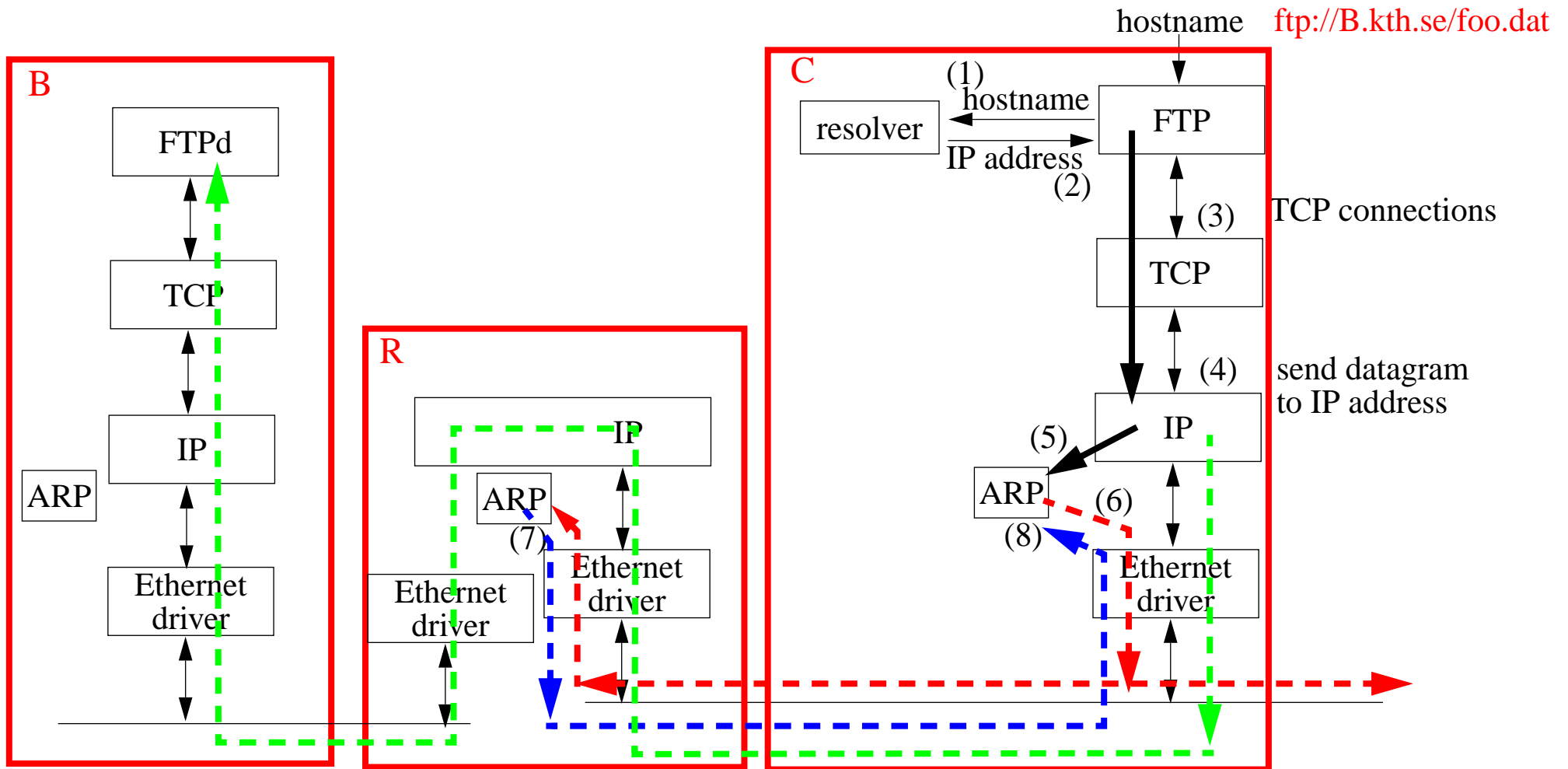


Figure 23: Router (R) doing a Proxy ARP to provide MAC address of B

Proxy ARP (RFC 826)

Lets a **router** on the network answer for a host which is NOT necessarily on the local network segment.

But how does this router know?

- It can make an ARP request itself or
- Perhaps it already knows - because it has an entry in it's ARP cache

For an example of using proxy arp with subnetting see:

- <http://www.linuxdoc.org/HOWTO/mini/Proxy-ARP-Subnet/why.html> and
- <http://www.linuxdoc.org/HOWTO/mini/Proxy-ARP-Subnet/how.html>

Gratuitous ARP

Host sends a request for its own address

- generally done at boot time to inform other machines of its address (possibly a new address) - gives these other hosts a chance to update their cache entries immediately
- lets hosts check to see if there is another machine claiming the same address ⇒

“duplicate IP address sent from Ethernet address a:b:c:d:e:f”

As noted before, hosts have paid the price by servicing the broadcast, so they can cache this information - this is one of the ways the proxy ARP server could know the mapping.

Note that **faking** that you are another machine can be used to provide **failover** for servers (see for example heartbeat, fake, etc. at <http://www.linux-ha.org/download/> for a send_arp program). [It can also be used very various **attacks!**]

Additional ARP commands

- **publish** entries (i.e., mechanically make an entry and answer replies)

Publishing entries is one way that (embedded) devices can learn their IP address.

```
# arp -s birkexample 08:00:2B:00:EE:0B pub
# arp -an
(192.168.1.1) at 0:4:5a:de:e8:f9 ether
...
(172.16.32.20) at 8:0:2b:0:ee:b ether permanent published
```

where `birkexample` has the IP address: `172.16.32.20`

- explicitly **delete** entries

```
# arp -d birkexample
birkexample (172.16.32.20) deleted
# arp -an
(192.168.1.1) at 0:4:5a:de:e8:f9 ether
```

ARP - as seen with ethereal

Time	Source	Destination	Protocol	Info
1.995245	172.16.33.3	Broadcast	ARP	Who has 172.16.33.2? Tell 172.16.33.3

Frame 2 (60 bytes on wire, 60 bytes captured)
Arrival Time: Mar 23, 2005 11:32:45.184792000
Time delta from previous packet: 1.995245000 seconds
Time since reference or first frame: 1.995245000 seconds

IEEE 802.3 Ethernet

Destination: ff:ff:ff:ff:ff:ff (Broadcast)
Source: 00:40:8c:30:d4:32 (172.16.33.3)
Length: 36
Trailer: 00000000000000000000
Type: [ARP \(0x0806\)](#)

Address Resolution Protocol (request)

Hardware type: IEEE 802 (0x0006)
Protocol type: IP (0x0800)
Hardware size: 6
Protocol size: 4 Opcode: request (0x0001)
Sender MAC address: 00:40:8c:30:d4:32 (172.16.33.3)
Sender IP address: 172.16.33.3 (172.16.33.3)
Target MAC address: ff:ff:ff:ff:ff:ff (Broadcast)
Target IP address: 172.16.33.2 (172.16.33.2)

```
0000  ff ff ff ff ff ff 00 40 8c 30 d4 32 00 24 aa aa  .....@.0.2.$..
0010  03 00 00 00 08 06 00 06 08 00 06 04 00 01 00 40  .....@
0020  8c 30 d4 32 ac 10 21 03 ff ff ff ff ff ff ac 10  .0.2..!..... <<< unlike what page 163 says it is not all zeros!
0030  21 02 00 00 00 00 00 00 00 00 00 00 00 00 00  !.....
```

non ARP example 1

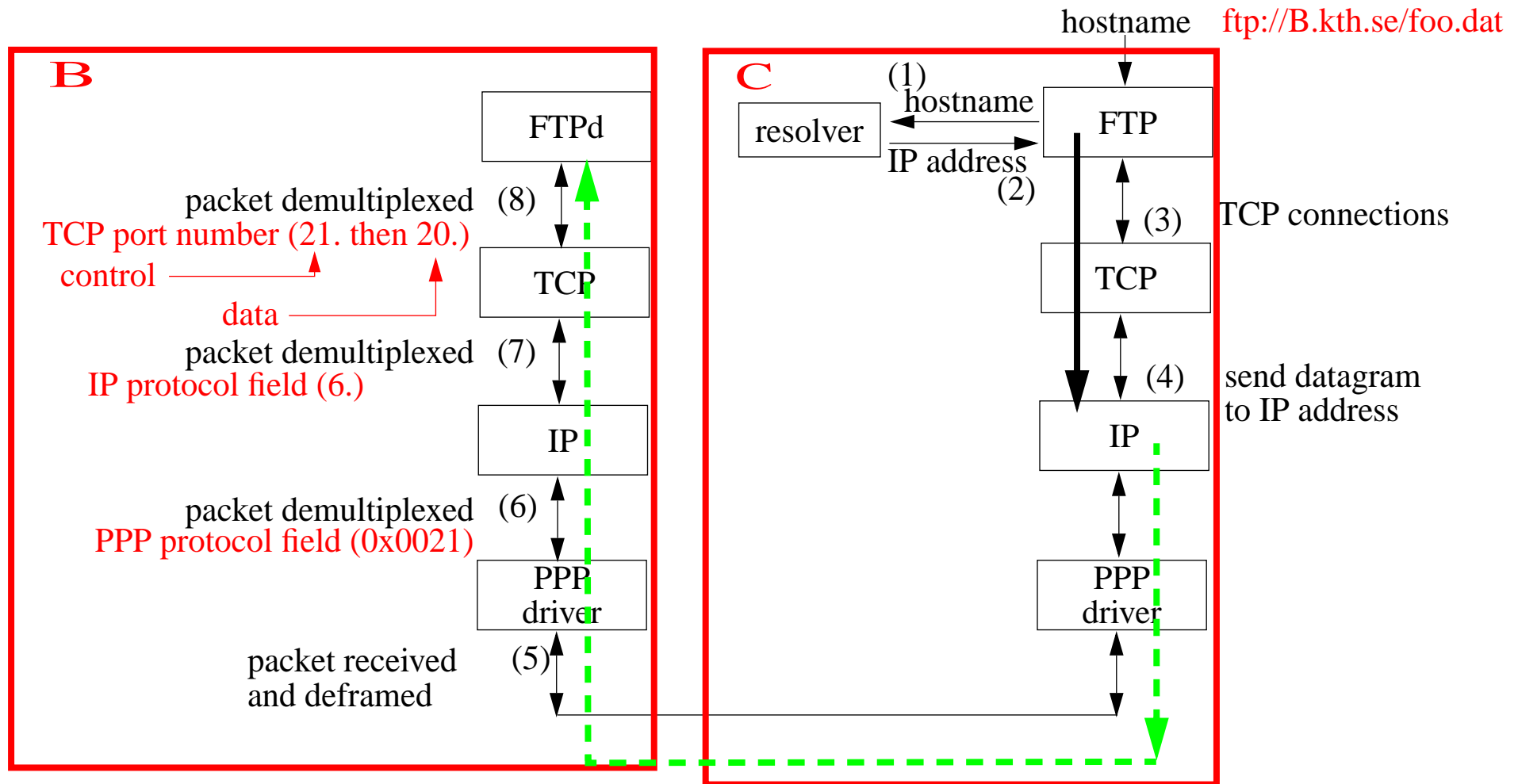


Figure 24: On a point-to-point link there is no need for ARP (figure also shows explicitly the demultiplexing)

Note that the PPP protocol field plays a role similar to the ethernet [frame type](#).

RARP: Reverse Address Resolution Protocol (RFC 903)

How do you get you own IP address, when all you know is your link address?

- Necessary if you don't have a disk or other stable store
- RARP request - broadcast to every host on the network (i.e., EtherDST=0xFFFFFFFFFFFFFFF), TYPE=0x8035
- RARP server: "I know that address!" and sends an RARP reply
- Source host - receives the RARP reply, and now knows its own IP addr

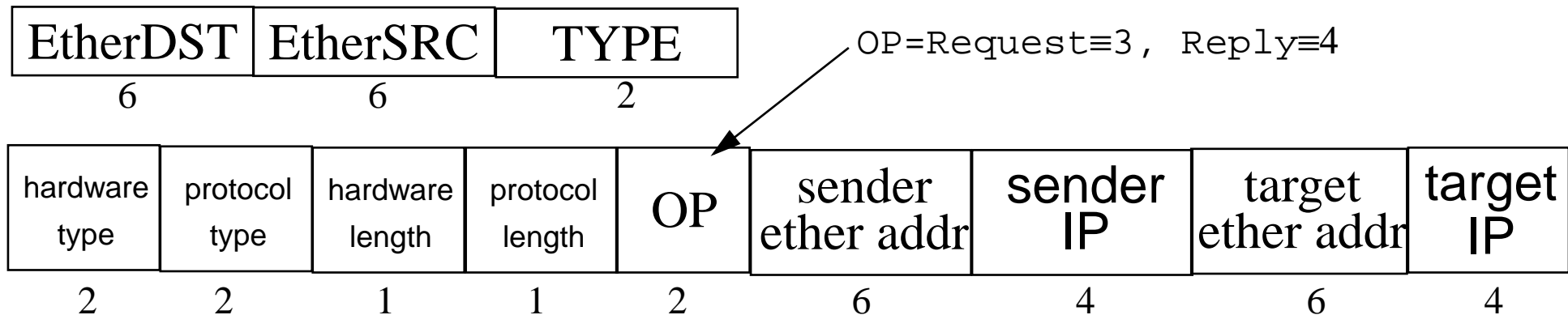


Figure 25: Format of RARP request/reply packet

Note: You can now see what the “publish” aspect of the `arp` command is for.

RARP - as seen with ethereal

Time	Source	Destination	Protocol	Info
0.000000	172.16.33.3	Broadcast	RARP	Who is 00:40:8c:30:d4:32? Tell 00:40:8c:30:d4:32

Frame 1 (60 bytes on wire, 60 bytes captured)
Arrival Time: Mar 23, 2005 11:32:43.189547000
Time delta from previous packet: 0.000000000 seconds
Time since reference or first frame: 0.000000000 seconds

Ethernet II, Src: 00:40:8c:30:d4:32, Dst: ff:ff:ff:ff:ff:ff
Destination: ff:ff:ff:ff:ff:ff (Broadcast)
Source: 00:40:8c:30:d4:32 (172.16.33.3)
Type: **RARP (0x8035)**

Trailer: 00000000000000000000000000000000...

Address Resolution Protocol (reverse request)
Hardware type: Ethernet (0x0001)
Protocol type: IP (0x0800)
Hardware size: 6
Protocol size: 4
Opcode: reverse request (0x0003)
Sender MAC address: 00:40:8c:30:d4:32 (172.16.33.3)
Sender IP address: 0.0.0.0 (0.0.0.0)
Target MAC address: 00:40:8c:30:d4:32 (172.16.33.3)
Target IP address: 0.0.0.0 (0.0.0.0)

```
0000  ff ff ff ff ff ff 00 40 8c 30 d4 32 80 35 00 01  .....@.0.2.5..
0010  08 00 06 04 00 03 00 40 8c 30 d4 32 00 00 00 00  .....@.0.2.... <<< as the source does not know its own IP address
0020  00 40 8c 30 d4 32 00 00 00 00 00 00 00 00 00 00  .@.0.2..... <<< as the source does not know the target's IP address
0030  00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00  .....
```

RARP server

Someone has to know the mappings - quite often this is in a file “/etc/ethers”

Since this information is generally in a file, RARP servers are generally implemented as **user processes** (because a kernel process should **not** do file I/O!)

- Unlike ARP responses which are generally part of the TCP/IP implementation (often part of the kernel).
- How does the process get the packets - since they aren't IP and won't come across a socket?
 - BSD Packet filters
 - SVR4 Data Link Provider Interface (DLPI)
 - SUN's Network Interface Tap (NIT)
 - Interestingly in the appendix to RFC 903 an alternative to having data link level access was to have two IOCTLS, one that would "sleep until there is a translation to be done, then pass the request out to the user process"; the other means: "enter this translation into the kernel table"
- RARP requests are sent as hardware level broadcasts - therefore are **not** forwarded across routers:
 - multiple servers per segment - so in case one is down; the first response is used
 - having the router answer

Alternatives to RARP

In a later lecture we will examine:

- BOOTP and DHCP (for both IPv4 and IPv6) and
- autoconfiguration for IPv6.

Novel IPX/SPX Addresses

Another approach to [network addresses](#) - which are tied to the MAC address

IPX/SPX == INternetwork Packet Exchange/Sequenced Packet Exchange

IPX address: 32 bits of network ID and 48 bits of host ID (the ethernet address)

Problems:

- There is no central authority for allocating the network IDs
 - ✗ So if you interconnect multiple IPX networks you may have to renumber every network
- If you change ethernet cards, you get a new address!
- Assumes that all machines are attached to a high capacity LAN.

Advantages

- You only have to assign network numbers, then the hosts figure out their own address. Simpler administration.

Novell NetWare provides: Service Advertising Protocol (SAP), Routing Information Protocol (RIP), and NetWare Core Protocol (NCP).

Useful tools

For looking at and generating packets!

tcpdump

Under HP-UX 11.0

```
# ./tcpdump -i /dev/dlpi0
tcpdump: listening on /dev/dlpi0
22:25:43.217866 birk2.5900 > nucmed35.50251: . ack 3089200293 win 8080 (DF)
22:25:43.290636 birk2.5900 > nucmed35.50251: P 0:4(4) ack 1 win 8080 (DF)
22:25:43.360064 nucmed35.50251 > birk2.5900: . ack 4 win 32768
22:25:43.363786 birk2.5900 > nucmed35.50251: P 4:167(163) ack 1 win 8080 (DF)
22:25:43.364159 nucmed35.50251 > birk2.5900: P 1:11(10) ack 167 win 32768
22:25:43.543867 birk2.5900 > nucmed35.50251: . ack 11 win 8070 (DF)
22:25:43.577483 birk2.5900 > nucmed35.50251: P 167:171(4) ack 11 win 8070 (DF)
22:25:43.640052 nucmed35.50251 > birk2.5900: . ack 171 win 32768
22:25:43.643793 birk2.5900 > nucmed35.50251: P 171:334(163) ack 11 win 8070 (DF)
22:25:43.644132 nucmed35.50251 > birk2.5900: P 11:21(10) ack 334 win 32768
22:25:43.750062 birk2.5900 > nucmed35.50251: . ack 21 win 8060 (DF)
22:25:43.873349 birk2.5900 > nucmed35.50251: P 334:338(4) ack 21 win 8060 (DF)
22:25:43.940073 nucmed35.50251 > birk2.5900: . ack 338 win 32768
13 packets received by filter
0 packets dropped by kernel
```

tcpdump - Linux

```
nucmed30:/home/maguire # /usr/sbin/tcpdump -i eth1
```

```
tcpdump: verbose output suppressed, use -v or -vv for full protocol decode  
listening on eth1, link-type EN10MB (Ethernet), capture size 96 bytes
```

```
14:21:52.736671 IP nucmed30.local.domain.must-p2p > jackb.ssh: P 1818006646:1818006726(80) ack 307068981 win 591>  
14:21:52.737291 IP jackb.ssh > nucmed30.local.domain.must-p2p: P 1:113(112) ack 80 win 32768 <nop,nop,timestamp >  
14:21:52.737917 IP nucmed30.local.domain.must-p2p > jackb.ssh: P 80:160(80) ack 113 win 5910 <nop,nop,timestamp >  
14:21:52.802719 IP jackb.ssh > nucmed30.local.domain.must-p2p: . ack 160 win 32768 <nop,nop,timestamp 25983516 2>
```

...

```
14:21:57.782196 arp who-has jackscan tell nucmed30.local.domain  
14:21:57.784218 arp reply jackscan is-at 00:40:8c:30:d4:32  
14:21:57.784253 IP nucmed30.local.domain > jackscan: icmp 64: echo request seq 1  
14:21:57.784971 IP jackscan > nucmed30.local.domain: icmp 64: echo reply seq 1  
14:21:58.782187 IP nucmed30.local.domain > jackscan: icmp 64: echo request seq 2  
14:21:58.782912 IP jackscan > nucmed30.local.domain: icmp 64: echo reply seq 2  
14:21:59.783036 IP nucmed30.local.domain > jackscan: icmp 64: echo request seq 3  
14:21:59.783759 IP jackscan > nucmed30.local.domain: icmp 64: echo reply seq 3
```

...

```
14:21:59.802600 IP jackb.ssh > nucmed30.local.domain.must-p2p: . ack 2864 win 32768 <nop,nop,timestamp 25984216 >  
14:22:00.739485 IP nucmed30.local.domain.must-p2p > jackb.ssh: P 2864:2944(80) ack 897 win 5910 <nop,nop,timesta>
```

```
84 packets captured  
84 packets received by filter  
0 packets dropped by kernel
```

Tools Used: tcpdump Program

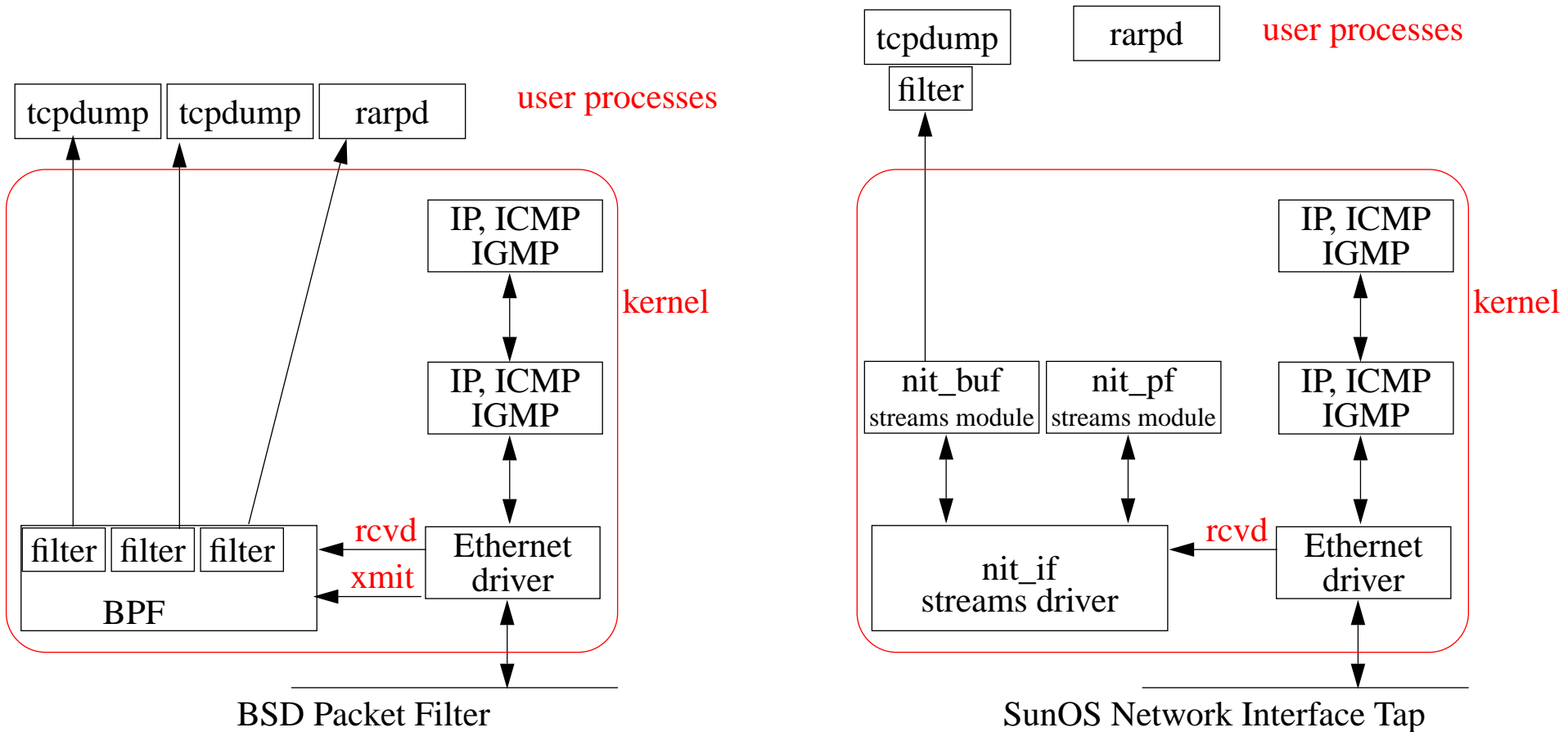


Figure 26: Two alternatives to get packets

Note the BSF packet filter gets a copy of both the received and transmitted packets.

Ethereal

The screenshot shows the Ethereal network protocol analyzer interface. The main window displays a list of captured packets. Packet 13 is highlighted, showing it is an ARP request from 172.16.33.3 to a broadcast destination. The detailed view below shows the packet structure: Ethernet II, Address Resolution Protocol (request), and the specific ARP fields including hardware and protocol types, sizes, opcode, and MAC/IP addresses.

No.	Time	Source	Destination	Protocol	Info
12	1.755378	172.16.33.3	Broadcast	ARP	Who has 172.16.33.2? Tell
13	1.755556	172.16.33.3	Broadcast	ARP	Who has 172.16.33.2? Tell
14	1.802828	172.16.33.16	172.16.33.17	SSH	Encrypted request packet 1
15	1.869279	172.16.33.17	172.16.33.16	TCP	ssh > must-p2p [ACK] Seq=2
16	2.467211	172.16.33.16	172.16.33.17	SSH	Encrypted request packet 1
17	2.467710	172.16.33.17	172.16.33.16	SSH	Encrypted response packet
18	2.468194	172.16.33.16	172.16.33.17	SSH	Encrypted request packet 1

Frame 13 (60 bytes on wire, 60 bytes captured)
Ethernet II, Src: 00:40:8c:30:d4:32, Dst: ff:ff:ff:ff:ff:ff
Address Resolution Protocol (request)
Hardware type: Ethernet (0x0001)
Protocol type: IP (0x0800)
Hardware size: 6
Protocol size: 4
Opcode: request (0x0001)
Sender MAC address: 00:40:8c:30:d4:32 (172.16.33.3)
Sender IP address: 172.16.33.3 (172.16.33.3)
Target MAC address: ff:ff:ff:ff:ff:ff (Broadcast)

```
0000  ff ff ff ff ff ff 00 40  8c 30 d4 32 08 06 00 01  .....@ .0.2....
0010  08 00 06 04 00 01 00 40  8c 30 d4 32 ac 10 21 03  ....@ .0.2.!.
0020  ff ff ff ff ff ff ac 10  21 02 8c 30 d4 32 00 00  ..... !..0.2..
0030  00 00 00 00 00 00 00 00  00 00 00 00  ..... ..
```

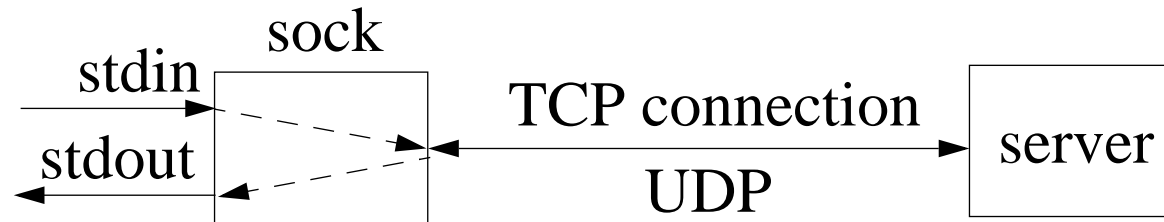
Opcode (arp.opcode), P: 135 D: 135 M: 0

Linux Socket filter

If you want to sniff the network your self (with a program) - try the Linux Socket Filter [16] and [17].

Tools Used: sock Program

- A simple test program to generate TCP, UDP data
- To test and debug TCP, UDP implementations



- Interactive client: default
- Interactive server: -s
- Source client: -i
- Sink server: -i -s
- Default TCP, -u for UDP

Source Code Available: (Tcpdump and sock)

For Win95/98/2000/NT: <http://netgroup-serv.polito.it/windump/>

For BSD alike: <ftp://ftp.uu.net/published/books/stevens.tcpipiv1.tar.Z>

Tools Used: sock + tcpdump

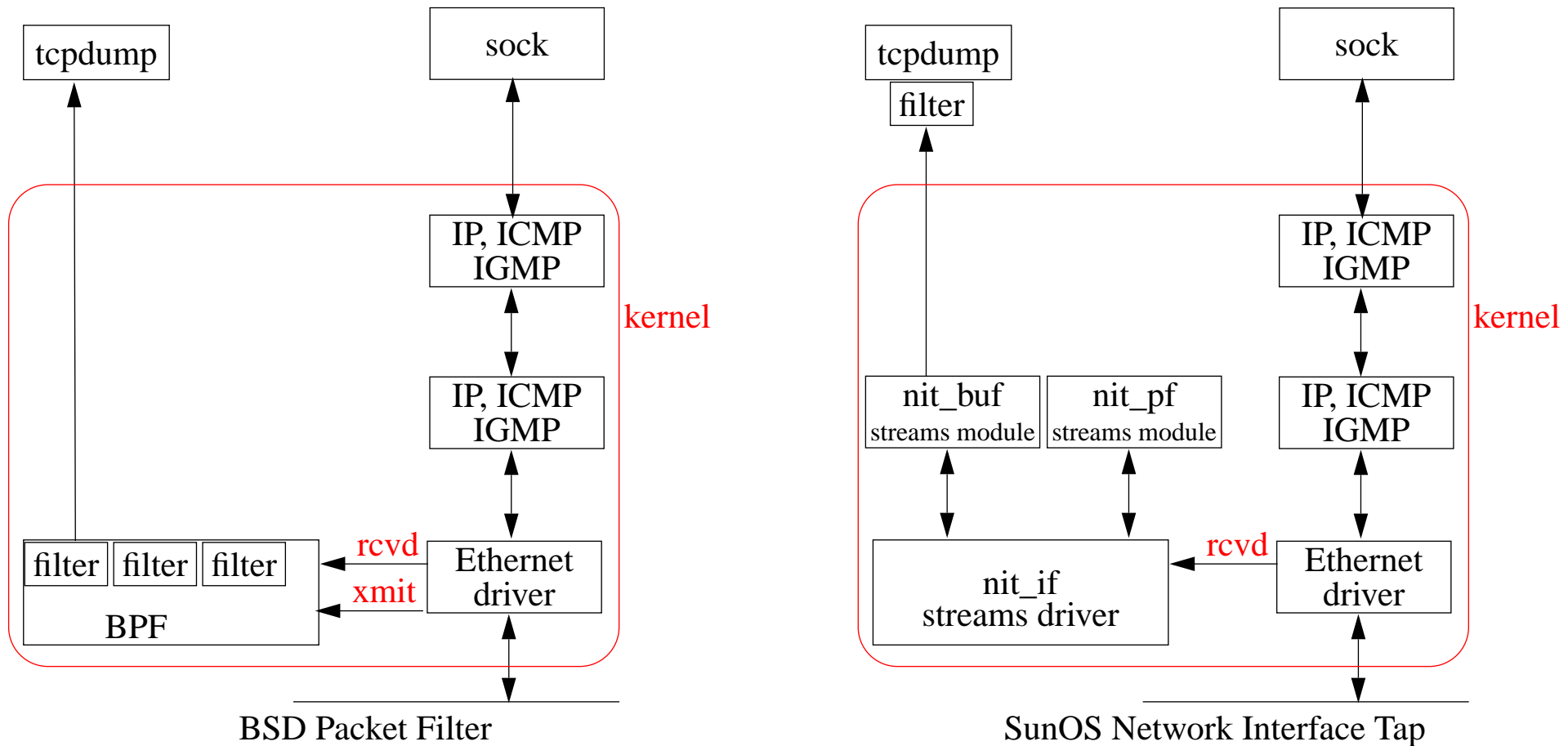


Figure 27: Two alternatives to generate and dump packets

Traffic generators

- Distributed Internet Traffic Generator (D-ITG) [18] -
<http://www.grid.unina.it/software/ITG/>
- Gensyn generate multiple TCP streams in parallel
<http://www.item.ntnu.no/~poulh/GenSyn/gensyn.html>
- Iperf <http://dast.nlanr.net/Projects/Iperf/>
- MGEN: network performance tests and measurements using UDP/IP traffic <http://mgen.pf.itd.nrl.navy.mil/>
- RUDE & CRUDE - Real-time UDP Data Emitter (RUDE) and Collector for RUDE (CRUDE) <http://rude.sourceforge.net/>
- SUN's Packet Shell - <http://playground.sun.com/psh/>
- TG <http://www.caip.rutgers.edu/~arni/linux/tg1.html>
- UDPgen <http://www.fokus.fhg.de/usr/sebastian.zander/private/udpgen>
- Netcom's SmartBits - hardware tester

For additional traffic generators see: <http://www.icir.org/models/trafficgenerators.html> and
<http://www.ip-measurement.org/>

Summary

This lecture we have discussed:

- Routing Principles
 - Routing **Mechanism**: Use the *most specific* route
 - IP provides the mechanism to route **packets**
 - Routing **Policy**: What routes should be put in the routing **table**?
 - Use a routing daemon to provide the *routing policy*
- Routing table
- ARP and RARP
- IPX/SPX Addresses - we will see something similar when we talk about IPv6
- tcpdump, ethereal, sock

For further information about routing see:

Bassam Halabi, *Internet Routing Architectures*, Cisco Press, 1997, ISBN 1-56205-652-2. -- especially useful for IGRP.

We will examine routing policies and algorithms in a later lecture.

References

- [7] http://www.renesas.com/fmwk.jsp?cnt=tcam_series_landing.jsp&fp=/applications/network/network_memory/tcam/
- [8] Fany Yu, Randy H. Katz, and T. V. Lakshman, "Gigabit Rate Multiple-Pattern Matching with TCAM",
http://sahara.cs.berkeley.edu/jan2004-retreat/slides/Fang_retreat.ppt
- [9] Geoff Huston, "Analyzing the Internet BGP Routing Table", Cisco Systems web page,
http://www.cisco.com/en/US/about/ac123/ac147/ac174/ac176/about_cisco_ipj_archive_article09186a00800c83cc.html
- [10] Tian Bu, Lixin Gao, and Don Towsley, "On Characterizing BGP Routing Table Growth", Proceedings of Globe Internet 2002, 2002
http://www-unix.ecs.umass.edu/~lgao/globalinternet2002_tian.pdf
- [11] H Narayan, R Govindan, G Varghese, "The Impact of Address Allocation and Routing on the Structure and Implementation of Routing Tables",

Proceedings of the 2003 Conference on Applications, technologies, architectures, and protocols for computer communications, 2003, pp 125-136, ISBN:1-58113-735-4 and SIGCOMM 03, August 25 29, 2003, Karlsruhe, Germany <http://www.cs.ucsd.edu/~varghese/PAPERS/aram.pdf>

- [12] Ravikumar V.C Rabi Mahapatra J.C. Liu, "Modified LC-Trie Based Efficient Routing Lookup",

<http://faculty.cs.tamu.edu/rabi/Publications/Mascot-final-proceeding.pdf>

- [13] APNIC, Routing Table Report 04:00 +10GMT Sat 19 Mar, 2005, North American Network Operators Group, Weekly Routing Table Report, From: Routing Table Analysis, Mar 18 13:10:37 2005, "This is an automated weekly mailing describing the state of the Internet Routing Table as seen from APNIC's router in Japan. Daily listings are sent to bgp-stats@lists.apnic.net" <http://www.merit.edu/mail.archives/nanog/2005-03/msg00401.html>

- [14] Geoff Huston, Routing Table Status Report, Policy SIG, APNIC19, Kyoto, Japan, Feb 24 2005

<http://www.apnic.net/meetings/19/docs/sigs/routing/routing-pres-info-huston-routing-table.pdf>

- [15] Bassam Halabi, *Internet Routing Architectures*, Cisco Press, 1997, ISBN 1-56205-652-2.
- [16] Gianluca Insolvibile, “The Linux Socket Filter: Sniffing Bytes over the Network”, Linux Journal, 31 May 2001 <http://www.linuxjournal.com/article/4659>
- [17] Gianluca Insolvibile, “Inside the Linux Packet Filter, Part II”, Linux Journal, 1 March 2002 <http://www.linuxjournal.com/article/5617>
- [18] Stefano Avallone, Antonio Pescapé, and Giorgio Ventre, “Analysis and experimentation of Internet Traffic Generator”, International Conference on Next Generation Teletraffic and Wired/Wireless Advanced Networking (NEW2AN’04), February 02-06, 2004
- <http://www.grid.unina.it/software/ITG/D-ITGpublications/New2an-ITG.pdf>