CS419: Computer Networks

Lecture 3: Feb 2, 2005

IP (Internet Protocol)

A hypothetical service

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- You want a mail delivery service
- You have two choices:
  - Acme Guaranteed Mail Delivery Service
    - “We never fail”
  - Rocko’s Mail Delivery and Hubcap
    - “We’ll get it there if we feel like it”
- Which do you choose???

Some selection criteria???

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Some selection criteria

- What is the price?
  - Rocko: $1, Acme: $2
- How often do they fail?
  - Rocko: 5%, Acme: Never
- How important is the mail?
  - Important: Worth $100,000!!!
- Which do you choose???

A selection analysis

- Rocko’s service costs $5001/mail on average
  - Because 1/20 mails are lost at a cost of $100000!!!
- Acme’s service costs $2/mail
- Acme appears to be the best choice…

But….more selection criteria

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- What is being delivered (copy or original)?
  - Copy
- How long does it take?
  - Acme and Rocko, both one day max
- How soon do we need delivery?
  - Within a week
- Now which do we choose???

More selection analysis

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- Assume that the recipient calls to report delivery. If no call, make another copy and send mail again
  - Rocko gets 7 tries at .05 failure per try means $.05^7$ = .00000000078 failure prob
- Now Rocko costs ~*$1/mail*, Acme costs *$2/mail*???
  - Ah, but assume phone call costs $2
- Rocko costs ~*$3/mail*, Acme costs *$2/mail*
- Still appears that Acme is the best choice…

A couple of network layer service models

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- Datagram (IP)
  - “Best Effort” (packets may not arrive, they may be out of order, they may be duplicated)
  - Send packet anytime
- Virtual Circuit (X.25)
  - Guaranteed (no loss, in order, no duplicate)
  - Send packet only if VC established
    - Can try to establish a VC anytime
  - Send packet only if network is ready to receive

This was the choice about 20 years ago

- Many people did an analysis and concluded that virtual circuit (VC) services made more sense
  - In fact, the whole idea of an unreliable network service seemed absurd!
- In part: VC services implied simple end devices, complex switches
  - But far more end devices than switches, and switches easier to access (for management and repair)

This was the choice about 20 years ago

- But datagram service won in the marketplace
- Why????

One reason (of many): The end-to-end argument

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- This may be the single most important concept in network design….

Mail selection criteria again: Something fishy???

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- What is the price?
  - Rocko: $1, Acme: $2
- How often do they fail?
  - Rocko: 1%, Acme: Never
- How important is the mail?
  - Important: Worth $100,000!!!
- Which do you choose???

Mail selection criteria again: Something fishy???

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- You would definitely make a $2 phone call to make sure a $100,000 document was received!!!
  - End-to-end verification
- Turns out that a “reliable” network fails enough that you want end-to-end verification
  - End systems no simpler after all

End-to-end argument

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- Ultimately the end system must be responsible for insuring reliability
  - The network can’t fully be trusted
- If the end system has to insure reliability, no reason to do it in the middle!
- Keep the middle simple!
- This is the design principle behind IP

IP Problem Statement

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- Design a network protocol that can operate over and bridge multiple different kinds of packet networks
- Why this problem statement?
  - Because at the time, DARPA had multiple networks and wanted to make them interwork

IP Problem Statement

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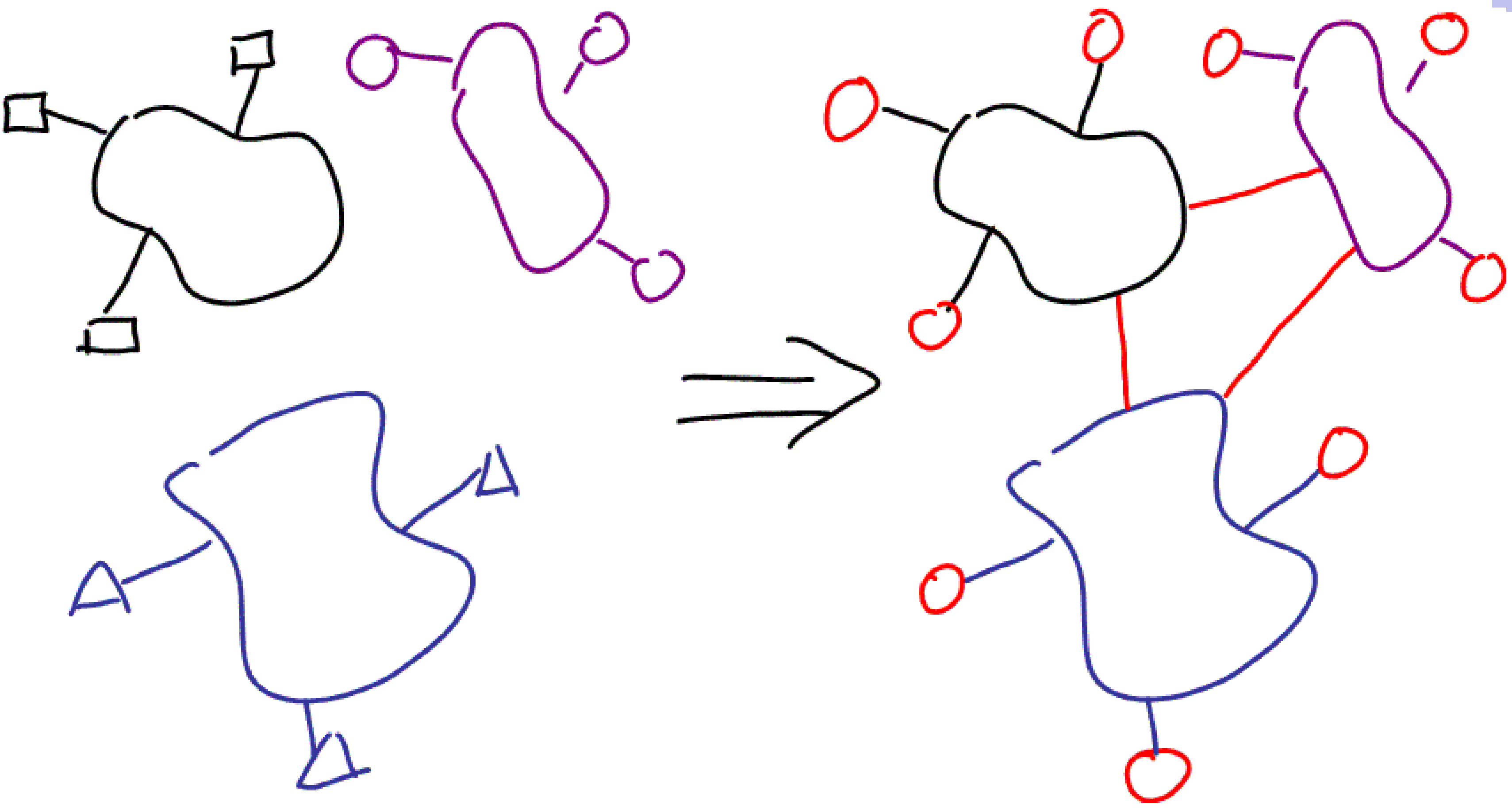
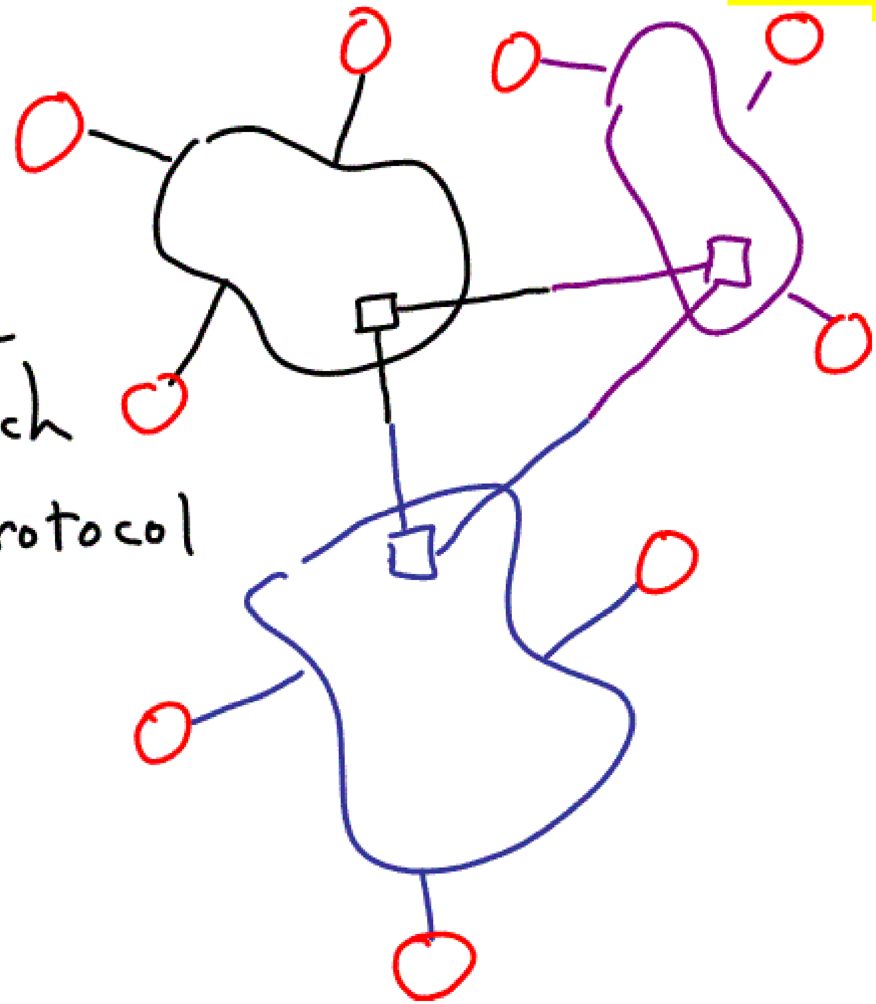


IP Problem Statement

But, can't directly connect a switch running one protocol to a switch running another protocol



Two basic approaches were considered

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- Build a translation *gateway* for every pair of network protocols
  - N^2 types of gateways
  - Every host has an address on every network
  - Gateways know how to map from an address in one network address space to an address in another network space
- Create a new protocol layer that runs above the existing network protocols
  - This of course is IP

Translation versus new layer

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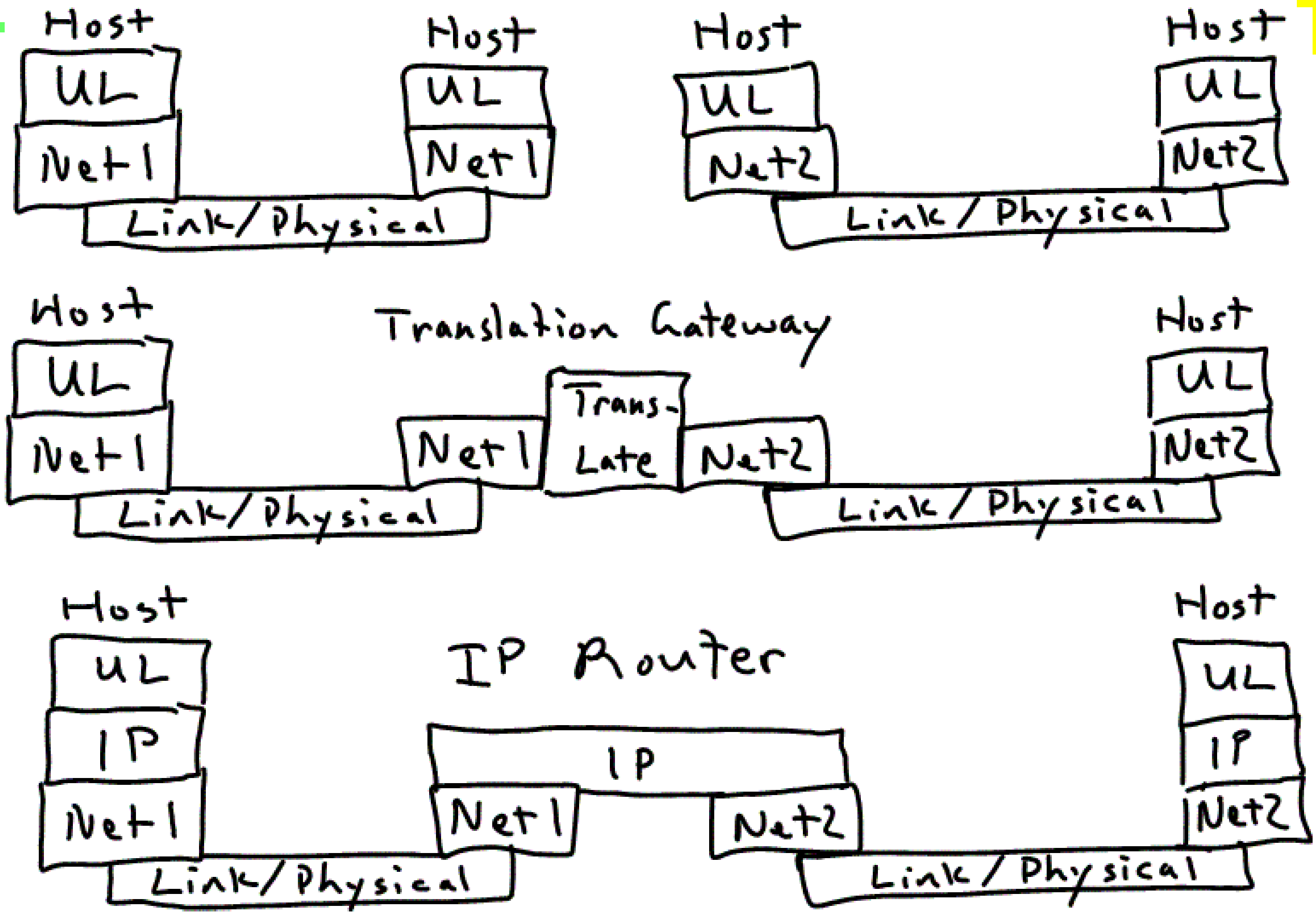

Contrast with previous protocol stack picture

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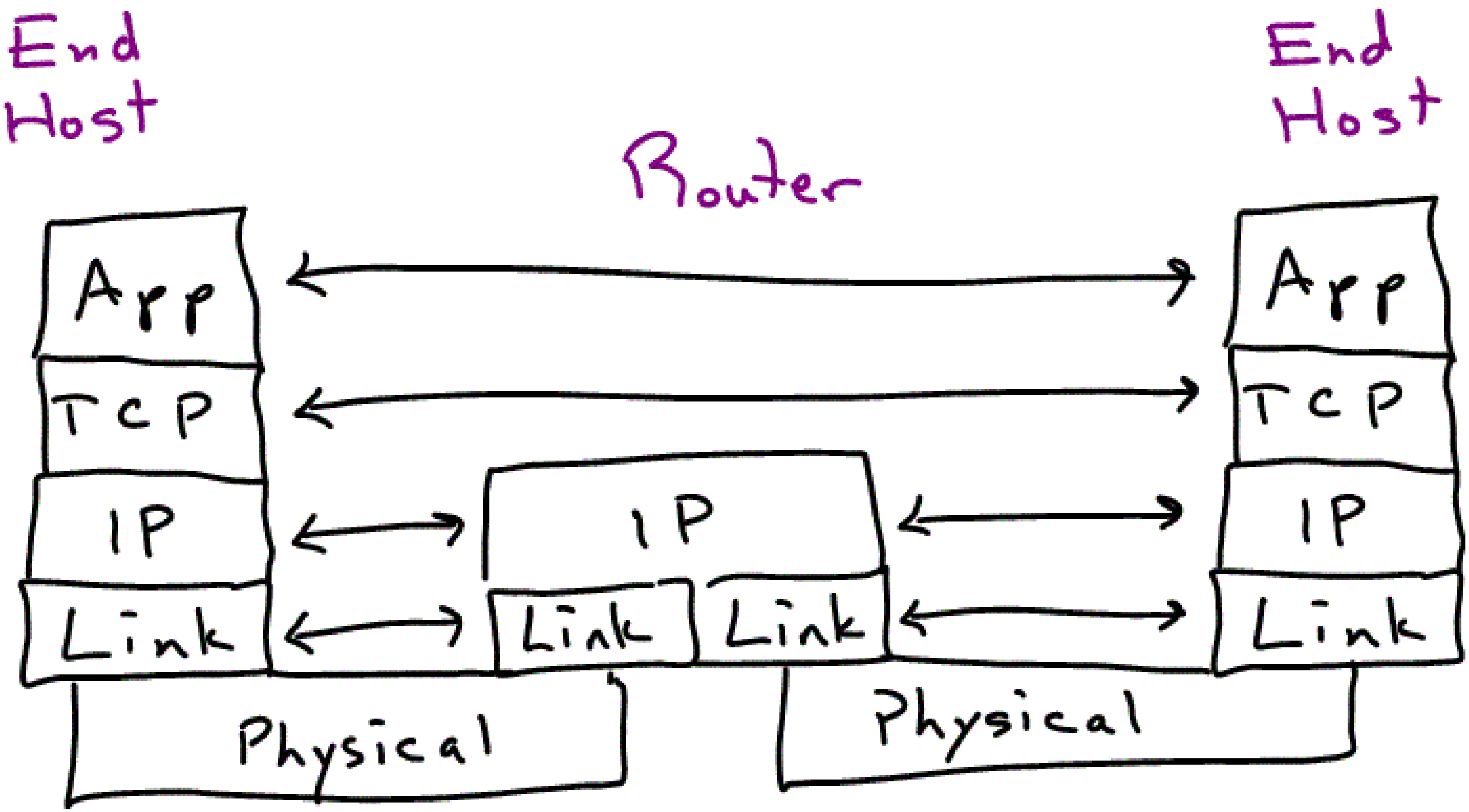

This is a more accurate stack picture

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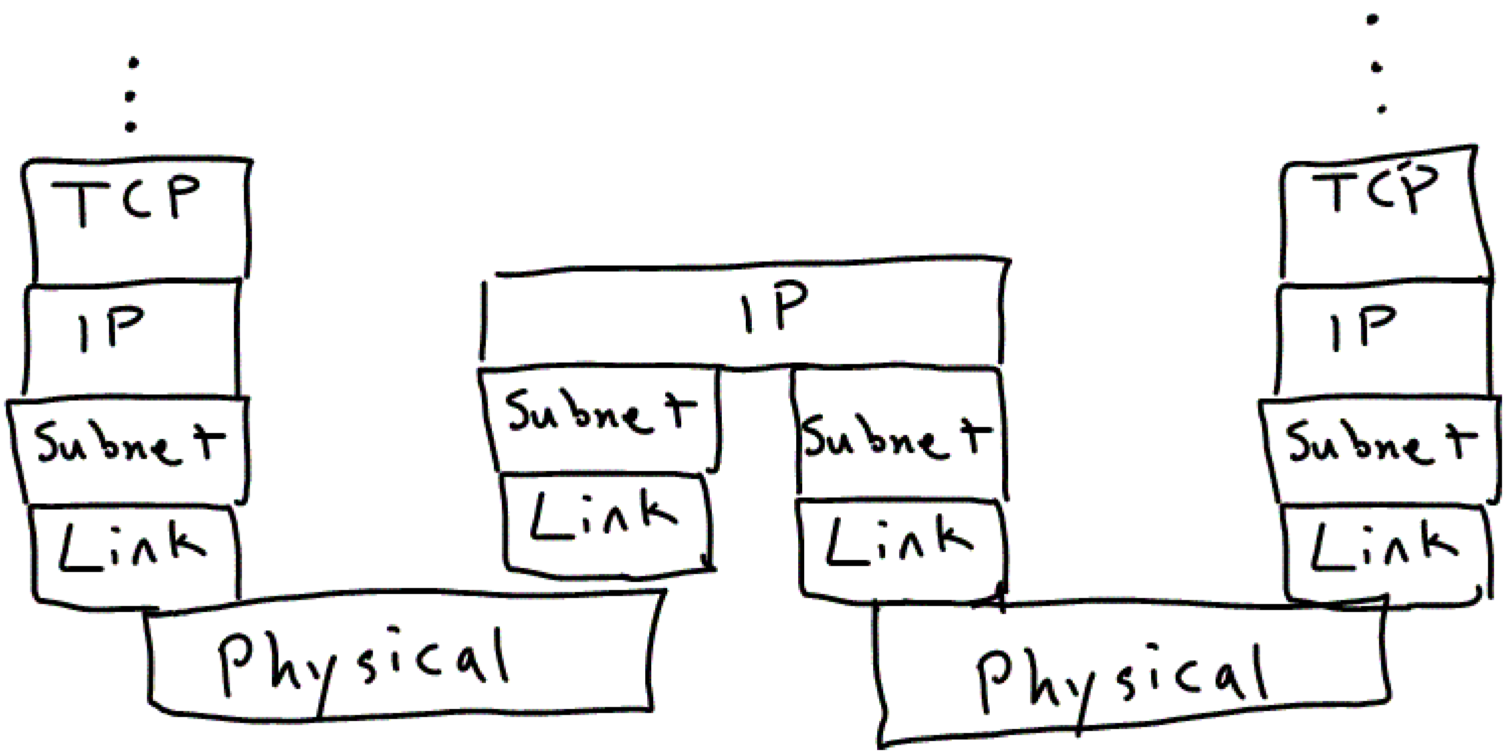
If there is a "network" below IP, we often call it a "subnet".



Advantage of translation gateway approach

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- No changes to existing hosts required
  - Each host thinks the remote host is on the same network
- This was a nice advantage (and is an approach often used today), but . . .

Main problems with translation gateway approach

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- Service mismatch
  - Networks may offer different services
    - Reliability or not, resource reservation or not, congestion control or not
  - A host on one network “thinks” the remote host is on the same network, and so has the same services
- Lack of address space
  - Most networks built with only enough address space for themselves
  - Can’t accommodate hosts on other networks

New Protocol Layer

- Can make the address space as big as needed
  - This solves the “lack of address space” problem
- But what service should the new protocol layer provide?

New Protocol Layer Services

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- Reliability (sequencing):
  - This can be provided by the end hosts
  - Don’t need it from the networks
- Resource reservation:
  - This is hard to provide unless every network in the middle participates
  - Can’t get it from the networks
- Congestion control:
  - This is useful even if not all networks provide it
  - Provide this service (even though different networks may signal this differently and require different responses)!

New functions required by the new protocol layer

- Address resolution
  - How to determine the subnet address of the next hop (router or host)
  - A hard problem in the general case
- Fragmentation and reassembly
  - How to accommodate different MTUs (Maximum Transmission Unit) in different subnets

Maximum Transmission Unit (MTU)

- Every subnet/link has a maximum packet size it can handle
  - This fixes design of incoming buffers, etc., in hardware
- This is called the MTU
- With multiple subnets, an IP packet may be larger than some MTUs in the path
- The smallest MTU in the path is known as the Minimum MTU

Minimum MTU Example

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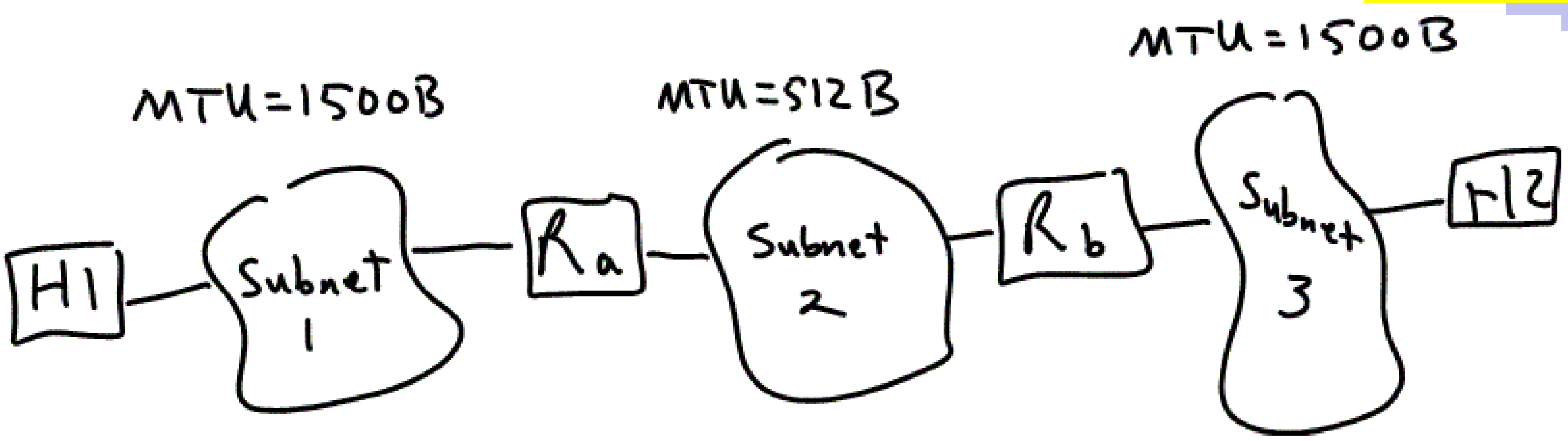

Three basic approaches

1. Use a routing protocol that conveys Minimum MTU of the path
   - Host picks the right MTU size from the start
2. Router drops packet and sends an error message to the Host
3. Router fragments packet into smaller packets

- IP uses a combination of 2 and 3

Fragmentation and reassembly

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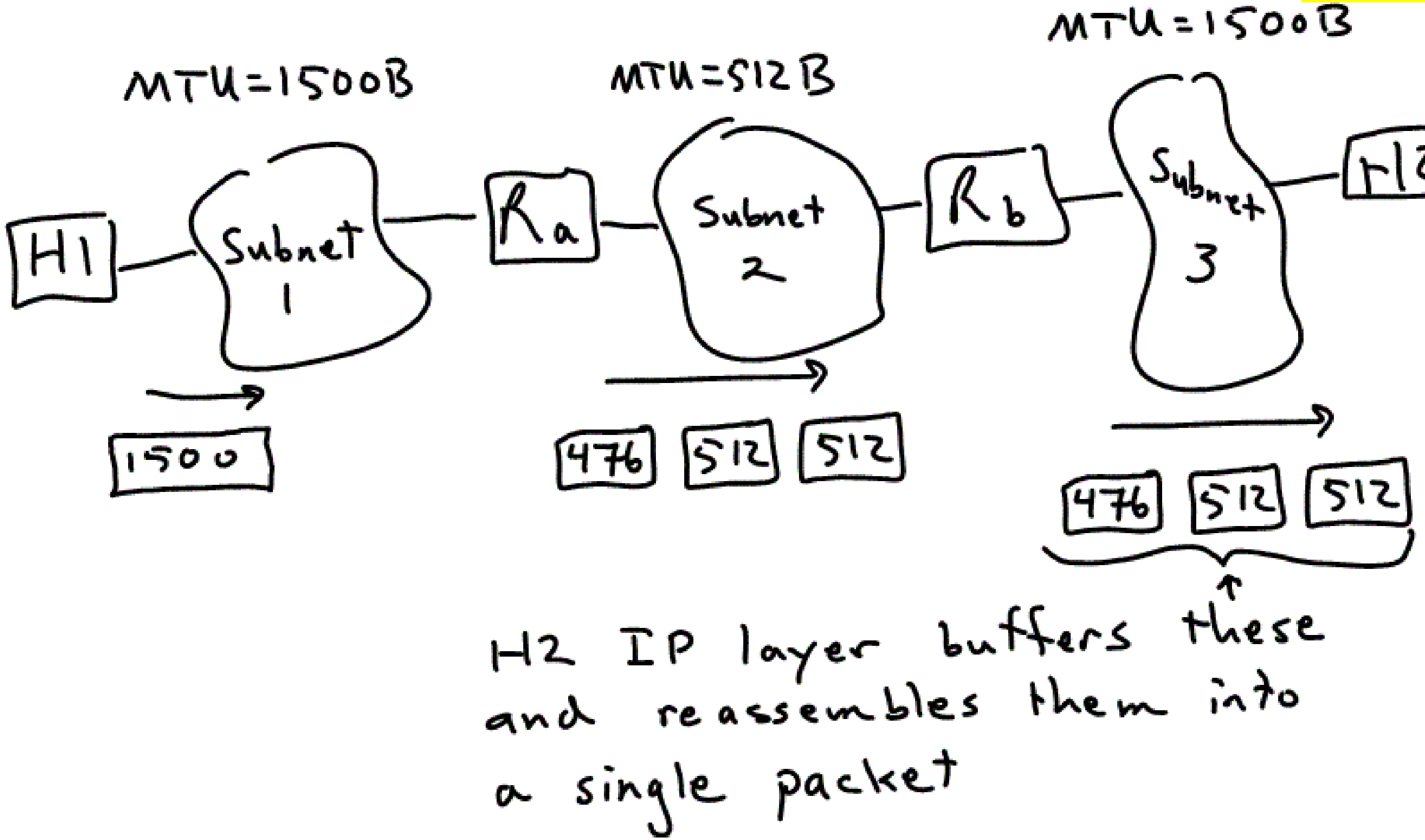
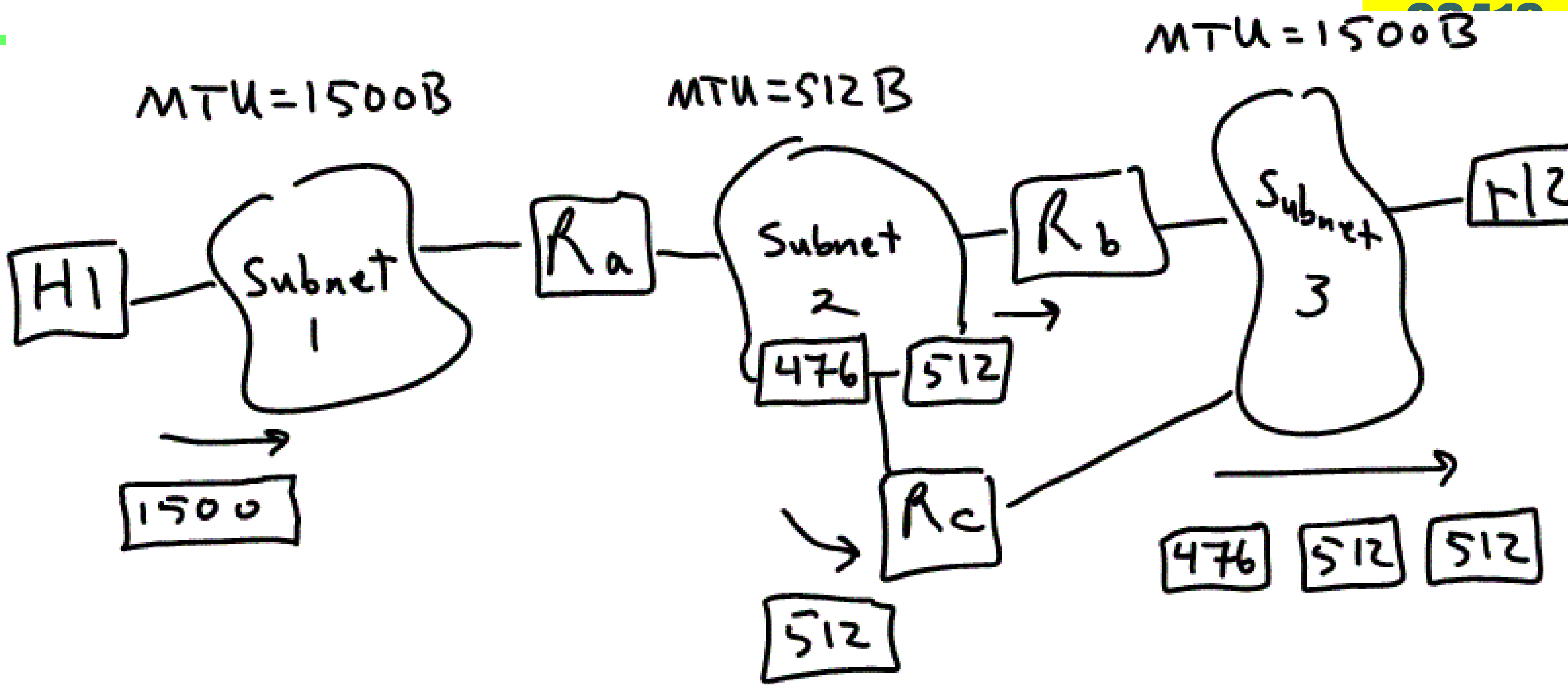


Why doesn't Rb reassemble the packet?



Different fragments might take different paths, besides it is complex for the routers.

IP Header (RFC 791)

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```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version|  IHL  |Type of Service|          Total Length         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Identification        |Flags|      Fragment Offset    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Time to Live |    Protocol   |         Header Checksum       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                       Source Address                          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination Address                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Options                    |    Padding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

IP Header

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- Version = 4
- IHL = IP Header Length (in units of 32 bit words)
  - Usually 5
- ToS: RFC791 is out of date
- Total Length = packet length (max 65K bytes)
- Identification, Flags, and Fragment Offset
  - Controls fragmentation
- TTL: decrement at each hop, drop packet if 0
  - In case of routing loop

IP Header

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- Protocol: identifies the next layer
  - The “where” of IP
  - TCP=6, UCP=17
  - About ½ assigned
- Header Checksum
  - A simple checksum of the IP header
  - Router checks and modifies at TTL decrement
- Source and Destination address
  - Ex: 128.42.33.58
- Options
  - Source route
  - Timestamp
  - Security, etc.
  - Not used in practice
- Padding
  - Must pad to integral 32-bit boundary

Compare with the IPv6 Header! (RFC 2460)

No Fragmentation, no checksum
(Appears also to be no options and no header length, but these are hidden in an "overloaded" next header field)

```
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Version| Traffic Class |           Flow Label                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Payload Length        |  Next Header  |   Hop Limit   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                   Source Address (128 bits)                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                Destination Address (128 bits)                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Why no fragmentation and checksum in IPv6?

- Actually there is fragmentation (as an “option”), but only the source host can fragment
  - Routers cannot fragment, because this is too costly
  - Indeed fragmentation is rare in IPv4
- Checksum is expensive in routers, and not a disaster if header corrupted
  - It just gets misrouted and eventually dropped

IP has a related control protocol

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- ICMP: Internet Control Message Protocol (RFC 792)
- Three primary purposes:
  1. Give routing directives to hosts
  2. Debug routing problems
  3. Give error feedback to hosts
- ICMP runs over IP

Primary ICMP messages

- Redirect
  - Tell host to use another router
- Destination Unreachable
  - Tells host that packet can’t be delivered for various reasons
  - Dest subnet, host, protocol, port unavailable
  - Don’t fragment (DF) Flag set, but needed to fragment
- TTL exceeded
- “Ping” (Echo and Echo Reply)
  - Destination host replies…good for aliveness checking

Not used ICMP messages

- Source quench
  - This was the attempt at getting congestion control from subnets (as well as routers)
- Parameter problem
- Timestamp
- Information Request

Traceroute is a clever use of ICMP TTL Exceeded message

- Traceroute discovers the path from source to destination
  - But not from destination to source!
- It also discovers where in the path delay is taking place
  - Or where in the path a failure occurs
- (tracert in windows)

How traceroute works

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- It sends out a series of ping packets with increasing TTL (1, 2, …)
- When TTL=1, the first router returns an ICMP TTL exceeded message
  - Now we know who the first router is
  - And how long it took to get to the first router and back
- When TTL=2, the second router returns an ICMP TTL exceeded message
  - Now we know who the second router is!
- And so on