CS519: Computer Networks

Lecture 2: Feb 2, 2004

IP (Internet Protocol)

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

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- 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

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- 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….

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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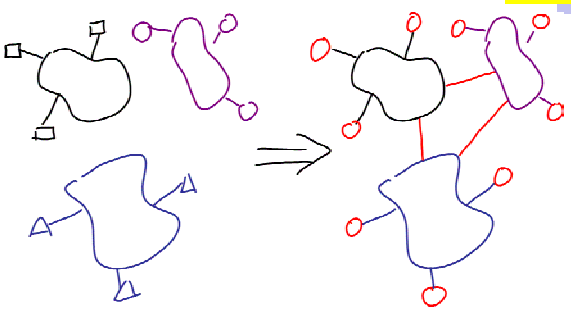

IP Problem Statement

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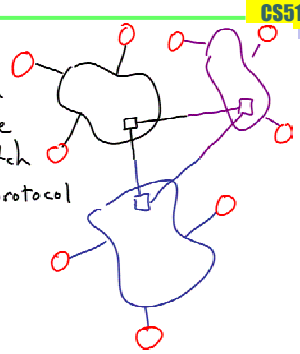
But, can't directly connect a switch running one protocol to a switch running another protocol



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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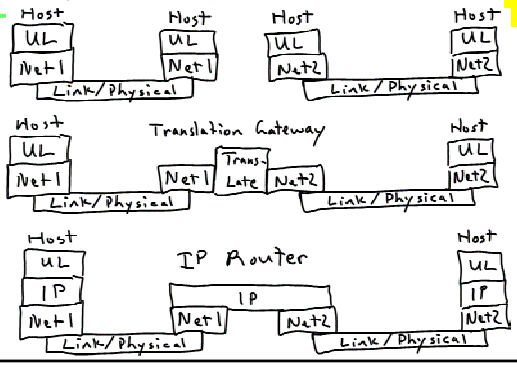

Contrast with previous protocol stack picture

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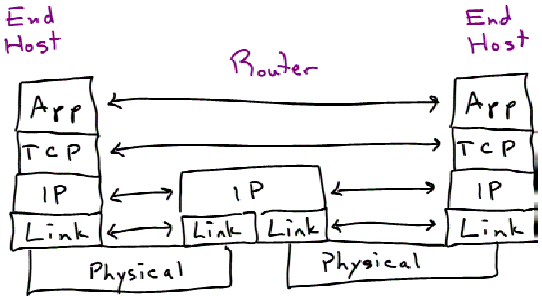

This is a more accurate stack picture

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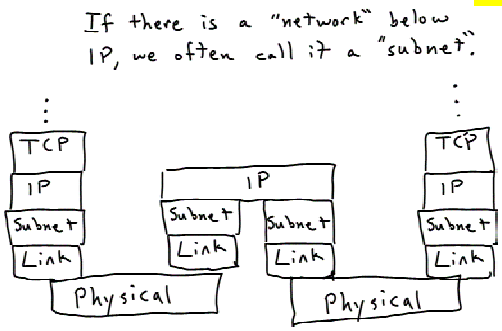

Advantage of translation gateway approach

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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

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- 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

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- 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)

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- 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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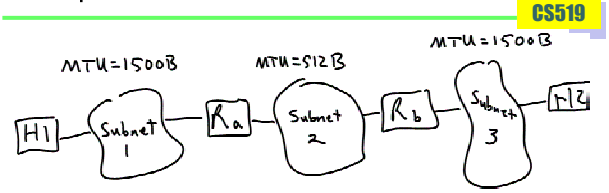

Three basic approaches

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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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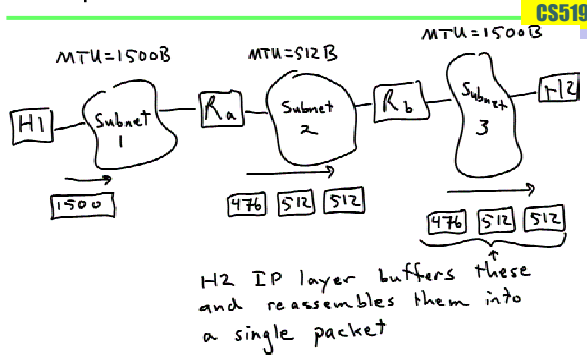
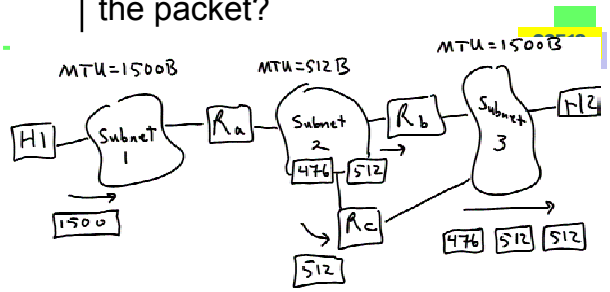


Why doesn't Rb reassemble the packet?



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)

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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                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Destination Address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Why no fragmentation and checksum in IPv6?

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- 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

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- 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

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- 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

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- 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
- When TTL=2, the second router returns an ICMP TTL exceeded message
  - Now we know who the second router is!
- And so on