Computer Networks
CS3001
(Section BDS-7A)
Lecture 22

Instructor: Dr. Syed Mohammad Irteza

Assistant Professor, Department of Computer Science

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Network layer: “data plane” roadmap

- Network layer: overview
- What’s inside a router
- IP: the Internet Protocol
- Generalized Forwarding
- **Middleboxes**
  - middlebox functions
  - evolution, architectural principles of the Internet

Middleboxes

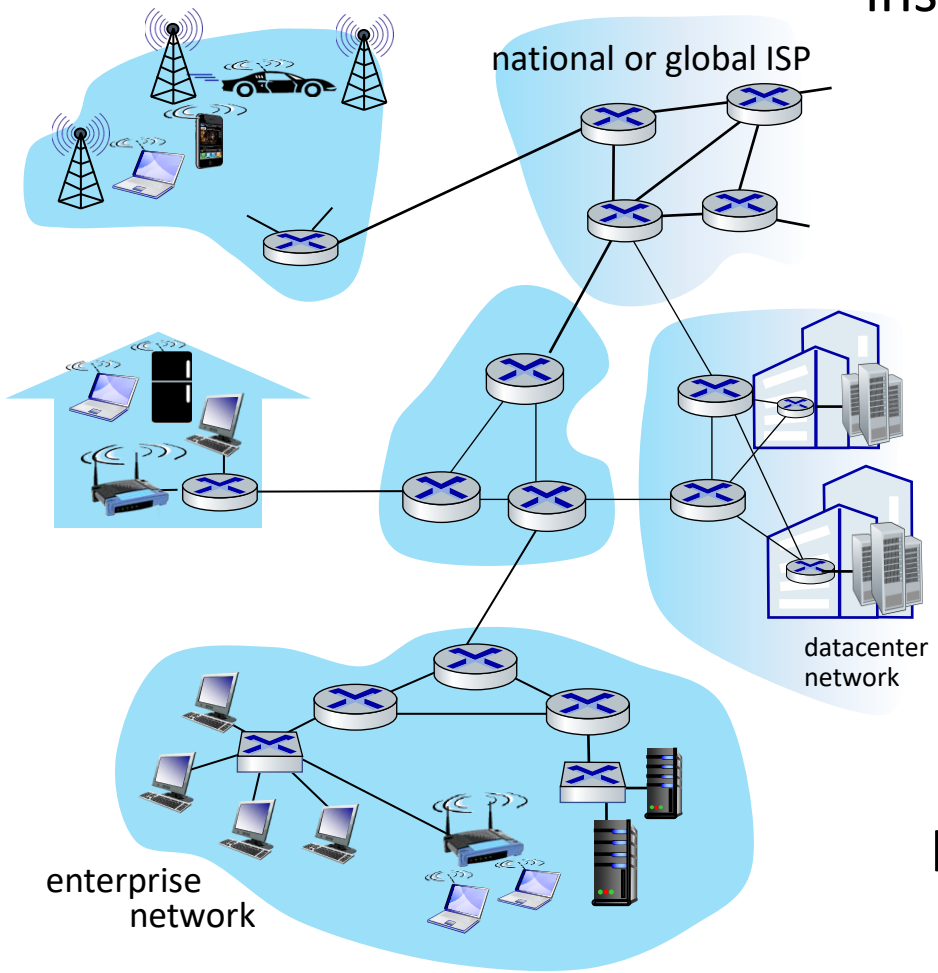
Middlebox (RFC 3234)

"any intermediary box performing functions apart from normal, standard functions of an IP router on the data path between a source host and destination host"

Middleboxes everywhere!

NAT: home, cellular, institutional

Application-specific: service providers, institutional, CDN



Firewalls, IDS: corporate, institutional, service providers, ISPs

Load balancers: corporate, service provider, data center, mobile nets

Caches: service provider, mobile, CDNs

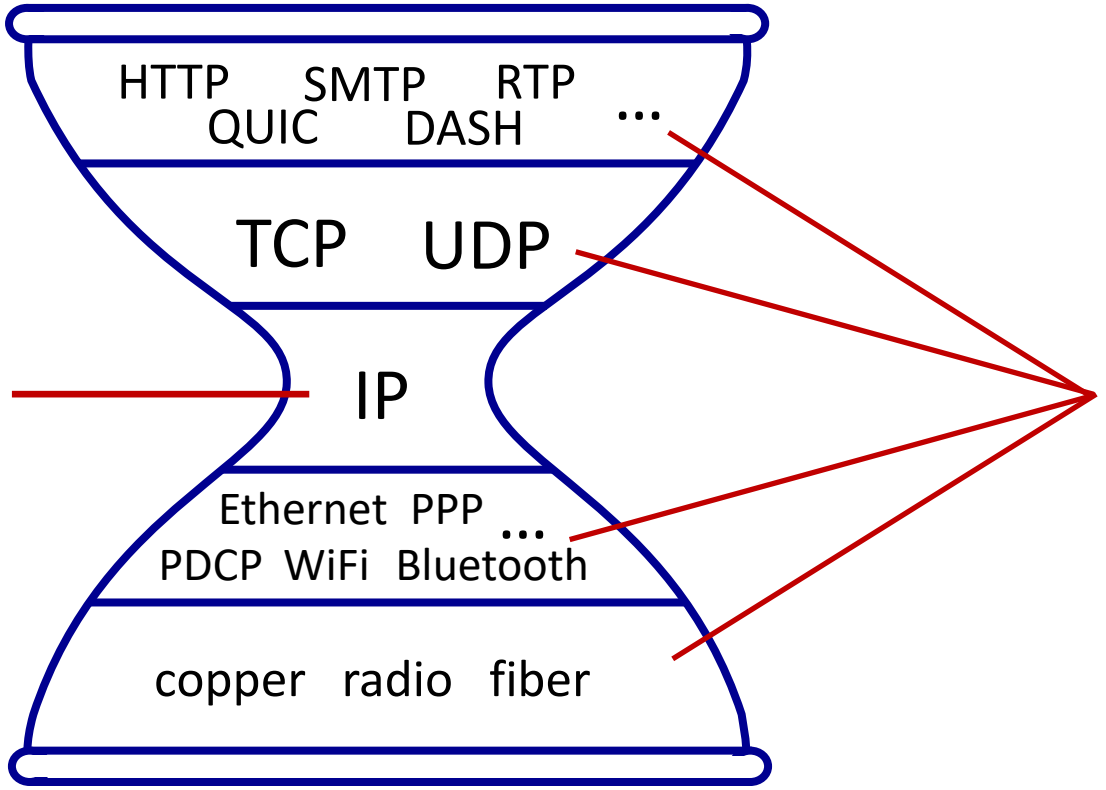
Middleboxes

- initially: proprietary (closed) hardware solutions
- move towards "whitebox" hardware implementing open API
  - move away from proprietary hardware solutions
  - programmable local actions via match+action
  - move towards innovation/differentiation in software
- SDN: (logically) centralized control and configuration management often in private/public cloud
- network functions virtualization (NFV): programmable services over white box networking, computation, storage

The IP hourglass

Internet's "thin waist":

- *one* network layer protocol: IP
- *must* be implemented by every (billions) of Internet-connected devices

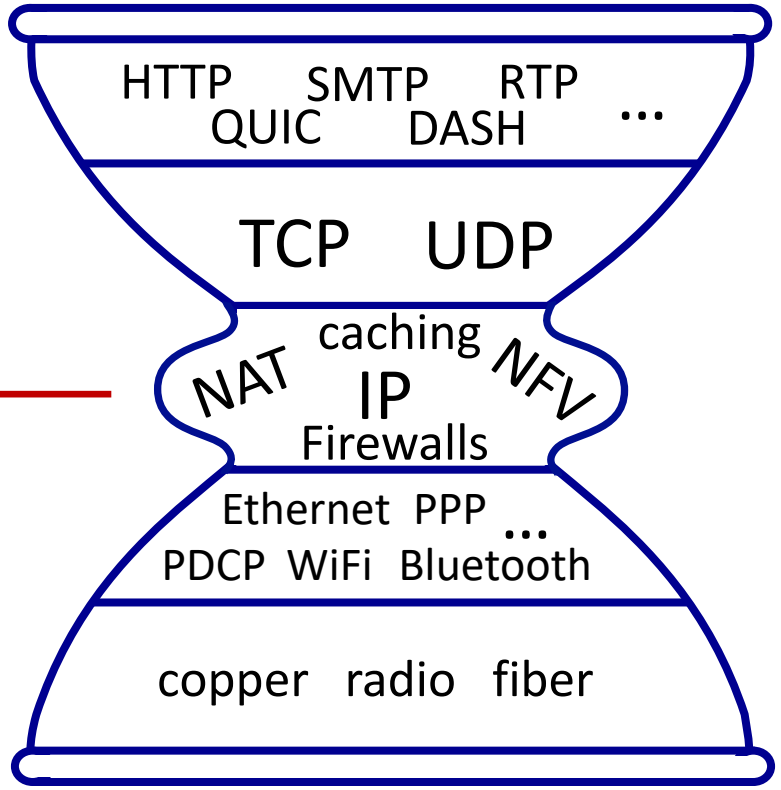


many protocols in physical, link, transport, and application layers

The IP hourglass, at middle age

Internet's middle age "motaapa"?

- middleboxes, operating inside the network



Architectural Principles of the Internet

RFC 1958

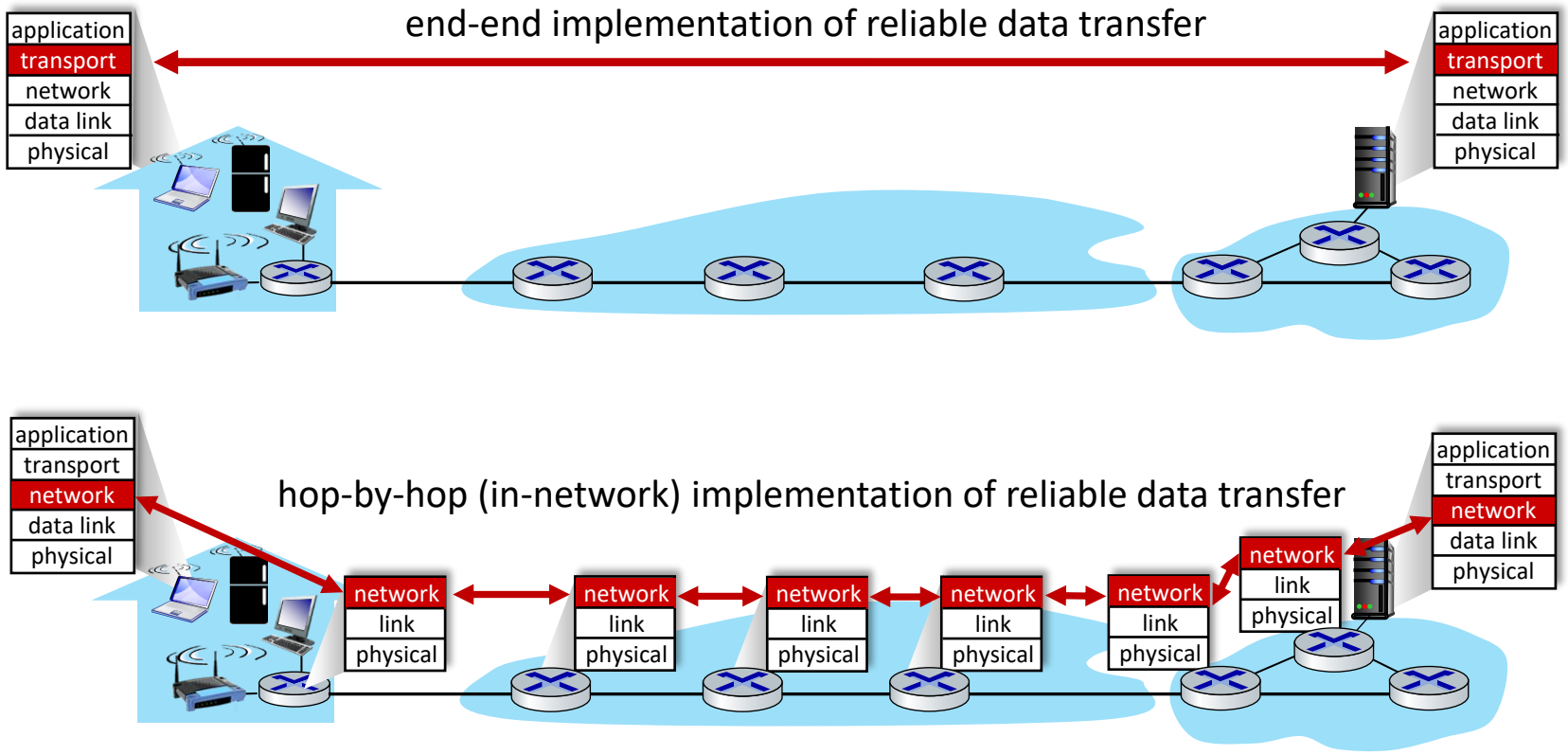
"Many members of the Internet community would argue that there is no architecture, but only a tradition, which was not written down for the first 25 years (or at least not by the IAB). However, in very general terms, the community believes that the goal is connectivity, the tool is the Internet Protocol, and the intelligence is end to end rather than hidden in the network."

Three cornerstone beliefs:

- simple connectivity
- IP protocol: that narrow waist
- intelligence, complexity at network edge

The end-end argument

- some network functionality (e.g., reliable data transfer, congestion) can be implemented in network, or at network edge

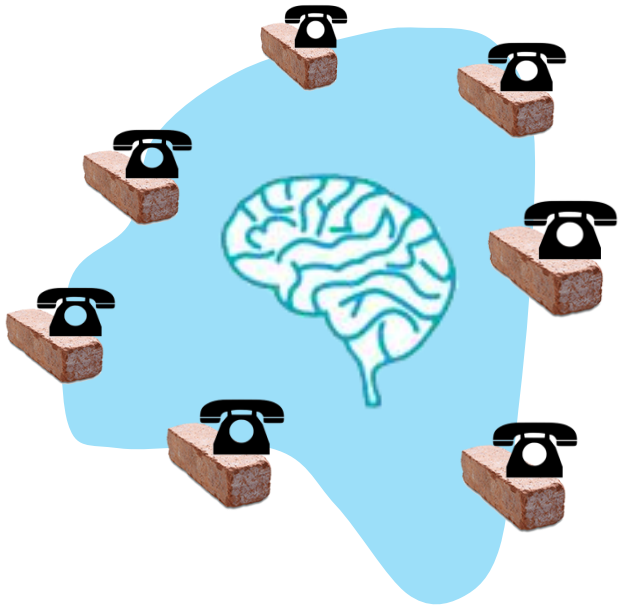


The end-end argument

- some network functionality (e.g., reliable data transfer, congestion) can be implemented in network, or at network edge

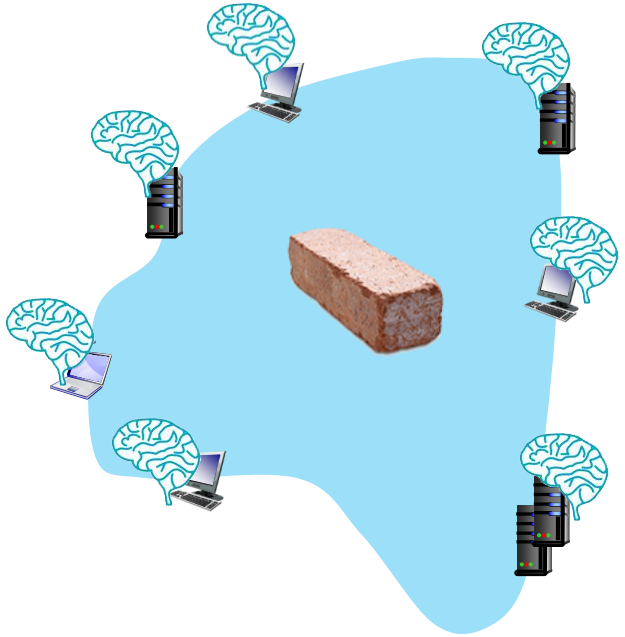
> "The function in question can completely and correctly be implemented only with the knowledge and help of the application standing at the end points of the communication system. Therefore, providing that questioned function as a feature of the communication system itself is not possible. (Sometimes an incomplete version of the function provided by the communication system may be useful as a performance enhancement.)
>
> We call this line of reasoning against low-level function implementation the "end-to-end argument."
>
> Saltzer, Reed, Clark 1981

Where's the intelligence?



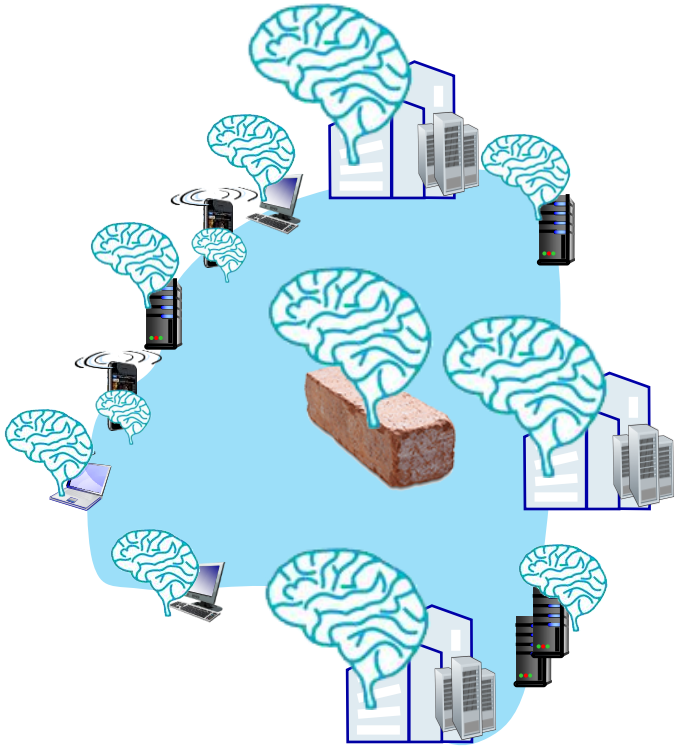
20th century phone net:

- intelligence/computing at network switches



Internet (pre-2005)

- intelligence, computing at edge

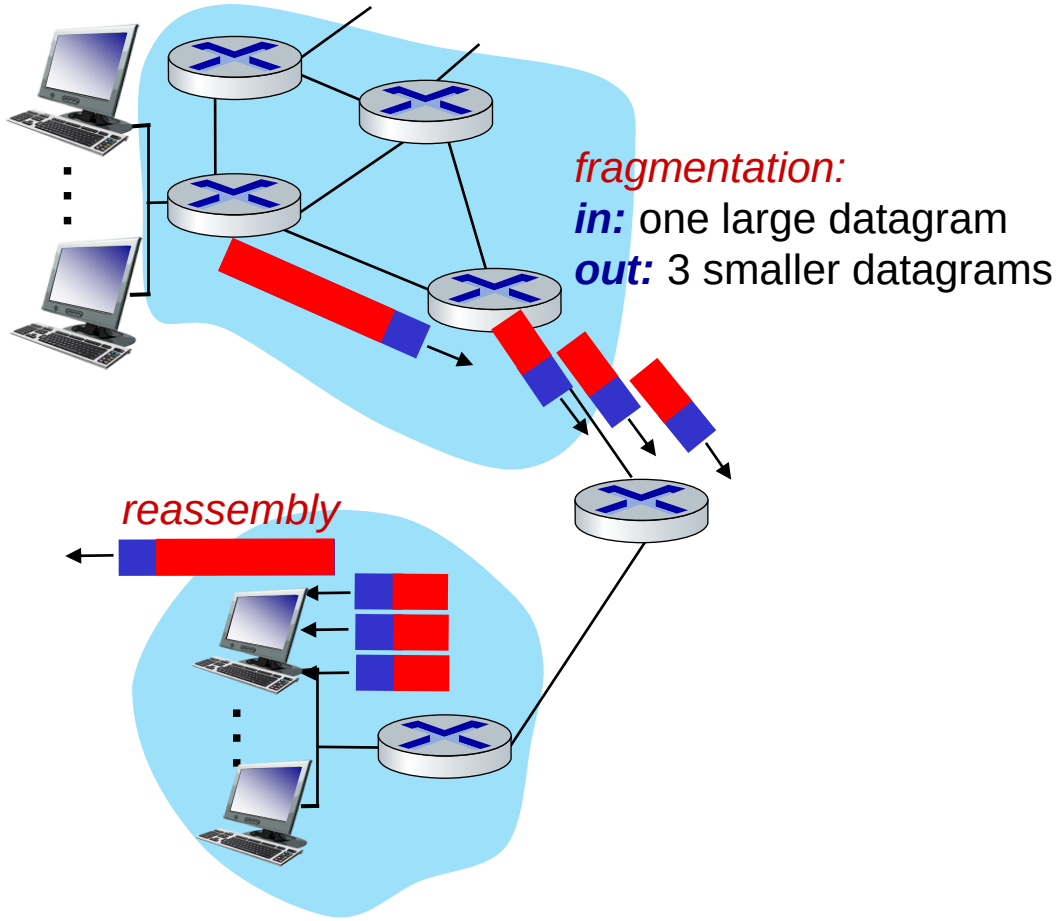


Internet (post-2005)

- programmable network devices
- intelligence, computing, massive application-level infrastructure at edge

IP fragmentation/reassembly

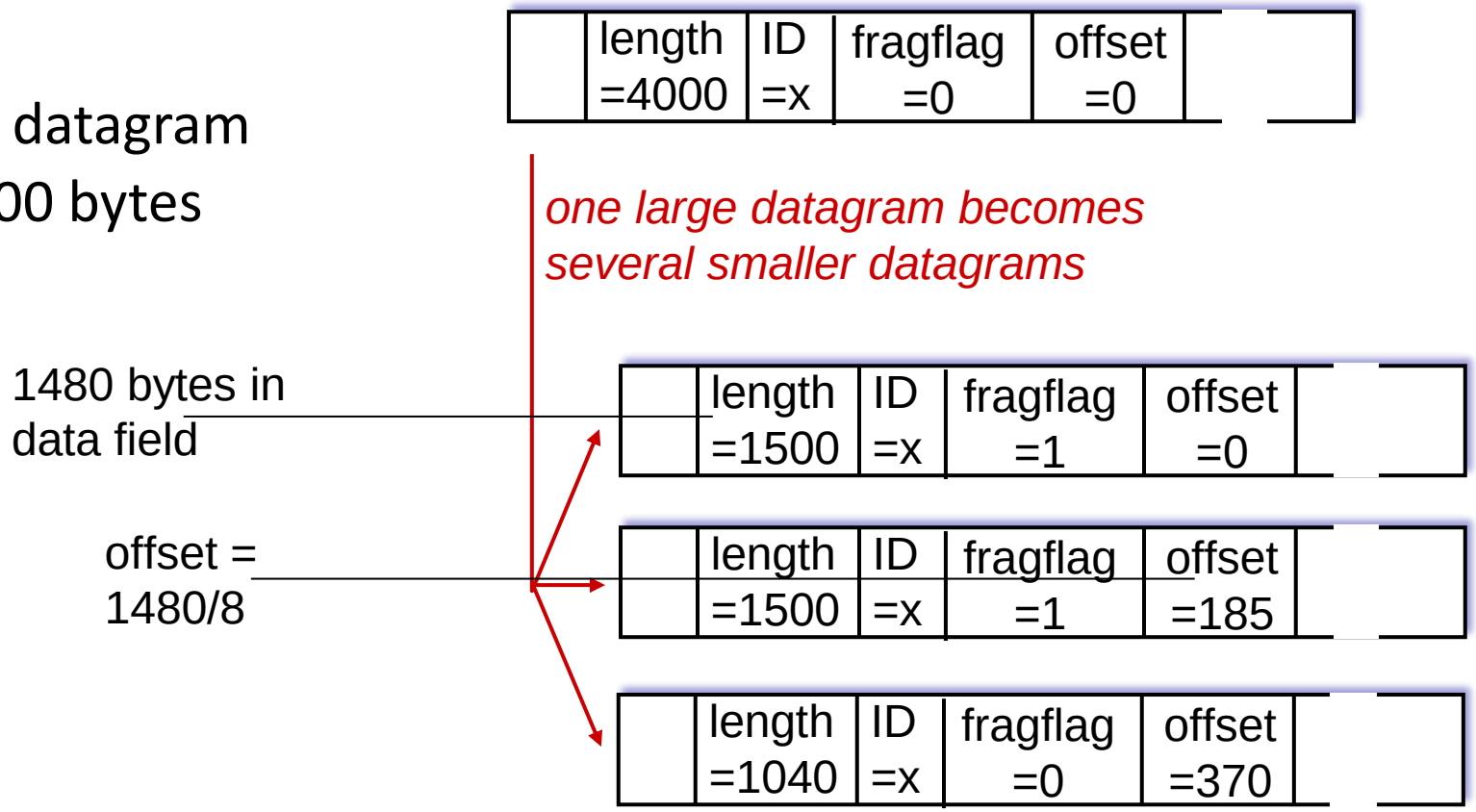
- network links have MTU (max. transfer size) - largest possible link-level frame
  - different link types, different MTUs
- large IP datagram divided ("fragmented") within net
  - one datagram becomes several datagrams
  - "reassembled" only at *destination*
  - IP header bits used to identify, order related fragments



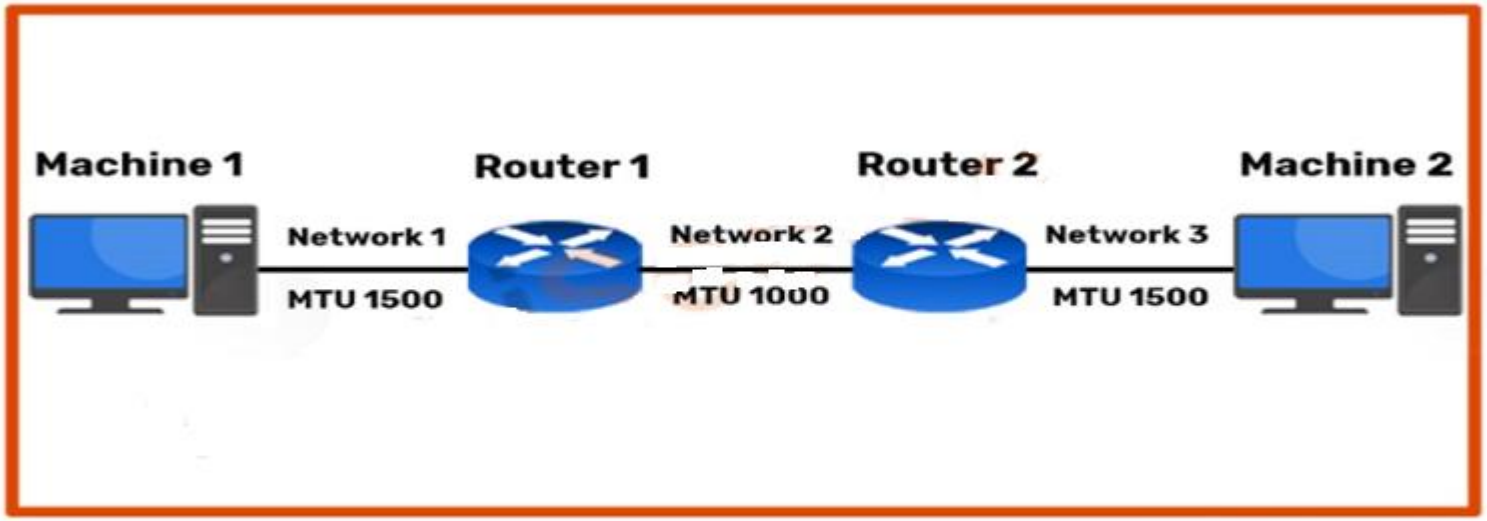
IP fragmentation/reassembly

example:

- 4000 byte datagram
- MTU = 1500 bytes

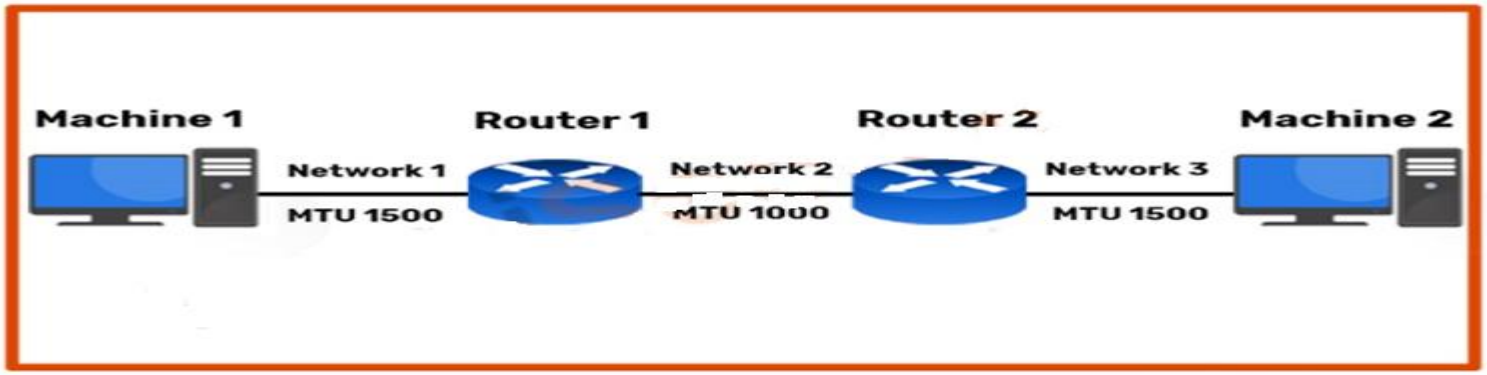


IP fragmentation



Network 1 and Network 3 has MTUs of 1500 bytes each and the MTU of Network 2 is only 1000 bytes.
If Machine 1 sends a 1,500 byte Datagram (20-byte header and 1,480 bytes of data) to Machine 2, Router 1 must fragment the Datagram into two fragments, since the MTU for the Network 2 is only 1000 bytes.

IP fragmentation



1) First will contain 20 bytes header and 976 bytes of data.
   - offset is set to "0" (Since first fragment) and the MF (More Fragments) flag is set to "1".
2) Second will contain a 20 byte header and 504 bytes of data. The fragment offset is set to 122 (976/8 = 122) and the MF (More Fragments) flag is set to "0".

Chapter 4: done!

- Network layer: overview
- What's inside a router
- IP: the Internet Protocol
- Generalized Forwarding, SDN
- Middleboxes

Question: how are forwarding tables (destination-based forwarding) or flow tables (generalized forwarding) computed?

Answer: by the control plane (next chapter)