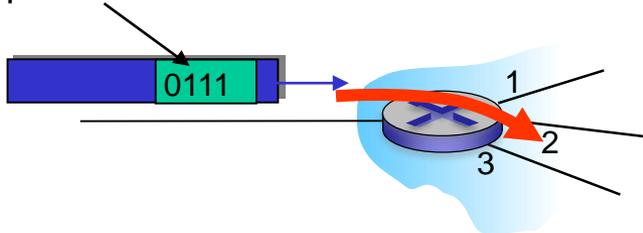


Network layer: data plane, control plane

Data plane

- local, per-router function
- determines how datagram arriving on router input port is forwarded to router output port
- forwarding function

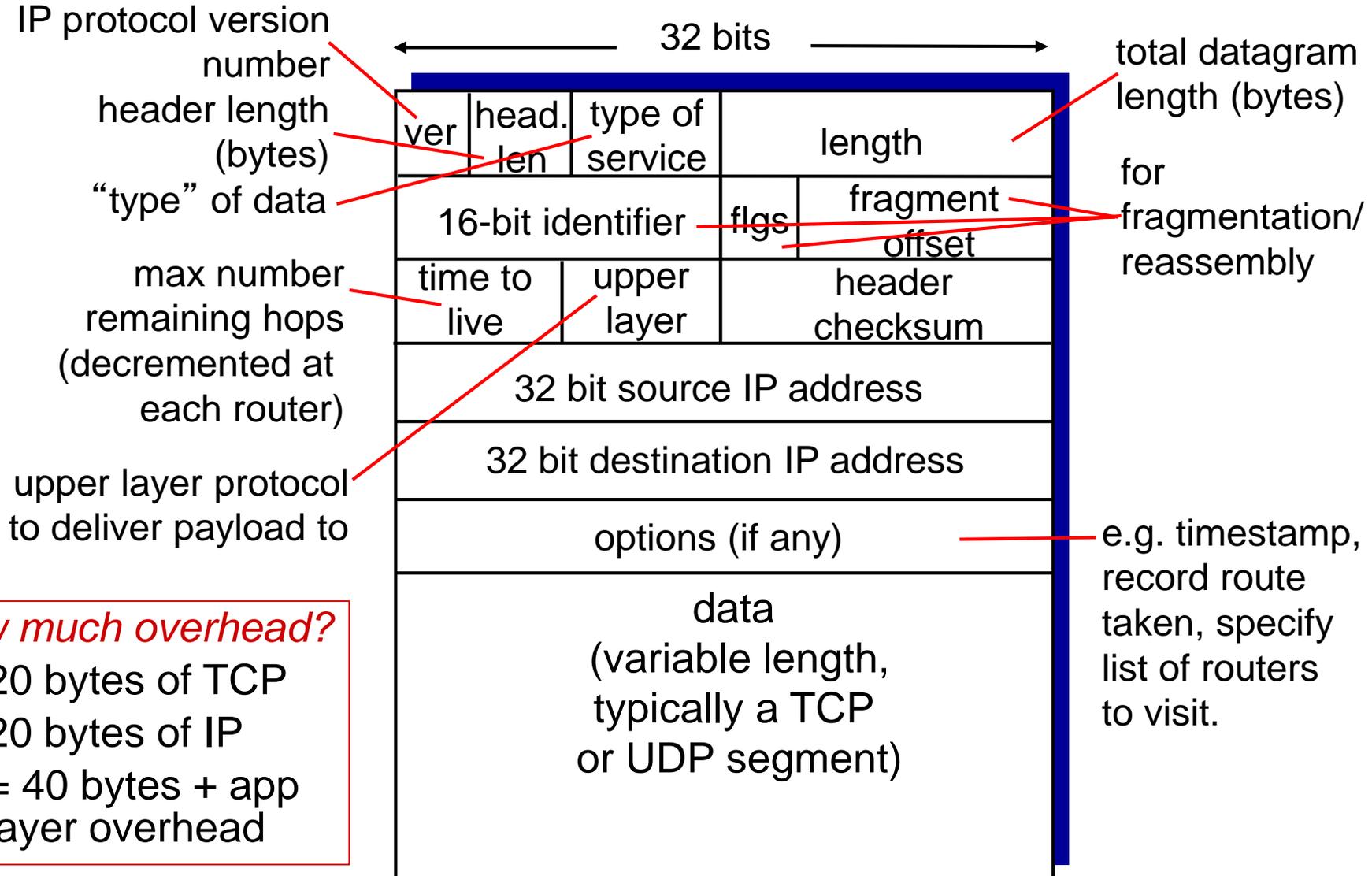
values in arriving packet header



Control plane

- network-wide logic
- determines how datagram is routed among routers along end-end path from source host to destination host
- two control-plane approaches:
 - *traditional routing algorithms*: implemented in routers
 - *software-defined networking (SDN)*: implemented in (remote) servers

IP datagram format

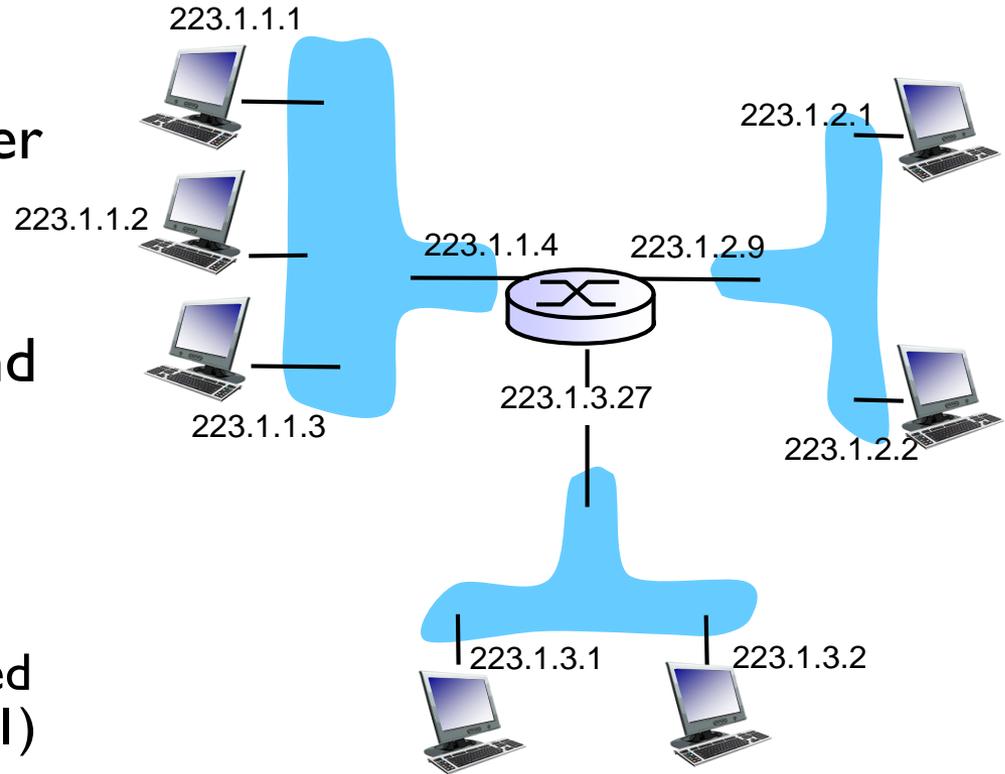


how much overhead?

- ❖ 20 bytes of TCP
- ❖ 20 bytes of IP
- ❖ = 40 bytes + app layer overhead

IP addressing: introduction

- **IP address:** 32-bit identifier for host, router interface
- **interface:** connection between host/router and physical link
 - router's typically have multiple interfaces
 - host typically has one or two interfaces (e.g., wired Ethernet, wireless 802.11)
- **IP addresses associated with each interface**



$$223.1.1.1 = \underbrace{11011111}_{223} \underbrace{0000001}_{1} \underbrace{0000001}_{1} \underbrace{0000001}_{1}$$

Comparison of LS and DV algorithms

message complexity

- **LS:** with n nodes, E links, $O(nE)$ msgs sent
- **DV:** exchange between neighbors only
 - convergence time varies

speed of convergence

- **LS:** $O(n^2)$ algorithm requires $O(nE)$ msgs
 - may have oscillations
- **DV:** convergence time varies
 - may be routing loops
 - count-to-infinity problem

robustness: what happens if router malfunctions?

LS:

- node can advertise incorrect *link* cost
- each node computes only its own table

DV:

- DV node can advertise incorrect *path* cost
- each node's table used by others
 - error propagate thru network

Internet approach to scalable routing

aggregate routers into regions known as “**autonomous systems**” (AS) (a.k.a. “domains”)

intra-AS routing

- routing among hosts, routers in same AS (“network”)
- all routers in AS must run *same* intra-domain protocol
- routers in *different* AS can run *different* intra-domain routing protocol
- gateway router: at “edge” of its own AS, has link(s) to router(s) in other AS'es

inter-AS routing

- routing among AS'es
- gateways perform inter-domain routing (as well as intra-domain routing)

Internet inter-AS routing: BGP

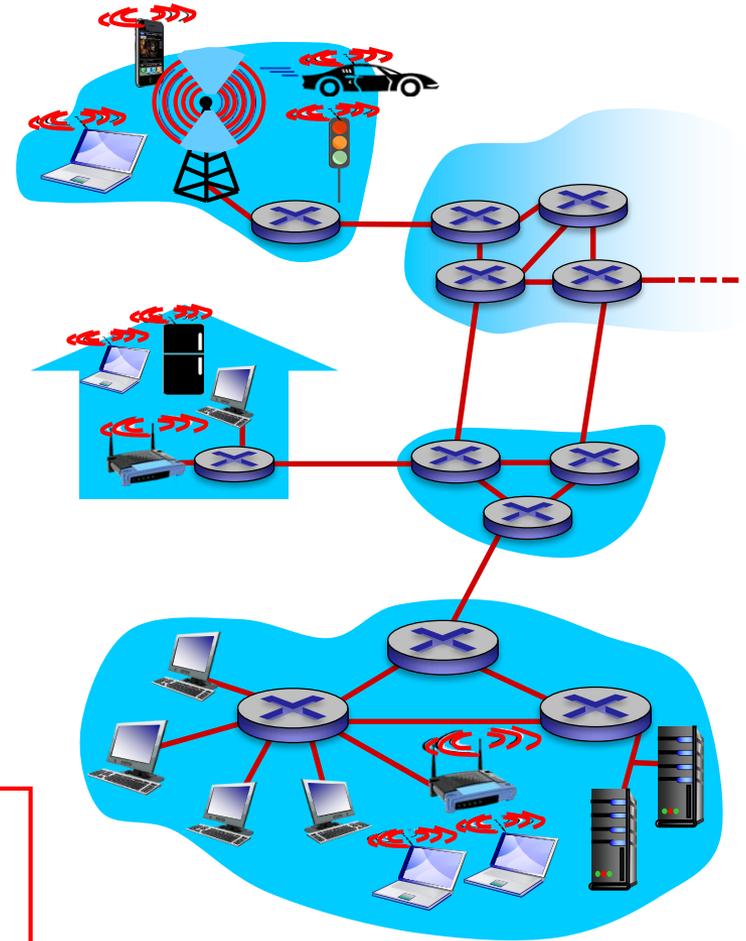
- **BGP (Border Gateway Protocol):** *the de facto inter-domain routing protocol*
 - “glue that holds the Internet together”
- BGP provides each AS a means to:
 - **eBGP:** obtain subnet reachability information from neighboring ASes
 - **iBGP:** propagate reachability information to all AS-internal routers.
 - determine “good” routes to other networks based on reachability information and *policy*
- allows subnet to advertise its existence to rest of Internet: *“I am here”*

Link layer: introduction

terminology:

- hosts and routers: **nodes**
- communication channels that connect adjacent nodes along communication path: **links**
 - wired links
 - wireless links
 - LANs
- layer-2 packet: **frame**, encapsulates datagram

data-link layer has responsibility of transferring datagram from one node to *physically adjacent* node over a link



Summary of MAC protocols

- *channel partitioning*, by time, frequency or code
 - Time Division, Frequency Division
- *random access* (dynamic),
 - ALOHA, S-ALOHA, CSMA, CSMA/CD
 - carrier sensing: easy in some technologies (wire), hard in others (wireless)
 - CSMA/CD used in Ethernet
 - CSMA/CA used in 802.11
- *taking turns*
 - polling from central site, token passing
 - Bluetooth, FDDI, token ring

Ethernet: unreliable, connectionless

- *connectionless*: no handshaking between sending and receiving NICs
- *unreliable*: receiving NIC doesn't send acks or nacks to sending NIC
 - data in dropped frames recovered only if initial sender uses higher layer rdt (e.g., TCP), otherwise dropped data lost
- Ethernet's MAC protocol: unslotted *CSMA/CD with binary backoff*

Switches vs. routers

both are store-and-forward:

- **routers:** network-layer devices (examine network-layer headers)
- **switches:** link-layer devices (examine link-layer headers)

both have forwarding tables:

- **routers:** compute tables using routing algorithms, IP addresses
- **switches:** learn forwarding table using flooding, learning, MAC addresses

