Network Layer 1

Overview of Network Layer

1. Overview of Network layer
2. Router
3. Internet Protocol

Goal:

- Understand principles behind network layer services, focusing on data plane:
  - Network layer service models
  - Forwarding versus routing
  - How a router works
  - Generalized forwarding
- Instantiation, implementation in the Internet

Introduction:

- Transport segment from sending to receiving host
  从发送主机到接收主机的传输段
- On sending side encapsulates segments into datagrams
  在发送端将 Segment 封装到数据报中
- On receiving side, delivers segments to transport layer
  在接收端，将 Segment 传送到传输层
- Network layer protocols in every host, router
  每台主机、路由器中的网络层协议
- Router examines header fields in all IP datagrams passing through it
  路由器检查通过它的所有 IP 数据报中的报头字段

Two key network-layer functions 两个关键的网络层功能

Network-layer functions:

网络层功能

- Forwarding: move packets from router's input to appropriate router output
  转发：将数据包从路由器的输入移动到适当的路由器输出
- Routing : determine route taken by packets from source to destination
  路由：确定数据包从源到目标的路由
- Routing algorithms
  路由算法

Analogy: taking a trip 类比：去旅行

- forwarding: process of getting through single interchange

转发：通过单一立交的过程

- routing: process of planning trip from source to destination

  路由：从源头到目的地的行程规划过程

Network layer: data plane, control plane 网络层：数据平面、控制平面

数据平面与控制平面紧耦合

Data plane 数据平面

- Local, per-router function

  本地、每个路由器的功能

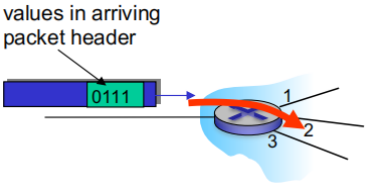
- Determines how datagram arriving on router input port is forwarded to router output port

  确定如何将到达路由器输入端口的数据报转发到路由器输出端口

- Forwarding function

  转发功能

  - 传统方式：基于目标地址+转发表（路由表）
  - SDN方式：基于多个子段+段表



Control plane 控制平面

- Network-wide logic

  网络范围的逻辑

- Determines how datagram is routed among routers along end-end path from source host to destination host

  确定如何沿从源主机到目标主机的终端路径在路由器之间路由数据报

- Two control-plane approaches:

  两种控制平面方法：

  - *traditional routing algorithms:* implemented in routers

    在路由器中实现的 *传统路由* 算法

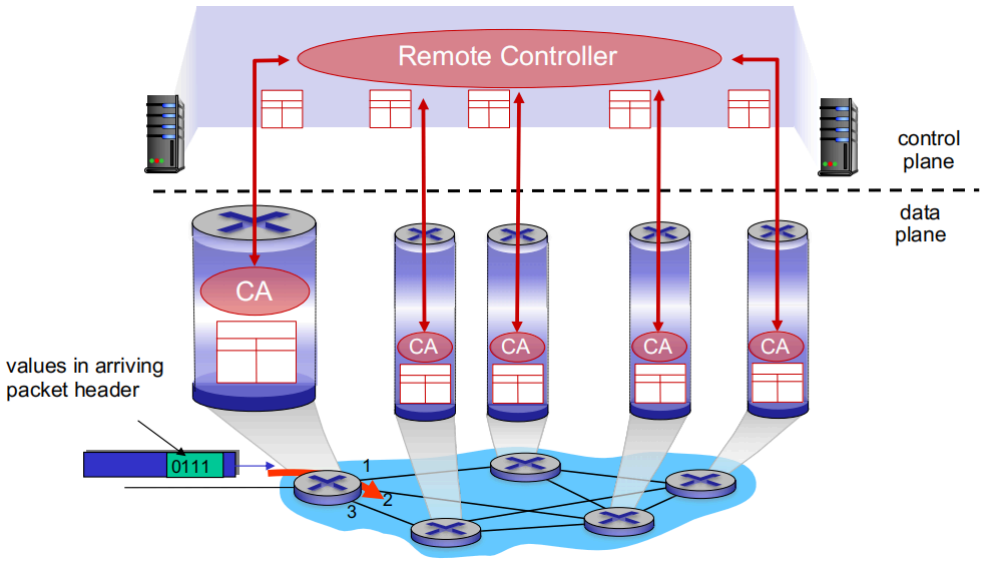
  - *software-defined networking (SDN)*: implemented in (remote) servers

    软件定义网络 （SDN）：在（远程）服务器中实现

Per-router control plane 每台路由器控制平面

A distinct (typically remote) controller interacts with local control agents (CAs)

不同的（通常是远程的）控制器与本地控制代理 （CA） 交互



Network service model 网络服务模型

Q: What service model for “channel ” transporting datagrams from sender to receiver?

将数据报从发送方传输到接收方的 “信道 ” 是什么服务模型?

example services for individual datagrams:

单个数据报的示例服务:

- Guaranteed delivery

  保证交货
- Guaranteed delivery with less than 40 msec delay

  保证延迟小于 40 毫秒的传输

example services for a flow of datagrams:

数据报流的示例服务:

- In-order datagram delivery

  按顺序数据报交付
- Guaranteed minimum bandwidth to flow

  保证最小流带宽
- Restrictions on changes in inter packet spacing

  对数据包间间距变化的限制

Network layer service models: 网络层服务模型

Network Architecture	Service Model	Guarantees ?				Congestion feedback
		Bandwidth	Loss	Order	Timing	
Internet	best effort	none	no	no	no	no (inferred via loss)
ATM	CBR	constant rate	yes	yes	yes	no congestion
ATM	VBR	guaranteed rate	yes	yes	yes	no congestion
ATM	ABR	guaranteed minimum	no	yes	no	yes
ATM	UBR	none	no	yes	no	no

Router 路由器

Router architecture overview 路由器架构概述

- **High-level view of generic router architecture:**

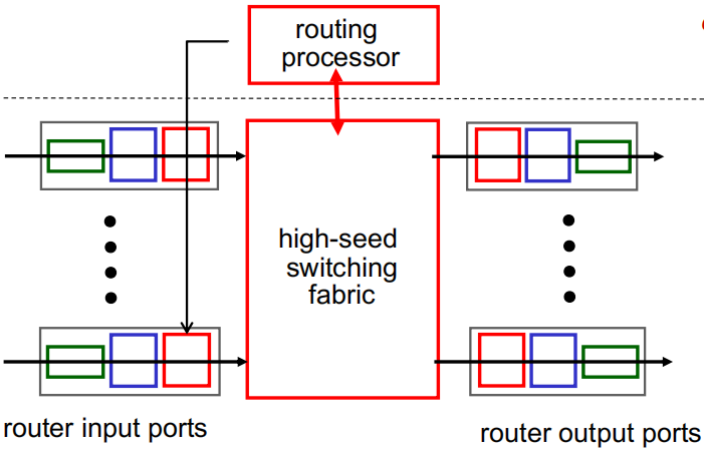
  通用路由器体系结构的高级视图：

  - *routing, management control plane* (software)operates in millisecond time frame

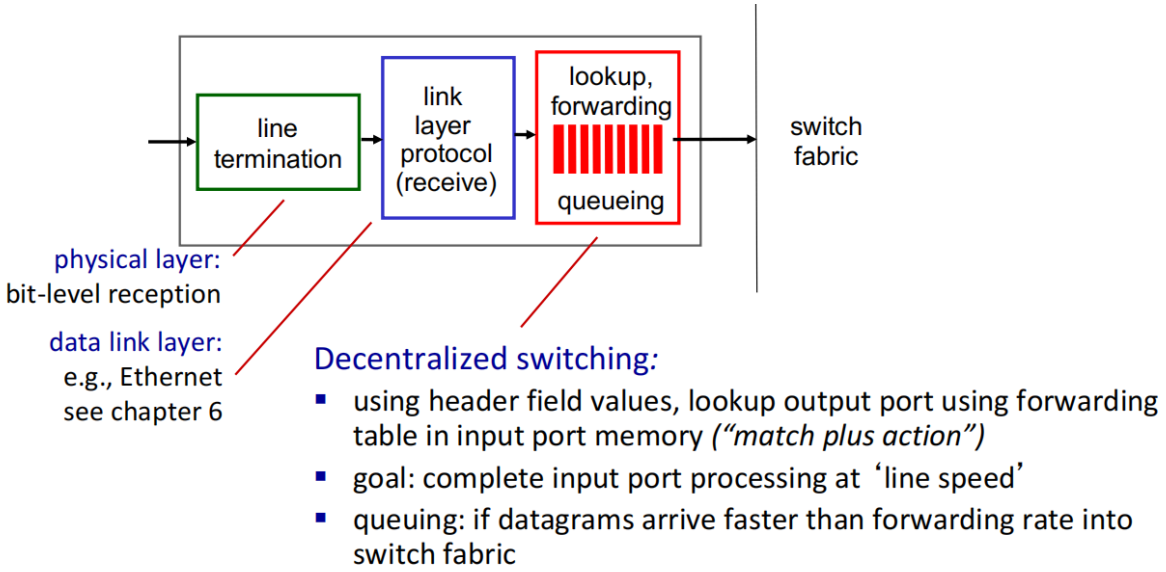
    路由、管理控制平面（软件）以毫秒为单位运行 (图像虚线上半部分)

  - *forwarding data plane* (hardware) operates in nanosecond timeframe

    转发数据平面（硬件）以纳秒级时间帧运行(图像虚线下半部分)



Input port functions 输入端口功能



- physical layer: bit-level reception

  物理层：比特级接收

- data link layer: e.g., Ethernetsee chapter 6

  数据链路层：例如，以太网参见第 6 章

- Decentralized switching: 分布式开关
  - using header field values, lookup output port using forwarding table in input port memory *("match plus action")*

    使用标头字段值，使用输入端口内存中的转发表查找输出端口 *("匹配加操作")*
  - goal: complete input port processing at 'line speed'

    目标：以"线速"完成输入端口处理
  - queuing: if datagrams arrive faster than forwarding rate into switch fabric

    排队：如果数据报到达的速度比转发到交换机结构的速率更快
  - *destination-based forwarding:* forward based only on destination IP address (traditional)

    基于目的地的转发： 仅基于目的地 IP 地址的转发（传统）
  - *generalized forwarding:* forward based on any set of header field values

    广义转发: 基于任何一组 Header 字段值进行转发（SDN）

forwarding table

	Destination Address Range	Link Interface
200.23.16.0 through 200.23.23.255	11001000 00010111 00010000 00000000 through 11001000 00010111 00010111 11111111	0
200.23.24.0 through 200.23.24.255	11001000 00010111 00011000 00000000 through 11001000 00010111 00011000 11111111	1
200.23.25.0 through 200.23.31.255	11001000 00010111 00011001 00000000 through 11001000 00010111 00011111 11111111	2
	otherwise	3

Q: but what happens if ranges don't divide up so nicely?

但是，如果范围没有很好地划分呢?

Longest prefix matching

When looking for forwarding table entry for given destination address, use longest address prefix that matches destination address.

在查找给定目标地址的转发表条目时，请使用与目标地址匹配的最长地址前缀。

Destination Address Range	Link interface
11001000 00010111 00010*** *********	0
11001000 00010111 00011000 *********	1
11001000 00010111 00011*** *********	2
otherwise	3

Examples:

- DA: 11001000 00010111 00010110 10100001 which interface? 0
- DA: 11001000 00010111 00011000 10101010 which interface? 1

We'll see why longest prefix matching is used shortly, when we study addressing.

当我们研究寻址时，我们将看到为什么很快就会使用最长前缀匹配

Longest prefix matching: often performed using ternary content addressable memories (TCAMs)

最长前缀匹配：通常使用三元内容可寻址存储器 （TCAM） 执行

- *Content addressable:* present address to TCAM: retrieve address in one clock cycle, regardless of table size

  内容可寻址： 将地址呈现给 TCAM：在一个时钟周期内检索地址，无论表大小如何

- Cisco Catalyst: can up ~1M routing table entries in TCAM

  Cisco Catalyst：可以在 TCAM 中增加 ~1M 路由表条目

Switching fabrics 交换结构

- Transfer packet from input buffer to appropriate output buffer

  将数据包从输入缓冲区传输到适当的输出缓冲区

- Switching rate: rate at which packets can be transfer from inputs to outputs

  交换速率：数据包从输入传输到输出的速率

  - Often measured as multiple of input/output line rate

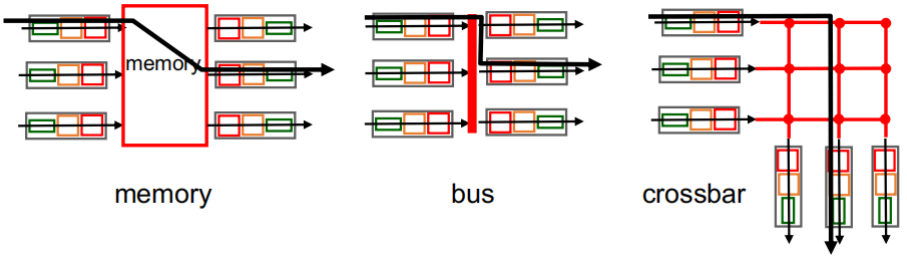
    通常以输入/输出线路速率的倍数来衡量

  - N inputs: switching rate N times line rate desirable

    N 个输入：交换机的交换速率通常需要是输入速率的N倍以上才不会形成瓶颈

- Three types of switching fabrics:

  三种类型的交换结构：



Switching via memory 通过内存切换

First generation routers:

第一代路由器：

- Traditional computers with switching under direct control of CPU

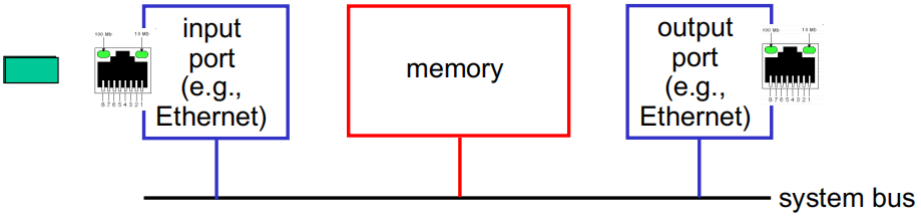
  在 CPU 直接控制下进行切换的传统计算机

- Packet copied to system' s memory

  数据包已复制到系统内存

- Speed limited by memory bandwidth (2 bus crossings per datagram)

  速度受内存带宽限制（每个数据报 2 个总线交叉）



Switching via a bus

- Datagrams from input port memory to output memory via a shared bus

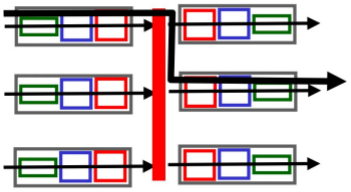
  通过共享总线从输入端口内存到输出内存的数据报

- Bus contention: switching speed limited by bus bandwidth

  总线争用：开关速度受总线带宽限制

- Cisco 5600: 32 Gbps bus

Cisco 5600：32 Gbps 总线



bus

Switching via interconnection network 通过互连网络进行交换

- Overcome bus bandwidth limitations

  克服总线带宽限制

- Banyan networks, crossbar, other interconnection nets initially developed to connect processors in multiprocessor

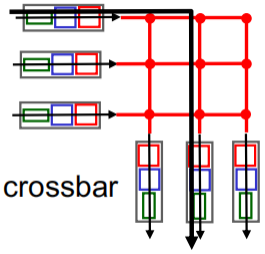
  Banyan networks、crossbar、其他互连网络最初开发用于连接多处理器中的处理器

- Advanced design: fragmenting datagram into fixed length cells, switch cells through the fabric.

  高级设计：将数据报碎片化为固定长度的单元，通过结构切换单元。

- Cisco 12000: switches 60 Gbps through the interconnection network

  Cisco 12000：通过互连网络进行 60 Gbps 的交换机



Input port queuing 输入端口排队

- Fabric slower than input ports combined -> queueing may occur at input queues

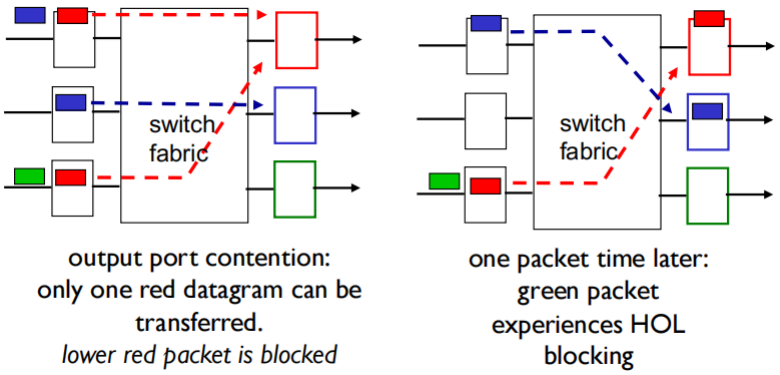
  结构速度慢于输入端口组合 - > 排队可能发生在输入队列中

  - queueing delay and loss due to input buffer overflow!

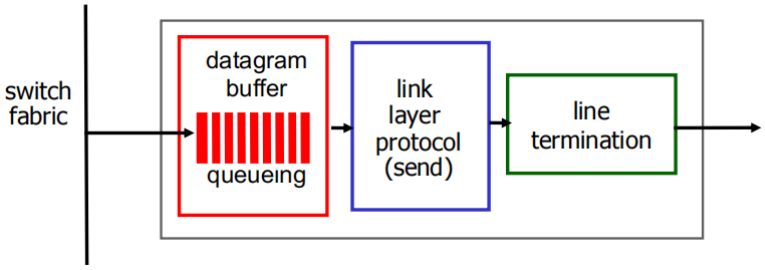
    由于输入缓冲区溢出而导致的排队延迟和丢失！

- Head-of-the-Line (HOL) blocking: queued datagram at front of queue prevents others in queue from moving forward

  队头 （HOL） 阻塞：队列前面的排队数据报会阻止队列中的其他人向前移动



Output ports 输出端口



- *Buffering* required when datagrams arrive from fabric faster than the transmission rate

  当数据报从结构到达的速度比传输速率快时，需要缓冲

  - Datagram (packets) can be lost due to congestion, lack of buffers

    数据报（数据包）可能会因拥塞、缺少缓冲区而丢失

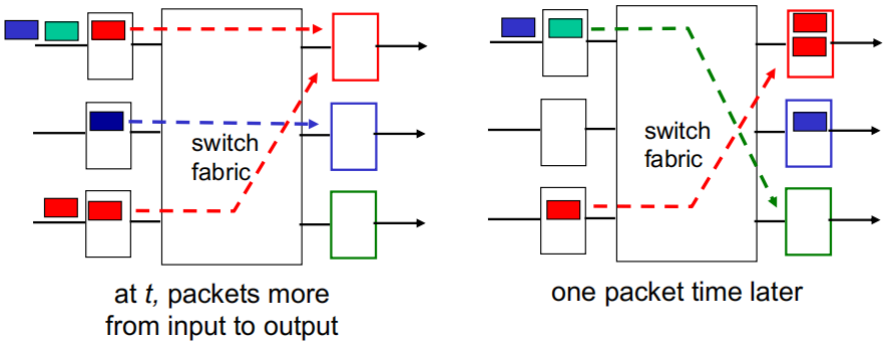
- *Scheduling discipline* chooses among queued datagrams for transmission

  调度规则 在排队的数据报中进行选择以进行传输

  - Priority Scheduling - who gets best performance, network neutrality

    优先调度谁获得最佳性能，网络中立性

Output port queueing 输出端口排队



- Buffering when arrival rate via switch exceeds output line speed

  当通过交换机的到达速率超过输出线路速度时进行缓冲

- *Queueing (delay) and loss due to output port buffer overflow!*

  由于输出端口缓冲区溢出而导致的排队（延迟）和丢失!

How much buffering?

- RFC 3439 rule of thumb: average buffering equal to “typical” RTT (say 250 msec) times link capacity C

  RFC 3439 经验法则：平均缓冲等于“典型”RTT（比如 250 毫秒）乘以链路容量 C

  - e.g., C = 10 Gpbs link: 2.5 Gbit buffer
- More recent recommendation: with N TCP flows, buffering equal to

  最近的建议：对于 N 个 TCP 流，缓冲等于

  - (RTT * C) / √N

Scheduling mechanisms

- **Scheduling**: choose next packet to send on link

  调度：选择下一个数据包在链接上发送
- **FIFO (first in first out) scheduling**: send in order of arrival to queue

  FIFO （先进先出） 调度：按到达顺序发送到队列

  - Real-world example? 真是世界的例子
  - *Discard policy:* if packet arrives to full queue: who to discard?

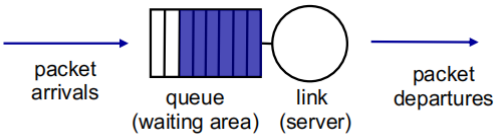
    丢弃策略： 如果数据包到达完整队列：丢弃谁?

    - *Tail drop:* drop arriving packet

      尾部投递： 投递到达数据包
    - *Priority:* drop/remove on priority basis

      优先级： 按优先级删除
    - *Random:* drop/remove randomly

      随机： 随机放置/删除



Scheduling policies: priority 调度策略：优先

Priority scheduling: send highest priority queued packet

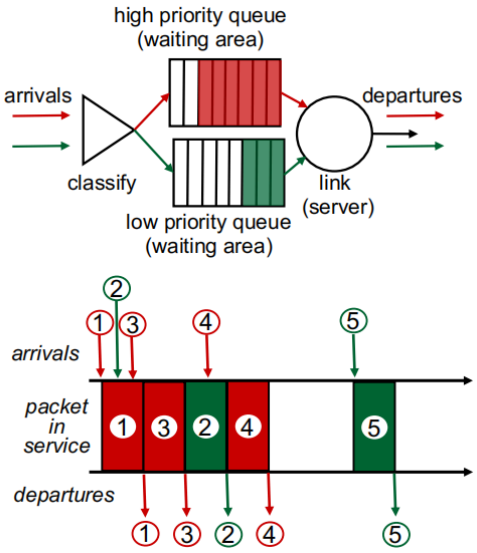
优先级调度：发送优先级最高的排队数据包

- Multiple classes, with different priorities

  多个类，具有不同的优先级

  - Class may depend on marking or other header info, e.g. IP source/dest, port numbers, etc.

    类可能取决于标记或其他标头信息，例如 IP 源/目标、端口号等。
  - real world example?



Round Robin (RR) scheduling:

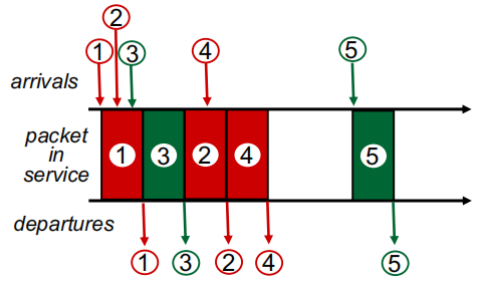
- Multiple classes

  多个类

- Cyclically scan class queues, sending one complete packet from each class (if available)

  循环扫描类队列，从每个类发送一个完整的数据包（如果可用）

- Real world example?



Weighted Fair Queuing (WFQ):

- Generalized Round Robin

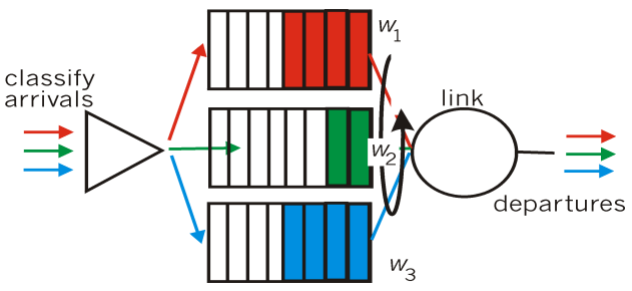
  广义轮询

- Each class gets weighted amount of service in each cycle

  每个职业在每个周期中获得加权的服务量

- Real-world example?

  真实世界的例子?

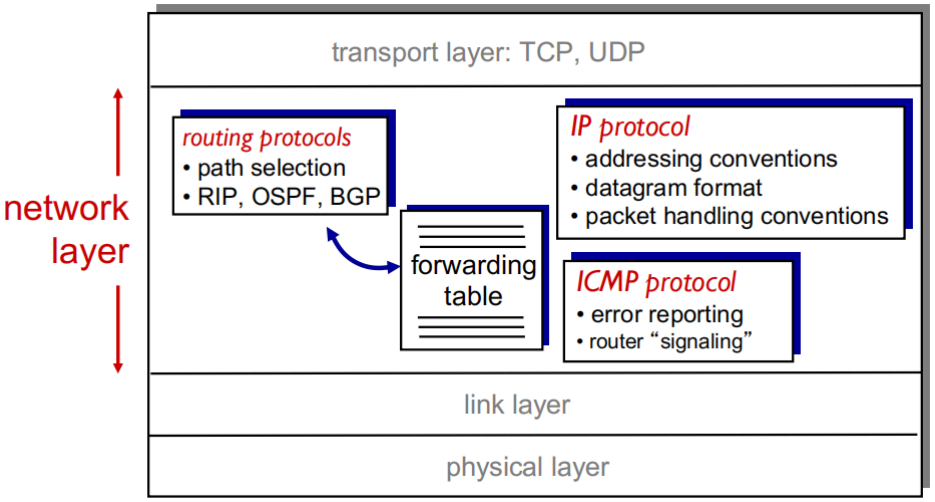


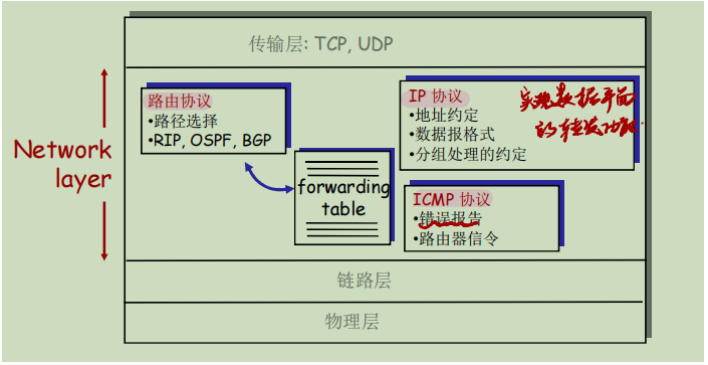
Internet Protocol 网际协议

The Internet network layer 互联网网络层

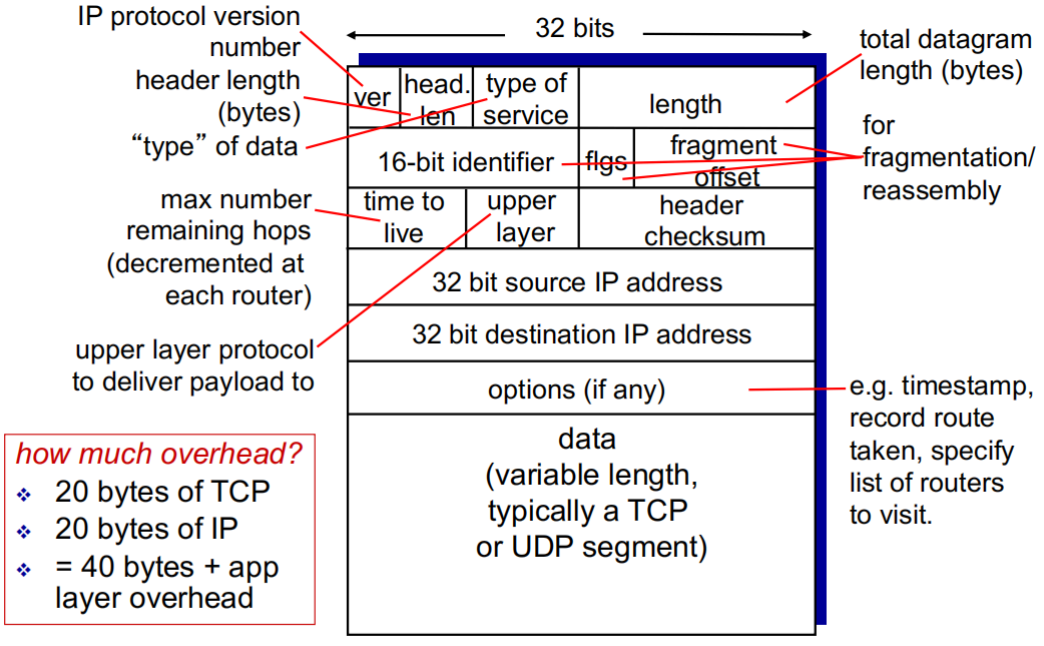
Host, router network layer functions:

主机、路由器网络层功能：

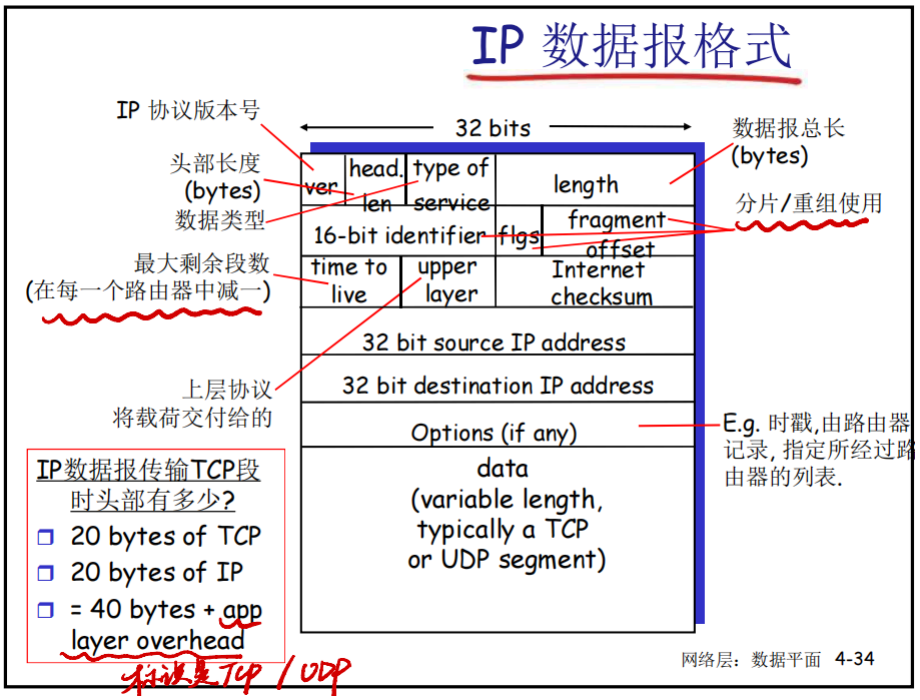




IP datagram format



IP datagram format



IP fragmentation, reassembly IP 分段、重组

- Network links have MTU (max.transfer size) - largest possible link-level frame

  网络链路具有 MTU （max.transfer size） 最大可能的链路级帧

  - Different link types, different MTUs

    不同的链路类型，不同的 MTU

- Large IP datagram divided (“fragmented”) within net

  在网络内划分（“分段”）的大型 IP 数据报

  - One datagram becomes several datagrams

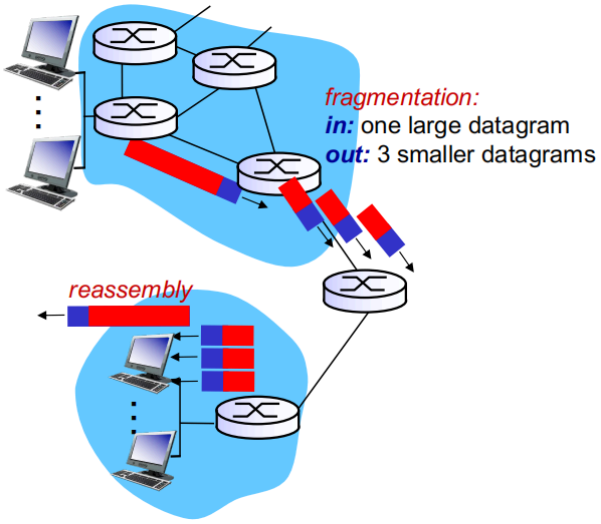
    一个数据报变成多个数据报

  - “Reassembled” only at final destination

    仅在最终目的地“重新组装”

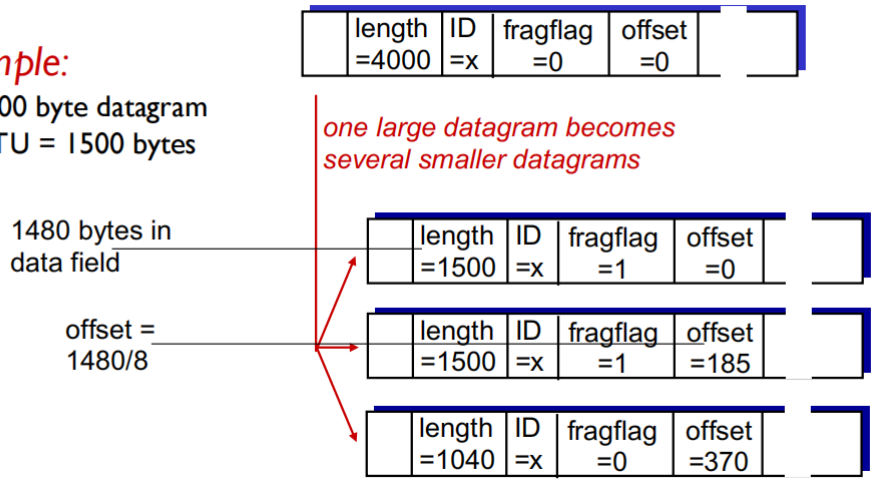
  - IP header bits used to identify, order related fragments

    用于识别、排序相关片段的 IP 报头位



example:

- 4000 byte datagram
- MTU = 1500 bytes

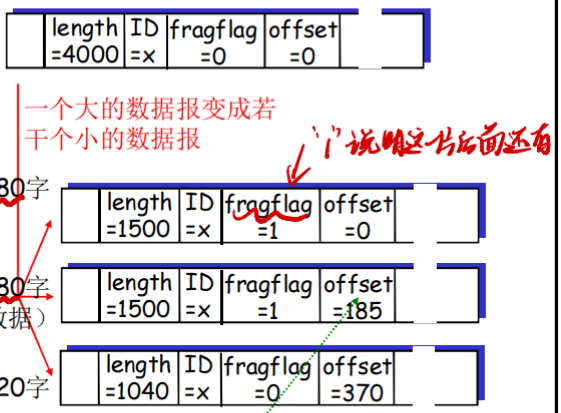


IP 分片和重组

例子

- 4000 字节数据报
  - 20字节头部
  - 3980字节数据
- MTU = 1500 bytes
- 第一片：20字节头部+1480字节数据
  - 偏移量：0
- 第二片：20字节头部+1480字节数据（1480字节应用数据）
  - 偏移量：1480/8=185
- 第三片：20字节头部+1020字节数据（应用数据）
  - 偏移量：2960/8=370

1480 x 2



网络层：数据平面 4-36

目标主机若没能在时间内收全所有分片.

⇒ 将收到的所有分片也丢掉.