3 Network Core

packet switching

Lecture 1 P47

Store and forward

⇒ queueing delay, loss

丢失分组 { retransmitted by previous node / source end system / not at all

优缺点 ok

packet switching allows more users to use network.

Packet Switching特点

优点：

- resource sharing共享网络资源
- simpler, no call setup想连就连

缺点：

- excessive congestion possible: delay and loss
- protocols needed for reliable data transfer, congestion control

还需下层提供可靠数据传输和拥塞控制等服务

How to provide circuit-like behavior PS?

- Bandwidth guarantees 对钞能力要求很高 带宽要求
- New methods should be developed

Circuit switching

P55

Circuit switching

线路交换的优点：

1.Dedicated resources: no sharing

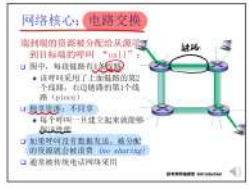
2.circuit-like (guaranteed) performance

- Circuit segment is idle if not used by call (no sharing)
- Commonly used in traditional telephone networks

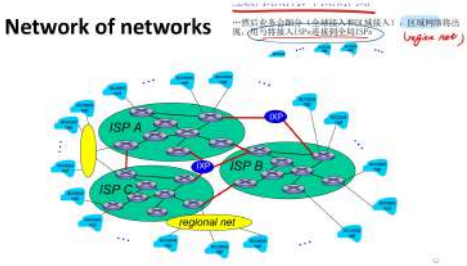
应用方式：

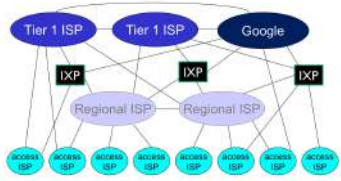
FDM: 按频率划分给多条线路中每一条各占一个频率区间

TDM: 按时间块划分给多条线路中的一条使用, 在终点可根据顺序复原合成完整数据



端系统通过ISP接入Internet ⇒ connect each access ISP to one global transit ISP





- Small view of well-connected large networks
  - "tier-1" commercial ISPs (e.g., ChineTel, Sprint, AT&T, NTT), national & international coverage
  - content provider network (e.g., Google): private network that connects it data centers to Internet, often bypassing tier-1, regional ISPs

四种延迟.

Lecture 1 P68

Delay in Packet-Switched Networks

延迟通常由四部分组成：

1. Transmission delay传输延迟，指将整个分组packet完整的从路由器打出的时间
2. Propagation delay传播延迟，指在链路上的客观物理传输时间
3. Queuing delay排队延迟，存在于过多用户占用带宽超过链路带宽上限的情况，涉及到流量强度的问题
4. Nodal processing delay路由处理延迟，通常不会问可以当没有

吞吐量.

Lecture 1 P72

Throughput 吞吐量

- Throughput: rate (bits/time unit) at which bits transferred between sender/receiver.由多段链路中最小的带宽来决定

R19. 假定主机 A 要向主机 B 发送一个大文件。从主机 A 到主机 B 的路径上有 3 段链路，其速率分别为 $R_1 = 500$kbps，$R_2 = 2$Mbps，$R_3 = 1$Mbps。

a. 假定该网络中没有其他流量，该文件传送的吞吐量是多少？

b. 假定该文件为 4MB，用吞吐量除以文件长度，将该文件传输到主机 B 大致需要多长时间？

c. 重复（a）和（b），只是这时 R_2 减小到 100kbps。

1 kbps = 10^3 bps

1 Mbps = 10^6 bps.

- 由此实例可知，吞吐量由最小的R1决定，故文件传输时只能以最小的带宽来传输，所以是4MB/500kbps。
- 如果R2带宽减小到100kbps比R1带宽还小，那就只能按R2的带宽来传了

分层的好处

Why layering? 分层的好处.

- Divide complex systems to simple components
- Easy for maintenance
- Flexible for updating

△ Application Layer

client-server architectures.

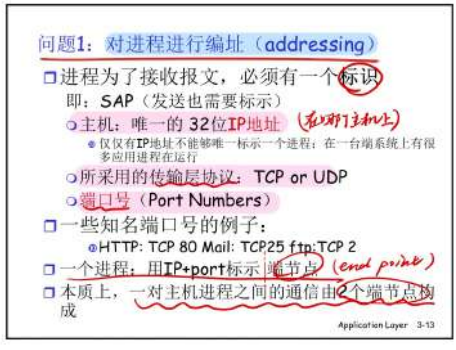
Lecture 2 P1

可扩展性差. poor scalability.

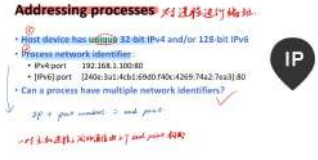
P2P architecture

self-scalability. 难以管理. Lecture 2 P10.

进程通信.



一个进程可以有多个network identifiers.



IP + port 标识一个 process.

传输层提供的服务：data integrity, throughput, timing, security.

TCP

Lecture 2 P22

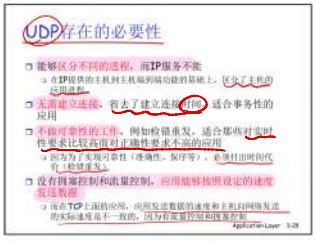
SSL: provides encrypted TCP connection

UDP

Lecture 2 P24

存在的必要性 / 优点.

tcp, UDP 都不提供的服务：delay guarantees, bandwidth guarantees



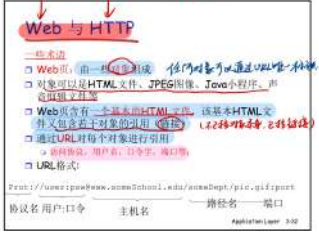
transmitted data may be lost or received out-of-order.

- Two socket types for two transport services:
  - UDP: unreliable datagram
  - TCP: reliable, byte stream-oriented

(Application Layer)

HTTP

Lecture 2 P32



CS model

use TCP

stateless (server 不维持 client 的信息

为状态的 server 和支持更多的 client)

关注下 Http 请求，响应报文格式

非持久 & 持久.

Http request, response 报文

Cookies

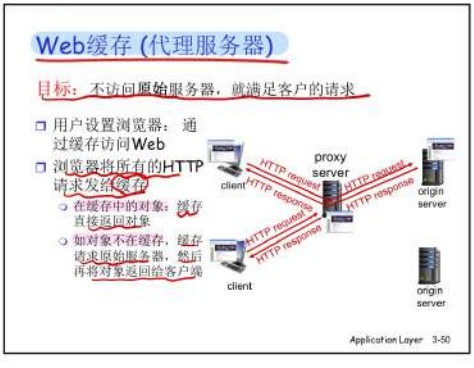
Lecture 2 P63.

使得 HTTP: stateless → stateful.

隐私问题

Web Caches

Lecture 2 P67.



Web 缓存的好处（个别）

Why Web caching?

- reduce response time for client request
- reduce traffic on an institution's access link
- Internet dense with caches: enables "poor" content providers to effectively deliver content (so too does P2P file sharing)

相对于增加接入链路的带宽，Web 缓存更廉价。（通过更小）
(increased access link speed)

应用层协议：HTTP, SMTP, FTP

DNS

C/S model

Lecture 3 P5

实现主机名—IP地址的转换.

(a distributed, hierarchical database)

不集中管理:

Why not centralize DNS?
- Single point of failure
- Traffic volume
- Distant centralized database
- Maintenance

UDP

P9 Authoritative DNS servers: 组织和网络的DNS服务器

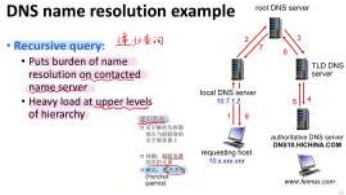
TLD name server

local name server → root name server → TLD → authoritative DNS server → local

Recursive query

P11

Iterated query

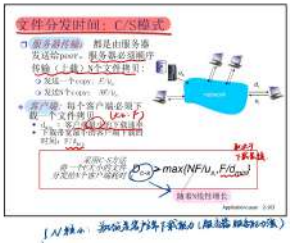


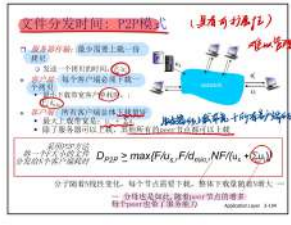
⇒

P2P

P29.

△文件分发



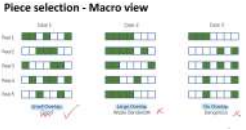


老师

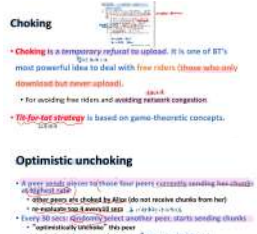
Lecture 3 P60

Bit Torrent Lecture 3 P36

△Socket programming

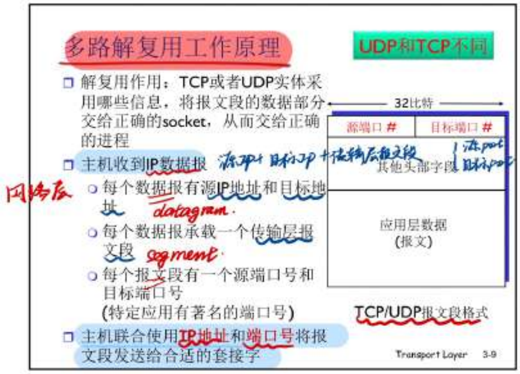


⇒ selection policy



多路复用/解复用

Lecture 4 P11



UDP

具备相同目标IP地址和目标端口号，即使是源IP地址或/且源端口号的IP数据报，将会被传到相同的目标UDP套接字上

TCP

四元组中只要有任何一个不一样，就是指示)不同的进程

不同的socket

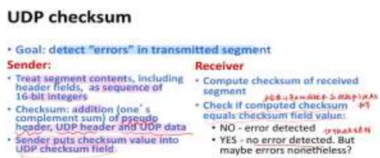
源IP地址
源端口号
目的IP地址
目的端口号

UDP checksum

Lecture 4 P25

→ detect "errors" in transmitted segment (eg: bit errors)

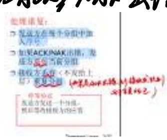
addition of pseudo header, UDP header, UDP data

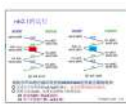


Reliable data transfer (RDT)

Lecture 4 P46

- rdt 2.0 → 若ACK/NAK出错？ 解决 → 每个分组中加入序号.
- rdt 2.1 →



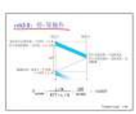


Lecture 5, 6 还没看

- rdt 2.2 → 无NAK.

- rdt 3 → 超时重传机制 (可能会丢失分组)

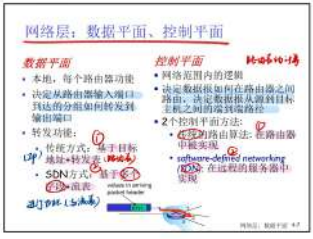
缺陷 →



链路容量大时性能差

一次只能发一个 → Pipelined protocols.

△ Network layer



Lecture 6 P18

Two key network-layer functions

•转发和路由

Network-layer functions:

- **Forwarding**: move packets from router's input to appropriate router output
- **Routing**: determine route taken by packets from source to destination
  - Routing algorithms

Analogy: taking a trip

- forwarding: process of getting through single interchange
- routing: process of planning trip from source to destination

路由器结构

Lecture6 P23.

~~最长前缀匹配~~ P27

Longest prefix matching

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

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?

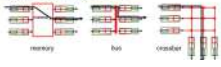
DA: 11001000 00010111 00011000 10101010 which interface?

input → switch fabric → output

- switching fabrics 交换结构 P29.

Switching fabrics 交换结构

- Transfer packet from input buffer to appropriate output buffer
- Switching rate: rate at which packets can be transfer from inputs to outputs
  - Often measured as multiple of input/output line rate
  - N inputs: switching rate N times line rate desirable
- Three types of switching fabrics:



- output ports P34.

⇒ 优先权调度. P37.

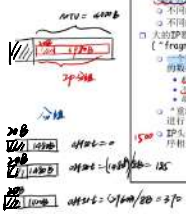
{ FIFO
priority
RR
Weighted Fair Queuing

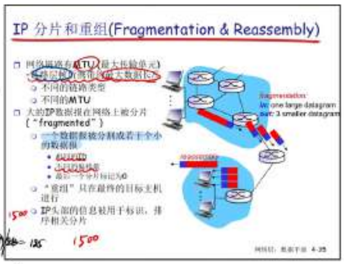
数据平面

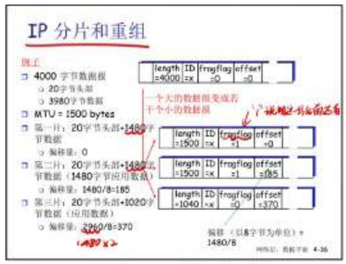
• IP datagram.

• IP 分片和重组 (Fragmentation & Reassembly)

MTU 计算



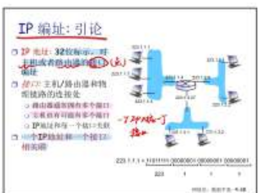


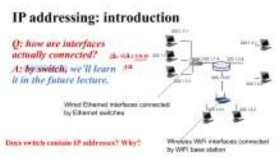


目标主机如果没能在时间内收到所有分片.

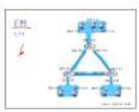
⇒ 将收到的所有分片丢掉

• IP addressing   Lecture 7 P6





Lecture 7 P7. • Subnets   判断子网个数.



地址的子网部分可以是任意长度.

⇒ a.b.c.d /x
↑
subnet mask.

CIDR.

192.168.2.1

- 主机如何获得IP addresses. ⇒ DHCP Lecture 7 P12

DHCP: Dynamic Host Configuration Protocol

(UDP)

Goal: allow host to *dynamically* obtain its IP address from network server when it joins network

- Can renew its lease on address in use
- Allows reuse of addresses (only hold address while connected/ "on")
- Support for mobile users who want to join network (more shortly)

DHCP overview:

- host broadcasts "DHCP discover" msg [optional]
- DHCP server responds with "DHCP offer" msg [optional]
- host requests IP address: "DHCP request" msg
- DHCP server sends address: "DHCP ack" msg

> broadcast

DHCP: more than IP addresses

DHCP can return more than just allocated IP address on subnet:

- Address of first-hop router for client
- Name and IP address of DNS sever
- Network mask (indicating network versus host portion of address)

- Subnet 如何获得IP.?

IP addresses: how to get one?

Q: how does *network* get subnet part of IP addr?

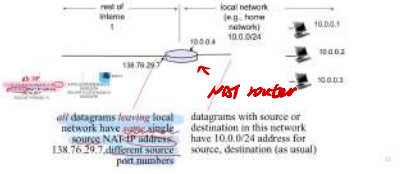
A: gets allocated portion of its provider ISP's address space

ISP's block	11001000 00010111 00010000 00000000	200.23.16.0/20
Organization 0	11001000 00010111 00010000 00000000	200.23.16.0/23
Organization 1	11001000 00010111 00010010 00000000	200.23.18.0/23
Organization 2	11001000 00010111 00010100 00000000	200.23.20.0/23
...	...	...
Organization 7	11001000 00010111 00011110 00000000	200.23.30.0/23

- NAT.

NAT: network address translation

Why NAT? If the subnet grows bigger, what if the ISP had already allocated the contiguous portions of address range? And what typical network admin wants to know how to manage IP addresses in the first place?



all datagrams *leaving* local network have *same* single source NAT IP address: 138.76.29.7, *different* source port numbers

datagrams with source or destination in this network have 10.0.0/24 address for source, destination (as usual)

NAT: network address translation

Motivation: local network uses just one IP address as far as outside world is concerned:

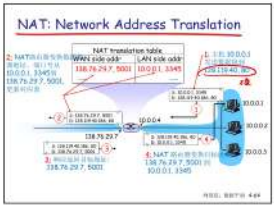
- Range of addresses not needed from ISP: just one IP address for all devices
- Can change addresses of devices in local network without notifying outside world
- Can change ISP without changing addresses of devices in local network
- Devices inside local net not explicitly addressable, visible by outside world (a security plus)

NAT: Network Address Translation

实现: NAT 路由器必须:

- 外出数据包，替换源地址和端口号为NAT IP地址和新的端口号，目标IP和端口不变
  ...远端的C/S将会用NAP IP地址，新端口号作为目标地址
- 记住每个转换替换对（在NAT转换表中）
  ... 源IP，端口 vs NAP IP，新端口
- 进入数据包，替换目标IP地址和端口号，采用存储在NAT表中的mapping表项，用（源IP，端口）

NAT: Network Address Translation



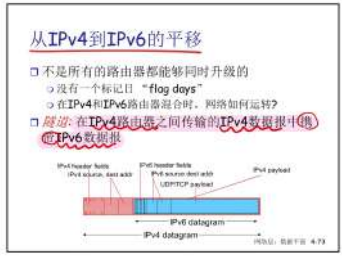
- IPv6

(IPv4 的 32bit) 不够用

头部格式改变帮助QoS

IPv6 数据报格式:

- 固定的40字节头部
- 数据报传输过程中，不允许分片



- SDN

Destination-based layer 2 (switch)

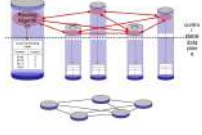
Switch Port	MAC src	MAC dst	Eth type	VLAN ID	IP Src	IP Dst	IP Prot	TCP sport	TCP dport	Action
*	22:A7:23:11:E1:02	*	*	*	*	*	*	*	*	port3

layer 4: 端到端
layer 3: 网络层
layer 2: 链路层

layer 2 frames from MAC address 22:A7:23:11:E1:02 should be forwarded to output port 3

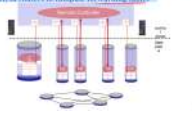
Per-router control plane

- Individual routing algorithm components *in each and every router* interact with each other in control plane to compute forwarding tables



Logically centralized control plane

- A distinct (typically remote) controller interacts with local control agents (CAs) in routers to compute forwarding tables



Two approaches to structuring network control plane:

- per-router control (traditional)
- logically centralized control (software defined networking)

SDN

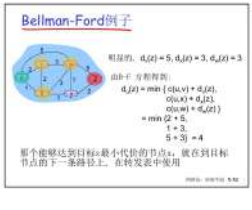
- Routing protocols

第5章.

- Dijkstra algorithm. Lecture 7 P53.
- Distance Vector algorithm. Lecture 8 P3.

Distance vector algorithm

- $D_x(y)$ = estimate of least cost from x to y
  - x maintains estimate of distance vector $D_x = [D_x(y): y \in N]$
- Node x:
  - Knows cost to each neighbor v: $c(x,v)$
  - Maintains its neighbors' distance vectors. For each neighbor v, x maintains $D_v = [D_v(y): y \in N]$

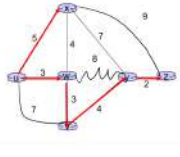


Dijkstra's algorithm: example 1

Step	N	D(v) p(v)	D(w) p(w)	D(x) p(x)	D(y) p(y)	D(z) p(z)
0	ux	7,x	2,x	5,x	∞	∞
1	uw	6, w		u 3,x	11,w	∞
2	uwx				11,w	14,x
3	uwxv				10,v	14,x
4	uwxvy					12,y
5	uwxvyz					

notes:

- construct shortest path tree by tracing predecessor nodes
- ties can exist (can be broken arbitrarily)



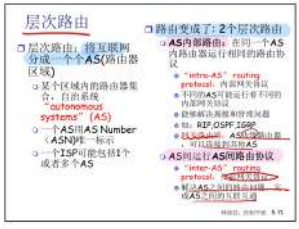
• Scalable routing Lecture 8 P14

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

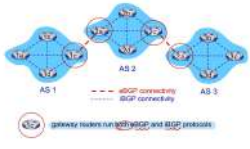
Inter-AS routing
- Routing among AS'es
- Gateways perform inter-domain routing (as well as intra-domain routing)



Internet inter-AS routing: BGP

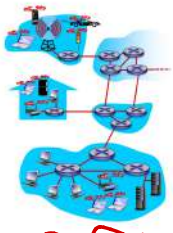
- **BGP (Border Gateway Protocol):** the *de facto* inter-domain routing protocol
  - "glue that holds the Internet together"
- BGP provides each AS router a means to:
  - eBGP: obtain subnet prefix reachability information from neighboring ASes. Allows subnet to advertise its existence to rest of Internet: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

eBGP, iBGP connections



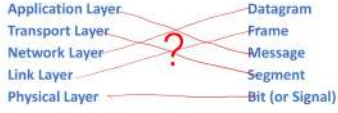
Link Layer.

What's Link Layer



- Data-Link Layer has responsibility of
  - transferring datagram
  - from one node to physically adjacent node
  - over a link
- Node:
  - Hosts and routers
- Link:
  - communication channel
  - connection adjacent nodes
- Layer-2 packet: frame
  - Encapsulates datagram

Data Unit

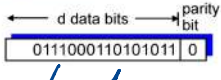


Detecting errors.

parity checking

Parity checking – Single bit parity

- Even/Odd parity scheme:
  - Add an additional bit
  - Total number of 1 (D+1) is even/odd
- Detect single bit errors

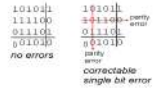


Even scheme or odd scheme?

Parity checking – 2D parity

- Detect and correct single bit errors

- Two-dimensional even parity

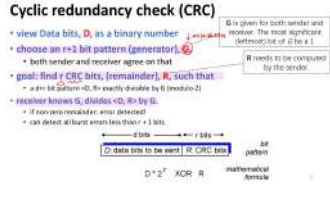


checksum

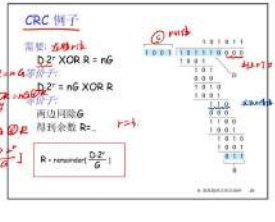
Checksum

- In the TCP and UDP protocols, the Internet checksum is computed over all fields (header and data fields included).
- In IP, the checksum is computed over the IP header (since the UDP or TCP segment has its own checksum).
- 发送方首先根据数据算出来一个校验和，然后接收方再自行计算，看看一不一样，使用addition (one's complement sum) of segment contents

Cyclic redundancy check (CRC)



CRC



Cyclic redundancy check (CRC)

- all CRC calculations are done in modulo-2 arithmetic without carries in addition or borrows in subtraction, including Addition, Subtraction, Bitwise exclusive-or (XOR) (异或运算, 同得0,异得1)
- 题目会给你用来除的多项式, 假设给你的是X8+ X2+X1+1, 展开1*X8+0*X7+0*X6+0*X5+0*X4+0*X3+1*X2+1*X1+1, 所以除数是100000111
- 在开始算CRC之前还要在原数据之后加上多项式最高阶数的0
- 算完以后的那部分就是加在原数据后面
- 校验的点在于接收方在收到数据和发送方算出的原数据的校验和后，还需自行计算出一个收到数据的校验和来与收到的进行比较，从而达到检验的效果

- 多点访问 Lecture 9 P21-33

- MAC address & ARP.

MAC addresses and ARP

- **IP address**
  - IPv4 (32 bits) and IPv6 (128 bits)
  - Network-layer address
  - Layer-3 forwarding
- **MAC (LAN) address**
  - 48 bits (e.g., 12-34-56-78-90-AB)
    hexadecimal (base 16) notation (each "numeral" represents 4 bits)
  - Burned in NIC ROM
  - Used "locally" get frame from one interface to another physically-connected interface (same network, in IP-addressing sense)

MAC addresses and ARP

Each adapter on LAN has unique LAN address (MAC)

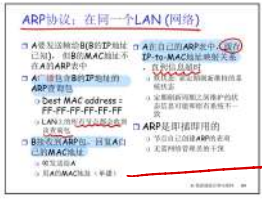
△ 同一LAN

ARP: address resolution protocol

- How to determine interface's MAC address, if knowing its IP address?

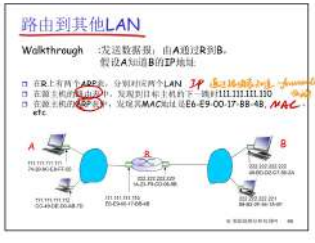
ARP table: each IP node (host, router) on LAN has the table
- An IP-to-MAC address mappings for LAN nodes:
  <IP address; MAC address; TTL>
- A TTL (Time To Live): time after which address mapping will be forgotten (typically 20 min)

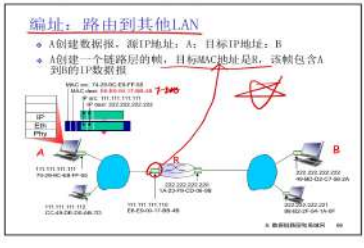
Notice that an ARP table is not necessary to contain an entry for every host and router on the subnet; some may have never been entered into the table, and others may have expired.



A与MAC地址对应从表格的请求报文中得出.

△ 不同LAN.





- Ethernet Frame. (protocols)

Ethernet frame structure

- Sending adapter **encapsulates IP datagram** (or other network layer protocol packet) in **Ethernet frame**

preamble: 8-byte
- 7 bytes with pattern 10101010 followed by one byte with pattern 10101011
- used to synchronize receiver, sender clock rates

Ethernet frame structure

- ***Addresses:*** 6 byte source, destination MAC addresses
  - If adapter receives frame with matching destination address, or with broadcast address (e.g. ARP packet), it passes data in frame to network layer protocol
  - Otherwise, adapter discards frame
- ***Type:*** indicates higher layer protocol (mostly IP but others possible, e.g., Novell IPX, AppleTalk)
- ***CRC:*** cyclic redundancy check at receiver
  - Error detected: frame is dropped

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 (using with sensing channel idle)***

ARP表：IP等上 —⊗— 两了ARP表.

路由表：　　路由器上

switch table：　交换机上.

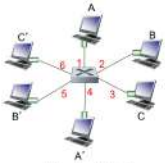
> for wanding table

- switch.

多路同时传输

Switch: multiple simultaneous transmissions

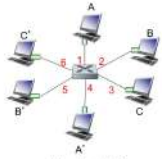
- Hosts have dedicated, direct link to switch
- Switches buffer packets
- Ethernet protocol used on each incoming link, but no collisions; full duplex
  - Each link is its own collision domain
- Switching, e.g.,: A-to-A' and B-to-B' can transmit simultaneously, without collisions



switch with six interfaces (1,2,3,4,5,6)

Switch (forwarding) table

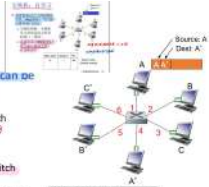
- Q: how does switch know A' reachable via interface 4, B' reachable via interface 5?
- A: each switch has a switch table, which contains entries, and each entry has:
  - (1) A MAC address, (2) the switch interface toward that MAC address, (3) the time stamp that the entry was placed.
  - looks like a routing table!
- Q: how are entries created, maintained in switch table?
  - something like a routing protocol?



switch with six interfaces (1,2,3,4,5,6)

Self-learning

- Switch learns which hosts can be reached through which interfaces
  - When frame received, switch "learns" location of sender: incoming LAN segment/link
  - Records MAC/interface (sender/location) pair in switch table
  - Entries get removed if no frames with that MAC received after timeout (which can be configured)

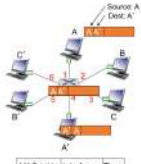


MAC addr	interface	Time
A	1	9:10

Switch table (initially empty)

Self-learning

- frame destination, A', location unknown: flood
- destination A location known: selectively send on just one link



MAC addr	interface	Time
A	1	9:10
A'	4	9:15

switch table (initially empty)

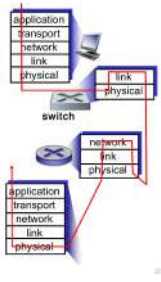
Switches vs. routers

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



Lecture 10 P25.

请求 google 网址的全过程.

Network Security

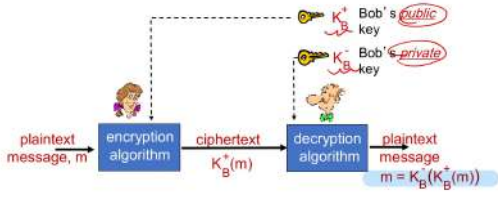
△ Symmetric key cryptography

DES, AES

symmetric key crypto

- requires sender, receiver know shared secret key
- **Q**: how to agree on key in first place (particularly if never "met")?

△ public key cryptography.



RSA算法 有了 K_B^+ 不能推出 K_B^- Lecture 10 P51

$K_B^-(K_B^+(m)) = m = K_B^+(K_B^-(m))$

RSA 优点: secure

缺点: computationally intensive; DES is faster than RSA

应用: use public key crypto to establish secure connection, then establish second key – symmetric session key – for encrypting data. faster.

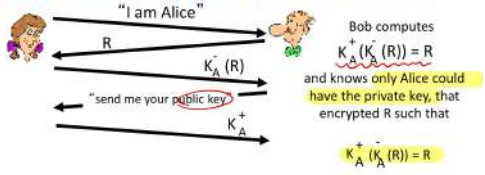
session key, K_S

- Bob and Alice use RSA to exchange a symmetric key K_S
- once both have K_S, they use symmetric key cryptography

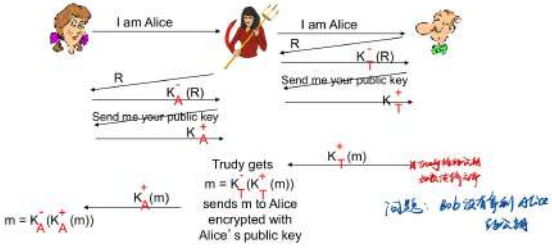
Authentication

ap4.0 requires shared symmetric key
- can we authenticate using public key techniques?

ap5.0: use nonce, public key cryptography



man (or woman) in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)



13

解决 Bob拿到 K_A^+ : K_{CA}^- (Alice, K_A^+)

Message integrity

Digital signatures

- suppose Alice receives msg m, with signature: m, $K_B^-(m)$
- Alice verifies m signed by Bob by applying Bob's public key K_B^+ to $K_B^-(m)$ then checks $K_B^+(K_B^-(m)) = m$.
- If $K_B^+(K_B^-(m)) = m$, whoever signed m must have used Bob's private key.

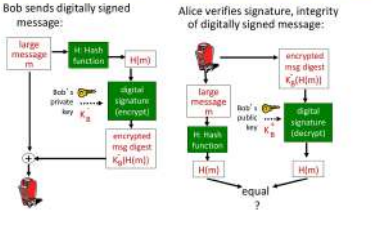
Alice thus verifies that:
- Bob signed m
- no one else signed m
- Bob signed m and not m'

non-repudiation:
- ✓ Alice can take m, and signature $K_B^-(m)$ to court and prove that Bob signed m

computationally expensive to public key-encrypt long messages

⇒ H(m) : Hash function.

Digital signature = signed message digest

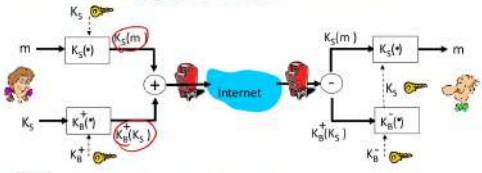


confidential

Secure e-mail

发送加密信息

Alice wants to send confidential e-mail, m, to Bob.



Alice:

- generates random symmetric private key, K_S
- encrypts message with K_S (for efficiency)
- also encrypts K_S with Bob's public key
- sends both $K_S(m)$ and $K_B^+(K_S)$ to Bob

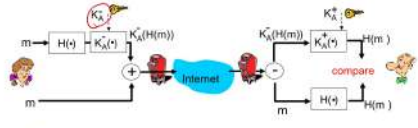
28

认证 + 完整性.

Secure e-mail (continued)

实现认证

Alice wants to provide sender authentication message integrity



- Alice digitally signs message
- sends both message (in the clear) and digital signature

发送信息(明文) + 数字签名

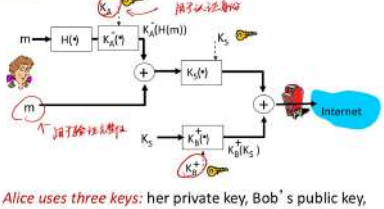
30

认证 + 完整性 + 加密

Secure e-mail (continued)

发送加密信息 + 实现认证

Alice wants to provide secrecy, sender authentication, message integrity.



Alice uses three keys: her private key, Bob's public key, newly created symmetric key

SSL: TCP上的 confidentiality / integrity / authentication

Ipsec: IP上的