Distributed Video Systems
Chapter 4
Network Technologies

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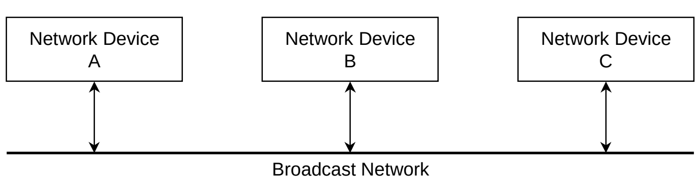
Contents

4.1 Introduction

- Basic Concepts
  - Classification by Transmission Technology:
    - Broadcast networks
    - Point-to-point networks
  - Broadcast Networks
    - A *single* communication channel is *shared* by all hosts.
    - A host sends packets on the channel, which are then received by all hosts. An *address field* within a packet is used to identify the intended receiver.
    - Special addresses: Broadcast address & multicast address

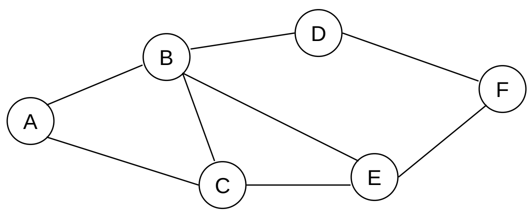
4.1 Introduction

- Basic Concepts
  - Broadcast Networks
    - Two or more hosts attempting to transmit will result in a collision.
    - A Medium Access Sublayer is needed to arbitrate accesses from multiple network devices to a shared broadcast network.



4.1 Introduction

- Basic Concepts
  - Point-to-Point Networks
    - Each communication channel links up two hosts.
    - To go from one host to another, intermediate hosts may need to be traversed (routing).



4.1 Introduction

- Basic Concepts
  - Classification by Scale or Distance

Interprocessor distance	Processors located in same	Example
0.1 m	Circuit board	Data flow machine
1 m	System	Multicomputer
10 m	Room	Local area network
100 m	Building	
1 km	Campus	
10 km	City	Metropolitan area network
100 km	Country	Wide area network
1,000 km	Continent	
10,000 km	Planet	The internet

4.1 Introduction

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- Local Area Networks (LANs)
  - Restricted in size (up to one km)
  - Mostly are broadcast networks
  - Speeds range from 10Mbps to 100Mbps
  - Low error rate
  - Low latency

```
c:\>ping 137.189.97.120

Pinging 137.189.97.120 with 32 bytes of data:

Reply from 137.189.97.120: bytes=32 time<10ms TTL=128
Reply from 137.189.97.120: bytes=32 time<10ms TTL=128
Reply from 137.189.97.120: bytes=32 time<10ms TTL=128
Reply from 137.189.97.120: bytes=32 time<10ms TTL=128
```


4.1 Introduction

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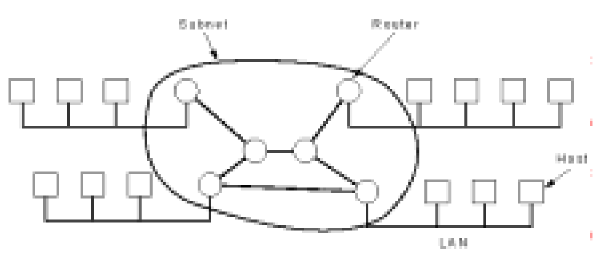
- Wide Area Networks (WANs)
  - Spans large geographical area (country or continent).
  - Connects subnets in a local area (LAN).



- Static Channel Allocation
  - Principle
    - Divide the broadcast channel among all stations.
  - Time Division Multiplexing (TDM)

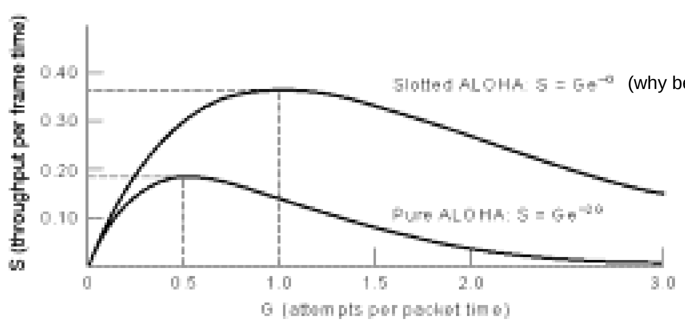
0	1	2	3	4	0	1	2	3	4	0	1	2	3	4	. . .

  - Advantages
    - Simple;
    - *Deterministic delay*.
  - Disadvantage
    - Poor channel utilization if traffic is bursty;
    - Difficult to accommodate stations with different bandwidth requirements

- Dynamic Channel Allocation
  - Principle
    - Channel assignments are dynamically determined.
    - A collision will occur if more than one device access the channel at the same time.
    - A multiple access protocol is used to arbitrate channel access and to recover from collision.
  - Advantage
    - Better channel utilization through *statistical multiplexing* of bursty traffics.
  - Disadvantages
    - Higher complexity;
    - Delay may become non-deterministic if collisions can occur.

- ALOHA
  - Invented in 1970s by Norman Abramson & his colleagues.
  - Two variants
    - The original ALOHA, called Pure ALOHA and;
    - Slotted ALOHA
  - Pure ALOHA
    - Each station transmits freely w/o any restriction.
    - Collisions can occur and is detected by the senders.
    - If collision occurs, a sender will wait for a random amount of time and then sends again.
    - Why wait random amount of time?
      - Otherwise the collision will repeat forever if two or more stations starts their transmission at the same time instance.

- ALOHA
  - Slotted ALOHA
    - Time is divided into discrete intervals (slots), each corresponding to one frame.
    - A station can only transmit at beginning of a time slot.
  - Performance



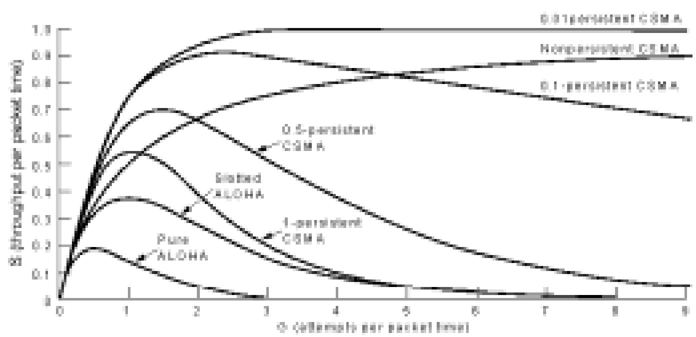
(why better?)

- Carrier Sense Multiple Access (CSMA) Protocols
  - Principle
    - Reduce collision by monitoring the channel (carrier sense) for any transmission in progress.
  - 1-Persistent CSMA
    - A station will listen to the channel before sending a frame.
    - The station will wait if the channel is busy (in use).
    - The station will start transmission when the busy becomes idle.
    - Can collision be completely avoided?
      - No! Why?
    - When a collision occurs, the affected station(s) will wait a random amount of time and restart again.

- Carrier Sense Multiple Access (CSMA) Protocols
  - 1-Persistent CSMA
    - A problem: what will happen if two stations detected a busy channel after attempting to transmit?
      - They will collide for sure!
  - Nonpersistent CSMA
    - Same as 1-Persistent CSMA excepts:
      - If the channel is busy, the station will not wait for it to become idle. The station will just wait for a random amount of time and check the channel again.
      - This prevents two (or more) waiting stations from colliding when a busy channel becomes idle.

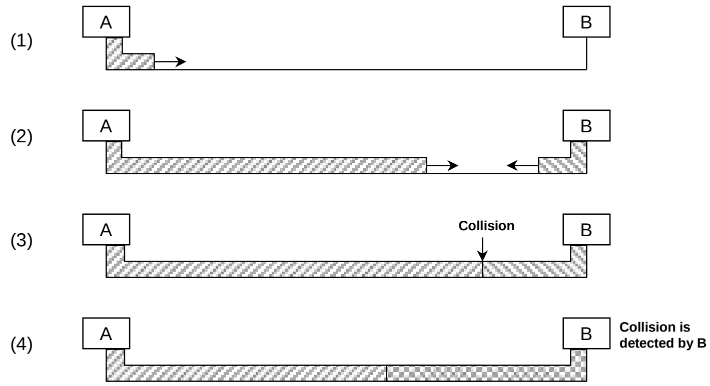
- Carrier Sense Multiple Access (CSMA) Protocols
  - *p*-Persistent CSMA
    - Applies to slotted channels.
    - If the channel is idle, a station transmits with prob. *p*.
    - With prob. *q*=(1-*p*), it will wait until the next time slot.
    - If next time slot is also idle, then repeat.
    - A busy channel is treated as collision, except the initial time slot, in which case it just wait for the next time slot & repeat.

- Carrier Sense Multiple Access (CSMA) Protocols
  - Performance

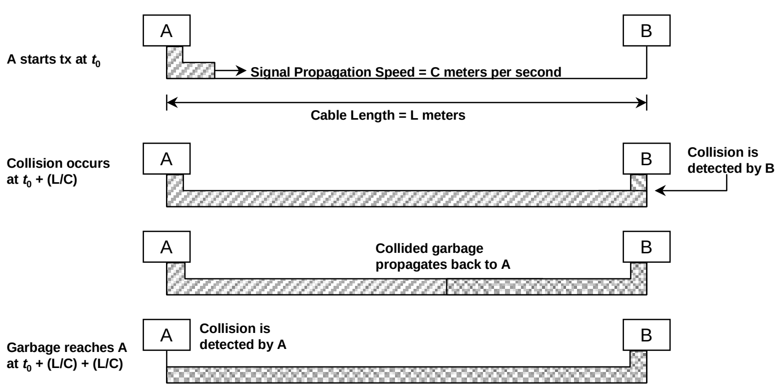


Offered load

- Carrier Sense Multiple Access (CSMA) Protocols
  - CSMA with Collision Detection (CSMA/CD)
    - Reduce wasted bandwidth due to collision by stopping transmission as soon as collision is detected.

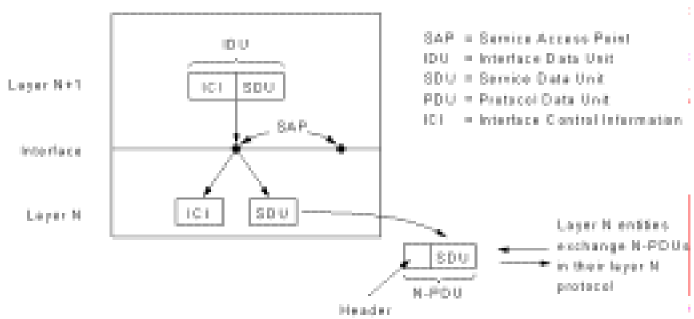


- Carrier Sense Multiple Access (CSMA) Protocols
  - CSMA with Collision Detection (CSMA/CD)
    - Collision Detection
      - What is the maximum time to detect a collision?



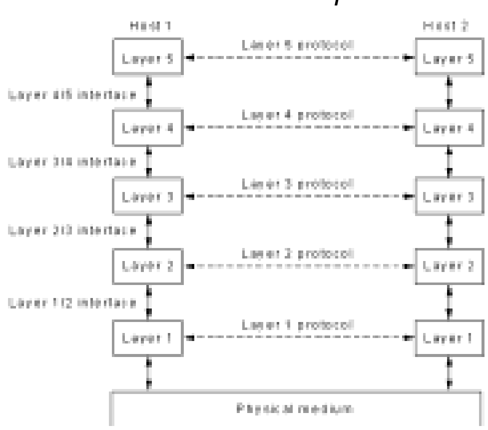
4.3 Network Software

- Protocol Hierarchies
  - Network systems are broken down into multiple *layers*.
  - Each layer offers a well-defined interface to provide *services* to the upper layers.

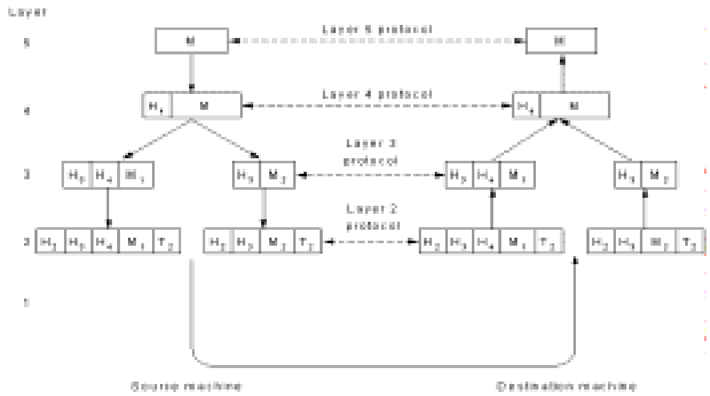


4.3 Network Software

- Protocol Hierarchies
  - A *protocol* is defined at each layer for exchanging information between two *peers*.



- Protocol Processing
  - Headers are added and removed
  - A message may be broken down into multiple segments



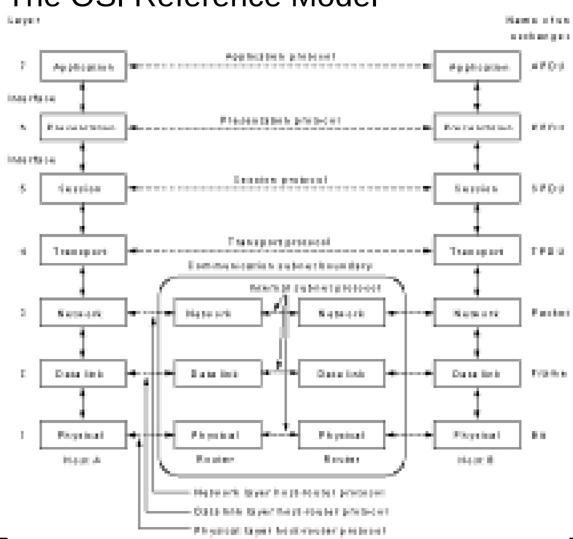
- Protocol Software
  - A protocol layer provides services to upper layers.
  - Types of Services
    - Connection-Oriented versus Connectionless Services
      - Connection setup required?
      - Analogy: Telephone versus Postal Mail
    - Reliable versus Unreliable Services
      - Automatic recover from errors?
    - Stream versus Message Services
      - Preserve message boundary?
    - Quality-of-service (QoS) guarantees
      - Delay and delay jitters
      - Maximum loss rate
      - Average and peak bandwidth, etc.

4.4 Reference Models

- What?
  - A reference model is an architecture for layered network communications.
- The OSI Reference Model
  - Developed by the International Standards Organization (ISO).
  - The model is called Open Systems Interconnection (OSI).
  - Consists of *seven* layers.

4.4 Reference Models

- The OSI Reference Model



- The OSI Reference Model
  - Physical Layer
    - Concerns transmitting *raw bits* (0 and 1) over a *physical communication channel* (copper wire, fibre optic cable, wireless media).
  - Data Link Layer
    - Provides a service which is free of *undetected* transmission errors.
    - Optionally provides error control and flow control.
    - Coordinating transmissions and receptions on the same link.
    - Resolve contentions in broadcast networks.

- The OSI Reference Model
  - The Network Layer
    - Concerned with controlling the operation of the *subnet*.
    - Handles routing of a packet from source to destination.
    - Handles congestions.
    - Keeps accounting information if needed.
    - Converts between incompatible addressing schemes and packet formats.
  - The Transport Layer
    - Provides an error-free connection on an *end-to-end* basis.
      (Unreliable messages service is also possible.)
    - Handles upward and downward multiplexing.
    - Handles name resolution across the entire network.
    - Handles flow control between sender and receiver.

4.4 Reference Models

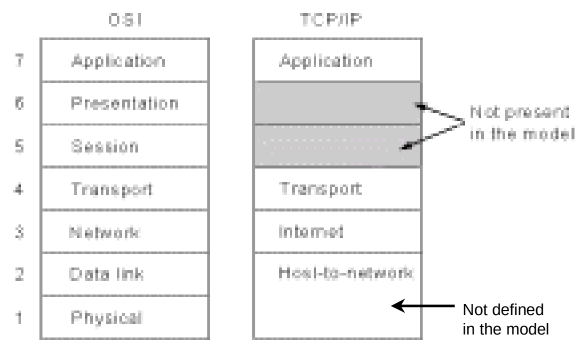
- The OSI Reference Model
  - The Session Layer
    - Provides session management
      - dialogue control
      - token management
      - synchronization or crash recovery
  - The Presentation Layer
    - Concerns the syntax and semantics of the information transmitted
    - Performs information encoding and decoding to facilitate the exchange of information
      - Text: ASCII versus Unicode
      - Numbers: byte ordering and byte size differences

4.4 Reference Models

- The OSI Reference Model
  - The Application Layer
    - Defines the protocols and services for a specific application.
    - Examples:
      - File Transfer (FTP)
      - Email (SMTP, POP3)
      - WWW (HTTP)
      - Network News (NNTP)

4.4 Reference Models

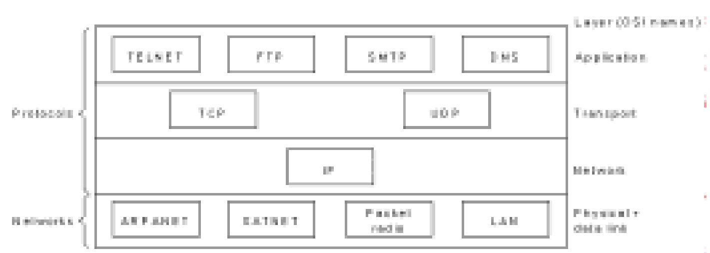
- The TCP/IP Reference Model



These are all reference models.

4.4 Reference Models

- The TCP/IP Reference Model
  - Protocols and Networks



This is a protocol stack conforming to the TCP/IP reference model.

- The TCP/IP Reference Model
  - The Internet Layer
    - Protocol used: Internet Protocol (IP)
    - Assumes a packet-switching network
    - Connectionless
    - Handles routing of IP packets
    - Handles congestion
    - Similar to OSI's network layer

- The TCP/IP Reference Model
  - The Transport Layer
    - Protocol one: Transmission Control Protocol (TCP)
      - Provides a *reliable*, *connection-oriented*, *stream* service.
      - Handles data packetization and reassembly.
      - Handles flow control, sequencing, and error recovery.
      - Handles designation among processes in the same host by means of service port numbers.
    - Protocol two: User Datagram Protocol (UDP)
      - Provides an *unreliable*, *connectionless*, *datagram* service.
      - Handles designation among processes in the same host by means of service port numbers.
      - No flow control, sequencing, and error recovery.

4.4 Reference Models

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- The TCP/IP Reference Model
  - The Application Layer

Services		Protocols
Virtual Terminal	-	TELNET
File Transfer	-	FTP
Electronic Mail	-	SMTP/POP3
Name Resolution	-	DNS
Network News	-	NNTP
World Wide Web	-	HTTP
Network File System	-	NFS
Network Management	-	SNMP

4.4 Reference Models

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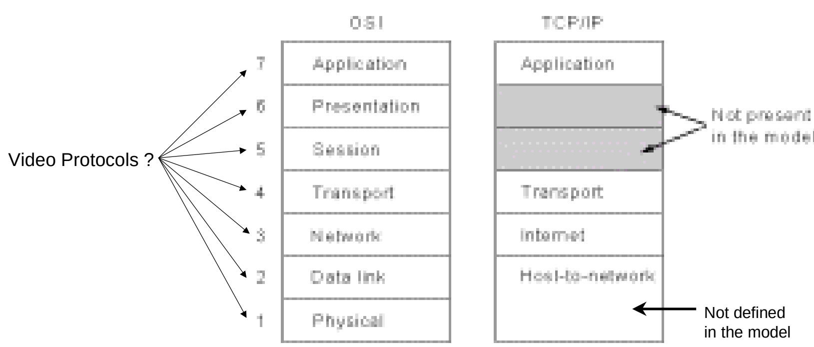
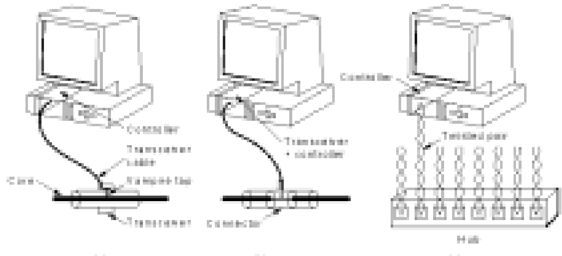
- What about video protocols?



- The IEEE 802 Series Standards
  - IEEE 802.1 - Introduction to the 802 series standards;
  - IEEE 802.2 - Logical Link Control (LLC) Protocol
  - IEEE 802.3 - CSMA/CD (Ethernet)
  - IEEE 802.4 - Token Bus
  - IEEE 802.5 - Token Ring
  - IEEE 802.6 - Distributed Queue Dual Bus (MAN)
- Others
  - FDDI (Fiber Distributed Data Interface)
  - ATM (Asynchronous Transfer Mode)

- Ethernet (IEEE 802.3)
  - Broadcast Physical Network (CSMA/CD)
  - Maximum end-to-end distance is 2500 meters
  - Speed is 10Mbps shared by all stations on the network
  - Cabling



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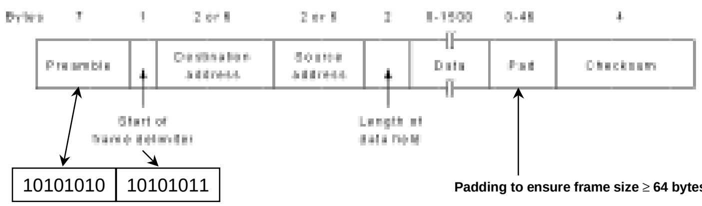
- IEEE 802.3
  - MAC Sublayer Protocol
    - Frame format



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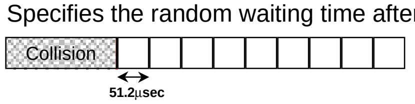
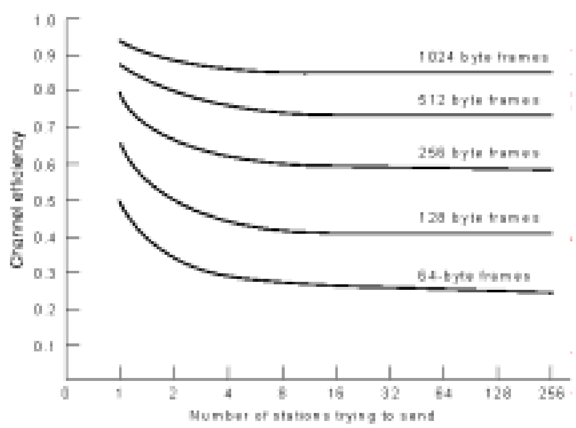
- IEEE 802.3
  - MAC Sublayer Protocol
    - Why set a minimum frame size at 64 bytes?
    - For collision detection,
      - Max time to detect collision is 2 x *max. propagation time*;
      - Propagation time for 2500 meters with 4 repeaters is 25.6μsec.
      - 10Mbps x 2 x 25.6μsec = 64 bytes!
    - The Binary Exponential Backoff Algorithm
      - Specifies the random waiting time after collision.



For 1st collision, waits either 0 or 1 time slots and retry;
If collided again at retry, then randomly waits 0~3 time slots and retry;
If collided again at 2nd retry, then randomly waits 0~(2^3-1) slots & retry;
After *i*th collisions, a random number between 0~(2^i-1) is choosen for waiting.
After reaching 10, *i* will not further increase. After 16 collisions, the controller will give up.

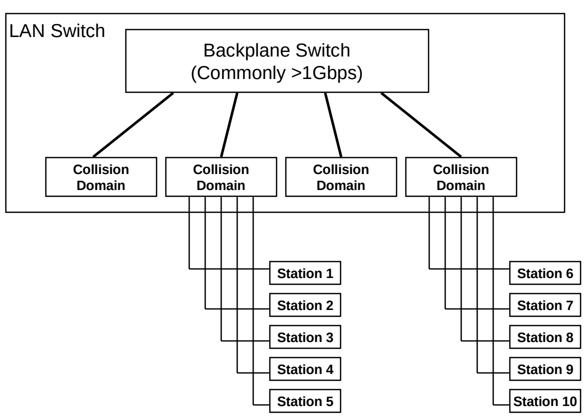
- IEEE 802.3
  - MAC Sublayer Protocol
    - The Binary Exponential Backoff Algorithm
      - Why not use fixed number of time slots for randomization?
      - Consider using large value such as 0~1023;
        - Delay will be significant if a collision occurs.
      - Consider using small value such as 0~1;
        - Collisions will reoccur very often if there are a large number of stations.
        - For example, if 100 stations collide, they will keep colliding over and over again until 99 of them picked 0 and the remaining one picked 1.

- IEEE 802.3
  - Performance



- Ethernet (IEEE 802.3)
  - Switched Ethernet
    - A 802.3 LAN will eventually saturate when more and more stations are added.
    - To increase capacity, one may upgrade to higher data rate such as 100Mbps or even 1Gbps.
      This approach is expensive because all network cards and associated equipment have to be upgraded (replaced).
    - The Solution is Switched LANs!

- Ethernet (IEEE 802.3)
  - Switched Ethernet



- Ethernet (IEEE 802.3)
  - Good
    - Most popular
    - Shortest delay at low load
    - Simple protocol, passive cable
  - Bad
    - Substantial analog operation (carrier sense, collision detection)
    - Frame size must be at least 64 bytes
    - Non-deterministic delay (due to collision)
    - No priorities
    - Cable length limited to 2.5km at 10Mbps
    - Performance deterioates at high load

- Token Ring (IEEE 802.5)
  - History
    - Proposed by IBM
    - Targeted at business networks
  - Physical Layer
    - Cabling: Shielded twisted pairs
    - Data Rate: 1, 4, or 16Mbps
  - MAC Sublayer
    - Token passing, collision free.

4.5 Network Hardware

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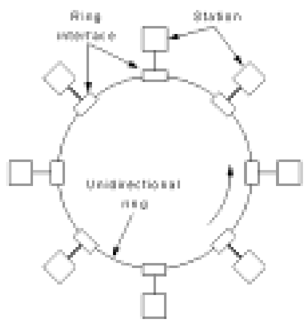
- Token Ring (IEEE 802.5)
  - Data bits circulate around the token ring in one direction.

Let data rate be R Mbps, then 1 bit is emitted every $1/R$ μsec.
With signal propagation speed of 200m/μsec,
each bit occupies $200/R$ meters on the ring.



4.5 Network Hardware

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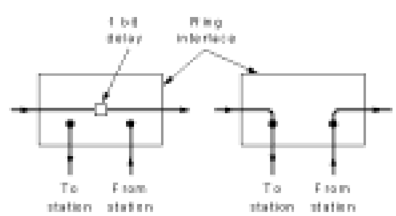
- IEEE 802.5 (Token Ring)
  - Principles
    - At each station, a 1-bit buffer is used to store and forward data.



• A 1-bit delay is introduced by each station.
• While in the buffer, a bit can be modified by the station.

- A special bit pattern called token circulates around the ring *whenever all stations are idle*.
  - – The ring must be long enough to contain the token (3 bytes).

4.5 Network Hardware

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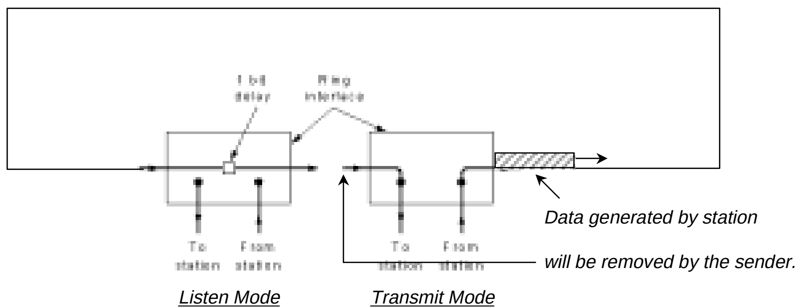
- IEEE 802.5 (Token Ring)
  - Principles
    - A station must first seize the token and removing it from the ring before transmitting.
      - Hence collision is impossible.
  - Ring Interface and Data Transmission



4.5 Network Hardware

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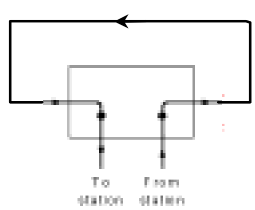
- IEEE 802.5 (Token Ring)
  - Ring Interface and Data Transmission
    - Would there be any upper limit on frame size?
      - No theoretical upper limits!



- When the last bit of a frame gone around and come back,
  the token is regenerated and the station switch back to listen mode.
- By default, the max. token holding time is 10ms.

4.5 Network Hardware

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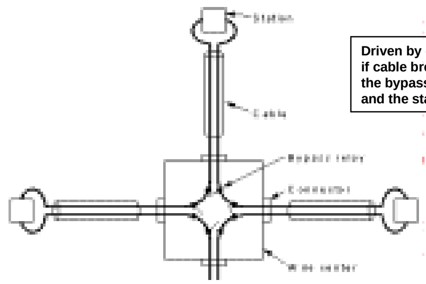
- IEEE 802.5 (Token Ring)
  - Ring Interface and Data Transmission
    - Problem
      - The entire ring will become inoperable if the cable breaks somewhere.
    - Solution
      - Use wire center



Driven by current from the station, if cable breaks or station goes down, the bypass relay will be released and the station bypassed.

4.5 Network Hardware

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- IEEE 802.5 (Token Ring)
  - Ring Maintenance
    - Monitor Station
      - One of the stations in a token ring act as a monitor station.
      - Monitor station is elected (or re-elected if one goes down) by a special protocol.
    - Maintenance Functions
      - Regenerate token if it is lost (e.g. due to station crash);
      - Detect ring breaks;
      - Remove garbled frames;
      - Remove orphan frames;
      - Insert artifical delay if the ring is too short to hold the token (3 bytes).

4.5 Network Hardware

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- Token Ring (IEEE 802.5)
  - Good
    - Fewer analog components
    - Supports any cabling
    - Resilience to cable failures (through the use of wire center)
    - Supports priorities
    - Excellent throughput and efficiency at high load
  - Bad
    - Substantial delay at low load (due to token passing)
    - Malfunction monitor station can bring down the ring
    - Less popular

4.6 High-Speed Technologies

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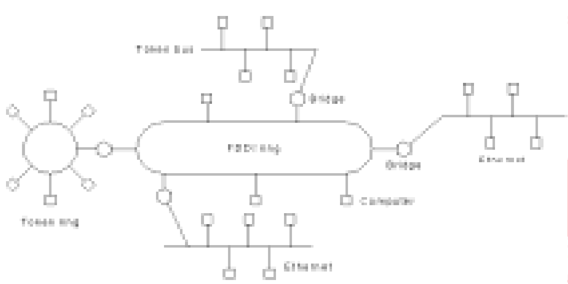
- FDDI (Fiber Distributed Data Interface)
  - A token ring running at 100Mbps on optical fibers.
  - Max ring size is 200km, up to 1000 stations.
  - Commonly used as backbone for connecting multiple LANs.

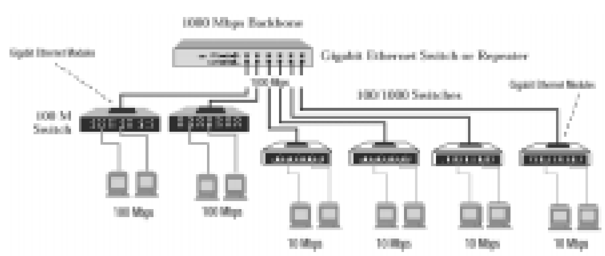


- Fast Ethernet
  - A faster version of 802.3 Ethernet, running at 100Mbps.
  - The max cable length is reduced by a factor of 10.
  - Cabling

Name	Cable	Max. segment	Advantages
100Base-T4	Twisted pair	100 m	Uses category 3 UTP
100Base-TX	Twisted pair	100 m	Full duplex at 100 Mbps
100Base-F	Fiber optics	2000 m	Full duplex at 100 Mbps; long runs

  - Full Duplex
    - A station can send and receive *simultaneously*.

- Gigabit Ethernet
  - An even faster version of 802.3 Ethernet, running at 1000Mbps (1Gbps).
  - Cabling: Fiber optic or CAT-5 UTP
  - The good thing about 802.3 series of Ethernet is that they are compatible with each other.



4.6 High-Speed Technologies

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- Asynchronous Transfer Mode (ATM)
  - Designed to integarte all existing types of communication networks, including
    - Plain Old Telephone Service (POTS)
    - Public Switched Data Networks (PSDN)
    - Telephone company call management network (SSN7)
    - Cable Television Network
    - Video-on-Demand Service Network

4.6 High-Speed Technologies

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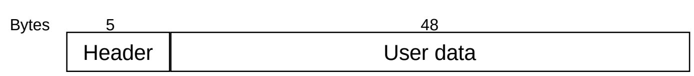
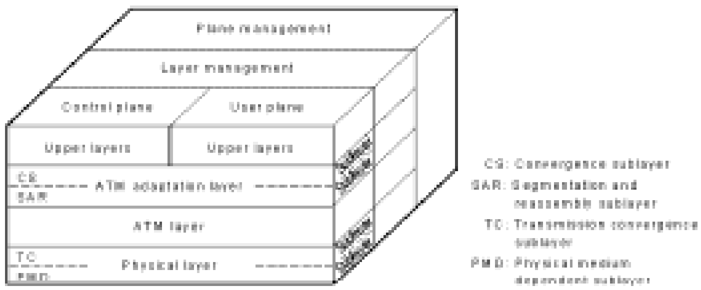
- Asynchronous Transfer Mode (ATM)
  - Basic ATM Technology
    - Packet switching with small packets (53 bytes) called cells.



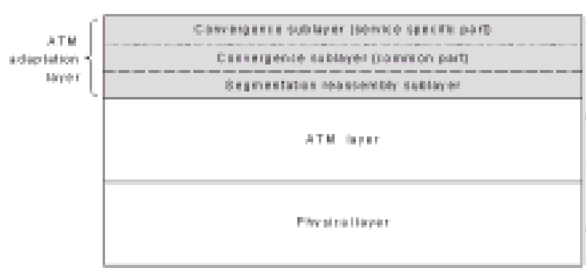
An ATM cell

- Connection-oriented, guarantees in-sequence but not delivery.
- Speeds range from 25Mbps to 622Mbps and further.
- Supports Quality-of-Service (QoS) on a connection.
  - Delay, delay jitter, average and peak bandwidth, loss rate, etc.

- Asynchronous Transfer Mode (ATM)
  - The ATM Protocol Stack



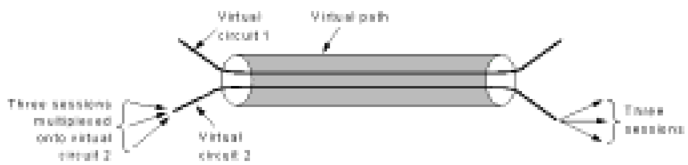
- Asynchronous Transfer Mode (ATM)
  - ATM Layer (Network Layer)
    - Connection-oriented.
    - Use fixed-size (53 bytes) packets called ATM cells.
  - ATM Adaptation Layer (Transport Layer, *sort of*)
    - Adds functionalities to provide specific services to different classes of applications.



- Asynchronous Transfer Mode (ATM)
  - Types of ATM Adaptation Layer Protocols
    - AAL 1, AAL2, AAL 3/4, AAL 5
  - AAL 1
    - Services
      - For real-time, constant bit rate, connection-oriented, stream traffic.
    - Applications
      - Such as uncompressed audio and video or
      - A/V compressed using Constant-Bit-Rate (CBR) compression.
    - Error Control
      - Notify application of cell loss, no automatic recovery.

- Asynchronous Transfer Mode (ATM)
  - AAL 2
    - Services
      - For variable-bit-rate, connection-oriented, datagram traffic.
    - Applications
      - A/V compressed using Variable-Bit-Rate (CBR) compression.
    - Catch!
      - AAL 2 is *not usable* because the standard does not specify length of header fields.
      - This is intentional(!) because AAL 2 has many problems which cannot be solved in time for standardization.

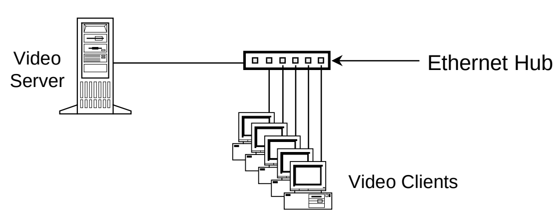
- Asynchronous Transfer Mode (ATM)
  - AAL 3/4
    - Originally two protocols, AAL 3 & AAL 4, for connection-oriented & connection-less services respectively.
    - Later merged into a single protocol due to too much overlapping functions.
    - Services (2 modes)
      - Supports stream & message, reliable & unreliable delivery.
      - Supports multiplexing:



- Asynchronous Transfer Mode (ATM)
  - AAL 5
    - History
      - AAL 1 to 3/4 are primary designed by the telecom industry.
      - AAL 5 is designed by the computer industry.
      - Similar to AAL 3/4 but more efficient.
    - Services
      - Reliable, non-real-time, with flow control.
      - Unreliable, non-real-time, unicast & multicast.
      - Stream or message modes.
    - Applications
      - Transporting IP packets over AAL 5.

- LAN-Based VoD Systems
  - Characteristics
    - Good Points:
      - Cost of network equipment is relatively low;
      - Most hardware and software are off-the-shelve products;
      - Mature and open platforms;
      - Network bandwidth can easily be added;
      - System expansion is easy;
      - Can coexist with existing computer applications.
    - Limitations:
      - Geographical span is limited to a few kilometers;
      - Limited user population;
      - More computer oriented (more demanding on the user).

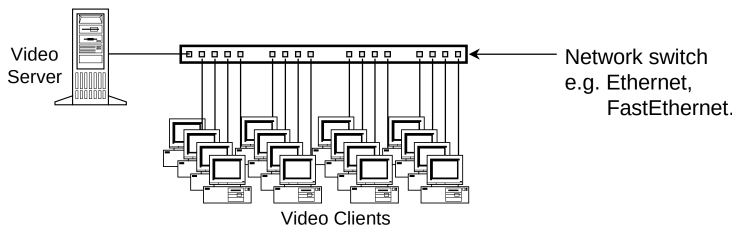
- LAN-Based VoD Systems
  - Shared Broadcast Networks (Ethernet)
    - Very low cost;
    - Very limited network capacity;
    - Collisions further reduces network throughput;
    - Network is the bottleneck.



A 10Mbps shared Ethernet segment can support 5~7 MPEG-1 video streams.

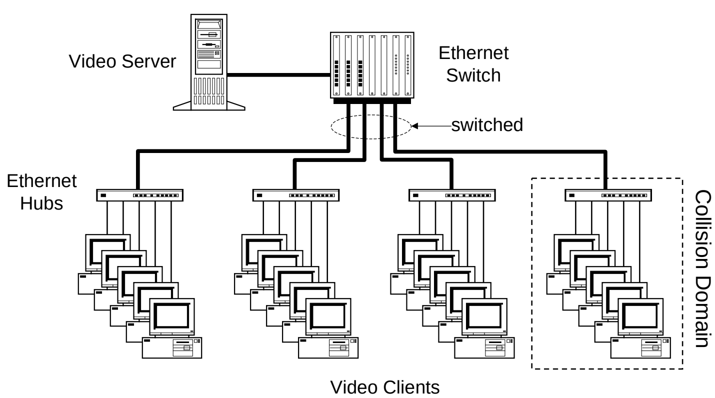
4.7 Video Delivery - LAN

- LAN-Based VoD Systems
  - Switched Broadcast Networks (Switched Ethernet)
    - Each switched-port is independent and has *dedicated* bandwidth (10Mbps for Ethernet, 100Mbps for FastEthernet);
    - More expensive hardware (switch);
    - More scalable (i.e. expandable to more users);
    - Off-the-shelve switches have 2~10Gbps capacity;
    - Video server is likely to be the bottleneck.



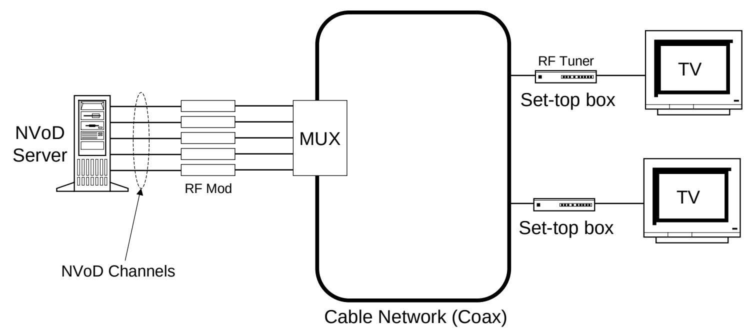
4.7 Video Delivery - LAN

- LAN-Based VoD Systems
  - Mixed Switched and Shared Broadcast Networks
    - More cost-effective than pure switch-based solution.



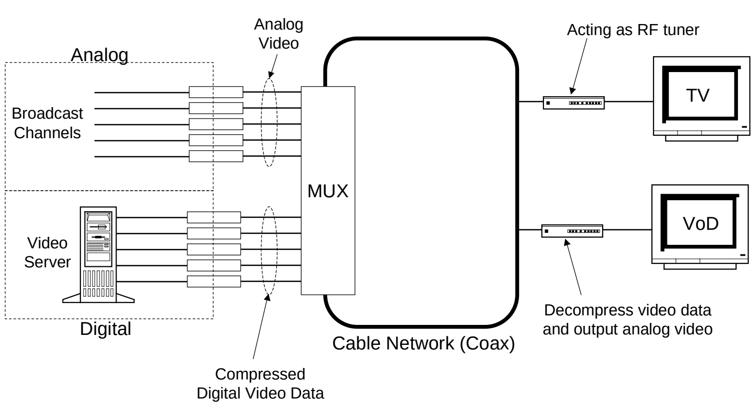
- WAN-Based VoD Systems
  - Challenges
    - Large geographical area;
    - Large user population;
    - Must coexist with the POTS (Plain Old Telephone System);
    - Cost of network equipment is relatively high;
    - Network bandwidth is expensive to add;
    - Network delay is much higher than LAN;
    - Upstream bandwidth is limited;
    - A substantial part of the infrastructure is analog.

- WAN-Based VoD Systems
  - Analog Near Video-on-Demand Approach



- WAN-Based VoD Systems
  - Analog Near Video-on-Demand Approach
    - Low-cost
      - Utilizing existing cable network infrastructure;
      - Simple set-top box (just a RF-tuner);
      - Coexist with broadcast and cable TV channels;
      - Independent of number of users.
    - Limited Interactive Control
      - No reverse path for control signalling (use the phone);
      - Limited number of channels on a cable (a 450Mhz plant using 6Mhz analog channels supports ~70 channels);
      - Not true VoD (e.g. waiting time ~15 minutes);
      - Little or no VCR control;
      - Limited number of movie selections.

- WAN-Based VoD Systems
  - Hybrid Fiber Coax (HFC) Approach

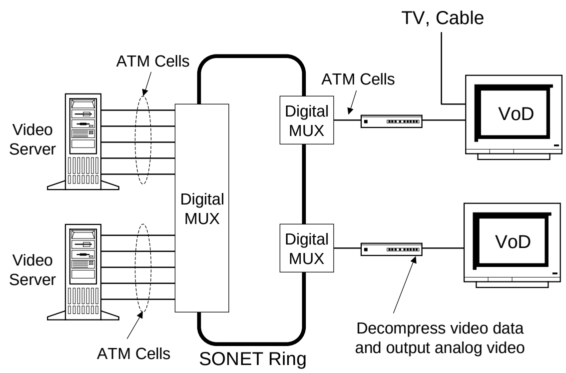


- WAN-Based VoD Systems
  - Hybrid Fiber Coax (HFC) Approach
    - Bandwidth
      - Assume a 750 Mhz cable network;
      - Each 6 Mhz channel can carry 1 analog video channel or 40 Mbps digital data;
      - One 6 Mhz channel can carry ~10 MPEG-2 streams;
    - Example:
      - Delivers 70 analog video broadcast channels using 450 Mhz;
      - Delivers 500 VoD streams in the remaining 300 Mhz bandwidth.

- WAN-Based VoD Systems
  - Approaches Using Twisted-Pair Telephone Cables
    - Asymmetric Digital Subscriber Line (ADSL)
      - ~6 Mbps downstream bandwidth shared by VoD, POTS and ISDN services.
    - High-speed Digital Subscriber Line (HDSL)
      - 1.544 Mbps full duplex bandwidth.
    - Asynchronous Transfer Mode (ATM)
      - >10 Mbps bandwidth.

4.8 Video Delivery - WAN

- WAN-Based VoD Systems
  - Approaches Using Twisted-Pair Telephone Cables



4.9 Video Delivery - Internet

- Internet-Based VoD Systems
  - Challenges
    - Non-stationary, unpredictable network performance;
    - High packet loss rate;
    - Long delay;
    - Limited MTU size;
    - Very limited support for multicast.
  - Current Status
    - Delivering high-quality video over the Internet is not feasible today;
    - Delivering low-frame-rate, low-quality video is possible;
    - The network is the limitation, not the protocols.

4.9 Video Delivery - Internet

Jack Y.B. Lee

- Approaches
  - Video over standard HTTP (i.e. TCP)
    - Allows streaming directly from web server;
    - Limited VCR control;
    - Poor performance due to TCP;
    - As interim solution only.
  - Video over UDP or IP
    - Requires dedicated video server;
    - Full VCR control can be supported;
    - Better performance due to application-specific flow control and error control;
    - The preferred solution in serious applications.