Asynchronous Transfer Mode

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(modified by Marc Abrams for Spring 1998)

Welcome to ATM!

- Loooooooooooooooots of acronyms!
- A lot of what's in ATM came from the phone and switching worlds, not the LAN world, so the terminology may be unfamiliar.
- OSI model doesn't really apply!

Asynchronous Mode Transfer

- ATM (asynchronous transfer mode) is …
  - Something of a revolution in both local and wide area networks
    - Innovations for LANs: scalable, switching-only, quality-of-service guarantees
    - Innovations for WANs: scalable, cell (packet)-switched, bandwidth-on-demand
  - Both a type of switching and a set of standards
  - Becoming widely used, but is not without real or proposed competition
    - 100-Mbps and 1-Gbps Ethernet
    - 100-Mbps FDDI
    - DS3, SMDS, Frame relay services

WAN Transmission: Digital Hierarchy

North America and Japan*
(rate in Mbps)

Name	Carrier	Rate	Channels
DS0		0.064	1
DS1	T1	1.544	24
DS1C	T1C	3.152	48
DS2	T2	6.312	96
DS3	T3	44.736	672
DS4	T4	274.176	4032

* a similar hierarchy exists in Europe (CEPT*n*, E*n*)

WAN Transmission: Fiber Optics and SONET

- Fiber optic transmission
  - AT&T completed first transcontinental fiber system in 1986
  - Nearly all high-density trunks are now fiber
- SONET (Synchronous Optical NETwork) hierarchy

Name	Rate (Mbps)	Equivalent
OC-1	51.84	28 DS1 or 1 DS3
OC-3	155.52	3 OC-1
OC-12	622.08	12 OC-1 or 4 OC-3
OC-48	2.488	48 OC-1
OC-192	9.953	

WAN Transmission: ISDN (1)

- Integrated Services Digital Network (ISDN) provides two standard types of service
  - Basic rate (basic service)
  - Primary rate (primary service)
- *Basic Rate Interface* (BRI): 2B+D
  - Delivers ISDN services over standard a twisted-pair telephone line to subscribers
  - Two 64 Kbps B channels -- Voice, circuit-switched connection, access to a packet switched network
  - One 16 Kbps D channel -- User packet data at 16 Kb/s and call control signals

WAN Transmission: ISDN (2)

- *Primary Rate Interface* (PRI)
  - Delivers ISDN services to digital PBXs, LANs, hosts, ...
  - Divides 1.544 Mbps T1 into:
    - 23 B channels, each at 64 Kbps
    - One D channel for messaging, also at 64 Kbps

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B-ISDN Concept (1)

- *B-ISDN*: Broadband Integrated Services Digital Network
  - Designed to provide similar services as ISDN
  - B-ISDN is substantially more capable than ISDN
- *B-ISDN versus ISDN* (or N-ISDN for narrowband ISDN)
  - N-ISDN uses existing telephone network (copper pairs); B-ISDN uses optical fiber
  - N-ISDN is primarily circuit switched; B-ISDN uses only packet switching (specifically ATM switching)
  - N-ISDN uses predefined channel rates; B-ISDN uses virtual channels without prespecified rates (bandwidth on demand)

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B-ISDN Overview (2)

- Integrated network for data, voice, video
  - Single system needed for the local loop
  - Single system for WANs and LANs
  - Economies of scale for collection of services
  - However, must support varied traffic types
  - Many political, economic, social issues
- Changes from traditional data and voice networks
  - Low processing complexity critical for high data rates
  - Voice/video require fixed bit rate/delay, but data networks have varying delays/data rates
  - Data rates may vary (1 bps to 100's of Mbps); but voice networks support constant data rates

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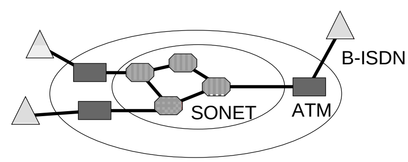
B-ISDN Components

- *B-ISDN* services to users
- *Asynchronous Transfer Mode* (ATM) for switching
- *Synchronous Digital Hierarchy* (SDH) or *Synchronous Optical Network* (SONET) for transmission



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SONET

- A *synchronous* protocol (unlike ATM or packet switching)
- A *physical* protocol (so it's can be used under ATM)
- Used for optical fiber
- Frame of 810 bytes
- Doesn't use "headers" as we're used to.
- Does use "pointers" to demultiplex traffic sent over one fiber path.
- Circuit switched: Allows a stream of ATM packets to be sent long distances purely at physical layer without ATM switches in the path

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ATM Overview

- ATM now exceeds BISDN in relevance
  - ATM first deployed in the LAN environment
  - ATM WANs dominated by data and video applications
- *ATM* versus Synchronous Transfer Mode (*STM*)
  - STM is circuit-switched; ATM is packet-switched
  - STM would require all channels to use some standard multiple of 64 Kbps; ATM is more flexible
    - – High complexity if many standard rates
    - – Inefficiencies if few standard rates
  - ATM benefits from high-speed packet switching -- very large scale integration (VLSI) circuits
    - Cell processing
    - Switching

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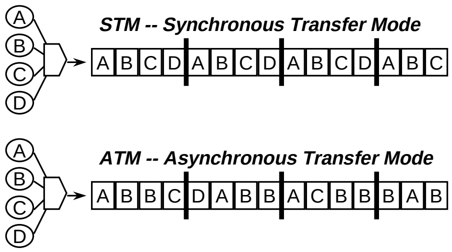
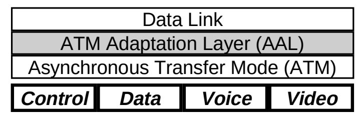
ATM versus STM

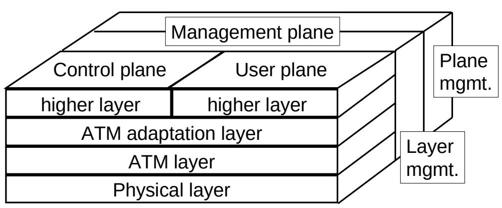


ATM Functionality

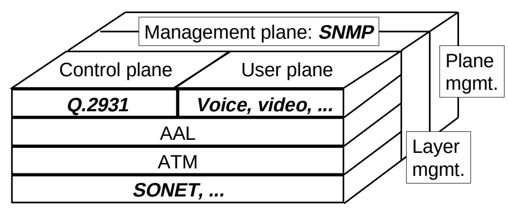
- ATM is difficult to map onto the OSI Reference Model
  - Performs layer 3 functions, such as switching
  - Used as a data link layer in some applications
- An *Adaptation Layer* above ATM
  - at sender, divides messages or bit streams from above into ATM *cells* (packets)
  - at receiver, reconstructs messages or streams
  - thus performs some layer 4 functions



B-ISDN Protocol Reference Model



Reference Model: Another View



Q.2931: for call setup/release

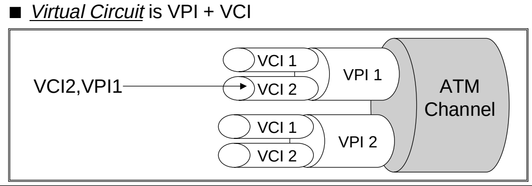
Management plane: uses management protocol like SNMP

ATM Basics (1)

- ATM is a <u>*connection-oriented (virtual circuit)*</u> network
  - Permanent virtual circuit (PVC) -- connections and paths through the network are established when network is established
  - Switched virtual circuit (SVC) -- connections and paths through the network are established on an as-needed basis
- Connection-oriented eliminates need for
  - Source and destination addresses in header
  - Sequence number for resequencing
- Error & flow control are only done on an end-to-end basis if needed either by
  - application or
  - special “signalling”

ATM’s Virtual Circuits

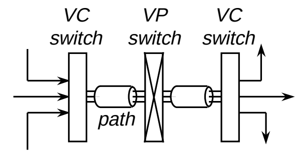
- Two multiplexing hierarchies:
  - <u>*Virtual Path Identifier (VPI):*</u>
    - Correspond to something that a switch switches
    - A bundle of Virtual Channels
  - <u>*Virtual Channel Identifier (VCI):*</u>
    - Correspond to sessions in an application
- <u>*Virtual Circuit*</u> is VPI + VCI



Virtual Channels and Virtual Paths (1)

- Virtual channel identifier (VCI) -- 16-bit field in header
  - Identify a virtual channel on a link between two ATM switches
  - Up to 2^{16} = 64K different channels can be carried over one link
- Virtual path identifier (VPI) -- 8- or 12-bit field in header
  - Identify a path over which the VCI does not change
  - Used for semi-permanent connections
  - Up to 2^{8} = 256 or 2^{12} = 4K paths can be carried over one link
  - There can be 64K VCIs over one VPI

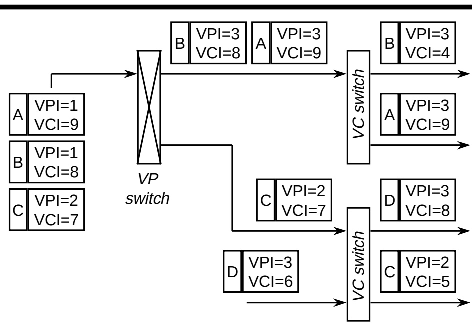
Virtual Channels and Virtual Paths (2)



Simple case:
- Same VCI is used at source, destination
- Multiple paths (hence VPIs are used)

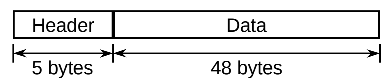
Complex case:
- Multiple VCIs are used (e.g., cross MCI/Sprint boundary)

Virtual Channels and Virtual Paths (3)



ATM Basics (2)

- ATM's basic unit of transfer is a fixed-length cell



- Fixed cell size simplifies switches (processing in hardware rather than software)
- Small size minimizes packetization delay for voice transmission
- Larger cell size would be more efficient for data -- due to per packet processing and header overhead

ATM Header Format (1)

- There are two header formats:
  - User network interface (UNI): user to subnet
  - Network node interface (NNI): internal subnet

UNI Header Format

	8 5	4	1
1	GFC	VPI	
2	VPI	VCI	
3	VCI		
4	VCI	PTI	CLP
5	HEC		

NNI Header Format

	8 5	4	1
1	VPI		
2	VPI	VCI	
3	VCI		
4	VCI	PTI	CLP
5	HEC		

ATM Header Format (2)

- The address field (channel identifier) consists of two subfields:
  - Virtual channel identifier (VCI): 16 bits
  - Virtual path identifier (VPI): 8 bits in UNI format, 12 bits in NNI format
- VCI and VPI together identify the virtual connection
  - 24 bits in UNI format
  - 28 bits in NNI format
- A special reserved address indicates "unassigned" or "idle" cells which carry no data but are needed to fill up a cell slot in transmission

ATM Header Format (3)

- 4-bit Generic Flow Control (GFC):
  - Can be used by the user to multiplex data from multiple applications or devices onto the access link to the network
- 3-bit PTI: Payload type indicator:
  - user data versus network control information
- 1-bit CLP: Cell loss priority bit
- 8-bit Header error control (HEC):
  - CRC check over the header (does not include data)
  - Not only detects, but corrects single bit errors
  - One bit error in VCI is deadly!

Reference Model -- Layers and Sublayers

Convergence	CS	AAL
Segmentation and reassembly	SAR	
Generic flow control		ATM
Cell VPI/VCI translation		
Cell multiplex and demultiplex		
Cell rate decoupling	TC	PHY
HEC header sequence generate/verify		
Cell delineation		
Transmission frame adaptation		
Transmission frame generate/recovery		
Bit timing	PM	
Physical medium		

CS: *convergence sublayer*

SAR: *segmentation and reassembly*

TC: *transmission convergence*

PM: *physical medium*

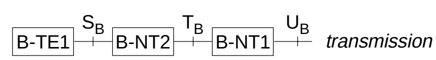
HEC: header error checking

Quality of Service (QoS) and Cell Loss

- Quality of service
  - Cell loss
  - Cell delay
  - Cell delay variation
- ATM standard provides for a cell loss priority (CLP) bit in the header; allows a user to identify two levels of priorities for each cell
  - CLP = 0 for high priority cells (e.g., voice)
  - A switch can discard CLP=1 cell (e.g., data)
  - Network can monitor high priority and low priority traffic and compare to negotiated bandwidth

Network Termination and Generic Flow Control

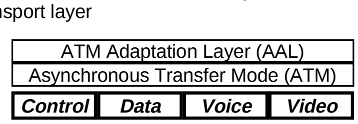
- Customer premises equipment, or Broadband Terminal Equipment-1 (B-TE1), connects to ATM network at Broadband Network Termination-1 (B-NT1) or Broadband Network Termination-2 (B-NT2)



- Multiple devices may share access to the S_B interface
- Each device should be ensured fair access to the interface
- Generic flow control is intended to support contention for the local interface

ATM Adaptation Layer -- AAL (1)

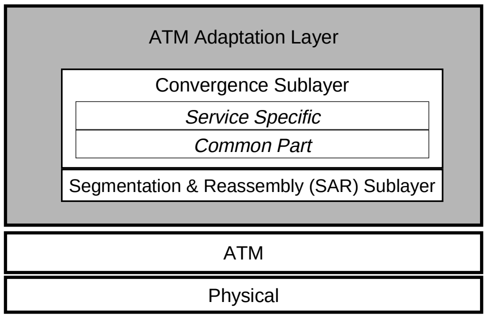
- The ATM Adaptation Layer (AAL) is responsible for breaking incoming source data into 48-byte pieces and reconstructing the data at the receiver
  - Used at entry and exit from network
  - If ATM is viewed as a network layer, then AAL is a transport layer



ATM Adaptation Layer -- AAL (2)

- Operation depends on the type of source traffic:
  - *Class 1* Constant bit rate (CBR) traffic, e.g. 64 Kbps voice and fixed-rate video
  - *Class 2* Variable bit rate (VBR) traffic to be delivered with fixed delay, e.g. compressed and packetized voice, video
  - *Class 3/4* Non-real-time data in messaging or streaming modes (may be connection-oriented)
  - *Class 5* Similar to class 3/4, but without multiplexing or error detection (always connection-oriented)
- Other classes being defined, e.g. for MPEG-2 video

Adaptation Layer Sublayers (1)



Adaptation Layer Sublayers (2)

- Convergence Sublayer (CS)
  - Upper-layer frames are basic data units
  - Concerned with flow control and error recovery for Class 3 (connection-oriented traffic)
- Segmentation and Reassembly (SAR) Sublayer
  - Segments of upper-layer frames are basic data units
  - Concerned with segmenting frames at source and reconstructing frames at destination

Class 1 AAL

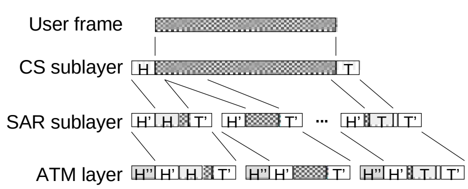
- Class 1 traffic is constant bit rate traffic and has no framing structure on input
- SAR sublayer must segment incoming data stream
- Occasional errors can be tolerated, but these need to be detected to maintain framing
- One-byte header (no trailer):
  - 1-bit convergence sublayer indicator
  - 3-bit segment number
  - 4-bit CRC

Class 2 AAL

- Class 2 traffic is similar to Class 1 traffic except that there is a frame structure on input
- Occasional errors can be tolerated, like Class 1
- Some Class 3/4 type functions needed to maintain input frame structure

Class 3/4 AAL (1)

- Non-real-time data
- Connection is coordinated by peer communication between the CS and SAR sublayers using header and trailers



Class 3/4 AAL (2)

- Segmentation and reassembly SAR sublayer
  - Two-byte header
    - *Segment Type* (2 bits): Indicates if this is first segment of a CS frame, middle segment, last segment, or an entire CS frame
    - *Sequence Number* (4 bits): Used to check for dropped or misdirected cells (cells delivered in order)
    - *Reserved/Multiplexing Identifier* (10 bits): May be used for multiplexing multiple user sessions on a single connection

Class 3/4 AAL (3)

- Segmentation and reassembly SAR sublayer (continued)
  - Two-byte trailer
    - *Length Indicator* (6 bits): For last segment and single segment SAR PDUs with less than 44 bytes of data
    - *CRC* (10 bits)

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Class 3/4 AAL (4)

- Common part convergence sublayer -- CPCS
  - Header
    - *Common part indicator (CPI)* (1 byte): indicates unit for length and size fields (possible future uses for multiplexing identifier allocation and operations/maintenance)
    - *Beginning tag (Btag)* (1 byte): Sequence number placed in header and trailer
    - *Buffer allocation size indication (BAsize)* (2 bytes): buffer requirements for this CPCS-PDU

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Class 3/4 AAL (5)

- Common part convergence sublayer -- CPCS (continued)
  - In PDU
    - *Padding (PAD)* (0 to 3 bytes): padding in header
  - Trailer
    - *Alignment (AL)* (1 byte): puts trailer on 32-bit boundary
    - *End tag (Etag)* (1 byte): matches Btag value
    - *Length (Length)* (2 bytes): length of CPCS-PDU

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Class 5 AAL (1)

- Class 5 AAL is similar to class 3/4 AAL
  - Lower overhead
  - No error detection in the SAR (just at CPCS)
  - No multiplexing
  - No buffer allocation information (BA field in class 3/4)
  - Supports connection-oriented only -- class 3/4 AAL supports both connection-oriented and connectionless
- Promoted by the ATM Forum to better match the needs of
  - LAN equipment manufacturers
  - High data rate, connection-oriented data service users

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Class 5 AAL (2)

- The only SAR information for each SAR-PDU is
  - BOM/COM (beginning/continuation of message) -- AUU=0
  - EOM/SSM (end of message/single segment message) -- AUU=1
- AAU (ATM-user-to-ATM-user) indication is in one bit of the ATM header, specifically payload type (PT) field

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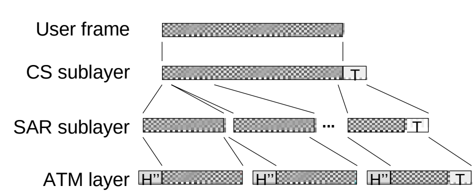
Class 5 AAL (3)



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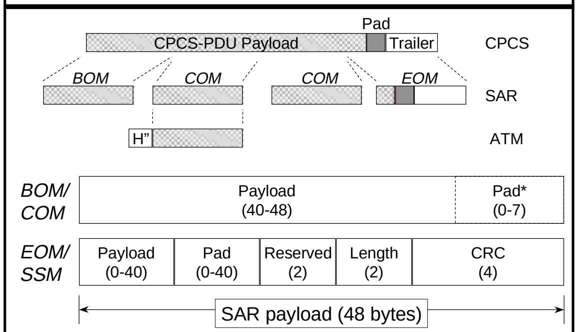
Class 5 AAL (4)



Class 5 AAL (5)

- AAU indicator is in ATM header PT field
  - AAU = 0: BOM/COM
  - AAU = 1: EOM/SSM
- Length is number of bytes in CPCS PDU payload
- Reserved (2 bytes) may be:
  - CPCS User-to-User indication (1 byte)
  - Comon Part Indicator (1 byte)
- BOM/COM padded only on next to last SAR-PDU (i.e., next is EOM) and following SAR-PDU (the EOM) has no payload

ATM Congestion Control

- Even with high data rates supported by a B-ISDN network, it is inevitable that congestion will occur
- Three elements of congestion control:
  1) Rate, burstiness, and quality of service are negotiated by user and network per connection
  2) Network can monitor (at CS of AAL) rate and burstiness of user traffic
  3) Priority bit in ATM header (CLP) indicates cells that can be dropped

Negotiated Rate, Burstiness, QoS

- The user and network can agree upon a data rate, burstiness of data, and quality of service (QoS) to be provided by the network
- Effects of constant bit rate traffic is fairly easy to determine, however, the effects of variable bit rate traffic is a complex and open issue
- Required quality of service varies for broadband services
  - Delivery latency
  - Variance of interframe delay
  - Probability of frame loss
  - ...

Monitoring and Regulating Incoming Traffic

- Network must monitor incoming traffic to ensure that it meets agreed upon limits
- Could accept excess traffic, if bandwidth is available, but mark it so that it can be discarded in the event of congestion
  - E.g., using the cell loss priority (CLP) bit in the ATM header
- Other schemes possible

Cell Loss Priority Bit

- Priority bit in ATM header indicates cells that may be discarded
- Can be used by the network to mark traffic beyond a negotiated limit
- Can be used by a user to mark data that can be lost, e.g. video frames

ATM Switches

- A single 155 Mbps connection can produce 155 Mb/s ÷ [(8 b/B)×(53 B/cell)] ≈ 366,000 cells/sec or 2.7 µs/cell
- Switches need to range from a few input ports to thousands of input ports
- VLSI and parallel implementation critical to achieve throughput

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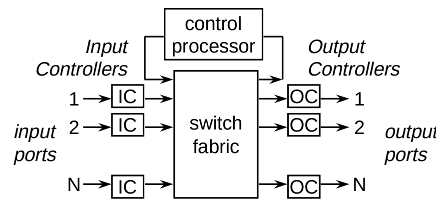
General Structure of an ATM Switch (1)



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General Structure of an ATM Switch (2)

- The control processor is used only for high-level functions such as connection establishment and release, bandwidth allocation, maintenance, and management
- All switching done by input controllers (ICs), switch fabric, and output controllers (OCs)
- Cell headers are aligned and IC, OC, and switch fabric operations are synchronous
- Input controllers translate a cell's VCI, VPI, or VPI/VCI to an output port -- contention may occur
- Design issues: switch fabric topology, cell buffer locations, contention mechanisms

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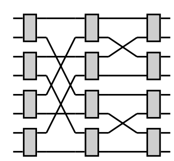
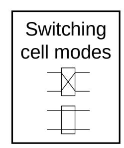
Example Switching Fabric Topology

- Banyan network provides a single path from each input to each output
- An $n \times n$ switch is constructed from $d \times d$ crossbar switches
- Requires $\lceil \log_d n \rceil$ columns of $\lceil n/d \rceil$ switches, or $\lceil \log_d n / \log_d p \rceil$ columns of $\lceil n/p \rceil$ chips for chips with p inputs



n=8, d=2



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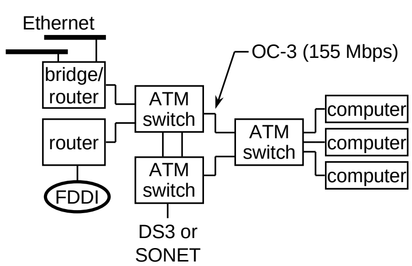
ATM in Local Area Networks

- ATM switches are available now for LAN applications



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ATM WAN Applications

- LAN-to-LAN internetworking
- Video services
  - Switched access television
  - Video-on-demand
- High resolution still image transfer
  - Medical imaging
- Multimedia services
  - Multimedia conferencing/class
  - Multimedia databases
  - Multimedia mail

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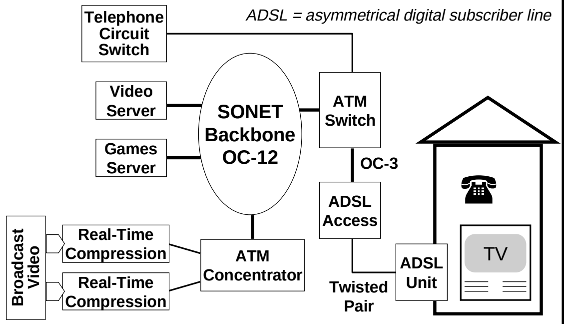
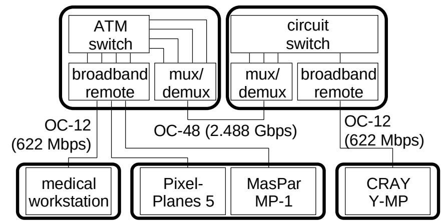
Video-on-Demand Network



VISTAnet Network Configuration



D. S. Stevenson and J. G. Rosenman, "VISTAnet gigabit testbed," *IEEE J. Selected Areas in Communications*, vol. 10, no. 9, pp. 1413-1420, Dec. 1992.