History of ISDN

• Traditionally, local loop connectivity has been with an analog signal on copper
  – Inefficient, prone to breakdown and noise, and not ideal for data traffic
  – Gradual conversion of the network backbone to all-digital transmission and switching began in the 1960s
  – By mid-1970s, demand for end-to-end digital voice and data services was apparent
  – In the US, while all voice switching is digital, the final connection from a local central office to customer equipment is still largely analog

• In 1984, the CCITT approved Recommendation I.20
  – Initial guidelines for implementing ISDN

• Local phone networks were initially slow to implement ISDN
  – Major switch manufacturers implemented the CCITT standards in non-interoperable ways

• In the early 1990s, an industry-wide effort began to establish a specific implementation for ISDN in the U.S.
History of ISDN

• Industry members agreed to create National ISDN 1 (NI-1) standard
  – Hardware and software compatible between different manufacturers
  – Initially, Southwestern Bell and U.S. West would not deploy NI-1 software in their central office switches due to incompatibilities with their existing ISDN networks
  – Ultimately, all Regional Bell Operating Companies (RBOCs) supported NI-1

• A more comprehensive National ISDN 2 (NI-2) standard, was more recently adopted

• More recent popularity of ISDN
  – Manufacturers’ standards
  – Competitive priced service
  – Inexpensive ISDN connection equipment
  – Desire to have relatively low-cost high-bandwidth connections for internet or video teleconferencing applications

• Competition from alternative end-user digital services such as "ADSL"
Integrated Services Digital Network (ISDN)

- ISDN refers to a specific set of digital services provided through a single, standard interface
  - Allows data to be transmitted simultaneously using end-to-end digital connectivity
  - The various services could be supported by different networks

- The ISDN standards define two interfaces between the user and the network
  - The Basic Rate Interface (BRI)
    - Two "B" channels and one "D" channel
  - The Primary Rate Interface (PRI)
    - 23B + 1 D channels in North America and Japan and 30B + 1D channels in Europe
    - chosen to fit the T-1 and CEPT-1 frame formats in the digital multiplexing hierarchy
### ISDN 2

- **Bearer (B) channels** carry voice and data  
  - Bandwidth of 64 kbps  
  - Some switches limit B channels to a capacity of 56 kbps  
  - Each B channel is bi-directional and provides a 64 kbps end-to-end digital connection that can carry PCM voice or data.

- **Data (D) channels** carry signaling information for the B channels  
  - Can also be used to access a packet network  
  - Full duplex synchronous connection  
  - Operates at 16 kbps (BRI) or 64 kbps (PRI)

- **H channels** aggregate B channels to provide higher rates  
  - H₀ = 384 kbps (6 B channels)  
  - H₁₀ = 1.472 Mbps (23 B channels)  
  - H₁₁ = 1.536 Mbps (24 B channels)  
  - H₁₂ = 1.920 Mbps (30 B channels) - International only
ISDN 3

- BRI was intended as a replacement for the basic telephone service
  - In North America, the associated transmission format over twisted wire pairs was selected to operate at 160 kbps and use the band that is occupied by traditional analog voice.
  - The two B channels could provide two digital voice connections and the D channel would provide signaling and access to a packet network.
  - In practice, often used in digital videoconferencing and in providing access to Internet Service at higher speeds than conventional modems

- PRI was intended for providing access from user premises equipment such as PBX's
Types of ISDN Service

- **Basic Rate Interface (BRI)**
  - Basic service
  - Meets the needs of most individual users
  - Consists of two 64 kbps B channels and one 16 kbps D channel (2B+D)
  - Using a channel aggregation protocol such as BONDING or Multilink-PPP, allows a 128 kbps uncompressed data rate

- **Primary Rate Interface (PRI)**
  - For users with greater capacity requirements
  - Typically the channel structure is 23 B channels plus one 64 kbps D channel (23B+D)
  - In Europe, PRI consists of 30 B channels plus one 64 kbps D channel (30B+D)
  - Non-Facility Associated Signaling (NFAS) supports multiple PRI lines with one 64kbps D channel
Advantages of ISDN

• **Speed & Quality**
  – Upper limit to the information transfer rate along analog telephone line - currently, about 56 kbps
  – Quality of the analog connection and routinely limit speeds to 26.4 or 28.8 kbps.
  – Major change when the telephone switches began supporting digital connections
  – The same physical wiring using digital signals permits a much higher data transfer rate
  – Digital links make it is easier to tolerate noise and interference

• **Multiple Devices**
  – Previously, it was necessary to have a phone line for each simultaneously connected device
  – ISDN allows multiple digital channels to be operated simultaneously through regular phone wiring
  – ISDN allows the combination of different digital data sources and have the information routed to the proper destination
• **Signaling**
  
  – Normally, the phone company sending a ring voltage signal to ring the bell in your phone ("In-Band signal")
  
  – ISDN sends a digital packet on a separate channel ("Out-of-Band signal")
    • Does not disturb established connections,
    • Call setup time is very fast
    • For example, a V.34 modem typically takes 30 seconds to establish a connection; an ISDN call usually takes less than 2 seconds.
  
  – The signaling also indicates who is calling, what type of call it is (data/voice), and what number was dialed
  
  – ISDN equipment is capable of making intelligent decisions on how to direct the call
ISDN Layers

• **Layer 1:**
  - Specified by ITU I-series and G-series documents
  - The U interface provided by the telco for BRI
    - Echo cancellation is used to reduce noise
    - Data encoding schemes permit relatively high (160 kbps) data rate over ordinary 2 wire local loops

• **Layer 2:** Link Access Protocol-D channel (LAP-D)
  - Almost identical to the X.25 LAP-B protocol
  - Specified by the ITU Q-series documents Q.920 through Q.923

• **Layer 3:**
  - Specified by the ITU Q-series documents Q.930 through Q.93
  - Connection-oriented

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**OSI Reference Model**

1. Physical
2. Data Link
3. Network
4. Transport
5. Session
6. Presentation
7. Application

**ISDN**

- Tele-Services
- Bearer Services
ISDN Interfaces

• Technically, ISDN devices must go through an Network Termination 2 (NT-2) device
  – NT-2 communicates with terminal equipment
  – Handles Layer 2 and 3 ISDN protocols
  – Converts the T interface into the S interface
  – S and T interfaces are electrically equivalent

• Virtually all ISDN devices include NT-2 functionality in their design
  – Most common ISDN devices expect an S/T interface
    e.g. ISDN capable telephones and FAX machines, video teleconferencing equipment, bridge/routers, and terminal adapters
  – Network Terminal Units 1 (NT-1) provide the U interface
ISDN Interfaces 2

- All devices that are designed specifically for ISDN are designated Terminal Equipment 1 (TE1)

- All other communication devices that are not ISDN capable, but have a standard telephone interface ("R interface")
  - e.g. ordinary analog telephones, FAX machines, and modems
  - Designated Terminal Equipment 2 (TE2)

- TE2 equipment can use Terminal Adapters (TA) to connect to an ISDN S/T bus

- The connection to other switches within the phone network performs the Line termination (LT) and Exchange Termination (ET) functions
  - The LT and ET functions communicate via the V interface
ISDN Interfaces 3

- **U interface**
  - Two-wire interface provided by telephone companies to BRI customers in the U.S.
  - The local loop connection between a switch and customer premises equipment
  - Performs the Line Termination (LT) function
  - Supports full-duplex data transfer
  - Only a single device can be connected to a U interface: Network Termination 1 (NT-1)

- **S/T interface**
  - Four-wire interface interface used when the NT1 is a separate device or provided to customer where Telcos supply the NT-1 device
  - One wire pair for receive and one for transmit provide full-duplex service
  - Up to 7 devices can be placed on a S/T bus
ISDN Equipment

• **Network Termination Device 1 (NT1)**
  - Simple device that serves as an interface between the ISDN BRI line and other ISDN equipment
  - Converts the 2-wire U interface delivered by the Telco to the 4-wire S/T wiring interface needed by ISDN equipment
  - Also provides a testing point for troubleshooting
  - Many Terminal Adapters and some ISDN Routers have the NT1 function built-in
    - Easier installation and reduced the total cost
    - A separate NT1 is more flexible in that it can support multiple ISDN devices

• **Power Supply**
  - Plugs into a standard wall outlet and provides power to the ISDN line
  - Unlike a standard phone line, many Telcos do not provide the power on the ISDN line
  - Many NT1 devices have the Power function built-in
  - Should have a separate analog phone service in case of emergency power outages
### ISDN Equipment 2

- **Terminal Adapters (TA)**
  - Convert the data stream from your computer into the ISDN data format
  - Provide a simple interface for a single computer
  - Many Terminal Adapters incorporate the NT1 function
  - External TAs are stand-alone devices that connect through an RS-232 port to a computer
  - Internal ISDN Adapters are cards on the computer internal bus

- **ISDN Routers**
  - Function similar to that of a standard router
  - Allow multiple computers on a LAN to share a single ISDN BRI connection
  - Connects to Ethernet Hubs
  - Many ISDN routers also support analog voice, modem, or fax applications, as well as network management capabilities
Broadband ISDN

- Requirements of high-definition television and high-speed data interconnections prompted work on a Broadband ISDN (BISDN) standard
  - Needed higher bit rates than those provided by ISDN
  - The BISDN effort resulted in an entirely new network architecture

- BISDN architecture is based on the connection-oriented transfer and switching of small fixed-length packets
  - “Asynchronous Transfer Mode (ATM)"
  - Targeting a very wide range of services
Asynchronous Transfer Mode (ATM)

- Protocol standard for implementing Broadband ISDN
  - Transmits data as fixed sized packets
  - Driven by telecommunications companies

- B-ISDN was an extension of ISDN that can provide integrated broadband services
  - Such as high-speed-data service, video phone, video conferencing, CATV services along with traditional ISDN services

- ATM is designed for switching short fixed length packets over Gigabit/sec links across very large distances

- In the US, ATM is being supported by the ANSI sponsored T1S1 subcommittee
  - In Europe, ATM is supported by ETS
  - Minor differences between the standards
  - CCITT study group XVIII working on merging differences and coming up with a single global B-ISDN standard for user interfaces
Synchronous Transfer Mode (STM)

- STM is used by telecommunication backbone networks for the long-haul transfer of packetized voice and data
  - It is a circuit switched networking mechanism
  - End points establish connection and allocate and bandwidth for the entire session
  - Bandwidth allocated even when they may not actually be transmitting the data

- STM divides the bandwidth of the STM links (e.g. T1 and T3 links)
  - Fundamental unit of transmission called time-slots or buckets
  - Fixed numbers of buckets, “trains” and are labeled from 1 to N
    - Trains repeat periodically every T time periods
    - Buckets in the train always in the same position with the same label
  - Up to M different trains labeled from 1 to M, repeat within the time period T
Inefficiency of STM

- Telecommunications companies were developing long distance links with Gigabit/sec speeds
  - Expensive infrastructure had to be used in an integrated way to be cost-effective
  - Traffic needs which represented the future of multi-media requirements:
    - real time traffic such as voice and video which can tolerate some loss but not delay
    - non real time traffic such as computer data and file transfer which may tolerate some delay but not loss

- The problem is the bursty nature of putting integrated traffic on the same medium
  - Peak bandwidth requirement may be high but the actual transmission duration may be small
  - Traffic must be transmitted at the peak rate of the burst, but the average arrival time between bursts may be quite long and randomly distributed
  - For such bursty traffic, STM represents a considerable waste of bandwidth
    - Each connection is reserved a full-time bucket based at their peak bandwidth requirements
  - If on the average only 1 in 10 buckets carries data, the unused buckets could be reused for another pending connection
Advent of ATM

• ATM was independently proposed by the AT&T in the US, and several large telecommunications companies in Europe

• Instead of identifying a connection by the bucket number, in ATM the connection identifier is carried along with the data in any bucket
  – Use small buckets so that if any bucket gets dropped due to congestion, not too much data would get lost, and could easily be recovered
  – "Fast packet switching with short fixed length packets"
  – The fixed size of the packets arose out of motivation to sustain the same transmitted voice quality as in STM networks, but in the presence of some lost packets on ATM networks
Virtual Circuit Identifier VCI

• The two end points in an ATM network are associated with each other via a VCI label
  – Vice a time-slot or bucket number as in a STM network

• The VCI number is carried in the header portion of the “Fast Packet” or “ATM Packet” or “ATM Cell”

• Convenient to consider an ATM interface as another communications port
  – From a system software point of view, it can be treated like any other data link layer method
  – An ATM port may be assigned an IP address like an Ethernet port on a host is assigned an IP address
ATM Cells

- The ATM cell is the basic unit of information transfer in the B-ISDN ATM protocol
  - Fixed cell size of 53 bytes
  - Five byte header field
    - VCI Label - 3 bytes
    - Control - 1 byte
    - Header checksum - 1 byte
    - (Optional Adaption Layer info - 4 bytes)
  - 48 bytes user information field
    - 44 bytes if adaption layer info is included

- ATM cells are transported via virtual channels and indirectly in virtual paths
  - A virtual channel is a unidirectional pipe
  - A virtual path is made from of a set of channels
ATM Protocol Layers

- **ATM Cell layer** is hardware-implemented and is approximately at the Data Link layer
  - Provides basic end-to-end connection, flow control, and routing services
  - Does not exactly fit the OSI model since it performs some functions defined at higher layers

- **The ATM Adaption layer** provides the interface between the ATM layer and higher layers
  - Resolve any disparity between a service required by the user and services available at the ATM layer

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**OSI Reference Model**

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<td>Physical</td>
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Higher Layers

ATM Adaption Layer (AAL)

ATM Cell Layer

Physical
ATM Delivery Services

- Sequential delivery in ATM networks
  - Cells may encounter congestion and suffer variable delay due to buffering within ATM switches
  - May even be dropped either due to congestion control or due to header checksum error.
  - Nevertheless, an ATM connection always transmits the cells in a connection (i.e. cells with the same VCI label) to arrive in order
  - No store and forwarding in the network, cells travel over a single virtual circuit path
  - ATM switches do not switch the cells in the same VCI out of order
  - No retransmissions are done at any point in the ATM network

- Connectionless datagram services are also supported
  - But implemented as a higher layer service layered over the ATM datalink layer
  - Cells may arrive out-of-order because datagrams may use multiple VCIs over multiple paths
  - The ATM Adaptation layer must generate Sequence numbers for each cell and correct any reordering of cells at reassembly time
  - Defined in the IEEE 802.6 protocol for its connectionless service class
ATM Services

• No end-to-end reliable delivery service at the ATM layer
  – The ATM layer does not do any retransmissions
  – No end-to-end acknowledgments for what has been received
  – Reliable delivery service can be implemented as a layer on top of the ATM layer
  – A TCP type transport layer protocol layered on top of the ATM layer is required for guaranteed delivery

• Bandwidth reservations
  – Fixed allocation - for a connection carrying a continuous bit stream traffic (e.g. 8khz voice)
  – Variable allocation - for variable frequency traffic (e.g. interactive compressed video)
  – No specific allocation - relies on statistical sharing among bursty sources
  – Multiple priorities can be established for any of the above categories

• ATM Relies on considerable user-supplied traffic profile information in order to provide the connection with the desired service quality
  – Effects the cost/performance of an ATM network
ATM Services

- Four categories of support services
  - Loss insensitive, delay sensitive
  - Loss insensitive, delay insensitive
  - Loss sensitive, delay insensitive
  - Loss sensitive, delay sensitive

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<td>Required</td>
<td>Variable</td>
<td>Connection - oriented</td>
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</tr>
<tr>
<td>Class C</td>
<td>Not Required</td>
<td>Variable</td>
<td>Connection - oriented</td>
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<tr>
<td>Class D</td>
<td>Not Required</td>
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