What is ISDN?

ISDN, which stands for **I**ntegrated **S**ervices **D**igital **N**etwork, is a system of digital phone connections which has been available for over a decade. This system allows data to be transmitted simultaneously across the world using end-to-end digital connectivity.

With ISDN, voice and data are carried by bearer channels (**B channels**) occupying a bandwidth of 64 Kbps (bits per second). Some switches limit B channels to a capacity of 56 Kbps. A data channel (**D channel**) handles signaling at 16 Kbps or 64 Kbps, depending on the service type. Note that, in ISDN terminology, "K" means 1000 (10^3), not 1024 (2^{10}) as in many computer applications; therefore, a 64 Kbps channel carries data at a rate of 64000 bps. A new set of standard prefixes has recently been created to handle this. Under this scheme, "K" (Kilo-) means 1000 (10^3), "M" (Mega-) means 1000000 (10^6), and so on, and "Ki" (Kibi-) means 1024 (2^{10}), "Mi" (Mebi-) means 1048576 (2^{20}), and so on.

There are two basic types of ISDN service: **Basic Rate Interface** (**BRI**) and **Primary Rate Interface** (**PRI**). BRI consists of two 64 kbps B channels and one 16 kbps D channel for a total of 144 kbps. This basic service is intended to meet the needs of most individual users.

PRI is intended for users with greater capacity requirements. Typically the channel structure is 23 B channels plus one 64 kbps D channel for a total of 1536 kbps. In Europe, PRI consists of 30 B channels plus one 64 kbps D channel for a total of 1984 kbps. It is also possible to support multiple PRI lines with one 64kbps D channel using **Non-Facility Associated Signaling (NFAS)**.

H channels provide a way to aggregate B channels. They are implemented as:

- H0=384 kbps (6 B channels)
- H10=1472 kbps (23 B channels)
- H11=1536 kbps (24 B channels)
- H12=1920 kbps (30 B channels) - International (E1) only

To access BRI service, it is necessary to subscribe to an ISDN phone line. Customer must be within 18000 feet (about 3.4 miles or 5.5 km) of the telephone company central office for BRI service; beyond that, expensive repeater devices are required, or ISDN service may not be available at all. Customers will also need special equipment to communicate with the phone company switch and with other ISDN devices. These devices include ISDN **Terminal Adapters** (sometimes called, incorrectly, "ISDN Modems") and **ISDN Routers**.

Advantages - Why Use ISDN?

Speed

The modem was a big breakthrough in computer communications. It allowed computers to communicate by converting their digital information into an analog signal to travel through the public phone network. There is an upper limit to the amount of information that an analog telephone line can hold. Currently, it is about 56 kbps. Commonly available modems have a maximum speed of 56 kbps, but are limited by the quality of the analog connection and routinely go about 45 kbps. Some phone lines do not support 56K connections at all, and there were currently 2 competing, incompatible 56K standards (X2 from U S Robotics (recently bought by 3Com), and K56flex from Rockwell/Lucent). This standards problem was resolved when the ITU released the V.90 standard for 56K modem communications.

ISDN allows multiple digital channels to be operated simultaneously through the same regular phone wiring used for analog lines. The change comes about when the telephone company's switches can support digital connections. Therefore, the same physical wiring can be used, but a digital signal, instead of an analog signal, is transmitted across the line. This scheme permits a much higher data transfer rate than analog lines. BRI ISDN, using a channel aggregation protocol such as BONDING or Multilink-PPP, supports an uncompressed data transfer speed of 128 kbps. In addition, the latency, or the amount of time it takes for a communication to begin, on an ISDN line is typically about half that of an analog line. This im proves response for interactive applications, such as games.

Multiple Devices

Previously, it was necessary to have a phone line for each device you wished to use simultaneously. For example, one line each was required for a telephone, fax, computer, bridge/router, and live video conference system. Transferring a file to someone while talking on the phone or seeing their live picture on a video screen would require several potentially expensive phone lines.

It is possible to combine many different digital data sources and have the information routed to the proper destination. Since the line is digital, it is easier to keep the noise and interference out while combining these signals. ISDN technically refers to a specific set of digital services provided through a single, standard interface. Without ISDN, distinct interfaces are required instead.

Signaling

Instead of the phone company sending a ring voltage signal to ring the bell in your phone ("In-Band signal"), it sends a digital packet on a separate channel ("Out-of-Band signal"). The Out-of-Band signal does not disturb established connections, and call setup time is very fast. For example, a V.34 modem typically takes 30-60 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. Available ISDN phone equipment is then capable of making intelligent decisions on how to direct the call.

Interfaces

In the U.S., the telephone company will be providing its BRI customers with a **U interface**. The U interface is a two-wire (single pair) interface from the phone switch. It supports full-duplex data transfer over a single pair of wires, therefore only a single device can be connected to a U interface. This device is called an **Network Termination 1 (NT-1)**. The situation is different elsewhere in the world, where the phone company is allowed to supply the NT-1, and thereby the customer is given an S/T interface.

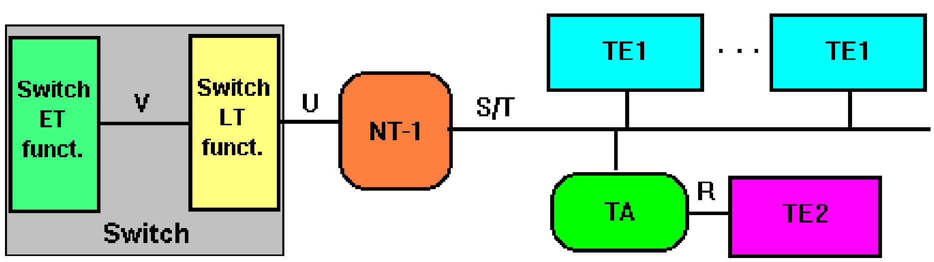
The NT-1 is a relatively simple device that converts the 2-wire U interface into the 4-wire **S/T interface**. The S/T interface supports multiple devices (up to 7 devices can be placed on the S/T bus) because, while it is still a full-duplex interface, there is now a pair of wires for receive data, and another for transmit data. Today, many devices have NT-1s built into their design. This has the advantage of making the devices less expensive and easier to install, but often reduces flexibility by preventing additional devices from being connected.

Technically, ISDN devices must go through an **Network Termination 2 (NT-2)** device, which converts the T interface into the S interface (Note: the S and T interfaces are electrically equivalent). Virtually all ISDN devices include an NT-2 in their design. The NT-2 communicates with terminal equipment, and handles the Layer 2 and 3 ISDN protocols. Devices most commonly expect either a U interface connection (these have a built-in NT-1), or an S/T interface connection.

Devices that connect to the S/T (or S) interface include ISDN capable telephones and FAX machines, video teleconferencing equipment, bridge/routers, and terminal adapters. All devices that are designed for ISDN are designated **Terminal Equipment 1 (TE1)**. All other communication devices that are *not* ISDN capable, but have a POTS telephone interface (also called the **R interface**), including ordinary analog telephones, FAX machines, and modems, are designated **Terminal Equipment 2 (TE2)**. A **Terminal Adapters (TA)** connects a TE2 to an ISDN S/T bus.

Going one step in the opposite direction takes us inside the telephone switch. Remember that the U interface connects the switch to the customer premisis equipment. This local loop connection is called *Line Termination* (LT function). The connection to other switches within the phone network is called *Exchange Termination* (ET function). The LT function and the ET function communicate via the **V interface**.

This can get rather confusing. This diagram should be helpful:



ET – Exchange Termination
LT – Line Termination
NT-1 – Network Termination 1
TE1 – Terminal Equipment 1
TE2 – Terminal Equipment 2
TA – Termination Adapter

The ISDN Physical Layer is specified by the ITU I-series and G-series documents. The U interface provided by the telco for BRI is a 2-wire, 160 kbps digital connection. Echo cancellation is used to reduce noise, and data encoding schemes (2B1Q in North America, 4B3T in Europe) permit this relatively high data rate over ordinary single-pair local loops.

Layer 1 - Physical Layer

2B1Q

2B1Q (2 Binary 1 Quaternary) is the most common signaling method on U interfaces. This protocol is defined in detail in 1988 ANSI spec T1.601. In summary, 2B1Q provides:

- two bits per baud
- 80 kbaud per second
- transfer rate of 160 kbps

Bits	Quaternary Symbol	Voltage Level
00	-3	-2.5
01	-1	-0.833
10	+3	+2.5
11	+1	+0.833

This means that the input voltage level can be one of 4 distinct levels (note: 0 Volts is not a valid voltage under this scheme). These levels are called **Quaternaries**. Each quaternary represents 2 data bits, since there are 4 possible ways to represent 2 bits, as in the table above.

Frame Format

Each U interface frame is 240 bits long. At the prescribed data rate of 160 kbps, each frame is therefore 1.5 msec long. Each frame consists of:

- Frame overhead - 16 kbps
- D channel - 16 kbps
- 2 B channels at 64 kbps - 128 kbps

Sync 18 bits	12 * (B_1 + B_2 + D) 216 bits	Maintenance 6 bits

- The Sync field consists of 9 Quaternaries (2 bits each) in the pattern +3 +3 -3 -3 -3 +3 -3 +3 -3.
- (B_1 + B_2 + D) is 18 bits of data consisting of 8 bits from the first B channel, 8 bits from the second B channel, and 2 bits of D channel data.
- The Maintenance field contains CRC information, block error detection flags, and "embedded operator commands" used for loopback testing without disrupting user data.

Data is transmitted in a **superframe** consisting of 8 240-bit frames for a total of 1920 bits (240 octets). The sync field of the first frame in the superframe is inverted (i.e. -3 -3 +3 +3 +3 -3 +3 -3 +3).

Layer 2 – Data Link Layer

The ISDN Data Link Layer is specified by the ITU Q-series documents Q.920 through Q.923. All of the signaling on the D channel is defined in the Q.921 spec.

LAP-D

Link Access Protocol - D channel (LAP-D) is the Layer 2 protocol used. This is almost identical to the X.25 LAP-B protocol.

Here is the structure of a LAP-D frame:

Flag	Address	Control	Information	CRC	Flag

Flag (1 octet) - This is always $7E_{16}$ ($0111\ 1110_2$)

Address (2 octets)							
1	2	3	4	5	6	7	8
SAPI (6 bits)						C/R	EA0
TEI (7 bits)							EA1

SAPI (Service access point identifier), 6-bits (see below)
C/R (Command/Response) bit indicates if the frame is a command or a response
EA0 (Address Extension) bit indicates whether this is the final octet of the address or not
TEI (Terminal Endpoint Identifier) 7-bit device identifier (see below)
EA1 (Address Extension) bit, same as EA0

Control (2 octets) - The frame level control field indicates the frame type (Information, supervisory, or Unnumbered) and sequence numbers (N(r) and N(s)) as required.
Information - Layer 3 protocol information and User data
CRC (2 octets) - Cyclic Redundancy Check is a low-level test for bit errors on the user data.
Flag (1 octet) - This is always $7E_{16}$ ($0111\ 1110_2$)

SAPIs

The Service Access Point Identifier (SAPI) is a 6-bit field that identifies the point where Layer 2 provides a service to Layer 3.

See the following table:

SAPI	Description
0	Call control procedures
1	Packet Mode using Q.931 call procedures
16	Packet Mode communications procedures
32-47	Reserved for national use
63	Management Procedures
Others	Reserved for Future Use

TEIs

Terminal Endpoint Identifiers (TEIs) are unique IDs given to each device (TE) on an ISDN S/T bus. This identifier can be dynamic; the value may be assigned statically when the TE is installed, or dynamically when activated.

TEI	Description
0-63	Fixed TEI assignments
64-126	Dynamic TEI assignment (assigned by the switch)
127	Broadcast to all devices

Establishing the Link Layer

The Layer 2 establishment process is very similar to the X.25 LAP-B setup, if you are familiar with it.

1. The TE (Terminal Endpoint) and the Network initially exchange Receive Ready (RR) frames, listening for someone to initiate a connection
2. The TE sends an Unnumbered Information (UI) frame with a SAPI of 63 (management procedure, query network) and TEI of 127 (broadcast)
3. The Network assigns an available TEI (in the range 64-126)
4. The TE sends a Set Asynchronous Balanced Mode (SABME) frame with a SAPI of 0 (call control, used to initiate a SETUP) and a TEI of the value assigned by the network
5. The network responds with an Unnumbered Acknowledgement (UA), SAPI=0, TEI=assigned.

At this point, the connection is ready for a Layer 3 setup.

Layer 3 – Network Layer

The ISDN Network Layer is also specified by the ITU Q-series documents Q.930 through Q.939. Layer 3 is used for the establishment, maintenance, and termination of logical network connections between two devices.

SPIDs

Service Profile IDs (SPIDs) are used to identify what services and features the telco switch provides to the attached ISDN device. SPIDs are optional; when they are used, they are only accessed at device initialization time, before the call is set up. The format of the SPID is defined in a recommendation document, but it is only rarely followed. It is usually the 10-digit phone number of the ISDN line, plus a prefix and a suffix that are sometimes used to identify features on the line, but in reality it can be whatever the telco decides it should be. If an ISDN line requires a SPID, but it is not correctly supplied, then Layer 2 initialization will take place, but Layer 3 will not, and the device will not be able to place or accept calls. See ITU spec Q.932 for details.

Information Field Structure

The Information Field is a variable length field that contains the Q.931 protocol data.

<table>
<tr><th colspan="8">Information Field</th></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td></tr>
<tr><td colspan="8">Protocol Discriminator</td></tr>
<tr><td>0</td><td>0</td><td>0</td><td>0</td><td colspan="4">Length of CRV</td></tr>
<tr><td colspan="8">Call Reference Value (1 or 2 octets)</td></tr>
<tr><td>0</td><td colspan="7">Message Type</td></tr>
<tr><td colspan="8">Mandatory & Optional
Information Elements (variable)</td></tr>
</table>

These are the fields in a Q.931 header:

- **Protocol Discriminator** (1 octet) - identifies the Layer 3 protocol. If this is a Q.931 header, this value is always 08_{16}.
- **Length** (1 octet) - indicates the length of the next field, the CRV.
- **Call Reference Value (CRV)** (1 or 2 octets) - used to uniquely identify each call on the user-network interface. This value is assigned at the beginning of a call, and this value becomes available for another call when the call is cleared.
- **Message Type** (1 octet) - identifies the message type (i.e., SETUP, CONNECT, etc.). This determines what additional information is required and allowed.
- **Mandatory and Optional Information Elements** (variable length) - are options that are set depending on the Message Type.

Layer 3 Call Setup

These are the steps that occurs when an ISDN call is established. In the following example, there are three points where messages are sent and received; 1) the Caller, 2) the ISDN Switch, and 3) the Receiver.

1. Caller sends a SETUP to the Switch.
2. If the SETUP is OK, the switch sends a CALL PROCeeding to the Caller, and then a SETUP to the Receiver.
3. The Receiver gets the SETUP. If it is OK, then it rings the phone and sends an ALERTING message to the Switch.
4. The Switch forwards the ALERTING message to the Caller.
5. When the receiver answers the call, is sends a CONNECT message to the Switch
6. The Switch forwards the CONNECT message to the Caller.

7. The Caller sends a CONNECT ACKnowledge message to the Switch
8. The Switch forwards the CONNECT ACK message to the Receiver.
9. Done. The connection is now up.