This tutorial will cover the basics of ISDN. Topics covered will include:

- What is ISDN?
- What is ISDN's history?
- Why use ISDN?
- What are BRI and PRI? What are Channels?
- What do the layers look like?
- What protocols are used?
- What happens when a call is set up?
- How can I get more information?

ISDN, which stands for Integrated Services Digital Network, is a system of digital phone connections which has been available for over a decade. This system allows voice and 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 kb/s (bits per second). Some switches limit B channels to a capacity of 56 kb/s. A data channel (D channel) handles signaling at 16 kb/s or 64 kb/s, depending on the service type. Note that, in ISDN terminology, "k" means 1000 \( (10^3) \), not 1024 \( (2^{10}) \) as in many computer applications (the designator "K" is sometimes used to represent this value); therefore, a 64 kb/s channel carries data at a rate of 64000 b/s. 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.

(An alert reader pointed out some inconsistencies in my use of unit terminology throughout this Tutorial. He also referred me to a definitive web site. As a result, I have made every effort to both conform to standard terminology, and to use it consistently. I appreciate helpful user input like this!)

There are two basic types of ISDN service: Basic Rate Interface (BRI) and Primary Rate Interface (PRI). BRI consists of two 64 kb/s B channels and one 16 kb/s D channel for a total of 144 kb/s. 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 kb/s D channel for a total of 1536 kb/s. In Europe, PRI consists of 30 B channels plus one 64 kb/s D channel for a total of 1984 kb/s. It is also possible to support multiple PRI lines with one 64 kb/s D channel using Non-Facility Associated Signaling (NFAS).

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

- \( H_0 = 384 \) kb/s (6 B channels)
- \( H_{10} = 1472 \) kb/s (23 B channels)
- \( H_{11} = 1536 \) kb/s (24 B channels)
- \( H_{12} = 1920 \) kb/s (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.

The early phone network consisted of a pure analog system that connected telephone users directly by a mechanical interconnection of wires. This system was very inefficient, was very prone to breakdown and noise, and did not lend itself easily to long-distance connections. Beginning in the
1960s, the telephone system gradually began converting its internal connections to a packet-based, digital switching system. Today, nearly all voice switching in the U.S. is digital within the telephone network. Still, the final connection from the local central office to the customer equipment was, and still largely is, an analog Plain-Old Telephone Service (POTS) line.

A standards movement was started by the International Telephone and Telegraph Consultative Committee (CCITT), now known as the International Telecommunications Union (ITU). The ITU is a United Nations organization that coordinates and standardizes international telecommunications. Original recommendations of ISDN were in CCITT Recommendation I.120 (1984) which described some initial guidelines for implementing ISDN.

Local phone networks, especially the regional Bell operating companies, have long hailed the system, but they had been criticized for being slow to implement ISDN. One good reason for the delay is the fact that the two major switch manufacturers, Northern Telecom (now known as Nortel Networks), and AT&T (whose switch business is now owned by Lucent Technologies), selected different ways to implement the CCITT standards. These standards didn't always interoperate. This situation has been likened to that of earlier 19th century railroading. "People had different gauges, different tracks... nothing worked well."

In the early 1990s, an industry-wide effort began to establish a specific implementation for ISDN in the U.S. Members of the industry agreed to create the National ISDN 1 (NI-1) standard so that end users would not have to know the brand of switch they are connected to in order to buy equipment and software compatible with it. However, there were problems agreeing on this standard. In fact, many western states would not implement NI-1. Both Southwestern Bell and U.S. West (now Qwest) said that they did not plan to deploy NI-1 software in their central office switches due to incompatibilities with their existing ISDN networks.

Ultimately, all the Regional Bell Operating Companies (RBOCs) did support NI-1. A more comprehensive standardization initiative, National ISDN 2 (NI-2), was later adopted. Some manufacturers of ISDN communications equipment, such as Motorola and U S Robotics (now owned by 3Com), worked with the RBOCs to develop configuration standards for their equipment. These kinds of actions, along with more competitive pricing, inexpensive ISDN connection equipment, and the desire for people to have relatively low-cost high-bandwidth Internet access have made ISDN more popular in recent years.

Most recently, ISDN service has largely been displaced by broadband internet service, such as xDSL and Cable Modem service. These services are faster, less expensive, and easier to set up and maintain than ISDN. Still, ISDN has its place, as backup to dedicated lines, and in locations where broadband service is not yet available.

**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 kb/s bidirectionally. Commonly available modems have a maximum speed of 56 kb/s, but are limited by the quality of the analog connection and routinely go about 45-50 kb/s. Some phone lines do not support 56 kb/s connections at all. There were currently 2 competing, incompatible 56 kb/s 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, and later V.92, standard for 56 kb/s 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 kb/s, plus bandwidth for overhead and signaling. 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 improves response for interactive applications, such as games.

**Multiple Devices**

Previously, it was necessary to have a separate 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.

ISDN allows multiple devices to share a single line. 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, no bandwidth is taken from the data channels, and call setup time is very fast. For example, a V.90 or V.92 modem typically takes 30-60 seconds to establish a connection; an ISDN call setup 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.

In the U.S., the telephone company provides its BRI customers with a U interface. The U interface is a two-wire (single pair) interface from the phone switch, the same physical interface provided for POTS lines. 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 premises 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:

![Diagram](image)

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 kb/s 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.

**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 kilobaud *(baud = 1 modulation per second)*
- Transfer rate of 160 kb/s

<table>
<thead>
<tr>
<th>Bits</th>
<th>Quaternary Symbol</th>
<th>Voltage Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>-3</td>
<td>-2.5</td>
</tr>
<tr>
<td>01</td>
<td>-1</td>
<td>-0.833</td>
</tr>
<tr>
<td>10</td>
<td>+3</td>
<td>+2.5</td>
</tr>
<tr>
<td>11</td>
<td>+1</td>
<td>+0.833</td>
</tr>
</tbody>
</table>

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 kb/s, each frame is
therefore 1.5 ms long. Each frame consists of:

- Frame overhead - 16 kb/s
- D channel - 16 kb/s
- 2 B channels at 64 kb/s - 128 kb/s

<table>
<thead>
<tr>
<th>Sync</th>
<th>12 * (B₁ + B₂ + D)</th>
<th>Maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 bits</td>
<td>216 bits</td>
<td>6 bits</td>
</tr>
</tbody>
</table>

- The Sync field consists of 9 Quaternaries (2 bits each) in the pattern +3 +3 -3 -3 +3 -3 +3 -3.
- (B₁ + B₂ + 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).

The ISDN Data Link Layer is specified by the ITU [Q-series documents](https://www.itu.int/en/ITU-T/standards/documents/Pages/Q920-Q923.aspx) 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:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Address</th>
<th>Control</th>
<th>Information</th>
<th>CRC</th>
<th>Flag</th>
</tr>
</thead>
</table>

**Flag** (1 octet) - This is always 7E₁₆ (0111 1110₂)

<table>
<thead>
<tr>
<th>Address (2 octets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>SAPI (6 bits)</td>
</tr>
<tr>
<td>TEI (7 bits)</td>
</tr>
</tbody>
</table>

**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 7E₁₆ (0111 1110₂)
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:

<table>
<thead>
<tr>
<th>SAPI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Call control procedures</td>
</tr>
<tr>
<td>1</td>
<td>Packet Mode using Q.931 call procedures</td>
</tr>
<tr>
<td>16</td>
<td>Packet Mode communications procedures</td>
</tr>
<tr>
<td>32-47</td>
<td>Reserved for national use</td>
</tr>
<tr>
<td>63</td>
<td>Management Procedures</td>
</tr>
<tr>
<td>Others</td>
<td>Reserved for Future Use</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>TEI</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-63</td>
<td>Fixed TEI assignments</td>
</tr>
<tr>
<td>64-126</td>
<td>Dynamic TEI assignment (assigned by the switch)</td>
</tr>
<tr>
<td>127</td>
<td>Broadcast to all devices</td>
</tr>
</tbody>
</table>

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.

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>
<thead>
<tr>
<th>Information Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>Protocol Discriminator</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>Call Reference Value (1 or 2 octets)</td>
</tr>
<tr>
<td>0</td>
</tr>
<tr>
<td>Mandatory &amp; Optional Information Elements (variable)</td>
</tr>
</tbody>
</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.