11

Data Networks

11.1. INTRODUCTION

Communication between two computers over the telephone lines begun around 1968. Previously, to transfer information between equipments or computers, a vendor or a company had to rent the interface equipment from the telephone company. As this causes the delayed procedure and led to monopolizing of telephone company, the Federal communications commission (FCC) produced a rule 67, by which a vendor can directly connect an equipment to telephone company network. The device Modem was developed which converts the serial digital data form produced by a computer to a form of analog signal that can be sent through the telephone voice circuits. Thus, a communication networks enable users to transfer information in the form of voice, video, E-mail and computer files.

When a network is to transfer a stream of data from a source to destination, it must assign to the data stream a route, that is, a sequence of links or channels connecting the source to the destination. The network should also allocate the data stream a portion of the capacity or BW in each channel along the route to be used. These decisions are performed by switches (or sometimes routers) in telephone exchanges. The process is called switching. There are three types of switching namely message switching, circuit switching and packet switching. The circuit and message switching were explained in the section 4.7. The packet switching is explained in the section 11.3.

In 1978, the International Organization for Standards (ISO) was asked to come up with a solution that would allow the transparent communication and data transfer between and among systems regardless of manufacturer. The model developed by ISO is the OSI reference model. OSI stands for the open systems interconnect reference model. This model allows any two different systems to communicate regardless of their underlying architecture. The purpose of the OSI model is to open communication between different systems without requiring changes to the logic of the underlying hardware and software. In this chapter, the OSI model is described in the section 11.4.

Till 1980's, OSI model was widespread and dominated the entire networking, commercially as well as by architecture. In 1990's TCP/IP has become firmly established as the dominant commercial architecture. Now the TCP/IP is the protocol of choice in many LAN-to-WAN environments. The concepts of TCP/IP is explained in the section 11.5. LAN technologies become almost a necessity for small offices. Experts predicts that within a few years, LAN setups will find their way into homes. Various LAN technologies are explained in the section 11.6.

Asynchronous transfer mode (ATM) is a high performance, cell oriented switching and multiplexing technology that uses fixed length packets to carry different types of traffic. ATM is defined as a transport and switching method in which information does not occur periodically with some reference (hence the name asynchronous). The ATM concept is described in the section 11.7.

The internet is a social as well as a technological phenomenon. Internet is the world's largest computer network. It was created nearly twenty five years ago as ARPA net. Its goal was to create a method for widely separated computers to transfer data efficiently even in the event of nuclear attack. The internet is a network formed by the co-operative interconnection of various computing networks.

11.2. DATA TRANSMISSION IN PSTN

The transmission medium is the physical foundation for all the data communications. The amount of data carried across the networks crossed the voice traffic level. The data is growing at a rate of 30 percent per year. It will take 12 years to double the amount of voice carried on the network at the current growth rate, whereas the data is doubling approximately every 90 days. In the beginning, data transmission was organized using telegraph or telex networks as they could carry digital signals directly. But teletype machines were slow, noisy and consumed large amounts of power. The speed was limited to 110 bauds. (Baud rate is a measure of the rate at which binary data are transmitted and received). But data rates for transmission have been on the rise. With public switched telephone network, there is a possibility of carrying signals at higher speeds. Public switched telephone networks and electronic PABX's are designed to carry analog voice signals. They can be used for data transmission by employing suitable interfaces.

11.2.1. Data Rates in PSTN

Baud rate. The maximum rate of signal transitions that can be supported by a channel is known as baud rate. Baud rate is a close measure of information throughput, or the effective information data transfer rate from sender to receiver. Thus, baud rate is one that can be supported in a noiseless channel.

We know, a voice channel in a PSTN is bandlimited with a nominal bandwidth of 3.1 kHz. A maximum data rate that a noiseless or ideal voice channel can support can be obtained from the Nyquist theorem

$$D = 2\,B \log_2 L \text{ bps} \qquad \text{...(11.1)}$$

where D = Maximum data rate (in Baud or bps) B =

Bandwidth of the channel

L = Number of discrete levels in the signals.

For a 3 kHz channel, and a binary signal, the maximum data rate is 6000 bps, if the signal level is two.

For higher data rates, we translate information rate into symbols per second. A symbol is any element of an electrical signal that can be used to represent one or more binary data bits. The rate at which symbols are transmitted is the symbol rate. This rate may be represented as a systems baud rate. Fig. 11.1 illustrates the pulse representation of the binary numbers used to code the samples (Fig. 11.1 (*a*)) and representation by voltage levels (symbols) rather than pulses (Fig. 11.1 (*b*)).

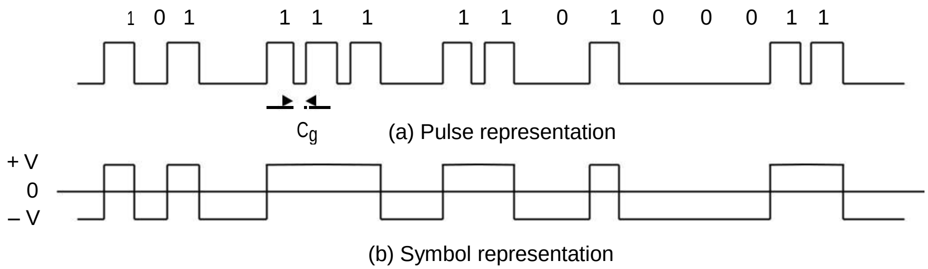

Fig. 11.1. Binary bits represented as (*a*) pulse and (*b*) symbol.

In Fig. 11.1 shown, each three digit binary number that specifies a quantized sample value is called a word. C_g is called guard time between pulses.

Bit rate. In the noisy channel, there is an absolute maximum limit for the bit rate. This limit arises because the difference between two adjacent signal levels become comparable to the noise level when the number of signal level is increased. For noisy channel, data rate is calculated by

$$D_b = B \log_2 (1 + S/N) \quad \text{...(11.2)}$$

Where D_b = Data rate in noisy channel (in bps) B =

Bandwidth of the channel

S/N = Signal to noise ratio.

For S/N of 30 dB and 3 kHz Bandwidth noisy channel, D_b is 30000 bps.

Relation between baud rate (or symbol rate) and bps : The baud rate and bit rate are related as

$$D_b = D \times n \quad \text{...(11.3)}$$

where *n* = number of bits required to represent signal levels.

In the example considered for baud rate explanation *n* is assumed as one. Hence baud rate is equal to bps. Fig. 11.2 illustrates the relation between baud and bit rates.

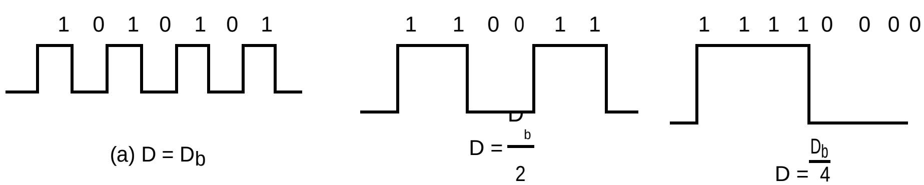

Fig. 11.2. Relation between baud and bit rates.

Fig. 11.2 (*a*) shows the baud rate equal to bit rate. Fig. 11.2 (*b*) and (*c*) shows the baud rate equal to one-half and one-fourth of bit rate respectively. It is proved that up to 2400 bauds may be transmitted reliably through a PSTN voice channel. By increasing the signal levels, the effective bit rate increases.

For low-speed applications, the difference between baud and bit rate are insignificant. Thus 300 and 1200 bps modems orginally used with personal computers were frequently referred to as 300 or 1200 baud modems.

11.2.2. Data Communications Link

In order to communicate from a terminal, computer or any equipment, the following six parts have to be put together in proper order.

1. The transmission medium that carries the traffic between source and destination.
2. Data communication equipment or data circuit terminating equipment (DCE).
3. Data terminal equipment (DTE).
4. Communication protocols and software.
5. Terminal devices.
6. Interface.

Fig. 11.3 shows the typical arrangement of the communication link for the data communication. Data link refers to the process of connecting or linking two stations together.

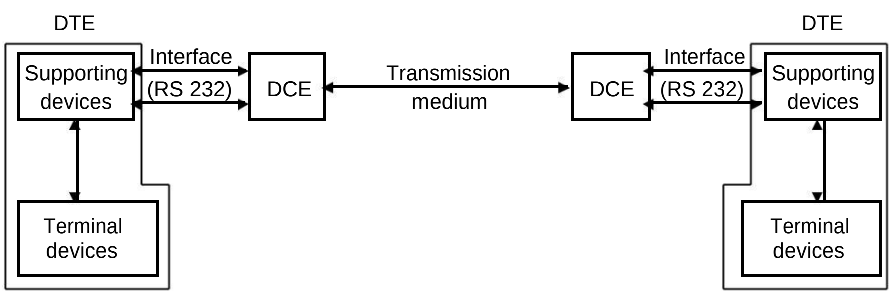

Fig. 11.3. Data communication link.

Transmission medium. The transmission medium include communication channels, path, links, trunks and circuits. The transmission medium may be a telephone lines, coaxial cable, twisted pair, Fiber cable, radio waves (free space), microwave link or satellite link.

Terminal devices. These are the end points in a communication link. Terminal devices are also called as nodes. For the two point network, the node points are the primary station and the remote or secondary station. A primary station is responsible for establishing and maintaining the data link between it and a secondary station. The terminal devices includes main frame computer, personal computer, peripherals such as printers, keyboards, FAX machines and data display terminals.

Data terminal equipment (DTF). The terminal devices, communication station, UART, and line control unit (LCU) grouped together and named as DTE. Fig. 11.4 shows typical arrangement of DTE.

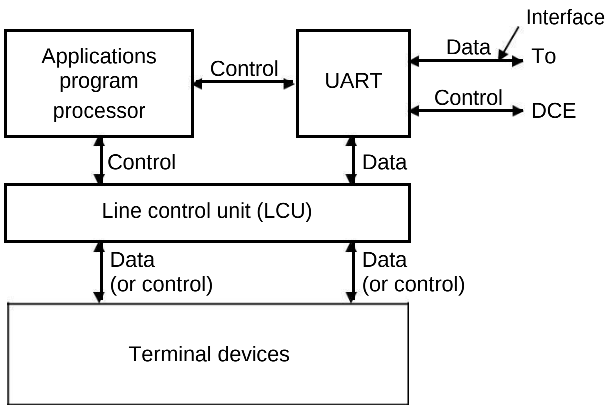

Fig. 11.4. Data terminal equipment.

UART. The universal asynchronous receiver transmitter (UART) and the universal synchronous/asynchronous receiver transmitter (USART) performs the parallel to serial conversion (and vice versa at the receiving station).

Application programme processor. An application program used by the DTE, called a protocol, defines a set of rules that determine requirements for the successful establishment of a data link and the transfer of actual information between stations. Protocols are key components of communication architectures. Protocols provide the rules for communication between counterpart components on different devices. The application programs also direct control information to the line control unit and UART to allow data flow from the peripheral currently serviced by the LCU to the UART and out to the DCE.

Line control unit (LCU). Data sent from one station to another usually originates in parallel binary form from one or more peripheral devices connected to that station through a LCU. The unit acts as an interface between terminal devices and UART and the application programme processor.

Interface. RS 232 interface is used to connect UART and the DCE. The RS-232 interface defines the electrical function of the pins and the mechenical function of the connector. The Electrical Industry Association (EIA) revised RS-232 C in 1989 and called the revision RS-232 D (connector with 25 pins). RS-232 is a standard connection for serial communication. All modems use RS 232 connections and all PCS have a RS 232 port.

Data communication equipment (DCE). The DCE is a modem. This device is used to convert the serial data stream into a form which is suitable for transmission. This serial data stream transferred through a transmission medium. At the receiver side, the serial data stream are converted back to digital and sent to DTE. DCE may be a modem or a computer based node in a data network.

Some of the standards defined by CCITT known as V series are :

V.5 — Standardisation of data signalling rates for synchronous data transmission in PSTN.

V.24 — DTE-DCE interface and control signals.

V-28 — DTE-DCE electrical characteristics for unbalenced double current interchange circuits.

V-53 — Limits the maintenance of telephone type circuits used for data transmission. Some of the important V-series modem standards are given in Table 11.1.

Table 11.1. V-series modem standards

V-series	Speed (bps)	Modulation	Application
V-22 bis	2400 (1200 bps fall back)	16 ary QAM	FD, D-UP, 2-W
V-29	9600	16 ary QAM	FD, 4-W
V-32	up to 9600 bps	32 ary QAM	FD, D-UP, 2-W
V-33	14,400	128 ary AM-PM	FD, 4-W

FD—Full duplex, D-up = dial up connection, 4-W-4 wire based circuit.

11.3. PACKET SWITCHING

There are three types of switching used in PSTN network. The circuit switching and message switching were explained in the section 4.7. Circuit switching was designed for voice communication. Circuit switching creates temporary (dialed) or permanent (leased) dedicated links that are well suited to this type of connection. The circuit switching also limits the flexibility and not suitable for connecting variety of digital devices. More efficient utilization of the network requires greater control channel bandwidth and increased call processing capacities in the switches. But the circuit switching not providing these capabilities. Message switching overcomes the limitations of circuits switching. This switching stores the incoming messages into a computer memory and forward it to the destination when available. This causes delay in switching. The packet switching overcomes all the limitations of message and circuit switching. Thus it is highly suitable for the data communication.

The first packet switching system Arpanet, was developed by the U.S. Defence Advanced Research Projects Agency (DARPA) in 1969. The system used PDP-8 minicomputers made by Digital Equipment Corporation as packet switches, which were connected by dedicated 50 kbps telephone lines. Since then, many private and public packet switching networks, notably the X-25 system with speeds varying from 56/64 kbps to 1.5/2 Mbps (T1/E1) have been deployed.

11.3.1. Packet Switching Principles

The datastream originating at the source is divided into packets of fixed or variable size. The data communication system typically have bursty traffic. Thus, the time interval between consecutive packets may vary, depending on the burstiness of the data stream. A typical upper bound on packet length is 512 octets (bytes). Each packet contains a portion of the user's data plus some control information. As the bits in a packet arrive at a switch or router, they are read into a buffer. When the entire packet is stored, the switch routes the packet over one of its outgoing links. The packet remains quenced in its buffer until the outgoing link becomes idle. This technique is called store and forward technique. Fig. 11.5 illustrates the flow of packet switching.

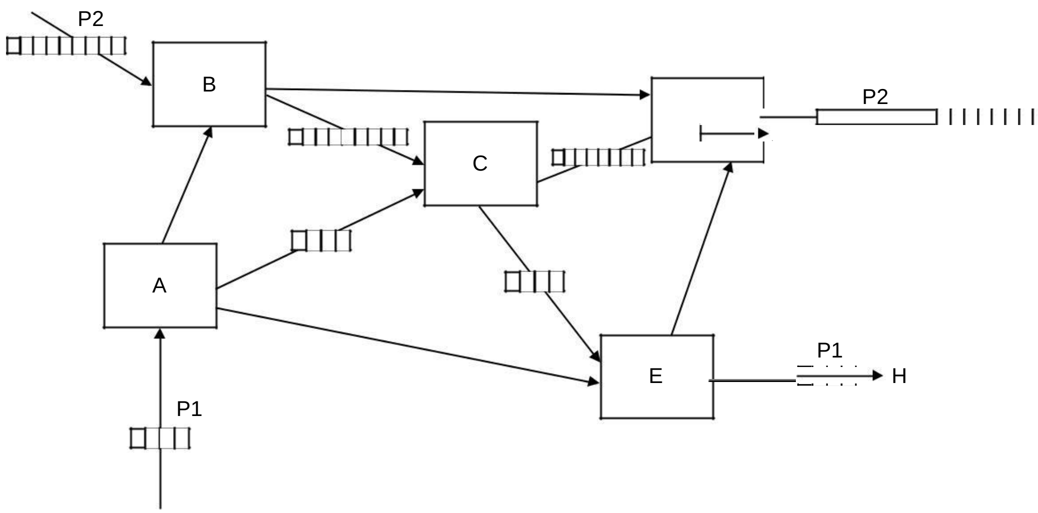

Fig. 11.5. Packet switching principle.

In Fig. 11.5, two packets (P1, P2) are entering at station A and B. The packet (P1) entering at A is targetted to the station H and the packet (P2) entering at B is targetted to the station G. Depends on the path availability the packet P1 choses the path as station A–C–E– H. Similarly the packet P2 choses the path as station B–C–D–G. In each station, the packets are stored in a buffer and forwarded to the next station after the availability.

11.3.2. Routing Control

From the previous section, it is clear that in packet switching, messages are broken into packets and sends one at a time to the network. Routing control decides how the network will handle the stream of packets as it attempts to route them through the network and deliver them to the intended destination. The routing decision is determined in one of two ways. They are

1. Datagram and
2. Virtual circuit.

Datagram. In datagram, each packet within a stream is independently routed. A routing table stored in the router (switch) specifies the outgoing link for each destination. The table may be static or it may be periodically updated. In the second case, the routing depends on the router's estimate of the shortest path to the destination. Since the estimate may change with time, consecutive packets may be routed over different links. Therefore each packet must-contain bits denoting the source and destination. Thus may be a significant overhead.

Fig. 11.6 shows a simple communication network where the concept of datagram is explained. The circled one are called the switching nodes whose purpose is to provide a switching facility that will move the data from node to node until they reach the destination. The squared one are called the stations. The stations may be computers, terminals, telephones or other communication devices. These stations also referred as end devices are the communi-cating devices.

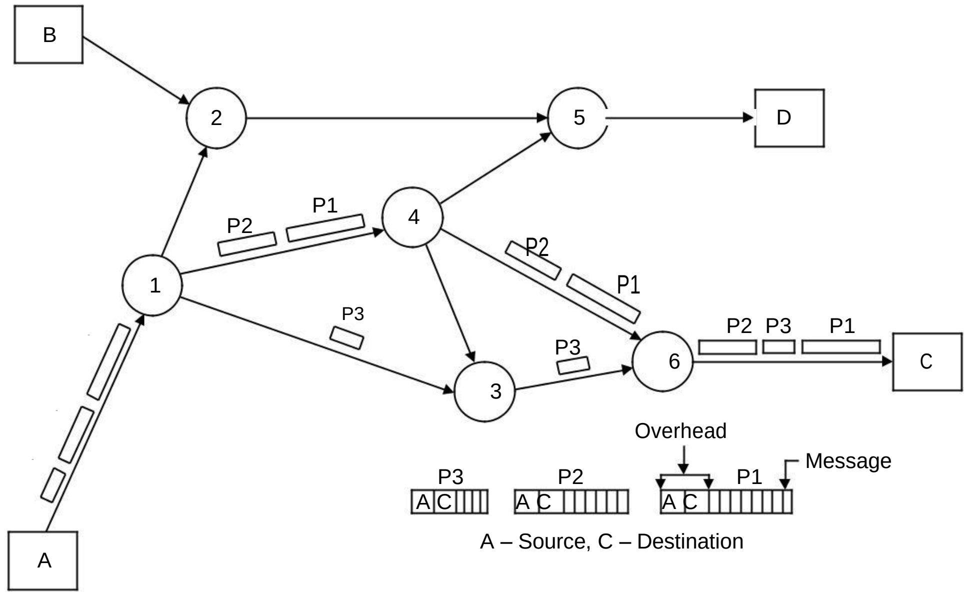

Fig. 11.6. Concept of datagram.

In the datagram approach, each packet is treated independently. In the Fig. 11.6. shown, the station A is assumed to send three packets of message namely P1, P2 and P3 (for explanation purpose named so). At first, A transmits these packets to node 1. Node 1 makes decision on routing of these packets. Node 1 finds node 4 as shortest compared to node 3. Thus it passes P1 and P2 to node 4. Accidently, if node 4 is not accessible, node 1 finds node 3 as shortest and sends packet P3 to node 3.

Node 3 and 4 sends its received messages to the destination C through node 6. It is shown that the order of the packet is changed due to the different routing of the packets. Thus in datagram, it is the responsibility of destination station to reorder the packets in proper sequence. Also if a packet crashes in a switching node, the destination C may not receive, all packets. In such a case also, it is the responsibility of station C to recover the lost packet.

Virtual circuit. In virtual circuit, a fixed route is selected before any data is transmitted in a call setup phase similar to circuit switched network. All packets belonging to the same data stream follow this fixed route called a vitrual circuit. Packet must now contain a virtual circuit identifier. This bit string is usually shorter than the source and destination address identifiers needed for datagram. Once the virtual circuit is established, the message is transmitted in packets. Fig. 11.7 shows the concept of virtual circuit.

In the Fig. 11.7 shown, suppose that end station B has two messages to send to the destination D. First B sends a control packet refered as call-request packet to node 2, requesting logical connection to D. Node 2 decides to route the request and the subsequent message packets through node 3 and 4 to destination D. If D prepared to accept the connection, it sends a call-accept packet to node 4. Node 4 sends the call-accept packet to B through node 3 and 2. Because the route is fixed for the duration of the logical connection, it is somewhat similar to a circuit switching network and is referred to as a virtual circuit.

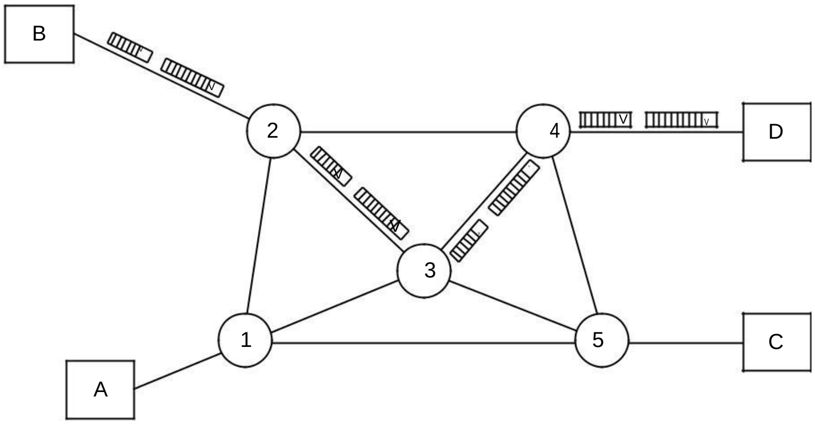

Fig. 11.7. Concept of virtual circuit.

Every data packet with virtual circuit identifier and data from B intended for D traverses node 2, 3 and 4. Similarly every data packet from D intended for B traverses nodes 4, 3 and 2. Any station can terminate the connection with a clear-request packet. At any time, each station can have more than one virtual circuit to any other station and can have virtual circuits to more than one station. As all packets follow the same route, they reach the destination in the same order. So there is no need of reording work for destination station. Error control is the additional advantage of virtual circuit. Error control is a service that assures error free reception. For example, if a packet in a sequence from node 3 to 4 fails to arrive at node 4, or arrives with an error, node 4 can request a retransmission of that packet from node 4. As there is no necessity of routing decision during transition of packets from source to destination, with virtual circuit, packets transit rapidly. Currently available packet switching networks make use of virtual circuits for their internal operations.

Packet size. If an organization has large amounts of data to send, then the data can be delivered to a packet assembler/disassembler (PAD). The PAD (software package) receives the data and breaks it down into manageable packets. In the data communication, a packet can be a variable length. Usually upto 128 bytes of data is in one packet. X-25 services have created packets upto 512 bytes, but the average is 128. The 128 byte capability is also referred to as fast select. There is a significant relationship between packet size and transmission time. The process of using more smaller packets (for example 30 byte information may be sent as a single packet with header of 3 byte or two packets with 15 byte each plus the header in each packet or 5 packets with 6 bytes plus header) increases the speed of transmission.

11.3.3. Comparison of Circuit Switching and Packet Switching

There are two types of approaches in packet switching. Datagram and virtual circuit. The circuit switching is compared with these two approaches.

Datagram switching achieves higher link utilization than circuit switching especially when the traffic is bursty. No dedicated path is required as circuit switching. But the datagram have the disadvantage over virtual circuit wire.

1. End to end delay may be so large or so random as to preclude applications that demant guaranteed delay.

2. The overhead due to source and destination identifiers and bits needed to delimit packets may waste a significant fraction of the transmission capacity if the packet are very short.

3. A datagram switch does not have the state information to recognize if a packet belongs to a particular application. Hence the switch can not allocate resources (bandwidth and buffers) that the application may require.

Virtual circuits are more advantages and currently the packet switching network uses the virtual circuit approach. The overhead is comparable to circuit switching. As the packets arrives in sequence, no resequencing is needed. Statistical multiplexing of packets at the router or switch can achieve better utilization than in circuit switching. Since packets contains their virtual circuit identifiers (VCI), the switch can allocate resources depending on the VCI. During the connection setup phase, the switches may be notified that a particular VCI should be given extra resources.

11.3.4. Packet Formats

The format of a packet in packet switching network can vary significantly from one network to another. Generally header includes all related control information. In some cases, control information is communicated through a special control packets. Fig. 11.8 shows typical packet format.

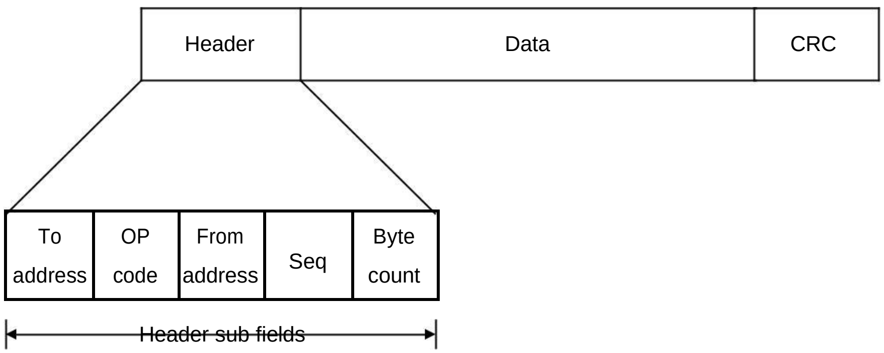

Fig. 11.8. Typical packet format.

A packet contains 3 major fields.

1. **Header.** It contains sub fields in addition to the necessary address fields. Other than the to and from address field, the following are the useful control information.

(*a*) **Op code.** It designates whether the packet is a message (text) packet or control packet.

(*b*) A **sequence number (Seq)** to reassemble messages at the destination node, detect faults and facilitates recovery procedures.

(*c*) **Byte count.** Used to indicate the length of a packet.

2. **Data.** A portion of a data stream to be transferred in the data field. Some packets may not contain a message field if they are being used strictly for control purposes.

3. **CRC.** The cyclic redundancy checks (CRC) field contains a set of parity bits that cover overlapping fields of message bits. The fields overlap in such a way that small numbers of errors are always detected. The probability of not detecting the occurance of 2 large number of errors is 1 in 2^M, where M is the number of bits in the cheek code.