Ethernet Tutorial: Networking Basics

Computer networking has become an integral part of business today. Individuals, professionals and academics have also learned to rely on computer networks for capabilities such as electronic mail and access to remote databases for research and communication purposes. Networking has thus become an increasingly pervasive, worldwide reality because it is fast, efficient, reliable and effective. Just how all this information is transmitted, stored, categorized and accessed remains a mystery to the average computer user.

This tutorial will explain the basics of some of the most popular technologies used in networking, and will include the following:

- Types of Networks – including LANs, WANs and WLANs
- The Internet and Beyond – The Internet and its contributions to intranets and extranets
- Types of LAN Technology – including Ethernet, Fast Ethernet, Gigabit Ethernet, 10 Gigabit Ethernet, ATM, PoE and Token Ring
- Networking and Ethernet Basics – including standard code, media, topographies, collisions and CSMA/CD
- Ethernet Products – including transceivers, network interface cards, hubs and repeaters

Types of Networks

In describing the basics of networking technology, it will be helpful to explain the different types of networks in use.

Local Area Networks (LANs)

A network is any collection of independent computers that exchange information with each other over a shared communication medium. Local Area Networks or LANs are usually confined to a limited geographic area, such as a single building or a college campus. LANs can be small, linking as few as three computers, but can often link hundreds of computers used by thousands of people. The development of standard networking protocols and media has resulted in worldwide proliferation of LANs throughout business and educational organizations.

Wide Area Networks (WANs)

Often elements of a network are widely separated physically. Wide area networking combines multiple LANs that are geographically separate. This is accomplished by connecting the several LANs with dedicated leased lines such as a T1 or a T3, by dial-up phone lines (both synchronous and asynchronous), by satellite links and by data packet carrier services. WANs can be as simple as a modem and a remote access server for employees to dial into, or it can be as complex as hundreds of branch offices globally linked. Special routing protocols and filters minimize the expense of sending data over vast distances.

Wireless Local Area Networks (WLANs)

Wireless LANs, or WLANs, use radio frequency (RF) technology to transmit and receive data over the air. This minimizes the need for wired connections. WLANs give users mobility as they allow connection to a local area network without having to be physically connected by a cable. This freedom means users can access shared resources without looking for a place to plug in cables, provided that their terminals are mobile and within the designated network coverage area. With mobility, WLANs give flexibility and increased productivity, appealing to both entrepreneurs and to home users. WLANs may also enable network administrators to connect devices that may be physically difficult to reach with a cable.

The Institute for Electrical and Electronic Engineers (IEEE) developed the 802.11 specification for wireless LAN technology. 802.11 specifies over-the-air interface between a wireless client and a base station, or between two wireless clients. WLAN 802.11 standards also have security protocols that were developed to provide the same level of security as that of a wired LAN. The first of these protocols is Wired Equivalent Privacy (WEP). WEP provides security by encrypting data sent over radio waves from end point to end point.

The second WLAN security protocol is Wi-Fi Protected Access (WPA). WPA was developed as an upgrade to the security features of WEP. It works with existing products that are WEP-enabled but provides two key improvements: improved data encryption through the temporal key integrity protocol (TKIP) which scrambles the keys using a hashing algorithm. It has means for integrity-checking to ensure that keys have not been tampered with. WPA also provides user authentication with the extensible authentication protocol (EAP).

Wireless Protocols

Specification	**Data Rate**	**Modulation Scheme**	**Security**
802.11	1 or 2 Mbps in the 2.4 GHz band	FHSS, DSSS	WEP and WPA
802.11a	54 Mbps in the 5 GHz band	OFDM	WEP and WPA
802.11b/High Rate/Wi-Fi	11 Mbps (with a fallback to 5.5, 2, and 1 Mbps) in the 2.4 GHz band	DSSS with CCK	WEP and WPA
802.11g/Wi-Fi	54 Mbps in the 2.4 GHz band	OFDM when above 20Mbps, DSSS with CCK when below 20Mbps	WEP and WPA

The Internet and Beyond

More than just a technology, the Internet has become a way of life for many people, and it has spurred a revolution of sorts for both public and private sharing of information. The most popular source of information about almost anything, the Internet is used daily by technical and non-technical users alike.

The Internet: The Largest Network of All

With the meteoric rise in demand for connectivity, the Internet has become a major communications highway for millions of users. It is a decentralized system of linked networks that are worldwide in scope. It facilitates data communication services such as remote log-in, file transfer, electronic mail, the World Wide Web and newsgroups. It consists of independent hosts of computers that can designate which Internet services to use and which of their local services to make available to the global community.

Initially restricted to military and academic institutions, the Internet now operates on a three-level hierarchy composed of backbone networks, mid-level networks and stub networks. It is a full-fledged conduit for any and all forms of information and commerce. Internet websites now provide personal, educational, political and economic resources to virtually any point on the planet.

Intranet: A Secure Internet-like Network for Organizations

With advancements in browser-based software for the Internet, many private organizations have implemented *intra*nets. An intranet is a private network utilizing Internet-type tools, but available only within that organization. For large organizations, an intranet provides easy access to corporate information for designated employees.

Extranet: A Secure Means for Sharing Information with Partners

While an intranet is used to disseminate confidential information *within* a corporation, an *extra*net is commonly used by companies to share data in a secure fashion with their business partners. Internet-type tools are used by content providers to update the extranet. Encryption and user authentication means are provided to protect the information, and to ensure that designated people with the proper access privileges are allowed to view it.

Types of LAN Technology

Ethernet

Ethernet is the most popular physical layer LAN technology in use today. It defines the number of conductors that are required for a connection, the performance thresholds that can be expected, and provides the framework for data transmission. A standard Ethernet network can transmit data at a rate up to 10 Megabits per second (10 Mbps). Other LAN types include Token Ring, Fast Ethernet, Gigabit Ethernet, 10 Gigabit Ethernet, Fiber Distributed Data Interface (FDDI), Asynchronous Transfer Mode (ATM) and LocalTalk.

Ethernet is popular because it strikes a good balance between speed, cost and ease of installation. These benefits, combined with wide acceptance in the computer marketplace and the ability to support virtually all popular network protocols, make Ethernet an ideal networking technology for most computer users today.

The Institute for Electrical and Electronic Engineers developed an Ethernet standard known as IEEE Standard 802.3. This standard defines rules for configuring an Ethernet network and also specifies how the elements in an Ethernet network interact with one another. By adhering to the IEEE standard, network equipment and network protocols can communicate efficiently.

Fast Ethernet

The Fast Ethernet standard (IEEE 802.3u) has been established for Ethernet networks that need higher transmission speeds. This standard raises the Ethernet speed limit from 10 Mbps to 100 Mbps with only minimal changes to the existing cable structure. Fast Ethernet provides faster throughput for video, multimedia, graphics, Internet surfing and stronger error detection and correction.

There are three types of Fast Ethernet: 100BASE-TX for use with level 5 UTP cable; 100BASE-FX for use with fiber-optic cable; and 100BASE-T4 which utilizes an extra two wires for use with level 3 UTP cable. The 100BASE-TX standard has become the most popular due to its close compatibility with the 10BASE-T Ethernet standard.

Network managers who want to incorporate Fast Ethernet into an existing configuration are required to make many decisions. The number of users in each site on the network that need the higher throughput must be determined; which segments of the backbone need to be reconfigured specifically for 100BASE-T; plus what hardware is necessary in order to connect the 100BASE-T segments with existing 10BASE-T segments. Gigabit Ethernet is a future technology that promises a migration path beyond Fast Ethernet so the next generation of networks will support even higher data transfer speeds.

Gigabit Ethernet

Gigabit Ethernet was developed to meet the need for faster communication networks with applications such as multimedia and Voice over IP (VoIP). Also known as “gigabit-Ethernet-over-copper” or 1000Base-T, GigE is a version of Ethernet that runs at speeds 10 times faster than 100Base-T. It is defined in the IEEE 802.3 standard and is currently used as an enterprise backbone. Existing Ethernet LANs with 10 and 100 Mbps cards can feed into a Gigabit Ethernet backbone to interconnect high performance switches, routers and servers.

From the data link layer of the OSI model upward, the look and implementation of Gigabit Ethernet is identical to that of Ethernet. The most important differences between Gigabit Ethernet and Fast Ethernet include the additional support of full duplex operation in the MAC layer and the data rates.

10 Gigabit Ethernet

10 Gigabit Ethernet is the fastest and most recent of the Ethernet standards. IEEE 802.3ae defines a version of Ethernet with a nominal rate of 10Gbits/s that makes it 10 times faster than Gigabit Ethernet.

Unlike other Ethernet systems, 10 Gigabit Ethernet is based entirely on the use of optical fiber connections. This developing standard is moving away from a LAN design that broadcasts to all nodes, toward a system which includes some elements of wide area routing. As it is still very new, which of the standards will gain commercial acceptance has yet to be determined.

Asynchronous Transfer Mode (ATM)

ATM is a cell-based fast-packet communication technique that can support data-transfer rates from sub-T1 speeds to 10 Gbps. ATM achieves its high speeds in part by transmitting data in fixed-size cells and dispensing with error-correction protocols. It relies on the inherent integrity of digital lines to ensure data integrity.

ATM can be integrated into an existing network as needed without having to update the entire network. Its fixed-length cell-relay operation is the signaling technology of the future and offers more predictable performance than variable length frames. Networks are extremely versatile and an ATM network can connect points in a building, or across the country, and still be treated as a single network.

Power over Ethernet (PoE)

PoE is a solution in which an electrical current is run to networking hardware over the Ethernet Category 5 cable or higher. This solution does not require an extra AC power cord at the product location. This minimizes the amount of cable needed as well as eliminates the difficulties and cost of installing extra outlets.

LAN Technology Specifications

Name	IEEE Standard	Data Rate	Media Type	Maximum Dista
Ethernet	802.3	10 Mbps	10Base-T	100 meters
Fast Ethernet/ 100Base-T	802.3u	100 Mbps	100Base-TX 100Base-FX	100 2000 meters
Gigabit Ethernet/ GigE	802.3z	1000 Mbps	1000Base-T 1000Base-SX 1000Base-LX	100 275/550 550/5000 meters
10 Gigabit Ethernet	IEEE 802.3ae	10 Gbps	10GBase-SR 10GBase-LX4 10GBase-LR/ER 10GBase-SW/LW/EW	300 300m MMF/ 10km/40km 300m/10km/40k

Token Ring

Token Ring is another form of network configuration. It differs from Ethernet in that all messages are transferred in one direction along the ring at all times. Token Ring networks sequentially pass a "token" to each connected device. When the token arrives at a particular computer (or device), the recipient is allowed to transmit data onto the network. Since only one device may be transmitting at any given time, no data collisions occur. Access to the network is guaranteed, and time-sensitive applications can be supported. However, these benefits come at a price. Component costs are usually higher, and the networks themselves are considered to be more complex and difficult to implement. Various PC vendors have been proponents of Token Ring networks.

Protocols

After a physical connection has been established, network protocols define the standards that allow computers to communicate. A protocol establishes the rules and encoding specifications for sending data. This defines how computers identify one another on a network, the form that the data should take in transit, and how this information is processed once it reaches its final destination. Protocols also define procedures for determining the type of error checking that will be used, the data compression method, if one is needed, how the sending device will indicate that it has finished sending a message, how the receiving device will indicate that it has received a message, and the handling of lost or damaged transmissions or “packets”.

The main types of network protocols in use today are: TCP/IP (for UNIX, Windows NT, Windows 95 and other platforms); IPX (for Novell NetWare); DECnet (for networking Digital Equipment Corp. computers); AppleTalk (for Macintosh computers), and NetBIOS/NetBEUI (for LAN Manager and Windows NT networks).

Although each network protocol is different, they all share the same physical cabling. This common method of accessing the physical network allows multiple protocols to peacefully coexist over the network media, and allows the builder of a network to use common hardware for a variety of protocols. This concept is known as “protocol independence,” which means that devices which are compatible at the physical and data link layers allow the user to run many different protocols over the same medium.

The Open System Interconnection Model

The Open System Interconnection (OSI) model specifies how dissimilar computing devices such as Network Interface Cards (NICs), bridges and routers exchange data over a network by offering a networking framework for implementing protocols in seven layers. Beginning at the application layer, control is passed from one layer to the next. The following describes the seven layers as defined by the OSI model, shown in the order they occur whenever a user transmits information.

Layer 7: Application

This layer supports the application and end-user processes. Within this layer, user privacy is considered and communication partners, service and constraints are all identified. File transfers, email, Telnet and FTP applications are all provided within this layer.

Layer 6: Presentation (Syntax)

Within this layer, information is translated back and forth between application and network formats. This translation transforms the information into data the application layer and network recognize regardless of encryption and formatting.

Layer 5: Session

Within this layer, connections between applications are made, managed and terminated as needed to allow for data exchanges between applications at each end of a dialogue.

Layer 4: Transport

Complete data transfer is ensured as information is transferred transparently between systems in this layer. The transport layer also assures appropriate flow control and end-to-end error recovery.

Layer 3: Network

Using switching and routing technologies, this layer is responsible for creating virtual circuits to transmit information from node to node. Other functions include routing, forwarding, addressing, internet working, error and congestion control, and packet sequencing.

Layer 2: Data Link

Information in data packets are encoded and decoded into bits within this layer. Errors from the physical layer flow control and frame synchronization are corrected here utilizing transmission protocol knowledge and management. This layer consists of two sub layers: the Media Access Control (MAC) layer, which controls the way networked computers gain access to data and transmit it, and the Logical Link Control (LLC) layer, which controls frame synchronization, flow control and error checking.

Layer 1: Physical

This layer enables hardware to send and receive data over a carrier such as cabling, a card or other physical means. It conveys the bitstream through the network at the electrical and mechanical level. Fast Ethernet, RS232, and ATM are all protocols with physical layer components.

This order is then reversed as information is received, so that the physical layer is the first and application layer is the final layer that information passes through.

Standard Ethernet Code

In order to understand standard Ethernet code, one must understand what each digit means. Following is a guide:

Guide to Ethernet Coding

10	at the beginning means the network operates at 10Mbps.
BASE	means the type of signaling used is baseband.
2 or 5	at the end indicates the maximum cable length in meters.
T	the end stands for twisted-pair cable.
X	at the end stands for full duplex-capable cable.

FL	at the end stands for fiber optic cable.

For example: *100BASE-TX indicates a Fast Ethernet connection (100 Mbps) that uses a twisted pair cable capable of full-duplex transmissions.*

Media

An important part of designing and installing an Ethernet is selecting the appropriate Ethernet medium. There are four major types of media in use today: Thickwire for 10BASE5 networks; thin coax for 10BASE2 networks; unshielded twisted pair (UTP) for 10BASE-T networks; and fiber optic for 10BASE-FL or Fiber-Optic Inter-Repeater Link (FOIRL) networks. This wide variety of media reflects the evolution of Ethernet and also points to the technology's flexibility. Thickwire was one of the first cabling systems used in Ethernet, but it was expensive and difficult to use. This evolved to thin coax, which is easier to work with and less expensive. It is important to note that each type of Ethernet, Fast Ethernet, Gigabit Ethernet, 10 Gigabit Ethernet, has its own preferred media types.

The most popular wiring schemes are 10BASE-T and 100BASE-TX, which use unshielded twisted pair (UTP) cable. This is similar to telephone cable and comes in a variety of grades, with each higher grade offering better performance. Level 5 cable is the highest, most expensive grade, offering support for transmission rates of up to 100 Mbps. Level 4 and level 3 cable are less expensive, but cannot support the same data throughput speeds; level 4 cable can support speeds of up to 20 Mbps; level 3 up to 16 Mbps. The 100BASE-T4 standard allows for support of 100 Mbps Ethernet over level 3 cables, but at the expense of adding another pair of wires (4 pair instead of the 2 pair used for 10BASE-T). For most users, this is an awkward scheme and therefore 100BASE-T4 has seen little popularity. Level 2 and level 1 cables are not used in the design of 10BASE-T networks.

For specialized applications, fiber-optic, or 10BASE-FL, Ethernet segments are popular. Fiber-optic cable is more expensive, but it is invaluable in situations where electronic emissions and environmental hazards are a concern. Fiber-optic cable is often used in inter-building applications to insulate networking equipment from electrical damage caused by lightning. Because it does not conduct electricity, fiber-optic cable can also be useful in areas where heavy electromagnetic interference is present, such as on a factory floor. The Ethernet standard allows for fiber-optic cable segments up to two kilometers long, making fiber-optic Ethernet perfect for connecting nodes and buildings that are otherwise not reachable with copper media.

Cable Grade Capabilities

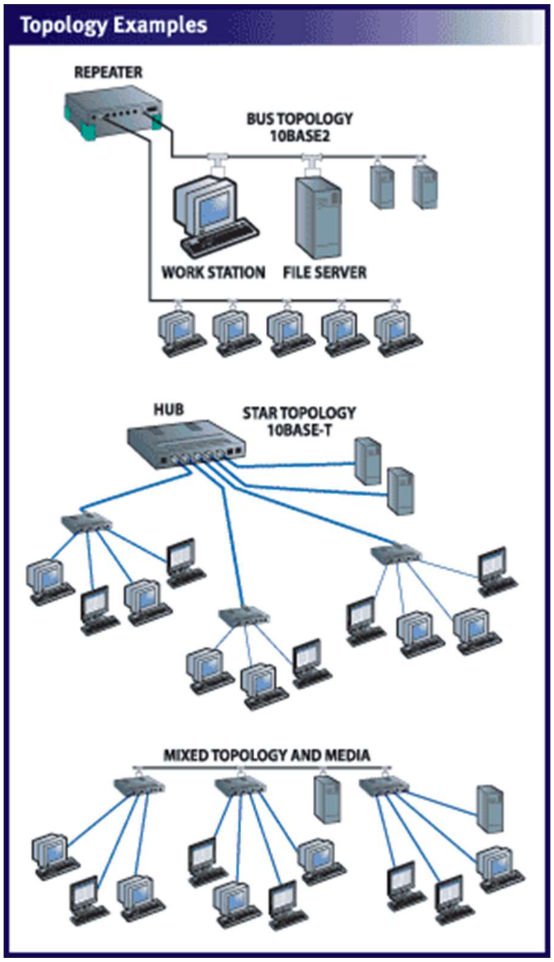
Cable Name	**Makeup**	**Frequency Support**	**Data Rate**	**Network Co**
Cat-5	4 twisted pairs of copper wire — terminated by RJ45 connectors	100 MHz	Up to 1000Mbps	ATM, Ring,1000Ba 100Base-TX

Cat-5e	4 twisted pairs of copper wire — terminated by RJ45 connectors	100 MHz	Up to 1000Mbps	10Base-T, 1000Base-T
Cat-6	4 twisted pairs of copper wire — terminated by RJ45 connectors	250 MHz	1000Mbps	10Base-T, 1000Base-T

Topologies

Network topology is the geometric arrangement of nodes and cable links in a LAN. Two general configurations are used, bus and star. These two topologies define how nodes are connected to one another in a communication network. A node is an active device connected to the network, such as a computer or a printer. A node can also be a piece of networking equipment such as a hub, switch or a router.

A bus topology consists of nodes linked together in a series with each node connected to a long cable or bus. Many nodes can tap into the bus and begin communication with all other nodes on that cable segment. A break anywhere in the cable will usually cause the entire segment to be inoperable until the break is repaired. Examples of bus topology include 10BASE2 and 10BASE5.



General Topology Configurations

10BASE-T Ethernet and Fast Ethernet use a star topology where access is controlled by a central computer. Generally a computer is located at one end of the segment, and the other end is terminated in central location with a hub or a switch. Because UTP is often run in conjunction with telephone cabling, this central location can be a telephone closet or other area where it is convenient to connect the UTP segment to a backbone. The primary advantage of this type of network is reliability, for if one of these 'point-to-point' segments has a break; it will only affect the two nodes on that link. Other computer users on the network continue to operate as if that segment were non-existent.

Collisions

Ethernet is a shared medium, so there are rules for sending packets of data to avoid conflicts and to protect data integrity. Nodes determine when the network is available for sending packets. It is possible that two or more nodes at different locations will attempt to send data at the same time. When this happens, a packet collision occurs.

Minimizing collisions is a crucial element in the design and operation of networks. Increased collisions are often the result of too many users on the network. This leads to competition for network bandwidth and can slow the performance of the network from the user's point of view.

Segmenting the network is one way of reducing an overcrowded network, i.e., by dividing it into different pieces logically joined together with a bridge or switch.

CSMA/CD

In order to manage collisions Ethernet uses a protocol called Carrier Sense Multiple Access/Collision Detection (CSMA/CD). CSMA/CD is a type of contention protocol that defines how to respond when a collision is detected, or when two devices attempt to transmit packages simultaneously. Ethernet allows each device to send messages at any time without having to wait for network permission; thus, there is a high possibility that devices may try to send messages at the same time.

After detecting a collision, each device that was transmitting a packet delays a random amount of time before re-transmitting the packet. If another collision occurs, the device waits twice as long before trying to re-transmit.

Ethernet Products

The standards and technology just discussed will help define the specific products that network managers use to build Ethernet networks. The following presents the key products needed to build an Ethernet LAN.

Transceivers

Transceivers are also referred to as Medium Access Units (MAUs). They are used to connect nodes to the various Ethernet media. Most computers and network interface cards contain a built-in 10BASE-T or 10BASE2 transceiver which allows them to be connected directly to Ethernet without the need for an external transceiver.

Many Ethernet devices provide an attachment unit interface (AUI) connector to allow the user to connect to any type of medium via an external transceiver. The AUI connector consists of a 15-pin D-shell type connector, female on the computer side, male on the transceiver side.

For Fast Ethernet networks, a new interface called the MII (Media Independent Interface) was developed to offer a flexible way to support 100 Mbps connections. The MII is a popular way to connect 100BASE-FX links to copper-based Fast Ethernet devices.

Network Interface Cards

Network Interface Cards, commonly referred to as NICs, are used to connect a PC to a network. The NIC provides a physical connection between the networking cable and the computer’s internal bus. Different computers have different bus architectures. PCI bus slots are most commonly found on 486/Pentium PCs and ISA expansion slots are commonly found on 386 and older PCs. NICs come in three basic varieties: 8-bit, 16-bit, and 32-bit. The larger the number of bits that can be transferred to the NIC, the faster the NIC can transfer data to the network cable. Most NICs are designed for a particular type of network, protocol, and medium, though some can serve multiple networks.

Many NIC adapters comply with plug-and-play specifications. On these systems, NICs are automatically configured without user intervention, while on non-plug-and-play systems, configuration is done manually through a set-up program and/or DIP switches.

Cards are available to support almost all networking standards. Fast Ethernet NICs are often 10/100 capable, and will automatically set to the appropriate speed. Gigabit Ethernet NICs are 10/100/1000 capable with auto negotiation depending on the user's Ethernet speed. Full duplex networking is another option where a dedicated connection to a switch allows a NIC to operate at twice the speed.

Hubs/Repeaters

Hubs/repeaters are used to connect together two or more Ethernet segments of any type of medium. In larger designs, signal quality begins to deteriorate as segments exceed their maximum length. Hubs provide the signal amplification required to allow a segment to be extended a greater distance. A hub repeats any incoming signal to all ports.

Ethernet hubs are necessary in star topologies such as 10BASE-T. A multi-port twisted pair hub allows several point-to-point segments to be joined into one network. One end of the point-to-point link is attached to the hub and the other is attached to the computer. If the hub is attached to a backbone, then all computers at the end of the twisted pair segments can communicate with all the hosts on the backbone. The number and type of hubs in any one-collision domain is limited by the Ethernet rules. These repeater rules are discussed in more detail later.

A very important fact to note about hubs is that they only allow users to share Ethernet. A network of hubs/repeaters is termed a "shared Ethernet," meaning that all members of the network are contending for transmission of data onto a single network (collision domain). A hub/repeater propagates all electrical signals including the invalid ones. Therefore, if a collision or electrical interference occurs on one segment, repeaters make it appear on all others as well. This means that individual members of a shared network will only get a percentage of the available network bandwidth.

Basically, the number and type of hubs in any one collision domain for 10Mbps Ethernet is limited by the following rules:

Network Type	**Max Nodes Per Segment**	**Max Distance Per Segment**
10BASE-T	2	100m
10BASE-FL	2	2000m