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Networks are classified on the basis of geographic span.

- Local Area Networks (LANs)
- Metropolitan Area Networks (MANs)
- Wide Area Networks (WANs)

The difference in geographical extent between WANs and LANs account for significant differences in their respective design issues.
Local Area Networks (LANs)
LAN Characteristics

- LANs are designed to:
  - Operate within a limited geographic area
  - Allow multi-access to high-bandwidth media
  - Control the network privately under local administration
  - Provide full-time connectivity to local services
  - Connect physically adjacent devices
LAN Characteristics

- All nodes are connected by a single high speed shared channel.
- Data is packetized and packets are carried past all nodes in the network.
LAN Characteristics

- **Transmission Medium**
  - Twisted pair, Coax, CATV, Fiber Optic, or Wireless.

- **Topology: Star, Bus, Ring**

- **Transmission method: Base vs Broadband**

- **Medium Access Technique**
  - Random Access (CSMA/CD)
  - Controlled Access (Token Passing)
LAN Characteristics (Cont.)

- Others
  - Type (Peer-to-Peer or Server-based)
  - Speed: in bits per second (bps)
  - Span: distance between end stations
  - Load: number of stations.
Server-Based LANs

- **Server-based:** A server-based network consists of a group of user-oriented PCs called clients that request and receive network services from specialized computers called servers.
Peer-to-Peer LANs

- **Peer-to-peer**: A peer-to-peer network is a group of user-oriented PCs that basically operate as equals. Each PC is called a peer. The peers share resources, such as files and printers, but no specialized servers exist. Each peer is responsible for its own security, and, in a sense, each peer is both a client and a server.
Peer-to-Peer Networking (Workgroup)

- Resources are distributed throughout the network on computer systems that may act as both service requesters and service providers.

- The user of each PC is responsible for the administration and sharing of resources for his PC.

- Ideal for small organizations where security is not of concern.
LAN Standards
MAC Standards

- **CSMA (Carrier Sense Multiple Access) Protocols**
- **CSMA/CD (Ethernet), Token Bus, Token Ring, FDDI, 100VG-AnyLAN**
- **Wavelength Division Multiple Access Protocols**
- **Wireless LAN Protocols**
CSMA/CD
(CSMA with Collision Detection)

- **CSMA/CD:**
  1. if the medium is idle, transmit; else, go to step 2.
  2. if the medium is busy, continue to listen until the channel is idle, then transmit.
  3. if a collision is detected during transmission, transmit a brief jamming signal.
  4. after transmitting a jamming signal, wait a random amount of time, then attempt to transmit.
Token Bus (IEEE 802.4)

- Disadvantages of IEEE 802.3 CSMA/CD:
  - Unpredictable delays
  - No support for priorities
- Physically, the token bus is a linear cable onto which stations are attached. Logically, stations are organized into a ring.
- A special control frame called token is transmitted from one station to the next, with each station knowing the addresses of the stations to its "left" and "right".
- Token bus defines four priority classes: 0, 2, 4, and 6 for traffic, with 0 the lowest and 6 the highest.
Token Bus (IEEE 802.4)
Token Ring

- IEEE 802.5 Medium Access Protocol
- The token ring technique is based on the use of a small frame, called a token that circulates.
  - A station wishing to transmit must wait until it detects a token passing by.
  - It then seizes the token by changing one bit in the token which transforms it from a token into a start-of-frame sequence for a data frame.
  - The station then appends and transmits the remainder of the fields needed to construct a data frame.
Note that under lightly loaded conditions, there is some inefficiency with token ring because a station must wait for the token to come around before transmitting.

Principal disadvantage of token ring is the token maintenance.
The 802.5 standard includes a specification for an optional priority mechanism. Eight levels of priority are supported by providing two 3-bit fields in each data frame and token: a priority field and a reservation field.

- **P(f):** priority of frame
- **P(s):** service priority; priority of current token
- **R(s):** reservation value in current token

- A station wishing to transmit must wait for a token with **P(s) <= P(f).**
- While waiting, a station may reserve a future token at its priority level **P(f).**
FDDI

● The FDDI standard specifies a ring topology operating at 100 Mbps.

● Optical fiber or twisted pair are used for medium.

  » Optical fiber uses 4B/5B NRZI encoding. Maximum length between repeaters is 2 km. Maximum number of repeaters is 100.

  » Two twisted pair media are specified: 100-ohm Category 5 unshielded twisted pair and 150-ohm shielded twisted pair. Maximum length between repeaters is 100m. Maximum number of repeaters is 100.
FDDI as a Campus Backbone

All of the protocols are converted to the FDDI transport protocol.

Data is Bridged/Routed from the high-speed Backbone to destination LAN.
FDDI Strengths

+ FDDI is tailor-made and very effective as a high-speed LAN for workstation traffic and as a Backbone for LANs.

+ Provides a framework for inter-networking between various LAN protocols.
FDDI Strengths (Contd.)

+ Compared to legacy LANs, FDDI provides greater data capacity and performance, transmitting at 100 Mbps.

+ Can accommodate large networks of up to 500 Backbone nodes.
FDDI Strengths (Contd.)

+ Because of its dual-ring architecture, FDDI offers a high degree of network availability & reliability.

+ Using Token passing, traffic is dealt with on a deterministic basis.

+ Provides long distance communication  
  (Ring perimeter can be 100 Km with a distance of up to 2Km between Stations)
FDDI Weaknesses

-- Can accommodate LAN traffic only. Not capable for transporting real-time signals (voice, host-to-terminal, etc.)

-- Non scaleable (fixed at 100 Mbps).

-- High implementation cost (Processor intensive).
How FDDI Works?

- It is a token passing fiber ring with a data rate of 100 Mbps.

- Ring can be as large as 100 Km with a distance of 2 Km between stations.

- Most prevalent standard is multi-mode fiber. However, some manufacturers are producing multi-mode to single-mode FDDI adapter.
How FDDI Works? (Contd.)

- Others proposed amendments to the standard to support FDDI on twisted pair (CDDI).

- Routers are used to convert competing LAN protocols to FDDI and back.
How FDDI Works? (Contd.)

- Dual-counter rotating rings:
  - Primary link for carrying data.
  - Secondary link for failure recovery.

- In the event of a node or cable failure, the data on the primary link wraps on to the secondary link, making a U-turn, thus maintaining ring integrity.
How FDDI Works? (Contd.)
FDDI Specification

- ANSI Standard.
- Ring as large as 100 Km with a distance of 2 Km between stations.
- 62.5 μ core / 125 μ cladding.
- 1300 nano-meter LED transmitter
- Two types of FDDI networking devices:
  » Class A devices have dual attachment.
  » Class B are typically workstations.
FDDI Specification

- **Class A Devices**
  
  » To exploit counter-rotating rings. The failure wrapping feature is implemented through Class A devices.
  
  » Can be any networking device, but are usually **Bridges, Routers, Concentrators, Servers, or other devices comprising the network Backbone**.
Class A Devices (Contd.)

» Each dual-attached station constantly receives Handshaking information from its neighbors via the secondary link.

» If station stops receiving Handshaking information, it wraps data from the primary to the secondary ring so that the disabled node is avoided and ring integrity is maintained.
FDDI Specification (Contd.)

- **Class B Devices**
  - They are single-attached stations.
  - They are typically workstations, printers, and other nodes that are attached only indirectly to the primary link.
  - They access the ring by plugging into a concentrator that is dual-attached to the ring.

- **An FDDI network can operate with up to 500 dual-attached stations.**
FDDI Specification (Contd.)
100VG-AnyLAN

- Intended to be a 100 Mbps extension to the 10 Mbps Ethernet and to support IEEE 802.3 frame types.
- Uses a MAC scheme known as demand priority; it has been standardized under IEEE 802.12.
  » Its MAC algorithm is a round-robin scheme with two priority levels.
- Single-Hub Network
  » When a station wishes to transmit a frame, it first issues a request to the central hub and then awaits permission from the hub to transmit.
A station must designate each request as normal-priority or high-priority.

The central hub continually scans all of its ports for a request in round-robin fashion.

The central hub maintains two pointers: a high-priority pointer and a normal-priority pointer.

If at any time there are no pending high-priority requests, the hub will grant any normal-priority requests that it encounters.
Hierarchical Network

- All of the end-system ports on all hubs are treated as a single set of ports for purposes of round-robin.
- Port ordering is done **preorder traversal**:
  - Visit the root
  - Traverse the subtrees from left to right.
Hierarchical topology

- There is a single root Hub (at level 1)
- A level 1 Hub may have one or more subordinate level 2 hubs
- A level 2 hub can have one or many subordinate level 3 hubs, and so on, to an arbitrary depth

Hub is responsible for converting between 802.3 and 802.5 frame formats if necessary
Example 100VG-AnyLAN Configuration

100VG-AnyLAN Hub

10/100 Ethernet

100VG-AnyLAN Hub

Bridge

100VG-AnyLAN Hub

Ethernet LAN
The MAC algorithm for 802.12 is a round-robin scheme with two priority levels.

A station wishing to transmit:
- it first issues a request to the central hub
- it then awaits permission from the hub to transmit
- A station must designate each request as normal priority or high priority.
The central hub continually scans all of its ports for request in round-robin fashion.

The hub maintains two pointers:
- a high priority pointer and
- a low priority pointer

During one cycle, the hub grants each high priority request in the order encountered.

When there are no pending high priority requests, the hub grants normal priority requests in the order encountered.
100VG-AnyLAN Priority Scheme

If a request remains in the normal priority buffer for too long (default= 500 ms), it is moved to the corresponding position in the high-priority buffer.
Hierarchical LAN

- The set of all hubs are treated logically as one single hub
  - The port order is generated by performing a pre-order traversal of the tree (depth-first)
    - Visit the root
    - Traverse the subtrees from left to right
  - Each hub is running its own round-robin algorithm to service end-systems directly attached to it.
Port Ordering in a Two-Level IEEE 802.12 Network

Level 1 “Root” Repeater

- Level 1: "Root" Repeater
  - Port 1-1
  - Port 1-2
  - Port 1-4
  - Port 1-6
  - Port 1-7

- Level 2: Repeater
  - Port 3-1, 3-2, ..., 3-k
  - Port 5-1, 5-2, ..., 5-n

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LAN and WAN Standards/Habib Youssef
Frame Sequence in a Single-Repeater Network

1. High priority request
2. Normal priority request
3. High priority request
4. Normal priority request
5. High priority request
6. Normal priority request
7. High priority request
8. Normal priority request

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IEEE 802.3 CSMA/CD Labeling Terminology

IEEE 802.3 CSMA/CD

100BASE-X

100BASE-TX
Two Category 5 UTP

100BASE-FX
Two Optical Fiber

100BASE-T4
Four Category 3 or Category 5 UTP

April 1999
LAN and WAN Standards/Habib Youssef
45
### 3 100BASE-T Physical Layer Medium Alternatives

<table>
<thead>
<tr>
<th></th>
<th>100BASE-TX</th>
<th>100BASE-FX</th>
<th>100BASE-T4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transmission medium</strong></td>
<td>Two pair STP</td>
<td>Two pair cat 5 UTP</td>
<td>Two optical fibers</td>
</tr>
<tr>
<td></td>
<td>4B5B, NRZI</td>
<td>4B5B, NRZI</td>
<td>Four pair, cat 3, 4 or 5 UTP</td>
</tr>
<tr>
<td><strong>Signaling technique</strong></td>
<td></td>
<td></td>
<td>8B6T, NRZ</td>
</tr>
<tr>
<td><strong>Data rate</strong></td>
<td>100 Mbps</td>
<td>100 Mbps</td>
<td>100 Mbps</td>
</tr>
<tr>
<td><strong>Max. Segment length</strong></td>
<td>100 m</td>
<td>100 m</td>
<td>100 m</td>
</tr>
<tr>
<td><strong>Network Span</strong></td>
<td>200 m</td>
<td>200 m</td>
<td>400 m</td>
</tr>
</tbody>
</table>

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April 1999    LAN and WAN Standards/Habib Youssef  46
Wavelength Division Multiple Access Protocols

- Are used on fiber optic LANs in order to permit different conversations to use different wavelengths (frequencies) at the same time. (wavelength X frequency = speed of light)

- A simple way to build an all optical-LAN is to use a passive star.

- To allow multiple transmissions at the same time, the spectrum is divided up into channels (wavelength bands)

- Each station is assigned two channels: one as a control channel to signal the station, and the other for the station to output data frames.
Wireless LANs

- **IEEE 802.11** has developed a set of wireless LAN standards.
- A system of portable computers that communicate by radio (or infrared) signals is regarded as a wireless LAN.
- **Three physical media** are defined in 802.11:
  - Infrared at 1 Mbps and 2 Mbps operating at a wavelength between 850 and 950 nm.
  - Direct-sequence spread spectrum operating in the 2.4-GHz. Up to 7 channels, each with a data rate of 1 Mbps or 2 Mbps.
  - Frequency-hopping spread spectrum operating in the 2.4 GHz.
Wireless LANs (cont)

- IEEE 802.11: **CSMA/CA** (CSMA with collision avoidance).
  - Sender to stimulate the receiver into outputting a short frame, so stations nearby can detect this transmission and avoid transmitting themselves for the upcoming large data frame. Sender sends an **RTS (Request To Send)** frame. Receiver replies with a **CTS (Clear To Send)** frame.
  - An **ACK** frame is sent after each successful data frame.
  - **Binary exponential backoff algorithm** is used if a transmitter does not hear anything from receiver.
Wide Area Networks (WANs)
WANs

- **WANs** cover a large geographical area.

- To make optimum use of expensive communication links, WANs are structured with irregular placement of the nodes. Store-and-Forward packet switching is used to deliver packets to their destination.
WANs
WANs (contd.)

- Traditionally, WANs have been implemented using one of two technologies: circuit switching and packet switching. Recently, frame relay and ATM networks have assumed major roles.
  - **Circuit switching**: a dedicated communication path is established between two stations through the nodes of the network. Example: the telephone network.
  - **Packet switching**: At each node, a packet is received, stored briefly, and then transmitted to the next node. Example: X.25 network
  - To compensate errors, there is a considerable amount of overhead built into the packet-switched schemes.
Packet and Circuit switching
WANs are deployed over the existing telecommunications infrastructure using technologies such as:

» Leased line services.
» Switched services.
» Packet services.
» Cell-based services.
» Shared-media services.
Leased-line services

- Leased lines are digital or analog telephone lines dedicated exclusively to the use of the lessee.
  - T1: 24 multiplexed channels at 64 Kbps each.
  - E1: 30 multiplexed channels at 64 Kbps each.
  - T2: multiplexes 4 T1 data streams.
  - T3: carries 672 multiplexed channels.
  - Fractional T1 services.
Switched Services

- Switched services are dial-up point-to-point communication lines through the PSTN.
- End station should communicate at the same speed.
- Examples:
  - Modems.
  - Switched 56 Kbps service (CSU/DSU).
  - Switched ISDN.
Packet Service

- Public Data Networks (X.25) use packet-switching protocols for worldwide data transfer between computers.
- The two end stations can communicate at different data rates.
- Examples:
  - Frame Relay (CSU/DSU).
  - X.25.
  - ISDN.
Shared Media

• Examples:
  » Cable Modems, and
  » Satellite links.
PPP Protocol

- Point-to-point protocol provides physical layer and Data Link Layer functionality.
- PPP provides the following features:
  - Simultaneous support for multiple protocols on the same link.
  - Dynamic IP addressing.
  - Error control.
DCE/DTE Interfaces

- **DCE**: Data circuit-terminating equipment. It is a female interface.
  - Modems have DCE serial interface.
- **DTE**: Data terminal equipment. It is a male interface.
  - Terminals, PCs, Routers have DTE serial interfaces.
Communication over a Dial-up Connection

- A serial point-to-point link is established.
- Datagrams are transmitted over the serial point-to-point links using the ppp (point-to-point protocol) protocol.
**PPP Frame Format**

<table>
<thead>
<tr>
<th>Field length in bytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>Flag</td>
</tr>
</tbody>
</table>

Flag: 01111110 beginning or end of a frame

Address: 11111111 (Standard broadcast domain)

Control: 00000011 transmission of data rate

Protocol: identifies the protocol encapsulated
Establishment of communications over a point-to-point link

- A physical link is established.
- Install ppp encapsulation.
- PPP sends LCP (Link Control Protocol) packets to configure the data link.
- PPP sends NCP (Network Control Protocol) packets to configure network layer protocols.
- Datagrams from each network-layer protocol can be sent over the link.
**X.25 Networks**

- **Was developed during 1970s** by CCITT to provide an interface between public packet-switched networks and their customers. X.25 calls for three layers of functionality: physical layer, data link layer, and packet (or network) layer.

- **The physical layer protocol, called X.21**, specifies the physical, electrical, and procedural interface between the host and the network.

- **Very few public networks actually support this standard.** It requires digital, rather than analog signaling on the telephone lines.
X.25 Networks (contd)

- The **data link layer** protocol deals with transmission errors on the telephone line between the user’s equipment (host or terminal) and the public network (router).
- The **network layer** protocol deals with addressing, flow control, delivery confirmation, interrupts, and related issues.
  - Establishes virtual circuits and sends packets of up to 128 bytes on them. These packets are delivered reliably in order.
  - Most X.25 networks work at speeds up to 64 kbps
- Both data link layer and network layer include flow control and error control mechanisms.
X.25 Networks (contd)

- X.25 is connection-oriented. At network layer, X.25 provides multiplexing: a DTE is allowed to establish up to 4095 simultaneous virtual circuits with other DTEs over a single physical DTE-DCE link.
- X.25 supports both switched virtual circuits and permanent ones.
- A switched virtual circuit is created when one computer sends a packet to the network asking to make a call to a remote computer.
  - Once established, packets are sent over the connection, always arriving in order.
  - X.25 provides flow control, to make sure a fast sender cannot swamp a slow or busy receiver.
X.25 Networks (contd)

- **A permanent virtual circuit**
  - is used the same way as a switched one, but it is set up in advance by agreement between the customer and the carrier.
  - It is always present, and no call setup is required to use it. It is analogous to a leased line.

- If the user terminal does not speak X.25, then the terminal is connected to a “black box” called a **PAD (Packet Assembler Disassembler)** whose function is defined in the document X.3.
  - The protocol **X.28** is defined between terminal and PAD.
  - The protocol **X.29** is defined between PAD and the network.
WANs (cont)

- **Frame relay** was developed to take advantage of high data rates and low error rates that are available in modern high-speed communication systems. It operates efficiently at user data rates up to 2 Mbps. It uses variable-length packets, called frames.

- **ISDN** is intended to be a worldwide public telecommunications network to replace existing public telecommunications networks and deliver a wide variety of services.
  - Narrowband ISDN
  - Broadband ISDN (B-ISDN)
WANs (cont)

- **ATM (Asynchronous Transfer Mode):**
  - Is a culmination of all of the developments in circuit switching and packet switching.
  - Can be viewed as an evolution from frame relay.
  - ATM uses fixed-length packets, called cells.
Frame Relay

- **Frame relay** is designed to eliminate much of the overhead that X.25 imposes on end-user systems and on the packet-switching network.

- **Frame relay** can best be thought of as a virtual leased line on which data bursts may be sent at full speed, but the long-term average usage must be below a predetermined level. Therefore, the carrier charges much less for a virtual line than a physical one.

- **Frame relay** competes with leased lines and X.25 permanent virtual circuits, except that frame relay operates at higher speeds.
Frame Relay (cont.)

- Frame Relay offers data transfer rates from 56 Kbps to T1 or E1 speed.
- Frame Relay networks are used to interconnect individual LANs into a WAN.
- A CSU/DSU provides the interface between the subscriber’s computer equipment and the telephone line.
The principal disadvantage of frame relay, compared to X.25, is that we lost the ability to do **link-by-link** flow and error control.

---

**Packet-switching**

1. Source
2. Destination
3. Source
4. Destination
5. Source
6. Destination
7. Source
8. Destination
9. Source
10. Destination
11. Source
12. Destination
13. Source
14. Destination
15. Source
16. Destination

---

**Frame relay**

2. Source
3. Destination
4. Source
5. Destination
6. Source
7. Destination
8. Source
9. Destination
10. Source
11. Destination
12. Source
13. Destination
14. Source
15. Destination
16. Source

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April 1999

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### Frame Relay Frame Format

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>Variable</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flags</td>
<td>Address</td>
<td>Data</td>
<td>FCS</td>
<td>Flags</td>
<td></td>
</tr>
</tbody>
</table>

10 bits of the bytes Address field comprise the actual circuit ID (called the DLCI, for *data link connection identifier*).
ISDN, B-ISDN, and ATM

- Telephone companies are faced with a fundamental problem: maintaining multiple networks. Also, want to control cable television network.
- The solution was to invent a single new network that will replace the entire telephone system and all the specialized networks.
- The new wide area service is first called ISDN (Integrated Services Digital Network) that has as its primary goal the integration of voice and nonvoice services.
Narrow Band-ISDN

- The ISDN bit pipe supports multiple channels interleaved by time division multiplexing. Several channel types have been standardized:
  - A: 4-kHz analog telephone channel
  - B: 64-kbps digital PCM channel for voice or data
  - C: 8-kbps or 16-kbps digital channel
  - D: 16-kbps digital channel for out-of-band signaling
  - E: 64-kbps digital channel for internal ISDN signaling
  - H: 384-kbps, 1536-kbps, or 1920-kbps digital channel

- Three combinations of channels:
  - Basic rate: 2B+1D
  - Primary rate: (1) 23B+1D (U.S. and Japan), (2) 30B+1D (Europe)
  - Hybrid: 1A+1C
B-ISDN and ATM

- **B-ISDN** offers video on demand, live television from many sources, full motion multimedia, electronic mail, CD-quality music, LAN interconnection, high-speed data transfer.

- The transfer mode of **B-ISDN ATM** (Asynchronous Transfer Mode).

- **ATM** is the standard technology for **switching and multiplexing** in B-ISDN.
How ATM Works?

- **Data Units:** Fixed-length cells of size 53 bytes each (5 Header + 48 payload).
- **Operates at the equivalent of MAC sublayer.** Operates above physical layer which could be SONET, Fibre channel,...
- **Connection-oriented.**
- **Layered architecture.**
ATM Layered Architecture

- Higher Layers
  - User Services & applications
  - ATM Adaptation Layer
    - Fragmentation and de-fragmentation of frames
    - Cell header insertion/removal
    - Cell relaying & multiplexing
    - Connection establishment
  - Physical Medium Dependent Layer
    - Transmission & receipt of bits
    - Synchronization
How ATM Works?

Data packet

AAL

ATM

Physical Layer
How ATM Works (Contd.)?

Entire process is reversed
B-ISDN and ATM (contd)

- ATM networks are organized like traditional WANs, with lines and switches (routers).
- The intended speeds for ATM networks are **155.52 Mbps** and **622.08 Mbps** to make them compatible with SONET that is the standard used on fiber optic links.
- ATM uses **cell switching** because
  - it is highly flexible can handle both constant rate traffic (audio, video) and variable rate traffic (data) easily,
  - at the very high speeds, digital switching of cells is easier than using traditional multiplexing techniques, especially using fiber optics
  - cell switching can provide broadcasting, circuit switching cannot.
ATM Backbone

ATM Backbone

ATM-Attached Client

ATM-Attached Servers

LAN Attached Clients

Workstation
Internet

- Is a large collection of interconnected networks, all of which use TCP/IP protocol suite
- Began with the development of ARPANET in 1969 (ARPA: Advanced Research Project Agency)
- ARPANET protocols were not suitable for running over multiple networks. This led to the invention of the TCP/IP model and protocols by Cerf and Kahn in 1974.
- TCP/IP became the only official protocol on Jan. 1, 1983. The glue that holds the Internet together is the TCP/IP protocol stack.
A machine is on the Internet if it runs the TCP/IP protocol stack, has an IP address, and can send IP packets to any machine on the Internet.

Until the early 1990s, Internet users were academic, industrial, and government researchers. But, WWW (World Wide Web) brought millions of nonacademic users.

WWW made the underlying facilities of the Internet easier to use.