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ELEC S332
Computer Networks
(Free Courseware)

香港公開大學
THE OPEN UNIVERSITY OF HONG KONG

Contents

Chapter 1 Introduction to Computer Networks

1.1 About this module

Welcome to this free courseware module 'Introduction to computer networks'!

This module is taken from the OUHK course *ELEC S332 Computer Networks (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&lang=eng&ncode=ELEC%20S332&shopping=Y&TYPE=CI&CODE=CT332)*, a ten-credit, higher-level course that forms the core of a number of degree programmes (Computing and Networking, Communications Technology, Communications Technology with Management; and Computer Engineering) offered by the School of Science and Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcSubWeb&l=C_ST&lid=191133000200&lang=eng) of the OUHK. *ELEC S332* is designed to provide a step-by-step approach to grasping the basic concepts of computer networks and their applications in everyday life. The course adopts the 5-layer Internet model and makes use of the widely used Internet-related protocols to explain the different layers of practical computer networks.

ELEC S332 is mainly presented in printed format and comprises 10 study units. Each unit contains study content, activities, self-tests, assigned readings, etc for students' self-learning. This module (The materials for this module, taken from the print-based course ELEC S332, have been specially adapted to make them more suitable for studying online, and multimedia elements have been added where appropriate. In addition to this topic on 'Introduction to computer networks', which is an extract from Unit 1 of the course, the original Unit 1 also includes the topic 'Protocols and standards', 'Layered tasks', 'Brief history and present status of the Internet' and 'Overview of the five-layer Internet model and the seven-layer OSI model'.) retains most of these elements, so you can have a taste of what an OUHK course is like. Please note that no credits can be earned on completion of this module. If you would like to pursue it further, you are welcome to enrol in *ELEC S332 Computer Networks (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&lang=eng&ncode=ELEC%20S332&shopping=Y&TYPE=CI&CODE=CT332)*.

This module will take you about eight hours to complete, including the time for completing the activities and self-tests (but not including the time for assigned readings). Owing to copyright issues, textbook and assigned readings are not included in the free courseware.

Good luck, and enjoy your study!

1.2 Introduction

Welcome to *ELEC S332 Computer Networks*.

Nowadays, everyone is using the Internet. We have hooked our computers to the Internet, where we can access information and transmit messages. The Internet is a very large computer network. Computer networks are so important in our daily life that they have become indispensable to us.

The closest cousin of a computer network is a transportation network, but computer networks are now taking work away from the transportation networks. Transportation networks — like traffic engineering — had a body of knowledge that could readily be applied to computer networks. For example, we used to rely on sending letters to communicate with friends and relatives living far away. All these letters needed to use transportation vehicles such as trucks, ships or aeroplanes. Now, many letters have been replaced by electronic mail (e-mail). Computer networks deliver e-mails, thereby reducing the work of physically delivering letters through the transportation network.

Computer systems, including both hardware and software, emerged as big machines called mainframe computers. In the 1960s, mainframe computers were accommodated inside a computer room. Cables ran from this room to connect to the terminals of the end users. In the late 1970s, mini computers became affordable. They challenged the mainframe computer. In the early 1980s, affordable personal computers (PCs) also came onto the market, challenging both mainframe and mini computers. PCs allowed end users to get the benefits of tremendous computing power at an affordable price.

During the initial adoption of PCs, data transfer between personal computers was done through 5¼-inch floppy disks. People then saw the need to connect all these mini and personal computers together. Physical cables were used to link them. The connected computers, together with the cable links, formed a network, though the distance between these connected computers was usually relatively short. The computers were 'local' to a particular office location, and hence this type of configuration was called a local area network (LAN). LANs were originally targeted to meet the data transfer requirements for PCs within a private company, and also originally used for data, not voice traffic. Hence, there was little motivation to connect the LAN to a public telephone or telecom network.

The need for distributed computing arose after more end users had been educated in using a personal computer. The proliferation of the Internet pushed to break through this private network 'barrier' to allow connection of every computer through the standard Internet interface. With the advancement of Internet technologies, networks can now support various services including e-mail, Web browsing, multimedia communication, real-time voice communication and video streaming.

But what is a network, exactly? How does it really work? In this module, we will discuss about the importance and the basic concepts of computer networks.

1.3 Importance of computer networks

Both computers and computer networks are indispensable to us now. All workplaces contain computers, and they are invariably interconnected. If they are connected via a LAN, they can communicate with other computers. In most residential flats, computers are connected to the Internet through dial-up or broadband connections for e-mail, Web browsing, and the like.

Apart from at home and in the office, computer networks are present in all mass transport systems for the smooth operation of ticketing systems, carriage signalling, and safety protection and performance analysis. Doing business requires computer networks as well. When we eat or shop, computer networks come in to connect the ordering, inventory and payment systems.

The administration of a country or a city also needs computers and computer networks. For example, computer networks are required to allow access to information, including citizen and business registration information, at different government offices. Computer networks are required to support checking our identity at border control points, and for operating traffic lights

Computer networks have the following three goals:

- **Overcoming geographic separation**
  Computer networks overcome geographical separation in a city and across countries. Computers that need to communicate with other computers are often located in different parts of the world, and they need computer networks to pass information across long distances to overcome that geographical separation.
- **Allowing information sharing**
  Computer networks allow information sharing by allowing connected people or computers to access information on databases distributed in different locations. There are databases hosted on many computers. People or computers may need to access the data in these databases. Without a computer network, it would take a long time to select and transport the required data from the database to the requiring users. With computer networks, we can conveniently access the databases to retrieve data.
- **Supporting distributed processing**
  Computer networks support processing distributed in different locations. These different locations can be physically close together inside a single computer room, or they can be separated by a long distance across mountains and oceans. Physical transportation of the intermediately processed data is impractical. Hence, a computer network becomes indispensable in distributed processing. It allows timely passing of semi-processed data between computers located in distributed locations.

Computer networks have indeed become indispensable now. Hence we need to study computer networks in terms of their basic components, their architecture and how they support the Internet applications in a typical enterprise. All of these affect our daily life.

1.4 Data communications basics

In a transportation network, we transport goods. In a computer network, we transport data, so we study data communications, and how data are transmitted from one computer and received by another.

In a transportation network, traffic can move in two directions between a sender and a receiver. In Hong Kong, most roads carry two-way traffic, but there are some roads that allow only one-way traffic. If there is roadwork in progress, a single lane may be shared between up and down traffic.

Similarly, in regard to data communications in computer networks, in general data can flow in both directions:

- If a link allows only a single direction of data flow, we call this *simplex* communication.
- If a link allows two-way data flow *simultaneously*, we call this *full-duplex* communication.
- If it allows two-way data flow, in *one direction at a time but not simultaneously*, we call this *half-duplex* (or semi-duplex) communication.

You will get an overview of data communications and networking in your first reading. You will learn about the *five* key components of data communication first. Then you will learn about data representation such as text, numbers, audio, and video. Lastly, you will learn more about *simplex, half-duplex* and *full-duplex* data flows.

At the end of the reading, you should be able to explain the importance of computer networks in the modern information society. You should be able to discuss what constitutes effective data communication, and match the conceptual components of data communication and data representation with those in practical implementation.

Reading

Read section 1.1, pp. 3–7, in Forouzan (your textbook).

You should now understand the five components of data communication, namely *message, sender, receiver, medium* and *protocol*. In short, the sender sends a message to the receiver over a medium using a communication *protocol* between the sender and receiver. The protocol is essential to ensure consistent interpretation of the message on the sender and receiver sides. The message can include different data representations, e.g. text, images, audio, and video to name a few.

Data flow can be categorized into *simplex, half-duplex,* or *full-duplex*, as shown in Figure 1.1.

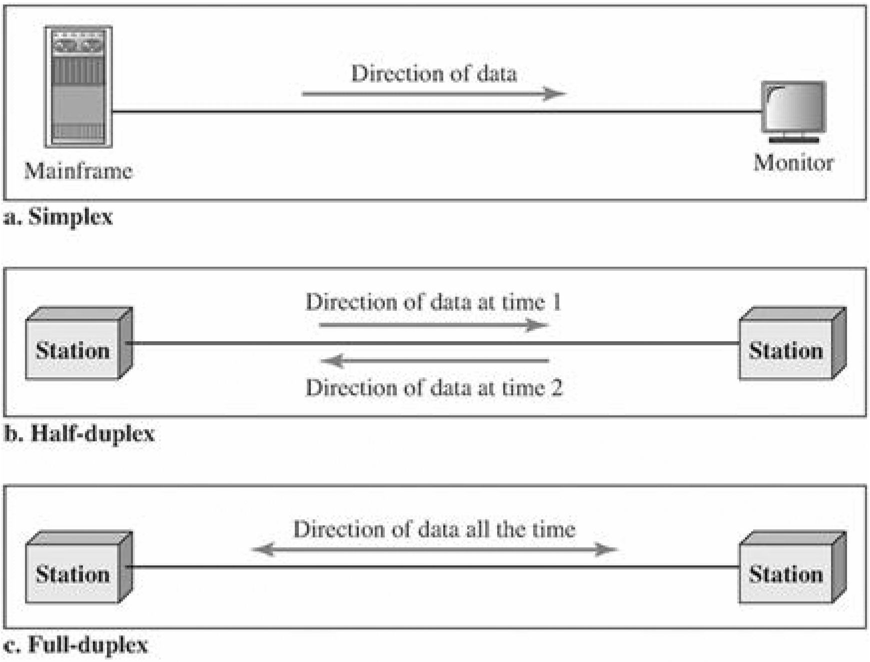


Fig. 1.1: Data flow (simplex, half-duplex, and full-duplex) (Forouzan 2007, 6)

An analogy between a transportation network and a computer network is summarized in Table 1.1.

Transportation network	Computer network
Cities, sender or receiver	Computer, sender or receiver
Letter, goods	Message, data
Physical roads (pathways)	Medium (channels)
Agreed packing and unpacking method	Protocol
One-way traffic	Simplex
Time-shared single lane for both traffic directions	Half-duplex
Both traffic directions allowed simultaneously	Full-duplex

Table 1.1: Analogy between a transportation network and a computer network

Now please try Activity 1.1 (Page 6) to learn more about data communication.

1.4.1 Activity 1.1

1. Common communication and information devices that we use daily are listed in the table below. Identify their attributes in the following table.

Communication or information devices	Message content: text/video/audio/image	Data flow: simplex/half-duplex/full-duplex	Network connected: fixed telephone/mobile telephone/coaxial network/wireless broadcast
Telephone			
Fax			
Mobile voice			
Personal digital assistant with wireless access			
Personal computer			
Television broadcasting			
Radio broadcasting			
pager			

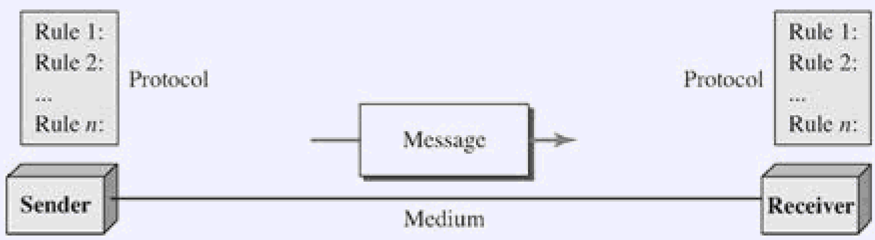
1.4.2 Self-test 1.1

1. Draw a diagram to capture all the five components of data communication. Explain the relationships among them.
2. Explain the importance and the functioning of protocols in data communications.
3. Explain the relationship between computer and network, and the effect of this relationship with the advent of distributed processing.
4. Match the following three pairs.

A. Simplex	1. internet access
B. Half-duplex	2. Sending stock information to pager
C. Full-duplex	3. Push-to-talk walkie-talkie

1.4.2.1 Self-test 1.1 feedback

1. The *sender* sends a message to the *receiver* over a medium, using a common agreed-upon *protocol* for the interpretation of the message content.



(Forouzan 2007, 4)

2. Protocol is important to data communications as the sender and the receiver should know the correct format in which to send the message via the medium, and should know how to interpret the message content. Protocols are present in the telephone network, in data communication, and on the Internet.
3. Computers are used to build modern networks, and the network is used to serve the computer by linking up the computer servers and the computer terminals. This is a vicious cycle. The advent of distributed processing deepens this vicious cycle. Before the advent of distributed processing, a computer network was used mainly to connect a mainframe computer to its terminals, or to link up big computers for data exchange. With the advent of distributed processing, intermediate processed data are passed between hosts on the computer network.
4.

A. Simplex	2. Sending stock information to pager
B. Half-duplex	3. Push-to-talk walkie-talkie
C. Full-duplex	1. Internet access

1.5 Network basics

As discussed earlier, networks are used to connect communication parties — the senders and the receivers. The communication relationships among these parties are different in different scenarios. In a *broadcast* network, there is *one sender*, but there are *many receivers*. The communication is one-way — that is, it's a simplex transmission. In most data communication sessions, there is one sender and one receiver. In a telephone conference call, there is a group of people who are both senders and receivers. In the following, we will focus on the common case of one-to-one communication.

A network is made of components of **nodes** and **links**. Let's explore some properties of the transportation network and the computer network.

nodes
A node is the device where two or more links are terminated (or 'originate'). A node serves to switch from an incoming link to an outgoing link. The nodes are sometimes referred to as*switching* or *routing hubs.*

links
A link is a connection between two nodes. The two nodes so connected become adjacent nodes. A link serves to connect, or to link up, the two nodes when there is a need for data flow between the two nodes. The links are sometimes referred to as*transmission links* or *channels*.

The need for network

- **Transportation network**
  Using a transportation network as an example, if there were only isolated villages, each of which was self-sufficient, there would only be a need for small paths within each village. There would be a limited need for roads to connect a village to the outside world. With the development of the economy with specialization and division of labour, some villages grow into cities with more people and business activities. We begin to need roads to carry raw material, goods and people around between cities and villages.

- **Computer network**
  The same is true for computer networks. If there were no demand for data transfer between computers, there would be no computer networks. But we have big computers that need connections to other computers or terminals. Hence, there is a need for a computer network. With more specialization of processing in different computers, the need for a computer network grows. The processing of data is distributed among different computers, and semi-processed data are passed between computers. This is called *distributed processing*, which has become common nowadays.

Network criteria

- **Transportation network**
  A transportation network has criteria of *performance*. For example, one key performance parameter of a highway is the time a car takes to travel between the two connected cities. Of course, it depends on the length of the road, the speed limit allowed, and other factors like traffic conditions. A transportation network has other criteria such as *reliability* and *security*. A highway is reliable if there is no failure or breakdown, and drivers can use its service under all circumstances, even during extreme weather conditions. A highway is secure if external unauthorized access can be denied and, if there is an accident, it will be quickly identified, isolated, and controlled so as not to affect normal traffic flow.
- **Computer network**
  Similarly, a computer network has criteria of performance, reliability and security. One key performance parameter is the *transit time* between the two connected computers. This depends on the speed of the transmission medium and other factors like the number of simultaneous users. A computer network has the other criteria of *reliability* and *security* too. A computer network is reliable if it is available whenever the users want service. This means there is no breakdown, and even if there is a breakdown, it should be able to recover from the breakdown within the shortest time. Computer security covers a wide range of aspects, including prevention of unauthorized access and data privacy. Security will be discussed in greater detail in *Unit 9*.

Connection and physical structure

- **Transportation network**
  A transportation network has different types of connection and different types of physical structure. Connecting roads can be point-to-point highways or multi-entry and multi-exit highways. Physical structures can be a *mesh-connected* (i.e. fully-connected) network with roads linking each pair of cities. This is complicated when there are many cities. Physical structures can take the form of a star, with roads radiating from a central big city to connect to the adjacent cities. They can take the form of big roads with side-ways, or ring-roads around the outer part of the city.
- **Computer network**
  Computer networks similarly have different types of connection. They have point-to-point and multi-point (also called multi-drop) connections. Likewise, they have

different types of physical topology. Physical topology can take the form of *mesh*, *star*, *bus* and *ring*.

Categorization

- **Transportation network**
  Transportation networks can be categorized into within a city (metropolitan), intercity, interstate or international.
- **Computer network**
  Similarly, computer networks can be categorized into local area networks (LAN) for a network within the same office, metropolitan-area networks (MAN) for a network within the same metropolitan area, and wide-area networks (WAN) for a network linking computers spread far apart.

In the following sections, we will discuss about the above basic concepets of network in more detail.

1.5.1 Distributed processing

Historically, and to some extent even today, mainframe computer systems were used to run a number of applications that serve many users. Mainframe computers were housed in a central location called a *data centre*. They were connected to the terminals of different user departments. These terminals had little processing power when compared to the personal computers of today, and were often referred to as *dumb terminals*.

A single mainframe computer was used to serve many different departmental users. It had a number of central processing units, each of which could execute programs independently. The users ran their applications on the mainframe on a time-sharing basis. At a particular instant, a number of applications of different departments were run on a single mainframe computer with a number of computer processing units.

The development of such programs is very structural, as the impact of application bugs and/or operating procedures could cause problems on a very wide scale. They could affect the operation of many different departments. In most companies, there was only one mainframe computer for the whole company. Hence, mainframe systems needed very stringent application development and operational control.

Some modern software applications (not networks) use distributed processing, in which a task is divided among multiple processes residing on different computers, called *servers* or *hosts*. There could be many servers in a company. They may still reside in a single data room. During the design of an application, the processing is distributed among different programs, which are to be hosted on different hardware servers. This provides flexibility in design. Since the applications for different departments are scattered in different servers, distributed processing also offers flexibility. Computer networks are used to interconnect servers, which need to work together like an integrated application.

PCs can contribute to the distributed processing as well. The powerful PC improves user interfaces in data input and output data presentation. Computer networks serve a critical role in distributed processing. They can link the servers and end-user PC terminals, and help in passing data around in a timely manner. For multi-location enterprises and big companies operating across national boundaries, distributed processing is essential. Even in a local company, a properly designed distributed processing application provides flexibility for design, future upgrades and maintenance. There may well be cost advantages from using distributed processing.

A mainframe computer does have distinct advantages in some cases. Mainframes are still widely used in banks and governments in which centralized intensive processing and centralized secure storage are required. Super mainframes are used in weather forecasting, which requires lots of speedy but tedious numerical computations. Computer networks in these cases still have their roles, however: they are used to connect the mainframe to the terminals.

1.5.2 Network criteria

As briefly mentioned earlier in this unit, a network needs to meet certain requirements, or criteria, to serve a particular situation. There are many different dimensions for such requirements.

Performance is the most important criterion as it affects users constantly. There are many parameters related to performance. From a single end user's perspective, **transit time** and **response time** are key performance parameters.

transit time

The transit time is the time a message needs to travel from the originating end of the network to the intended destination in the network.

response time

The response time of a network is the time between a user making a request for a network service and the network responding to this request.

For massive data transfers between network links, **bandwidth** and **delay** are key performance parameters.

bandwidth

The bandwidth limits the maximum data rate at which a user can send data across a network.

delay

The delay is the time measured from the time when the data first enter the network to the time the data finally exit the network to reach the intended destination.

The *technology* used in the computer network also affects the set of parameters. Performance depends on various factors; e.g. the number of simultaneous users, the number of connected computers — and their traffic profiles. Given these factors, we can design a network to meet the performance criteria. If network traffic increases beyond the designed capacity, performance will deteriorate.

Reliability is another key criterion of a network. Since computers and computer networks support our daily life, network reliability is an important criterion to ensure normalcy.

Computer networks are widespread and the Internet has made them conveniently accessible. Company data including customer profiles and financial information are extremely valuable to a company. Personal data are sensitive, and various governments including the Hong Kong SAR Government have data protection regulations. Inside a company, network security has become important to ensure proper access. With the advent of the Internet in the last decade, there has been a lot of concern and discussion about information security. Hence, a computer network needs to meet certain security criteria as well. You will learn more about network security in *Unit 9*.

1.5.3 Physical topologies

Physical topologies can be summarized into the following four types:

- Mesh topology (Page 12)
- Star topology (Page 13)
- Bus topology (Page 14)
- Ring topology (Page 14)

1.5.3.1 Mesh topology

The mesh topology, as shown in Figure 1.2, is the most robust topology, but it is impractical for connecting a large number of computers together. For a network with *N* nodes, the number of links is $\frac{N(N-1)}{2}$. Therefore, for a large network with many nodes, a mesh topology is simply not practical. Mesh does have its applications, however. A mesh network is used to connect local telephone switches in busy commercial areas (e.g. Central and Wanchai), because the business users form a close community with heavy traffic between them. The traffic between any pairs of switches in the business area justifies the mesh connection routing as the primary routing algorithm. There are overflow routes from these local switches to the transit switches.

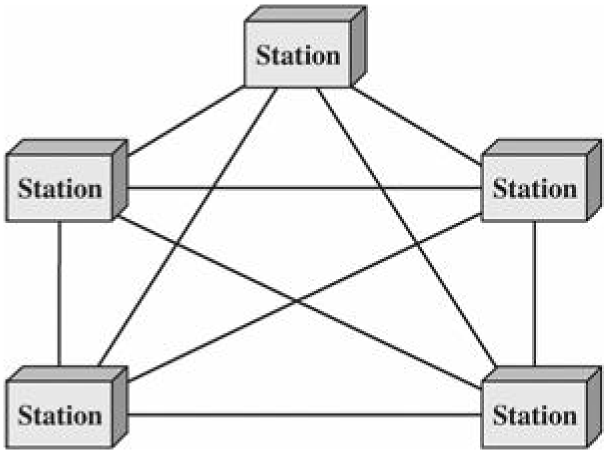


Fig. 1.2: A fully connected mesh topology (Forouzan 2007, 10)

The mesh topology is also used to interconnect switches at the higher level of the switch architecture, where connectivity and reliability among a manageable number of switches are essential.

1.5.3.2 Star topology

Star topology, as shown in Figure 1.3, is a very common topology. Local telephone networks use star topology from the telephone socket at home to the telephone switch in the telephone building. The local telephone switches are invariably star-connected to several transit switches, which belong to the next higher level of the switch architecture.

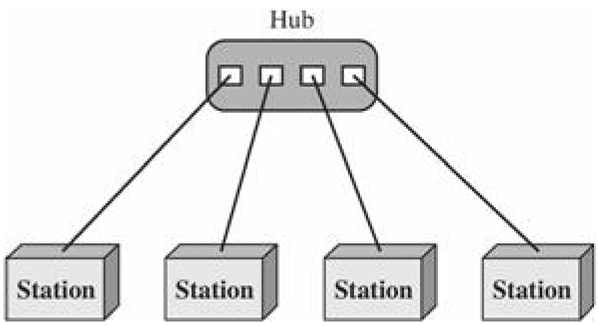


Fig. 1.3: A star topology connecting four stations (Forouzan 2007, 11)

Old local area networks (LAN) using bus topology have changed to star topology. The role of the central hub varies: it can passively repeat all data to all links, or it can screen the data and pass data only to selected links.

1.5.3.3 Bus topology

Bus topology, as shown in Figure 1.4, is used for end-point devices. For example, bus topology is used to chain a printer with a less critical device at the tail. It allows *ad hoc* modification of a network's structure. In the early 1990s, bus topology was common for connecting PCs to a LAN server using shielded coaxial cable. Details of coaxial cable will be discussed in *Unit 2*. But nowadays, most PC and LAN connections use star topology. Bus topology is used in cable TV distribution in residential blocks.

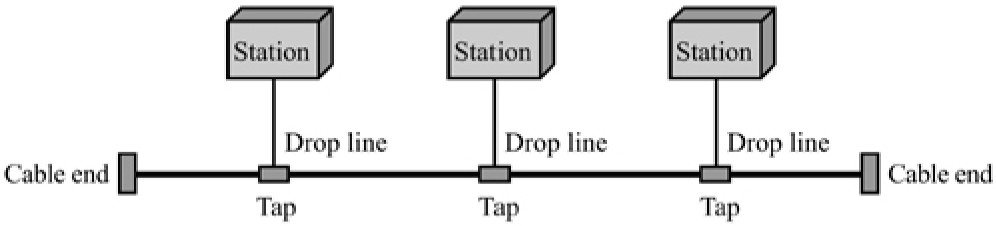


Fig. 1.4: A bus topology connecting three stations (Forouzan 2007, 11)

1.5.3.4 Ring topology

Ring topology, as shown in Figure 1.5, is robust, while it does not have the complexity of the full mesh topology. Hence it is used in core transmission backbone networks.

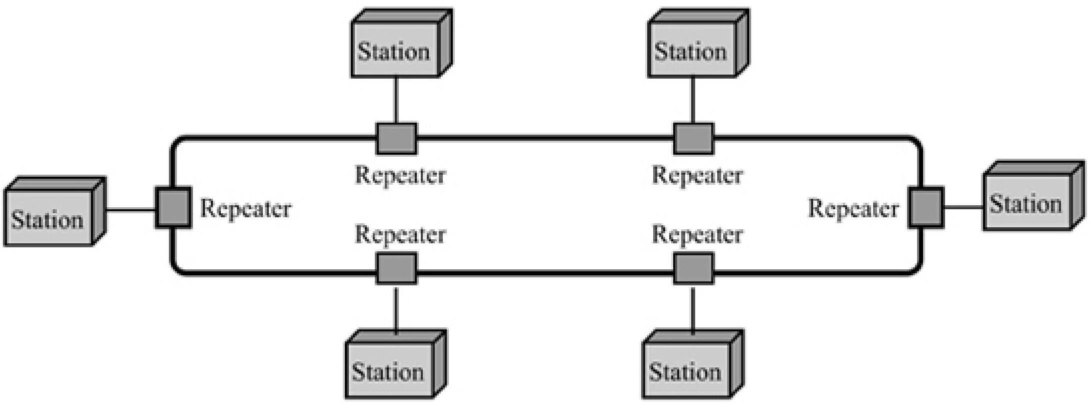


Fig. 1.5: A ring topology connecting six stations (Forouzan 2007, 12)

A comparison of the different physical topologies is summarized in Table 1.2.

	Mesh	Star	Bus	Ring
Advantages	Robust, data privacy	Less costly than mesh, easier fault identification and isolation	Ease of installation, cost-effective for long line of devices	Better reliability than bus
Disadvantages	Complex and costly for a large number of devices	Hub failure causing total network breakdown	Difficult fault isolation, path break causing isolation into two groups of devices	Path break does not cause isolation into a dual ring
Application examples	Switching backbone connecting the main computers	Local area network in offices	Coaxial cable TV in households or buildings	Long haul transmission backbone network connecting cities

Table 1.2: A comparison of different physical topologies

1.5.4 Categories of network

Computer networks can be categorized in different ways. Distance is one key categorization parameter. Using distance as our criterion, we can categorize networks into *local area networks (LANs)*, *metropolitan area networks (MANs)* and *wide area networks (WANs)*.

local area networks (LANs)

The word local in local area network means that the connected computers are in close proximity, usually on the same floor or within the same premises. They are usually privately-owned networks. LANs can be distinguished from the other two kinds of networks by three characteristics: their size, their transmissiontechnology and their topology. LANs are restricted in geographic coverage. They are commonly used in offices and factories nowadays. Some people who have more than one PC may set up a LAN at home.

The physical topology of a LAN can take the form of mesh, star, bus, or ring. Bus was a very common LAN topology 20 years ago. Star topology is very common nowadays, together with its associated technical standard called Ethernet. Ring received interest for a time, but it is less common as the token ring standard has lost ground to the Ethernet standard in the past 20 years. You will learn about Ethernet and token ring LANs in Unit 4.

metropolitan area networks (MANs)

MANs have wider coverage than LANs. A MAN is usually a public network. It is used to connect computers and LANs in different locations of the city. The LANs residing in different buildings of a city can be inter-connected by a MAN. The Cable television network is a typical example of a MAN.

wide area networks (WANs)

A WAN has an even wider geographical coverage, across countries or even continents. Most WANs use the telephone network transmission lines and equipment as building blocks. The MANs in different cities or countries can be interconnected by a WAN.

As an additional remark, networks can be divided into different categories. For example, we have narrowband versus broadband networks, wire versus wireless networks, among others. These different dimensions of categorization cut across one another. So there is wireless LAN, wireless WAN, and so on. As a concluding remark on network basics, an analogy between transportation networks and computer networks is summarized in Table 1.3.

Transportation network	Computer network
City	Node

Table 1.3: An analogy between transportation and computer networks on network basics

Transportation network	Computer network
Inter-city road	Link
Manufacturing with specialization and hence distributed among different cites	Distributed processing
Transportation network criteria of performance reliability and security	Computer network criteria of performance, reliability and security
Road connections of point-to-point highway, and multi-entry and multi-exit highway	Computer connections of point-to-point, and multipoint (also called multi-drop)
Physical road topology of mesh, star, bus and ring	Physical road topology of mesh, star, bus and ring

Table 1.3: An analogy between transportation and computer networks on network basics

The above analogy helps to relate computer networks to your daily experience in transportation. You will learn more about *distributed processing, network criteria, physical topologies and network classifications* in the next reading. At the end of this reading, you should be able to differentiate *point-to-point* from *point-to-multipoint* communication; and differentiate and explain the different physical topologies of *mesh, star, bus* and *ring* topologies. You should be able to differentiate and explain the various types of network (including LAN, MAN and WAN).

Reading

Read section 1.2, pp. 7–16, in Forouzan.

You should now have a basic understanding of the network basics, the importance of distributed processing, network criteria, the different physical topologies and network categorization.

1.6 Conclusion

In this module, we went through the historical development of computers and computer networks. You should now understand the following:

1. the five basic components of data communications — namely sender, receiver, message, medium, and protocol
2. the different physical topologies — namely mesh, star, bus, and ring.

We hope you have enjoyed this introduction to computer networks. Understanding how such networks really work gives you insights into many of the most exciting and interesting developments in communications technology.

If you would like to learn more on this subject, you are welcome to enrol in ELEC S332 Computer Networks (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcGenericPage2010&lang=eng&ncode=ELEC%20S332&shopping=Y&TYPE=CI&CODE=CT332) offered by the School of Science and Technology (http://www.ouhk.edu.hk/wcsprd/Satellite?pagename=OUHK/tcSubWeb&l=C_ST&lid=191133000200&lang=eng) of the OUHK.