

Chapter 2

Network Architectures

Abstract The networks have evolved significantly since the first network architecture has been proposed. Lately, the architecture is seen more as a framework which specifies not only the network topology, network type, network components, and their functionality, but also presents data communication protocols, data formats used, and supported services. This chapter introduces network topologies, network types, and network components, and discusses several network communication technologies.

2.1 Introduction

Designing network architectures and proposing or improving various data communication protocols were at the center of extensive research and development interest. Various network architectures have been proposed since 1950s when the first architecture involving several communication links only used to connect central processors to remote peripherals (e.g., printers). The networks have evolved significantly since, and currently a network architecture is seen as a framework which specifies not only network topology, network type, network components, and their functionality, but also presents data communication protocols available, data formats employed, and a set of services supported. Often billing aspects are also considered.

The first two chapters of this book discuss network architectures and data communication protocols focusing on two directions. This chapter details network topologies, types, components, and communications technologies, and the next chapter presents communication protocols and services, respectively.

Network components include many network devices which enable data exchange between different network parts alongside end-user devices. *Network topologies* indicate how network devices are interconnected by links and how all these are arranged to form a functional communication network. When discussing *network types*, one refers to the classification of networks based on various aspects, including size, communication technology, etc., and when mentioning *network components*, the focus is on both network links and network devices. *Communication technologies* are concerned with the mechanisms employed to exchange data between interconnected network or user devices via the communication links, whereas *protocols* are seen as formal mechanisms to exchange messages between network compo-

nents. A protocol architecture includes all the protocols used to transport messages over a certain network infrastructure and indicates the way these protocols interact with each other. Although there is a thin line separating *services* from protocols, the latter are seen mostly application-linked and related to the network interface with end-users or devices.

All these aspects are of extreme importance for application developers, especially when performance constraints are involved. This chapter introduces network architectures' major aspects with the focus on existing and future network technologies.

2.2 Network Topologies

A network topology refers to the arrangement of nodes (i.e., network devices, servers, and host machines) and links between them to form a computer network. Nowadays, various types of topologies have been proposed and are in use. Among these topologies, most known are *ring*, *star*, *bus*, *tree*, *mesh*, and *ad-hoc*. These will be discussed in detail next.

2.2.1 Ring Topology

In a ring topology, each node is connected with exactly two other nodes forming a single data path in a form of a ring. Such a network arrangement is presented in Fig. 2.1.

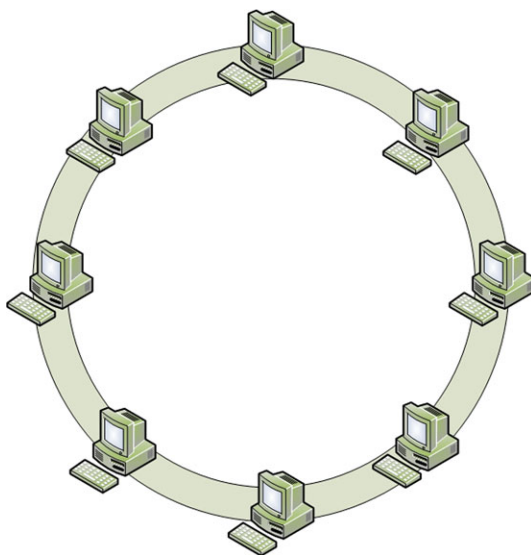
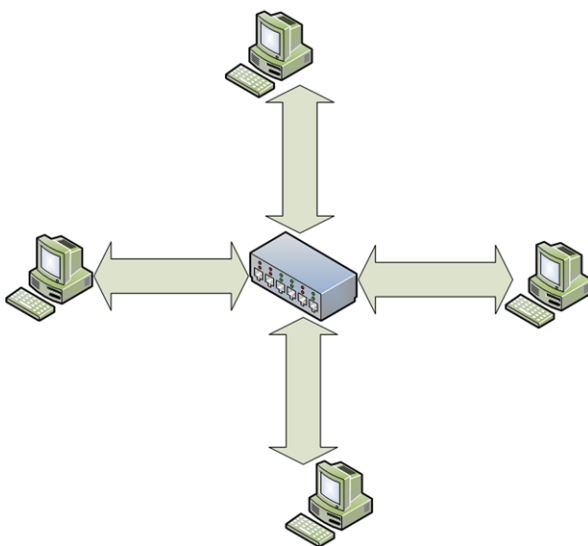
In the basic ring network topology, the messages (data bits) travel in one direction only. Each node has a dual role, as a host and as a relay. As a host, each node will send data messages to other nodes and will receive messages addressed to it. As a relay, each node forwards messages addressed to other nodes to the next node on the ring.

The main issue concerning ring networks is their reliability. If a single link is broken, the communication between certain nodes is impeded. Dual ring solutions, where communication is possible both clockwise and anticlockwise, have been proposed to improve reliability through redundancy. The increase in redundancy comes with higher deployment and maintenance costs.

Standardization related to the ring topology includes the Token Ring protocol (IEEE 802.5), initially proposed by IBM. Apart from the specifications of the protocol, IEEE 802.5 also includes details on the data formats.

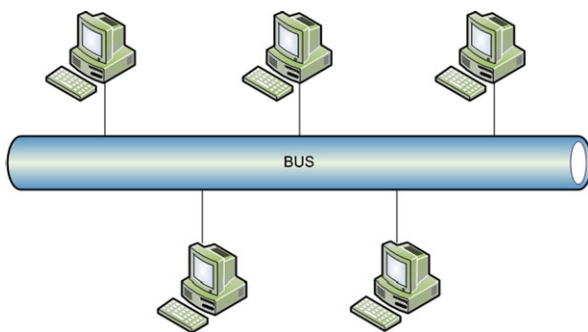
2.2.2 Star Topology

In a star topology, every host is connected to a central network component (denoted as *hub*), which may be a network hub, a switch, or a router, as illustrated in Fig. 2.2.

Fig. 2.1 Ring topology**Fig. 2.2** Star topology

This topology is very popular for home networks where various devices such as desktop PCs, laptops, and mobile devices are connected to a local router, which is further connected to the broadband modem.

In terms of link failure, star topologies are more robust. If a certain link fails, only the hosts using those links will be disconnected from the network, while all the other hosts will not experience any disruptions in communications. The negative aspects of a star topology include the existence of a single point of failure and increased

Fig. 2.3 Bus topology

deployment costs. The latter has been mitigated with the latest advancements in wireless networking.

2.2.3 Bus Topology

In a bus topology, a common backbone link is used to connect all the devices in the network with each other, as presented in Fig. 2.3. The hosts compete for accessing the backbone (a single cable) for data transmissions, which is a common communication medium.

When a host gains access to the medium, it sends data messages which are then received by all the hosts connected to the same backbone. However, only the host to which the messages are addressed will react to these messages, while the rest of the hosts will discard them.

The bus-based interconnection of hosts in a local network has been highly popular in the past when a small number of devices have required wired network connectivity. Today there are many diverse devices in need for network connectivity. However, bus networks work the best when a limited number of hosts are connected to the common bus and their efficiency is affected severely when a large number of stations require network access. This is mainly determined by the contention-based access to the common medium. As a consequence, bus topologies are less popular nowadays, in the context of the increasing demand for network connectivity and large growth of data traffic.

Standardization efforts related to the bus topology include the Token Bus protocol (IEEE 802.4) and the Fiber Distributed Data Interface (RFC 1188), which extends the token bus approach.

2.2.4 Tree Topology

The tree topology consists of a combination of bus and star topologies. As it can be seen in Fig. 2.4, the hosts are connected to a network hub which is further connected

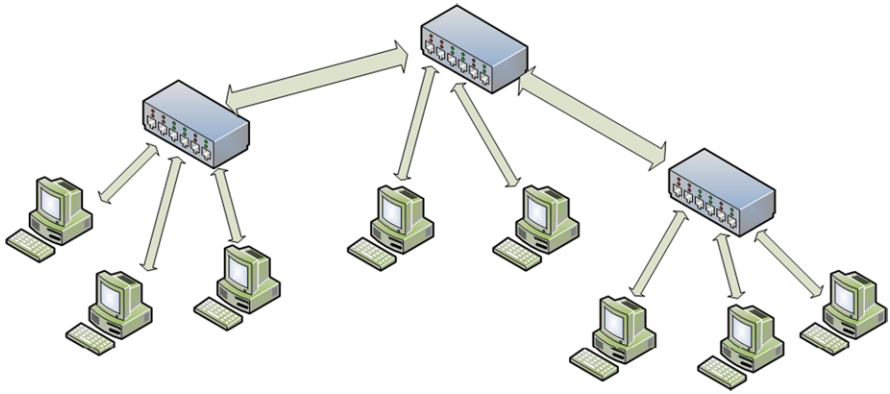


Fig. 2.4 Tree topology

to other hubs in a tree-like structure. Each hub acts as a root and router for a tree of hosts.

Routing messages in ring, bus, and star topologies is performed by broadcasting the messages to all hosts connected in the network. When tree topologies are used, messages originating at a host travel up the tree as far as necessary and then down the structure towards the destination host. Routing solutions become more important when tree topologies are involved, as efficiency is of high importance. In general, tree topologies support more scalable networks than bus and ring topologies. However, their maintenance may incur higher costs.

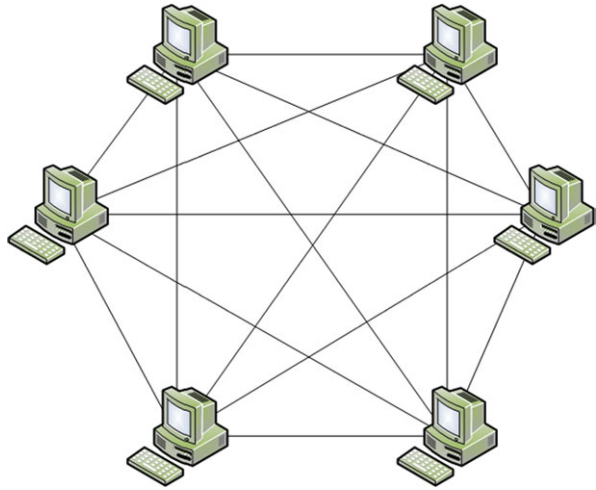
2.2.5 Mesh Topology

In a full mesh network topology, each host or network device is directly connected to any other device or host within that network. Although extremely robust, in general mesh topologies are very expensive, as they involve a high level of redundancy. This makes them less used for wired connectivity.

However, mesh topologies are most popular for wireless networks, as wireless links can be easily and cost effectively established and maintained. Full mesh topologies are also used for backbone networks.

Using partial mesh topologies is a more cost effective option. In such a topology, some of the devices are connected in a full mesh manner, while others are only connected to one or two devices.

There are several advantages brought by mesh topologies. Mesh networks can withstand high data traffic, as multiple independent paths can be formed to connect different devices within the network. Robustness is another advantage of mesh networks. Expansion and modification of the networks can also be done with minimum traffic disruption.

Fig. 2.5 Mesh topology

However, as already mentioned, the main disadvantage of the mesh networks is related to the high redundancy which leads to high costs of deployment and maintenance.

A full mesh topology is presented in Fig. 2.5.

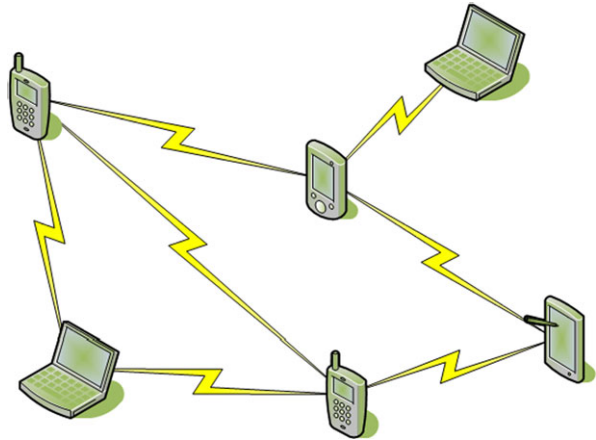
2.2.6 Ad-Hoc Topology

Lately there is an increased effort put on providing support for user mobility, and wireless connectivity already enables this. A step further is performed by wireless ad-hoc networks in which each node (potentially mobile in this case) dynamically establishes a communication link with the devices in its proximity. Each mobile node has a dual role, both as a mobile host and as a mobile router.

Ad-hoc networks do not rely on any infrastructure. Remote hosts communicate over dynamically formed paths based on links established between neighboring nodes. The messages travel over multiple links in an multi-hop manner in order to reach their destination. Such a network is graphically depicted in Fig. 2.6, but its topology is dynamically changing.

The main advantage of this type of network is its ease of deployment, low cost, and flexibility. As there is no previously deployed infrastructure, the network is formed on the go, as mobile hosts come and go. As each host in the network also acts as a router, the network range is also variable, adding scalability to the list of advantages.

Despite the advantages, ad-hoc networks suffer from unpredictable routes and data throughput. Due to host/router mobility, each route can be broken at any time due to a mobile device on the route moving away or going off-line.

Fig. 2.6 Ad-hoc topology

Furthermore, host mobility complicates paths formation, maintenance, and routing messages between senders and receivers, affecting both delivery efficiency and performance.

2.3 Network Components

Regardless of the network architecture employed, the major network components are their nodes and the inter-connecting links.

Based on the physical media used for data transmission between devices, the networks links may use: twisted pair, coaxial cable, fiber optics, as well as wireless media such as radio waves, microwaves, infra-red, and even visible light waves. Note that all these media have different characteristics which highly influence the communication properties and consequently determine their usage.

A twisted pairs cable consists of two insulated copper wires twisted together in a helical form. This cable was at the base of the first widely distributed network which enabled both telephony and later on basic data communications at very low bitrates.

A coaxial cable consists of a stiff copper core covered in a insulating material. The insulator is further surrounded by a cylindrical conductor, usually in the form of a mesh. This outer conductor is further protected by a plastic insulator. By making use of coaxial cables, the data transmission rate was improved, the interference was reduced and networks offering richer services such as cable TV were supported.

Fiber communications are very popular mainly due to their large bandwidth and low effect of interferences. They are performed over fiber optic cables which consist of three elements: a glass core, a glass cladding and some plastic cover. The glass core is the main light propagation medium and is at the center of the fiber cable. The plastic cover is like a shell and is used to protect the fiber. The glass cladding has a lower refraction index and is introduced to keep the light within the core and the plastic cover.

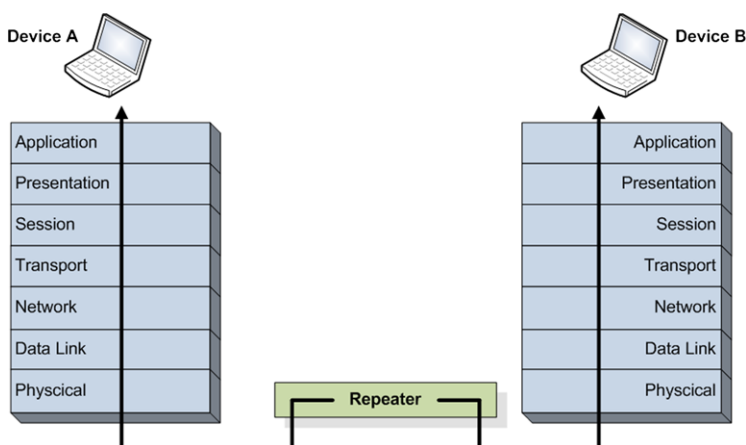


Fig. 2.7 Repeaters operate at physical layer

Wireless communication networks use modulated electromagnetic waves to send messages between directly linked devices. These devices can communicate directly among themselves in a distributed manner, forming ad-hoc networks or rely on a centralized network device to handle inter-end-device communication in the infrastructure mode. Among wireless networks, some use line-of-sight, others non-line-of-sight transmissions; some use low-latency channels (e.g., satellite communications), others fast communication channels; some use low frequency channels, despite the low bandwidth (e.g., military use), others high frequency-high bandwidth, etc.

In terms of network nodes, most visible are the end-user devices which range from smartphones, netbooks, and laptops to desktops and even servers. Lately, diverse consumer devices have also been enabled to exchange data via the networks. This is in the context of smart homes, but the trend is set to continue, supporting also networked device control.

The classic network nodes, also known as inter-networking devices, consist of intermediate devices which provide various support for data exchange and enable networking. Each type of inter-networking device is deployed at different network layers and provides different services. The most known are repeaters, bridges, routers, and gateways.

A repeater is a network device which amplifies, reshapes, and/or retimes the input signal in order to increase the distance, improve the signal quality, and boost efficiency of transmitted data. As repeaters do not attempt to make sense of the content of the data transmitted in any way, performing on the physical signal only, they are seen as operating at the physical network layer, as shown in Fig. 2.7. Repeaters' reshaping function is illustrated in Fig. 2.8.

A bridge is a network device which reduces the amount of traffic on a LAN by dividing it into two segments or enables communication between two LANs by inter-connecting them. Bridges filter data traffic at network boundary and take

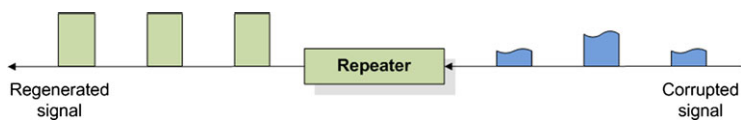


Fig. 2.8 Repeaters operate at physical layer

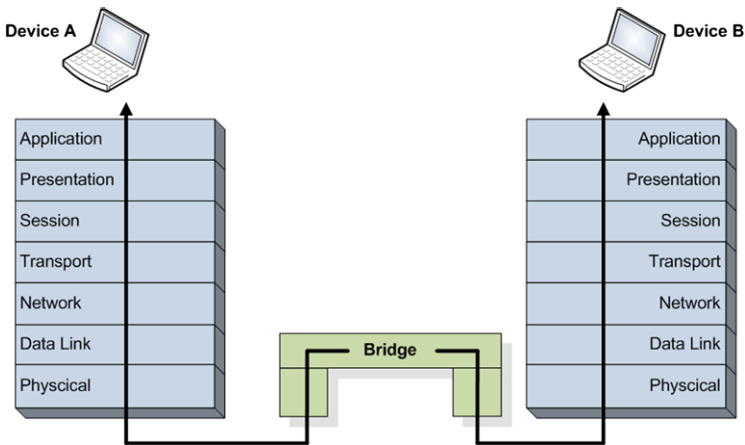


Fig. 2.9 Bridges operate at data link layer

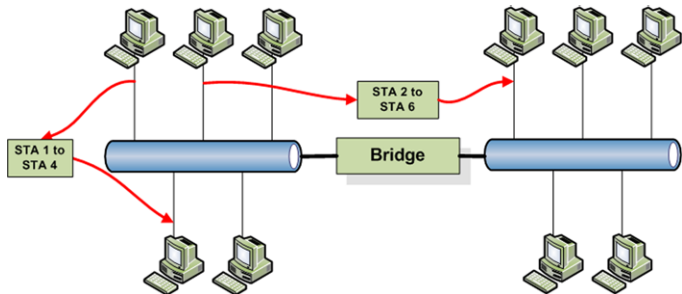


Fig. 2.10 Bridges filter the traffic between network segments

decisions whether or not to allow traffic passage. As bridges require some network-related information, they operate at the level of frames at the data link network layer, as illustrated in Fig. 2.9. A very important task bridges do when dividing networks into segments is confining local traffic to the various network segments, supporting overall network scalability and increasing communication efficiency. An equally important task bridges do when enabling inter-LAN communication is accommodating data exchange despite having different frame formats, payload sizes, data rates, bit order of addresses, usage of priority bits, existence of acknowledgments or negative acknowledgments (ACK/NACK), etc. The principle of bridges performing traffic

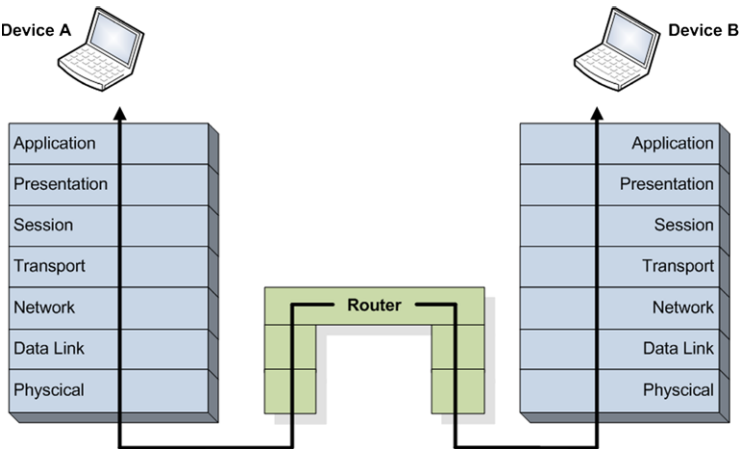
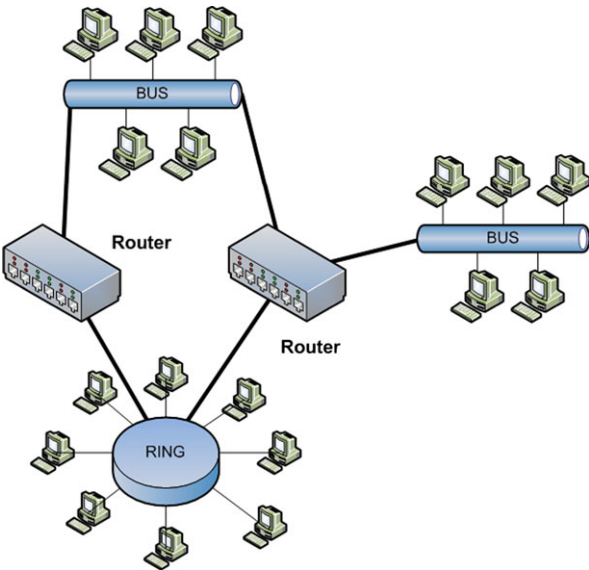


Fig. 2.11 Routers operate at network layer

Fig. 2.12 Routers interconnect and enable data exchange between different networks



filtering and reducing the amount of data exchanged across two network segments is shown in Fig. 2.10.

A router is a network device which inter-connects different networks and relays packets from a network to another according to their destination address. Routers communicate with each other and are involved in network information collection which they store in forwarding tables. Based on this information, the routers run routing algorithms to determine the best path between any two hosts and forward the data packets on those paths. Routers are active at the network layer as shown in Fig. 2.11 and are deployed as illustrated in Fig. 2.12.

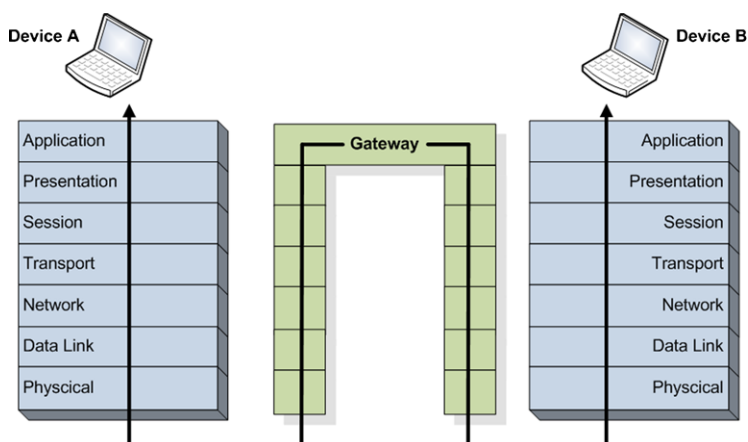


Fig. 2.13 Gateways operate at application layer

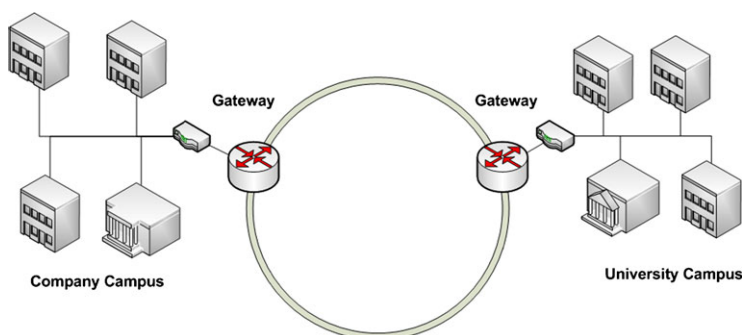


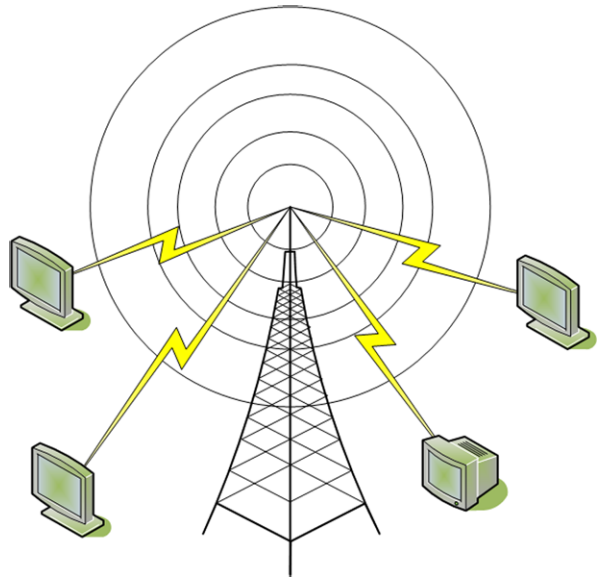
Fig. 2.14 Gateways interconnect and control data exchange between different networks

A gateway is a network device which extends the functionality of a router to include the application layer as illustrated in Fig. 2.13. Modifications of the data packets could include filtering or blocking certain type of traffic, changing values in the header and/or trailer fields, adjustments of data rates, modifications in the size of packets, applying security, etc. An example of gateway deployment is presented in Fig. 2.14.

2.4 Network Types and Communication Technologies

Networks differ in many aspects, not only in their topology, from communication technology to range. In this context, there are many criteria which can be used to classify the networks.

Fig. 2.15 Broadcast networks



Based on their *transmission technology*, the networks can be classified as broadcast or point-to-point networks.

In a broadcast network, all nodes share the same communication medium. A message sent by a node is heard by all other nodes connected to the network. This constitutes a major advantage of the broadcast networks as it allows the possibility to send the same message to all receivers attached to the network in the most efficient manner. A well known example of a broadcast network is the television network as presented in Fig. 2.15. The same content (TV channels) is delivered to all devices attached to the network, a mechanism suitable for distribution of highly popular non-interactive services.

As opposed to broadcast networks, point-to-point networks use many connections to link individual pairs of devices. A message travels from the source to its destination by traversing multiple interconnected devices. All these intermediate devices and the links connecting them form a communication route. A source node may be connected to a destination node by multiple routes, as presented in Fig. 2.16. Choosing the right route for message transportation is very important in point-to-point networks. These networks are suitable for delivering differentiated content based on various requests.

However, potentially the most important criterion for classifying networks is their scale. In general, the network scale dictates the transmission technology used and often the corresponding communication protocols.

Based on their scale, networks can be classified as personal area networks, local area networks, metropolitan area networks, wide area networks, and the Internet. Next these network categories are discussed in detail.

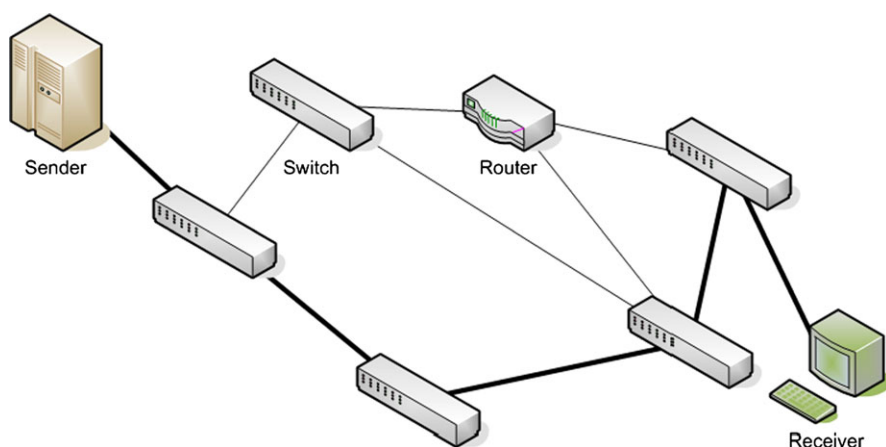
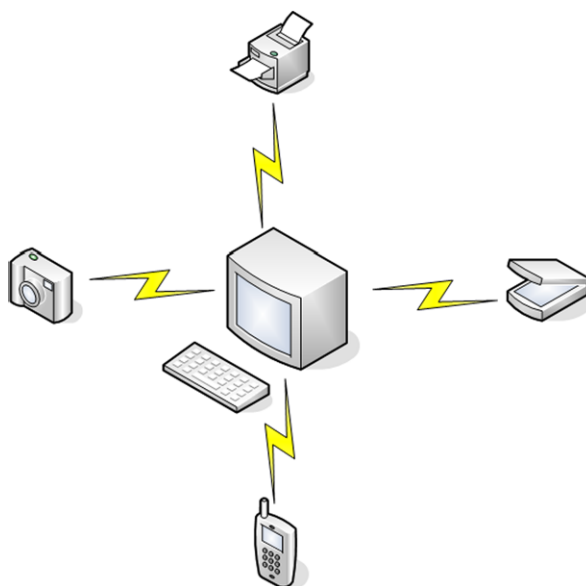


Fig. 2.16 Point-to-point networks

Fig. 2.17 Personal area network



2.4.1 Personal Area Networks

Personal Area Networks, or PANs, use short range transmission technologies (1 m) and are usually intended to serve one person, hence their name.

An example of a PAN is presented in Fig. 2.17. In this case, wireless communication technology is used to link various peripherals, such as a printer, scanner, as well as keyboard and mouse with the computer. Moreover, devices such as smartphones and video cameras can also be connected to computers forming PANs.

Wireless Personal Area Networks (WPANs) are increasingly popular, and the IEEE 802.15 Working Group has been established especially in order to standardize WPAN technologies. Their work has resulted in several standards, among which most important are briefly introduced next.

IEEE 802.15.1 (2002, 2005) standardizes the well known Bluetooth wireless communication technologies used by many portable devices to interconnect or communicate with peripherals or personal computers.

IEEE 802.15.2 (2003) address the coexistence of WPANs with other wireless networks such as wireless local area networks.

IEEE 802.15.3 (2003), IEEE 802.15.3b (2005), IEEE 802.15.3c (2009) address the physical and MAC layers for high-rate WPANs.

IEEE 802.15.4 (2011) specifies the MAC and PHY layer for low-rate, low-range, and low-power wireless network communications. Based on this standard, protocols such as Zigbee and 6LoWPAN define the network layer specialized on ad-hoc networking and the application layer targeting WPAN networks.

IEEE 802.15.5 (2009) provides an architectural framework for mesh networks deployed on low-power wireless communication technologies.

IEEE 802.15.6 (2012) is focused on low-power and short-range wireless technologies to be used around the human body or even in the human body for specific medical applications.

IEEE 802.15.7 (2011) targets the standardization of short-range wireless optical communication based on visible light.

2.4.2 Local Area Networks

Local area networks (LANs) are usually contained within a single building, campus or geographical area, up to a few kilometers in size. LANs are usually privately owned and their main purpose is to interconnect computers and resources such as printers and data storage units belonging to a single functional unit such as an office building, factory, school or university.

LANs are usually small in size, and LAN communications benefit from short delays and reduced error rates. Typical data transmission rates range between 10 and 100 Mbps with newer technologies reaching transmission speeds of up to 10 Gbps.

The most popular technology for LANs is Ethernet, standardized as IEEE 802.3. Other technologies such as token ring, token bus, and FDDI can also be used.

Often Ethernet uses a star topology, where multiple computers are interconnected using wires (usually twisted pairs) or fiber optics to a central active network device.

Fast, Gigabit, and 10 Gigabit Ethernet refer to Ethernet networks capable of reaching transmission speeds of up to 100 Mbps, 1 Gbps, and 10 Gbps, respectively, over twisted wired cables or fiber optics.

Figure 2.18 illustrates three typical LAN topologies.

Wireless Local Area Networks (WLANs) are increasingly popular, mostly due to the reduced cost of deployment and maintenance and their support for mobility.

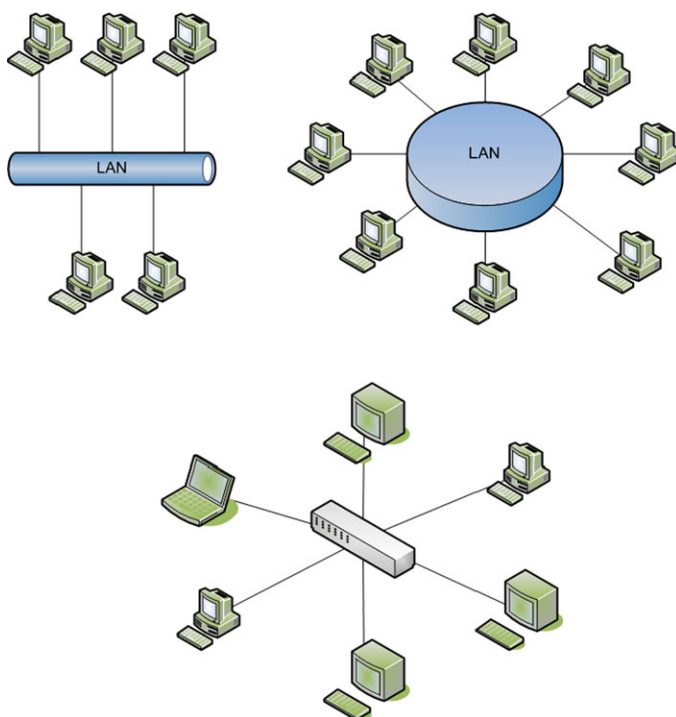


Fig. 2.18 Local area network

Currently, the IEEE 802.11 family of standards has been widely adopted and is being heavily used worldwide for WLANs. This family (also known as WiFi) includes the original standard and various extensions which address different issues including higher bit rates, QoS support, security, etc.

The standards for wireless access networks usually cover the physical layer and the medium access control protocol (MAC) sub-layer. The original IEEE 802.11 standard first released in 1997 [1] supports data rates up to 2 Mbps and was initially developed for best effort traffic only.

Each host connected to a certain IEEE 802.11 access point shares the wireless medium with the other mobile hosts associated with the same access point. This leads to race conditions for medium access which determine high collision rates and consequently low data rates, especially when the number of mobile hosts involved in simultaneous data communications increases.

The IEEE 802.11 MAC layer provides mechanisms for medium access coordination, including the Distributed Coordination Function (DCF) and the partially centralized Point Coordination Function (PCF).

A group of mobile stations connected to a single Access Point (AP) form the basic building block defined by this standard as a Basic Service Set (BSS). The geographical area covered by a BSS is called a Basic Service Area (BSA). Connect-

ing several BSSs through a Distribution System (DS) determines the creation of an Extended Service Set (ESS).

The first IEEE 802.11 extension, IEEE 802.11b [2] increased the maximum data rate to 11 Mbps, which was a huge step forward. Following additional efforts, the data rate was further increased to 54 Mbps in the IEEE 802.11a and IEEE 802.11g standard extensions [3, 4].

Maintaining high QoS levels by using the two coordination methods, DCF and PCF, is difficult, thus novel QoS enhancements for IEEE 802.11 MAC layer were standardized by IEEE 802.11e [5].

Consequently, two new mechanisms are described by the new standard, namely the Hybrid Coordination Function (HCF) and the Enhanced Distributed Coordination Function (EDCF). HCF is based on PCF, and EDCF relies on its implementation on DCF. Further enhancements brought by this standard extension are block acknowledgments which allows acknowledging more than one MAC frame by sending only one acknowledgment packet and *No Ack* which allows time critical data frames not to be acknowledged. To enhance QoS provisioning for time sensitive and bandwidth hungry applications, traffic prioritization was proposed for IEEE 802.11 [6]. Four traffic categories are defined: voice, video, best effort, and background, and in this order, IEEE 802.11e offers prioritization support.

The emerging IEEE 802.11n standard [7] aims at providing even higher bitrates, of up to 600 Mbps. The data rate enhancement approach of IEEE 802.11n is oriented on improving MAC layer techniques, unlike other IEEE 802.11 which aim at increasing the data rates at the physical layer. IEEE 802.11n uses the same QoS support techniques proposed for IEEE 802.11e.

The currently under study IEEE 802.11 VHT (Very High Throughput) [8] aims at offering data rates of up to 1 Gbps for low velocity mobile hosts.

The IEEE 802.11 family supports limited host mobility except for the IEEE 802.11s standard [9, 10] which specifies support for wireless mesh networks and which addresses host mobility within the wider range mesh network.

IEEE 802.11p standardizes wireless access in vehicular environments which represents a short to medium range communication service providing high data transfer rates for roadside-to-vehicle or vehicle-to-vehicle data communications.

The IEEE 802.11 family groups several other standards addressing various aspects of wireless data networks, including security, management, and compatibility. A more detailed overview of IEEE 802.11 family of standards can be found in [11].

Tables 2.1 and 2.2 summarize the characteristics of the most important IEEE 802.11 standards and extensions, including maximum data rates and frequencies.

2.4.3 Metropolitan Area Networks

Metropolitan Area Networks (MANs) usually cover an area the size of a city. Figure 2.19 graphically depicts a MAN interconnecting various areas of a city. Originally, MANs have been developed to distribute television services over the cable TV

Table 2.1 IEEE 802.11 family of standards

Standard	Bitrate	Frequency	Description
802.11	1 Mb/s (2 Mb/s)	2.4 GHz	Initial standard
802.11b	11 Mb/s	2.4 GHz	Data rate enhancement
802.11a	54 Mb/s	5 GHz	Data rate enhancement
802.11g	54 Mb/s	2.4 GHz	Backward compatibility
802.11n	600 Mb/s	2.4 and 5 GHz	Data rate enhancement
802.11p	27 Mb/s	5.9 GHz	Vehicular communication
802.11ac (VHT)	1 Gb/s	<6 GHz	Data rate enhancement
802.11ad (VHT)	1 Gb/s	60 GHz	Data rate enhancement

Table 2.2 IEEE 802.11 family of standards

Standard	Description
802.11e	Extension for QoS support
802.11aa	Extension for audio/video streaming
802.11r	Handoff support
802.11s	Transparent multi-hop operation (Mesh)
802.11u	Interworking with external networks (cellular)

network. The development and increased popularity of the Internet has determined the operators to adapt the cable TV network for the delivery of Internet services.

Several technologies have been used for implementing MANs. These technologies include Asynchronous Transfer Mode (ATM), Fiber Distributed Data Interface (FDDI), and Switched Multi-megabit Data Service (SMDS). These technologies are currently in the process of being replaced by Ethernet-based solutions.

Wireless MAN links interconnecting local area networks have been built based on either microwave, radio, or infra-red laser communication technologies.

Distributed Queue Dual Bus (DQDB), standardized as IEEE 802.6, has been developed specifically for MANs. This technology offers communication infrastructure over long distances, up to 160 km. The operating speed ranges from 34 to 155 Mbps.

Wireless Metropolitan Area Networks (WMANs) were developed to cover whole cities and to interconnect LANs or WLANs as well as individual users, both static and mobile. WMANs use two types of connectivity: *line of sight*, when there is a requirement for communication success such as no obstacles between senders and receivers can exist, and *non-line of sight*, when senders and receivers are not required to see each other in a straight line for communications.

Companies producing equipment for WMANs have formed the Worldwide Interoperability for Microwave Access (WiMAX) forum concerned with the standardization and technology development in this area of wireless communications.

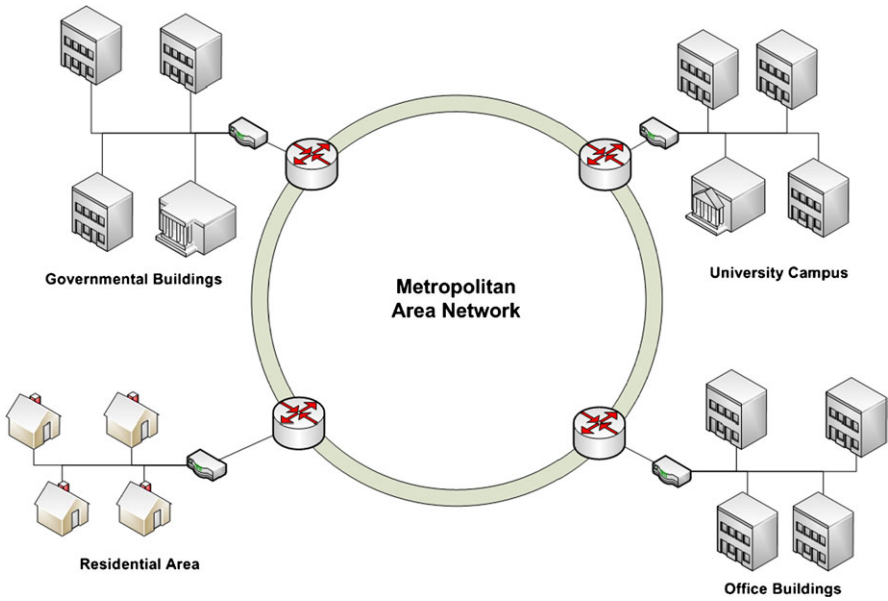


Fig. 2.19 Metropolitan area network

Specific to WMANs is the IEEE 802.16 family of standards. The IEEE 802.16 is based on two systems: the Multichannel Multipoint Distribution System (MMDS) and Local Multipoint Distribution System (LMDS) [12].

The MMDS system offers better coverage (i.e., typical cell radius is 50 km), but the throughput is quite low, between 0.5 and 30 Mbps. LMDS has lower coverage (e.g., 3 to 5 km radius), but provides higher bandwidth (e.g., 34 to 38 Mbps with an increase to 36 Gbps for the newer versions).

IEEE 802.16 provides QoS provisioning support. This is achieved mainly through connections, service flows, and service scheduling. QoS provisioning is negotiated at the initiation of the session, and QoS requirements are mapped on the QoS parameters in the IEEE 802.16 MAC layer. Mobility is supported in the new IEEE 802.16e standard which permits mobile hosts to change their base station while the data connection is still active. Both soft and hard handover mechanisms are supported, while several enhancement solutions are being proposed [13].

WiMAX is relatively popular as a wireless broadband solution, with several types of mobile devices already having WiMAX interfaces. However, new technologies are already threatening WiMAX.

High Performance Radio Access (HiperACCESS) standardized by ETSI offers non-line of sight broadband wireless access using frequencies between 11 and 43.5 GHz. The typical cell radius is 5 km, and the data rates per cell range between 25 and 100 Mbps [14].

High Performance Radio Metropolitan Access Network (HiperMAN), also standardized by ETSI, offers broadband connectivity targeting residential and small of-

fice areas. HiperMAN works in the frequency bands below 11 GHz and offers non-line of sight connectivity with aggregated data rates of up to 25 Mbps [15].

WiBro is another WMAN solution developed in Korea which offers broadband connectivity to both stationary and mobile users. WiBro operates in the 2.3–2.4 GHz frequency band offering data rates of up to 50 Mbps [16]. The major advantage of WiBro over the other WMAN technologies is the mobility feature which is very well developed.

High Altitude Platforms (HAP) [17] use a quasi-stationary aerial platform equipped with wireless transceivers offering broadband wireless access with data rates of 120 Mbps or up to 10 Gbps in some configurations. This type of wireless technology offers good coverage with better line of sight connections.

IEEE 802.22 Wireless Regional Area Network (WRAN) offers data rates up to 18 Mbps for rural and remote areas using the unoccupied TV channels between 54 and 862 MHz [18].

Cellular networks which initially offered only voice services are already offering broadband Internet access through the current third generation (3G) and the future fourth generation (4G) networks.

The first to provide mobile communication services were the first generation (1G) cellular networks which supported only analog voice calls and very limited data applications. This technology was replaced by the second generation cellular networks (2G) which is entirely digital and apart from voice communication also supports low bit rate data communication in the form of Short Message Service, Multimedia Message Service.

The current cellular network technologies can be grouped in two main families: Global System for Mobile Communications (GSM) based on time division, multiple access (TDMA), and code division multiple access (CDMA) [19].

The maximum bit rate in GSM was 9.6 kbps; however, throughput enhancement solutions have been developed for this standard including the 2.5G General Packet Radio Service (GPRS) and the 2.75G Enhanced Data Rates for GSM Evolution (EDGE).

GPRS supports theoretical data rates around 114 kbps, but in reality the throughput reaches values around 40 kbps only. EDGE is the first to open the door for multimedia applications over cellular networks. It supports theoretical throughputs around 400 kbps.

The third generation cellular network (3G) supports voice and continues the improvement of the data communication rates.

In the GSM category, the Universal Mobile Telecommunications System (UMTS) makes use of wideband CDMA (WCDMA) and High-Speed Packet Access (HSPA) technologies in order to support bit rates of up to 2 Mbps.

The CDMA-based standards for 3G networks include the CDMA2000 family among which CDMA 1xRTT, supports average data rate of 40–80 kbps with peak data rate of 150 kbps. CDMA 2000 1xEV-DO supports only data communications with maximum data rates of 2.4 Mbps.

As the demand for higher bandwidth and QoS support is increasing with the increased popularity of bandwidth-hungry, real-time applications, the forth generation network (4G) is in the process of being defined and standardized.

The technologies which are principal candidates for 4G networks are Long-Term Evolution (LTE), Ultra Mobile Broadband (UMB), and 802.16m (WiMAX II) [19].

LTE is developed based on the GSM technology with data rates around 250 Mbps. LTE will support QoS provisioning for real-time applications like multimedia streaming [20].

UMB is developed based on the CDMA technology and provides data rates up to 288 Mbps. UMB incorporates control mechanisms which optimize data transmission in order to meet the QoS requirements of various user applications [21]. UMB also supports inter-technology handover with CDMA2000 standards [21].

IEEE 802.16m (WiMAX II) is developed based on the WiMAX standard with adaptation for cellular networks. 802.11m aims at supporting higher data rates and QoS support for various multimedia services. The data rate is expected to reach 100 Mbps for mobile users and 1 Gbps for static users.

2.4.4 Wide Area Networks

Wide Area Networks (WANs) usually cover larger geographical areas such as a whole country or even a continent. The biggest WAN known today is the Internet, spanning the whole globe. However, a typical WAN may interconnect several LANs, MANs, or even other WANs, providing the backbone infrastructure to transport data between the interconnected networks.

As it can be seen in Fig. 2.20, a WAN may use several technologies for the communication subsystem.

Wired infrastructure, including fiber optics or telephone lines, as well as wireless technologies, including terrestrial or satellite-based communication systems, can be used for data transfer within a WAN.

In general, a WAN consists of two basic elements: communication lines (i.e., copper wires, optical fibers, radio links) and switching elements (i.e., routers).

The switching element connects two or more communications lines. Whenever data is received by the switching element on a communication line, it decides on which line the data should be forwarded and transmits the messages on that particular line.

For long distance communications over wired links, WANs tend to use technologies such as Multiprotocol Label Switching (MPLS), Asynchronous Transfer Mode (ATM), Frame Relay, and X.25.

Similar to the wired WANs, the Wireless Wide Area Networks have the largest coverage area among the wireless networks. WWANs can be used as separate networks or as interconnection backbones for MANs.

WWANs are usually satellite networks, but terrestrial versions are also considered. A terrestrial WWAN is standardized by the IEEE 802.20 [22]. This standard targets high mobility users with speeds of up to 250 km/h. QoS preservation methods as well as handover management schemes are supported by this technology.

Satellite WWANs have the advantages of global coverage, high mobility support and broadcast capabilities [12]. Initially satellite networks had only broadcast

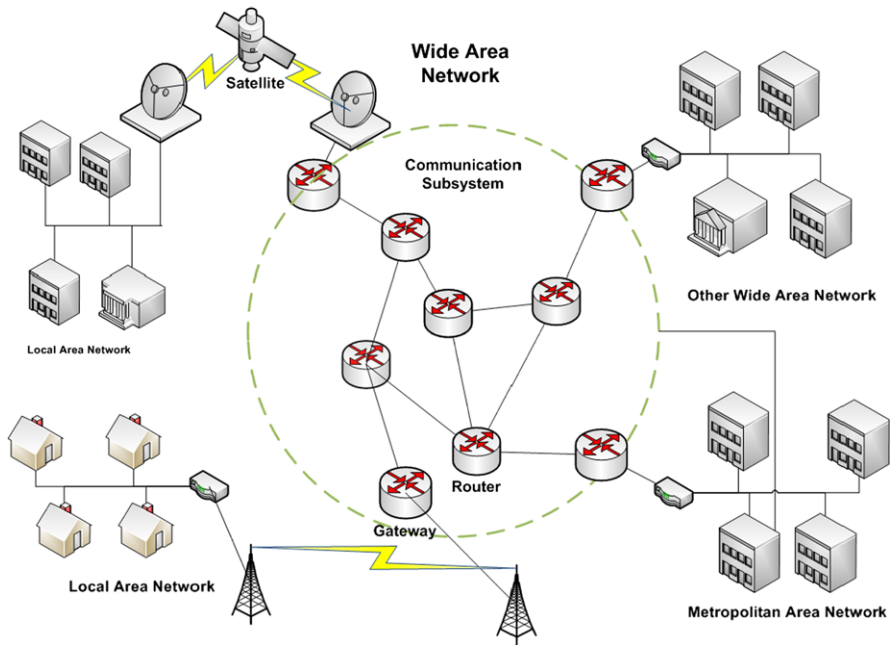


Fig. 2.20 Wide area network

capabilities, but within the Next Generation Satellite System (NGSS) unicast and multicast is also provided.

The Digital Video Broadcasting (DVB) standard family started first by supporting digital video and data broadcasting through the satellite networks. DVB-S (satellite) enables down-link data transfer with rates of up to 45 Mbps only. The newer DVB-S2 increases the downlink rate to 60 Mbps. For uplink DVB-RCS (return channel satellite) standard was developed supporting rates of up to 2 Mbps.

Apart from the satellite versions (DVB-S) DVB has also standardized a terrestrial wireless data service through the DVB-T, and more recently DVB-T2.

DVB-T offers much flexibility in terms of data rates. Depending on the particular configuration of the various parameters specific to the wireless transmission it offers a wide range of bitrates starting from 3.7 up to 31 Mbps [23].

Although DVB-T broadcasts multimedia content to static and mobile users, including vehicular receivers, it is not optimized for highly mobile handheld devices.

Consequently, DVB team has developed DVB-H (handheld) [24] for multimedia content delivery to mobile devices. DVB-H is developed based on the DVB-T (terrestrial), whose infrastructure it uses. Similar to DVB-T, DVB-H offers one way (downlink) point-to-multipoint data communication over wireless links with indoor and outdoor coverage. Considering the limited radio capabilities of a mobile handheld device as well as the higher error rates due to device mobility, DVB-H incorporates powerful error correction mechanisms. Time-multiplexing technologies are used to improve power consumption to cope with the energy constraints of battery

powered handheld devices. Seamless handover between base stations is also supported, and loss is highly reduced due to the time-slicing techniques used for power efficiency even with only one radio interface [25].

DVB-H supports mainly downlink communication, interactivity being achieved through separate backward point-to-point channels using other wireless data communication technologies like GPRS or UMTS. Supporting mainly broadcast services, DVB-H scales well offering downlink data rates between 3.3 and 31.6 Mbps. DVB-H specifies only the protocol layers below the network layer.

DVB-H provides an Internet Protocol (IP) interface for higher transport layers which is defined by the IP-based Data Broadcast (IP Datacast) specification. IP Datacast also offers the option of accessing an external cellular network for the backward channels and to create the so-called hybrid networks [26].

2.4.5 *The Internet*

The Internet can be best described as a network of networks. The Internet is not a single network, but instead a collection of a vast diversity of networks in terms of topologies and communication technologies which use, however, a common set of protocols to offer certain services.

Figure 2.21 schematically presents an overview of the Internet structure. As it can be seen in the figure, networks such as LANs owned by universities or small communities, regional Internet Service Provider (ISP) distribution networks, cellular networks, offering also data services, can be interconnected via backbones allowing for the creation of a global inter-network.

To describe how user hosts are interconnected and are allowed to communicate over the Internet, we will start from the client location. The client PC or home LAN router will be connected to the ISP modem/router which is designed to interconnect the user's LAN with the ISP Point of Presence (PoP) over the telephone lines or cable network. At the PoP level, the signals originating at the home are sent to the ISP's regional network.

Often, the local telecommunication company or the cable TV operator is also the ISP, so the telephone or cable networks and ISP regional networks are overlapping.

Except for the cable and telephone lines, home users may be offered access to the ISP core network using fiber or wireless links such as WiMAX or cellular.

The ISP's regional network consists of interconnected routers and links spread across the area served by the ISP. The ISP regional network is further connected to the backbone network owned by a backbone operator. Backbone operators are companies owning and operating large international networks consisting of thousands of routers interconnected by high-bandwidth fiber optical links. These backbone networks can transport huge amounts of traffic and usually link countries and even continents.

The end user usually does not get direct access to a backbone. The ISP regional networks or distribution networks are connected to the backbones. However, large

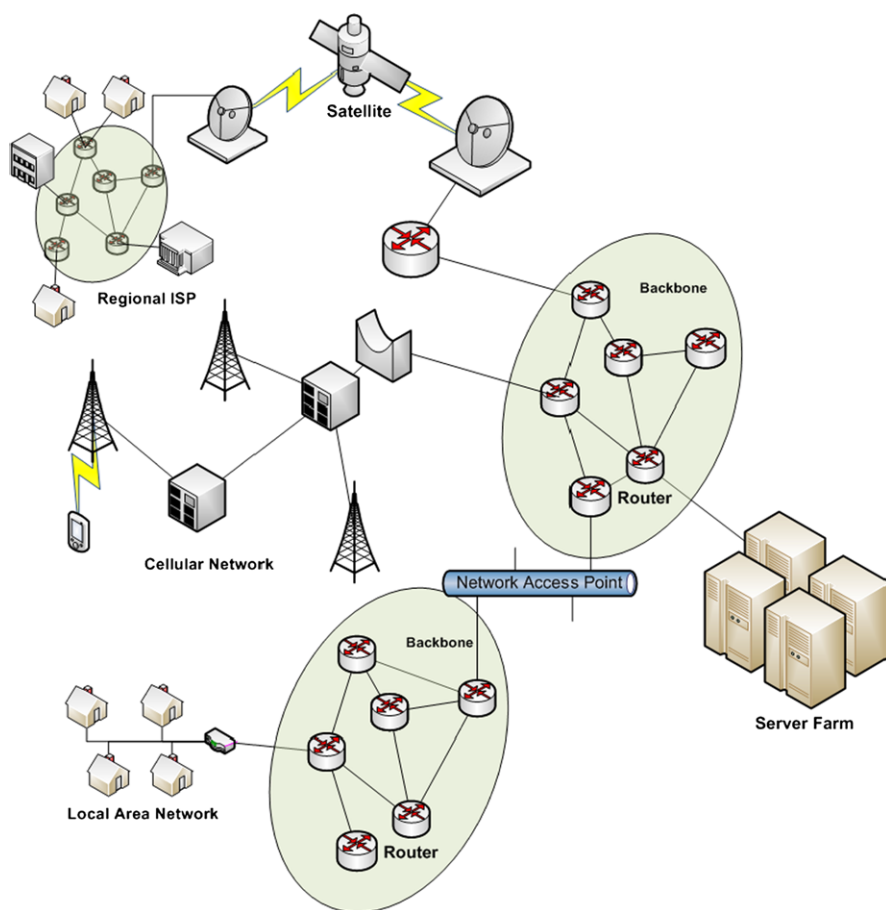


Fig. 2.21 Overview schematic of the Internet

corporations may be connected directly to the backbone, especially those operating high capacity server farms capable of handling millions of service requests and high amount of data traffic.

Various backbones exist, interconnecting all regions of the world, and being operated by various companies. In order to reach a global coverage, all these backbones are interconnect at Network Access Points (NAP). These NAPs basically consist of a high speed LAN interconnecting routers corresponding to different backbones.

Moreover, NAPs are not the only technique to interconnect backbones. Private peering is a well known technique where various routers belonging to distinct backbones have direct links between them allowing data packets to be exchanged between distinct backbones.

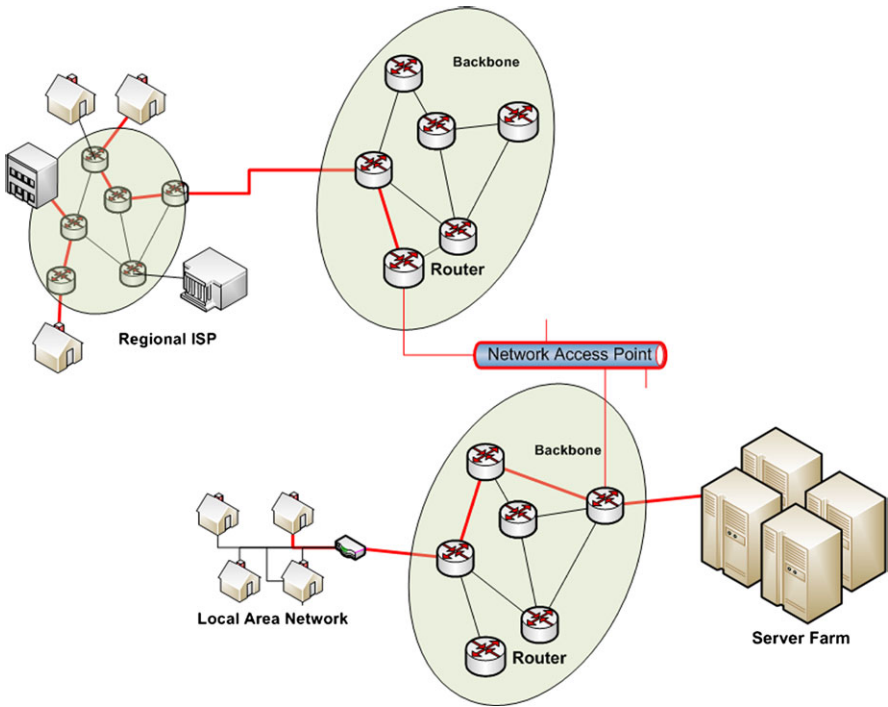


Fig. 2.22 Data communication in the Internet

Figure 2.22 describes how data is exchanged between two hosts over the Internet. As it can be observed in the figure, if two hosts communicate and are connected to the same ISP regional network then the traffic is routed within the ISP network only.

If, for example, a host accesses a service (e.g., a website) located on a server farm, the traffic will be routed from the ISP's network to the corresponding backbone and then through the farm's local network to the destination server.

If two hosts are connected to distinct ISP networks which are further connected to distinct backbones, the data packets will travel from the ISP regional network to the backbone, and then over the NAP to the other backbone and further to the destination ISP's regional network.

2.5 Conclusions

This chapter introduced the various network topologies used today, presented the major network components, and discussed various criteria used to classify the networks. Among the criteria identified, coverage area is accepted as one of the most relevant and with the greatest impact on network cost, complexity, and performance. Various network types identified based on size have been discussed along with the specific communication technologies used by each type of network.

Although the technologies and network characteristics discussed so far represent the foundation of any network, there is still a need for additional support to provide robust and performance-oriented network communications.

There is a need for a set of protocols to govern the way data is produced, formatted, transported, and consumed by various interconnected nodes communicating to each other and a set of services to be offered to the end-users.

The next chapter introduces these protocols and presents major network-based services.

References

1. IEEE (June 1999) IEEE standard for local and metropolitan area networks specific requirements—Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications
2. IEEE (September 1999) IEEE standard for local and metropolitan area networks specific requirements—Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications high speed physical layer extension in the 2.4 GHz band
3. IEEE (1999) IEEE standard for local and metropolitan area networks specific requirements—Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications high speed physical layer in the 5 GHz band
4. IEEE (June 2003) IEEE standard for local and metropolitan area networks specific requirements—Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications amendment 4: further higher data rate extension in the 2.4 GHz band
5. IEEE (2005) IEEE standard for local and metropolitan area networks specific requirements—Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications MAC enhancements for QoS
6. Xiao Y (2005) Performance analysis of priority schemes for IEEE 802.11 and IEEE 802.11e wireless LANs. *IEEE Trans Wirel Commun* 4(4):1506–1515
7. IEEE (September 2008) IEEE draft standard for local and metropolitan area network-specific requirements—Part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications mendment 5: enhancements for higher throughput
8. Eastwood L, Migaldi S, Xie Q, Gupta V (2008) Mobility using IEEE 802.21 in a heterogeneous IEEE 802.16/802.11-based, IMT-advanced (4G) network. *IEEE Wirel Commun* 15(2):26–34
9. IEEE (December 2009) IEEE draft standard for information technology—telecommunications and information exchange between system—LAN/MAN specific requirements—Part 11: Wireless medium access control (MAC) and physical layer (PHY) specifications: amendment 10: mesh networking
10. Hiertz G, Denteneer D, Max S, Taori R, Cardona J, Berleemann L, Walke B (2010) IEEE 802.11s: the WLAN mesh standard. *IEEE Wirel Commun* 17(1):104–111
11. Hiertz G, Denteneer D, Stibor L, Zang Y, Costa X, Walke B (2010) The IEEE 802.11 universe. *IEEE Commun Mag* 48(1):62–70
12. Kuran MS, Tugcu T (2007) A survey on emerging broadband wireless access technologies. *Comput Netw* 51(11):3013–3046
13. Lee DH, Kyamakya K, Umondi J (2006) Fast handover algorithm for IEEE 802.16e broadband wireless access system. 6 pp
14. ETSI (March 2002) Broadband radio access net-works (BRAN) HIPERACCESS system overview
15. ETSI (March 2001) Broadband radio access networks (BRAN); Functional requirements for fixed wireless access systems below 11 GHz: HIPERMAN

16. Kim D (2005) Wibro overview and tta activities. Technical report, TTA
17. Cianca E, Prasad R, De Sanctis M, De Luise A, Antonini M, Teotino D, Ruggieri M (2005) Integrated satellite-hap systems. *IEEE Commun Mag* 43(supl 12):33–39
18. Chouinard G (2005) Status of work in the IEEE 802.22 WG. Technical report
19. Ortiz S (2007) 4G wireless begins to take shape. *Computer* 40(11):18–21
20. Anas M, Rosa C, Calabrese F, Michaelsen P, Pedersen K, Mogensen P (2008) Qos-aware single cell admission control for utran LTE uplink, pp 2487–2491
21. Gozalvez J (2007) Ultra mobile broadband [mobile radio]. *IEEE Veh Technol Mag* 2(1):51–55
22. Bolton W, Xiao Y, Guizani M (2007) IEEE 802.20: mobile broadband wireless access. *IEEE Wirel Commun* 14(1):84–95
23. Ladebusch U, Liss C (2006) Terrestrial DVB (DVB-T): a broadcast technology for stationary portable and mobile use. *Proc IEEE* 94(1):183–193
24. DVB (November 2004) Transmission system for handheld terminals (DVB-H), ETSI EN 302304 v1.1.1
25. Kornfeld M, Daoud K (2008) The DVB-H mobile broadcast standard [standards in a nutshell]. *IEEE Signal Process Mag* 25(4):118–122, 127
26. Kornfeld M, May G (2007) DVB-H and IP datacast mdash; broadcast to handheld devices. *IEEE Trans Broadcast* 53(1):161–170

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