Chapter 1

Introduction and Historical Background of Computer Networks

1.1 Scope of Computer Networks

Perhaps the most significant change in computer science over the past twenty years has been the enormous growth of networks and their importance in the daily lives of billions of people. Because of this growth, and the diversity of networks now widespread across the globe, it would be impossible to cover all essential topics about computer networks in one semester. Instead, this course focuses on the basic fundamentals of computer networks as they were established and as they have grown.

This course is about computer networks. Our working definition of a computer network will be “any system that allows communication between devices that perform algorithms on data.” Although devices that perform data processing are now invariably digital systems, not all of the devices connected to networks are data processing devices. For example, a microphone, a refrigerator, an analog telephone, and other devices may not necessarily be for information per se. The history of networks, described below, includes many non-digital devices and, as networks become more ubiquitous, more and more types of devices are connected to networks.

The historical and anthropological study of social networks, how humans interact and communicate, is not limited to communication by electricity,
radio, and optical systems. However, for our discussion it is more useful to begin with the electrical telegraph and telephone systems that became the foundation for what would become the first computer networks.

1.2 Telegraphy and Broadcasting

The first telegraph systems had no mechanical repeating. Repeating is necessary because an electrical signal can only travel so long before it is too weak to be useful (as we will learn in Lesson 3, about basic communication concepts). So for longer distances, a person had to listen to the Morse code or other coded signal and repeat the message by entering it again, physically tapping it on a key. A repeater is a device that does the job of repeating a signal cleanly and clearly so that it can travel for longer distances without signal degradation. Telegraph lines with repeaters were really the beginning of networks as we know them today. Many types of repeater are still essential to networks. There are similar limitations on wireless signals and signals transmitted through optical fiber so these networks also often use repeaters.

After communication systems became more than just one line with one transmitter and one receiver at a time, the next problem was how to get a message from one end to another on a network that had many possible destinations. One possibility is to have each message broadcast to all destinations at once over the whole network. Many networks still use this principle. Radio and television networks have operated on the same broadcast principles for over half a century, except for various changes in the format of information being sent and received (for example FM vs. AM, analog vs. digital, etc.). One problem with broadcasting is that most systems could only take one message at a time per channel or per line. On such systems there must be a way to avoid collisions, messages interfering with each other because of more than one sender using a single medium. Avoiding collisions is still an important task in modern communication networks.

The data transmitted by telegraph was essentially digital and in a binary form. This binary form was usually in a form not based on binary numbers but easy for human operators. Mechanization of the codes meant switching to regular-length codes based on binary numbers, such as the Baudot code. Developed by Émile du Sautoy, this code was a five-bit binary code for sending (upper case) alphabetic characters, other characters, and control sequences. This code was later developed into the ASCII (American Standard Code for
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Information Interchange) we still use in many programming languages and other computer applications.

1.3 Telephony

Unlike telegraph, the telephone could transmit analog data. The developers of the telephone (like the developers of many networks) did not foresee its main purpose, for voice transmission. Suddenly special training was no longer necessary and smaller businesses, organizations, and homes could be part of the network. However, the increase in the number of possible receivers and the need to send to just one (or a small number) is a problem on an open network.

Point-to-point access requires some kind of switching. As with repeating, this job was originally done by human operators who listened for signals (voice or code) and physically connected the lines or turned switches. Automatic electromechanical switches were developed to take the place of human operators and automatic switching became such an essential change that we still call a telephone network a Public Switched Telephone Network or PSTN. In many countries, public companies were given a monopoly over providing telephone services, in exchange for providing broad PSTN coverage.

Telephone monopolies at first resisted connection of unapproved devices, such as a modem (modulator-demodulator). Legal rulings opened the way for these and other devices and modems became more common in businesses and homes during the same time that other legal rulings began to break the telephone monopolies into smaller corporations. As more computers connected, the global PSTN and its various networks became the foundation for many early computer networks and still has a major role in computer networks, both on a local and a global level.

1.4 The First Computer Networks

Military research groups began to investigate the large-scale coordination of digital information in the 1950’s. The Semi-Automatic Ground Environment (SAGE) was a US Air Force project designed to bring together various military data, such as radar data. One developer of SAGE brought the networking ideas to business with the airline reservation system called the
Semi-Automated Business Research Environment (SABRE). These and other advances resulted in a variety of different networks developing around the world, networks with completely different protocols. A protocol is a mutually understood method of transaction, without which meaningful communication is impossible. The Internet as we know it today requires some way of uniting these various networks under shared protocols.

In the late 1960’s, the Advanced Research Projects Agency Network, known as ARPANET, was formed from smaller networks. ARPANET was a military project but, at a very early stage, it began to connect many non-military organizations, including educational institutions. Under this project, the first large-scale integration of networks was attempted. It was called “internetworking” but this adjective was shortened to internet. Eventually the word became a proper noun and the National Science Foundation (NSF) took over the growing Internet, as NSFNET. By this time, the expansion of Unix distributions, especially BSD Unix (Berkeley Software Distribution Unix), had allowed many universities to join the new global network. Corporations had been involved as research partners but the network was still not open to specifically commercial uses. The NSF opened the Internet for commercial use in 1991. Whether we look at number of devices connected or the amount of traffic, the growth of the Internet has been exponential in the two decades since.

1.5 Conclusion

Networks, like all evolving systems, incorporate much of the structure and concepts of previous network systems. So knowing the history gives engineers a good background of the subject. In each lesson of this course, there will be historical references, some of them based on the systems discussed here and some based on other systems.

From the development of signaling by electrical devices, the major trend was the continual replacement of human operators. The telegraph gave us the first widely-used binary codes, including Baudot Code. The basic ideas of networks were formed, including network speed, until relatively recently (and still for many devices) called Baud rate. In telegraph networks, a major issue was the relaying of information. The history of the information revolution can be traced back to the devices that were developed to amplify telegraph signals and the machines that handled binary signals.
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Broadcast networks, such as radio and TV introduce the concept of sharing the electromagnetic spectrum and government regulation of the “airways” for communication. Almost all electronic devices, whether or not they use wireless, must conform to these regulations. In later lessons, we will learn more about the electromagnetic spectrum, including how its bands are allocated and used for communication in various kinds of network.

The PSTN networks grew very quickly to include terminals (telephone sets) at small businesses and even homes. Unlike a telegraph message which could be transcribed, voice communication meant switching had to be in “real time”. The switching on a telephone network is handled by telephone exchanges. Each local exchange may handle a segment of the network and these local segments may overlap. Connection between individual numbers over wide areas, even internationally, can be handled with various telephone numbering plans.

The Internet took advantage of the infrastructure of the PSTN, especially for connecting individual homes and small businesses by modem. At the same time, the Internet is making those previous technologies obsolete. Telegraph, for example, has been replaced by e-mail. Telephony is increasingly being conducted over computer networks, including VoIP, Voice Over IP. Few, if any, of the developers of the Internet could understand these possibilities at the beginning. However, much of the original foundations and concepts have survived. In the next lesson, we will take a look at the abstract concepts developed for these early networks, useful frameworks for discussing the general problem of communication over a network.

1.6 Glossary

**American Standard Code for Information Interchange (ASCII)** — A 7-bit code that includes the printable Roman letters, digits and punctuation symbols found in English as well as 32 non-printable device control codes. The standard was published in 1963.

**Baudot Code** — A five-bit character set used to encode and transmit the Roman alphabet plus some punctuation and control signals. Invented by the French telegraph engineer Émile Baudot in 1870.

**broadcast** — A mode of transmission in which a single sender communicates with multiple receivers.
channel — In radio communication: a specific frequency (or range of frequencies) designated for the broadcast of a single radio, TV or other communications station. In networking: a physical or logical communications connection between two devices. A physical channel corresponds to a dedicated communications line. A logical channel corresponds to a multiplexed connection over a shared medium, such as a radio channel or shared line.

collision — A conflict when two devices attempt to transmit information on the same channel at the same time.

computer network — A communication system linking many computers to facilitate communication between them.

Internet — The global public internetworking system.

line — A physical medium (such as electrical wire or fibre optic cable) over which information can be sent. A line can support one communications channel, or more than one multiplexed communications channels.

modem — A device that converts digital signals to analogue for transmission over a telephone line, and analogue signals back to digital for reception. ‘Modem’ is a contraction of the words modulator-demodulator.

monopoly — A situation in which a single company is given exclusive access to a particular market or technology.

Morse Code — A method of transmitting symbols as a series of short and long tones, lights or clicks that can be understood directly by a skilled listener. Invented by Samuel Morse in 1836 and modernised in 1848 Friedrich Clemens Gerke, Morse Code was in extensive use as a radio communications code for over a century, from 1890 until 1999. It is still in use by amateur radio enthusiasts (for text communication) and in aviation (for audible identification of radio navigation beacons).

operator — (1) A person who manually sends or receives messages over a telegraph or telephone line. (2) A company that implements and runs a communication network, such as a national telephone service.

protocol — A set of rules governing the organisation of information in messages exchanged between computers for a specific purpose. Network protocols in use today include TCP (for connection-oriented communication) and UDP (for packet-oriented communication).
1.6. GLOSSARY

**PSTN** — Public Switched Telephone Network. The collective name for the world’s telephone networks operated by national, regional, or local telephone companies. Originally a network of fixed, analogue, electrical telephone systems it has evolved into a digital network that includes fixed and mobile communications operating over electrical and fiber optic cables, microwave transmission links, cellular networks, communications satellites, and underwater telephone cables.

**receiver** — The device or person that receives a communication message.

**repeater** — A device or person that repairs signal degradation by receiving a message and then retransmitting it unmodified.

**social network** — A logical group made up of a set of individuals or organizations who routinely exchange between themselves or monitor information generated by members of the group.

**switching** — The act of establishing a temporary physical or logical connection between two network devices within a shared network infrastructure for the purposes of communication between them. An example would be connecting two telephones to each other, within a PSTN, for the duration of a telephone call made between them. Switching was originally performed manually by a telephone operator, but was replaced by automatic exchanges as the volume of calls increased.

**telegraph** — The long-distance transmission of symbolic messages (such as Morse Code or text) without physical exchange of an object (such as a pigeon) carrying the message. Telegraphy usually refers to communication using electrical signals conveyed over physical lines with a human operator at each end.

**telephone** — A telecommunications terminal device that allows two or more people to exchange verbal communication. In early computer networks, telephones were used in conjunction with *modems* to provide digital communication between two computers.

**telephone exchange** — An automatic switching device within telephone network. It connects two telephones together, for the purpose of making a call, without the need for a human operator.

**transmitter** — The device or person that sends a communication message.
ubiquitous — An adjective meaning ‘present everywhere’. A ubiquitous communications medium (such as satellite telephone) is, in principle, available everywhere in the world.