Communication Physics

Huey Witherspoon

First Edition, 2012

ISBN 978-81-323-4109-3

Published by:
White Word Publications
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter 1

Telecommunication

A Gower telephone, at the *Musée des Arts et Métiers* in Paris

Telecommunication is the transmission of information, over significant distances, for the purpose of communication. In earlier times, telecommunications involved the use of visual signals, such as beacons, smoke, semaphore telegraphs, signal flags, and optical heliographs, or audio messages via coded drumbeats, lung-blown horns, or sent by loud whistles, for example. In the modern age of electricity and electronics, telecommunications now also includes the use of electrical devices such as telegraphs, telephones, and teletypes, the use of radio and microwave communications, as well as fiber optics and their associated electronics, plus the use of the orbiting satellites and the Internet.

The first breakthrough into modern electrical telecommunications came with the push to fully develop the telegraph starting in the 1830s. The use of these electrical means of communications exploded into use on all of the continents of the world during the 19th century, and these also connected the continents via cables on the floors of the ocean. The use of the first three popular systems of electrical telecommunications, the telegraph, telephone and teletype, all required the use of conducting metal wires.

A revolution in wireless telecommunications began in the first decade of the 20th century, with Guglielmo Marconi winning the Nobel Prize in Physics in 1909 for his pioneering developments in wireless radio communications. Other highly notable pioneering inventors and developers in the field of electrical and electronic telecommunications include Charles Wheatstone and Samuel Morse (telegraph), Alexander Graham Bell (telephone), Nikola Tesla, Edwin Armstrong, and Lee de Forest (radio), as well as John Logie Baird and Philo Farnsworth (television).

Telecommunications play an important role in the world economy and the worldwide telecommunication industry's revenue was estimated to be $3.85 trillion in 2008. The service revenue of the global telecommunications industry was estimated to be $1.7 trillion in 2008, and is expected to touch $2.7 trillion by 2013.

History

Ancient systems

Greek hydraulic semaphore systems were used as early as the 4th century BCE. The hydraulic semaphores, which worked with water filled vessels and visual signals, functioned as optical telegraphs. However, they could only utilize a very limited range of pre-determined messages, and as with all such optical telegraphs could only be deployed during good visibility conditions.

During the Middle Ages, chains of beacons were commonly used on hilltops as a means of relaying a signal. Beacon chains suffered the drawback that they could only pass a single bit of information, so the meaning of the message such as "the enemy has been sighted" had to be agreed upon in advance. One notable instance of their use was during the Spanish Armada, when a beacon chain relayed a signal from Plymouth to London that signaled the arrival of the Spanish warships.

Systems since the Middle Ages

A replica of one of Chappe's semaphore towers in Nalbach

In 1792, Claude Chappe, a French engineer, built the first fixed visual telegraphy system (or semaphore line) between Lille and Paris. However semaphore systems suffered from the need for skilled operators and the expensive towers at intervals of ten to thirty kilometers (six to twenty miles). As a result of competition from the electrical telegraph, Europe's last commercial semaphore line in Sweden was abandoned in 1880.

The telegraph and telephone

The first commercial electrical telegraph was constructed by Sir Charles Wheatstone and Sir William Fothergill Cooke, and its use began on April 9, 1839. Both Wheatstone and Cooke viewed their device as "an improvement to the [already-existing, so-called] electromagnetic telegraph" not as a new device.

The businessman Samuel F.B. Morse and the physicist Joseph Henry of the United States developed their own, simpler version of the electrical telegraph, independently. Morse successfully demonstrated this system on September 2, 1837. Morse's most important technical contribution to this telegraph was the rather simple and highly efficient Morse Code, which was an important advance over Wheatstone's complicated and significantly more expensive telegraph system. The communications efficiency of the Morse Code anticipated that of the Huffman code in digital communications by over 100 years, but Morse and his associate Alfred Vail developed the code purely empirically, unlike Huffman, who gave a detailed theoretical explanation of how his method worked.

The first permanent transatlantic telegraph cable was successfully completed on 27 July 1866, allowing transatlantic electrical communication for the first time. An earlier transatlantic cable had operated for a few months in 1859, and among other things, it carried messages of greeting back and forth between President James Buchanan of the United States and Queen Victoria of the United Kingdom.

However, that transatlantic cable failed soon, and the project to lay a replacement line was delayed for five years by the American Civil War. Also, these transatlantic cables would have been completely incapable of carrying telephone calls even had the telephone already been invented. The first transatlantic telephone cable (which incorporated hundreds of electronic amplifiers) was not operational until 1956.

The conventional telephone now in use worldwide was first patented by Alexander Graham Bell in March 1876. That first patent by Bell was the *master patent* of the telephone, from which all other patents for electric telephone devices and features flowed. Credit for the invention of the electric telephone has been frequently disputed, and new controversies over the issue have arisen from time-to-time. As with other great inventions such as radio, television, the light bulb, and the digital computer, there were several inventors who did pioneering experimental work on *voice transmission over a wire*, and then they improved on each other's ideas. However, the key innovators were Alexander Graham Bell and Gardiner Greene Hubbard, who created the first telephone company, the Bell Telephone Company in the United States, which later evolved into American Telephone & Telegraph (AT&T).

The first commercial telephone services were set up in 1878 and 1879 on both sides of the Atlantic in the cities of New Haven, Connecticut, and London, England.

Radio and television

In 1832, James Lindsay gave a classroom demonstration of wireless telegraphy via conductive water to his students. By 1854, he was able to demonstrate a transmission across the Firth of Tay from Dundee, Scotland, to Woodhaven, a distance of about two miles (3 km), again using water as the transmission medium. In December 1901, Guglielmo Marconi established wireless communication between St. John's, Newfoundland and Poldhu, Cornwall (England), earning him the Nobel Prize in Physics for 1909, one which he shared with Karl Braun. However *small-scale* radio communication had already been demonstrated in 1893 by Nikola Tesla in a presentation before the National Electric Light Association.

On March 25, 1925, John Logie Baird of Scotland was able to demonstrate the transmission of moving pictures at the Selfridge's department store in London, England. Baird's system relied upon the fast-rotating Nipkow disk, and thus it became known as the mechanical television. It formed the basis of experimental broadcasts done by the British Broadcasting Corporation beginning September 30, 1929. However, for most of the 20th century, television systems were designed around the cathode ray tube, invented by Karl Braun. The first version of such an electronic television to show promise was produced by Philo Farnsworth of the United States, and it was demonstrated to his family in Idaho on September 7, 1927.

Computer networks and the Internet

On 11 September 1940, George Stibitz was able to transmit problems using teletype to his Complex Number Calculator in New York and receive the computed results back at Dartmouth College in New Hampshire. This configuration of a centralized computer or mainframe computer with remote "dumb terminals" remained popular throughout the 1950s and into the 60's. However, it was not until the 1960s that researchers started to investigate packet switching — a technology that allows chunks of data to be sent between different computers without first passing through a centralized mainframe. A four-node network emerged on December 5, 1969. This network soon became the ARPANET, which by 1981 would consist of 213 nodes.

ARPANET's development centred around the Request for Comment process and on 7 April 1969, RFC 1 was published. This process is important because ARPANET would eventually merge with other networks to form the Internet, and many of the communication protocols that the Internet relies upon today were specified through the Request for Comment process. In September 1981, RFC 791 introduced the Internet Protocol version 4 (IPv4) and RFC 793 introduced the Transmission Control Protocol (TCP) — thus creating the TCP/IP protocol that much of the Internet relies upon today.

However, not all important developments were made through the Request for Comment process. Two popular link protocols for local area networks (LANs) also appeared in the 1970s. A patent for the token ring protocol was filed by Olof Soderblom on October 29, 1974, and a paper on the Ethernet protocol was published by Robert Metcalfe and David

Boggs in the July 1976 issue of *Communications of the ACM*. The Ethernet protocol had been inspired by the ALOHAnet protocol which had been developed by electrical engineering researchers at the University of Hawaii.

Key concepts

A number of key concepts reoccur throughout the literature on modern telecommunication systems. Some of these concepts are discussed below.

Basic elements

A basic telecommunication system consists of three primary units that are always present in some form:

- A transmitter that takes information and converts it to a signal.
- A transmission medium, also called the "physical channel" that carries the signal. An example of this is the "free space channel".
- A receiver that takes the signal from the channel and converts it back into usable information.

For example, in a radio broadcasting station the station's large power amplifier is the transmitter; and the broadcasting antenna is the interface between the power amplifier and the "free space channel". The free space channel is the transmission medium; and the receiver's antenna is the interface between the free space channel and the receiver. Next, the radio receiver is the destination of the radio signal, and this is where it is converted from electricity to sound for people to listen to.

Sometimes, telecommunication systems are "duplex" (two-way systems) with a single box of electronics working as both a transmitter and a receiver, or a *transceiver*. For example, a cellular telephone is a transceiver. The transmission electronics and the receiver electronics in a transceiver are actually quite independent of each other. This can be readily explained by the fact that radio transmitters contain power amplifiers that operate with electrical powers measured in the watts or kilowatts, but radio receivers deal with radio powers that are measured in the microwatts or nanowatts. Hence, transceivers have to be carefully designed and built to isolate their high-power circuitry and their low-power circuitry from each other.

Telecommunication over telephone lines is called point-to-point communication because it is between one transmitter and one receiver. Telecommunication through radio broadcasts is called broadcast communication because it is between one powerful transmitter and numerous low-power but sensitive radio receivers.

Telecommunications in which multiple transmitters and multiple receivers have been designed to cooperate and to share the same physical channel are called multiplex systems.

Analog versus digital communications

Communications signals can be either by analog signals or digital signals. There are analog communication systems and digital communication systems. For an analog signal, the signal is varied continuously with respect to the information. In a digital signal, the information is encoded as a set of discrete values (for example, a set of ones and zeros). During the propagation and reception, the information contained in analog signals will inevitably be degraded by undesirable physical noise. (The output of a transmitter is noise-free for all practical purposes.) Commonly, the noise in a communication system can be expressed as adding or subtracting from the desirable signal in a completely random way. This form of noise is called ***"additive noise"***, with the understanding that the noise can be negative or positive at different instants of time. Noise that is not additive noise is a much more difficult situation to describe or analyze, and these other kinds of noise will be omitted here.

On the other hand, unless the *additive noise* disturbance exceeds a certain threshold, the information contained in digital signals will remain intact. Their resistance to noise represents a key advantage of digital signals over analog signals.

Telecommunication networks

A communications network is a collection of transmitters, receivers, and communications channels that send messages to one another. Some digital communications networks contain one or more routers that work together to transmit information to the correct user. An analog communications network consists of one or more switches that establish a connection between two or more users. For both types of network, repeaters may be necessary to amplify or recreate the signal when it is being transmitted over long distances. This is to combat attenuation that can render the signal indistinguishable from the noise.

Communication channels

The term "channel" has two different meanings. In one meaning, a channel is the physical medium that carries a signal between the transmitter and the receiver. Examples of this include the atmosphere for sound communications, glass optical fibers for some kinds of optical communications, coaxial cables for communications by way of the voltages and electric currents in them, and free space for communications using visible light, infrared waves, ultraviolet light, and radio waves. This last channel is called the "free space channel". The sending of radio waves from one place to another has nothing to do with the presence or absence of an atmosphere between the two. Radio waves travel through a perfect vacuum just as easily as they travel through air, fog, clouds, or any other kind of gas besides air.

The other meaning of the term "channel" in telecommunications is seen in the phrase communications channel, which is a subdivision of a transmission medium so that it can be used to send multiple streams of information simultaneously. For example, one radio station can broadcast radio waves into free space at frequencies in the neighborhood of 94.5 MHz (megahertz) while another radio station can simultaneously broadcast radio waves at frequencies in the neighborhood of 96.1 MHz. Each radio station would transmit radio waves over a frequency bandwidth of about 180 kHz (kilohertz), centered at frequencies such as the above, which are called the "carrier frequencies". Each station in this example is separated from its adjacent stations by 200 kHz, and the difference between 200 kHz and 180 kHz (20 kHz) is an engineering allowance for the imperfections in the communication system.

In the example above, the "free space channel" has been divided into communications channels according to frequencies, and each channel is assigned a separate frequency bandwidth in which to broadcast radio waves. This system of dividing the medium into channels according to frequency is called "frequency-division multiplexing" (**FDM**).

Another way of dividing a communications medium into channels is to allocate each sender a recurring segment of time (a "time slot", for example, 20 milliseconds out of each second), and to allow each sender to send messages only within its own time slot. This method of dividing the medium into communication channels is called "time-division multiplexing" (**TDM**), and is used in optical fiber communication. Some radio communication systems use TDM within an allocated FDM channel. Hence, these systems use a hybrid of TDM and FDM.

Modulation

The shaping of a signal to convey information is known as modulation. Modulation can be used to represent a digital message as an analog waveform. This is commonly called "keying" - a term derived from the older use of Morse Code in telecommunications - and several keying techniques exist (these include phase-shift keying, frequency-shift keying, and amplitude-shift keying). The "Bluetooth" system, for example, uses phase-shift keying to exchange information between various devices. In addition, there are combinations of phase-shift keying and amplitude-shift keying which is called (in the jargon of the field) "quadrature amplitude modulation" (QAM) that are used in high-capacity digital radio communication systems.

Modulation can also be used to transmit the information of low-frequency analog signals at higher frequencies. This is helpful because low-frequency analog signals cannot be effectively transmitted over free space. Hence the information from a low-frequency analog signal must be impressed into a higher-frequency signal (known as the "carrier wave") before transmission. There are several different modulation schemes available to achieve this [two of the most basic being amplitude modulation (AM) and frequency modulation (FM)]. An example of this process is a disc jockey's voice being impressed into a 96 MHz carrier wave using frequency modulation (the voice would then be received on a radio as the channel "96 FM"). In addition, modulation has the advantage of being about to use frequency division multiplexing (FDM).

Society and telecommunication

Telecommunication has a significant social, cultural. and economic impact on modern society. In 2008, estimates placed the telecommunication industry's revenue at $3.85 trillion (USD) or just under 3.0 percent of the gross world product (official exchange rate). Several following sections discuss the impact of telecommunication on society.

Economic impact

Microeconomics

On the microeconomic scale, companies have used telecommunications to help build global business empires. This is self-evident in the case of online retailer Amazon.com but, according to academic Edward Lenert, even the conventional retailer Wal-Mart has benefited from better telecommunication infrastructure compared to its competitors. In cities throughout the world, home owners use their telephones to organize many home services ranging from pizza deliveries to electricians. Even relatively-poor communities have been noted to use telecommunication to their advantage. In Bangladesh's Narshingdi district, isolated villagers use cellular phones to speak directly to wholesalers and arrange a better price for their goods. In Côte d'Ivoire, coffee growers share mobile phones to follow hourly variations in coffee prices and sell at the best price.

Macroeconomics

On the macroeconomic scale, Lars-Hendrik Röller and Leonard Waverman suggested a causal link between good telecommunication infrastructure and economic growth. Few dispute the existence of a correlation although some argue it is wrong to view the relationship as causal.

Because of the economic benefits of good telecommunication infrastructure, there is increasing worry about the inequitable access to telecommunication services amongst various countries of the world—this is known as the digital divide. A 2003 survey by the International Telecommunication Union (ITU) revealed that roughly one-third of countries have fewer than one mobile subscription for every 20 people and one-third of countries have fewer than one land-line telephone subscription for every 20 people. In terms of Internet access, roughly half of all countries have fewer than one out of 20 people with Internet access. From this information, as well as educational data, the ITU was able to compile an index that measures the overall ability of citizens to access and use information and communication technologies. Using this measure, Sweden, Denmark and Iceland received the highest ranking while the African countries Nigeria, Burkina Faso and Mali received the lowest.

Social impact

Telecommunication has played a significant role in social relationships. Nevertheless devices like the telephone system were originally advertised with an emphasis on the practical dimensions of the device (such as the ability to conduct business or order home services) as opposed to the social dimensions. It was not until the late 1920s and 1930s that the social dimensions of the device became a prominent theme in telephone advertisements. New promotions started appealing to consumers' emotions, stressing the importance of social conversations and staying connected to family and friends.

Since then the role that telecommunications has played in social relations has become increasingly important. In recent years, the popularity of social networking sites has increased dramatically. These sites allow users to communicate with each other as well as post photographs, events and profiles for others to see. The profiles can list a person's age, interests, sexual preference and relationship status. In this way, these sites can play important role in everything from organising social engagements to courtship.

Prior to social networking sites, technologies like short message service(SMS) and the telephone also had a significant impact on social interactions. In 2000, market research group Ipsos MORI reported that 81% of 15 to 24 year-old SMS users in the United Kingdom had used the service to coordinate social arrangements and 42% to flirt.

Other impacts

In cultural terms, telecommunication has increased the public's ability to access to music and film. With television, people can watch films they have not seen before in their own home without having to travel to the video store or cinema. With radio and the Internet, people can listen to music they have not heard before without having to travel to the music store.

Telecommunication has also transformed the way people receive their news. A survey by the non-profit Pew Internet and American Life Project found that when just over 3,000 people living in the United States were asked where they got their news "yesterday", more people said television or radio than newspapers. The results are summarised in the following table (the percentages add up to more than 100% because people were able to specify more than one source).

Local TV	National TV	Radio	Local paper	Internet	National paper
59%	47%	44%	38%	23%	12%

Telecommunication has had an equally significant impact on advertising. TNS Media Intelligence reported that in 2007, 58% of advertising expenditure in the United States was spent on mediums that depend upon telecommunication. The results are summarised in the following table.

	Internet	Radio	Cable TV	Syndicated TV	Spot TV	Network TV	Newspaper	Magazine	Outdoor	Total
Percent	7.6%	7.2%	12.1%	2.8%	11.3%	17.1%	18.9%	20.4%	2.7%	100%
Dollars	$11.31 billion	$10.69 billion	$18.02 billion	$4.17 billion	$16.82 billion	$25.42 billion	$28.22 billion	$30.33 billion	$4.02 billion	$149 billion

Telecommunication and government

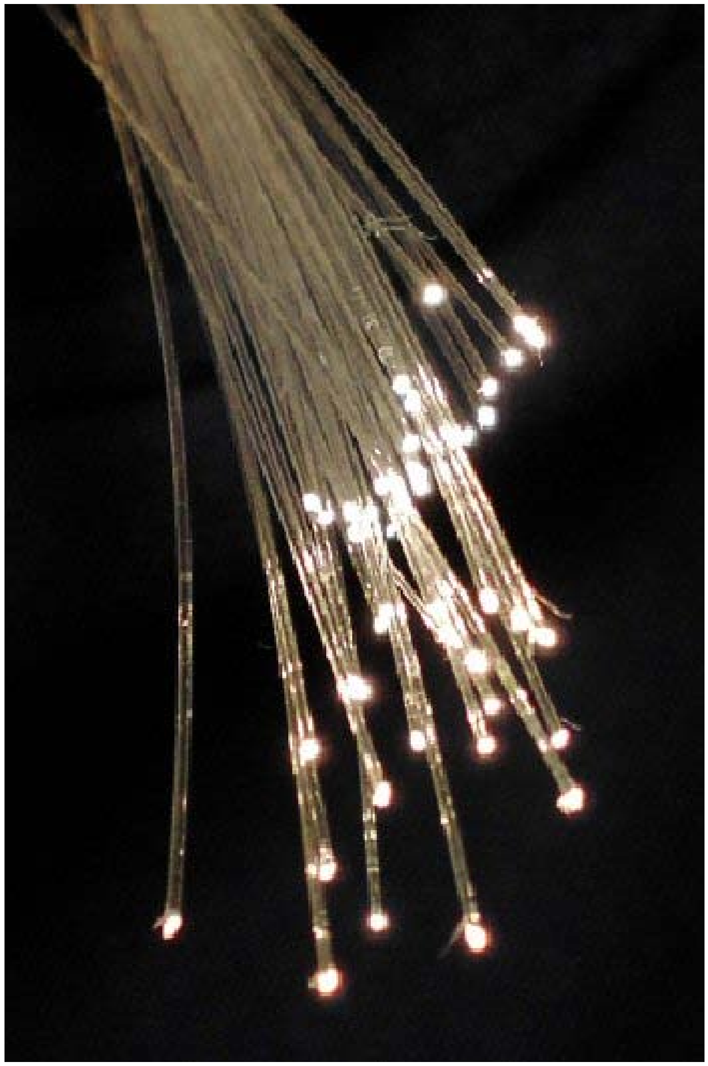
Many countries have enacted legislation which conform to the *International Telecommunication Regulations* establish by the International Telecommunication Union (ITU), which is the "leading United Nations agency for information and communication technology issues." In 1947, at the Atlantic City Conference, the ITU decided to "afford international protection to all frequencies registered in a new international frequency list and used in conformity with the Radio Regulation." According to the ITU's *Radio Regulations* adopted in Atlantic City, all frequencies referenced in the *International Frequency Registration Board*, examined by the board and registered on the *International Frequency List* "shall have the right to international protection from harmful interference."

From a global perspective, there have been political debates and legislation regarding the management of telecommunication and broadcasting. The history of broadcasting discusses some of debates in relation to balancing conventional communication such as printing and telecommunication such as radio broadcasting. The onset of World War II brought on the first explosion of international broadcasting propaganda. Countries, their governments, insurgents, terrorists, and militiamen have all used telecommunication and broadcasting techniques to promote propaganda. Patriotic propaganda for political movements and colonization started the mid 1930s. In 1936, the BBC did broadcast propaganda to the Arab World to partly counter similar broadcasts from Italy, which also had colonial interests in North Africa.

Modern insurgents, such as those in the latest Iraq war, often use intimidating telephone calls, SMSs and the distribution of sophisticated videos of an attack on coalition troops within hours of the operation. "The Sunni insurgents even have their own television station, Al-Zawraa, which while banned by the Iraqi government, still broadcasts from Erbil, Iraqi Kurdistan, even as coalition pressure has forced it to switch satellite hosts several times."

Modern telecommunication

Telephone



Optical fiber provides cheaper bandwidth for long distance communication

In an analog telephone network, the caller is connected to the person he wants to talk to by switches at various telephone exchanges. The switches form an electrical connection between the two users and the setting of these switches is determined electronically when the caller dials the number. Once the connection is made, the caller's voice is transformed to an electrical signal using a small microphone in the caller's handset. This electrical signal is then sent through the network to the user at the other end where it is transformed back into sound by a small speaker in that person's handset. There is a separate electrical connection that works in reverse, allowing the users to converse.

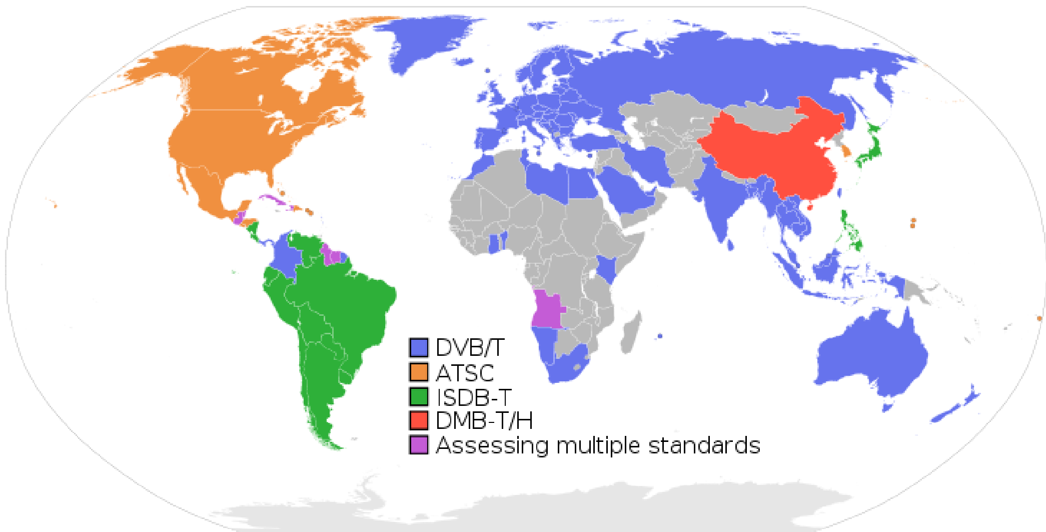
The fixed-line telephones in most residential homes are analog — that is, the speaker's voice directly determines the signal's voltage. Although short-distance calls may be handled from end-to-end as analog signals, increasingly telephone service providers are transparently converting the signals to digital for transmission before converting them back to analog for reception. The advantage of this is that digitized voice data can travel side-by-side with data from the Internet and can be perfectly reproduced in long distance communication (as opposed to analog signals that are inevitably impacted by noise).

Mobile phones have had a significant impact on telephone networks. Mobile phone subscriptions now outnumber fixed-line subscriptions in many markets. Sales of mobile phones in 2005 totalled 816.6 million with that figure being almost equally shared amongst the markets of Asia/Pacific (204 m), Western Europe (164 m), CEMEA (Central Europe, the Middle East and Africa) (153.5 m), North America (148 m) and Latin America (102 m). In terms of new subscriptions over the five years from 1999, Africa has outpaced other markets with 58.2% growth. Increasingly these phones are being serviced by systems where the voice content is transmitted digitally such as GSM or W-CDMA with many markets choosing to depreciate analog systems such as AMPS.

There have also been dramatic changes in telephone communication behind the scenes. Starting with the operation of TAT-8 in 1988, the 1990s saw the widespread adoption of systems based on optic fibres. The benefit of communicating with optic fibers is that they offer a drastic increase in data capacity. TAT-8 itself was able to carry 10 times as many telephone calls as the last copper cable laid at that time and today's optic fibre cables are able to carry 25 times as many telephone calls as TAT-8. This increase in data capacity is due to several factors: First, optic fibres are physically much smaller than competing technologies. Second, they do not suffer from crosstalk which means several hundred of them can be easily bundled together in a single cable. Lastly, improvements in multiplexing have led to an exponential growth in the data capacity of a single fibre.

Assisting communication across many modern optic fibre networks is a protocol known as Asynchronous Transfer Mode (ATM). The ATM protocol allows for the side-by-side data transmission mentioned in the second paragraph. It is suitable for public telephone networks because it establishes a pathway for data through the network and associates a traffic contract with that pathway. The traffic contract is essentially an agreement between the client and the network about how the network is to handle the data; if the network cannot meet the conditions of the traffic contract it does not accept the connection. This is important because telephone calls can negotiate a contract so as to guarantee themselves a constant bit rate, something that will ensure a caller's voice is not delayed in parts or cut-off completely. There are competitors to ATM, such as Multiprotocol Label Switching (MPLS), that perform a similar task and are expected to supplant ATM in the future.

Radio and television



Digital television standards and their adoption worldwide.

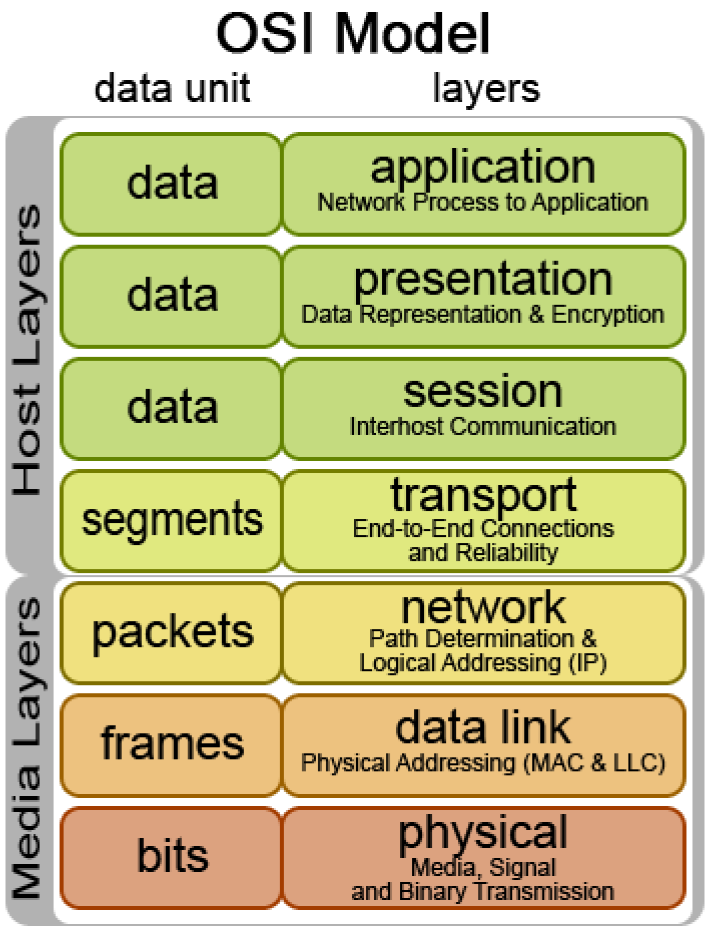
In a broadcast system, the central high-powered broadcast tower transmits a high-frequency electromagnetic wave to numerous low-powered receivers. The high-frequency wave sent by the tower is modulated with a signal containing visual or audio information. The receiver is then tuned so as to pick up the high-frequency wave and a demodulator is used to retrieve the signal containing the visual or audio information. The broadcast signal can be either analog (signal is varied continuously with respect to the information) or digital (information is encoded as a set of discrete values).

The broadcast media industry is at a critical turning point in its development, with many countries moving from analog to digital broadcasts. This move is made possible by the production of cheaper, faster and more capable integrated circuits. The chief advantage of digital broadcasts is that they prevent a number of complaints common to traditional analog broadcasts. For television, this includes the elimination of problems such as snowy pictures, ghosting and other distortion. These occur because of the nature of analog transmission, which means that perturbations due to noise will be evident in the final output. Digital transmission overcomes this problem because digital signals are reduced to discrete values upon reception and hence small perturbations do not affect the final output. In a simplified example, if a binary message 1011 was transmitted with signal amplitudes [1.0 0.0 1.0 1.0] and received with signal amplitudes [0.9 0.2 1.1 0.9] it would still decode to the binary message 1011 — a perfect reproduction of what was sent. From this example, a problem with digital transmissions can also be seen in that if the noise is great enough it can significantly alter the decoded message. Using forward error correction a receiver can correct a handful of bit errors in the resulting message but too much noise will lead to incomprehensible output and hence a breakdown of the transmission.

In digital television broadcasting, there are three competing standards that are likely to be adopted worldwide. These are the ATSC, DVB and ISDB standards; the adoption of these standards thus far is presented in the captioned map. All three standards use MPEG-2 for video compression. ATSC uses Dolby Digital AC-3 for audio compression, ISDB uses Advanced Audio Coding (MPEG-2 Part 7) and DVB has no standard for audio compression but typically uses MPEG-1 Part 3 Layer 2. The choice of modulation also varies between the schemes. In digital audio broadcasting, standards are much more unified with practically all countries choosing to adopt the Digital Audio Broadcasting standard (also known as the Eureka 147 standard). The exception being the United States which has chosen to adopt HD Radio. HD Radio, unlike Eureka 147, is based upon a transmission method known as in-band on-channel transmission that allows digital information to "piggyback" on normal AM or FM analog transmissions.

However, despite the pending switch to digital, analog television remains being transmitted in most countries. An exception is the United States that ended analog television transmission (by all but the very low-power TV stations) on 12 June 2009 after twice delaying the switchover deadline. For analog television, there are three standards in use for broadcasting color TV. These are known as PAL (British designed), NTSC (North American designed), and SECAM (French designed). (It is important to understand that these are the ways from sending color TV, and they do not have anything to do with the standards for black & white TV, which also vary from country to country.) For analog radio, the switch to digital radio is made more difficult by the fact that analog receivers are sold at a small fraction of the price of digital receivers. The choice of modulation for analog radio is typically between amplitude modulation (**AM**) or frequency modulation (**FM**). To achieve stereo playback, an amplitude modulated subcarrier is used for stereo FM.

The Internet



The OSI reference model

The Internet is a worldwide network of computers and computer networks that can communicate with each other using the Internet Protocol. Any computer on the Internet has a unique IP address that can be used by other computers to route information to it. Hence, any computer on the Internet can send a message to any other computer using its IP address. These messages carry with them the originating computer's IP address allowing for two-way communication. The Internet is thus an exchange of messages between computers.

As of 2008, an estimated 21.9% of the world population has access to the Internet with the highest access rates (measured as a percentage of the population) in North America (73.6%), Oceania/Australia (59.5%) and Europe (48.1%). In terms of broadband access, Iceland (26.7%), South Korea (25.4%) and the Netherlands (25.3%) led the world.

The Internet works in part because of protocols that govern how the computers and routers communicate with each other. The nature of computer network communication lends itself to a layered approach where individual protocols in the protocol stack run more-or-less independently of other protocols. This allows lower-level protocols to be customized for the network situation while not changing the way higher-level protocols operate. A practical example of why this is important is because it allows an Internet browser to run the same code regardless of whether the computer it is running on is connected to the Internet through an Ethernet or Wi-Fi connection. Protocols are often talked about in terms of their place in the OSI reference model (pictured on the right), which emerged in 1983 as the first step in an unsuccessful attempt to build a universally adopted networking protocol suite.

For the Internet, the physical medium and data link protocol can vary several times as packets traverse the globe. This is because the Internet places no constraints on what physical medium or data link protocol is used. This leads to the adoption of media and protocols that best suit the local network situation. In practice, most intercontinental communication will use the Asynchronous Transfer Mode (ATM) protocol (or a modern equivalent) on top of optic fibre. This is because for most intercontinental communication the Internet shares the same infrastructure as the public switched telephone network.

At the network layer, things become standardized with the Internet Protocol (IP) being adopted for logical addressing. For the World Wide Web, these "IP addresses" are derived from the human readable form using the Domain Name System. At the moment, the most widely used version of the Internet Protocol is version four but a move to version six is imminent.

At the transport layer, most communication adopts either the Transmission Control Protocol (TCP) or the User Datagram Protocol (UDP). TCP is used when it is essential every message sent is received by the other computer where as UDP is used when it is merely desirable. With TCP, packets are retransmitted if they are lost and placed in order before they are presented to higher layers. With UDP, packets are not ordered or retransmitted if lost. Both TCP and UDP packets carry port numbers with them to specify what application or process the packet should be handled by. Because certain application-level protocols use certain ports, network administrators can manipulate traffic to suit particular requirements. Examples are to restrict Internet access by blocking the traffic destined for a particular port or to affect the performance of certain applications by assigning priority.

Above the transport layer, there are certain protocols that are sometimes used and loosely fit in the session and presentation layers, most notably the Secure Sockets Layer (SSL) and Transport Layer Security (TLS) protocols. These protocols ensure that the data transferred between two parties remains completely confidential and one or the other is in use when a padlock appears in the address bar of your web browser. Finally, at the application layer, are many of the protocols Internet users would be familiar with such as HTTP (web browsing), POP3 (e-mail), FTP (file transfer), IRC (Internet chat), BitTorrent (file sharing) and OSCAR (instant messaging).

Local Area Networks and Wide Area Networks

Despite the growth of the Internet, the characteristics of local area networks ("LANs" - computer networks that do not extend beyond a few kilometers in size) remain distinct. This is because networks on this scale do not require all the features associated with larger networks and are often more cost-effective and efficient without them. When they are not connected with the Internet, they also have the advantages of privacy and security. However, purposefully lacking a direct connection to the Internet will not provide 100% protection of the LAN from hackers, military forces, or economic powers. These threats exist if there are any methods for connecting remotely to the LAN.

There are also independent wide area networks ("WANs" - private computer networks that can and do extend for thousands of kilometers.) Once again, some of their advantages include their privacy, security, and complete ignoring of any potential hackers - who cannot "touch" them. Of course, prime users of private LANs and WANs include armed forces and intelligence agencies that *must* keep their information completely secure and secret.

In the mid-1980s, several sets of communication protocols emerged to fill the gaps between the data-link layer and the application layer of the OSI reference model. These included Appletalk, IPX, and NetBIOS with the dominant protocol set during the early 1990s being IPX due to its popularity with MS-DOS users. TCP/IP existed at this point, but it was typically only used by large government and research facilities.

As the Internet grew in popularity and a larger percentage of traffic became Internet-related, LANs and WANs gradually moved towards the TCP/IP protocols, and today networks mostly dedicated to TCP/IP traffic are common. The move to TCP/IP was helped by technologies such as DHCP that allowed TCP/IP clients to discover their own network address — a function that came standard with the AppleTalk/ IPX/ NetBIOS protocol sets.

It is at the data-link layer, though, that most modern LANs diverge from the Internet. Whereas Asynchronous Transfer Mode (ATM) or Multiprotocol Label Switching (MPLS) are typical data-link protocols for larger networks such as WANs; Ethernet and Token Ring are typical data-link protocols for LANs. These protocols differ from the former protocols in that they are simpler (e.g. they omit features such as Quality of Service guarantees) and offer collision prevention. Both of these differences allow for more economical systems. Despite the modest popularity of IBM token ring in the 1980s and 90's, virtually all LANs now use either wired or wireless Ethernets. At the physical layer, most wired Ethernet implementations use copper twisted-pair cables (including the common 10BASE-T networks). However, some early implementations used heavier coaxial cables and some recent implementations (especially high-speed ones) use optical fibers. When optic fibers are used, the distinction must be made between multimode fibers and single-mode fiberes. Multimode fibers can be thought of as thicker optical fibers that are cheaper to manufacture devices for but that suffers from less usable bandwidth and worse attenuation - implying poorer long-distance performance.

Chapter 2

Optical Communication and Nanonetwork

Optical communication

Optical communication is any form of telecommunication that uses light as the transmission medium.

An optical communication system consists of a *transmitter*, which encodes a *message* into an optical *signal*, a *channel*, which carries the signal to its destination, and a *receiver*, which reproduces the message from the received optical signal.

Forms of optical communication

Naval signal

There are many forms of non-technological optical communication, including body language and sign language.

Techniques such as semaphore lines, ship flags, smoke signals, and beacon fires were the earliest form of technological optical communication.

The heliograph uses a mirror to reflect sunlight to a distant observer. By moving the mirror the distant observer sees flashes of light that can be used to send a prearranged signaling code. Navy ships often use a signal lamp to signal in Morse code in a similar way.

Distress flares are used by mariners in emergencies, while lighthouses and navigation lights are used to communicate navigation hazards.

Aircraft use the landing lights at airports to land safely, especially at night. Aircraft landing on an aircraft carrier use a similar system to land correctly on the carrier deck. The light systems communicate the correct position of the aircraft relative to the best landing glideslope. Also, many control towers still have an Aldis lamp to communicate with planes whose radio failed.

Optical fiber is the most common medium for modern digital optical communication.

Free-space optical communication is also used today in a variety of applications.

Optical fiber communication

Optical fiber is the most common type of channel for optical communications, however, other types of optical waveguides are used within computers or communications gear, and have even formed the channel of very short distance (e.g. chip-to-chip, intra-chip) links in laboratory trials. The transmitters in optical fiber links are generally light-emitting diodes (LEDs) or laser diodes. Infrared light, rather than visible light is used more commonly, because optical fibers transmit infrared wavelengths with less attenuation and dispersion. The signal encoding is typically simple intensity modulation, although historically optical phase and frequency modulation have been demonstrated in the lab. The need for periodic signal regeneration was largely superseded by the introduction of the erbium-doped fiber amplifier, which extended link distances at significantly lower cost.

Free-space optical communication

Free Space Optics (FSO) systems are generally employed for 'last mile' communications and can function over distances of several kilometers as long as there is a clear line of sight between the source and the destination, and the optical receiver can reliably decode the transmitted information. IrDA is an example of low-data-rate, short distance free-space optical communications using LEDs.

Nanonetwork

A **nanonetwork** or **nanoscale network** is a set of interconnected nanomachines, i.e., devices in the order of a few hundred nanometers or a few micrometers at most, which are able to perform only very simple tasks such as computing, data storing, sensing and actuation. Nanonetworks are expected to expand the capabilities of single nanomachines both in terms of complexity and range of operation by allowing them to coordinate, share and fuse information. Nanonetworks enable new applications of nanotechnology in the biomedical field, environmental research, military technology and industrial and consumer goods applications.

Communication approaches

Classical communication paradigms need to be revised for the nanoscale. The two main alternatives for communication in the nanoscale are based either on electromagnetic communication or on molecular communication.

Electromagnetic

This is defined as the transmission and reception of electromagnetic radiation from components based on novel nanomaterials. Recent advancements in carbon and molecular electronics have opened the door to a new generation of electronic nanoscale components such as nanobatteries, nanoscale energy harvesting systems, nano-memories, logical circuitry in the nanoscale and even nano-antennas. From a communication perspective, the unique properties observed in nanomaterials will decide on the specific bandwidths for emission of electromagnetic radiation, the time lag of the emission, or the magnitude of the emitted power for a given input energy, amongst others.

For the time being, two main alternatives for electromagnetic communication in the nanoscale have been envisioned. First, it has been experimentally demonstrated that is possible to receive and demodulate an electromagnetic wave by means of a nanoradio, i.e., an electromechanically resonating carbon nanotube which is able to decode an amplitude or frequency modulated wave. Second, graphene-based nano-antennas have been analyzed as potential electromagnetic radiators in the Terahertz band

Molecular

Molecular communication is defined as the transmission and reception of information by means of molecules. The different molecular communication techniques can be classified according to the type of molecule propagation in walkaway-based, flow-based or diffusion-based communication.

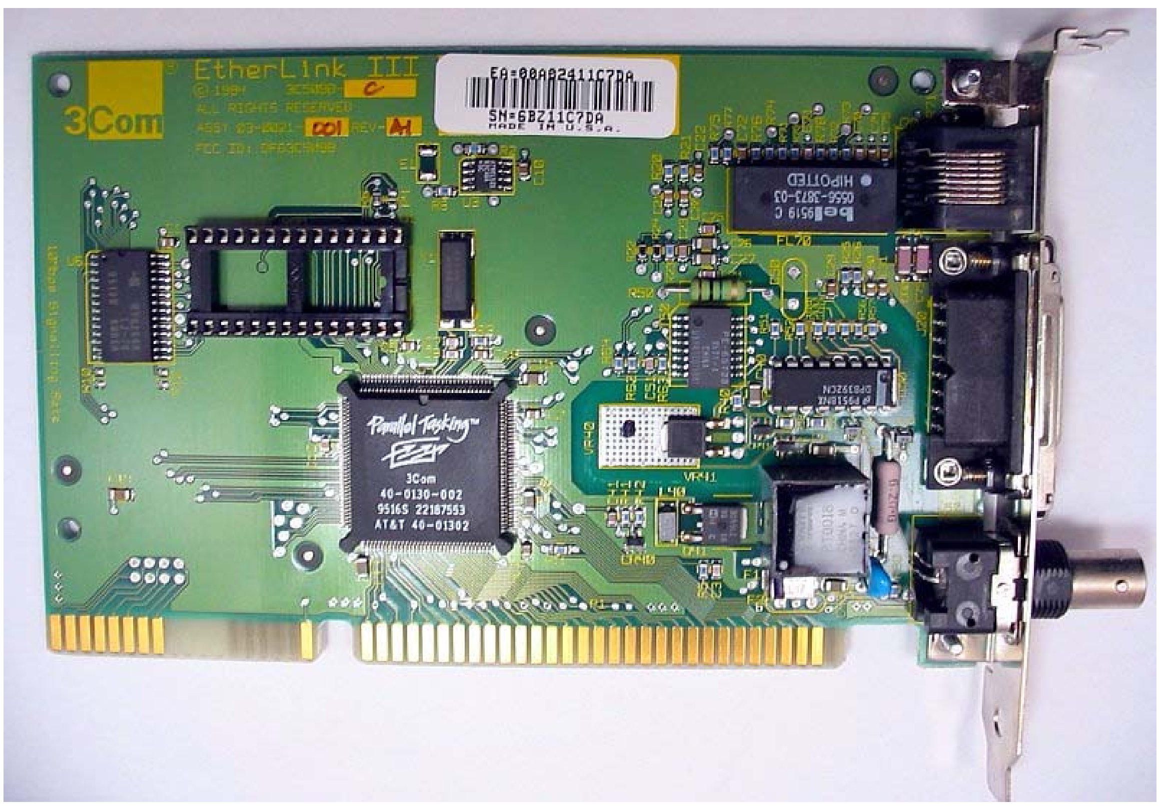
In **walkway-based** molecular communication, the molecules propagate through pre-defined pathways by using carrier substances, such as molecular motors. This type of molecular communication can also be achieved by using E. coli bacteria as chemotaxis.

In **flow-based** molecular communication, the molecules propagate through diffusion in a fluidic medium whose flow and turbulence are guided and predictable. The hormonal communication through blood streams inside the human body is an example of this type of propagation. The flow-based propagation can also be realized by using carrier entities whose motion can be constrained on the average along specific paths, despite showing a random component. A good example of this case is given by pheromonal long range molecular communications.

In **diffusion-based** molecular communication, the molecules propagate through spontaneous diffusion in a fluidic medium. In this case, the molecules can be subject solely to the laws of diffusion or can also be affected by non-predictable turbulence present in the fluidic medium. Pheromonal communication, when pheromones are released into a fluidic medium, such as air or water, is an example of diffusion-based architecture. Other examples of this kind of transport include calcium signaling among cells, as well as quorum sensing among bacteria.

Chapter 3

Computer Networking



Network cards such as this one can transmit and receive data at high rates over various types of network cables. This card is a 'Combo' card which supports three cabling standards.

Computer networking or **Data communications** (**Datacom**) is the engineering discipline concerned with the communication between computer systems or devices. A computer network is any set of computers or devices connected to each other with the ability to exchange data. Computer networking is sometimes considered a sub-discipline of telecommunications, computer science, information technology and/or computer engineering since it relies heavily upon the theoretical and practical application of these scientific and engineering disciplines. The three types of networks are: the Internet, the intranet, and the extranet. Examples of different network methods are:

- Local area network (LAN), which is usually a small network constrained to a small geographic area. An example of a LAN would be a computer network within a building.
- Metropolitan area network (MAN), which is used for medium size area. examples for a city or a state.
- Wide area network (WAN) that is usually a larger network that covers a large geographic area.
- Wireless LANs and WANs (WLAN & WWAN) are the wireless equivalent of the LAN and WAN.

All networks are interconnected to allow communication with a variety of different kinds of media, including twisted-pair copper wire cable, coaxial cable, optical fiber, power lines and various wireless technologies. The devices can be separated by a few meters (e.g. via Bluetooth) or nearly unlimited distances (e.g. via the interconnections of the Internet). Networking, routers, routing protocols, and networking over the public Internet have their specifications defined in documents called RFCs.

Views of networks

Users and network administrators typically have different views of their networks. Users can share printers and some servers from a workgroup, which usually means they are in the same geographic location and are on the same LAN, whereas a Network Administrator is responsible to keep that network up and running. A community of interest has less of a connection of being in a local area, and should be thought of as a set of arbitrarily located users who share a set of servers, and possibly also communicate via peer-to-peer technologies.

Network administrators can see networks from both physical and logical perspectives. The physical perspective involves geographic locations, physical cabling, and the network elements (e.g., routers, bridges and application layer gateways that interconnect the physical media. Logical networks, called, in the TCP/IP architecture, subnets, map onto one or more physical media. For example, a common practice in a campus of buildings is to make a set of LAN cables in each building appear to be a common subnet, using virtual LAN (VLAN) technology.

Both users and administrators will be aware, to varying extents, of the trust and scope characteristics of a network. Again using TCP/IP architectural terminology, an intranet is a community of interest under private administration usually by an enterprise, and is only accessible by authorized users (e.g. employees). Intranets do not have to be connected to the Internet, but generally have a limited connection. An extranet is an extension of an intranet that allows secure communications to users outside of the intranet (e.g. business partners, customers).

Unofficially, the Internet is the set of users, enterprises, and content providers that are interconnected by Internet Service Providers (ISP). From an engineering viewpoint, the Internet is the set of subnets, and aggregates of subnets, which share the registered IP address space and exchange information about the reachability of those IP addresses using the Border Gateway Protocol. Typically, the human-readable names of servers are translated to IP addresses, transparently to users, via the directory function of the Domain Name System (DNS).

Over the Internet, there can be business-to-business (B2B), business-to-consumer (B2C) and consumer-to-consumer (C2C) communications. Especially when money or sensitive information is exchanged, the communications are apt to be **secured** by some form of communications security mechanism. Intranets and extranets can be securely superimposed onto the Internet, without any access by general Internet users, using secure Virtual Private Network (VPN) technology.

History of computer networks

Before the advent of computer networks that were based upon some type of telecommunications system, communication between calculation machines and early computers was performed by human users by carrying instructions between them. Many of the social behaviors seen in today's Internet were demonstrably present in the nineteenth century and arguably in even earlier networks using visual signals.

- In September 1940 George Stibitz used a teletype machine to send instructions for a problem set from his Model at Dartmouth College to his Complex Number Calculator in New York and received results back by the same means. Linking output systems like teletypes to computers was an interest at the Advanced Research Projects Agency (ARPA) when, in 1962, J.C.R. Licklider was hired and developed a working group he called the "Intergalactic Network", a precursor to the ARPANET.
- In 1964, researchers at Dartmouth developed the Dartmouth Time Sharing System for distributed users of large computer systems. The same year, at Massachusetts Institute of Technology, a research group supported by General Electric and Bell Labs used a computer to route and manage telephone connections.
- Throughout the 1960s Leonard Kleinrock, Paul Baran and Donald Davies independently conceptualized and developed network systems which used packets that could be used in a network between computer systems.
- 1965 Thomas Merrill and Lawrence G. Roberts created the first wide area network (WAN).
- The first widely used telephone switch that used true computer control was introduced by Western Electric in 1965.
- In 1969 the University of California at Los Angeles, the Stanford Research Institute, University of California at Santa Barbara, and the University of Utah

were connected as the beginning of the ARPANET network using 50 kbit/s circuits.
- Commercial services using X.25 were deployed in 1972, and later used as an underlying infrastructure for expanding TCP/IP networks.

Today, computer networks are the core of modern communication. All modern aspects of the Public Switched Telephone Network (PSTN) are computer-controlled, and telephony increasingly runs over the Internet Protocol, although not necessarily the public Internet. The scope of communication has increased significantly in the past decade, and this boom in communications would not have been possible without the progressively advancing computer network. Computer networks, and the technologies needed to connect and communicate through and between them, continue to drive computer hardware, software, and peripherals industries. This expansion is mirrored by growth in the numbers and types of users of networks from the researcher to the home user.

Networking methods

One way to categorize computer networks is by their geographic scope, although many real-world networks interconnect Local Area Networks (LAN) via Wide Area Networks (WAN) and wireless wide area networks (WWAN). These three (broad) types are:

Local area network (LAN)

A local area network is a network that spans a relatively small space and provides services to a small number of people.

A peer-to-peer or client-server method of networking may be used. A peer-to-peer network is where each client shares their resources with other workstations in the network. Examples of peer-to-peer networks are: Small office networks where resource use is minimal and a home network. A client-server network is where every client is connected to the server and each other. Client-server networks use servers in different capacities. These can be classified into two types:

1. Single-service servers
2. Print servers

The server performs one task such as file server, while other servers can not only perform in the capacity of file servers and print servers, but also can conduct calculations and use them to provide information to clients (Web/Intranet Server). Computers may be connected in many different ways, including Ethernet cables, Wireless networks, or other types of wires such as power lines or phone lines.

The ITU-T G.hn standard is an example of a technology that provides high-speed (up to 1 Gbit/s) local area networking over existing home wiring (power lines, phone lines and coaxial cables).

Wide area network (WAN)

A wide area network is a network where a wide variety of resources are deployed across a large domestic area or internationally. An example of this is a multinational business that uses a WAN to interconnect their offices in different countries. The largest and best example of a WAN is the Internet, which is a network composed of many smaller networks. The Internet is considered the largest network in the world. The PSTN (Public Switched Telephone Network) also is an extremely large network that is converging to use Internet technologies, although not necessarily through the public Internet.

A Wide Area Network involves communication through the use of a wide range of different technologies. These technologies include Point-to-Point WANs such as Point-to-Point Protocol (PPP) and High-Level Data Link Control (HDLC), Frame Relay, ATM (Asynchronous Transfer Mode) and Sonet (Synchronous Optical Network). The difference between the WAN technologies is based on the switching capabilities they perform and the speed at which sending and receiving bits of information (data) occur.

Wireless networks (WLAN, WWAN)

A wireless network is basically the same as a LAN or a WAN but there are no wires between hosts and servers. The data is transferred over sets of radio transceivers. These types of networks are beneficial when it is too costly or inconvenient to run the necessary cables.

The most common IEEE 802.11 WLANs cover, depending on antennas, ranges from hundreds of meters to a few kilometers. For larger areas, either communications satellites of various types, cellular radio, or wireless local loop (IEEE 802.16) all have advantages and disadvantages. Depending on the type of mobility needed, the relevant standards may come from the IETF or the ITU.

Network topology

The network topology defines the way in which computers, printers, and other devices are connected, physically and logically. A network topology describes the layout of the wire and devices as well as the paths used by data transmissions.

Network topology has two types:

- Physical
- Logical

Commonly used topologies include:

- Bus
- Star
- Tree (hierarchical)

- Linear
- Ring
- Mesh
  - partially connected
  - fully connected (sometimes known as *fully redundant*)

The network topologies mentioned above are only a general representation of the kinds of topologies used in computer network and are considered basic topologies

Chapter 4

Radio Broadcasting

Long wave radio broadcasting station, Motala, Sweden

Broadcasting tower in Trondheim, Norway

Radio broadcasting is a one-way transmission over radio waves intended to reach a wide audience. Stations can be linked in radio networks to broadcast common programming, either in syndication or simulcast or both. Audio broadcasting also can be done via cable FM, local wire networks, satellite and the Internet.

History

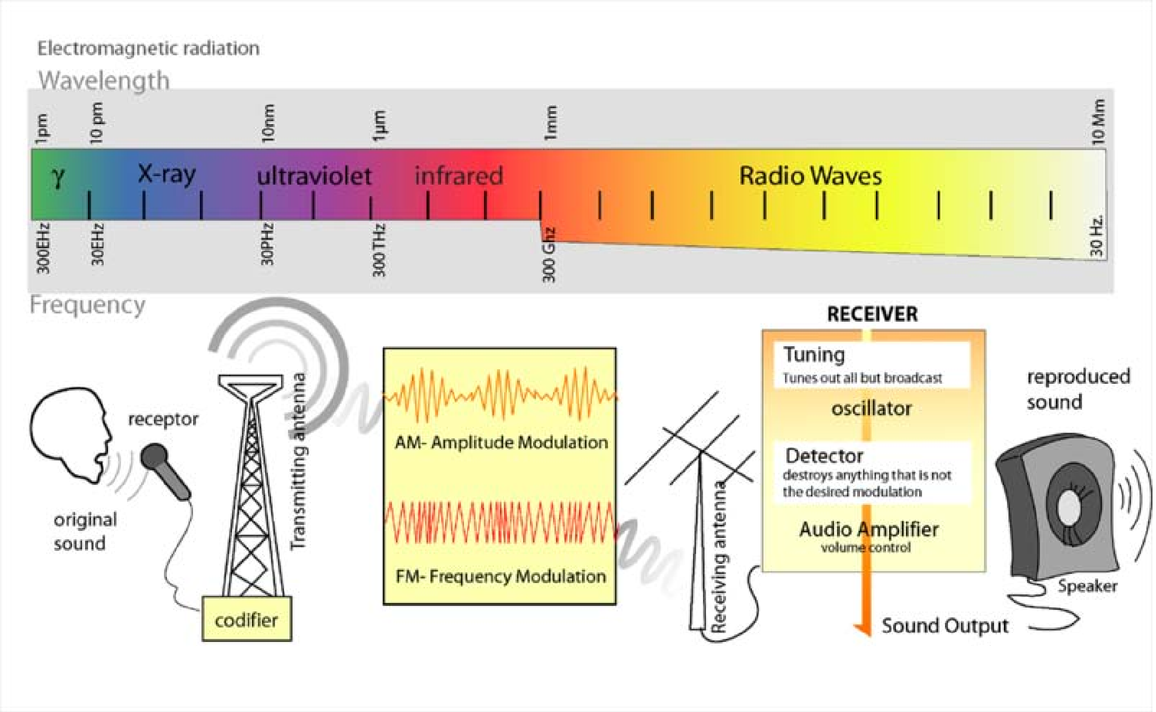
The earliest radio stations were simply radiotelegraphy systems and did not carry audio. The first claimed audio transmission that could be termed a *broadcast* occurred on Christmas Eve in 1906, and was made by Reginald Fessenden. Whether this broadcast actually took place is disputed. While many early experimenters attempted to create systems similar to radiotelephone devices where only two parties were meant to communicate, there were others who intended to transmit to larger audiences. Charles Herrold started broadcasting in California in 1909 and was carrying audio by the next year. (Herrold's station eventually became KCBS).

For the next decade, radio tinkerers had to build their own radio receivers. In The Hague, the Netherlands, PCGG started broadcasting on November 6, 1919. In 1916, Frank Conrad, an employee for the Westinghouse Electric Corporation, began broadcasting from his Wilkinsburg, Pennsylvania garage with the call letters 8XK. Later, the station was moved to the top of the Westinghouse factory building in East Pittsburgh, Pennsylvania and, as claiming to be "the world's first commercially licensed radio station", Westinghouse relaunched the station as KDKA on November 2, 1920. The commercial designation came from the type of license; advertisements did not air until years later. The first licensed broadcast in the United States came from KDKA itself: the results of the Harding/Cox Presidential Election. The Montreal station that became CFCF began program broadcasts on May 20, 1920, and the Detroit station that became WWJ began program broadcasts beginning on August 20, 1920, although neither held a license at the time.

Radio Argentina began regularly scheduled transmissions from the Teatro Coliseo in Buenos Aires on August 27, 1920, making its own priority claim. The station got its license on November 19, 1923. The delay was due to the lack of official Argentine licensing procedures before that date. This station continued regular broadcasting of entertainment and cultural fare for several decades.

Radio in education soon followed and colleges across the U.S. began adding radio broadcasting courses to their curricula. Curry College in Milton, Massachusetts introduced one of the first broadcasting majors in 1932 when the college teamed up with WLOE in Boston to have students broadcast programs.

Types



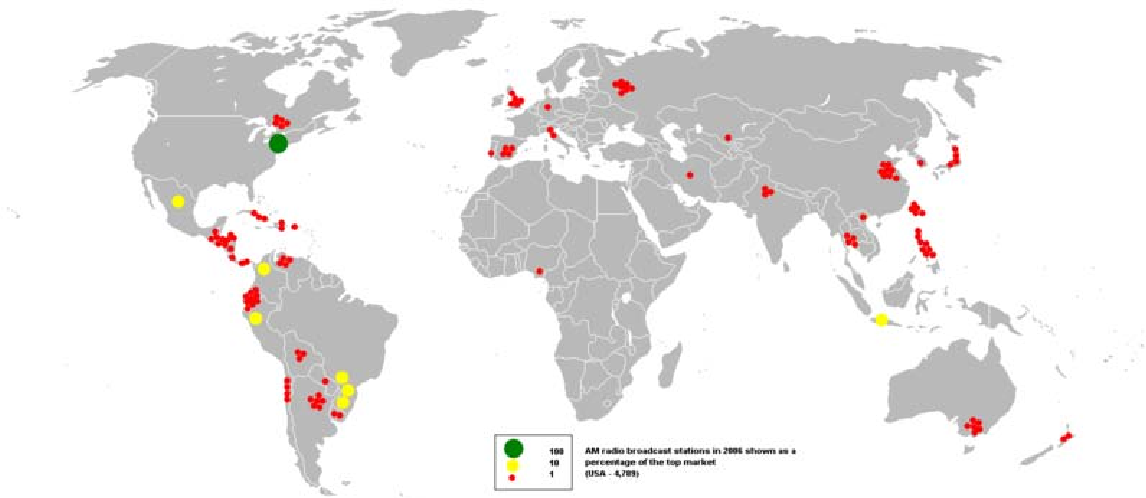
Transmission and reception schematic

Broadcasting by radio takes several forms. These include AM and FM stations. There are several subtypes, namely commercial, public and nonprofit varieties as well as student-run campus radio stations and hospital radio stations can be found throughout the world.

Many stations broadcast on shortwave bands using AM technology that can be received over thousands of miles (especially at night). For example, the BBC, VOA, VOR, and Deutsche Welle have transmitted via shortwave to Africa and Asia. These broadcasts are very sensitive to atmospheric conditions and solar activity.

Arbitron, the United States-based company that reports on radio audiences, defines a "radio station" as a government-licensed AM or FM station; an HD Radio (primary or multicast) station; an internet stream of an existing government-licensed station; one of the satellite radio channels from XM Satellite Radio or Sirius Satellite Radio; or, potentially, a station that is not government licensed.

AM



AM radio broadcast stations in 2006

AM stations were the earliest broadcasting stations to be developed. AM refers to amplitude modulation, a mode of broadcasting radio waves by varying the amplitude of the carrier signal in response to the amplitude of the signal to be transmitted.

The medium-wave band is used worldwide for AM broadcasting. Europe also uses the long wave band. In response to the growing popularity of FM radio stereo radio stations in the late 1980s and early 1990s, some North American stations began broadcasting in AM stereo, though this never gained popularity, and very few receivers were ever sold.

One of the advantages of AM is that its signal can be detected (turned into sound) with simple equipment. If a signal is strong enough, not even a power source is needed; building an unpowered crystal radio receiver is a common childhood project.

AM broadcasts occur on North American airwaves in the medium wave frequency range of 530 to 1700 kHz (known as the "standard broadcast band"). The band was expanded in the 1990s by adding nine channels from 1620 to 1700 kHz. Channels are spaced every 10 kHz in the Americas, and generally every 9 kHz everywhere else.

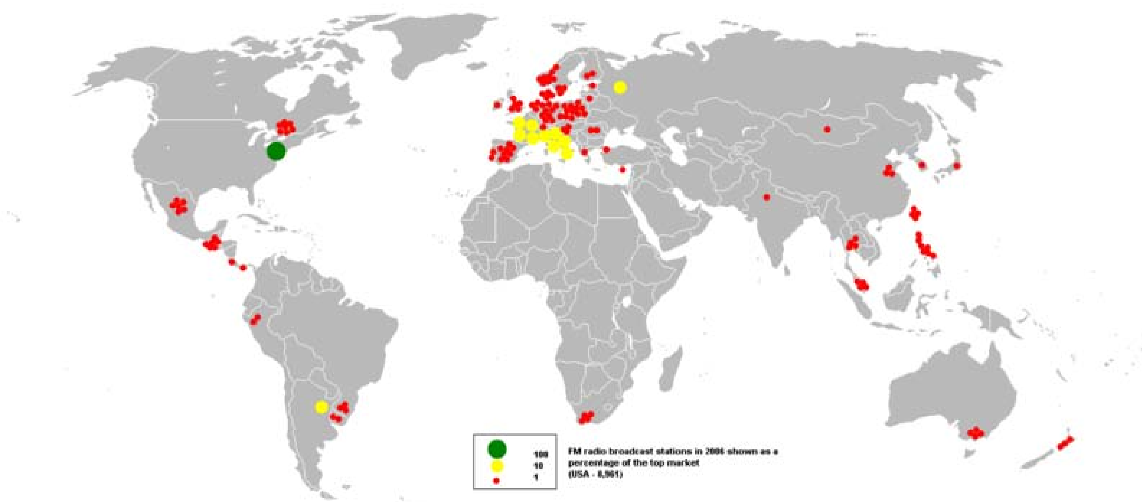
The signal is subject to interference from electrical storms (lightning) and other EMI.

AM transmissions cannot be ionospherically propagated during the day due to strong absorption in the D-layer of the ionosphere. In a crowded channel environment this means that the power of regional channels which share a frequency must be reduced at night or directionally beamed in order to avoid interference, which reduces the potential nighttime audience. Some stations have frequencies unshared with other stations in North America; these are called clear-channel stations. Many of them can be heard across much of the country at night. This is not to be confused with Clear Channel Communications, merely a brand name, which currently owns many U.S. radio stations on both the AM and

FM bands. During the night, this absorption largely disappears and permits signals to travel to much more distant locations via ionospheric reflections. However, fading of the signal can be severe at night.

AM radio transmitters can transmit audio frequencies up to 15 kHz (now limited to 10 kHz in the US due to FCC rules designed to reduce interference), but most receivers are only capable of reproducing frequencies up to 5 kHz or less. At the time that AM broadcasting began in the 1920s, this provided adequate fidelity for existing microphones, 78 rpm recordings, and loudspeakers. The fidelity of sound equipment subsequently improved considerably, but the receivers did not. Reducing the bandwidth of the receivers reduces the cost of manufacturing and makes them less prone to interference. AM stations are never assigned adjacent channels in the same service area. This prevents the sideband power generated by two stations from interfering with each other. Bob Carver created an AM stereo tuner employing notch filtering that demonstrated that an AM broadcast can meet or exceed the 15 kHz baseband bandwidth allocted to FM stations without objectionable interference. After several years, the tuner was discontinued. Bob Carver had left the company and the Carver Corporation later cut the number of models produced before discontinuing production completely. AM stereo broadcasts declined with the advent of HD Radio.

FM



FM radio broadcast stations in 2006

FM refers to frequency modulation, and occurs on VHF airwaves in the frequency range of 88 to 108 MHz everywhere (except Japan and Russia). Japan uses the 76 to 90 MHz band. Russia has two bands widely used by the Soviet Union, 65.9 to 74 MHz and 87.5 to 108 MHz worldwide standard. FM stations are much more popular since higher sound fidelity and stereo broadcasting became common in this format.

FM radio was invented by Edwin H. Armstrong in the 1930s for the specific purpose of overcoming the interference problem of AM radio, to which it is relatively immune. At the same time, greater fidelity was made possible by spacing stations further apart. Instead of 10 kHz apart, as on the AM band in the US, FM channels are 200 kHz (0.2 MHz) apart. In other countries greater spacing is sometimes mandatory, such as in New Zealand, which uses 700 kHz spacing (previously 800 kHz). The improved fidelity made available was far in advance of the audio equipment of the 1940s, but wide interchannel spacing was chosen to take advantage of the noise-suppressing feature of wideband FM.

Bandwidth of 200 kHz is not needed to accommodate an audio signal — 20 kHz to 30 kHz is all that is necessary for a narrowband FM signal. The 200 kHz bandwidth allowed room for ±75 kHz signal deviation from the assigned frequency, plus guard bands to reduce or eliminate adjacent channel interference. The larger bandwidth allows for broadcasting a 15 kHz bandwidth audio signal plus a 38 kHz stereo "subcarrier"—a piggyback signal that rides on the main signal. Additional unused capacity is used by some broadcasters to transmit utility functions such as background music for public areas, GPS auxiliary signals, or financial market data.

The AM radio problem of interference at night was addressed in a different way. At the time FM was set up, the available frequencies were far higher in the spectrum than those used for AM radio - by a factor of approximately 100. Using these frequencies meant that even at far higher power, the range of a given FM signal was much shorter; thus its market was more local than for AM radio. The reception range at night is the same as in the daytime.

The original FM radio service in the U.S. was the Yankee Network, located in New England. Regular FM broadcasting began in 1939, but did not pose a significant threat to the AM broadcasting industry. It required purchase of a special receiver. The frequencies used, 42 to 50 MHz, were not those used today. The change to the current frequencies, 88 to 108 MHz, began after the end of World War II, and was to some extent imposed by AM broadcasters as an attempt to cripple what was by now realized to be a potentially serious threat.

FM radio on the new band had to begin from the ground floor. As a commercial venture it remained a little-used audio enthusiasts' medium until the 1960s. The more prosperous AM stations, or their owners, acquired FM licenses and often broadcast the same programming on the FM station as on the AM station ("simulcasting"). The FCC limited this practice in the 1970s. By the 1980s, since almost all new radios included both AM and FM tuners, FM became the dominant medium, especially in cities. Because of its greater range, AM remained more common in rural environments.

Pirate radio

Pirate radio is radio broadcasting not sanctioned by the regulations of the originating country. Pirate radio may be a commercial enterprise supported by advertising targeted to listeners in the reception area, or may be privately run for entertainment, or political reasons, sometimes on a very small scale covering only a few city blocks.

Terrestrial digital radio

Digital radio broadcasting has emerged, first in Europe (the UK in 1995 and Germany in 1999), and later in the United States, France, the Netherlands, South Africa and many other countries worldwide. The most simple system is named DAB Digital Radio, for Digital Audio Broadcasting, and uses the public domain EUREKA 147 (Band III) system. DAB is used mainly in the UK and South Africa. Germany and Holland use the DAB and DAB+ systems, and France use the L-Band system of DAB Digital Radio.

In the United States digital radio isn't used in the same way as Europe and South Africa. Instead, the IBOC system is named HD Radio and owned by a consortium of private companies that is called iBiquity. An international non-profit consortium Digital Radio Mondiale (DRM), has introduced the public domain DRM system.

Satellite

Satellite radio broadcasters are slowly emerging, but the enormous entry costs of space-based satellite transmitters, and restrictions on available radio spectrum licenses has restricted growth of this market. In the USA and Canada, just two services, XM Satellite Radio and Sirius Satellite Radio exist. Both XM and Sirius are owned by Sirius XM Radio, which was formed by the merger of XM and Sirius on July 29, 2008, whereas in Canada, XM Radio Canada and Sirius Canada remain separate companies.

Program formats

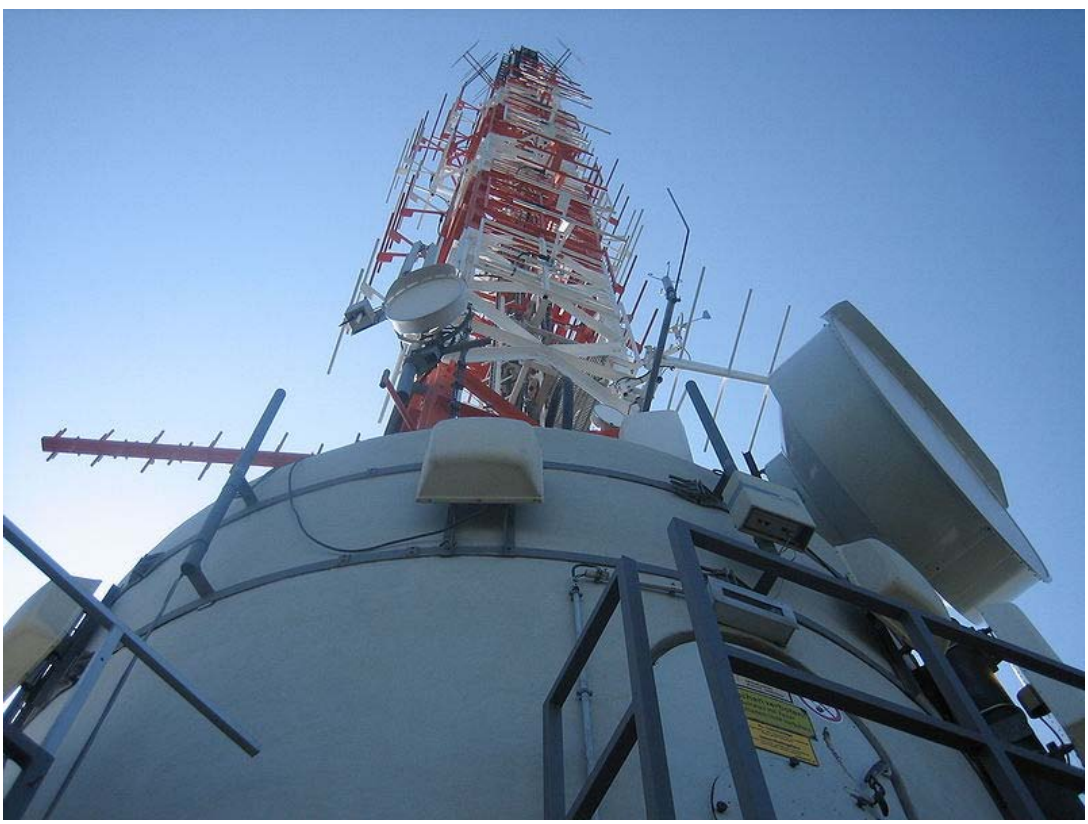
Radio program formats differ by country, regulation and markets. For instance, the U.S. Federal Communications Commission designates the 88–92 megahertz band in the U.S. for non-profit or educational programming, with advertising prohibited.

In addition, formats change in popularity as time passes and technology improves. Early radio equipment only allowed program material to be broadcast in real time, known as *live* broadcasting. As technology for sound recording improved, an increasing proportion of broadcast programming used pre-recorded material. A current trend is the automation of radio stations. Some stations now operate without direct human intervention by using entirely pre-recorded material sequenced by computer control.

Chapter 5

Broadcasting

Broadcasting is the distribution of audio and video content to a dispersed audience via radio, television, or other. Receiving parties may include the general public or a relatively large subset of thereof.



Broadcasting antenna in Stuttgart

The original term *broadcast* referred to the literal *sowing of seeds* on farms by scattering them over a wide field. It was first adopted by early radio engineers from the Midwestern United States to refer to the analogous dissemination of radio signals. Broadcasting forms a very large segment of the mass media. Broadcasting to a very narrow range of audience is called narrowcasting.

Forms of electronic broadcasting

Historically, there have been several different types of electronic broadcasting media:

- Telephone broadcasting (1881–1932): the earliest form of electronic broadcasting (not counting data services offered by stock telegraph companies from 1867, if ticker-tapes are excluded from the definition). Telephone broadcasting began with the advent of Théâtrophone ("Theatre Phone") systems, which were telephone-based distribution systems allowing subscribers to listen to live opera and theatre performances over telephone lines, created by French inventor Clément Ader in 1881. Telephone broadcasting also grew to include telephone newspaper services for news and entertainment programming which were introduced in the 1890s, primarily located in large European cities. These telephone-based subscription services were the first examples of electrical/electronic broadcasting and offered a wide variety of programming.
- Radio broadcasting (experimentally from 1906, commercially from 1920): radio broadcasting is an audio (sound) broadcasting service, broadcast through the air as radio waves from a transmitter to an antenna and, thus, to a receiving device. Stations can be linked in radio networks to broadcast common programming, either in syndication or simulcast or both.
- Television broadcasting (telecast), experimentally from 1925, commercially from the 1930s: this video-programming medium was long-awaited by the general public and rapidly rose to compete with its older radio-broadcasting sibling.
- Cable radio (also called "cable FM", from 1928) and cable television (from 1932): both via coaxial cable, serving principally as transmission mediums for programming produced at either radio or television stations, with limited production of cable-dedicated programming.
- Satellite television (from circa 1974) and satellite radio (from circa 1990): meant for direct-to-home broadcast programming (as opposed to studio network uplinks and downlinks), provides a mix of traditional radio or television broadcast programming, or both, with satellite-dedicated programming.
- Webcasting of video/television (from circa 1993) and audio/radio (from circa 1994) streams: offers a mix of traditional radio and television station broadcast programming with internet-dedicated webcast programming.

Economic models

Economically there are a few ways in which stations are able to broadcast continually. Each differs in the method by which stations are funded:

- in-kind donations of time and skills by volunteers (common with community broadcasters)
- direct government payments or operation of public broadcasters
- indirect government payments, such as radio and television licenses
- grants from foundations or business entities
- selling advertising or sponsorships
- public subscription or membership

Broadcasters may rely on a combination of these business models. For example, National Public Radio, a non-commercial network within the U.S., receives grants from the Corporation for Public Broadcasting (which, in turn, receives funding from the U.S. government), by public membership and by selling "extended credits" to corporations.

Recorded broadcasts and live broadcasts

A television studio control room in Olympia, Washington, August 2008.

The first regular television broadcasts began in 1937. Broadcasts can be classified as "recorded" or "live". The former allows correcting errors, and removing superfluous or undesired material, rearranging it, applying slow-motion and repetitions, and other techniques to enhance the program. However, some live events like sports telecasts can include some of the aspects including slow-motion clips of important goals/hits, etc., in between the live telecast.

American radio-network broadcasters habitually forbade prerecorded broadcasts in the 1930s and 1940s requiring radio programs played for the Eastern and Central time zones to be repeated three hours later for the Pacific time zone. This restriction was dropped for special occasions, as in the case of the German dirigible airship *Hindenburg* disaster at Lakehurst, New Jersey, in 1937. During World War II, prerecorded broadcasts from war correspondents were allowed on U.S. radio. In addition, American radio programs were recorded for playback by Armed Forces Radio stations around the world.

A disadvantage of recording first is that the public may know the outcome of an event from another source, which may be a "spoiler". In addition, prerecording prevents live announcers from deviating from an officially approved script, as occurred with propaganda broadcasts from Germany in the 1940s and with Radio Moscow in the 1980s.

Many events are advertised as being live, although they are often "recorded live" (sometimes called "live-to-tape"). This is particularly true of performances of musical artists on radio when they visit for an in-studio concert performance. Similar situations have occurred in television ("*The Cosby Show* is recorded in front of a live studio audience") and news broadcasting.

A broadcast may be distributed through several physical means. If coming directly from the studio at a single radio or television station, it is simply sent through the air chain to the transmitter and thence from the antenna on the tower out to the world. Programming may also come through a communications satellite, played either live or recorded for later transmission. Networks of stations may simulcast the same programming at the same time, originally *via* microwave link, now usually by satellite.

Distribution to stations or networks may also be through physical media, such as analog or digital videotape, compact disc, DVD, and sometimes other formats. Usually these are included in another broadcast, such as when electronic news gathering returns a story to the station for inclusion on a news programme.

The final leg of broadcast distribution is how the signal gets to the listener or viewer. It may come over the air as with a radio station or television station to an antenna and receiver, or may come through cable television or cable radio (or "wireless cable") *via* the station or directly from a network. The Internet may also bring either radio or television to the recipient, especially with multicasting allowing the signal and bandwidth to be shared.

The term "broadcast network" is often used to distinguish networks that broadcast an over-the-air television signal that can be received using a television antenna from so-called networks that are broadcast only *via* cable or satellite television. The term "broadcast television" can refer to the programming of such networks.

Legal definitions

United Kingdom

The Copyright, Designs and Patents Act of 1988 defines a broadcast as "a transmission by wireless telegraphy of visual images, sounds, or other information which is capable of lawful reception by the public or which is made for presentation to the public". Thus, it covers radio, television, teletext and telephones.

Social impact

The sequencing of content in a broadcast is called a schedule. As with all technological endeavours, a number of technical terms and slang have developed. A list of these terms can be found at List of broadcasting terms. Television and radio programs are distributed through radio broadcasting or cable, often both simultaneously. By coding signals and having decoding equipment in homes, the latter also enables subscription-based channels and pay-per-view services.

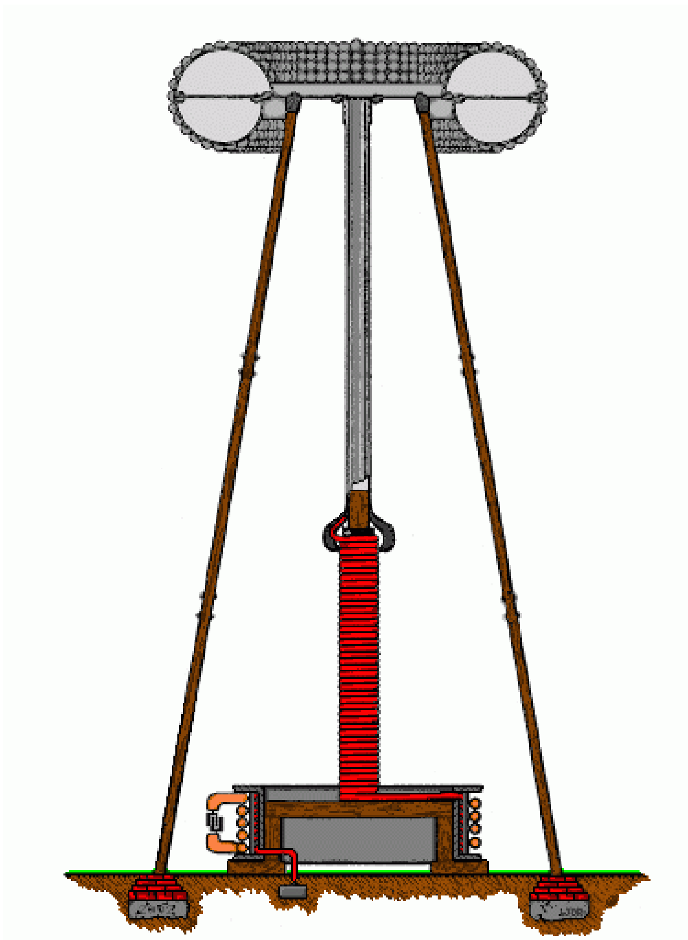
In his essay, John Durham Peters wrote that communication is a tool used for dissemination. Durham stated, “Dissemination is a lens- sometimes a usefully distorting one- that helps us tackle basic issues such as interaction, presence, and space and time…on the agenda of any future communication theory in general” (Durham, 211). Dissemination focuses on the message being relayed from one main source to one large audience without the exchange of dialogue in between. There’s chance for the message to be tweaked or corrupted once the main source releases it. There is really no way to predetermine how the larger population or audience will absorb the message. They can choose to listen, analyze, or simply ignore it. Dissemination in communication is widely used in the world of broadcasting.

Broadcasting focuses on getting one message out and it is up to the general public to do what they wish with it. Durham also states that broadcasting is used to address an open ended destination (Durham, 212). There are many forms of broadcast, but they all aim to distribute a signal that will reach the target audience. Broadcasting can arrange audiences into entire assemblies (Durham, 213).

In terms of media broadcasting, a radio show can gather a large number of followers who tune in every day to specifically listen to that specific disc jockey. The disc jockey follows the script for his or her radio show and just talks into the microphone. He or she does not expect immediate feedback from any listeners. The message is broadcast across airwaves throughout the community, but there the listeners cannot always respond immediately, especially since many radio shows are recorded prior to the actual air time.

Chapter 6

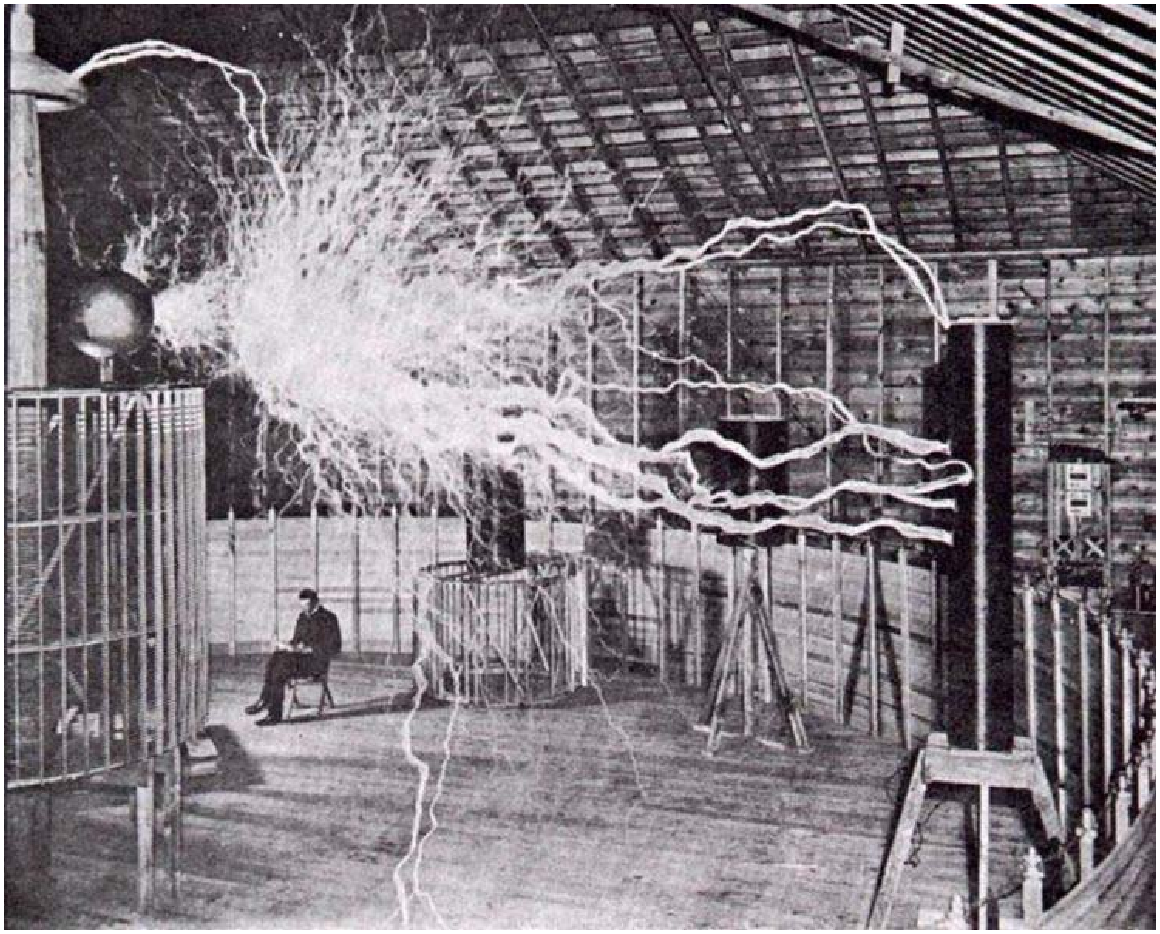
Magnifying Transmitter



The magnifying transmitter was designed to implement Wireless energy transmission by means of the *disturbed charge of ground and air method.*

The **magnifying transmitter** is an advanced version of Tesla coil transmitter. It is a high power harmonic oscillator that Nikola Tesla intended for the wireless transmission of electrical energy. In his autobiography, Tesla stated that "...I feel certain that of all my inventions, the Magnifying Transmitter will prove most important and valuable to future generations." The magnifying transmitter is an air-core, multiple-resonant transformer that can generate very high voltages.

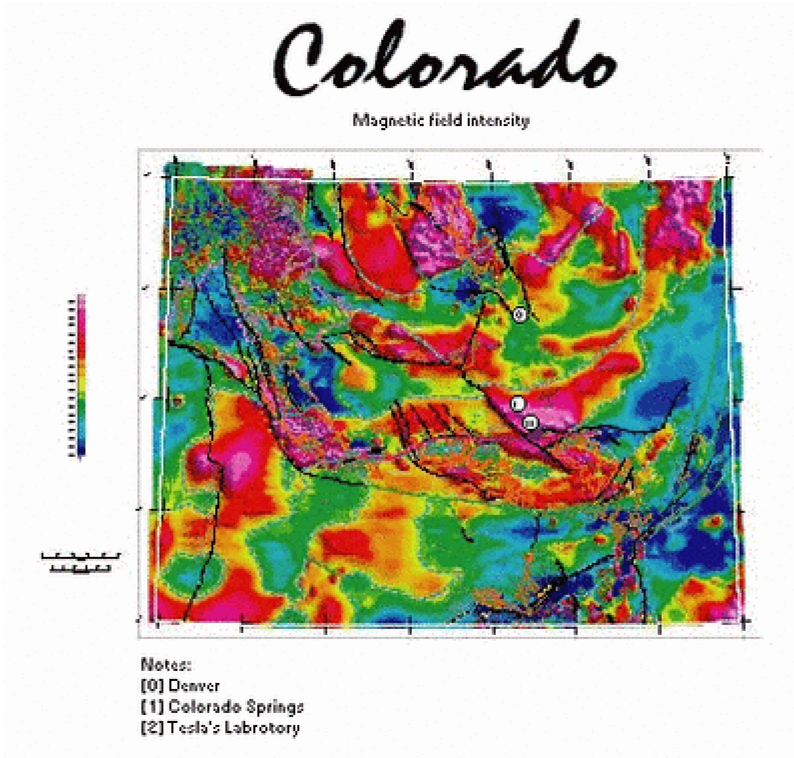
History



A publicity photo of Nikola Tesla sitting in the *Colorado Springs experimental station* with his "*Magnifying Transmitter*". The arcs are about 22 feet (7 m) long. (Tesla's notes identify this as a double exposure.)

The first 'Magnifier' was assembled in New York City between 1895 - 1898. In 1899 a larger magnifier was constructed in Colorado Springs, Colorado. This machine was used to conduct fundamental experiments in wireless telecommunications and electrical power transmission. Measuring fifty-one feet (15.5 m) in diameter, it developed a working potential estimated at 3.5 million to 4 million volts and was capable of producing electrical discharges exceeding one hundred feet (30 m) in length.

Colorado arrival



Tesla's Colorado lab was located in a highly geomagnetic location.

In 1899, Tesla moved his research to Colorado Springs. He chose this location because the polyphase alternating current power distribution system had been introduced there and he had associates who were willing to give him all the power he needed without charging for it. He kept a handwritten diary of his experiments in the Colorado Springs lab where he spent nearly nine months. It consists of 500 pages of notes and nearly 200 drawings, recorded chronologically between June 1, 1899 and January 7, 1900, as the work occurred, containing explanations of his experiments.

Tuned electrical circuits

While in Colorado, Tesla constructed many smaller resonance transformers and conducted further research on concatenated tuned electrical circuits. Tesla also designed various sensitive devices for detecting received electrical energy, including rotating coherers. These used a clockwork mechanism of gears driven by a coiled spring-drive which rotated a small glass cylinder containing metal filings. These experiments were the final stage after years of work on synchronized tuned electrical circuits. These instruments were constructed to demonstrate how a wireless receiver could be "tuned" to respond to a specific complex signal while rejecting others. Tesla logged in his diary on January 2, 1900 that a separate resonance transformer tuned to the same high frequency as a larger high-voltage resonance transformer (which acted as a transmitter) received energy from the larger coil, one of many demonstrations of the wireless *transmission* of electrical energy. These experiments helped to confirm Tesla's priority in the invention of radio during later disputes in the courts. These air core high-frequency resonant coils were the predecessors of systems ranging from radio to medical nuclear magnetic resonance imaging.

Energy transmission

On July 3, 1899, Tesla claimed to have discovered terrestrial stationary waves or standing waves extending across the earth to the antipode opposite his transmitter. He demonstrated that Earth behaves as a smooth polished conductor of very low resistance, and that it responds to certain predescribed frequencies of electrical vibrations. He conducted experiments that contributed to our understanding of electromagnetic propagation and the earth electrical resonances.

Tesla researched ways to transmit energy wirelessly over long distances, first by transverse waves, and then, possibly, by longitudinal waves. He transmitted extremely low frequency current through the earth with associated electric field energy propagating along the space between the Earth's surface and the Kennelly–Heaviside layer. He received patents on wireless transceivers designed to develop terrestrial standing waves by this method.

The magnifying transmitter was the basis for Tesla's Wardenclyffe Tower project. Although modern Tesla coils are designed to generate spark discharges, this system was designed for wireless telecommunications and electrical power transmission. In 1925, John B. Flowers advanced a proposal to test Tesla's system and to implement the system. H. L. Curtis, the chief of the Bureau of Standards Radio Laboratory in Washington D.C., and J. H. Dillinger, a physicist, reviewed the proposal but declined to implement the proposed plan. Flowers's mechanical analogy test was successful, though.

Electromechanical oscillator

Tesla developed the reciprocating electro-mechanical oscillator as a source of frequency stable or isochronous alternating electric current used in conjunction with both wireless transmitting and receiving apparatus. This circuit element was applied in the same manner as quartz crystal oscillators are now. He also proposed the use of this device for geophysical exploration by means of seismology—a technique that he called *telegeodynamics*.

Magnifying transmitter and the Wardenclyffe Tower

Transmitter details

The electrical oscillator, cited by Dr. Tesla as his most important and greatest invention, consists of three inductors:

- an air-core transformer (two-coil master oscillator)
- a third coil (extra coil)

The "extra coil" operates as a base-driven quarter-wave helical resonator.

The layout of the Wardenclyffe magnifying transmitter is well known, based upon Tesla's patents and various photographs in which the concept was implemented. The magnifying transmitter is not identical to the classic Tesla coil. It has the short thick primary and secondary inductor characteristic of the Tesla coil, although magnetic coupling between the two is tighter. Because of this, more aggressive measures have to be taken in terms of primary spark quenching and providing additional insulation between the primary and secondary. In addition to these two large-diameter coils that comprise the master oscillator, Tesla added a third inductor called the "extra coil."

Construction and theory of operation

In a classic Tesla coil the primary drives the ground end of the secondary coil to form the driver transformer, which resonates the entire secondary coil. In the magnifying transmitter the driving and resonating parts of the secondary are separate coils. From a circuit analysis standpoint, there is little difference between the classic coil and the magnifier.

The extra coil or helical resonator can be physically separated from the two close-coupled coils, which comprise the *master oscillator* or *driver* section. The power from the master oscillator is fed to the lower end of the extra coil resonator through a large diameter electrical conductor or pipe to minimize corona discharge. The magnifying transmitter's base-driven extra coil behaves as a slow-wave helical resonator, the axial disturbance propagating at a velocity of less than 1% up to around 10% the speed of light in free space. The axial velocity of the resonator's charge-coupled electromagnetic field is established by the coil pitch and electrical charge propagation speed through the circuit.

Operation

At Colorado Springs Tesla used his magnifying transmitter in an attempt to artificially stimulate terrestrial standing waves. Based upon observations made with the device, Tesla reported that earth resonance modes involving an electric current flowing through the earth can be excited. He claimed to have discovered a fundamental earth resonance frequency of nearly 11.78 Hz, which is somewhat higher than the fundamantal earth-ionosphere cavity Schumann resonance found to exist by researchers in the 1950s in the general vicinity of 7.3 Hz.

In normal operation the magnifying transmitter is relatively silent, generating a high power electric field, but if the output voltage exceeds the design voltage of the elevated terminal, high-voltage sparks will strike out from the electrode into the air.

Chapter 7

Wireless Energy Transfer

Wireless energy transfer or **wireless power** is the transmission of electrical energy from a power source to an electrical load without interconnecting wires. Wireless transmission is useful in cases where interconnecting wires are inconvenient, hazardous, or impossible. The problem of wireless power transmission differs from that of wireless telecommunications, such as radio. In the latter, the proportion of energy received becomes critical only if it is too low for the signal to be distinguished from the background noise. With wireless power, efficiency is the more significant parameter. A large part of the energy sent out by the generating plant must arrive at the receiver or receivers to make the system economical.

The most common form of wireless power transmission is carried out using direct induction followed by resonant magnetic induction. Other methods under consideration include electromagnetic radiation in the form of microwaves or lasers.

Electric energy transfer

An electric current flowing through a conductor carries electrical energy. When an electric current passes through a circuit there is an electric field in the dielectric surrounding the conductor; magnetic field lines around the conductor and lines of electric force radially about the conductor.

In a direct current circuit, if the current is continuous, the fields are constant; there is a condition of stress in the space surrounding the conductor, which represents stored electric and magnetic energy, just as a compressed spring or a moving mass represents stored energy. In an alternating current circuit, the fields also alternate; that is, with every half wave of current and of voltage, the magnetic and the electric field start at the conductor and run outwards into space with the velocity of light. Where these alternating fields impinge on another conductor a voltage and a current are induced.

Any change in the electrical conditions of the circuit, whether internal or external involves a readjustment of the stored magnetic and electric field energy of the circuit, that is, a so-called transient. A transient is of the general character of a condenser discharge through an inductive circuit. The phenomenon of the condenser discharge through an inductive circuit therefore is of the greatest importance to the engineer, as the foremost cause of high-voltage and high-frequency troubles in electric circuits.

Electromagnetic induction is proportional to the intensity of the current and voltage in the conductor which produces the fields and to the frequency. The higher the frequency the more intense the induction effect. Energy is transferred from a conductor that produces the fields (the primary) to any conductor on which the fields impinge (the secondary). Part of the energy of the primary conductor passes inductively across space into secondary conductor and the energy decreases rapidly along the primary conductor. A high frequency current does not pass for long distances along a conductor but rapidly transfers its energy by induction to adjacent conductors. Higher induction resulting from the higher frequency is the explanation of the apparent difference in the propagation of high frequency disturbances from the propagation of the low frequency power of alternating current systems. The higher the frequency the more preponderant become the inductive effects that transfer energy from circuit to circuit across space. The more rapidly the energy decreases and the current dies out along the circuit, the more local is the phenomenon.

The flow of electric energy thus comprises phenomena inside of the conductor and phenomena in the space outside of the conductor—the electric field—which, in a continuous current circuit, is a condition of steady magnetic and dielectric stress, and in an alternating current circuit is alternating, that is, an electric wave launched by the conductor to become far-field electromagnetic radiation traveling through space with the velocity of light.

In electric power transmission and distribution, the phenomena inside of the conductor are of main importance, and the electric field of the conductor is usually observed only incidentally. Inversely, in the use of electric power for *radio* telecommunications it is only the electric and magnetic fields outside of the conductor, that is electromagnetic radiation, which is of importance in transmitting the message. The phenomenon in the conductor, the current in the launching structure, is not used.

The electric charge displacement in the conductor produces a magnetic field and resultant lines of electric force. The magnetic field is a maximum in the direction concentric, or approximately so, to the conductor. That is, a ferromagnetic body tends to set itself in a direction at right angles to the conductor. The electric field has a maximum in a direction radial, or approximately so, to the conductor. The electric field component tends in a direction radial to the conductor and dielectric bodies may be attracted or repelled radially to the conductor.

The electric field of a circuit over which energy flows has three main axes at right angles with each other:

1. The *magnetic field*, concentric with the conductor.
2. The *lines of electric force*, radial to the conductor.
3. The *power gradient*, parallel to the conductor.

Where the electric circuit consists of several conductors, the electric fields of the conductors superimpose upon each other, and the resultant magnetic field lines and lines of electric force are not concentric and radial respectively, except *approximately in the immediate neighborhood* of the conductor. Between parallel conductors they are conjugate of circles. Neither the power consumption in the conductor, nor the magnetic field, nor the electric field, are proportional to the flow of energy through the circuit. However, the product of the intensity of the magnetic field and the intensity of the electric field is proportional to the flow of energy or the power, and the power is therefore resolved into a product of the two components **i** and **e**, which are chosen proportional respectively to the intensity of the magnetic field and of the electric field. The component called the current is defined as that factor of the electric power which is proportional to the magnetic field, and the other component, called the voltage, is defined as that factor of the electric power which is proportional to the electric field.

In *radio* telecommunications the electric field of the transmit antenna propagates through space as a radio wave and impinges upon the receive antenna where it is observed by its magnetic and electric effect. Radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X rays and gamma rays are shown to be the same electromagnetic radiation phenomenon, differing one from the other only in frequency of vibration.

Electromagnetic induction

Energy transfer by electromagnetic induction is typically magnetic but capacitive coupling can also be achieved.

Electrodynamic induction method

The electrodynamic induction wireless transmission technique is near field over distances up to about one-sixth of the wavelength used. Near field energy itself is non-radiative but some radiative losses do occur. In addition there are usually resistive losses. With electrodynamic induction, electric current flowing through a primary coil creates a magnetic field that acts on a secondary coil producing a current within it. Coupling must be tight in order to achieve high efficiency. As the distance from the primary is increased, more and more of the magnetic field misses the secondary. Even over a relatively short range the inductive coupling is grossly inefficient, wasting much of the transmitted energy.

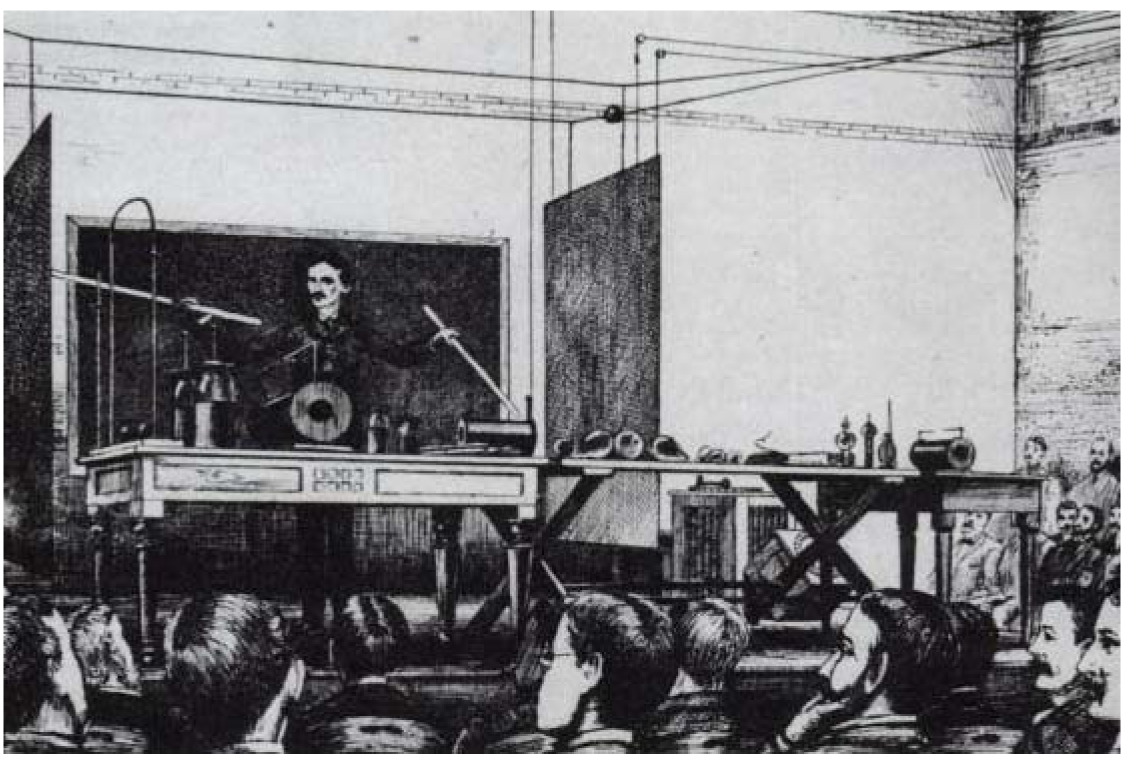
This action of an electrical transformer is the simplest form of wireless power transmission. The primary and secondary circuits of a transformer are not directly connected. Energy transfer takes place through a process known as mutual induction. Principal functions are stepping the primary voltage either up or down and electrical isolation. Mobile phone and electric toothbrush battery chargers, and electrical power distribution transformers are examples of how this principle is used. Induction cookers use this method. The main drawback to this basic form of wireless transmission is short range. The receiver must be directly adjacent to the transmitter or induction unit in order to efficiently couple with it.

The application of resonance improves the situation somewhat. When resonant coupling is used the transmitter and receiver inductors are tuned to a mutual frequency and the drive current is modified from a sinusoidal to a nonsinusoidal transient waveform. Pulse power transfer occurs over multiple cycles. In this way significant power may be transmitted over a distance of up to a few times the size of the primary coil. Transmitting and receiving coils are usually single layer solenoids or flat spirals with series capacitors, which, in combination, allow the receiving element to be tuned to the transmitter frequency.

Common uses of resonance-enhanced electrodynamic induction are charging the batteries of portable devices such as laptop computers and cell phones, medical implants and electric vehicles. A localized charging technique selects the appropriate transmitting coil in a multilayer winding array structure. Resonance is used in both the wireless charging pad (the transmitter circuit) and the receiver module (embedded in the load) to maximize energy transfer efficiency. This approach is suitable for universal wireless charging pads for portable electronics such as mobile phones. It has been adopted as part of the Qi wireless charging standard.

It is also used for powering devices having no batteries, such as RFID patches and contactless smartcards, and to couple electrical energy from the primary inductor to the helical resonator of Tesla coil wireless power transmitters.

Electrostatic induction method



The **Tesla effect**. is the illumination of two exhausted tubes by means of a powerful, rapidly alternating electrostatic field created between two vertical metal sheets suspended from the ceiling on insulating cords. It exploits the physics of electrostatic induction.

Electrostatic or capacitive coupling is the passage of electrical energy through a dielectric. In practice it is an electric field gradient or differential capacitance between two or more insulated terminals, plates, electrodes, or nodes that are elevated over a conducting ground plane. The electric field is created by an alternating current of high potential and high frequency. The capacitance between fixed plates and the powered device form a voltage divider.

The electric energy transmitted through the atmosphere can be utilized by receiving devices. Tesla demonstrated the illumination of wireless lamps by energy that was coupled to them through an alternating electric field.

"Instead of depending on *electrodynamic induction* at a distance to light the tube . . . [the] ideal way of lighting a hall or room would . . . be to produce such a condition in it that an illuminating device could be moved and put anywhere, and that it is lighted, no matter where it is put and without being electrically connected to anything. I have been able to produce such a condition by creating in the room a powerful, *rapidly alternating electrostatic field*. For this purpose I suspend a sheet of metal a distance from the ceiling on insulating cords and connect it to one terminal of the induction coil, the other terminal being preferably connected to the ground. Or else I suspend two sheets . . . each sheet being connected with one of the terminals of the coil, and their size being carefully determined. An exhausted tube may then be carried in the hand anywhere between the sheets or placed anywhere, even a certain distance beyond them; it remains always luminous."

The principle of electrostatic induction is applicable to the electrical conduction wireless transmission method.

Electromagnetic radiation

Far field methods achieve longer ranges, often multiple kilometer ranges, where the distance is much greater than the diameter of the device(s). The main reason for longer ranges with radio wave and optical devices is the fact that electromagnetic radiation in the far-field can be made to match the shape of the receiving area (using high directivity antennas or well-collimated Laser Beam) thereby delivering almost all emitted power at long ranges. The maximum directivity for antennas is physically limited by diffraction.

Beamed power, size, distance, and efficiency

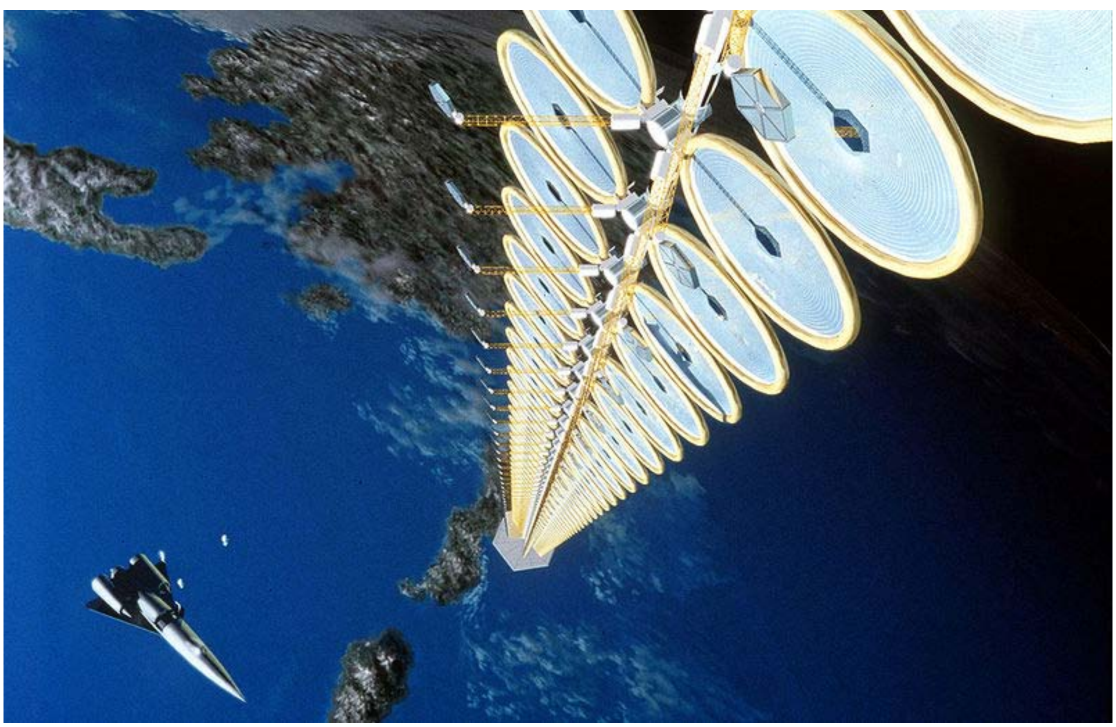
The size of the components may be dictated by the distance from transmitter to receiver, the wavelength and the Rayleigh criterion or diffraction limit, used in standard radio frequency antenna design, which also applies to lasers. In addition to the Rayleigh criterion Airy's diffraction limit is also frequently used to determine an approximate spot size at an arbitrary distance from the aperture.

The Rayleigh criterion dictates that any radio wave, microwave or laser beam will spread and become weaker and diffuse over distance; the larger the transmitter antenna or laser aperture compared to the wavelength of radiation, the tighter the beam and the less it will spread as a function of distance (and vice versa). Smaller antennae also suffer from excessive losses due to side lobes. However, the concept of laser aperture considerably differs from an antenna. Typically, a laser aperture much larger than the wavelength induces multi-moded radiation and mostly collimators are used before emitted radiation couples into a fiber or into space.

Ultimately, beamwidth is physically determined by diffraction due to the dish size in relation to the wavelength of the electromagnetic radiation used to make the beam. Microwave power beaming can be more efficient than lasers, and is less prone to atmospheric attenuation caused by dust or water vapor losing atmosphere to vaporize the water in contact.

Then the power levels are calculated by combining the above parameters together, and adding in the gains and losses due to the antenna characteristics and the transparency and dispersion of the medium through which the radiation passes. That process is known as calculating a link budget.

Microwave method



An artist's depiction of a solar satellite that could send electric energy by microwaves to a space vessel or planetary surface.

Power transmission via radio waves can be made more directional, allowing longer distance power beaming, with shorter wavelengths of electromagnetic radiation, typically in the microwave range. A rectenna may be used to convert the microwave energy back into electricity. Rectenna conversion efficiencies exceeding 95% have been realized. Power beaming using microwaves has been proposed for the transmission of energy from orbiting solar power satellites to Earth and the beaming of power to spacecraft leaving orbit has been considered.

Power beaming by microwaves has the difficulty that for most space applications the required aperture sizes are very large due to diffraction limiting antenna directionality. For example, the 1978 NASA Study of solar power satellites required a 1-km diameter transmitting antenna, and a 10 km diameter receiving rectenna, for a microwave beam at 2.45 GHz. These sizes can be somewhat decreased by using shorter wavelengths, although short wavelengths may have difficulties with atmospheric absorption and beam blockage by rain or water droplets. Because of the "thinned array curse," it is not possible to make a narrower beam by combining the beams of several smaller satellites.

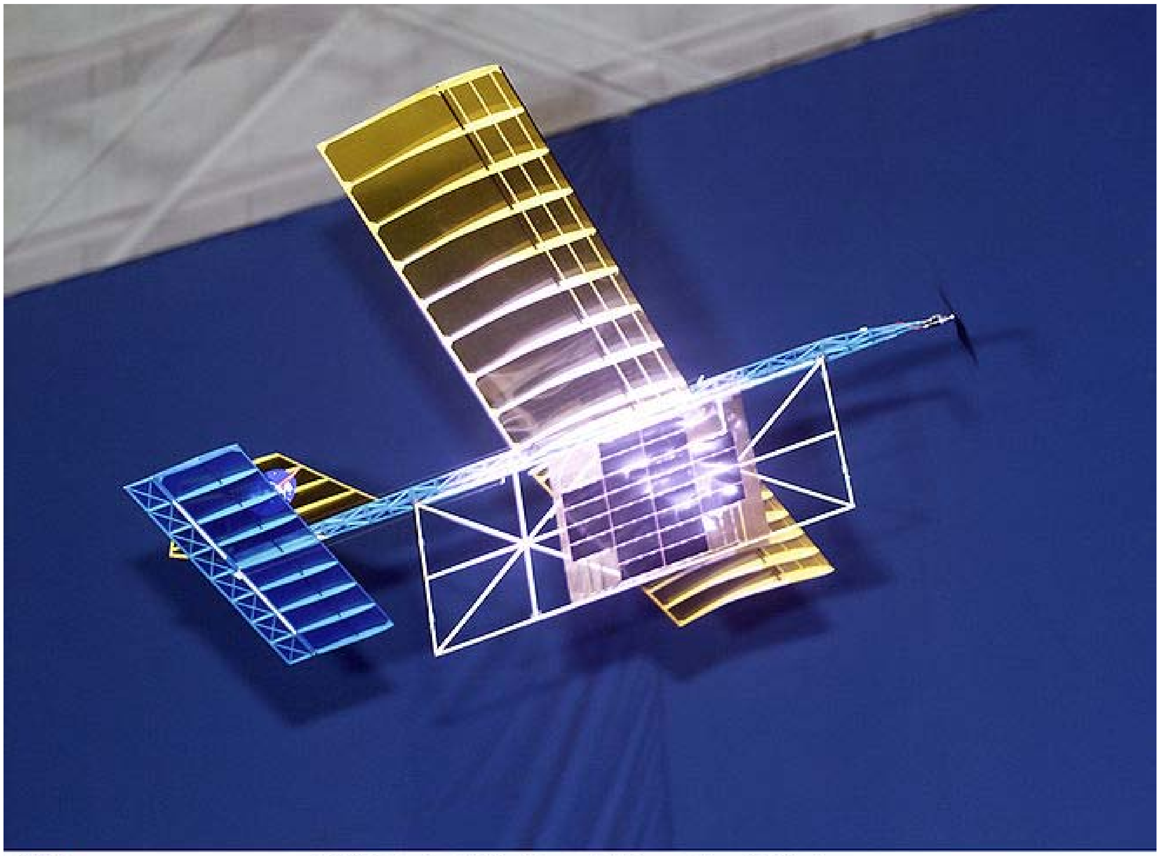
For earthbound applications a large area 10 km diameter receiving array allows large total power levels to be used while operating at the low power density suggested for human electromagnetic exposure safety. A human safe power density of 1 mW/cm^2 distributed across a 10 km diameter area corresponds to 750 megawatts total power level. This is the power level found in many modern electric power plants.

Following World War II, which saw the development of high-power microwave emitters known as cavity magnetrons, the idea of using microwaves to transmit power was researched. By 1964 a miniature helicopter propelled by microwave power had been demonstrated.

Japanese researcher Hidetsugu Yagi also investigated wireless energy transmission using a directional array antenna that he designed. In February 1926, Yagi and Uda published their first paper on the tuned high-gain directional array now known as the Yagi antenna. While it did not prove to be particularly useful for power transmission, this beam antenna has been widely adopted throughout the broadcasting and wireless telecommunications industries due to its excellent performance characteristics.

Wireless high power transmission using microwaves is well proven. Experiments in the tens of kilowatts have been performed at Goldstone in California in 1975 and more recently (1997) at Grand Bassin on Reunion Island. These methods achieve distances on the order of a kilometer.

Laser method



NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: ED03-0249-18 Date: September 18, 2003 Photo By: Tom Tschida

With a laser beam centered on its panel of photovoltaic cells, a model plane makes the first flight of an aircraft powered by a laser beam inside a building at NASA Marshall.

With a laser beam centered on its panel of photovoltaic cells, a lightweight model plane makes the first flight of an aircraft powered by a laser beam inside a building at NASA Marshall Space Flight Center.

In the case of electromagnetic radiation closer to visible region of spectrum (10s of microns (um) to 10s of nm), power can be transmitted by converting electricity into a laser beam that is then pointed at a solar cell receiver. This mechanism is generally known as "powerbeaming" because the power is beamed at a receiver that can convert it to usable electrical energy.

Advantages of laser based energy transfer compared with other wireless methods are:

1. collimated monochromatic wavefront propagation allows narrow beam cross-section area for energy transmission over large ranges.

2. compact size of solid state lasers-photovoltaics semiconductor diodes fit into into small products.
3. no radio-frequency interference to existing radio communication such as Wi-fi and cell phones.
4. control of access; only receivers illuminated by the laser receive power.

Its drawbacks are:

1. Conversion to light, such as with a laser, is inefficient
2. Conversion back into electricity is inefficient, with photovoltaic cells achieving 40%-50% efficiency. (Note that conversion efficiency is rather higher with monochromatic light than with insolation of solar panels).
3. Atmospheric absorption causes losses.
4. As with microwave beaming, this method requires a direct line of sight with the target.

The laser "powerbeaming" technology has been mostly explored in military weapons and aerospace applications and is now being developed for commercial and consumer electronics Low-Power applications. Wireless energy transfer system using laser for consumer space has to satisfy Laser safety requirements standardized under IEC 60825.

To develop an understanding of the trade-offs of Laser ("a special type of light wave"-based system):

1. Propagation of a laser beam (on how Laser beam propagation is much less affected by diffraction limits)
2. Coherence and the range limitation problem (on how spatial and spectral coherence characteristics of Lasers allows better distance-to-power capabilities)
3. Airy disk (on how wavelength fundamentally dictates the size of a disk with distance)
4. Applications of laser diodes (on how the laser sources are utilized in various industries and their sizes are reducing for better integration)

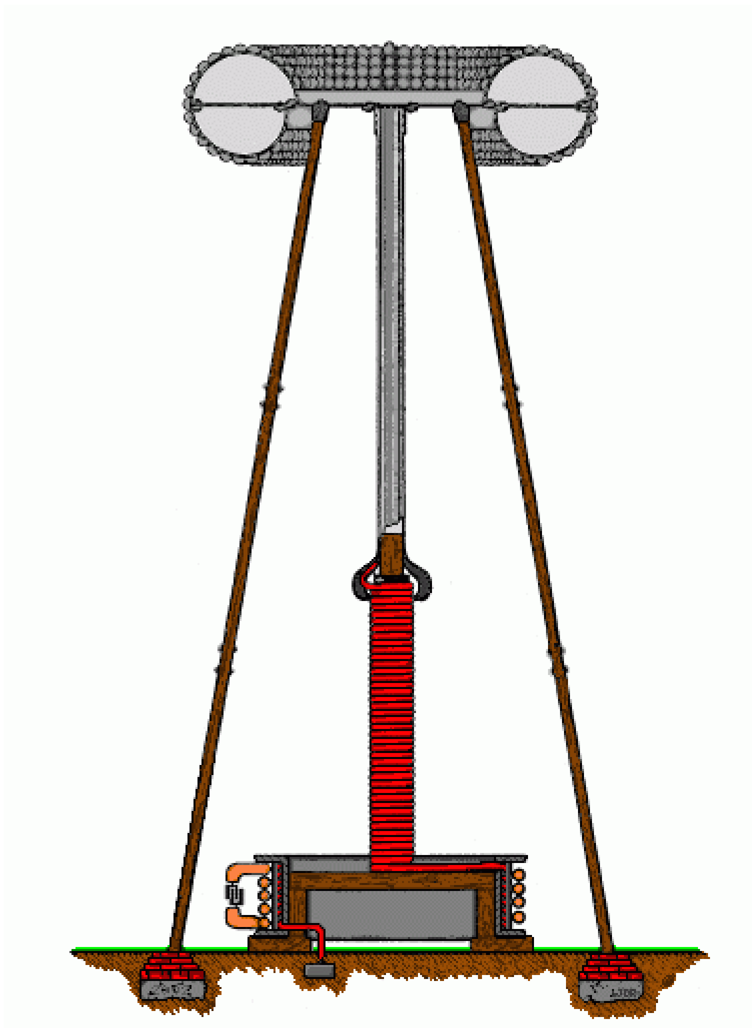
Geoffrey Landis is one of the pioneers of solar power satellite and laser-based transfer of energy especially for space and lunar missions. The continuously increasing demand for safe and frequent space missions has resulted in serious thoughts on a futuristic space elevator that would be powered by lasers. NASA's space elevator would need wireless power to be beamed to it for it to climb a tether.

NASA's Dryden Flight Research Center has demonstrated flight of a lightweight unmanned model plane powered by a laser beam. This proof-of-concept demonstrates the feasibility of periodic recharging using the laser beam system and the lack of need to return to ground.

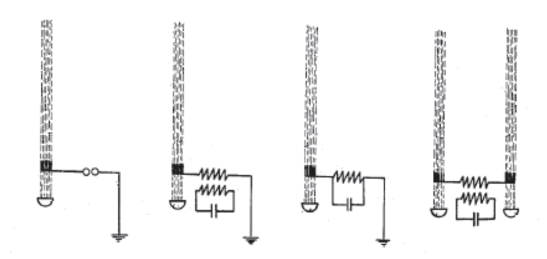
"Lasermotive" demonstrated laser powerbeaming at one kilometer during NASA's 2009 powerbeaming contest. Also "Lighthouse DEV" (a spin off of NASA Power Beaming

Team) along with "University of Maryland" is developing an eye safe laser system to power a small UAV. Since 2006, "PowerBeam" which originally invented the eye-safe technology and holds all crucial patents in this technology space, is developing commercially ready units for various consumer and industrial electronic products.

Electrical conduction



The Tesla coil wireless power transmitter **U.S. Patent 1,119,732**



Means for long conductors of electricity forming part of an electric circuit and electrically connecting said ionized beam to an electric circuit. Hettinger 1917 -(U.S. Patent 1,309,031)

Disturbed charge of ground and air method

Single wire with Earth return electrical power transmission systems rely on current flowing through the earth plus a single wire insulated from the earth to complete the circuit. In emergencies high-voltage direct current power transmission systems can also operate in the 'single wire with earth return' mode. Elimination of the raised insulated wire, and transmission of high-potential, high-frequency alternating current through the earth with an atmospheric return circuit has been investigated as a method of wireless electrical power transmission. Transmission of electrical energy through the earth alone, eliminating the second conductor is also being investigated.

Low frequency alternating current can be transmitted through the inhomogeneous earth with low loss because the net resistance between earth antipodes is considerably less than 1 ohm. The electrical displacement takes place predominantly by electrical conduction through the oceans, and metallic ore bodies and similar subsurface structures. The electrical displacement is also by means of electrostatic induction through the more dielectric regions such as quartz deposits and other non-conducting minerals.

Alternating current can be transmitted through atmospheric strata having a barometric pressure of less than 135 millimeters of mercury. Current flows by means of electrostatic induction through the lower atmosphere up to about two or three miles above the plants (this is the middle part in a three-space model) and the flow of ions, that is to say, electrical conduction through the ionized region above three miles. Intense vertical beams of ultraviolet light may be used to ionize the atmospheric gasses directly above the two elevated terminals resulting in the formation of plasma high-voltage electrical transmission lines leading up to the conducting atmospheric strata. The end result is a flow electrical current between the two elevated terminals by a path up to and through the troposphere and back down to the other facility. Electrical conduction through atmospheric strata is made possible by the creation of capacitively coupled discharge plasma through the process of atmospheric ionization.

Terrestrial transmission line with atmospheric return

Tesla discovered that electrical energy can be transmitted through the earth and the atmosphere. In the course of his research he successfully lit lamps at moderate distances and was able to detect the transmitted energy at much greater distances. The Wardenclyffe Tower project was a commercial venture for trans-Atlantic wireless telephony and proof-of-concept demonstrations of global wireless power transmission. The facility was not completed because of insufficient funding.

Earth is a naturally conducting body and forms one conductor of the system. A second path is established through the upper troposphere and lower stratosphere starting at an elevation of approximately 4.5 miles (7.2 km).

A global system for "the transmission of electrical energy without wires" called the World Wireless System, dependent upon the high electrical conductivity of plasma and the high electrical conductivity of the earth, was proposed as early as 1904.

Terrestrial single-conductor surface wave transmission line

The same transmitter used for the atmospheric conduction method is used for the terrestrial single-conductor earth resonance method.

The fundamental earth resonance frequency is claimed to be approximately 11.78 Hz. With the earth resonance method some harmonic of this fundamental frequency is used. "I would say that the frequency should be smaller then twenty thousand per second, through shorter waves might be practicable" and on the low end, "a frequency of nine hundred and twenty-five per second" is used, "when it is indispensable to operate motors of the ordinary kind."

Observations have been made that may be inconsistent with a basic tenet of physics related to the scalar derivatives of the electromagnetic potentials that are presently considered to be *nonphysical.*

Timeline of wireless power

- **1820**: André-Marie Ampère develops Ampere's law showing that electric current produces a magnetic field.
- **1831**: Michael Faraday develops Faraday's law of induction describing the electromagnetic force induced in a conductor by a time-varying magnetic flux.
- **1836**: Nicholas Callan invents the electrical transformer.
- **1864**: James Clerk Maxwell synthesizes the previous observations, experiments and equations of electricity, magnetism and optics into a consistent theory and mathematically models the behavior of electromagnetic radiation.
- **1888**: Heinrich Rudolf Hertz confirms the existence of electromagnetic radiation. Hertz's "*apparatus for generating electromagnetic waves*" was a VHF or UHF "radio wave" spark gap transmitter.
- **1891**: Tesla improves Hertz-wave wireless transmitter RF power supply or exciter in his patent No. 454,622, "System of Electric Lighting."
- **1893**: Tesla demonstrates the wireless illumination of phosphorescent lamps of his design at the World's Columbian Exposition in Chicago.
- **1893**: Tesla publicly demonstrates wireless power before a meeting of the National Electric Light Association in St. Louis.
- **1894**: Tesla lights incandescent lamps wirelessly at the 35 South Fifth Avenue laboratory in New York City by means of "electro-dynamic induction" or resonant inductive coupling.
- **1894**: Hutin & LeBlanc, espouse long held view that inductive energy transfer should be possible, they received U.S. Patent # 527,857 describing a system for power transmission at 3 kHz.

- **1894**: Jagdish Chandra Bose ignites gunpowder and rings a bell at a distance using electromagnetic waves, showing that communications signals can be sent without using wires.
- **1896**: Tesla demonstrates wireless transmission over a distance of about 48 kilometres (30 mi).
- **1897**: Tesla files his first patent application dealing specifically with wireless transmission.
- **1899**: Tesla continues his wireless power transmission research in Colorado Springs and writes, "the inferiority of the induction method would appear immense as compared with the *disturbed charge of ground and air method*."
- **1902**: Nikola Tesla vs. Reginald Fessenden - U.S. Patent Interference No. 21,701, System of Signaling (wireless); wireless power transmission, time and frequency domain spread spectrum telecommunications, electronic logic gates in general.
- **1904**: At the St. Louis World's Fair, a prize is offered for a successful attempt to drive a 0.1 horsepower (75 W) airship motor by energy transmitted through space at a distance of at least 100 feet (30 m).
- **1916**: Tesla states, "In my [*disturbed charge of ground and air*] system, you should free yourself of the idea that there is [electromagnetic] radiation, that energy is radiated. It is not radiated; it is conserved."
- **1917**: Tesla's Wardenclyffe tower is demolished. . . .

- **1926**: Shintaro Uda and Hidetsugu Yagi publish their first paper on Uda's *"tuned high-gain directional array"* better known as the Yagi antenna.

- **1961**: William C. Brown publishes an article exploring possibilities of microwave power transmission.
- **1964**: Brown demonstrates on CBS News with Walter Cronkite a model helicopter that receives all of the power needed for flight from a microwave beam. Between 1969 and 1975, Brown is technical director of a JPL Raytheon program that beams 30 kW over a distance of 1 mile at 84% efficiency.
- **1968**: Peter Glaser proposes wirelessly transmitting solar energy captured in space using "Powerbeaming" technology. This is usually recognized as the first description of a solar power satellite.
- **1971**: Prof. Don Otto develops a small trolley powered by induction at The University of Auckland, in New Zealand.
- **1973**: The world's first passive RFID system is demonstrated at Los-Alamos National Lab.
- **1975**: Goldstone Deep Space Communications Complex does experiments in the tens of kilowatts.
- **1988**: A power electronics group led by Prof. John Boys at The University of Auckland in New Zealand, develops an inverter using novel engineering materials and power electronics and conclude that power transmission by means of electrodynamic induction should be achievable. A first prototype for a contact-less power supply is built. Auckland Uniservices, the commercial company of The University of Auckland, patents the technology.

- **1989**: Daifuku, a Japanese company, engages Auckland Uniservices Ltd. to develop technology for car assembly plants and materials handling providing challenging technical requirements including multiplicity of vehicles.
- **1990**: Prof. John Boys team develops novel technology enabling multiple vehicles to run on the same inductive power loop and provide independent control of each vehicle. Auckland UniServices Patents the technology.
- **1996**: Auckland Uniservices develops an Electric Bus power system using electrodynamic induction to charge (30-60 kW) opportunistically commencing implementation in New Zealand. Prof John Boys Team commission 1st commercial IPT Bus in the world at Whakarewarewa, in New Zealand.
- **1998**: RFID tags are powered by electrodynamic induction over a few feet.
- **1999**: Dr. Herbert L. Becker powers a lamp and a hand held fan from a distance of 30 feet.
- **1999**: Prof. Shu Yuen (Ron) Hui and Mr. S.C. Tang of the City University of Hong Kong file a patent on "Coreless Printed-Circuit-Board (PCB) transformers and operating techniques", which form the basis for future planar charging surface with "vertical flux" leaving the planar surface. The circuit uses resonant circuits for wireless power transfer. EP(GB)0935263B
- **2000**: Prof. Shu Yuen (Ron) Hui invent a planar wireless charging pad using the "vertical flux" approach and resonant power transfer for charging portable consumer electronic products. A patent is filed on "Apparatus and method of an inductive battery charger," PCT Patent PCT/AU03/00 721, 2000.
- **2000**: Based on the coreless PCB transformer developed by Prof. Ron Hui, Prof. B. Choi and his team at Kyungpook National University publish a paper on "A new contactless battery charger for portable telecommunication/computing electronics," in Proc. ICCE'00 Int. Conf. Consumer Electron., 2000, pp. 58–59. The coreless PCB transformer is used to wirelessly charge a mobile phone.
- **2001** Prof. Shu Yuen (Ron) Hui and Dr. S.C. Tang file a patent on "Planar Printed-Circuit-Board Transformers with Effective Electromagnetic Interference (EMI) Shielding". The EM shield consists of a thin layer of ferrite and a thin layer of copper sheet. It enables the underneath of the future wireless charging pads to be shielded with a thin EM shield structure with thickness of typically 0.7mm or less. Patent: US6,501,364.
- **2001**: Prof. Ron Hui's team demonstrate that the coreless PCB transformer can transmit power close to 100W in 'A low-profile low-power converter with coreless PCB isolation transformer, IEEE Transactions on Power Electronics, Volume: 16 Issue: 3 , May 2001. A team of Philips Research Center Aachen, led by Dr. Eberhard Waffenschmidt, use it to power an 100W lighting device in their paper "Size advantage of coreless transformers in the MHz range" in the European Power Electronics Conference in Graz.
- **2001**: Splashpower formed in the UK. Uses coupled resonant coils in a flat "pad" style to transfer tens of watts into a variety of consumer devices, including lamp, phone, PDA, iPod etc.
- **2002**: Prof. Shu Yuen (Ron) Hui extends the planar wireless charging pad concept using the vertical flux approach to incorporate free-positioning feature for multiple loads. This is achieved by using a multilayer planar winding array

structure. Patent were granted as "Planar Inductive Battery Charger", GB2389720 and GB 2389767.

- **2004**: Electrodynamic induction used by 90 percent of the US$1 billion clean room industry for materials handling equipment in semiconductor, LCD and plasma screen manufacture.
- **2005**: Prof. Shu Yuen (Ron) Hui and Dr. W.C. Ho of City University of Hong Kong publish their work in the IEEE Transactions on a planar wireless charging platform with free-positioning feature. The planar wireless charging pad is able to charge several loads simultaneously on a flat surface.
- **2005**: Prof Boys' team at The University of Auckland, refines 3-phase IPT Highway and pick-up systems allowing transmission of power to moving vehicles in the lab.
- **2007**: A localized charging technique is reported by Dr. Xun Liu and Prof. Ron Hui for the wireless charging pad with free-positioning feature. With the aid of the double-layer EM shields enclosing the transmitter and receiver coils, the localized charging selects the right transmitter coil so as to minimize flux leakage and human exposure to radiation.
- **2007**: Using electrodynamic induction a physics research group, led by Prof. Marin Soljacic, at MIT, wirelessly power a 60W light bulb with 40% efficiency at a 2 metres (6.6 ft) distance with two 60 cm-diameter coils.
- **2008**: Bombardier offers a new wireless power transmission product PRIMOVE, a system for use on trams and light-rail vehicles.
- **2008**: Industrial designer Thanh Tran, at Brunel University make a wireless lamp incorporating a high efficiency 3W LED.
- **2008**: Intel reproduces Tesla's original 1894 implementation of electrodynamic induction and Prof. John Boys group's 1988 follow-up experiments by wirelessly powering a nearby light bulb with 75% efficiency.
- **2008**: Greg Leyh and Mike Kennan of the Nevada Lightning Laboratory publish a paper on Tesla's *disturbed charge of ground and air method* of wireless power transmission with circuit simulations and test results showing an efficiency greater than can be obtained using the electrodynamic induction method.
- **2009**: A Consortium of interested companies called the Wireless Power Consortium announce they are nearing completion for a new industry standard for low-power inductive charging
- **2009**: Palm (now a division HP) launches the Palm Pre smartphone with the Palm Touchstone wireless charger.
- **2009**: An Ex approved Torch and Charger aimed at the offshore market is introduced. This product is developed by Wireless Power & Communication, a Norway based company.
- **2009**: A simple analytical electrical model of electrodynamic induction power transmission is proposed and applied to a wireless power transfer system for implantable devices.
- **2009**: Lasermotive uses diode laser to win $900k NASA prize in power beaming, breaking several world records in power and distance, by transmitting over a kilowatt more than several hundred meters.

- **2009**: Sony shows a wireless electrodynamic-induction powered TV set, 60 W over 50 cm
- **2010**: Haier Group debuts “the world's first” completely wireless LCD television at CES 2010 based on Prof. Marin Soljacic's follow-up research on Tesla's electrodynamic induction wireless energy transmission method and the Wireless Home Digital Interface (WHDI).
- **2010**: System On Chip (SoC) group in University of British Columbia develops an optimization tool for the design of highly efficient wireless power transmission systems using multiple coils. The design is optimized for implantable applications and power transfer efficiency of 82% is achieved.

Chapter 8

Satellite Radio

Satellite radio is an analogue or digital radio signal that is relayed through one or more satellites and thus can be received in a much wider geographical area than terrestrial FM radio stations. While in Europe many primarily-FM radio stations provide an additional unencrypted satellite feed, there are also subscription based digital packages of numerous channels that do not broadcast terrestrially, notably in the US. In Europe, FM radio is used by many suppliers that use a network of several local FM repeaters to broadcast a single programme to a large area, usually a whole nation. Many of those have an additional satellite signal that can be heard in many parts of the continent. In contrast, US terrestrial stations are always local and each of them has a unique programme, albeit they are sometimes interconnected for syndicated contents; but each local station still carries its own commercial and news breaks even then. This means that a national distribution of the contents of original terrestrial stations via satellite makes no real sense in the US, wherefore satellite radio is used in a different way there. History: Began broadcasting January 5, 2001 at 11:17AM Eastern, Tim McGraw was the first artist ever played on satellite radio. He gave a special welcome introduction which segued into his song "Things Change" on Sirius! Mobile services, such as Sirius, XM, and Worldspace, allow listeners to roam across an entire continent, listening to the same audio programming anywhere they go. Other services, such as Music Choice or Muzak's satellite-delivered content, require a fixed-location receiver and a dish antenna. In all cases, the antenna must have a clear view to the satellites. In areas where tall buildings, bridges, or even parking garages obscure the signal, repeaters can be placed to make the signal available to listeners.

Radio services are usually provided by commercial ventures and are subscription-based. The various services are proprietary signals, requiring specialized hardware for decoding and playback. Providers usually carry a variety of news, weather, sports, and music channels, with the music channels generally being commercial-free.

In areas with a relatively high population density, it is easier and less expensive to reach the bulk of the population with terrestrial broadcasts. Thus in the UK and some other countries, the contemporary evolution of radio services is focused on Digital Audio Broadcasting (DAB) services or HD Radio, rather than satellite radio.

Business applications

Satellite radio, particularly in the United States, has become a major provider of background music to businesses such as hotels, retail chains, and restaurants. Compared to old-line competitors such as Muzak, satellite radio's significantly lower price, commercial-free channel variety, and more reliable technology make it a very attractive option. Both North American satellite radio providers offer business subscriptions, though given the merger of XM Satellite Radio with Sirius, the future of XM for Business is uncertain. Sirius's commercial services are provided nationally by third-party partner Applied Media Technologies Corporation.

System design

Satellite radio uses the 2.3 GHz S band in North America and generally shares the 1.4 GHz L band with local Digital Audio Broadcasting (DAB) stations elsewhere. It is a type of direct broadcast satellite and is strong enough that it requires no satellite dish to receive. Curvature of the earth limits the reach of the signal, but due to the high orbit of the satellites, two or three are usually sufficient to provide coverage for an entire continent.

Local repeaters similar to broadcast translator boosters enable signals to be available even if the view of the satellite is blocked, for example, by skyscrapers in a large town. Major tunnels can also have repeaters. This method also allows local programming to be transmitted such as traffic and weather in most major metropolitan areas, as of March 2004.

Each receiver has an Electronic Serial Number (ESN) Radio ID to identify it. When a unit is activated with a subscription, an authorization code is sent in the digital stream telling the receiver to allow access to the blocked channels. Most services have at least one "free to air" or "in the clear" (ITC) channel as a test. For example, Sirius uses channel 184, Sirius Weather & Emergency.

Most (if not all) of the systems in use now are proprietary, using different codecs for audio data compression, different modulation techniques, and/or different methods for encryption and conditional access.

Like other radio services, satellite radio also transmits program-associated data (PAD or metadata), with the artist and title of each song or program and possibly the name of the channel.

Satellite radio vs. other formats

Satellite radio differs from AM or FM radio and digital television radio (or DTR) in the following ways. The table applies primarily to the United States.

Radio format	Satellite radio	AM/FM	Digital television radio (DTR)
Monthly fees	US$12.95 and up	None	None for terrestrial. Very low for cable or satellite — DTR represents a small portion of the total monthly television fee.
Portability	Available	Prominent	None — a typical set consists of a stereo attached to a television set-top box (the primary function of the set top-box is normally designed for viewing digital television on an analogue set).
Listening availability	Very high — a satellite signal's footprint covers millions of square kilometres.	Low to moderate — implementation of FM service requires moderate to high population densities and is thus not practical in rural and/or remote locales; AM travels great distances at night.	Very high
Sound quality	Varies[2]	AM: Usually very low, but can be the highest FM: Usually Moderate, but can be very high	Varies[2]
Variety and depth of programming	Highest	Variable — highly dependent upon economic/demographic factors	Variable - dependent on location and the television provider - for cable and satellite,

			dependent on the various packages they provide and on the user's subscription.
Frequency of programming interruptions (by DJs or commercial advertising)[3]	None to high - mostly dependent on the channels, some of which have DJs; most channels are advertisement-free because of the paid subscription model of satellite radio.	Highest[4]	None to low - dependent on the provider; however, it is common that some stations will have DJs. Usually no advertisements on subscription services (DirecTV and Dish Network both claim to provide advertisement-free content).
Governmental regulation	Yes[5]	Yes — significant governmental regulations regarding content[6]	Yes for terrestrial. For cable and satellite, low to none [5]

[2] The sound quality with both satellite radio providers and DTR providers varies with each channel. Some channels have near CD-quality audio, and others use low-bandwidth audio suitable only for speech. Since only a certain amount of bandwidth is available within the licenses available, adding more channels means that the quality on some channels must be reduced. Both the frequency response and the dynamic range of satellite channels can be superior to most, but not all AM or FM radio stations, as most AM and FM stations clip the audio peaks to sound louder; even the worst channels are still superior to most AM radios, but a very few AM tuners are equal to or better than the best FM or satellite broadcasts when tuned to a local station, even if not capable of stereo. AM does not suffer from multipath distortion or flutter in a moving vehicle like FM, nor does it become silent as you go behind a big hill like satellite radio.

[3] Some satellite radio services and DTR services act as *in situ* repeaters for local AM/FM stations and thus feature a high frequency of interruption.

[4] Nonprofit stations and public radio networks such as CBC/Radio-Canada, NPR, and PRI-affiliated stations and the BBC are commercial-free. In the US, all stations are required to have periodic station identifications and public service announcements.

[5] In the United States, the FCC regulates technical broadcast spectrum only. Program content is unregulated. However, the FCC has tried in the past to expand its reach to regulate content to satellite radio and cable television, and its options are still open to

attempt such in the future. The FCC does issue licenses to both satellite radio providers (XM and Sirius) and controls who holds these licenses to broadcast.

[6] Degree of content regulation varies by country; however, the majority of industrialized nations have regulations regarding obscene and/or objectionable content.

Portable Satellite Radio

Portable satellite radios let you listen to satellite radio just about anywhere you go. They are very similar to standard portable music players, designed for music on the go. These however, feature built-in antennas that receive the satellite signal, and come with rechargeable batteries. In fact, all you have to do is plug in headphones, and you can easily listen to and carry them around easily. Reception can be tricky however, being blocked by buildings and tall trees, and sometimes by your own body depending you the way you are facing and how you are carrying it. However, the best reception will be received outdoors in the open.

United States

In the United States and Canada, one holding company, Sirius XM Radio, operates the two satellite radio services, after a merger (technically the acquisition of XM by Sirius) in July 2008. A monthly fee is charged for both services (as of 2005, Sirius also offers a one-time fee of nearly $500 valid for the lifetime of the equipment; however, there is a $70.00 USD fee for switching receiver, and this may be done only three times ever). Some XM music channels have commercials, while Sirius is commercial-free. Both services have commercial-free music stations, as well as talk and news stations, some of which include commercials. XM uses fixed-location geostationary satellites in two positions, and Sirius uses three geosynchronous satellites in highly elliptical orbits passing over North and South America, to transmit the digital streams. The net difference is that the Sirius signal comes from a higher elevation angle in the northern part of the U.S. and even more so in Canada. (This higher angle makes Sirius' signal less likely to drop out on cities, but more likely to drop out in parking garages, gas stations, tunnels, and other covered spaces.)

Both services are available mainly via portable receivers in automobiles, but both have many accessories so one can listen at home through a home stereo, with a portable boombox, or online through a personal computer. Both services now have some form of receiver that is completely portable.

Satellite radio's chief asset is the fact that it is not localized: drivers can receive the same programming anywhere in the footprint of the service. A stop at any truck stop will demonstrate the popularity of Sirius XM among long-haul drivers. In addition, both XM and Sirius carry programming that is simply not feasible on commercial radio stations. Specialty stations cover things such as family talk, radio drama, classical music, and live events.

The footprint of both Sirius and XM is only the United States (not including Alaska), Canada, and the upper third of Mexico; it does not cover Hawaii as satellite TV does.

Success so far

As of July 29, 2008 Sirius XM claims over 18.5 million subscribers. One critical factor for the success of satellite radio is the deployment of in-car receivers. Sirius XM has attempted to convince automakers to equip vehicles with their receiver. As of 2008, the following manufacturers offer satellite radio as original equipment:

Provider	BMW MINI Rolls-Royce	Chrysler Dodge Mercedes-Benz Jeep	Ford Lincoln Mercury Volvo Land Rover Jaguar Mazda	GM Cadillac Chevrolet Buick Pontiac GMC Saturn Saab	Honda Acura	Hyundai Kia	Mitsubishi	Nissan Infiniti	Porsche	Toyota Lexus Scion	VW Audi Bentley	Suzuki
Sirius	Yes	Yes	Yes	No	No	Yes	Yes	?	No	Yes	Yes	No
XM	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes

Sirius has an exclusive contract for VW and Audi vehicles from 2007 through 2012. Those brands previously offered both services. GM, Honda and Suzuki are all major investors in XM; Sirius is not offered as options in their vehicles. Bentley and Rolls-Royce come not only with receivers but lifetime subscriptions for Sirius service as well. XM is featured in select Harley-Davidson motorcycle models, while Sirius can be heard in several brands of recreational vehicles and boats.

One of the challenges for satellite radio has been to move away from cars and into the homes of consumers. Several portable satellite radio receivers have been made for this purpose. XM satellite radio has developed the XM2go line of "Walkman-like" portable receivers, such as the Delphi MyFi, the Pioneer AirWare and Giant International's Tao. Polk Audio makes a component-style home XM Reference Tuner and a tabletop entertainment system, the I-Sonic, with XM capability. Sirius has developed the Kenwood Portable Satellite Radio Tuner, Sirius S50, Here2Anywhere and the Sirius Stiletto 100. The Pioneer Inno and Samsung Helix for XM were among the first portable receivers to offer the ability of recording live content for playback later. Thus allowing for satellite radio to compete more fully with MP3 players.

While key agreements with automobile manufacturers are still being made, both companies have made the leap away from satellite radio only in the car and into the homes of consumers. One bump in the road to becoming more widely used in the home was both Sirius and XM running into legal issues in early 2006 with the FCC about their internal FM Transmitters. This required Sirius and XM to pull several of their models off the shelf and fix the problem. The FCC was claiming that the emissions of the internal FM Transmitters were too powerful and needed to be lowered. With these changes any customer buying a new satellite radio receiver doesn't achieve nearly the broadcast distance as the old models. Since this is a key point in the ability to use a satellite radio in the home (i.e. by taking the signal received and then broadcasting it to multiple points throughout the home at the same time and avoid having to bring the satellite radio with them as they move around the home) it has led many subscribers to use an external Personal FM transmitter to replace the lower powered internal FM Transmitter. Since these external FM Transmitters are Part 15 compliant they can broadcast the signal further than the new internal FM Transmitters now included in the satellite radios and still be legal. These external FM transmitters may prevent a slow down in the progress already made into the home consumer market for Sirius and XM satellite radio.

Satellite radio technology was inducted into the Space Foundation Space Technology Hall of Fame in 2002.

Canada

On November 1, 2004, the Canadian Radio-television and Telecommunications Commission (CRTC) began hearing applications for Canada's first satellite radio operations. Three applications were filed: one by Standard Broadcasting and the CBC in partnership with Sirius, one by Canadian Satellite Radio in partnership with XM, and one at the last minute by CHUM Limited and Astral Media.

The first two would use the same systems already set up for the U.S., while CHUM's application was for a subscription radio service delivered through existing terrestrial DAB transmitters rather than directly by satellite (although satellites would be used to deliver programming to the transmitters). The CHUM service is all-Canadian; the other two applications propose to offer a mix of Canadian-produced channels and existing channels from their American partner services.

A small "grey market" already exists for Sirius and XM receivers in Canada in which a Canadian would have an American order their receiver and setup.

On June 16, 2005, the CRTC approved all three services.

In its decision, the CRTC required the following conditions from the satellite radio licensees:

- A minimum of eight channels must be produced in Canada, and for each Canadian channel, nine foreign channels can be broadcast.
- At least 85% of the content on the Canadian-produced channels (whether musical or spoken word) must be Canadian.
- At least 25% of the Canadian channels must be French-language stations.
- At least 25% of the music aired on the Canadian channels must be new Canadian music.
- At least 25% of the music played on the Canadian channels must be from up-and-coming Canadian artists.

These conditions were an extension of the existing Canadian content rules applicable to all broadcasters in Canada. The applicants had until 13 November 2005, to notify the

CRTC of their decision. Both companies managed to negotiate the standards a little to their favor, and in return, they would instead play 50% French content as opposed to 25%. Also, XM Canada succeeded in getting an extra five channels of National Hockey League Play-by-Play onto their platform, without an additional channel creation, by agreeing to cover every Canadian team's game during the season.

CHUM appealed the decision, claiming they would not survive if Sirius and XM both were allowed in the Canadian market, and that the licence conditions regarding Canadian content imposed on Canadian Satellite Radio and Sirius Canada were too lax. Canadian Satellite Radio and Sirius Canada countered that CHUM was simply trying to create a monopoly in the Canadian market.

In late August 2005, Heritage Minister Liza Frulla asked the Federal Cabinet to review the CRTC decision and possibly send it back to the CRTC for further review. Lobbyists complained that the CRTC decision did not require enough Canadian content from the broadcasters. The broadcasters responded by promising to add additional Canadian and French content.

After vigorous lobbying from both sides, the federal cabinet officially accepted the CRTC decision on September 10, 2005.

XM satellite radio was launched in Canada on November 29, 2005. Sirius followed later on December 1, 2005. Monthly subscription rates are $12.99 for XM (85 channels) with a one-time activation fee of $19.99 and $14.99 for Sirius with a one-time activation fee of $19.99 (100 channels). (All prices are in Canadian dollars.) The CHUM/Astral service never launched, and its license expired on June 16, 2007.

Chapter 9

Cellular Network

Top of a cellular radio tower

A **cellular network** is a radio network distributed over land areas called cells, each served by at least one fixed-location transceiver known as a cell site or base station. When joined together these cells provide radio coverage over a wide geographic area. This enables a large number of portable transceivers (e.g., mobile phones, pagers, etc.) to communicate with each other and with fixed transceivers and telephones anywhere in the network, via base stations, even if some of the transceivers are moving through more than one cell during transmission.

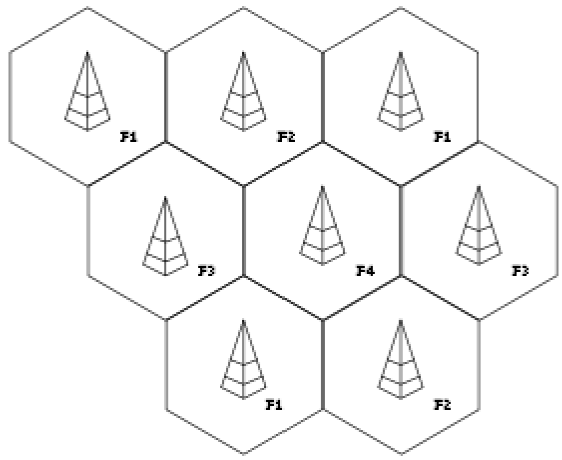
Cellular networks offer a number of advantages over alternative solutions:

- increased capacity

- reduced power use
- larger coverage area
- reduced interference from other signals

An example of a simple non-telephone cellular system is an old taxi driver's radio system where the taxi company has several transmitters based around a city that can communicate directly with each taxi.

The concept



Example of frequency reuse factor or pattern 1/4

In a cellular radio system, a land area to be supplied with radio service is divided into regular shaped cells, which can be hexagonal, square, circular or some other irregular shapes, although hexagonal cells are conventional. Each of these cells is assigned multiple frequencies (f_1 - f_6) which have corresponding radio base stations. The group of frequencies can be reused in other cells, provided that the same frequencies are not reused in adjacent neighboring cells as that would cause co-channel interference.

The increased capacity in a cellular network, compared with a network with a single transmitter, comes from the fact that the same radio frequency can be reused in a different area for a completely different transmission. If there is a single plain transmitter, only one transmission can be used on any given frequency. Unfortunately, there is inevitably some level of interference from the signal from the other cells which use the same frequency. This means that, in a standard FDMA system, there must be at least a one cell gap between cells which reuse the same frequency.

In the simple case of the taxi company, each radio had a manually operated channel selector knob to tune to different frequencies. As the drivers moved around, they would change from channel to channel. The drivers know which frequency covers approximately what area. When they do not receive a signal from the transmitter, they will try other channels until they find one that works. The taxi drivers only speak one at a time, when invited by the base station operator (in a sense TDMA).

Cell signal encoding

To distinguish signals from several different transmitters, frequency division multiple access (FDMA) and code division multiple access (CDMA) were developed.

With FDMA, the transmitting and receiving frequencies used in each cell are different from the frequencies used in each neighbouring cell. In a simple taxi system, the taxi driver manually tuned to a frequency of a chosen cell to obtain a strong signal and to avoid interference from signals from other cells.

The principle of CDMA is more complex, but achieves the same result; the distributed transceivers can select one cell and listen to it.

Other available methods of multiplexing such as polarization division multiple access (PDMA) and time division multiple access (TDMA) cannot be used to separate signals from one cell to the next since the effects of both vary with position and this would make signal separation practically impossible. Time division multiple access, however, is used in combination with either FDMA or CDMA in a number of systems to give multiple channels within the coverage area of a single cell.

Frequency reuse

The key characteristic of a cellular network is the ability to re-use frequencies to increase both coverage and capacity. As described above, adjacent cells must utilize different frequencies, however there is no problem with two cells sufficiently far apart operating on the same frequency. The elements that determine frequency reuse are the reuse distance and the reuse factor.

The reuse distance, D is calculated as

$$D = R\sqrt{3N},$$

where R is the cell radius and N is the number of cells per cluster. Cells may vary in radius in the ranges (1 km to 30 km). The boundaries of the cells can also overlap between adjacent cells and large cells can be divided into smaller cells

The frequency reuse factor is the rate at which the same frequency can be used in the network. It is $1/K$ (or K according to some books) where K is the number of cells which cannot use the same frequencies for transmission. Common values for the frequency reuse factor are 1/3, 1/4, 1/7, 1/9 and 1/12 (or 3, 4, 7, 9 and 12 depending on notation).

In case of N sector antennas on the same base station site, each with different direction, the base station site can serve N different sectors. N is typically 3. A **reuse pattern** of N/K denotes a further division in frequency among N sector antennas per site. Some current and historical reuse patterns are 3/7 (North American AMPS), 6/4 (Motorola NAMPS), and 3/4 (GSM).

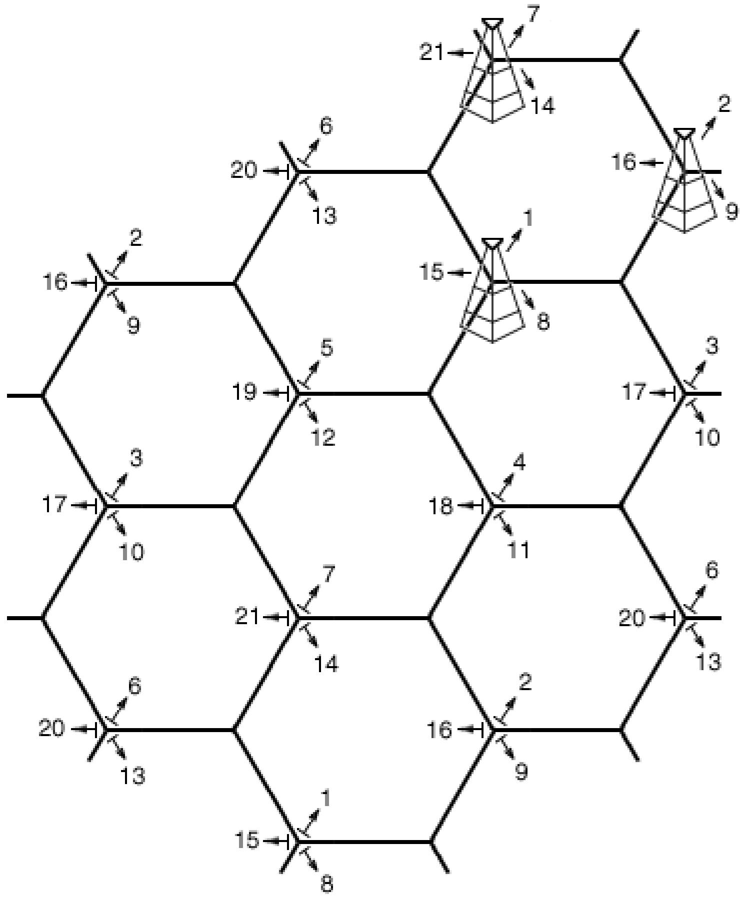
If the total available bandwidth is *B*, each cell can only utilize a number of frequency channels corresponding to a bandwidth of *B/K*, and each sector can use a bandwidth of *B/NK*.

Code division multiple access-based systems use a wider frequency band to achieve the same rate of transmission as FDMA, but this is compensated for by the ability to use a frequency reuse factor of 1, for example using a reuse pattern of 1/1. In other words, adjacent base station sites use the same frequencies, and the different base stations and users are separated by codes rather than frequencies. While *N* is shown as 1 in this example, that does not mean the CDMA cell has only one sector, but rather that the entire cell bandwidth is also available to each sector individually.

Depending on the size of the city, a taxi system may not have any frequency-reuse in its own city, but certainly in other nearby cities, the same frequency can be used. In a big city, on the other hand, frequency-reuse could certainly be in use.

Recently also orthogonal frequency-division multiple access based systems such as LTE are being deployed with a frequency reuse of 1. Since such systems do not spread the signal across the frequency band, inter-cell radio resource management is important to coordinates resource allocation between different cell sites and to limit the inter-cell interference. There are various means of Inter-cell Interference Coordination (ICIC) already defined in the standard . Coordinated scheduling, multi-site MIMO or multi-site beam forming are other examples for inter-cell radio resource management that might be standardized in the future.

Directional antennas



Cellular telephone frequency reuse pattern.

Although the original 2-way-radio cell towers were at the centers of the cells and were omni-directional, a cellular map can be redrawn with the cellular telephone towers located at the corners of the hexagons where three cells converge. Each tower has three sets of directional antennas aimed in three different directions with 120 degrees for each cell (totaling 360 degrees) and receiving/transmitting into three different cells at different frequencies. This provides a minimum of three channels (from three towers) for each cell. The numbers in the illustration are channel numbers, which repeat every 3 cells. Large cells can be subdivided into smaller cells for high volume areas.

Broadcast messages and paging

Practically every cellular system has some kind of broadcast mechanism. This can be used directly for distributing information to multiple mobiles, commonly, for example in mobile telephony systems, the most important use of broadcast information is to set up channels for one to one communication between the mobile transceiver and the base station. This is called **paging**.

The details of the process of paging vary somewhat from network to network, but normally we know a limited number of cells where the phone is located (this group of cells is called a Location Area in the GSM or UMTS system, or Routing Area if a data packet session is involved). Paging takes place by sending the broadcast message to all of those cells. Paging messages can be used for information transfer. This happens in pagers, in CDMA systems for sending SMS messages, and in the UMTS system where it allows for low downlink latency in packet-based connections.

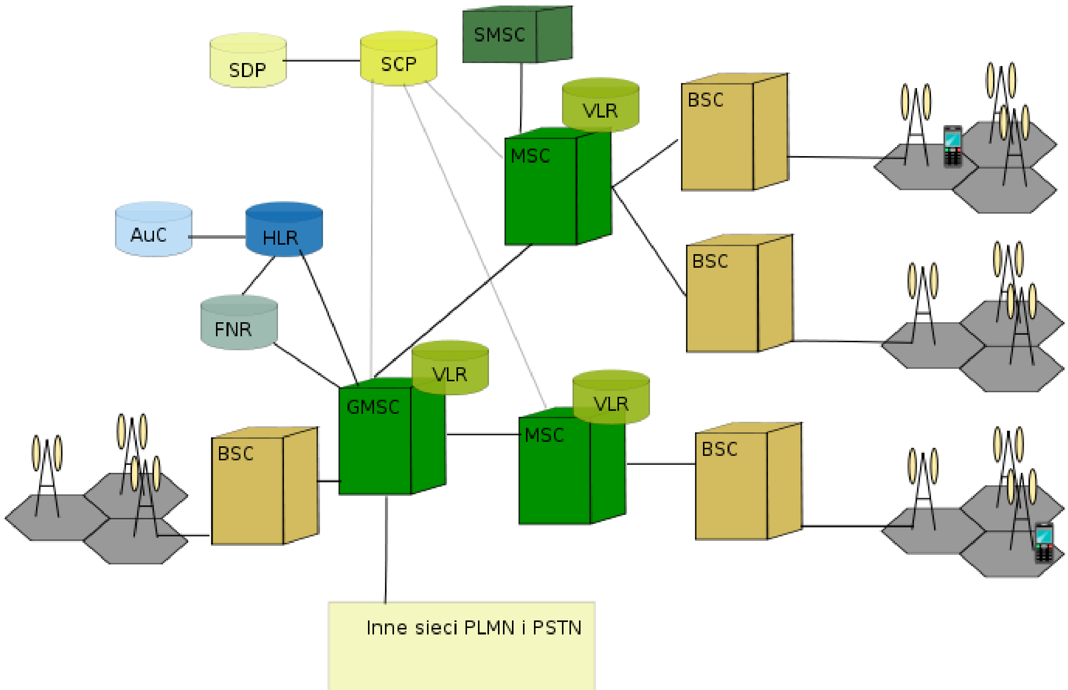
Movement from cell to cell and handover

In a primitive taxi system, when the taxi moved away from a first tower and closer to a second tower, the taxi driver manually switched from one frequency to another as needed. If a communication was interrupted due to a loss of a signal, the taxi driver asked the base station operator to repeat the message on a different frequency.

In a cellular system, as the distributed mobile transceivers move from cell to cell during an ongoing continuous communication, switching from one cell frequency to a different cell frequency is done electronically without interruption and without a base station operator or manual switching. This is called the handover or handoff. Typically, a new channel is automatically selected for the mobile unit on the new base station which will serve it. The mobile unit then automatically switches from the current channel to the new channel and communication continues.

The exact details of the mobile system's move from one base station to the other varies considerably from system to system.

Example of a cellular network: the mobile phone network



GSM network architecture

The most common example of a cellular network is a mobile phone (cell phone) network. A mobile phone is a portable telephone which receives or makes calls through a cell site (base station), or transmitting tower. Radio waves are used to transfer signals to and from the cell phone.

Modern mobile phone networks use cells because radio frequencies are a limited, shared resource. Cell-sites and handsets change frequency under computer control and use low power transmitters so that a limited number of radio frequencies can be simultaneously used by many callers with less interference.

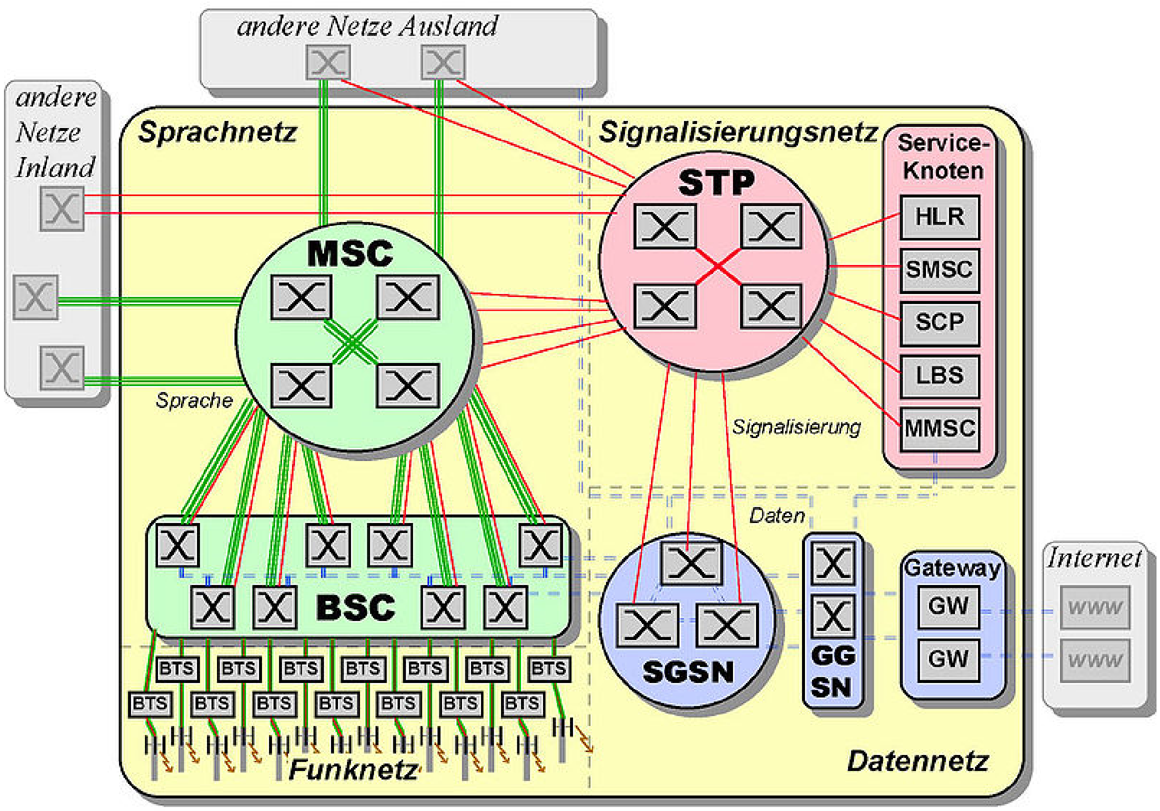
A cellular network is used by the mobile phone operator to achieve both coverage and capacity for their subscribers. Large geographic areas are split into smaller cells to avoid line-of-sight signal loss and to support a large number of active phones in that area. All of the cell sites are connected to telephone exchanges (or switches) , which in turn connect to the public telephone network.

In cities, each cell site may have a range of up to approximately ½ mile, while in rural areas, the range could be as much as 5 miles. It is possible that in clear open areas, a user may receive signals from a cell site 25 miles away.

Since almost all mobile phones use cellular technology, including GSM, CDMA, and AMPS (analog), the term "cell phone" is in some regions, notably the US, used interchangeably with "mobile phone". However, satellite phones are mobile phones that do not communicate directly with a ground-based cellular tower, but may do so indirectly by way of a satellite.

There are a number of different digital cellular technologies, including: Global System for Mobile Communications (GSM), General Packet Radio Service (GPRS), Code Division Multiple Access (CDMA), Evolution-Data Optimized (EV-DO), Enhanced Data Rates for GSM Evolution (EDGE), 3GSM, Digital Enhanced Cordless Telecommunications (DECT), Digital AMPS (IS-136/TDMA), and Integrated Digital Enhanced Network (iDEN).

Structure of the mobile phone cellular network



Structure of a 2G cellular network

A simple view of the cellular mobile-radio network consists of the following:

- A network of Radio base stations forming the Base station subsystem.
- The core circuit switched network for handling voice calls and text
- A packet switched network for handling mobile data
- The Public switched telephone network to connect subscribers to the wider telephony network

This network is the foundation of the GSM system network. There are many functions that are performed by this network in order to make sure customers get the desired service including mobility management, registration, call set up, and handover.

Any phone connects to the network via an RBS in the corresponding cell which in turn connects to the MSC. The MSC allows the onward connection to the PSTN. The link from a phone to the RBS is called an uplink while the other way is termed downlink.

Radio channels effectively use the transmission medium through the use of the following multiplexing schemes: frequency division multiplex (FDM), time division multiplex (TDM), code division multiplex (CDM), and space division multiplex (SDM). Corresponding to these multiplexing schemes are the following access techniques: frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and space division multiple access (SDMA).

Cellular handover in mobile phone networks

As the phone user moves from one cell area to another cell whilst a call is in progress, the mobile station will search for a new channel to attach to in order not to drop the call. Once a new channel is found, the network will command the mobile unit to switch to the new channel and at the same time switch the call onto the new channel.

With CDMA, multiple CDMA handsets share a specific radio channel. The signals are separated by using a pseudonoise code (PN code) specific to each phone. As the user moves from one cell to another, the handset sets up radio links with multiple cell sites (or sectors of the same site) simultaneously. This is known as "soft handoff" because, unlike with traditional cellular technology, there is no one defined point where the phone switches to the new cell.

In IS-95 inter-frequency handovers and older analog systems such as NMT it will typically be impossible to test the target channel directly while communicating. In this case other techniques have to be used such as pilot beacons in IS-95. This means that there is almost always a brief break in the communication while searching for the new channel followed by the risk of an unexpected return to the old channel.

If there is no ongoing communication or the communication can be interrupted, it is possible for the mobile unit to spontaneously move from one cell to another and then notify the base station with the strongest signal.

Cellular frequency choice in mobile phone networks

The effect of frequency on cell coverage means that different frequencies serve better for different uses. Low frequencies, such as 450 MHz NMT, serve very well for countryside coverage. GSM 900 (900 MHz) is a suitable solution for light urban coverage. GSM 1800 (1.8 GHz) starts to be limited by structural walls. UMTS, at 2.1 GHz is quite similar in coverage to GSM 1800.

Higher frequencies are a disadvantage when it comes to coverage, but it is a decided advantage when it comes to capacity. Pico cells, covering e.g. one floor of a building, become possible, and the same frequency can be used for cells which are practically neighbours.

Cell service area may also vary due to interference from transmitting systems, both within and around that cell. This is true especially in CDMA based systems. The receiver requires a certain signal-to-noise ratio. As the receiver moves away from the transmitter, the power transmitted is reduced. As the interference (noise) rises above the received power from the transmitter, and the power of the transmitter cannot be increased any more, the signal becomes corrupted and eventually unusable. In CDMA-based systems, the effect of interference from other mobile transmitters in the same cell on coverage area is very marked and has a special name, *cell breathing*.

One can see examples of cell coverage by studying some of the coverage maps provided by real operators on their web sites. In certain cases they may mark the site of the transmitter, in others it can be calculated by working out the point of strongest coverage.

Coverage comparison of different frequencies

Following table shows the dependency of frequency on coverage area of one cell of a CDMA2000 network:

Frequency (MHz)	Cell radius (km)	Cell area (km2)	Relative Cell Count
450	48.9	7521	1
950	26.9	2269	3.3
1800	14.0	618	12.2
2100	12.0	449	16.2

Chapter 10

Electrical Telegraph

A printing **electrical telegraph receiver**, and a **transmitter key** at bottom right.

An **electrical telegraph** is a telegraph that uses electrical signals, usually conveyed via telecommunication lines or radio. The *electromagnetic telegraph* is a device for human-to-human transmission of coded text messages.

The electrical telegraph, or more commonly just *'telegraph',* superseded optical semaphore telegraph systems, such as those designed by Claude Chappe for the French military, and Friedrich Clemens Gerke for the Prussian military, thus becoming the first form of electrical telecommunications. In a matter of decades after their creation, electrical telegraph networks permitted people and commerce to almost instantly transmit messages across both continents and oceans, with widespread social and economic impacts.

History

Early works and messages

'Early Telegraph' **historical marker** outside Elizabethtown, Pennsylvania

From early studies of electricity, electrical phenomena were known to travel with great speed, and many experimenters worked on the application of electricity to communications at a distance.

All the known effects of electricity - such as sparks, electrostatic attraction, chemical changes, electric shocks, and in later, more advanced studies, electromagnetism - were applied by various people to the problems of detecting controlled transmissions of electricity at various distances.

In 1746 the French scientist and abbé Jean-Antoine Nollet, gathered about two hundred monks into a circle about a mile (1.6 km) in circumference, with pieces of iron wire connecting them. He then discharged a battery of Leyden jars through the human chain and observed that each man reacted at substantially the same time to the electric shock, showing that the speed of electricity's propagation was very high.

In 1753 an anonymous writer in the *Scots Magazine* suggested an electrostatic telegraph. Using one wire for each letter of the alphabet, a message could be transmitted by connecting the wire terminals in turn to an electrostatic machine, and observing the deflection of pith balls at the far end. Telegraphs employing electrostatic attraction were the basis of early experiments in electrical telegraphy in Europe, but were abandoned as being impractical and were never developed into a useful communication system.

In 1800 Alessandro Volta invented the Voltaic Pile, allowing for a continuous current of electricity for experimentation. This became a source of a low-voltage current that could be used to produce more distinct effects, and which was far less limited than the momentary discharge of an electrostatic machine, which with Leyden jars were the only previously known man-made sources of electricity.

Another very early experiment in electrical telegraphy was an **electrochemical telegraph** created by the German physician, anatomist and inventor Samuel Thomas von Sömmering in 1809, based on an earlier, less robust design of 1804 by Catalan polymath and scientist Francisco Salvá i Campillo. Both their designs employed multiple wires (up to 35) in order to visually represent almost all Latin letters and numerals. Thus, messages could be conveyed electrically up to a few kilometers (in von Sömmering's design), with each of the telegraph receiver's wires immersed in a separate glass tube of acid. An electric current was sequentially applied by the sender through the various wires representing each digit of a message; at the recipient's end the currents electrolysed the acid in the tubes in sequence, releasing streams of hydrogen bubbles next to each associated letter or numeral. The telegraph receiver's operator would watch the bubbles and could then record the transmitted message, albeit at a very low baud rate. The principal disadvantage to the system was its prohibitive cost, due to having to manufacture and string-up the multiple wire circuits it employed, as opposed to the single wire (with ground return) used by later telegraphs.

In 1816, Francis Ronalds set up a primitive telegraph. He ran eight miles (13 km) of cable (encased in glass tubing) through his back garden suspending it from two wooden lattices. and succeeded in getting an electrical signal along the full length using static high voltage electricity. At both ends there were clockwork operated dials with numbers and letters of the alphabet.

Hans Christian Ørsted discovered in 1820 that an electric current produces a magnetic field which will deflect a compass needle. In the same year Johann Schweigger invented the galvanometer, with a coil of wire around a compass, which could be used as a sensitive indicator for an electric current.

In 1821, André-Marie Ampère suggested that telegraphy could be done by a system of galvanometers, with one wire per galvanometer to indicate each letter, and said he had experimented successfully with such a system. In 1824, Peter Barlow said that such a system only worked to a distance of about 200 feet (61 m), and so was impractical.

In 1825 William Sturgeon invented the electromagnet, with a single winding of uninsulated wire on a piece of varnished iron, which increased the magnetic force produced by electric current. Joseph Henry improved it in 1828 by placing several windings of insulated wire around the bar, creating a much more powerful electromagnet which could operate a telegraph through the high resistance of long telegraph wires.

In 1832 an electromagnetic telegraph was created by Baron Schilling in Russia, and in 1833 Carl Friedrich Gauss and Wilhelm Weber invented their own code to communicate over a distance of 1200 m within Göttingen, Germany.

Then in 1835 Joseph Henry invented the critical electrical relay, by which a weak current could operate a powerful local electromagnet over very long distances.

Schilling telegraph

The telegraph invented by Baron Schilling von Canstatt in 1832 had a transmitting device which consisted of a keyboard with 16 black-and-white keys. These served for switching the electric current. The receiving instrument consisted of six galvanometers with magnetic needles, suspended from the silk threads. Both stations of Shilling's telegraph were connected by eight wires; six were connected with the galvanometers, one served for the return current and one - for a signal bell. When at the starting station the operator pressed a key, the corresponding pointer was deflected at the receiving station. Different positions of black and white flags on different disks gave combinations which corresponded to the letters or numbers. Pavel Shilling subsequently improved its apparatus. He reduced the number of connecting wires from 8 to 2.

On October 21, 1832, Schilling managed a short-distance transmission of signals between two telegraphs in different rooms of his apartment. In 1836 the Schilling's telegraph was tested on a 5 km experimental underground - underwater cable, laid around the building of the main Admiralty in Saint Petersburg. Schilling was also one of the first to put into practice the idea of the binary system of signal transmission.

William Fothergill Cooke studied anatomy in Heidelberg in 1834-6, where the physics professor introduced him to the Schilling telegraph in 1836.

Gauss-Weber telegraph and Carl Steinheil

Carl Friedrich Gauss, one of the most influential mathematicians of the early 19th century, developed a new theory of the Earth's magnetism in 1831, together with the physics professor Wilhelm Weber in Göttingen. Among the most important inventions of the time was the unifilar and bifilar magnetometer, enabling them to measure even the smallest deflections of the needle. They installed a 1200 m long wire above the town's roofs, which they were given permission for on 6 May 1833. Gauss combined the Poggendorff-Schweigger multiplicator with his magnetometer to build a more sensitive device, the galvanometer. To change the direction of the electric current, he constructed a commutator of his own. As a result, he was able to make the distant needle move in the direction set by the commutator on the other end of the line.

At first, they used the telegraph to coordinate time, but soon they developed other signals; finally, their own alphabet. It was not binary, but based on four amplitudes of the needle. Gauss was convinced that this communication would be a help to his kingdom's towns.

Later in the same year, instead of a Voltaic pile, Gauss used an induction pulse, enabling him to transmit seven letters a minute instead of two. The inventors and university were too poor to develop the telegraph on their own, but received funding from Alexander von Humboldt. Carl August Steinheil in Munich was able to build a telegraph network within the city in 1835-6, and installed a telegraph line along the first German railroad in 1835.

Alter and the Elderton Telegraph

Across the Atlantic, in 1836 an American scientist, Dr. David Alter, invented the first known American electric telegraph, in Elderton, Pennsylvania, one year before the Morse telegraph. Alter demonstrated it to witnesses but never developed the idea into a practical system. He was interviewed later for the book Biographical and Historical Cyclopedia of Indiana and Armstrong Counties, in which he said: "I may say that there is no connection at all between the telegraph of Morse and others and that of myself.... Professor Morse most probably never heard of me or my Elderton telegraph."

Cooke & Wheatstone

Cooke and Wheatstone's electric telegraph

The first commercial electrical telegraph was co-developed by Sir William Fothergill Cooke and Charles Wheatstone. Cooke and Wheatstone patented it in May 1837 as an alarm system, and it was first successfully demonstrated on 25 July 1837 between Euston and Camden Town in London. It entered commercial use on the Great Western Railway over the 13 miles (21 km) from Paddington station to West Drayton on 9 April 1839. John Tawell was apprehended following the use of a needle telegraph message from Slough to Paddington on 1 January 1845. This is thought to be the first use of the telegraph to catch a murderer. The message was:

A MURDER HAS GUST BEEN COMMITTED AT SALT HILL AND THE SUSPECTED MURDERER WAS SEEN TO TAKE A FIRST CLASS TICKET TO LONDON BY THE TRAIN WHICH LEFT SLOUGH AT 742 PM HE IS IN THE GARB OF A KWAKER WITH A GREAT COAT ON WHICH REACHES NEARLY DOWN TO HIS FEET HE IS IN THE LAST COMPARTMENT OF THE SECOND CLASS COMPARTMENT

The Cooke-Wheatstone system did not support punctuation, lower case, or the letters J, Q, and Z; hence the misspelling of 'just' and 'Quaker'. "Second class compartment" should also probably read "second first-class carriage"; this information was not significant, however, as Tawell was not arrested at the station, but at a nearby coffee shop.

Morse telegraphs

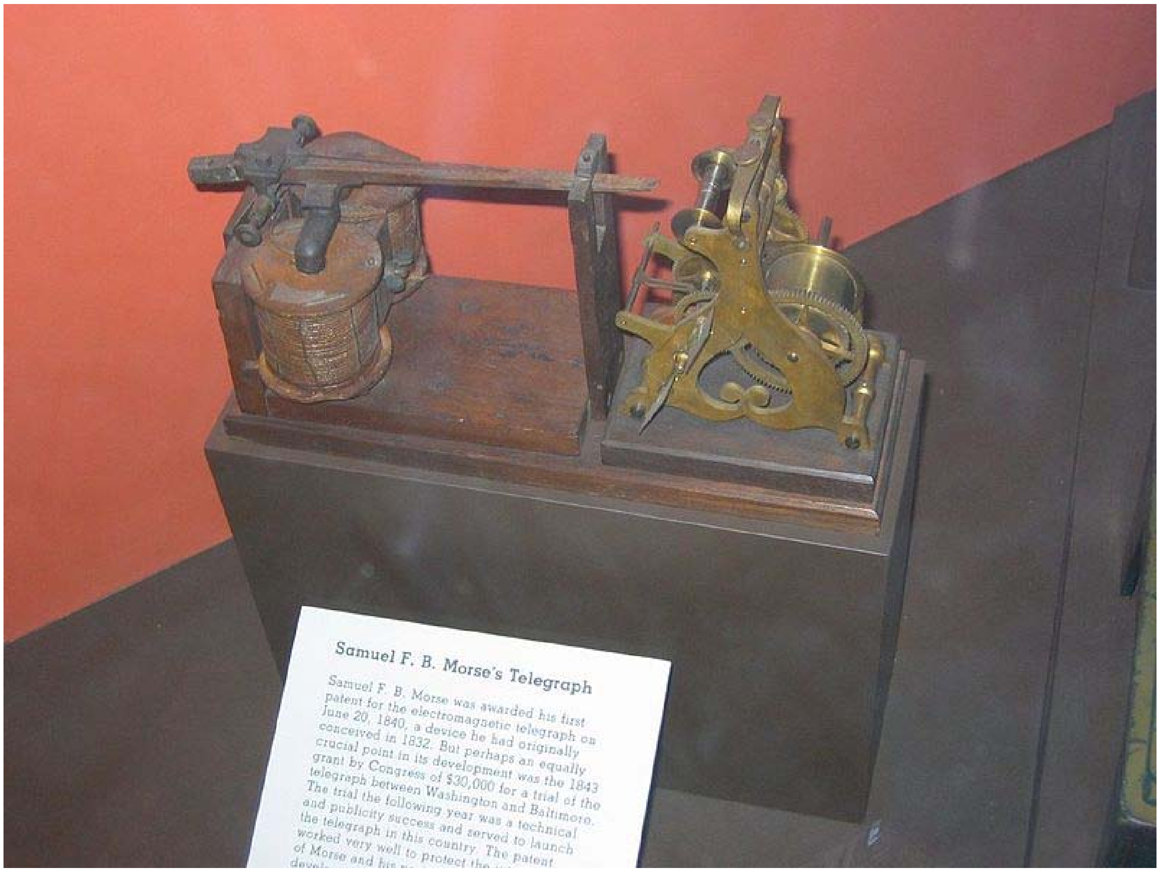
In the United States, the telegraph was developed by Samuel Morse and Alfred Vail. Samuel F. B. Morse independently developed an electrical telegraph in 1836, an alternative design that was capable of transmitting over long distances using poor quality wire. His assistant, Alfred Vail developed the Morse code signaling alphabet with Morse.

On 6 January 1838 Morse first successfully tested the device at the Speedwell Ironworks near Morristown, New Jersey, and on 8 February he publicly demonstrated it to a scientific committee at the Franklin Institute in Philadelphia, Pennsylvania.

In 1843 the U.S. Congress appropriated $30,000 to fund an experimental telegraph line from Washington, D.C. to Baltimore. By 1 May 1844, the line had been completed from the U.S. Capitol to Annapolis Junction in Maryland. That day the Whig Party nominated Henry Clay at its national convention in Baltimore. News of the nomination was hand-carried by railroad to Annapolis Junction where Vail wired it to Morse in the Capitol. On 24 May 1844, after the line was completed, Morse made the first public demonstration of his telegraph by sending a message from the Supreme Court Chamber in the U.S. Capitol in Washington, D.C. to the B&O Railroad "outer depot" (now the B&O Railroad Museum) in Baltimore. The famous message was: *What hath God wrought* (from the Biblical book of Numbers 23:23: *Surely there is no enchantment against Jacob, neither is there any divination against Israel: according to this time it shall be said of Jacob and of Israel, What hath God wrought!*).

The Americas' first telegram, transmitted via a repeater: "*What hath God wrought*" sent by Samuel F.B. Morse in 1844.

The Morse-Vail telegraph was quickly deployed in the following two decades. Morse failed to properly credit Vail for the powerful electromagnets used in his telegraph. The original Morse design, without the relay or the "intensity" and "quantity" electromagnets invented by Vail, only worked to a distance of 40 feet (12 m).



The electrical telegraph owned and built by Samuel F. B. Morse

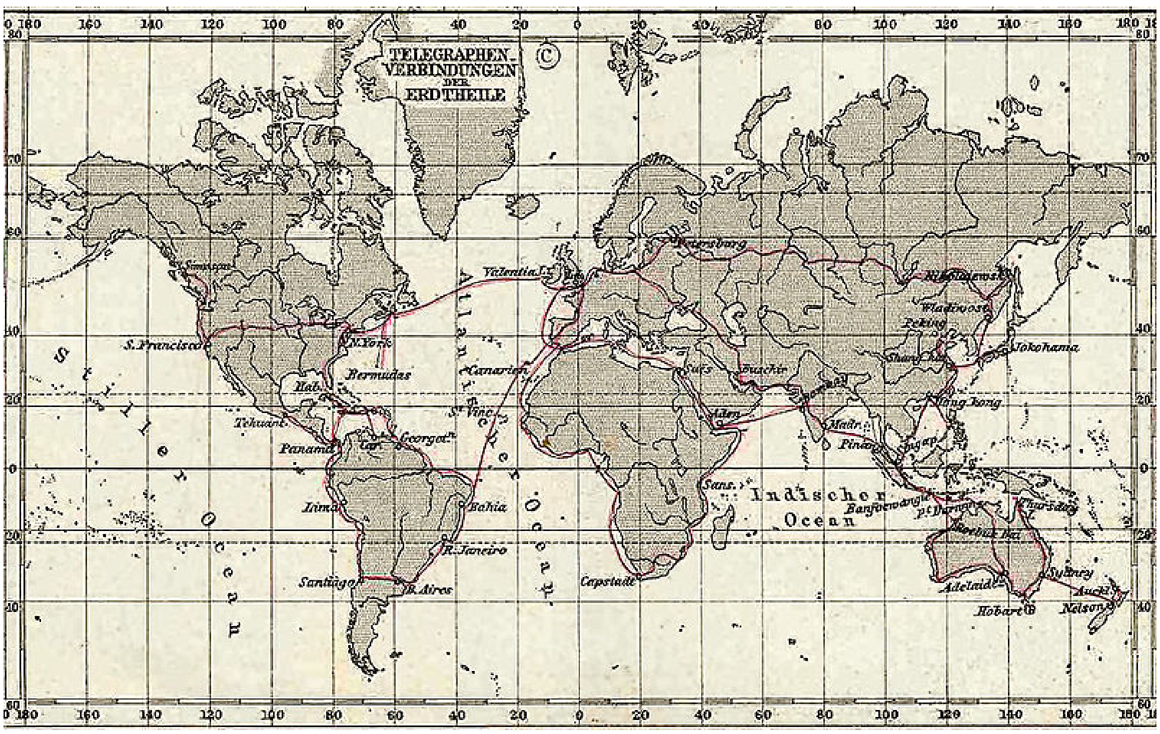
This was a practical electrical telegraph system, and subsequently *electrical telegraph* came to refer to a signaling telegram - a system where an operator makes and breaks an electrical contact with a telegraph key, which results in an audible signal at the other end produced by a telegraph sounder, which is interpreted and transcribed by a human. Morse and Vail's first telegraphs used a pen and paper system to record the marks of the Morse Code, and interpreted the marks visually, but operators soon realized that they could "read" the clicking of the receiver directly by ear. Systems which automatically read the signals and print formed characters are generally called teletype rather than telegraph systems. Some electrical telegraphs used indicators which were read visually rather than by ear. The most notable of these was the early transatlantic telegraph cable.

According to a Pennsylvania Historical and Museum Commission heritage marker installed along Pennsylvania Route 230 near Elizabethtown, Pennsylvania in 1947, the first commercial telegraph line in the United States ran along a railroad right-of-way (currently part of Amtrak's Keystone Corridor) between Lancaster, Pennsylvania and Harrisburg, Pennsylvania in 1845. The first message, received on January 8, 1846, was "Why don't you write, you rascals?"

As the transcontinental telegraph was laid it passed through Nebraska where Republican sympathizers prior to the American Civil War were eager to gain statehood for Nevada before the next presidential election so that Abraham Lincoln would have enough votes to win. They rushed to send the entire state constitution by telegraph to the United States Congress, which approved it and sent it to the President for signature. They did not believe sending it by train would guarantee it would arrive on time. The constitution was sent on 31 October, just eight days before the election on 7 November 1864.

On 24 October 1861, the first transcontinental telegraph system was established. Spanning North America, an existing network in the eastern United States was connected to the small network in California by a link between Omaha and Carson City via Salt Lake City. The first telegram on that line was sent by Brigham Young, then governor of Utah which affirmed that the Territory had not seceded. It read "Utah has not seceded but is firm for the Constitution and the laws of our once happy country." The slower Pony Express system ceased operation two days later. Carson City has another claim in the history of telegraphs for the largest and costliest transmission ever sent came from there.

Transatlantic era

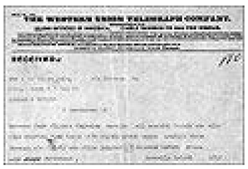


Major telegraph lines in 1891

Transatlantic era

- 

  19th Century map showing the early telegraph cables which connected Britain with the rest of the World.

- 

  THE WESTERN UNION TELEGRAPH COMPANY.

  This telegram was sent by Orville Wright in December 1903 from Kitty Hawk, North Carolina, following the first successful aeroplane flight.

The first successful transatlantic telegraph cable was completed on 27 July 1866, allowing transatlantic telegraph communications for the first time. The lasting connections were achieved by the ship SS *Great Eastern*, captained by Sir James Anderson. Earlier submarine transatlantic cables installed in 1857 and 1858 operated for only a few days or weeks before they failed. The study of underwater telegraph cables accelerated interest in mathematical analysis of these transmission lines.

In 1867, David Brooks (while working for the Central Pacific Railroad) was awarded U.S. Patent 63,206 and U.S. Patent 69,622 for his improvements to telegraph insulators. He was also awarded reissue number 2,717 in 1867, for U.S. Patent 45,221, which had originally been awarded to him in 1864, for his insulator design. Brooks' patents allowed the Central Pacific to communicate more easily with construction crews building the First Transcontinental Railroad in America; news of the completion of the railroad was broadcast by telegraph on 10 May 1869, with the telegrapher striking his key in unison with the strikes on the Golden Spike during the completion ceremony.

Another advancement in telegraph technology occurred on 9 August 1892, when Thomas Edison received a patent for a two-way telegraph (U.S. Patent 0,480,567, "*Duplex Telegraph*").

Global communication

Within 29 years of its first installation at Euston Station, the telegraph network crossed the oceans to every continent but Antarctica, making instant global communication possible for the first time. The telegraph's greatest accomplishment was to expand information boundaries, allowing data to reach its destination before its usefulness expired; information like any other goods is only of value for a certain period of time. For instance, a person making a speculation in stocks requires the current market price; the old market price is of no value. As long as information travels at the speed of transportation vehicles, the distance over which it held its freshness was small. A similar principle applies to news, so much so that the relationship between information and time results in the distinguishing news from history. Information about events that were at a significant distance were reported long after the events occurred, rendering it as history to the individuals that received it. Thus the telegraph liberated information transfer from transportation. The impetus of this was war, which created the need of expanding the telegraph's service. Its effects were immediate, reducing more than a day off delivery time.

News through newspapers also evolved due to the telegraph's inception. The telegraph could carry information, but there was a need for someone to obtain information to begin with. Through the rapid delivery of information created by the telegraph, it was no longer possible to rely on the delivery of distant newspapers. There was a need for an individual to gather the news at its distant source and deliver it to the telegraph office. Newspapers could not use their own reporters as they would obstruct other reporters, jamming the telegraph line. The solution was co-operation. In New York for instance, the six major newspapers established an association for foreign news and a separate one for other sources - the first wire service. Ultimately this resulted in the proliferation of news with competition breaking out between the original six papers and other rivals. Thus the telegraph did not only transport news but also played a dominant role in establishing the industry and the profession of journalism.

Applications

In many instances, applications of the electrical telegraph in the long period between its invention and demise as a significant carrier of information, were similar to the Internet. This has prompted the sobriquet "Victorian Internet" for 19th century telegraphy. According to the book *The Victorian Internet*, besides news reporting, telegraphy, as the first true global network, permitted applications such as message routing, social networking (between Morse operators—with gossiping and even marriages among operators being celebrated via telegraph), instant messaging, cryptography and text coding, abbreviated language slang, network security experts, hackers, wire fraud, mailing lists, spamming, e-commerce, stock exchange minute-by-minute reports (via the ticker tape machine invented by Thomas Alva Edison), and many others.

End of the telegraph era

In the United States, Western Union discontinued all telegram and commercial messaging services on 27 January 2006, although it still offered its electronic money transfer services.