

CENG 422

Design and Managment of Computer Networks Lecture Notes

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Chapter 1

Data and Signals - October 20, 2020

To be transmitted, data must be transformed to electronic signals. Data can be *analog* or it could be *digital*.

Analog Data is the information that is continuous. It may have a range of infinite values. They tend to be periodic.

Digital Data is the information that has discrete states. It can only have a limited number of values. They tend to be non-periodic.

1.1 Signal Types

1.1.1 Periodic Analog Signals

Periodic analog signals can be classified as *simple* or *composite*. Two signals may have the same phase and frequency but different amplitudes. The frequency determines the amount of repeats a signal has in a time period.

A period is the amount of time (in seconds) a signal needs to complete 1 cycle, given as $T = \frac{1}{f}$ where f is the frequency.

Frequency is the rate of change with respect to time. Change in a short span of time means high frequency. Otherwise a low frequency. If a frequency does not change at all, its frequency is zero. If the change is instantaneous, it is infinite.

The wavelength describes the distance a signal can travel during a period.

The waves may be represented using only their frequency domains, simplifying their graphs significantly.

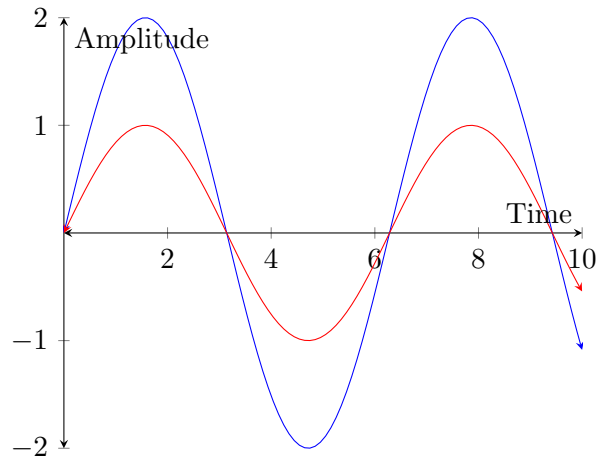


Figure 1.1: Two waves with same phase and frequency but different amplitude.

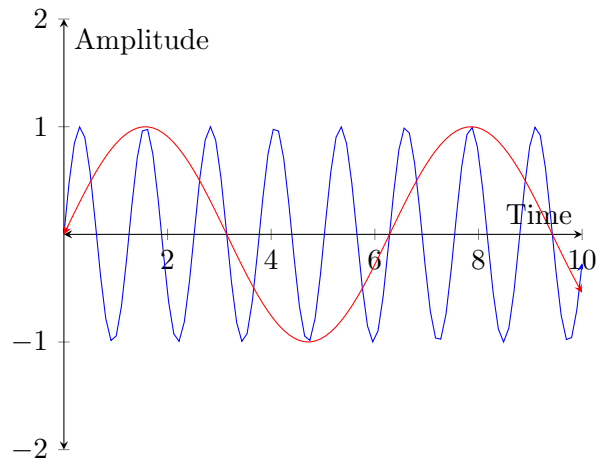


Figure 1.2: Two waves with same amplitude and phase but different frequency.

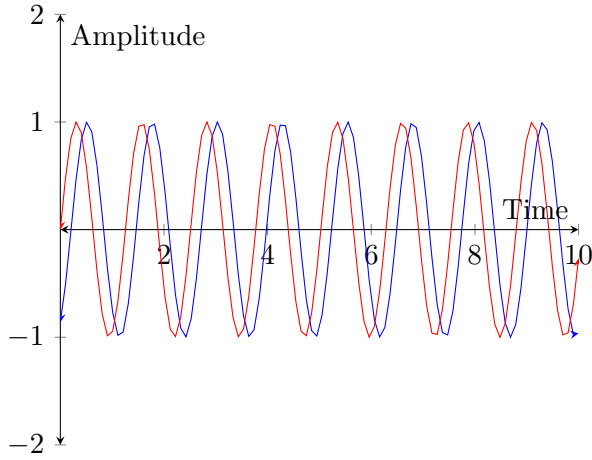


Figure 1.3: Two waves with same amplitude and frequency but different phase.

Composite Signals

According to Fourier analysis, any composite signal consists of simpler signals. If the composite signal is periodic, the decomposition gives a series of signals with discrete frequencies. If the composite signal is nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies.

The *bandwidth* of a signal is the difference between the maximum frequency and the minimum frequency it consists of.

$$B = f_h - f_l \quad (1.1)$$

1.1.2 Digital Signals

In digital signals, the amplitude is divided into levels, as the number of levels increase, so does the speed of the transmission. The **bitrate** represents the number of bits sent per second. Number of bits that can fit in a number of levels if the number of levels are n_L is:

$$n_B = \log_2 n_L \quad (1.2)$$

A **bit length** is the distance that a bit occupies on the transmission medium. Transmission speed times bitrate.

$$L_B = v \times r_b \quad (1.3)$$

A periodic digital signal occupies an infinite amount of discrete frequencies. Whereas non-periodic digital signals (which most of them are.) occupy

a continuous range of infinite frequencies.

Baseband transmission is sending a digital signal through a channel without changing it to analog first.

A digital signal necessitates a low-pass channel, a channel that starts from 0Hz.

In general, any transmission losses *some* information with regards to the wave form of the signal, to preserve the shape of the signal completely, one needs a low-pass channel with an infinite or very wide bandwidth. Sometimes, the digital signal may have to be converted to corresponding analog signals to preserve information.

The required bitrate for a bandwidth of b is at minimum $\frac{b}{2}$. To acquire better results, one can multiply this number with harmonic sequences.

Bandpass is a channel with a limited range of frequencies $f_1 < f < f_2$. A digital signal cannot pass through a bandpass, as it is not a lowpass channel, therefore, the signal is first converted to analog, sent through the channel and then converted back to the digital. These include telephone lines.

1.2 Transmission Impairment

Attenuation is the loss of amplitude in the medium, and an amplifier can be used to mitigate this issue. The loss and gain can be calculated with the dB unit.

Distortion Due to the difference of behaviour of the medium for different frequencies, parts of the composite signal may arrive out of phase, or different.

Noise They may be **Thermal Noise** due to the random motion of electrons in the wire. **Induced Noise** is noise due to motors or appliances in the environment. **Crosstalk Noise**, effect of one wire on the other and **Impulse Noise** is a sudden spike in electricity in the wire. The quality of the medium can be calculated via the SNR (Signal-to-Noise Ratio), higher the SNR, higher the quality of the signal.

1.3 Data Rate Limits

A very important consideration in communication is how fast the data can be sent, in bits per second, over a channel. Keep in mind that, increasing the levels of a signal may reduce the reliability of the system.

1.3.1 Formulas

Maximum data rate of a channel for a noiseless channel is the Nyquist formula $L \times n_B \times \log_2 L$ and for a noisy channel is the Shannon Formula, Capacity = bandwidth $\times \log_2(1 + \text{SNR})$

1.4 Performance

The bandwidth can be calculated in hertz or in bits per second. **Bandwidth** is the number of bits that can fit into a channel. **Delay** is the time taken for a signal to travel from the source to the destination.

Chapter 2

Transmission Media & Ethernet - October 27, 2020

Different media was used in history to transfer data. From telegraph to telephone.

The media itself can be divided to *Guided* and *Unguided* transmission media. Where guided is the wired and unguided is the wireless.

2.1 Guided Media

2.1.1 Twisted-pair Wire

Consists of two cables twisted around each other. Twisted-pair cables are more resilient against noises. As a twisted-pair of P^+ and P^- cables are affected by the noise the same amount, hence the receiver can understand the actual signal by $(P^+ + N) - (P^- + N) = P^+ - P^-$. Cancelling noise.

Twisted pairs come in two variants, UTP (the unshielded pair.) and STP (the shielded pair.), UTP tends to be more widespread due to its cheapness.

Attenuation, the amount of information loss, tends get worse *faster* the thinner it is, therefore, the loss of information is worse for thinner cables.

2.1.2 Coaxial Cable

The coaxial cable carries the ground connection as a shield, and the main signal as the cable.

2.1.3 Optical Fiber

Optical fiber is used to refract light in its core between two cladding between a sender and a receiver. This method uses the critical angle reflection of the light. When a light is sent at a critical angle to a less dense environment from a more dense environment, it reflects.

Propagation Modes

Light propagates in different ways inside a optical fiber, different fibers use different modes. Fiber optic cables are divided into **Multimode** and **Single mode** cables. Multi-mode cables are then divided to **Step index** and **Graded index** fiber optic cables.

Optical fiber cables has a zone in its wavelength, around 1400nm where there is high loss.

IN general fiber provides higher bandwidth, less signal attenuation, immune to electromagnetic interference, resistance to corrosion, lightweight, greater immunity to tapping however, it tends to be more difficult to install and maintain, has unidirectional light propagation and it costs more.

2.2 Unguided media

Wireless communication can use between 3kHz and 900THz. Different propagation methods can be used to send data. Ground propagation, where signals below 2MHz travels parallel to the ground, following curvature. Sky propagation, where signals between 2 and 30MHz can reflect off the Ionosphere and reach. And finally, line-of-sight propagation, where, above 30MHz, signals need to have a direct line-of-sight, as they tend to pass through the ionosphere.

Wireless transmission can be done using radiowave, microwave and infrared.

Antenna's also come in two variations, **omnidirectional**, where signal travels in all directions, as well as **unidirectional**, which comes in dish and horn antenna, where waves travel in single directions.

2.3 Ethernet

Ethernet was the culmination of IEEE project 802 in 1985, to set standards to enable intercommunication between different equipment

Version	Speed
Standard Ethernet	10Mbps
Fast Ethernet	100Mbps
Gigabit Ethernet	1Gbps
Ten-gigabit Ethernet	10Gpbs

Divided into two sublayers, logical link control (LLC) and Media access control (MAC).

Most upper layer protocols (such as IP), do not use LLC.

the standard ethernet A connectionless, unreliable service. Each frame was sent independently, when a frame is lost or corrupted, reciever drops it.

Ethernet consists of a preamble, 56 bits of alternating 1s and 0s. SFD, the start frame delimiter (10101011), destination address, source adress, length or type and data and padding, following that, a CRC.

Ethernet used to use Carrier sense multiple access with collision detection, called CSMA/CD. That is, the sender listens to the cable to detect collusion, in which case it waits for a while and resends the frame.

Data and padding portion of the data must be at least 46 bytes, and at most 1500 bytes. The existence of the minimum length arose from the fact that at least 46 bytes was necessary for CSMA/CD to work.

An example ethernet address in hexademical looks like $7a : 79 : 19 : 92 : d8 : 98$. The addresses are dividied into unicast and multicast addresses, where the lest significant bit of the first byte is 0 for unicast addresses, and 1 for multicast addresses.

The broadcast destination address is a special case of the multicast address in which all bits are 1s. This address are used to send to the DHCP server to retrieve information.

Standadr ethernet has different implementations, 10Base5, 10Base2, 10Base-T and 10Base-F.

In the standard ethernet, Manchester Encoding/Manchester Decoding was used. Where the transformations between 0 and 1 signals in data was themselves encoded using 1s and 0s.

The second revision of the ethernet removed the CSMA/CD, data transfer became bidirectional, moved all computers to their own domain, and introduced Fast Ethernet, which did not support bus topology. It was implemented into three forms. Manchester was also discarded due to it needing

too much bandwidth.

The third revision introduced the Gigabit ethernet, MAC layer was changed to the full-duplex version. It had four implementations.

The tenth gigabit ethernet is possible only with fiber-optic technology. Supporting LAN PHTY and WAN PHY, working in full-duplex.

Chapter 3

Bandwith Utilization - November 10, 2020

Bandwith utilization is different method of manuplating bandwith in order to decrease cost, increase privacy, or add noise tolarance.

3.1 Multiplexing

Whenever the bandwith of a medium linking two devices is greater than bandwith needed by both, the link can be shared by multiple connections[?]. This process is called *Multiplexing* with Multiplexers used to multiplex multiple signals and Demultiplexers (Demux) being used to convert them back to single signals.

3.1.1 Frequency Divison Multiplexing

An *analog* method of multiplexing is used when different baseband analog signals are recieved. They are moudlated with different modulator signals, and are summed together, being sent through the medium.

In the demultiplexing step, filters are used to distinguish signals, and then each signal is put through a demodulator, recieving the original signals.

In FDM, guard bands might be used as buffer zones between different channels to avoid channels from generating parasite.

Different ways of encoding signals may also be used in FDM, such as QAM, which uses phase shifting.

Multiple FDM multiplexers may be bound in chains, generating groups, supergroups, master groups and jumpgroups and so on. This methods are

[or were] conventionally used in telephone systems. This is called an *analog hierarchy*.

3.1.2 Wavelength Division Multiplexing

Another *analog* system, used in fiber cables which use light; WDM may use prism as multiplexers and demultiplexers.

3.1.3 Time Division Multiplexing

A *digital* method, TDM allocates time slots to each device, and uses buffers to accumulate data in between sending.

3.1.4 Synchronous TDM

Synchronous TDM sends frames, each frame subdivided to its own subdivisions. 2^n .

Synchronization must be achieved to make sure data being sent is received correctly. Sometimes, this issue is resolved via the introduction of a **framing bits**, additional bits added to the start of frames, adhering to a agreed upon synchronization pattern.

In sTDM, empty slots may occur, since data of each device is sent at the same time, sometimes a device may not send data at that time, its slots is left empty.

Likewise with analog methods, TDMs may also be chained together, creating a *digital hierarchy*.

Since analog signals can be converted to digital signals, telephone lines and other analog systems can also be used with TDM after conversion. [And, in fact, nowadays, most telephone systems have become digital.]

3.1.5 Statistical TDM

By introducing additional information before data, the occurrence of empty slots may be removed.

3.2 Spread Spectrum

In spread spectrum, signals from different sources are combined to fit into larger bandwidth, this may be to prevent eavesdropping, jamming, or to increase noise tolerance.

Frequency Hopping Spread Spectrum (FHSS) The original signal is spread using a frequency table, that generates frequencies using a synthesizer depending on the data originating from a pseudo-random code generator, this frequency is combined with the original signal using a modulator. FHSS results data *hopping* between frequencies, increasing noise tolerance and also making eavesdropping harder.

Direct-Sequence Spread Spectrum (DSSS) adds predefined data to the original data, making it harder for the signal to be understood by anyone who does not know about the predefined data.

Chapter 4

Wireless LANs: WiFi & Bluetooth - November 10, 2020

4.1 WiFi

Defined by IEEE 802.11 specification as a Basic Service Set (BSS) or an Extended Service Set (ESS).

4.1.1 Service Sets

A BSS without an Access Point (AP), a dedicated device like a router, is called an *ad hoc network*. A BSS with an AP is called an *infrastructure network*.

An Extended Service Set occurs when multiple Access Points are connected through a distribution system, and is controlled by a server or a gateway. It should be noted that a device might be connected to multiple BSSs simultaneously in an ESS.

4.1.2 Physical Layer

IEEE 802.11 consists of a physical layer which support many different protocols, and a data link layer consisting of a MAC sublayer and $!^*$.

Different protocols may use different modulations.

4.1.3 Data Layer

A variation of CSMA/CA (§2.3) that uses signals such as CTS (Continue to Send), RTS (Request to Send), ACK (Acknowledgment), as this process continues between a source and destination; at the same time, all other stations not partaking in this data transfer, stop transferring data, this is called NAV, since signals carry with them the time it will take for data transfer, they do not even listen to the conversation, avoiding noise. This entire process is called **DCF** [Distributed Coordination Function].

An alternative to DCF is called **PCF** (Point coordination Function). Here, the Access Point asks each station if it has any data to send (called **polling**), this occurs one-by-one. This process occurs in a round-robin style, and this time is called a **contention-free**. Since PCF must be backwards compatible, there is also a contention zone following each contention-free zone, where stations that do not support PCF can contact the AP in a DCF fashion.

[I just want to say the term robbin is also used when describing some chess tournaments.]

4.1.4 Frame Format

Frame format of WiFi contains four different addresses to define a data transfer. Depending on the value of the To DS and From DS flags, different addresses contain different data, for instance, if both flags are set to 1, addresses are used for sending AP, receiving AP, source station and destination station respectively.

4.1.5 Frequencies

WiFi uses three frequency bands chiefly, around 900MHz, around 2.4GHz and around 5.8 GHz. Different frequency bands are also subdivided into different channels. The

4.1.6 Problems

Wifi has its unique problems due to its wireless nature, where ranges of devices may cause significant issues.

Hidden Station Problem

Station A is inside the range of both C and B, but C and B cannot see each other, this causes CSMA/CA to function incorrectly, introducing problems.

This is solved by the fact that the RTS signal of the WiFi contains the time it will take for data to transfer, since CTS signal from A also contains this time data, this functions as a form of *handshaking*, where when a station realises a CTS signal isn't sent to itself, it goes into NAV.

Exposed Station Problem

Occurs when A-B and C-D pairs are trying to send data to each other, but A and C can hear each other, when D and B cannot, causing either A or B to go into NAV unnecessarily.

4.2 Bluetooth

A bluetooth network is called a **Piconet**, the device the bluetooth originates from is called a **primary**, whereas devices connected to it is called a **secondary**. A secondary on a piconet may become a primary for another piconet, creating a **scatternet**.

Logical Link Control and Adaption Protocol (L2CAP) is used for data exchange on an ACL link. It is equivalent to an LLC layer of ethernet, whereas the **Baseband Layer** corresponds to the MAC layer of LAN, it uses Time Division Multiplexing.

Communication in a piconet is handled in a round robin fashion, whereas a time slot is used to send data, another to receive data, and repeat until all secondaries have been given permission receive and asked to send data.

Chapter 5

Frame Relay & ATM - November 17, 2020

Frame Relay is a virtual-circuit wide-area network that was designed in response to demands for a new type of WAN in the late 1980s and early 1990s.

5.1 Point to Point Circuit

Dedication of a physical line between two routers. This method, although straightforward and simple, is high-cost, and not suitable for burst data. (Transmission of large amounts of data).

5.2 Frame Relay

The frame relay was created as a response to these complaints, where multiple routers are connected to a single source, the Frame Relay, and the frame relay directs the packages to their destinations.

Frame Relays consists of virtual circuits called DLCIs, Data Link Connection Identifier. They consists of two layers, Physical and Data Link layers, Physical layers support ANSI standards, and the Data Link layer consists of simplified core functions.

A frame layer frame consists of a flag, an address, information, FCS and a flag. The address section consists of 6 bits of DLCI, 1 bit for Command response, 1 bit for extended address flag, 4 bits of DLCI, 1 bit FECN, 1 bit of BECN, 1 bit DE, 1 bit of Extended Address flag. FECN and BECN holds information about congestion in the network. the DE Flag notifies if the package is eligible for discarding if congestion occurs.

Frame Relay does not contain error control. These must be provided in upper layers.

DLCI addresses may be two, three or four bits lengths.

FRADs can bridge between Frame Relays and different types of networks.

Frame Relay has a problem with Multiplexing, since the frames are big, small packages are congested by a channel sending big packages.

5.3 ATM

Asynchronous Transfer Mode is the cell relay protocol designed by the ATM forum and adopted by the ITU-T.

ATM was designed to make sure hardware handles as much of the communication as possible.

ATM solves the problem with multiplexing frames using **cells**, cells are small units of information, keeping congestion to a minimum.

ATM multiplexing also do not use the round robin system that causes empty package slots, instead the ATMs header has enough information on it that the switches know where the packages are going.

Much like the Frame Relay, ATM uses virtual connections, going through Virtual paths, going through virtual transmission paths.

A virtual connection is defined by a pair of numbers, the VPI (Virtual Path Identifier) and the VCI (Virtual Circuit Identifier).

UNI connections that occur between users and the switches has less space for VPI (16 bits VCI to 8 bits VPI) compared to NNI connections, which occur between networks (16 bits VCI to 12 bits VPI).

ATM consists of three layers, a Physical an ATM and finally a AAL (Application Adaptation Layer). Originally, the physical layer for ATM was SONET, a fiber-optic network standard designed to transfer large amount of data.

ATM provides routing, traffic management and multiplexing.

In the UNI cells, there is an extra ATM header for GFC (Generic Flow

Control) stealing space from VPI. otherwise, both cell structures consists of PT, CLP and HEC fields in the header.

AAL connections

AAL1 Supports continous data transmission.

AAL2 Packages of changing data size.

AAL3/4 Connection orianted services.

AAL5 Simple but large volumes of data. (Simple but Effective Layer)

In today's world, AAL1 (for Streaming Audio and Video) and AAL5 (for data communications) is used.

ATM LANs

ATM is mainly a Wide-Area network protcole (WAN ATM) but it is also possible to use ATM in LAN.

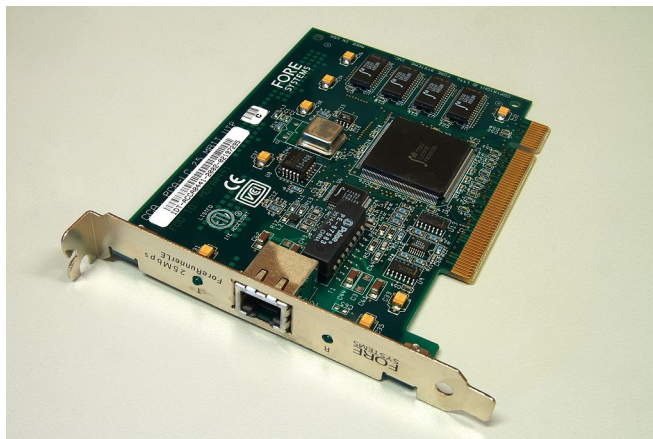


Figure 5.1: FORE Systems ForeRunnerLE 25 ATM Lan Card by Wikipedia user Barcex

Computers that will connect to the ATM LANs (without converters) will need a dedicated network card, just like an Ethernet Card. ATM LANs are not used widespread.

Chapter 6

Logical Addressing - November 17, 2020

A logical address is an address that stays the same. Physical addresses, in the meantime, changes while going from network to network.

6.1 IPv4 Addresses

An IPv4 address is a **32-bit** address that uniquely and universally defines the connection of a device (a computer, a computer, or a router) to the internet.

1. They are unique and universal.
2. They are 32-bits long.
3. The address space of IPv4 is 2^{32} .

It can be written in Dotted-decimal notation, such as 128.11.3.31 With each part being between 0 and 255.

6.1.1 Classful Addressing

In classful addressing, there are five classes of IP addresses. Each IP address consists of two parts, Network ID (netid) and Host ID. netid stays the same for an organization :(is the ID of the entire organization) Hostid, in the meanwhile, is a single machine at that organization.

Depending on the class (A, B, C) the size of the netid/hostid changes.

In Class A the first, the class B the second, and in the class C first three bits are specific.

	Network ID	Host ID
Class A	1	2, 3, 4
Class B	1, 2	3, 4
Class C	1, 2, 3	4
Class D/E	–	–

	Block Count	Block Size	Application
Class A	128	16,777,216	
Class B	16,384	65,536	
Class C	2,097,152	256	
Class D	1	2,147,483,648	Multicast
Class E	1	2,147,483,648	Reserved

6.1.2 Mask

The mask is a special bit sequence that, when anded with an IP address, returns the netid, this way, we can determine where to send the packages.

	Dotted-Decimal	CIDR
Class A	255.0.0.0	/8
Class B	255.255.0.0	/16
Class C	255.255.255.0	/24

Table 6.1: The default masks for classful addressing