Day 3 course

Transmission and Network Planning

Link Budget Analysis and Design

By NIAMEOGO W. Eric

1- Modulation

In telecommunications, **modulation** is the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. Modulation of a sine waveform is used to transform a baseband message signal to a passband signal, for example a radio-frequency signal (RF signal). In radio communications, cable TV systems or the public switched telephone network for instance, electrical signals can only be transferred over a limited passband frequency spectrum, with specific (non-zero) lower and upper cutoff frequencies.

1- Modulation

The three basic types of modulation are :

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

All of these techniques varies a parameter of a sinusoid to represent the information which we wish to send. A sinusoid has 3 different parameters that can be varied. These are amplitude, phase and frequency

1- Modulation

Amplitude Modulation (AM)

Varying the voltage of a carrier or a direct current in order to transmit analog or digital data. Amplitude modulation (AM) is the oldest method of transmitting human voice electronically. In an analog telephone conversation, the voice waves on both sides are modulating the voltage of the direct current loop connected to them by the telephone company.

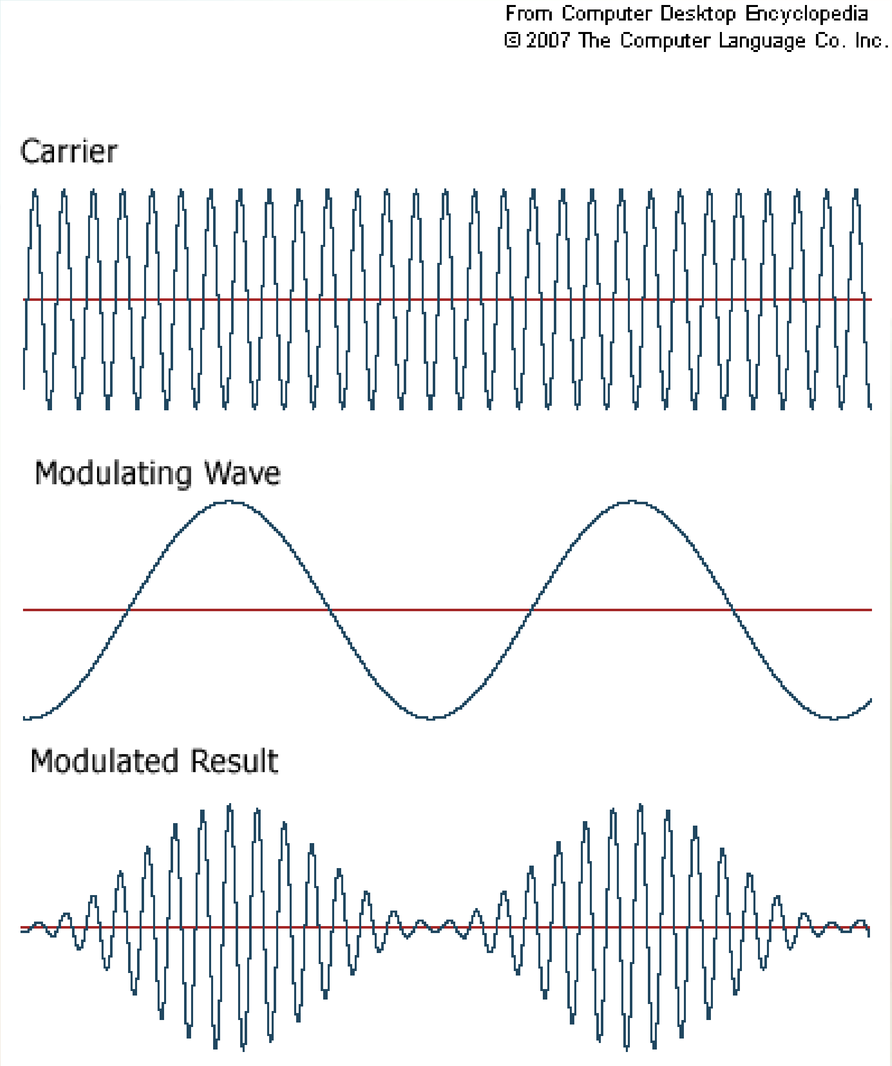
AM is also used for digital data. In quadrature amplitude modulation (QAM), both amplitude and phase modulation are used to create different binary states for transmission

1- Modulation

Amplitude Modulation (AM)

Vary the Amplitude

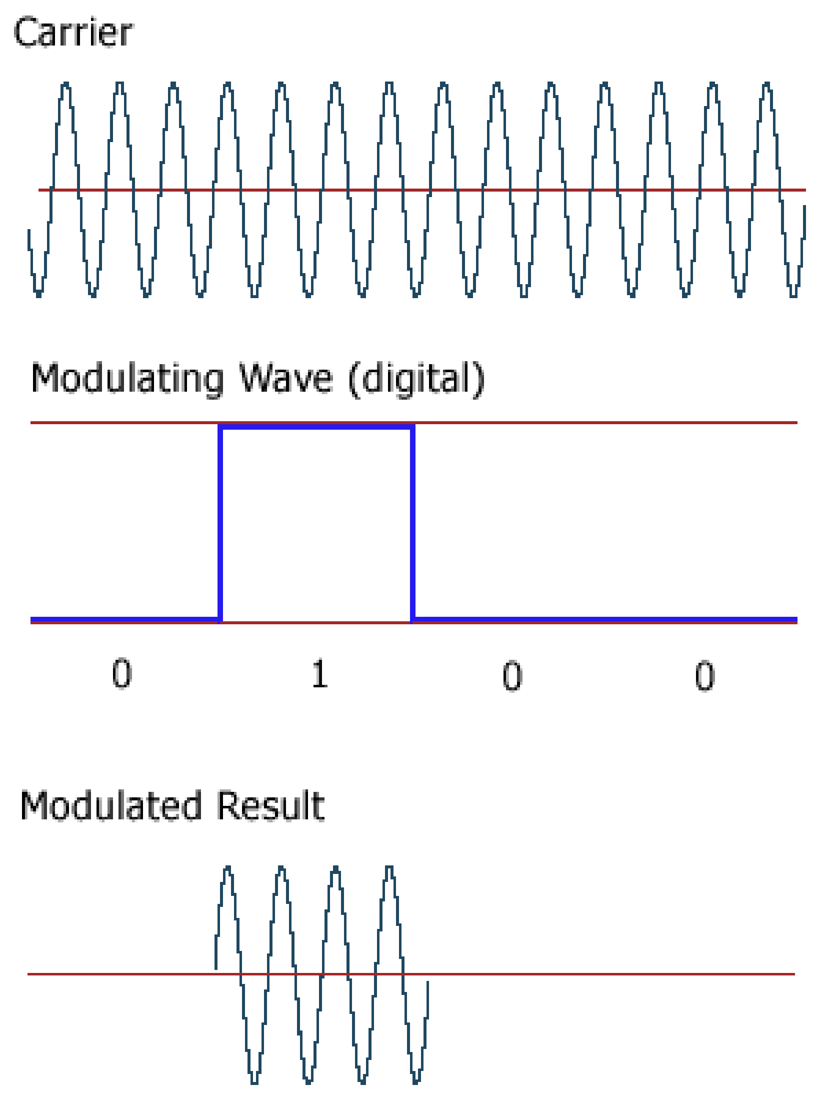
In AM modulation, the voltage (amplitude) of the carrier is varied by the incoming signal. In this example, the modulating wave implies an analog signal.



1- Modulation

Digital Amplitude Shift Keying (ASK)

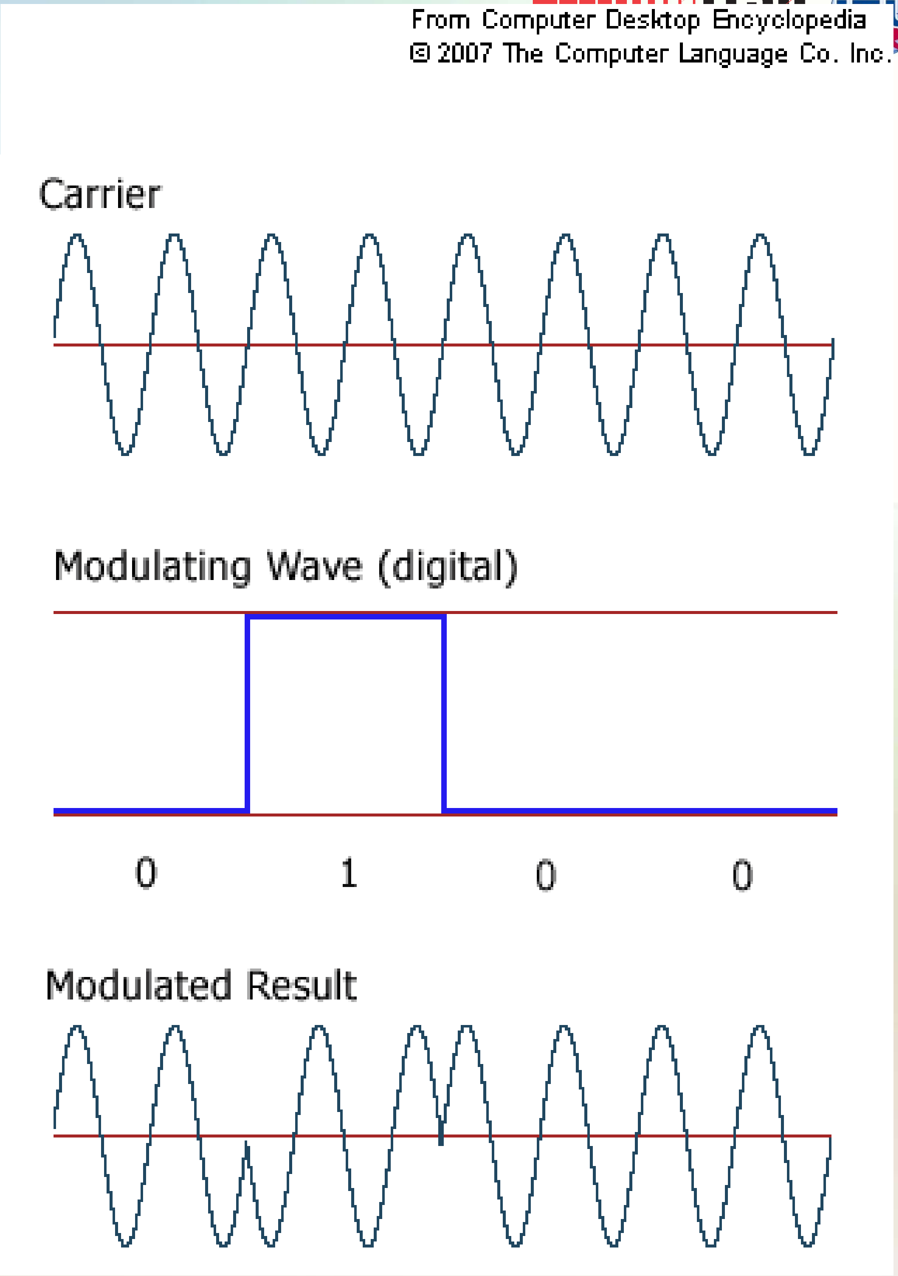
For digital signals, amplitude shift keying (ASK) uses two voltage levels for 0 and 1 as in this example.



1- Modulation

Phase Shift Keying (PSK)

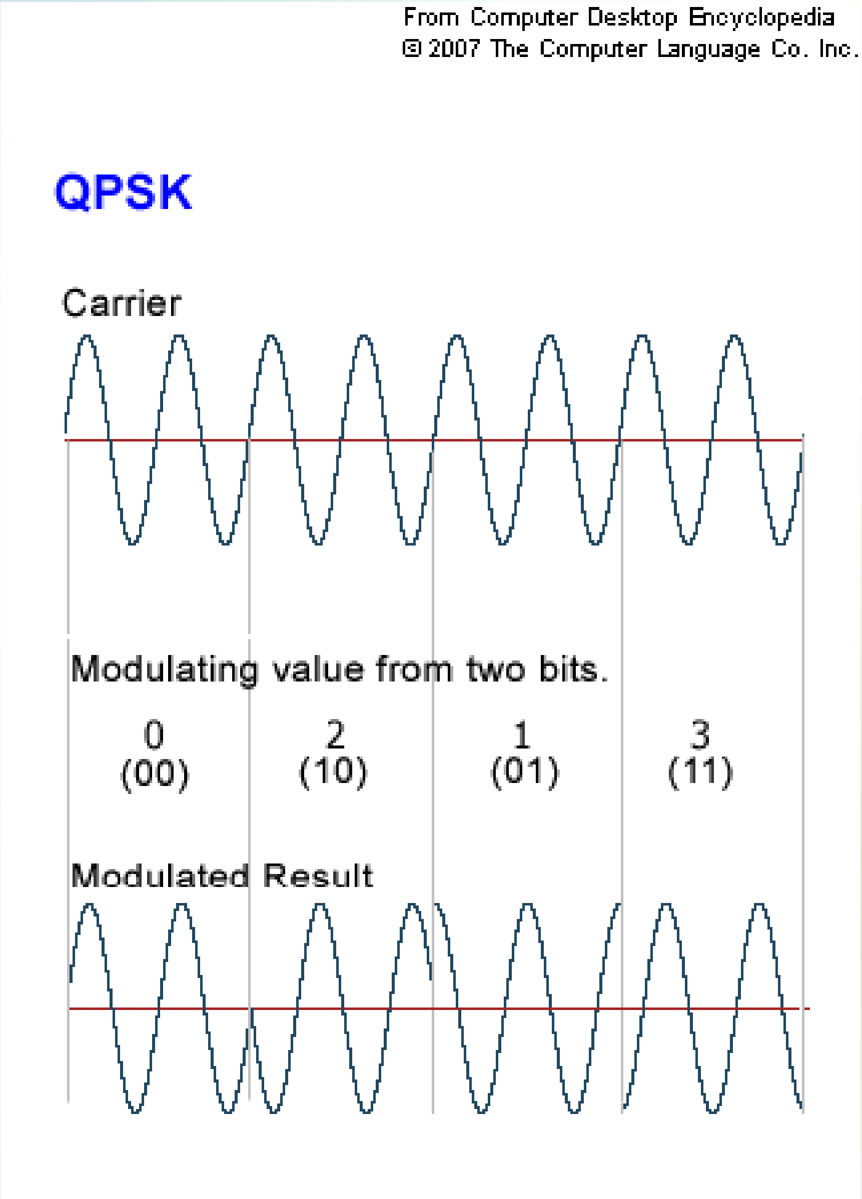
For digital signals, phase shift keying (PSK) uses two phases for 0 and 1 as in this example.



1- Modulation

Quadrature Phase Shift Keying (QPSK)

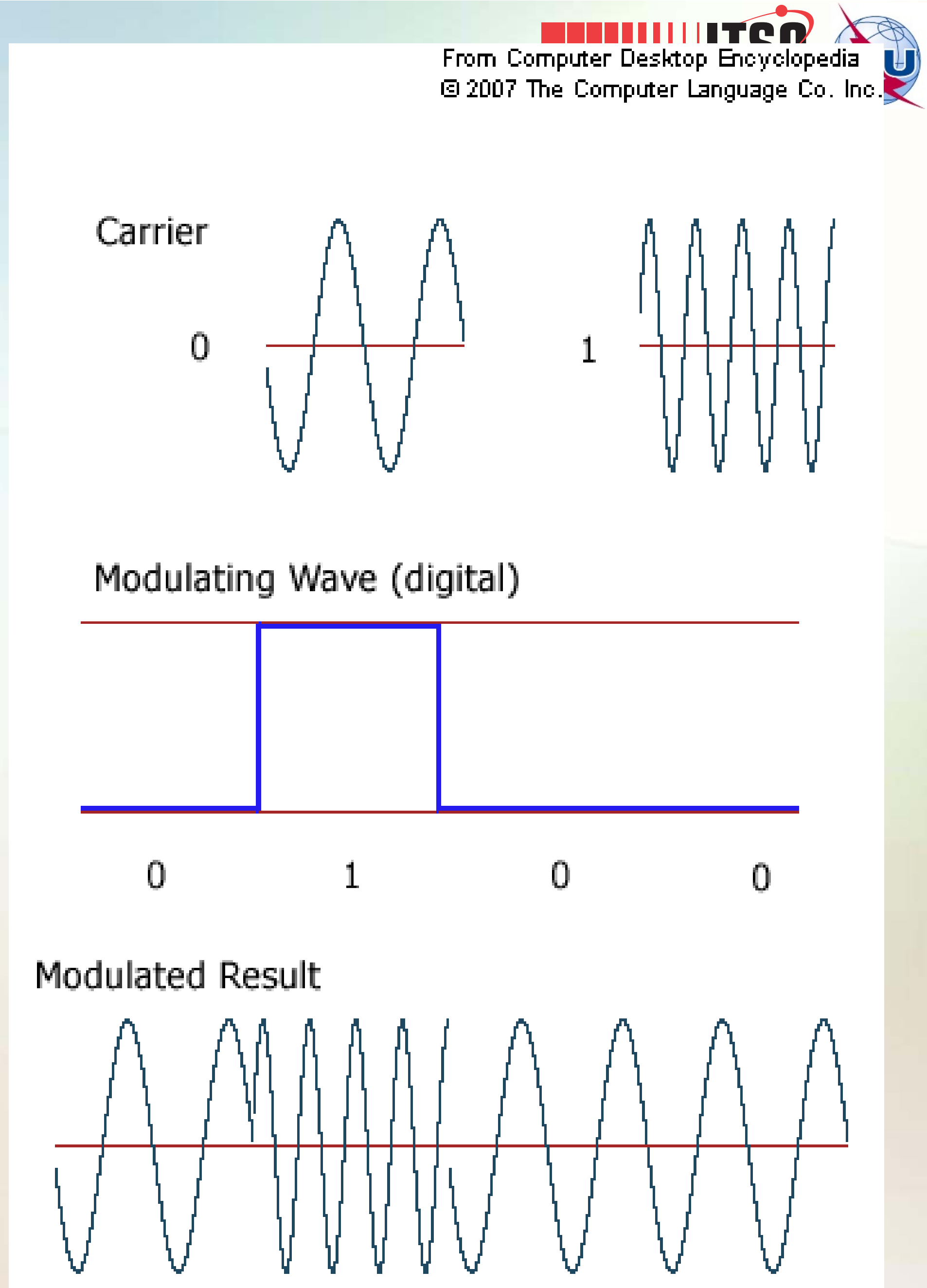
QPSK uses four phase angles to represent each two bits of input; however, the amplitude remains constant.



1- Modulation

Frequency Shift Keying (FSK)

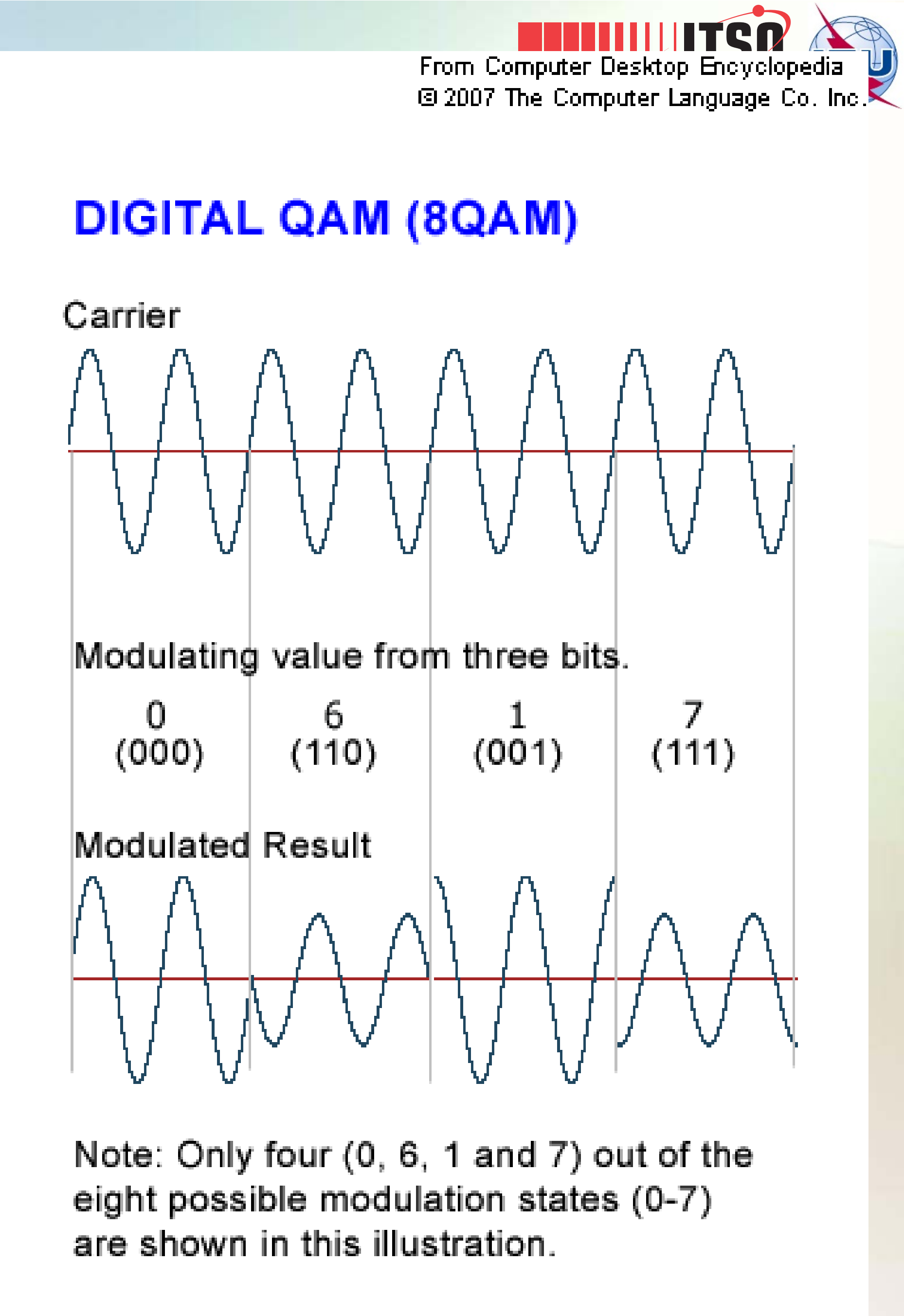
FSK is a simple technique that uses two frequencies to represent 0 and 1.



1- Modulation

Digital 8QAM

In this 8QAM example, three bits of input generate eight different modulation states (0-7) using four phase angles on 90 degree boundaries and two amplitudes: one at 50% modulation; the other at 100% (4 phases X 2 amplitudes = 8 modulation states). QAM examples with more modulation states become extremely difficult to visualize.



1- Modulation

Popular Modulation schemes used in satellite

Popular modulation types being used for satellite communications:

- Binary phase shift keying (BPSK);
- Quadrature phase shift keying (QPSK);
- 8PSK;
- Quadrature amplitude modulation (QAM), especially 16QAM.

2- Compression

Analog Video Compression

In communications, data compression is helpful because it enables devices to store or transmit the same amount of data in fewer bits, thus making the transmission of the data faster.

A hardware circuit that converts analog video (NTSC, PAL, SECAM) into digital code and vice versa. The term may refer to only the A/D and D/A conversion, or it may include the compression technique for further reducing the signal

2- Compression

Digital Video Compression

Hardware and/or software that compresses and decompresses a digital video signal. MPEG, Windows Media Video (WMV), H.264, VC-1 and QuickTime are examples of codecs that compress and decompress digital video.

2- VoiP

Definition

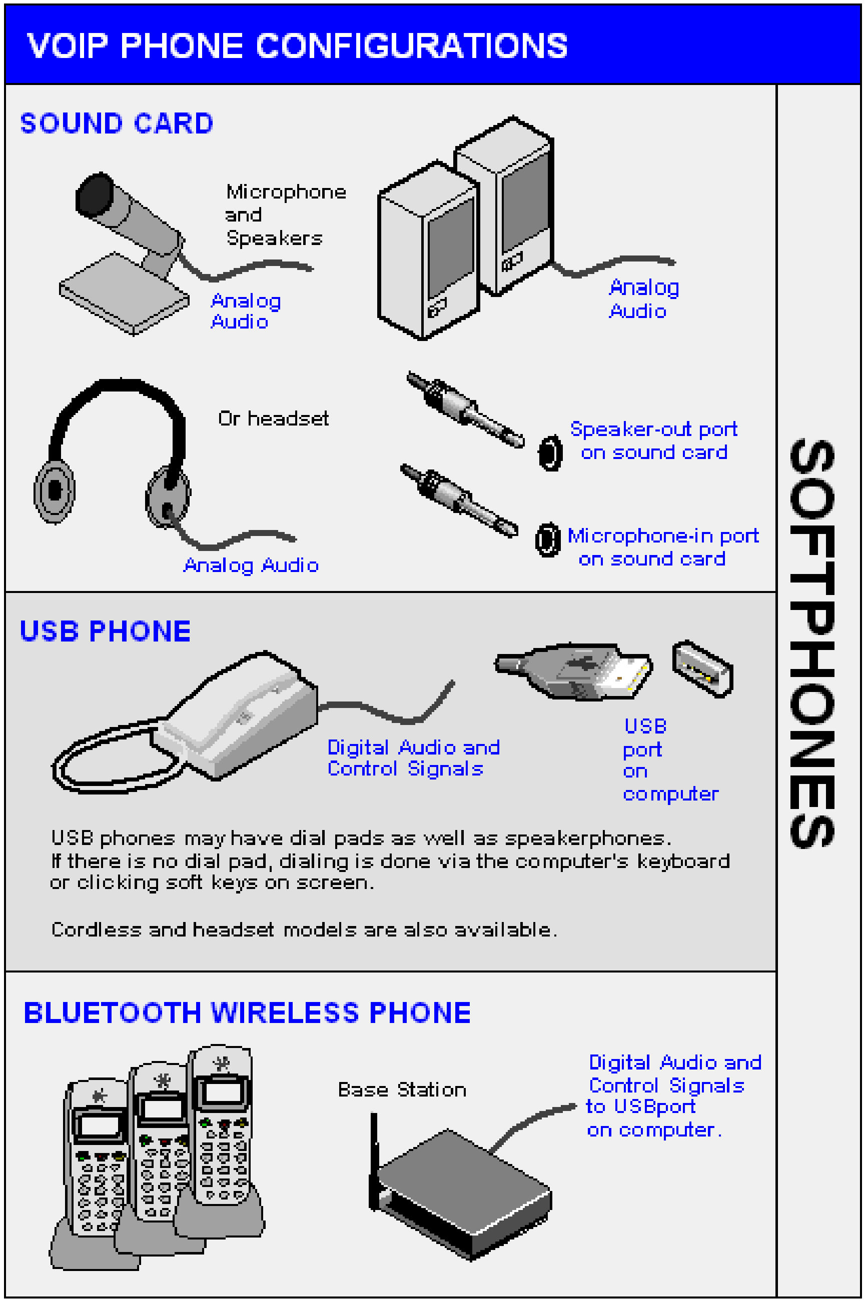
Referring to voice communications over the public Internet or any packet network employing the TCP/IP protocol suite. Specifically, VoIP operates in datagram mode, employing the Internet Protocol (IP) for addressing and routing, the User Datagram Protocol (UDP) for host-to-host data transfer between application programs, and the Real Time Transport Protocol (RTP) for end-to-end delivery services.

VoIP also typically employs sophisticated predictive compression algorithms, such as low delay code excited linear prediction (LD-CELP), to mitigate issues of latency and jitter over a packet-switched network.

2- VoiP

Softphone based

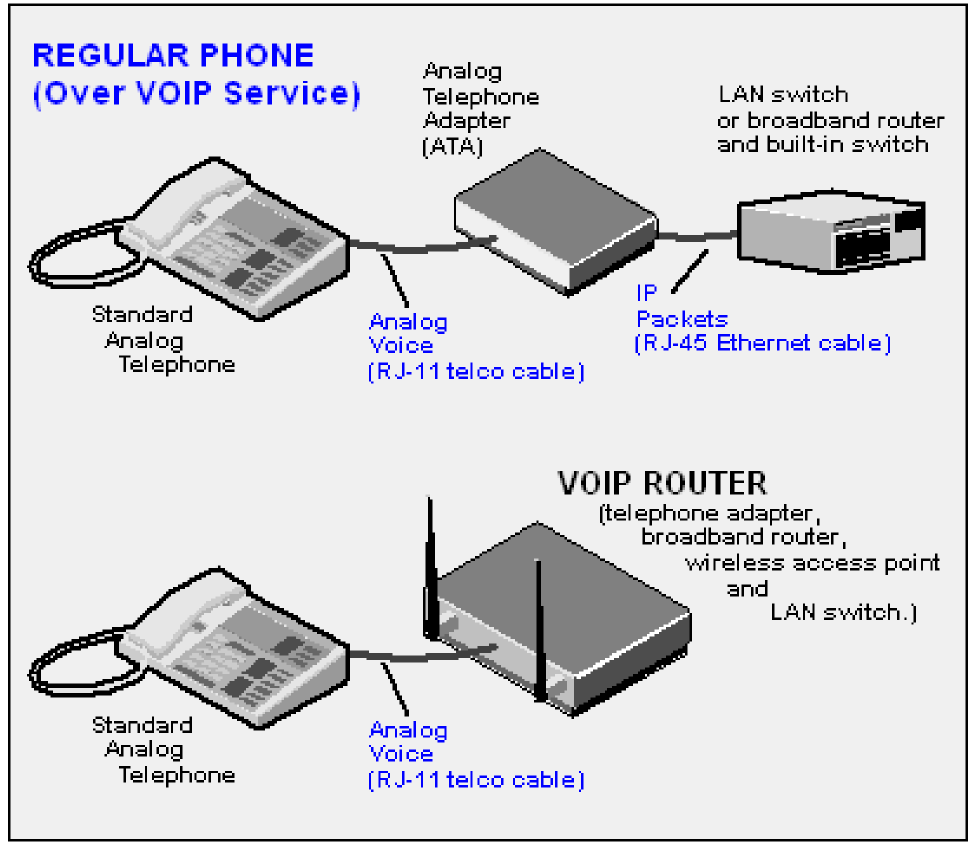
VoIP providers may be entirely softphone based, which requires a computer, phone software and microphone and speakers (or headset) to make and receive calls. Usually free of cost if both sides are on the same service, softphones let users call any phone in the world from their laptops and an Internet connection. Per-minute charges apply to call a regular phone number, but calls from a regular phone may not be possible



2- VoIP

Handset based

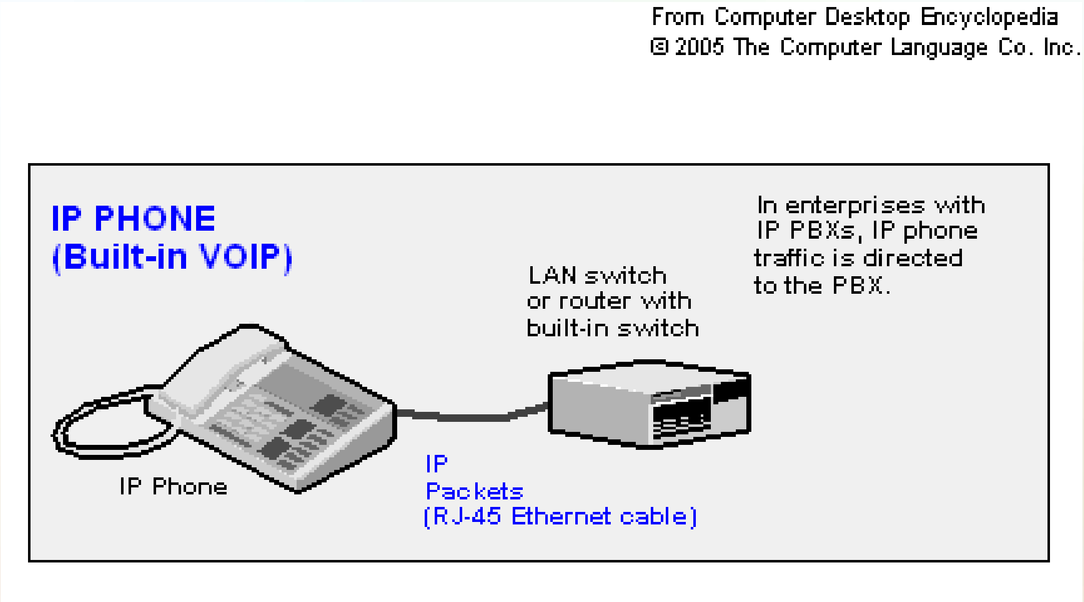
Regular phones can be used with many VoIP services by plugging them into an analog telephone adapter (ATA) provided by the VoIP provider or purchased from a third party. The ATA converts the phone to IP packets. IP phones can also be used that have built-in IP packet support.



2- VoiP

IP Phone Built in VoIP

IP Phones can be directly connected to the IP network.



2- IP Networks

TCP/IP Protocol

The immense influence of the Internet caused its communications protocol to become the world standard. Almost all networks, except for the circuit-switched networks of the telephone companies, have migrated to TCP/IP.

TCP/IP is a robust and proven technology that was first tested in the early 1980s on ARPAnet, the U.S. military's Advanced Research Projects Agency network, the world's first packet-switched network. TCP/IP was designed as an open protocol that would enable all types of computers to transmit data to each other via a common communications language.

2- IP Networks

Multiple Layers

TCP/IP is a layered protocol, which means that after an application initiates the communications, the message (data) to be transmitted is passed through a number of software stages, or layers, until it actually moves out onto the wire, or if wireless, into the air. The data are packaged with a different header at each layer. At the receiving end, the corresponding software at each protocol layer unpackages the data, moving it "back up the stack" to the receiving application.

TCP and IP

TCP/IP is composed of two parts: TCP (Transmission Control Protocol) and IP (Internet Protocol). TCP is a connection-oriented protocol that passes its data to IP, which is connectionless. TCP sets up a connection at both ends and guarantees reliable delivery of the full message sent. TCP tests for errors and requests retransmission if necessary, because IP does not.

2- IP Networks

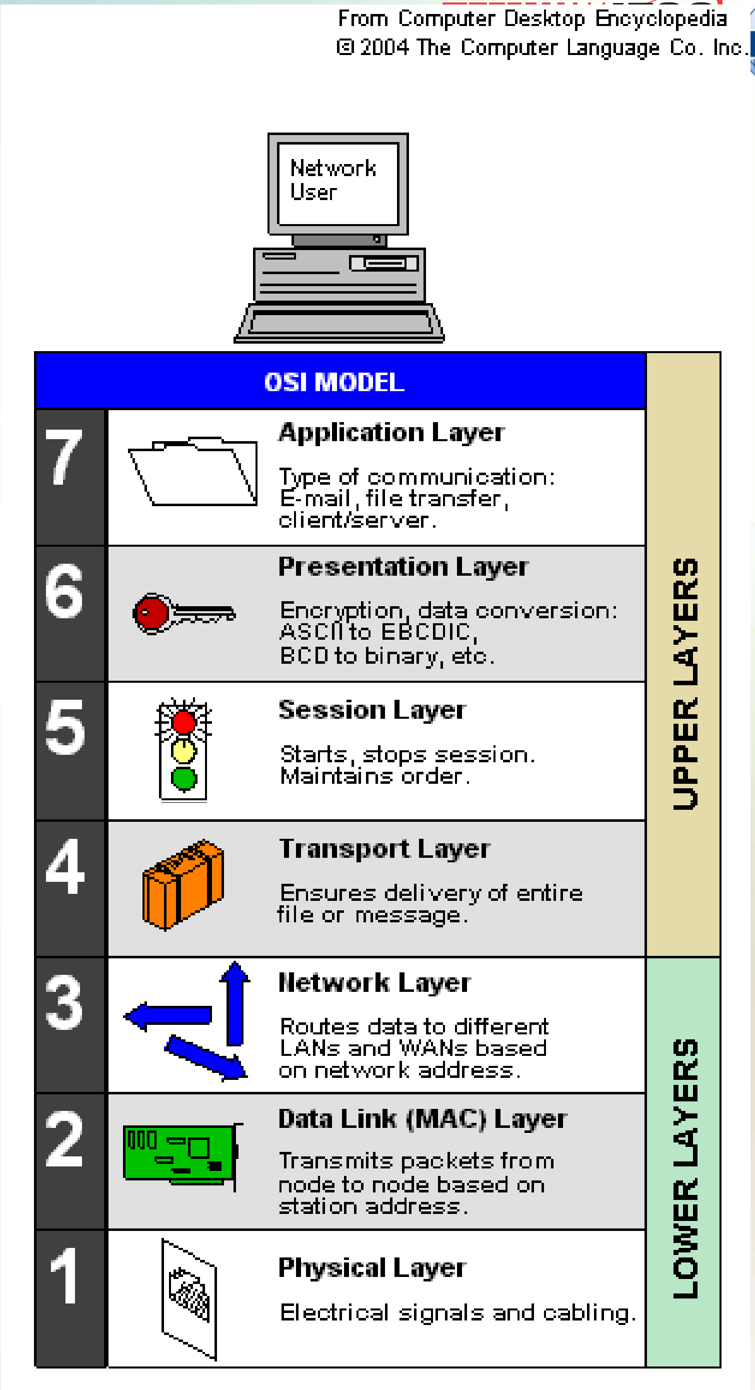
UDP

An alternative protocol to TCP within the TCP/IP suite is UDP (User Datagram Protocol), which does not guarantee delivery. Like IP, UDP is also connectionless, but very useful for transmitting audio and video that is immediately heard or viewed at the other end. If packets are lost in a UDP transmission (they can be dropped at any router junction due to congestion), there is neither time nor a need to retransmit them. A momentary blip in a voice or video transmission is not critical.

2- IP Networks

Upper Layers

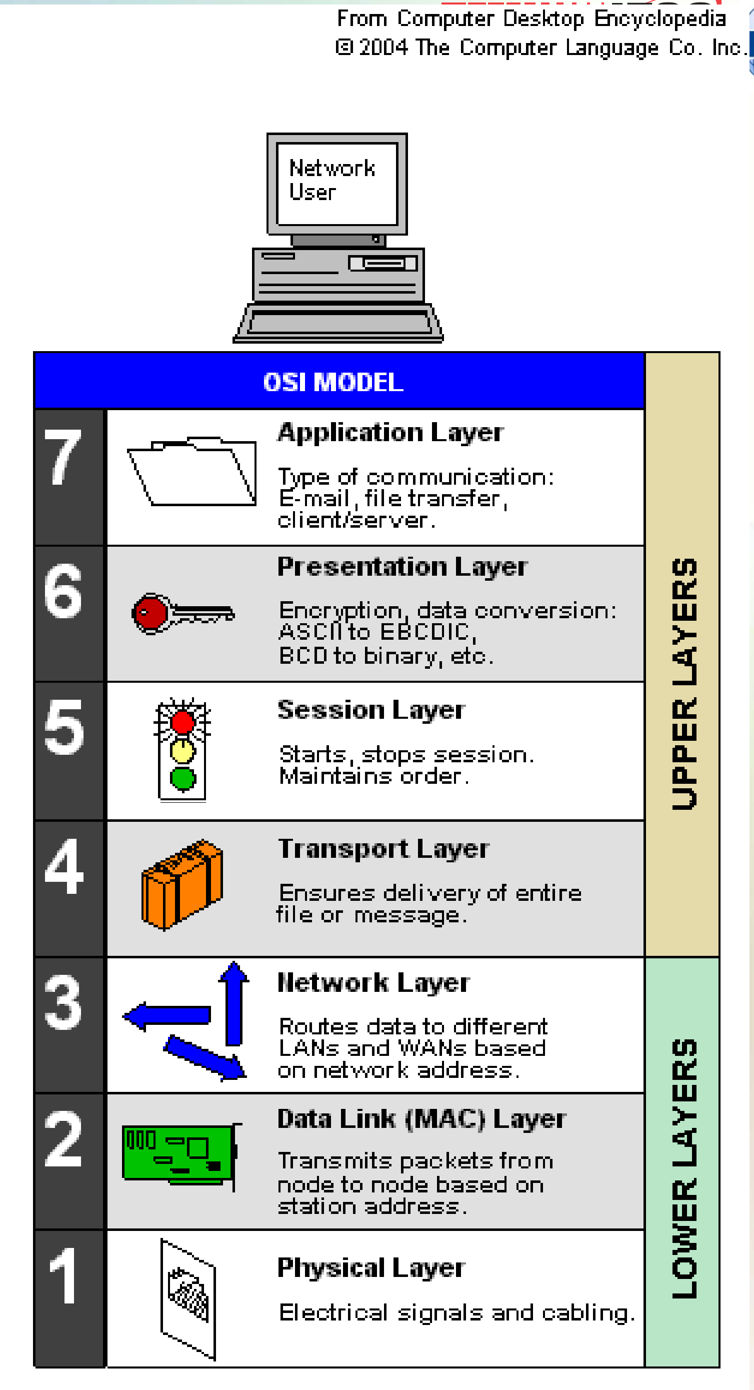
Layers 7 through 4 comprise the upper layers of the OSI protocol stack. They are more geared to the type of application than the lower layers, which are designed to move packets, no matter what they contain, from one place to another.



2- IP Networks

Application Layer 7

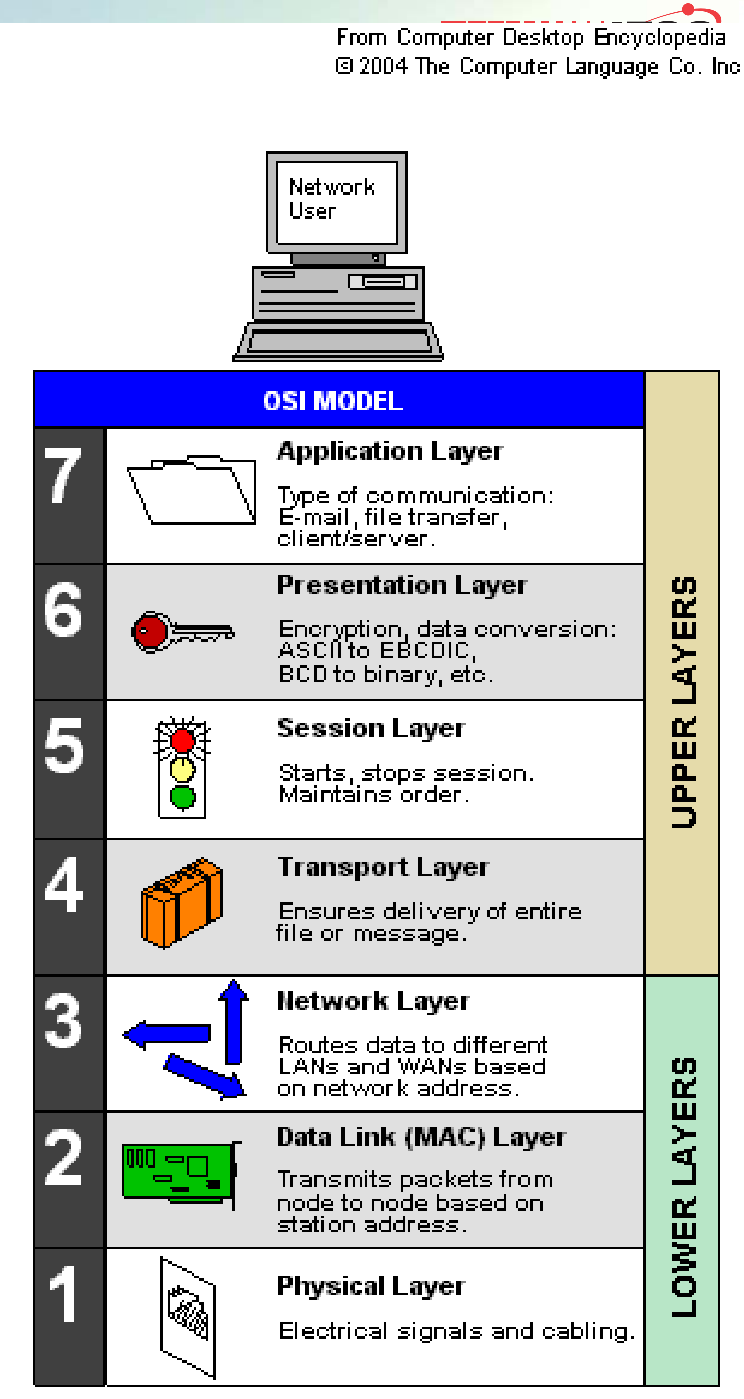
This top layer defines the language and syntax that programs use to communicate with other programs. The application layer represents the purpose of communicating in the first place. For example, a program in a client workstation uses commands to request data from a program in the server. Common functions at this layer are opening, closing, reading and writing files, transferring files and e-mail messages, executing remote jobs and obtaining directory information about network resources.



2- IP Networks

Presentation Layer 6

When data are transmitted between different types of computer systems, the presentation layer negotiates and manages the way data are represented and encoded. For example, it provides a common denominator between ASCII and EBCDIC machines as well as between different floating point and binary formats. Sun's XDR and OSI's ASN.1 are two protocols used for this purpose. This layer is also used for encryption and decryption.

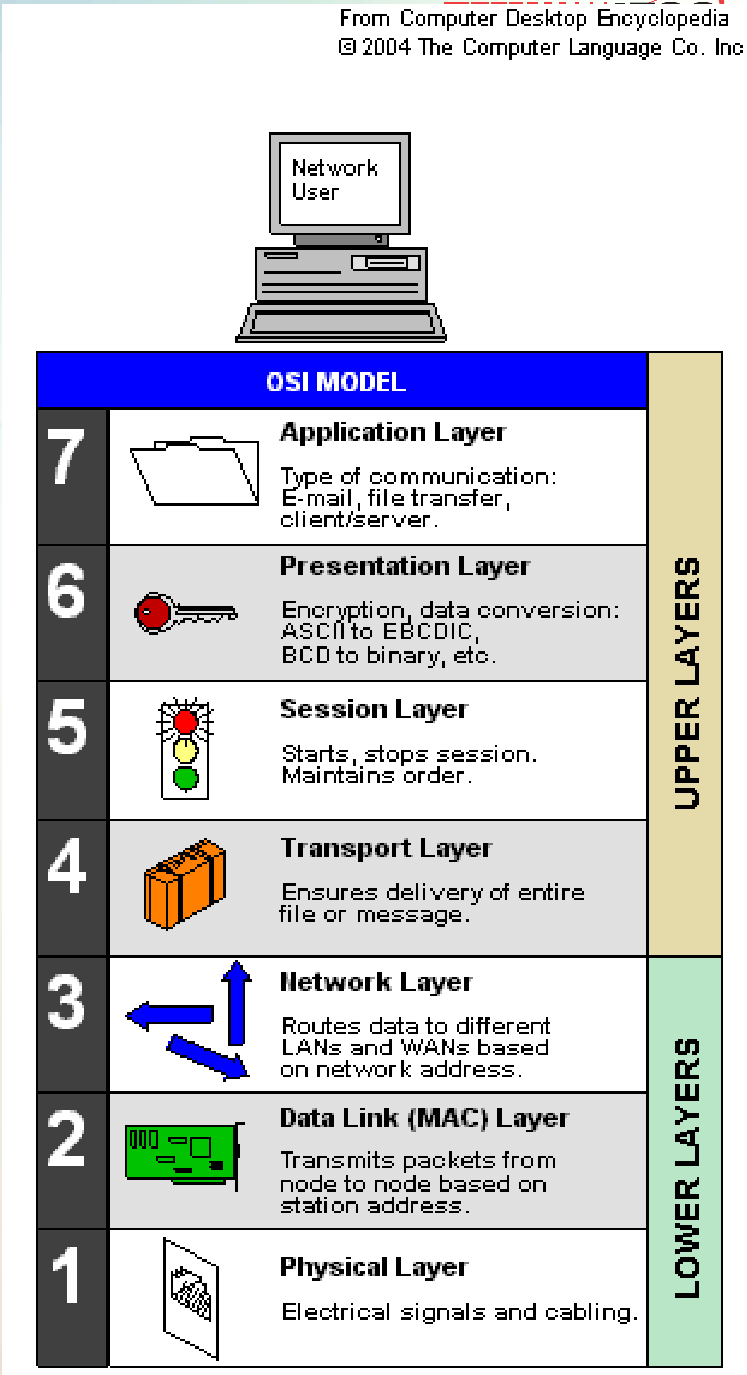


2- IP Networks

Session Layer 5

Provides coordination of the communications in an orderly manner. It determines one-way or two-way communications and manages the dialog between both parties; for example, making sure that the previous request has been fulfilled before the next one is sent. It also marks significant parts of the transmitted data with checkpoints to allow for fast recovery in the event of a connection failure.

In practice, this layer is often not used or services within this layer are sometimes incorporated into the transport layer.

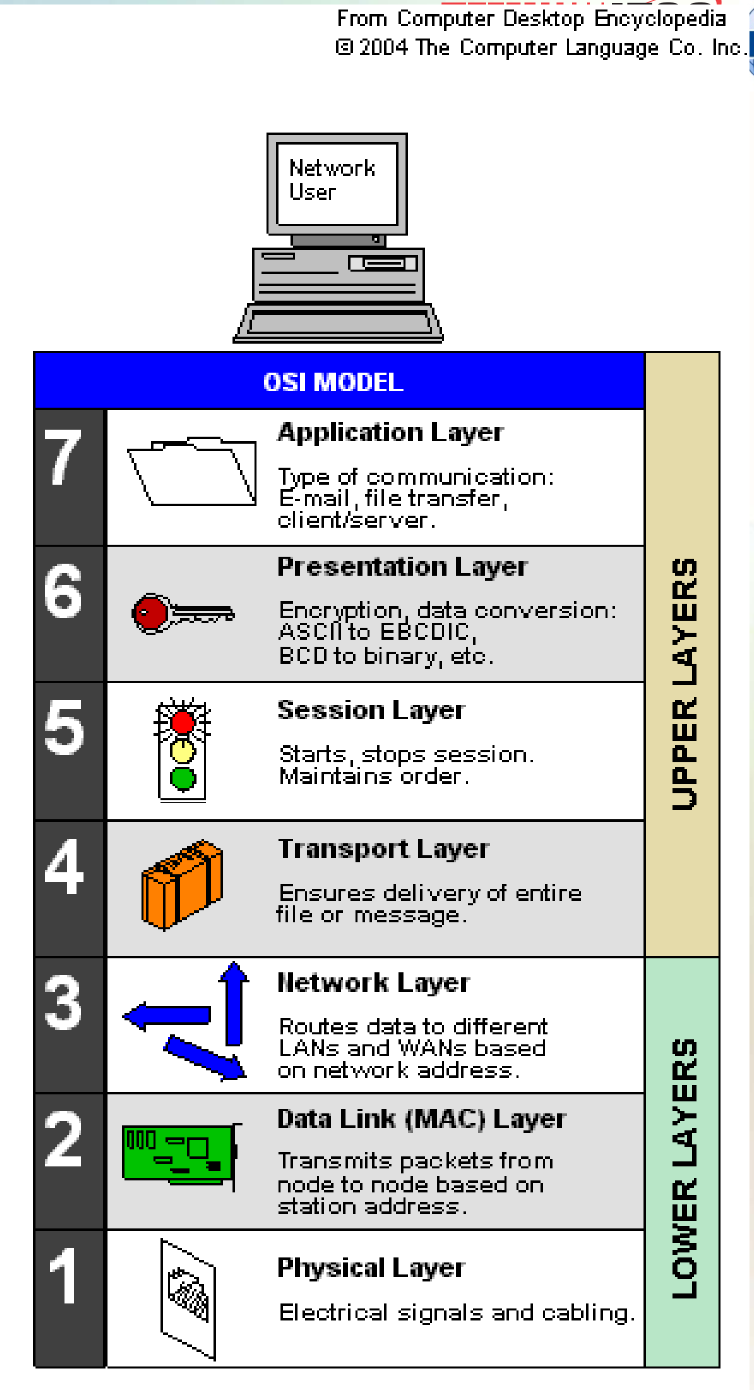


2- IP Networks

Transport Layer 4

This layer is responsible for overall end-to-end validity and integrity of the transmission. The lower layers may drop packets, but the transport layer performs a sequence check on the data and ensures that if a 12MB file is sent, the full 12MB is received.

"OSI transport services" include layers 1 through 4, collectively responsible for delivering a complete message or file from sending to receiving station without error.



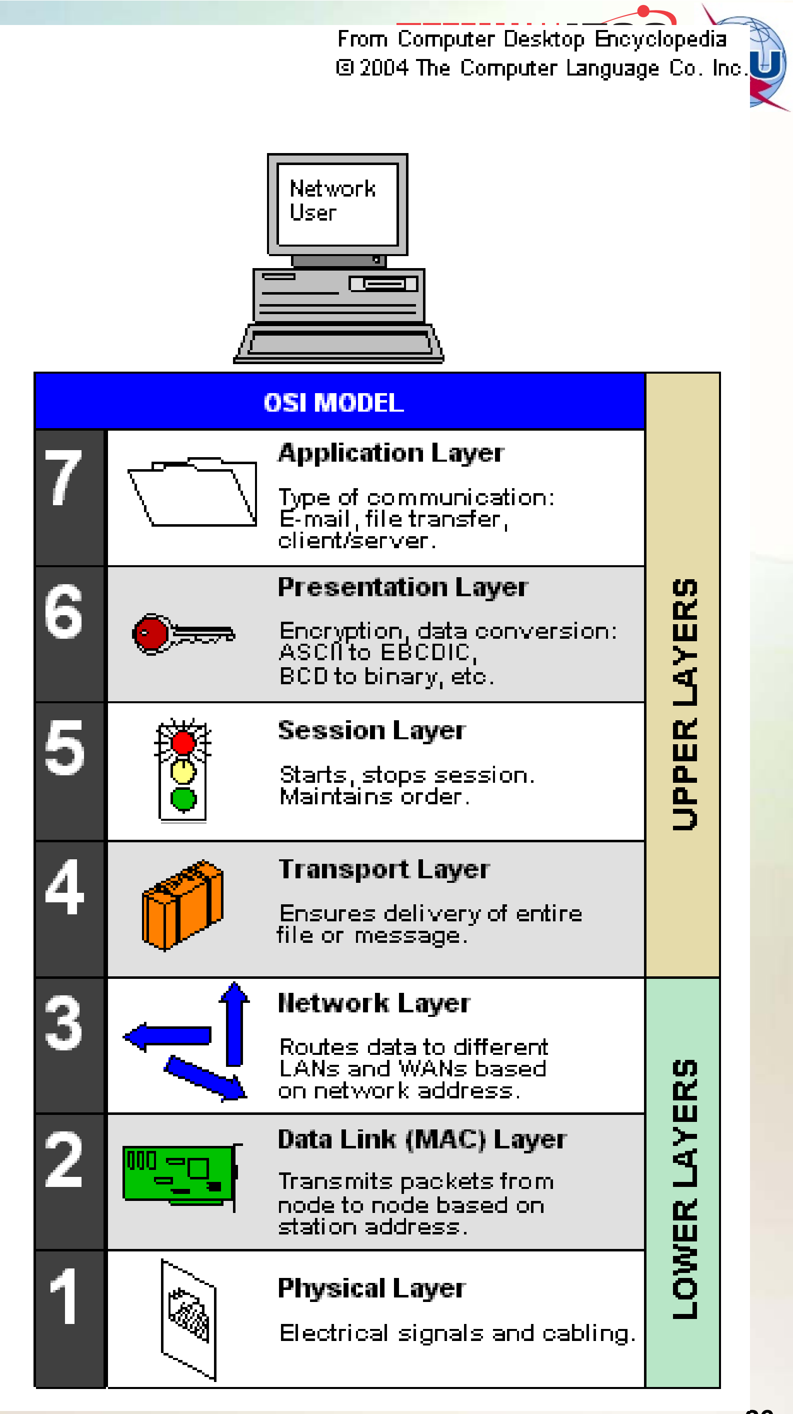
2- IP Networks

Lower Layers

Layers 3 through 1 are responsible for moving packets from the sending station to the receiving station.

Network Layer 3

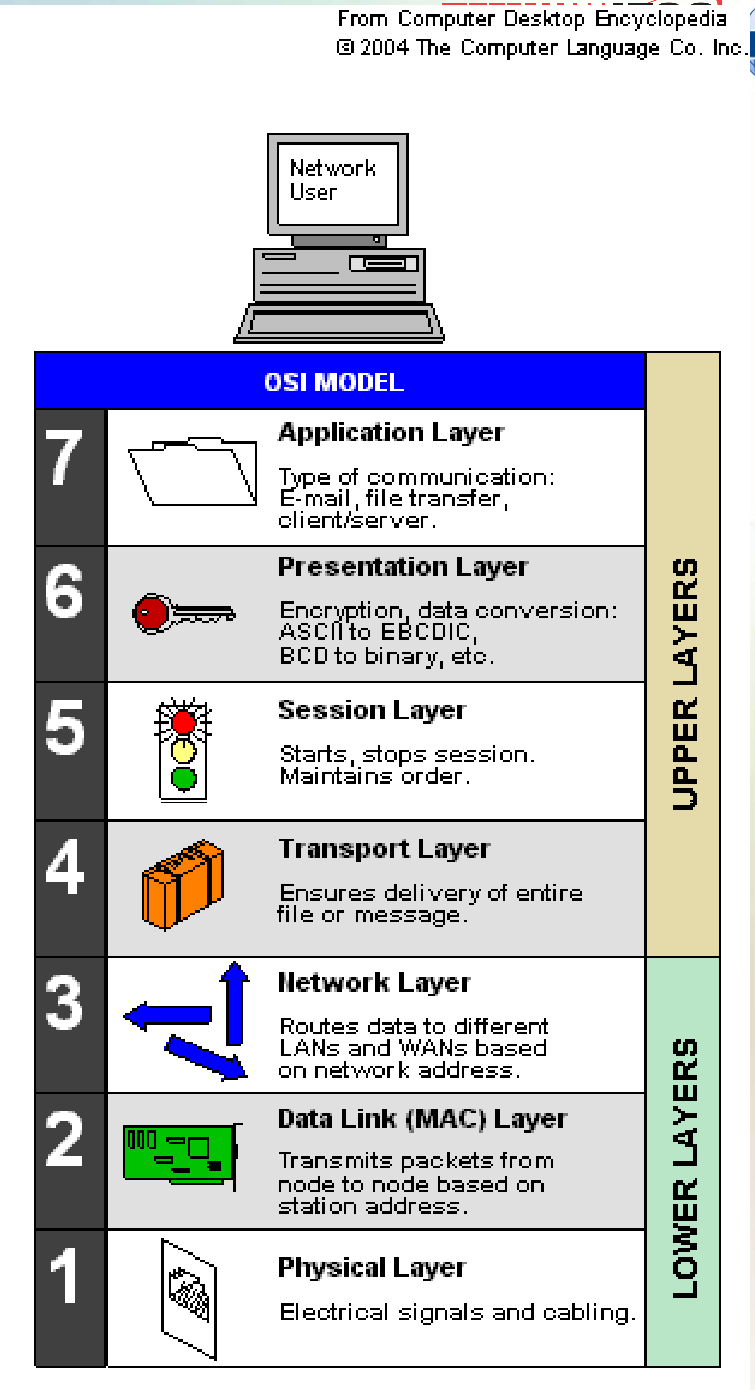
The network layer establishes the route between the sender and receiver across switching points, which are typically routers. The most ubiquitous example of this layer is the IP protocol in TCP/IP. IPX, SNA and AppleTalk are other examples of routable protocols, which means that they include a network address and a station address in their addressing system. This layer is also the switching function of the dial-up telephone system. If all stations are contained within a single network segment, then the routing capability in this layer is not required.



2- IP Networks

Data Link Layer 2

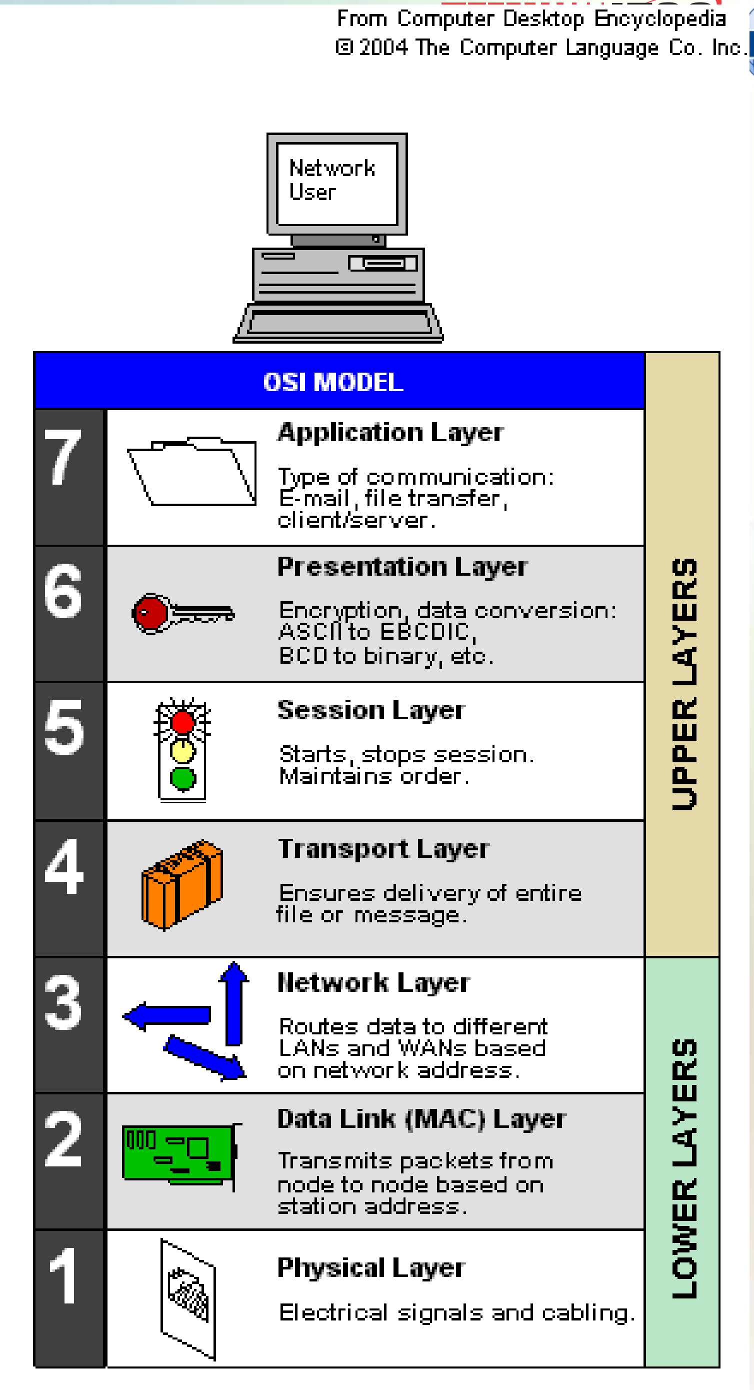
The data link is responsible for node to node validity and integrity of the transmission. The transmitted bits are divided into frames; for example, an Ethernet, Token Ring or FDDI frame in local area networks (LANs). Frame relay and ATM are also at Layer 2. Layers 1 and 2 are required for every type of communications.



2- IP Networks

Physical Layer 1

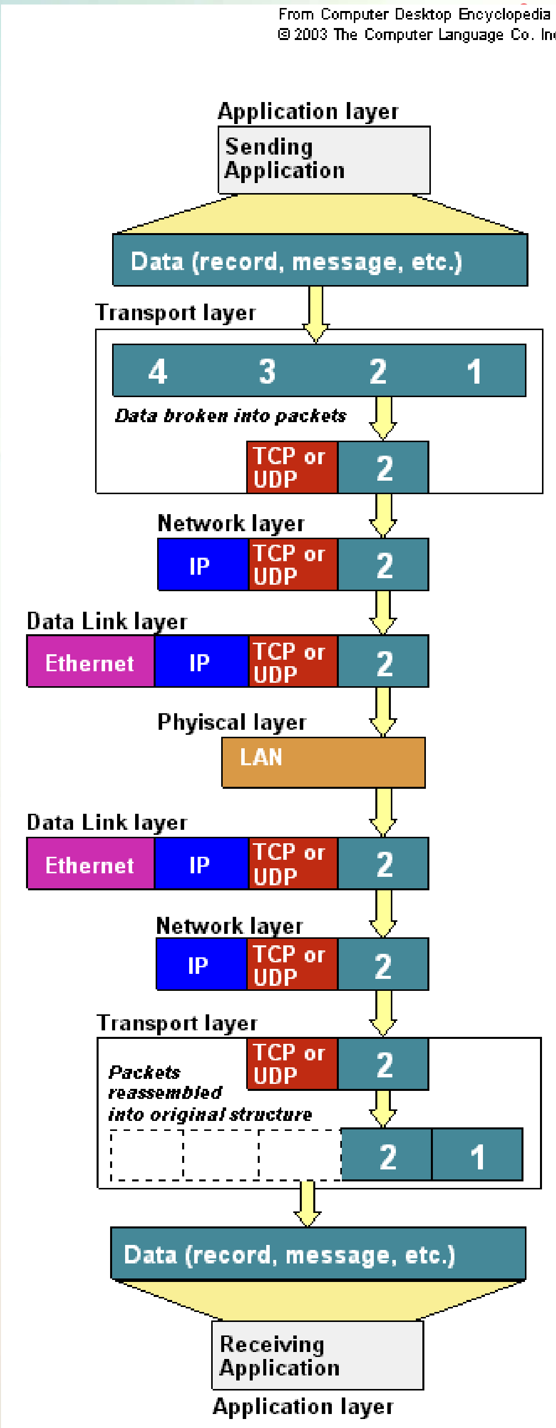
The physical layer is responsible for passing bits onto and receiving them from the connecting medium. This layer has no understanding of the meaning of the bits, but deals with the electrical and mechanical characteristics of the signals and signaling methods. For example, it comprises the RTS and CTS signals in an RS-232 environment, as well as TDM and FDM techniques for multiplexing data on a line. SONET also provides layer 1 capability.



2- IP Networks

The Protocol Stack

Using TCP/IP as a model, the sending application hands data to the transport layer, which breaks it up into the packets required by the network. It stores the sequence number and other data in its header. The network layer adds source and destination data in its header, and the data link layer adds station data in its header. On the other side, the corresponding layer reads and processes the headers and discards them.



3- C Band vs. Ku Band

C Band

The **C band** is a name given to certain portions of the electromagnetic spectrum, as well as a range of wavelengths of microwaves that are used for long-distance radio telecommunications. The IEEE C-band - and its slight variations - contains frequency ranges that are used for many satellite communications transmissions; by some Wi-Fi devices; by some cordless telephones; and by some weather radar systems. For satellite communications, the microwave frequencies of the C-band perform better in comparison with K_u band (11.2 GHz to 14.5 GHz) microwave frequencies, under adverse weather conditions, which are used by another large set of communication satellites. The adverse weather conditions all have to do with moisture in the air, such as during rainfalls, thunderstorms, sleet storms, and snowstorms.

- Downlink: 3.7 – 4.2 GHz
- Uplink: 5.9 – 6.4 GHz

3- C Band vs. Ku Band

C Band

C-Band Variations Around The World		
Band	Transmit Frequency (GHz)	Receive Frequency (GHz)
Extended C-Band	5.850–6.425	3.625–4.200
Super Extended C-Band	5.850–6.725	3.400–4.200
INSAT C-Band	6.725–7.025	4.500–4.800
Russian C-Band	5.975–6.475	3.650–4.150
LMI C-Band	5.7250–6.025	3.700–4.000

3- C Band vs. Ku Band

Ku Band

The **K_u band** is a portion of the electromagnetic spectrum in the microwave range of frequencies. This symbol refers to "K-under" (in the original German, "Kurz-unten", with the same meaning)—in other words, the band directly below the K-band. In radar applications, it ranges from 12 to 18 GHz according to the formal definition of radar frequency band nomenclature in IEEE Standard 521-2002.

- Downlink: 11.7 – 12.2 GHz
- Uplink: 14.0 – 14.5 GHz

3- C Band vs. Ku Band

Comparison between C Band and Ku Band

	Advantages	Disadvantages
C Band	✓ Less disturbance from heavy rain fade ✓ Cheaper Bandwidth	❖ Needs a larger satellite dish (diameters of minimum 2-3m) ❖ Powerful (=expensive) RF unit ❖ More expensive hardware ❖ Possible Interference from microwave links
Ku Band	✓ No interference from microwave links and other technologies ✓ Operates with a smaller satellite dish (diameters from 0.9m) -> cheaper and more easy installation ✓ Needs less power -> cheaper RF unit	❖ More expensive capacity ❖ Sensitive to heavy rain fade (significant attenuation of the signal) / possibly can be managed by appropriate dish size or transmitter power.

3- C Band vs Ku Band

Other frequency bands

L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
K_u band	12 to 18 GHz
K band	18 to 26.5 GHz
K_a band	26.5 to 40 GHz
Q band	30 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz
F band	90 to 140 GHz
D band	110 to 170 GHz

4- Satellite Network Topology

Topologies

Satellites networks have various topologies. We can enumerate the following :

- Star Networks
- Mesh Networks
- SCPC
- DVB
- Cellular backhaul

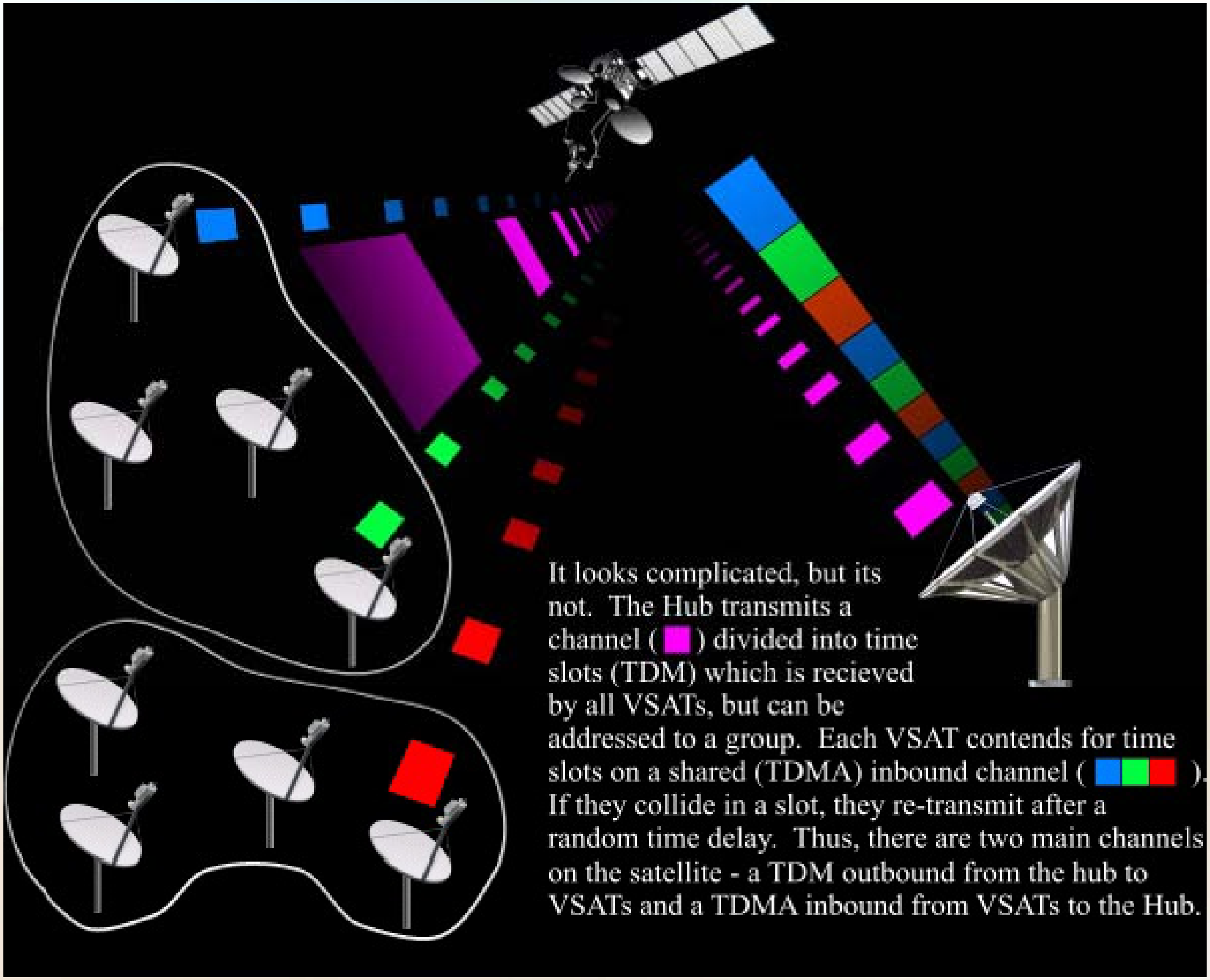
4- Satellite Network Topology

Star Network

This is how a star data, TDM/TDMA VSAT network works using a hub station, usually six metres or more in size and small VSAT antennas (between 75 centimetres and 2.4 metres). All the channels are shared and the remote terminals are online, offering fast response times. Historically, TDM/TDMA systems competed with terrestrial X.25 or frame relay connections, but as VSAT transmit data rates have risen to 2 Mbps or more and receive rates begin approaching 100 Mbps DSL and MPLS services have become the main competitors in most markets.

4- Satellite Network Topology

Star Network



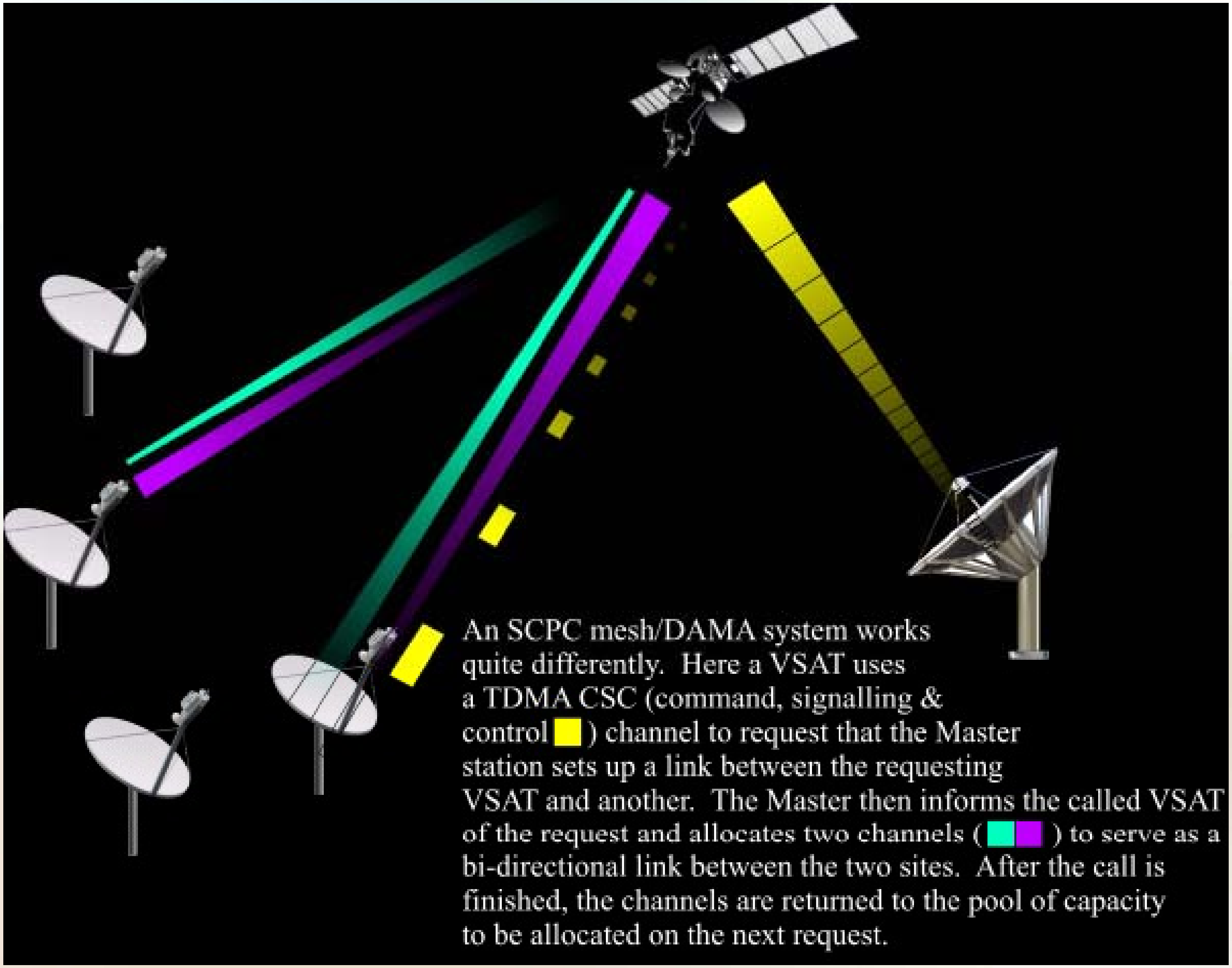
4- Satellite Network Topology

Mesh Network

However, mesh networks which use capacity on a demand assigned multiple access (DAMA) basis take a different approach. The master control station merely acts as a controller and facilitator rather than a hub through which traffic passes as in a star network. However, these connections take a little time to set-up and thus, mesh/DAMA systems are often equated to a terrestrial dial-up connection.

4- Satellite Network Topology

Mesh Network



4- Satellite Network Topology

Mesh Network

There are also mesh systems which use a TDMA access scheme where all of the terminals in a network receive and transmit to the same channel, selecting different time slots because each terminal is aware of what the others have reserved. In the past this type of system has been costly and therefore, reserved for large scale trunking applications, but, more recently, costs have come down considerably and now they can be cost competitive with SCPC/DAMA systems for thin route applications as well.

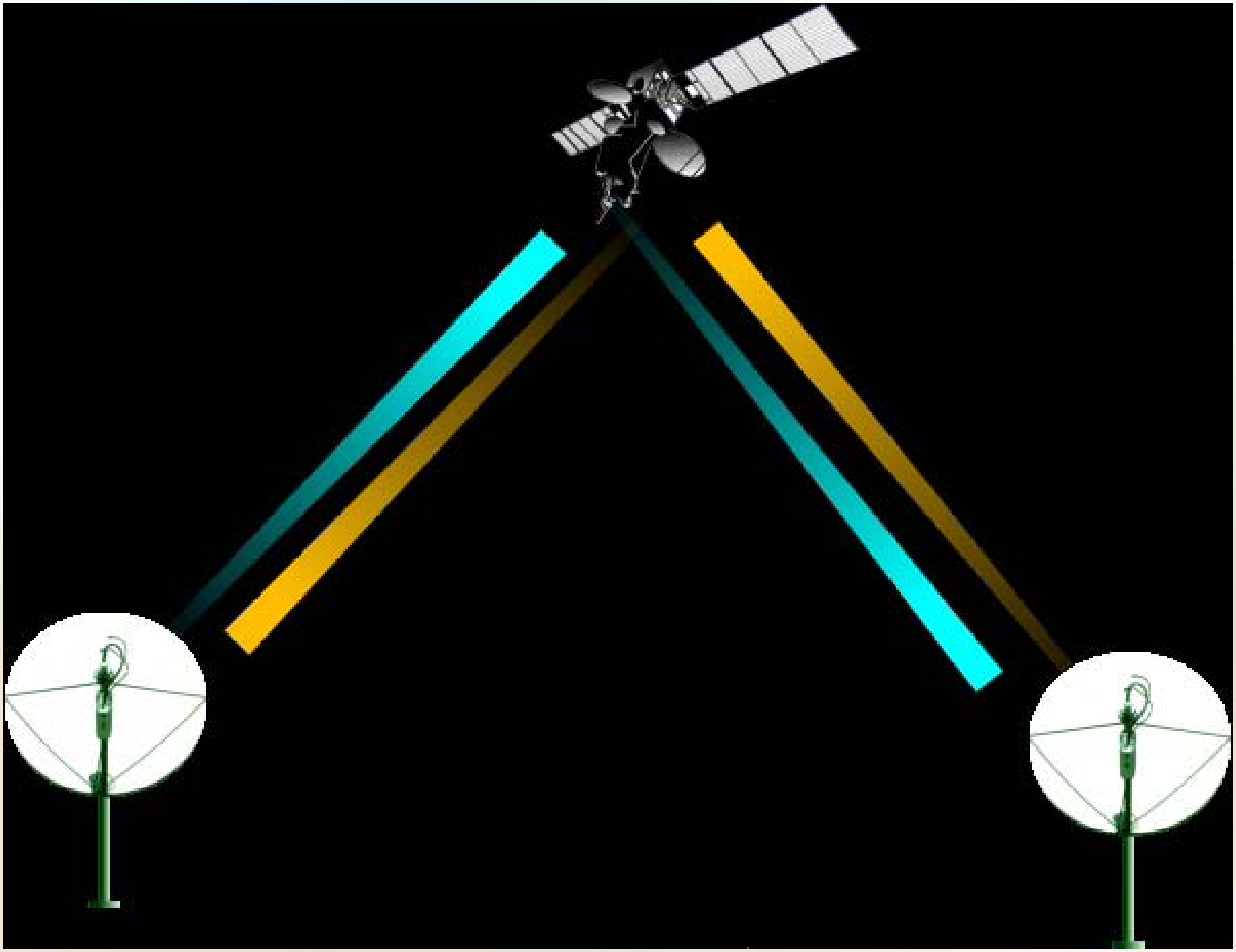
4- Satellite Network Topology

SCPC Network

Point-to-point SCPC (single channel per carrier) links are the satellite equivalent of a terrestrial leased line connection. They are usually set-up on a permanent, 24 hour basis and are thus more costly in satellite capacity and less efficient if not used all the time. However, they do support dedicated high bandwidth links without any sharing or contention. Typically we only classify terminals running rates from 9.6 kbps to 2 Mbps as VSATs (any) and can easily be used to carry data, voice and even video traffic.

4- Satellite Network Topology

SCPCNetwork



4- Satellite Network Topology

Other Networks

All other systems are usually a variation on one of the themes described above, either in a star, mesh or hybrid (star and mesh) configuration. Most of the TDM/TDMA manufacturers also offer a mesh product which can be deployed in a hybrid-ised configuration, sharing common components such as antennas and RF units, at a remote site.

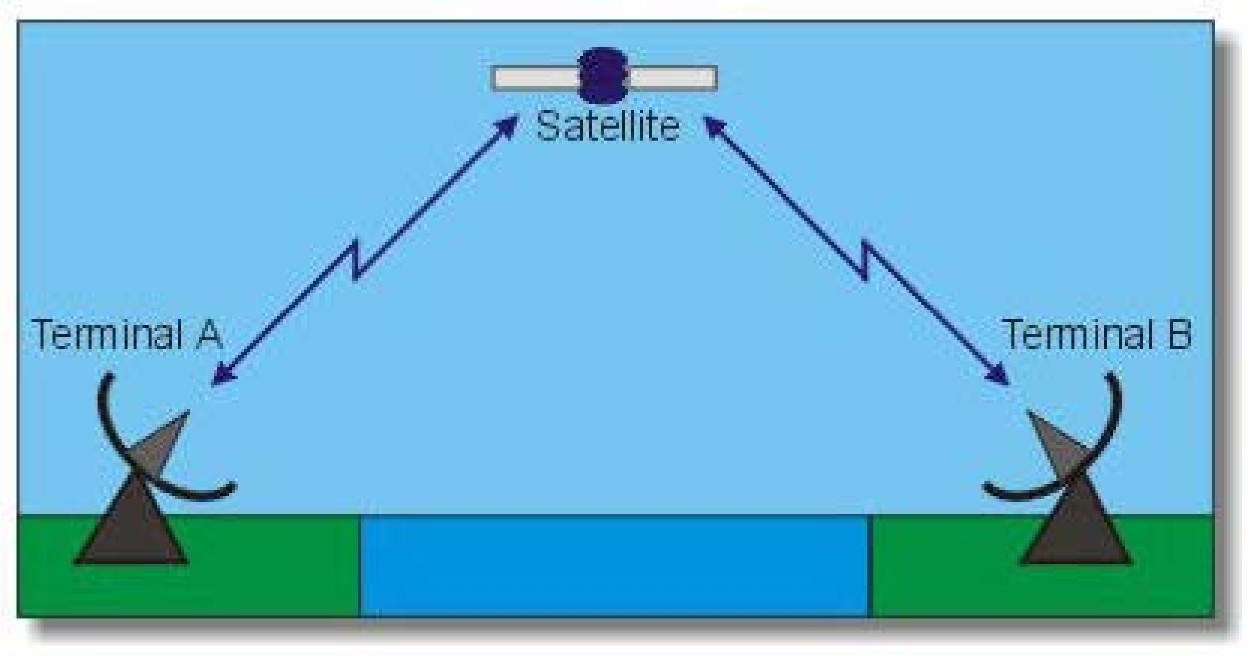
5- Link Budget Analysis and Design

Satellite link budget objective

The first step in designing a satellite network is performance of a satellite link budget analysis. The link budget will determine what size antenna to use, SSPA or TWTA PA power requirements, link availability and bit error rate, and in general, the overall customer satisfaction with your work.

5- Link Budget Analysis and Design

Sample



5- Link Budget Analysis and Design

Understand Link budget

A satellite link budget is a listing of all the gains and losses that will affect the signal as it travels from the spacecraft to the ground station. There will be a similar list of gains and losses for the link from the ground station to the satellite. Link budgets are used by the system engineers to determine the specifications necessary to obtain the desired level of system performance. After the system has been built, the link budget is invaluable to the maintenance personnel for isolating the cause of degraded system performance.

5- Link Budget Analysis and Design

Understand Link budget

None of the components of a link is fixed, but instead will have some variation. The link budget must account for this. Typically the variables will be listed with a maximum and minimum value or with a nominal value plus a tolerance. The design engineer will allocate signal power to each variable so that the variations don't result in unacceptable signal fade. It is usually too expensive to build a system that will work with the worst case scenario for all variables, so it is the engineer's job to find an acceptable balance between cost and link availability. The maintenance engineer must also be aware of the variations so that he can properly differentiate between expected link degradation and a link failure.

5- Link Budget Analysis and Design

Understand Link budget

The satellite link is composed of many variables and it's important to understand when specific variables need to be included and when they can be ignored. In this tutorial we will discuss the most common variables and provide guidelines to help determine when they can be ignored.

The first variable in our link budget will be the spacecraft EIRP. This is the power output from the spacecraft. All other variables will be gains or losses that will be added or subtracted from the EIRP. Variations in the EIRP are normally pretty small and can be ignored by the maintenance engineer once the nominal EIRP is known. There may be small variations due to temperature and a larger change can be expected if the spacecraft configuration is changed, such as switching to a backup HPA.

5- Link Budget Analysis and Design

Understand Link budget

Path loss (L_{path}) is the amount of signal attenuation due to the distance between the satellite and the ground station. This is the largest loss in the link. For example, the path loss for an S band signal from a geosyncronous satellite will be about 192 dB. Path loss varies with distance and frequency. The greater the distance, the greater the path loss. Higher frequencies suffer more loss than lower frequencies. Thus the path loss will be greater for a Ku band signal than for an S band signal at the same distance. For a geosyncronous satellite, the distance between the satellite and the ground station varies slightly over a 24 hour period. This variation may be important to the design engineer, but the maintenance engineer can usually work with a fixed average value for the path loss. For a low earth orbit (LEO) satellite the distance between the satellite and ground station is constantly changing. The maximum and minimum path loss will be important to both the design engineer and the maintenance engineer.

5- Link Budget Analysis and Design

Understand Link budget

The next loss we'll consider is the polarization loss (L_{pol}). The transmitting and receiving antennas are usually polarized to permit frequency reuse. Satellite links usually employ circular polarization, although linear polarization is occasionally used. In the case of circular polarization, the design engineer will use the axial ratio of the transmit and receive antennas to determine the maximum and minimum polarization loss. The maximum loss is usually small enough (0.3 dB typically) to be ignored by the maintenance engineer. There are, however, a couple of special cases that the maintenance engineer will need to keep in mind. If the ground antenna is capable of being configured for either LHCP or RHCP, a misconfiguration of the polarization will result in a significant loss, on the order of 20 dB or more. Also, polarization is affected by atmospheric conditions. If there is rain in the area, polarization loss may increase. More information on this is provided in the discussion of rain fade.

5- Link Budget Analysis and Design

Understand Link budget

Pointing loss (L_{point}) is the amount of signal loss due to inaccurate pointing of the antennas. To determine the expected amount of pointing loss, the design engineer will consider such things as antenna position encoder accuracy, resolution of position commands, and autotrack accuracy. The pointing accuracy of both the spacecraft antenna and the ground station antenna must be considered, although they may both be combined into one entry in the link budget. Pointing loss will usually be small, on the order of a few tenths of a dB. This is small enough for the maintenance engineer to ignore under normal circumstances. However, pointing loss is one of the most common causes of link failure. This is usually due to inaccurate commanded position of the antenna, but can also be caused by a faulty position encoder.

5- Link Budget Analysis and Design

Understand Link budget

Atmospheric loss (L_{atmos}) is the amount of signal that is absorbed by the atmosphere as the signal travels from the satellite to the ground station. It varies with signal frequency and the signal path length through the atmosphere, which is related to the elevation angle between the ground station and the spacecraft. Theoretically, the amount of signal absorbed by rain could also be considered an atmospheric loss, but because rain fade can be quite large and unpredictable, it is given its own variable in the link budget. In general, atmospheric loss can be assumed to be less than 1 dB as long as the look angle elevation from the ground station is greater than 20 degrees.

5- Link Budget Analysis and Design

Understand Link budget

Rain fade is a unique entry in the link budget because it is derived from the system specification instead of being dependent on the natural elements of the link. The actual rain fade on a link can be quite large and unpredictable. It probably isn't practical to attempt to design a link that will perform to specifications under worst case rain conditions. Instead, the system specification might specify the amount of rain fade that the system must be able to tolerate and still meet the performance specifications. Specified rain fade is typically in the range of 6 dB. Therefore the link budget will list a maximum rain fade of 6 dB and a minimum of 0 dB. If the link is designed to this budget, it will have an additional 6 dB of link margin to compensate for a rain fade

5- Link Budget Analysis and Design

Understand Link budget

The variables we've discussed so far (EIRP, path loss, polarization loss, pointing loss, atmospheric loss, rain fade) are sufficient to define the signal power level at the ground station. The power would be shown by:

$$\text{Power Level} = \text{EIRP} - L_{path} - L_{pol} - L_{point} - L_{atmos} - \text{rain fade}$$

5- Link Budget Analysis and Design

Understand Link budget

The last two items we're going to include in our link budget are the ground station antenna and LNA. These two items aren't really variables, but are constants that the design engineer will select. Based on the power level indicated by the link budget and the carrier to noise requirement indicated by the system specs, the engineer will select an antenna/LNA pair that will amplify the signal sufficiently for further processing without adding more noise than the system spec allows. The antenna gain and the LNA noise will be combined into a single parameter called the "*gain over noise temperature*", or G/T . This will be the final entry in our link budget.

5- Link Budget Analysis and Design

Understand Link budget

The carrier to noise ratio C/N0 for the link can now be calculated as:

$$C/N0 = EIRP - L_{path} - L_{pol} - L_{point} - L_{atmos} - \text{rain fade} + G/T - \text{Boltzmann's Constant}$$

This completes the link budget for the space to ground link. A link budget for the ground to space link would be composed of the same variables. The variables would need to be updated for the uplink frequencies, the G/T would be the spacecraft G/T, and the ground station design engineer would then select the ground station EIRP required to meet system specs.

5- Link Budget Analysis and Design

Understand Link budget

Boltzmann's Constant (k) Amount of noise power contributed by 1 degree of temperature, kelvin.

k = 1.38 * 10^(-23) Watt-second/K

or

-228.6 dBw/Hz

Satellite Link Design – Example of Satellite Link Budget

Table 1 C-band GEO Satellite link budget in clear air. [1]

C-band satellite parameters		
	Transponder saturated output power	20 W
	Antenna gain, on axis	20 dB
	Transponder bandwidth	36 MHz
	Downlink frequency band	3.7–4.2 GHz
Signal	FM-TV analog signal	
	FM-TV signal bandwidth	30 MHz
	Minimum permitted overall C/N in receiver	9.5 dB
Receiving C-band earth station		
	Downlink frequency	4.00 GHz
	Antenna gain, on axis, 4 GHz	49.7 dB
	Receiver IF bandwidth	27 MHz
	Receiving system noise temperature	75 K
Downlink power budget		
	P_t = Satellite transponder output power, 20 W	13.0 dBW
	B_o = Transponder output backoff	−2.0 dB
	G_t = Satellite antenna gain, on axis	20.0 dB
	G_r = Earth station antenna gain	49.7 dB
	L_p = Free space path loss at 4 GHz	−196.5 dB
	L_{ant} = Edge of beam loss for satellite antenna	−3.0 dB
	L_a = Clear air atmospheric loss	−0.2 dB
	L_m = Other losses	−0.5 dB
	P_r = Received power at earth station	−119.5 dBW
Downlink noise power budget in clear air		
	k = Boltzmann's constant	−228.6 dBW/K/Hz
	T_s = System noise temperature, 75 K	18.8 dBK
	B_n = Noise bandwidth, 27 MHz	74.3 dBHz
	N = Receiver noise power	−135.5 dBW
C/N ratio in receiver in clear air		
	$C/N = P_r - N = -119.5 \text{ dBW} - (-135.5 \text{ dBW}) = 16.0 \text{ dB}$	

Table 2 C-band GEO Satellite link budget in rain. [1]

	P_{rca} = Received power at earth station in clear air	−119.5 dBW
	A = Rain attenuation	−1.0 dB
	P_{rain} = Received power at earth station in rain	−120.5 dBW
	N_{ca} = Receiver noise power in clear air	−135.5 dBW
	ΔN_{rain} = Increase in noise temperature due to rain	2.3 dB
	N_{rain} = Receiver noise power in rain	−133.2 dBW
C/N ratio in receiver in rain		
	$C/N = P_{rain} - N_{rain} = -120.5 \text{ dBW} - (-133.2 \text{ dBW}) = 12.7 \text{ dB}$	

End of Day 3 course

Transmission and Network Planning

Link Budget Analysis and Design