20CYS301
Digital Communications
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Administration Matters
History
Introduction to Communication Systems

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I. History

History of Communications [1/6]

1864
James Clerk Maxwell

*Postulated **EM theory of light,** predicted existence of **radio waves** & gave the eponyomous **EM equations***

1884
Henrich Herz

*Demonstrated the existence of **radio waves** empirically*

1894-1900
Jagadish Chandra Bose

*Invented **WiFi technology** through work on detecting, generating & transmitting radio waves*

1901
Guglielmo Marconi

*Transceived the 1st **transatlantic radio signal** from Cornwall, England, to Newfoundland, Canada across c3,400 km*

1906
Reginald Fessenden

*1st radio broadcast that voice & music using what came to be known as **amplitude modulation (AM)***

1924
Harry Nyquist

*What is the **max signalling rate achievable over a fixed bandwidth channel for a given pulse shape** with 0 intersymbol interference*

History of Communications [2/6]

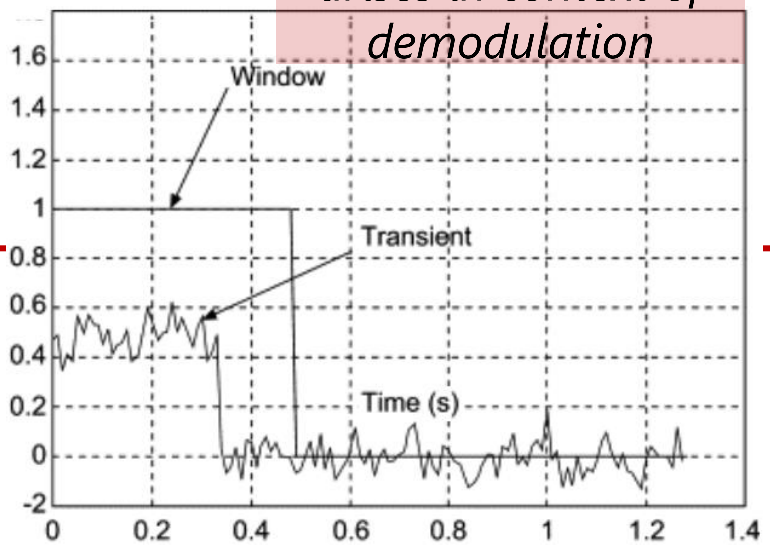
1928
Ralph Hartley

*What is the **max data rate** under Nyquist conditions **when using multiple bits/symbol** under amplitude accuracy of A_δ?*

1939
Kolmogorov

*Limits to **inferring the waveform** from a received signal in the presence of additive nose **[optimum Kolmogorov-Wiener linear filter]***

arises in context of demodulation



1948
Claude Shannon

*Defined **channel capacity** to capture extractable info content given received power & max bandwidth constraint & additive noise power*

1949
Marcel Golay

*Designed first nontrivial **error correction codes** for lossy channels*

History of Communications [3/6]

1950
Richard Hamming

*Hamming codes - a family of **linear error-correcting codes***

1954
Narinder Singh Kampani

***Father of fibre optics** – invented fibre optics cables to transmit optical images along a flexible axis*

1962
Robert Gallager

*Invented **Low Density Parity Check (LDPC) codes** which allow noise to approach max Shannon-allowable levels without information loss*

1971
US Defense Research

***ARPANET** – the precursor to the internet.*

1985
-

*ARPANET renamed as **'Internet'***

1988
Europe: Civilian Bureaucracy

Global System for Mobile (GSM) standard for digital cellular communications

History of Communications [4/6]

1990
Berners Lee

*Proposed a **software interface to the internet***

1993
Glavieux Berrou & Thitimjshima

***Turbo Codes** have near-optimum EC coding & decoding performance in AWGN. E.g. used in 4G*

1994
Corporations

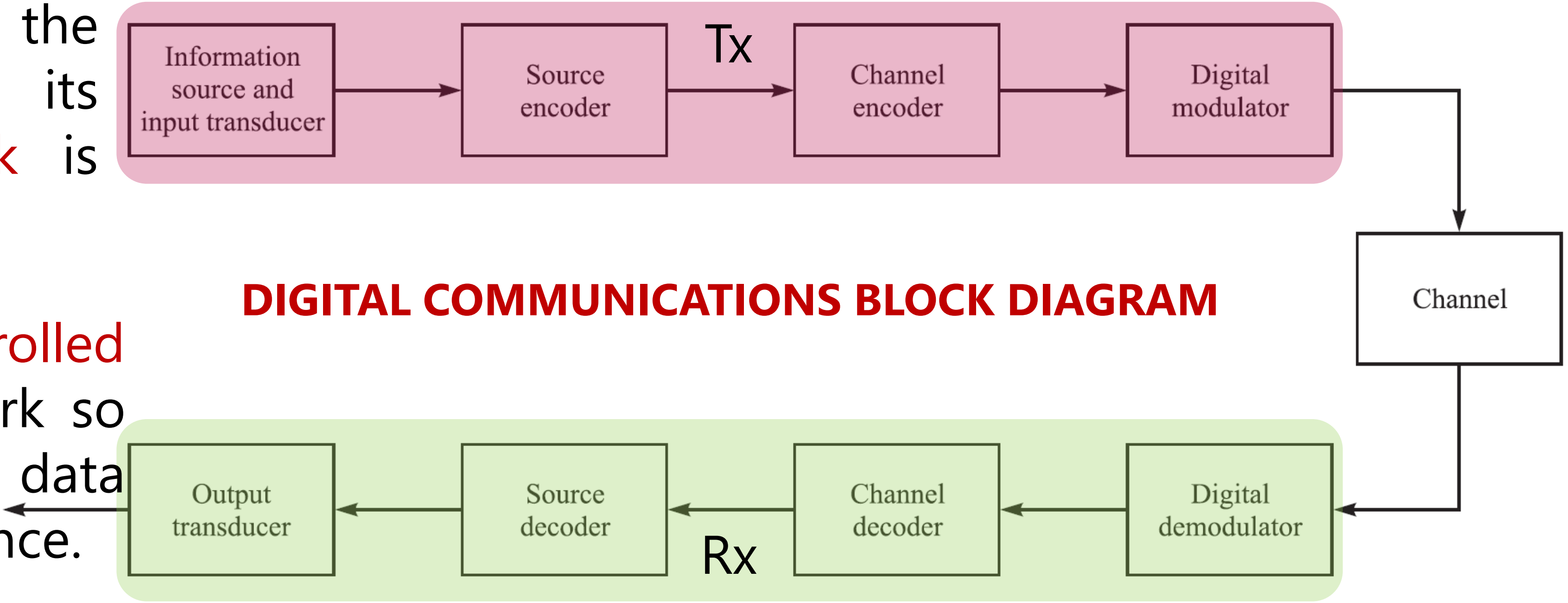
*Within 2 years of when it was proposed, the **World Wide Web** went from non-existent to global popularity*

II. Overview

Overview [1/17]

Source encoder: compresses the input data to reduce its redundancy. Source codework is the output symbol sequence.

Channel encoder: adds controlled redundancy to source codework so that the Rx can autocorrect the data despite channel noise/interference.



Channel codework is the output symbol sequence upon channel encoding. Some of the channel codes are *LDPC codes*, *Turbo codes*, *Convolution codes*, and *Reed-Solomon codes*.

The channel codework is dispatched to **Channel modulator.** The modulator converts each symbol in the channel codeword to one of the finite elements in a digitized version of an analog value set. The output sequence of channel modulator is called waveform. Some of the modulation techniques are *m-ary PSK, FSK, ASK & QAM.*

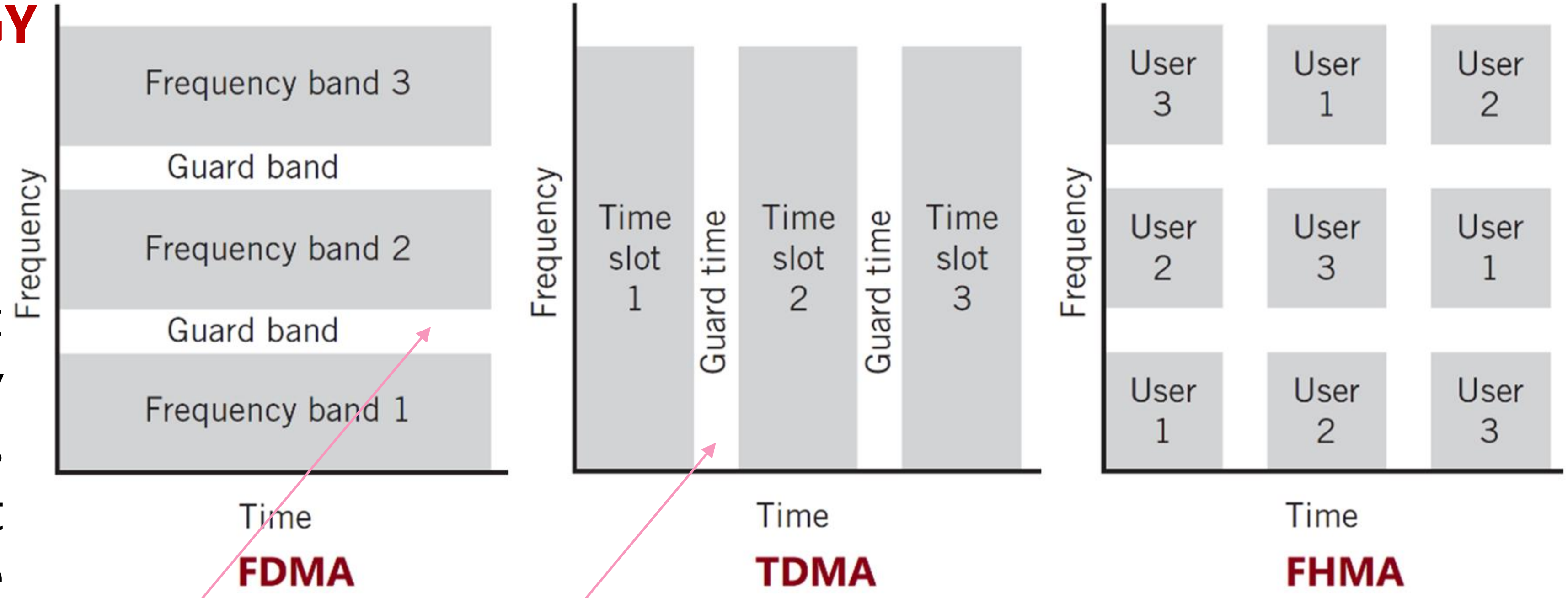
The processes are reversed at the receiver.

Overview [2/17]

COMMUNICATION TOPOLOGY

1. Point-to-point (email)
2. Broadcast (TV)

Channel Access methods: share the same frequency band, but at different times (e.g. LORA-WAN) or different frequencies at the same time (e.g. TV), or both (e.g. phone).



Guard Band is a part of the *spectrum kept unused* to minimize interference with other adjacent channel transmissions, or comprises *unused time* to account for synchronization issues.

Frequency Hopping Multiple Access **(FHMA) aka** Code Division Multiple Access **(CDMA)** is more secure than FDMA or TDMA. Spatial Division Multiple Access **(SDMA)** exploits spatial separation between users or uses a multi-beam antenna.

Overview [3/17]

CIRCUIT SWITCHING

1. A phone call request must propagate all the way to the destination and acknowledged before a transmission can begin.
2. Circuit switching refers to a communications process in which a dedicated path with allocated bandwidth is set up on an on-demand or a pre-set basis before the actual communication can take place.
3. It is performed by a centralized or a distributed hierarchical unit.

Is circuit switching suitable for WhatsApp messages? If yes, then, why? If no, then, why not?

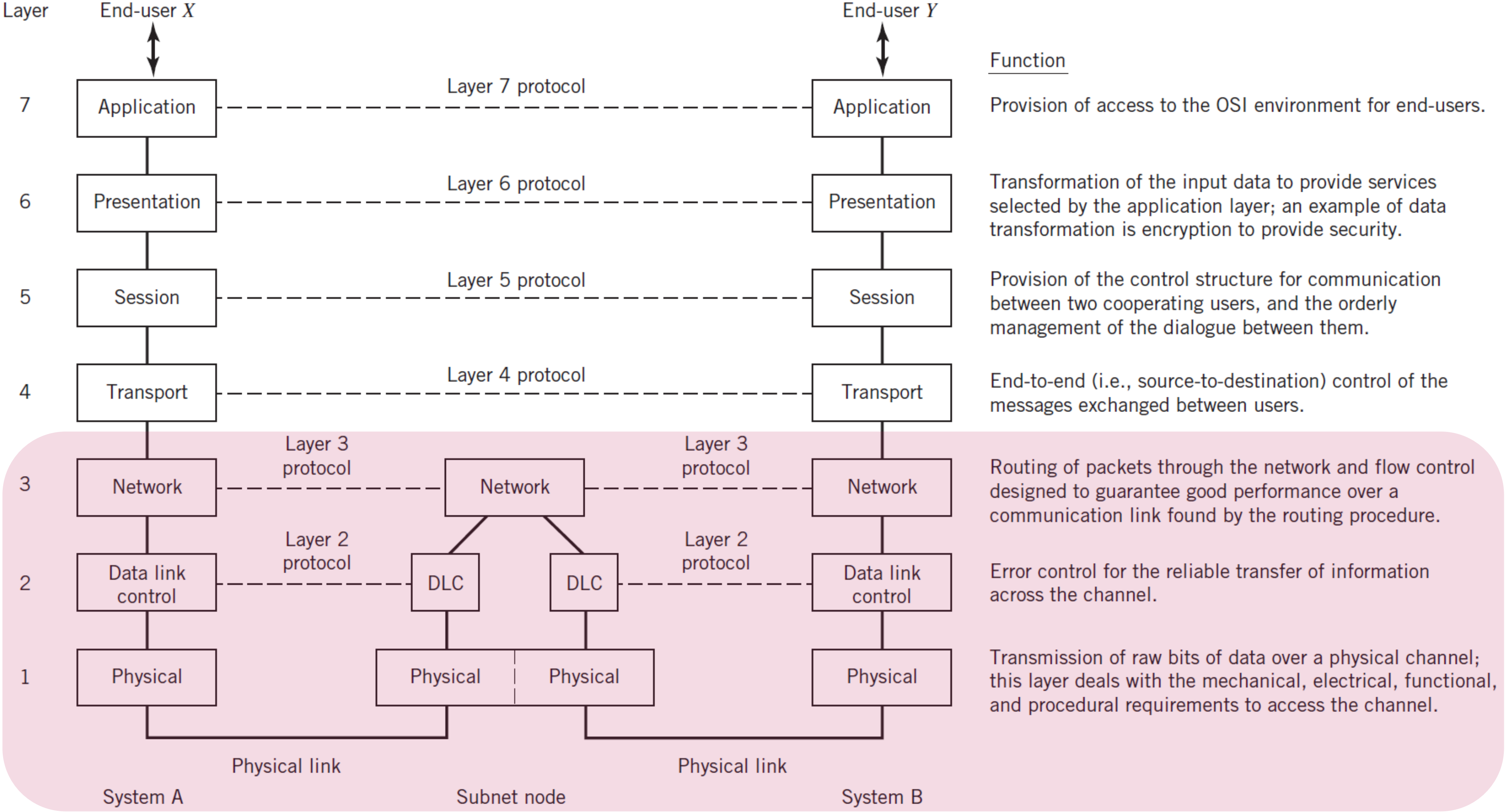
PACKET SWITCHING

1. It divides data into segments, each of which is wrapped in an envelope to form a packet.
2. The packet comprises data + envelope. An envelope includes fields such as addressing, sequencing, and error control.

Overview [4/17]

CONCEPTUAL MODEL FOR COMMUNICATIONS BETWEEN COMPUTING DEVICES

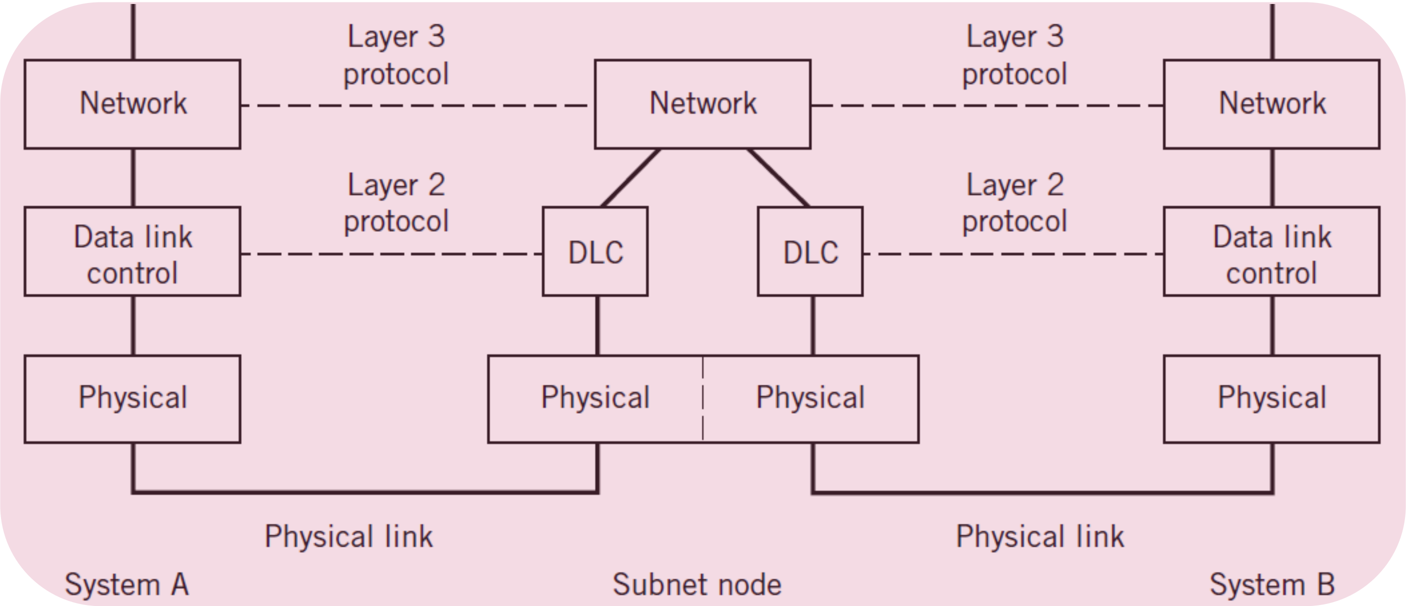
1. Open Systems Interconnection (OSI) is a conceptual model that "*provides a common basis for the coordination of standards development for the purpose of systems interconnection*".
2. It has a 7-layer architecture.



A layer comprises processes or devices inside the system that perform specific functions.

Overview [5/17]

PARTS OF OSI MODEL THAT IS FOCUS OF THE BOOK



1. **Physical layer.** It embodies the physical mechanism in transmitting bits between any pair of network nodes. Communications is accomplished by modulation at the Tx, use of transmission channel and demodulation at the Rx. Modem performs modulation & demodulation.
2. **Data-link layer.** This layer is for **a)** error control: error detection, error correction, **b)** allowing multiple users share the channel; in fact, a portion of this layer is called Medium Access control (MAC) sublayer. In some sense, the two functions are related: ill-managed channel accesses are one of the main sources for errors.
3. **Network layer.** This layer is responsible for **a)** handling routing, **b)** transferring variable-length network packets from a source to a destination, **c)** flow control to ensure the network does not become congested.

Overview [6/17]

TRANSMISSION MEDIUM I

1. **Twisted-pair wire:** A guided electromagnetic channel that provides a modest bandwidth (*e.g. those used in industrial control systems*).

2. **Co-axial cable:** A guided electromagnetic channel that provides bandwidth of several MHz (*e.g. those used by cable TV firms*).

3. **Fibre optic cable:** A guided communication that has several orders of magnitude of that of a coaxial cable (*e.g. those used by cable TV firms*).

   The Tx or modulator is either a light-emitting diode (LED) or a laser.

   Information is transmitted by varying (modulating) the intensity of the light source with the message signal.

   At the Rx, the light intensity is detected by a photodiode, whose output is an electrical signal that $\propto$ power of the light impinging on the photodiode.

   Noise sources in fiber-optic channels are photodiodes and electronic amplifiers.

Overview [7/17]

TRANSMISSION MEDIUM II

1. **Wireless electromagnetic channels:** In wireless communication systems, electromagnetic energy is coupled to the propagation medium by an antenna which serves as the radiator.

   The physical size and configuration of the antenna depends mainly on the wave frequency.

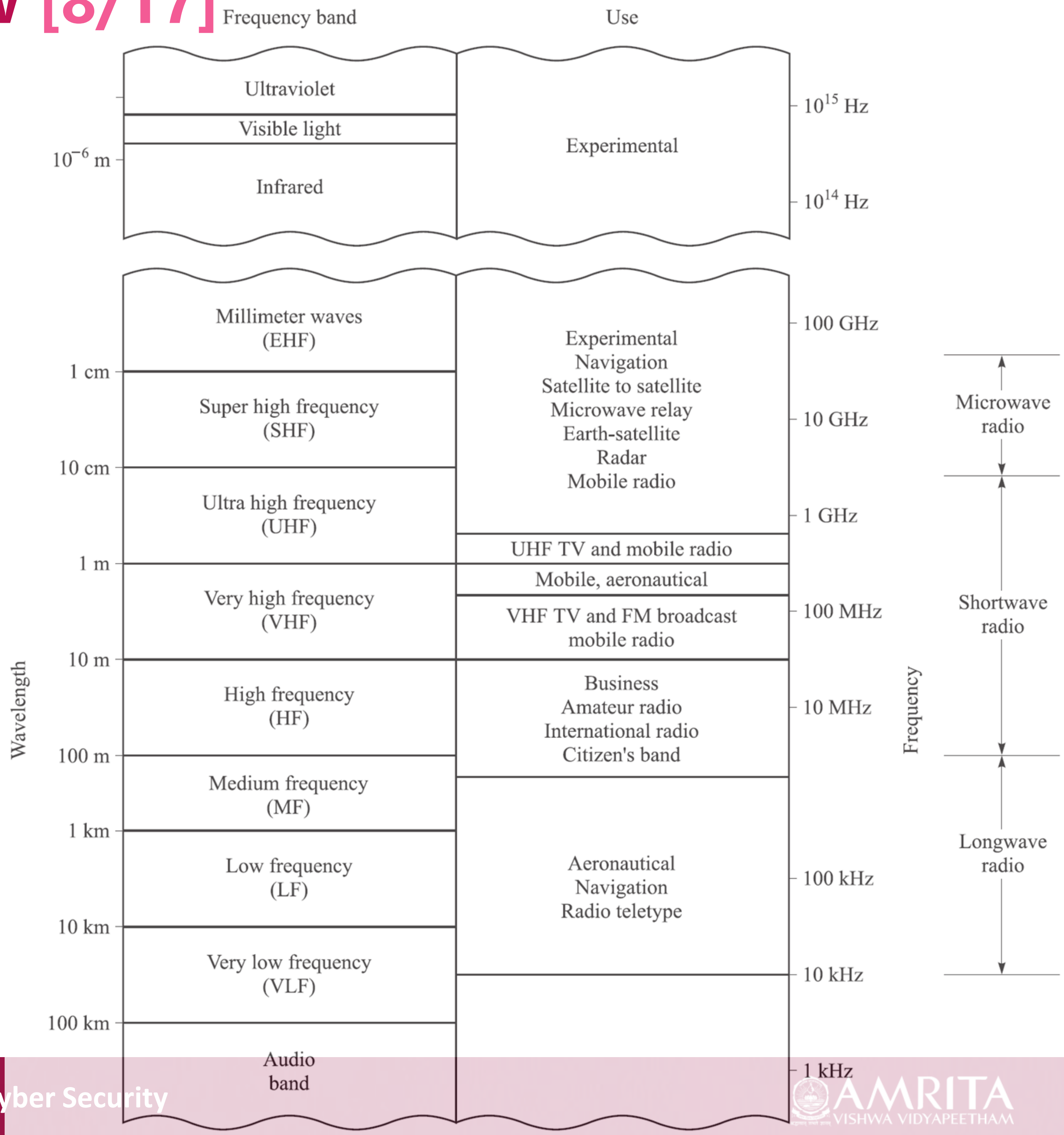
   For efficient coupling of generated to transmitted EM energy, antenna must be > $\frac{1}{10}\lambda$.

   E.g. ULF (ultra low frequency) used in submarine communication due to its high penetrative depth for seawater has an upper bound of 3 KHz has a λ of nearly 100 km [$\lambda = {}^{c}/_{f} = {}^{3\times10^5}/_{3\times10^3}$]. Thus, antenna must be > $\frac{1}{10}\lambda$, i.e., > $\frac{1}{10} * 100$, i.e., at least 10 km long!

   On the other hand, 500 Hz sound can also travel far in sea water. It's λ is 306 cm in sea water. Thus, an antenna must be at least a 1 ft long.

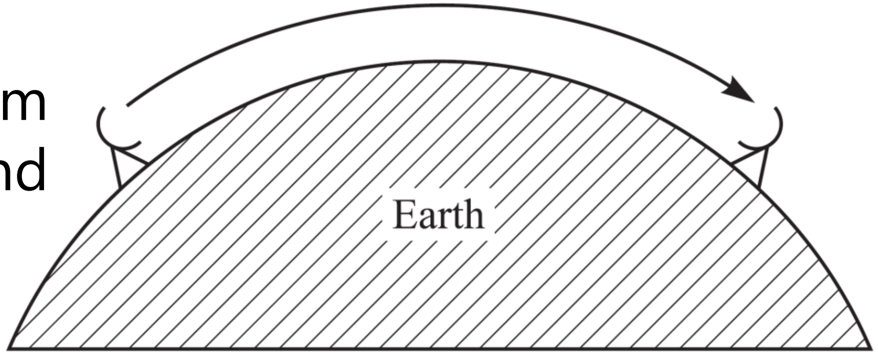
Overview [8/17]

TRANSMISSION MEDIUM III



Overview [9/17]

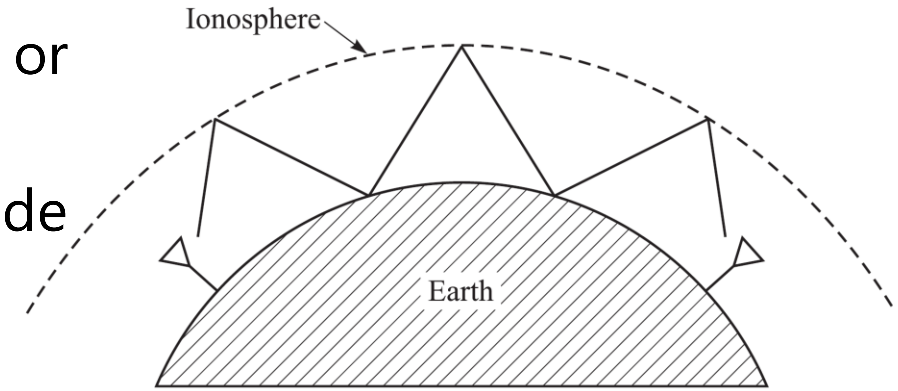
EM PROPAGATION MODES I



1. **Groundwave:** Dominant mode of propagation for medium frequency (MF) band, 0.3-3 MHz. It is used for AM and maritime radio broadcasting.

   Max range: even with powerful transmitters, is 150 km

   Noise: mainly, atmospheric noise and thermal noise



2. **Skywave:** Results from transmitted signals being reflected or refracted from the ionosphere.

   The ionosphere comprises charged particles in at an altitude of 80-400 km ASL (above sea level).

   Lower layers are formed due to heating by sun in daytime.

   The lower layers absorb frequencies < 3 MHz, thus severely limiting sky-wave propagation.

   AM reception is clearer during nighttime as, instead of bouncing off the lower, D-layer, signal bounces off the higher, F-layer.

Overview [10/17]

EM PROPAGATION MODES II

2. **Skywave:** … *continued* skywave propagation ceases above 30 MHz which is where HF spectrum ends. These ways penetrate through the ionosphere.

   Noise: multipath is the major concern. It results in intersymbol interference. Also, the it results in constructive/destructive interfere resulting in the fading phenomenon which one may have experienced while listening to a distant radio station at night.

   Additive noise is a combo of atmospheric (typically, 10-20 MHz) and thermal noise.

   Max usable bandwidth of a single channel is just about 100 Hz (there are ways to increase it!).

   Tropospheric scattering still works in the 40-300 MHz range. However, like MF, propagation losses are large and therefore, powerful transmitters/large antenna are needed.

3. **LOS (line-of-sight):** Satellite downlink is typically in the 2.0-4.0 GHz.

   Galactic noise is significant below 2.0 GHz (*typically, it ranges from 15 MHz to 160 GHz and, is particularly severe for antennae pointed at the Sun*).

   O_2 absorption begins to get significant above 4 GHz.

Overview [11/17]

EM PROPAGATION MODES III

3. **LOS (line-of-sight):** … *continued* coverage of VHF and UHF propagation is limited by curvature of the Earth.

   If the transmitter is at a height h above the surface of Earth then, in the absence of physical obstructions, transmission radius is $\mathrm{d} = \sqrt{15h}$ km. E.g. if $h = 300m$ then $\mathrm{d} = 67$ km.

   Noise: In VHF/UHF mainly thermal noise and cosmic noise.

   In super high frequency (SHF), above 10 GHz, atmospheric conditions play an important role.

   The attenuation ranges from c0.003 dB/km in light rain to c0.3 dB/km in heavy rain. At 100 GHz, it is c0.1 dB/km in light rain to c6 dB/km in heavy rain.

   At extremely high frequency (EHF), we have IR and visible light that provides LOS optical communication. EHF has been used in satellite-to-satellite experimental communications.

Overview [12/17]

UNDERWATER ACOUSTIC CHANNEL EM wave attenuation in seawater varies with penetration depth. Skin depth is distance over which a signal is attenuated by ($\frac{1}{e}$, i.e., by 36.8%).

It is $\delta = 250/\sqrt{f}$ where f is in Hz & δ is in meters. E.g., for 3 KHz, i.e., the upper limit of ULF, skin depth is $\delta = 250/\sqrt{3000}$ which is < 15 ft!

Acoustic transmissions at low frequencies can, on the other hand, travel several hundred km.

$\therefore$ these are preferred for inter-submarine communications.

Noise: mainly, multipath concerns due to:

- *reflection from sea surface, sea bottom and large ocean vessels*
- *varying sea depth due to waves*
- *varying sound speed due to differences in temperature and ocean depths*)

Ambient ocean acoustic noise is caused by shrimp, fishes and whales.

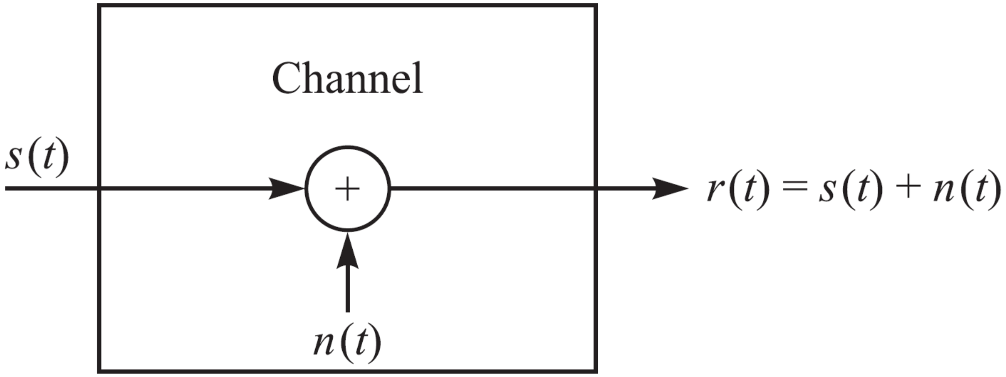
Manmade noise near harbors …

SOME MATH I

In this course, we focus on math for the physical, data link and network layers of the OSI model.

The models reflect the most important characteristics of the transmission medium, channel encoder, modulator and error detection and correction codes.

Noise introduced by electronic components may be characterized as thermal noise. The process underlying thermal noise is Gaussian. The noise is additive. Thus, the term additive gaussian noise.

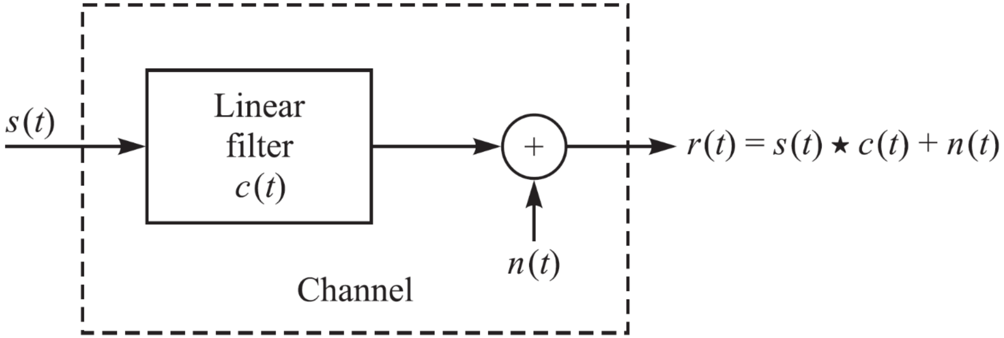


Additive Gaussian Noise

Let $c(t)$ be the instantaneous channel condition.

Then, signal $s(t)$ in presence of additive gaussian noise, $\eta(t)$, is received as $r(t) = s(t) * c(t) + \eta(t)$.

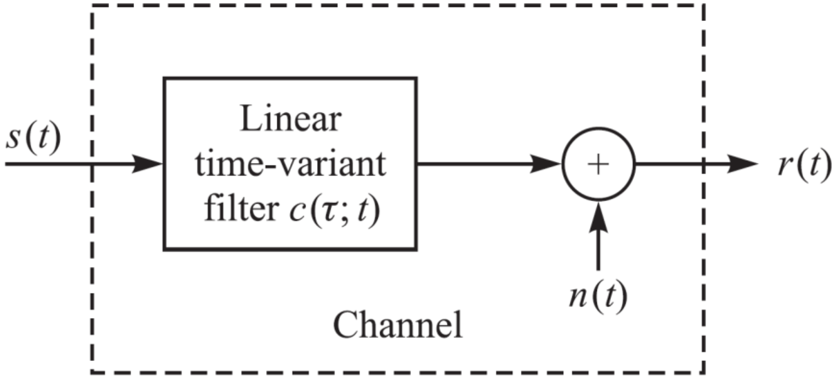
This in turn is simply $r(t) = \int_{-\infty}^{\infty} s(t-\tau) * c(\tau) d\tau + \eta(t)$



SOME MATH II

Linear Time-variant Filter Channel

Band-limit filters are used to ensure that transmitted signals do not exceed a certain bandwidth. This bandwidth itself could be dynamic depending on channel conditions or instantaneous pricing. The output on such channels are characterized as an outcome of the linear process given above.



If the channel conditions are time-variant, i.e., instead of having a LTI system we have a LTV system then, $r(t) = \int_{-\infty}^{\infty} s(t-\tau) * c(\tau, t) d\tau + \eta(t)$ **(i)**

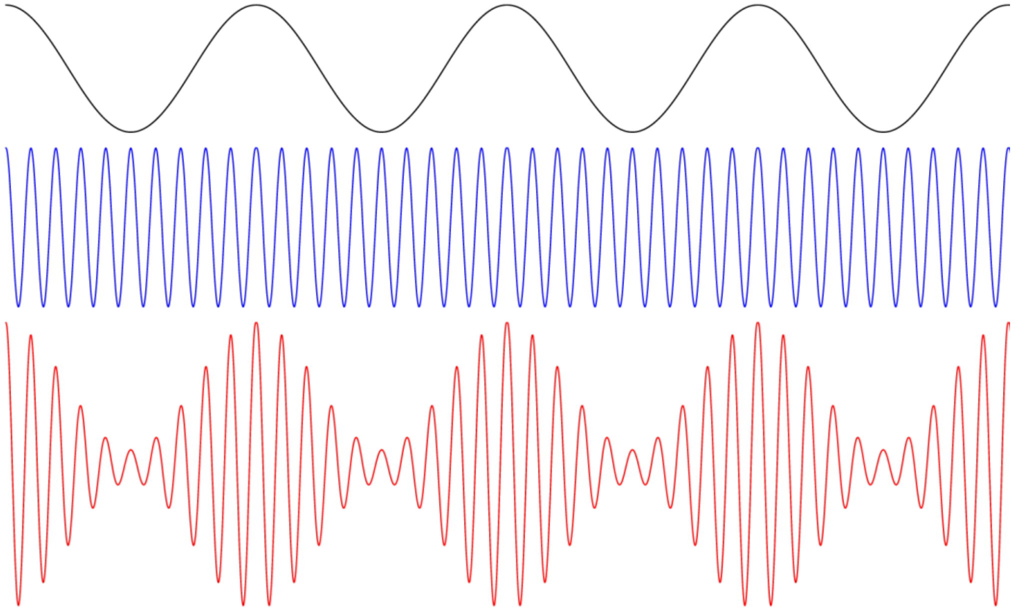
A good model for multipath signal propagation via ionosphere bounce (frequencies < 30 MHz) and mobile cellular radio channels, is a special case of the equation above:

$c(\tau, t) = \sum_{k=1}^{L} a_k(t)\delta(t-\tau_k)$ **(ii)** where $a_k(t)$ is the time-variant attenuation for L propagation paths and τ_k is corresponding time delays. Substituting this in (i) we get:

$r(t) = \int_{-\infty}^{\infty} s(t-\tau) * \sum_{k=1}^{L} a_k(t)\delta(t-\tau_k)\, d\tau + \eta(t)$, i.e., $r(t) = \sum_{k=1}^{L} a_k(t) s(t-\tau_k) + \eta(t)$ … **(iii)**

Overview [15/17]

MODULATION



What is modulation? It is the process of introducing small changes to a waveform (carrier) based changes in another waveform (signal/data).

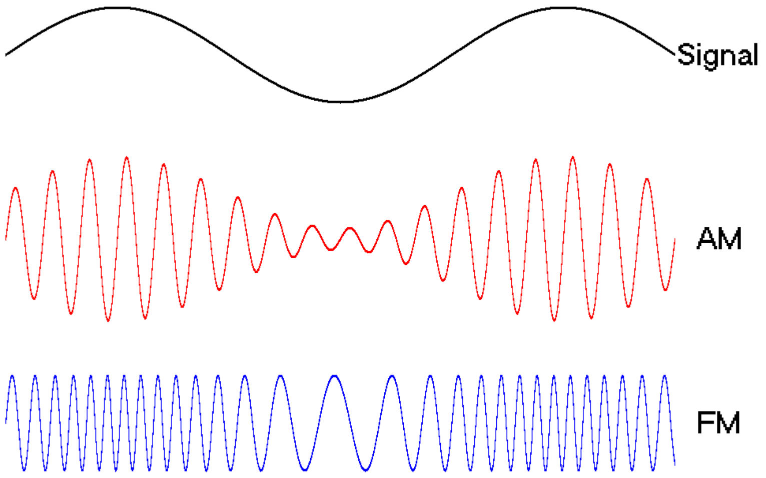
Why modulate? Without modulation:

1. The signals will simply collide. They can still collide even if you modulate but collision management is simpler for modulated signals.
2. Antenna length will be huge. E.g., a phone call at 64 kbps without modulation will need an antenna c470 meter long! For a 4G carrier, it requires an antenna only c1.3 cm long. These are theoretical values, nevertheless, illustrative.
3. Long-distance transmission infrastructure is expensive. It is far, far more efficient to bundle different types of transmitting devices on to a single infrastructure.
4. Improves quality of reception (AM *cannot do this*).

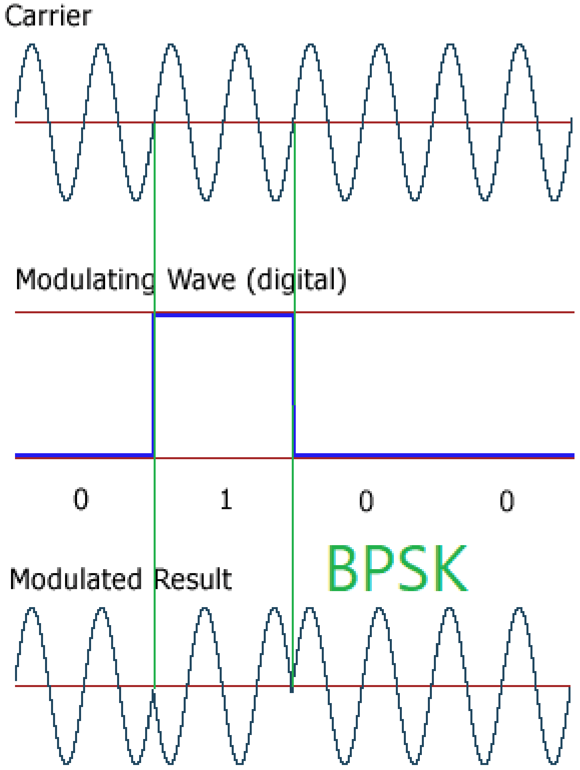
Overview [16/17]

EXAMPLES OF MODULATION

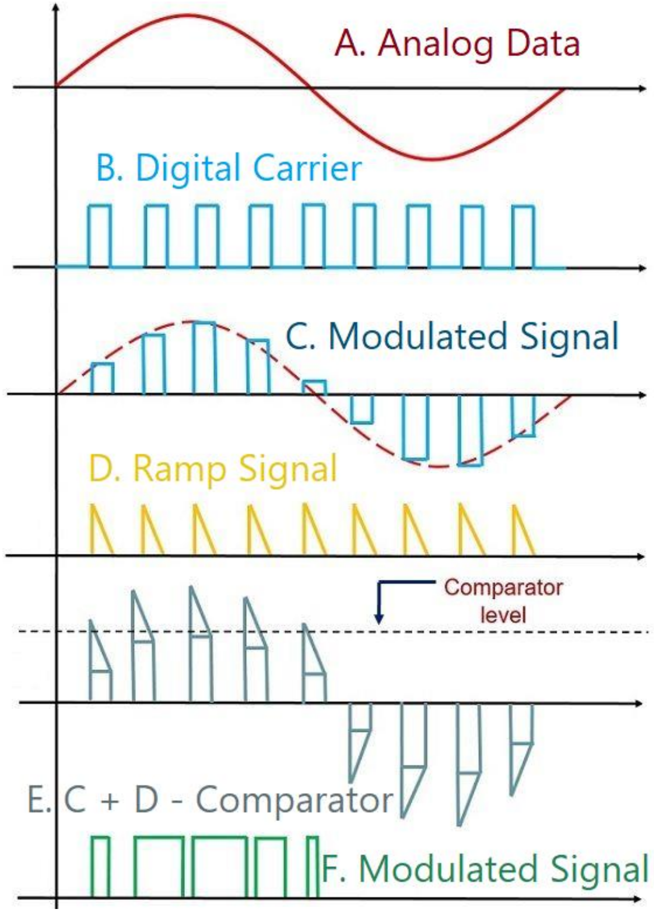
Analog data over analog channel



Digital data over analog channel



Analog data over digital channel



Digital data over digital channel

… … *left to imagination!*

Overview [17/17]

MODULATION MODES

Analog data over analog channel

Digital data over analog channel

Analog data over digital channel

Digital data over digital channel