# CS3200: Computer Networks
## Lecture 2

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# Layered Architecture

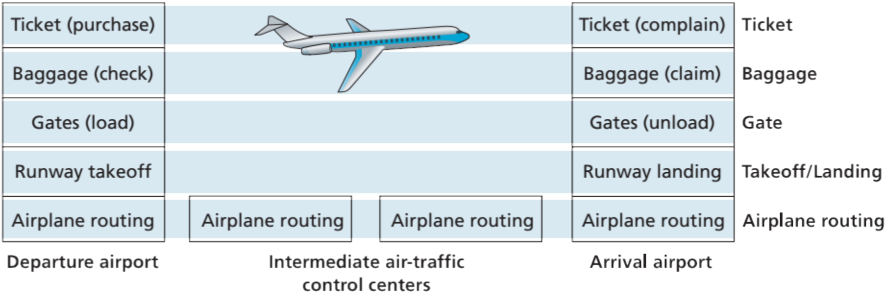



Figure: [Kurose and Ross] Layering of airline functionality.

# Protocol Layering

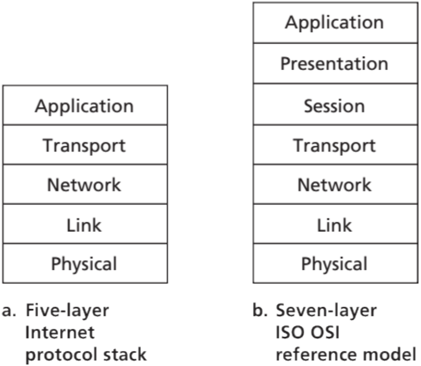



Figure: [Kurose and Ross] The Internet protocol stack (a) and OSI reference model (b).

# Protocol Layering: Encapsulation

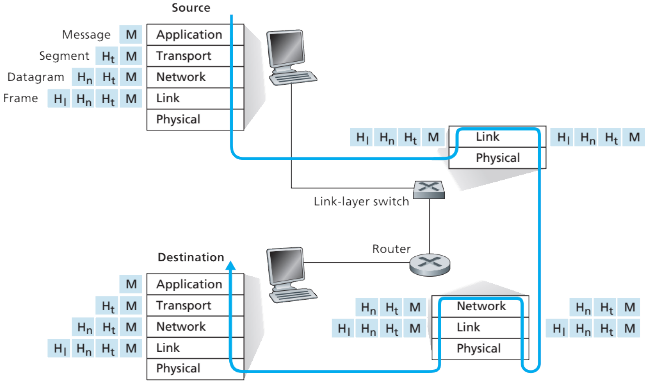



Figure: [Kurose and Ross] Hosts, routers, and link-layer switches; each contains a different set of layers, reflecting their differences in functionality.

# Physical Layer

# Physical Layer

- Lowest layer in the protocol stack.
- Defines the electrical, timing and other interfaces by which bits are sent as signals over channels.

# Theoretical Basis for Data Communication

## Fourier Analysis

Any reasonably behaved periodic function, $g(t)$ with period $T$, can be constructed as the sum of a (possibly infinite) number of sines and cosines:

$$g(t) = \frac{c}{2} + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft),$$

where $f = 1/T$ is known as the fundamental frequency.

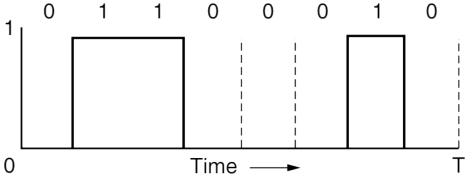
The constants can be computed as follows

$$a_n = \frac{2}{T}\int_0^T g(t)\sin(2\pi nft)dt \quad b_n = \frac{2}{T}\int_0^T g(t)\cos(2\pi nft)dt$$

$$c = \frac{2}{T}\int_0^T g(t)dt$$

# Bandwidth-Limited Signals

Suppose you would like to send the character 'b' encoded in an 8-bit byte




The Fourier series of this signal has the following coefficients:

$$a_n = \frac{1}{\pi n}[\cos(\pi n/4) - \cos(3\pi n/4) + \cos(6\pi n/4) - \cos(7\pi n/4)]$$

$$b_n = \frac{1}{\pi n}[\sin(3\pi n/4) - \sin(\pi n/4) + \sin(7\pi n/4) - \sin(6\pi n/4)]$$

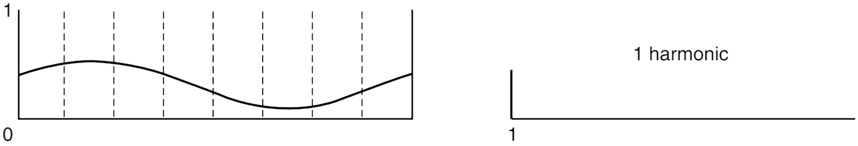
$$c = 3/4$$

# Bandwidth-Limited Signals

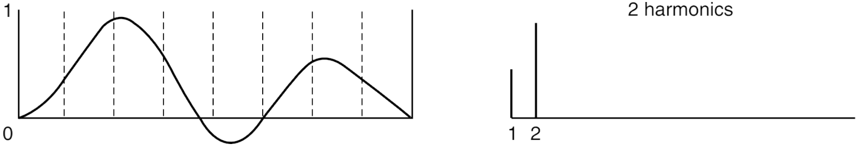
- No transmission facility can transmit signals without losing some power in the process.
- Almost all transmission facilities diminish different Fourier components by different amounts, thus introducing distortion.
- The width of frequency range transmitted without being strongly attenuated is called the **bandwidth**.
- Signals that run from 0 up to a maximum frequency are called **baseband** signals.
- Signals that are shifted to occupy a higher range of frequencies, as is the case for all wireless transmissions, are called **passband** signals.

# Bandwidth-Limited Signals

With only the first harmonic

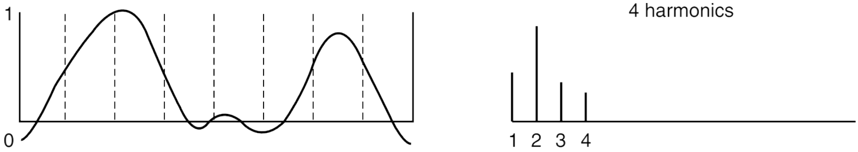



With the first two harmonics

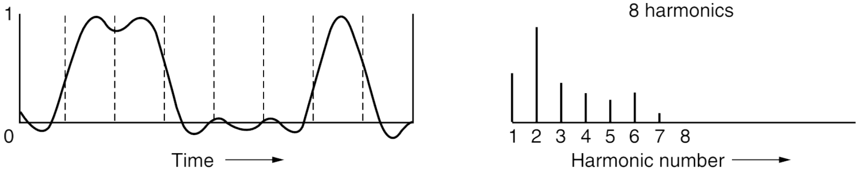


# Bandwidth-Limited Signals

With the first 4 harmonics




With the first 8 harmonics



# Maximum Data Rate

## Nyquist – Shannon Theorem

An arbitrary signal containing no frequencies higher than $B$ Hertz can be completely reconstructed by making only $2B$ samples per second.

If the signal consists of $V$ discrete levels, Nyquist's theorem states that maximum data rate $= 2B \log_2 V$ bits/sec.

The above is valid for noiseless channel. What is the channel has random noise present?

## Shannon – Hartley Theorem

Maximum data rate or capacity of a noisy channel whose bandwidth is $B$ Hz and whose signal-to-noise ratio is $S/N$, is given by $B \log_2(1 + S/N)$ bits/sec.