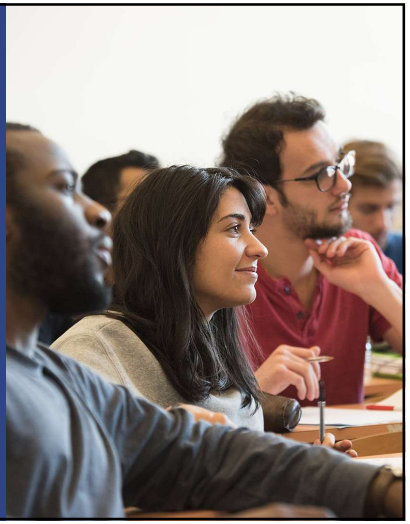
WWW.DAUPHINE.PSL.EU

Computer Networks

https://guilhermeir.github.io/L3Networks.html

Prof. Guilherme Iecker Ricardo
guilherme.iecker-ricardo@dauphine.psl.eu

Dauphine UNIVERSITÉ PARIS | PSL



Computer Networks
Class 2: Physical Layer (Continued)

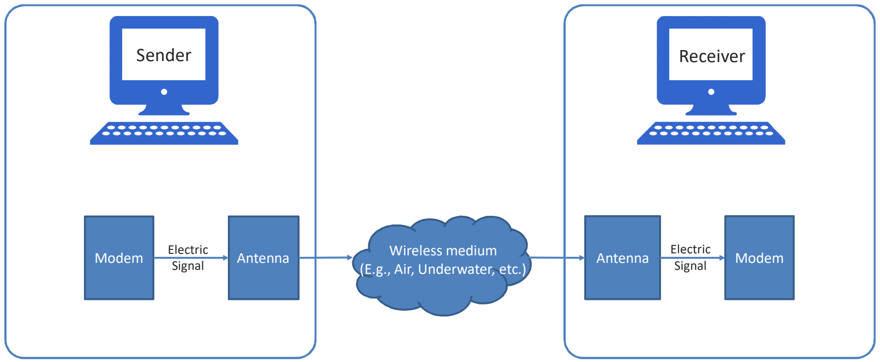
Physical Layer

Overview/roadmap:

- Preliminaries
- Guided Transmission
- **Wireless Transmission**
- Using the Spectrum for Transmission
- Fundamentals of Digital Communication

Physical Layer

Wireless Transmissions

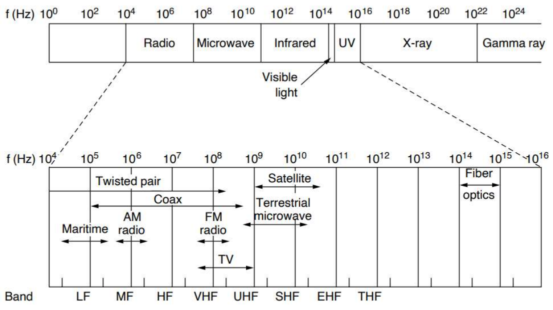


Eletromagnetic (EM) Spectrum

- Characteristics:
  - Frequency, f [Hz = 1/s]
  - Wavelength λ [m]
  - Amplitude
  - Phase
- Fundamental Relation:

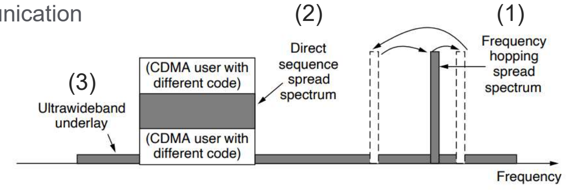
$$\lambda \cdot f = c$$

- Frequency Bands

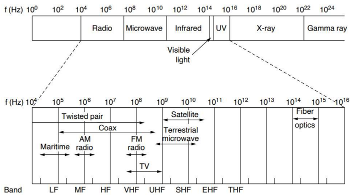


Types of Wireless Transmission

1. Frequency Hop Spread Spectrum
   - Military communication, Bluetooth, etc.
   - Trivia: Hedy Lamar
2. Direct Sequence Spread Spectrum
   - 3G, GPS, etc.
   - CDMA (Later!)
3. Ultra-wideband Communication
   - Indoor applications



Physical Layer



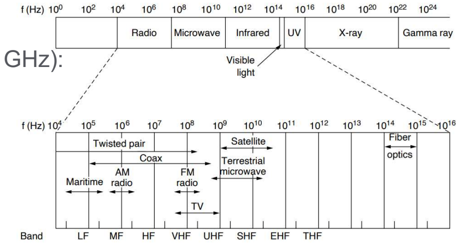
Overview/roadmap:

- Preliminaries
- Guided Transmission
- Wireless Transmission
- **Using the Spectrum for Transmission**
- Fundamentals of Digital Communication

Physical Layer

Radio Frequency (RF)

- Band: 1 Hz – 300 GHz (1000 km – 1 mm)
- Interference (electrical equipment)
- Low-frequency radio waves (< 300 MHz):
  - Omnidirectional
  - Obstacle penetration
  - Path loss : $1/r^2$
- Microwaves (>= 300 MHz and < 300 GHz):
  - More Directional
  - Partial obstacle reflection
  - Multi-path fading



Physical Layer

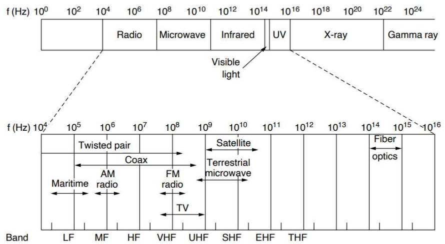
Higher frequency bands

Infrared Transmission

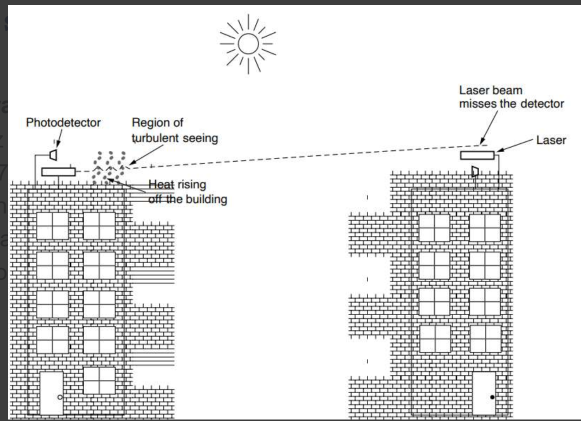
- 300 GHz – 430 THz
- 1 mm – 700 nm
- Short range communication
- Full obstacle reflection
- “Same room” applications

Light Transmission

- 430 THz – 750 THz
- 700 nm – 400 nm



Ðauphine | PSL



Physical Layer

Overview/roadmap:

- Preliminaries
- Guided Transmission
- Wireless Transmission
- Using the Spectrum for Transmission
- **Fundamentals of Digital Communication**

Physical Layer

Fundamentals of Digital Communication - Introduction

- Information transmission: varying physical properties (voltage, current, etc.)
  - General time-dependent notation: g(t)
  - Fourier series representation:

Sine and Cosine Amplitude of n-th harmonic

$$g(t) = \frac{1}{2}\underbrace{\boxed{c}}_{\text{Constant}} + \sum_{n=1}^{\infty} \boxed{a_n} \sin(2\pi \boxed{nf} t) + \sum_{n=1}^{\infty} \boxed{b_n} \cos(2\pi \boxed{nf} t)$$

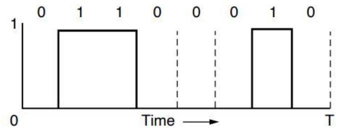
Fundamental Frequency f=1/T

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

Physical Layer

Fundamentals of Digital Communication – Example: Transmitting “b”

- 8-bit ASCII “b”: 0110 0010
- Power (Voltage) x Time signal representation:



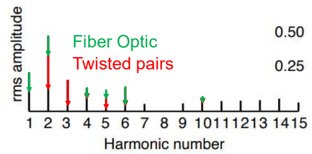
- Given that T=8, we have:

$$a_n = \frac{1}{\pi n}\left[\cos(\pi n/4) - \cos(3\pi n/4) + \cos(6\pi n/4) - \cos(7\pi n/4)\right]$$
$$b_n = \frac{1}{\pi n}\left[\sin(3\pi n/4) - \sin(\pi n/4) + \sin(7\pi n/4) - \sin(6\pi n/4)\right]$$
$$c = 3/4.$$

Physical Layer

Fundamentals of Digital Communication – Bandwidth

- Transmitted Power ∝ $\mathrm{RMS}_n = \sqrt{a_n^2 + b_n^2}$



- Different media, different amplitude attenuation
- *Cutoff frequency* f_c: severe attenuation (beyond recovery possibility)

Physical Layer

Fundamentals of Digital Communication – Bandwidth

- Transmitted Power \propto RMS=aaa

Definition: *Bandwidth* is a physical property of the transmission medium which defines the frequency interval from 0 up to the cutoff frequency f_c

- Different media, different amplitude attenuation
- *Cutoff frequency* f_c: severe attenuation (beyond recovery possibility)

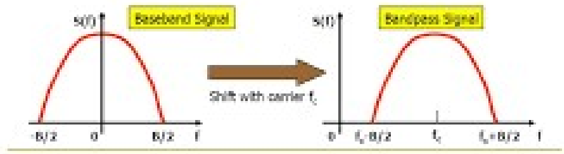
Dauphine | PSL EQUIS

Physical Layer

Fundamentals of Digital Communication – Bandwidth usage

- Filtering: Slices of the total bandwidth
- Examples:
  - 802.11 Wireless channels typically use ~20MHz
  - TV channels occupy 6MHz

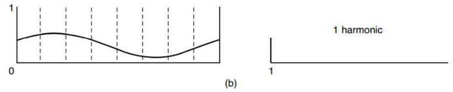
- Types of signal
  - Baseband
  - Passband

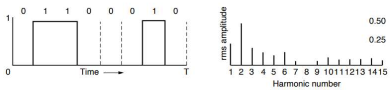


Dauphine | PSL EQUIS

Physical Layer

Signal Reconstruction

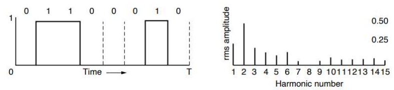


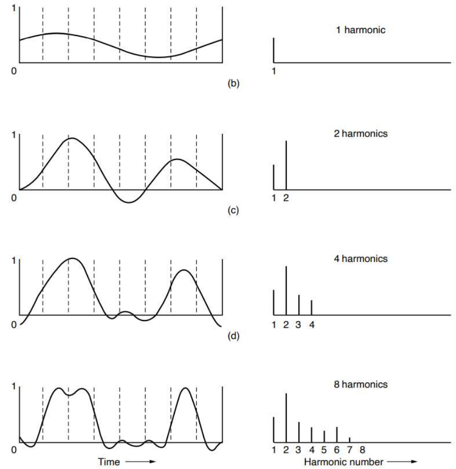


- Goal: receive signal with "enough" fidelity
- Larger f_c -> bigger n
- Bigger n -> better reconstruction
- For this example, n=8 looks enough!

Physical Layer

Signal Reconstruction





- Goal: receive signal with "enough" fidelity
- Larger f_c -> bigger n
- Bigger n -> better reconstruction
- For this example, n=8 looks enough!

Physical Layer

Transmission rate x Bandwidth

r: Transmission rate [bps]

T: Time to send 8 bits
T = 8 / r

First Harmonic: 1/T

Cutoff freq.: $f_c = 3kHz$

bps
300
600
1200
2400
4800
9600
19200
38400

Physical Layer

Transmission rate x Bandwidth

r: Transmission rate [bps]

T: Time to send 8 bits
T = 8 / r

First Harmonic: 1/T

Cutoff freq.: $f_c = 3kHz$
(Bandwidth 3kHz)

bps	T (msec)	First harmonic (Hz)	# Harmonics sent
300	26.67	37.5	80
600	13.33	75	40
1200	6.67	150	20
2400	3.33	300	10
4800	1.67	600	5
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

<8 harmonics
Insufficient reconstruction

Physical Layer

Transmission rate x Bandwidth

r: Transmission rate [bps]

T: Time to send 8 bits
T = 8 / r

First Harmonic: 1/T

Cutoff freq.: $f_c = 3kHz$

bps	T (msec)	First harmonic (Hz)	# Harmonics sent
[illegible]	[illegible]	[illegible]	[illegible]
9600	0.83	1200	2
19200	0.42	2400	1
38400	0.21	4800	0

<8 harmonics
Insufficient reconstruction

Transmission rate is limited by the **bandwidth**!

Dauphine | PSL

Physical Layer

The Maximum Data Rate of a Channel

Nyquist's Theorem

- Ideal (noiseless) channel
- Bandwidth: B [Hz]
- Number of discrete levels: V

Maximum data rate
$r_{\max} = 2 \cdot B \cdot \log_2 V$ [bps]

Dauphine | PSL

Physical Layer

The Maximum Data Rate of a Channel

Shannon's Capacity

- Channel subject to thermal noise
- Signal-to-Noise Ratio (SNR): S/N
  - S: Signal's transmission power [W]
  - N: Random thermal noise [W]
  - S/N is often expressed in dB
    - dB=10 log10(S/N)

Maximum data rate
(Channel Capacity)
$r_{\max} = B \cdot \log_2(1 + S/N)$ [bps]

Questions?

guilherme.iecker-ricardo@dauphine.psl.eu

UNIVERSITÉ PARIS DAUPHINE - PSL
Place du Maréchal de Lattre de Tassigny – 75775 Paris cedex 16