Chapter I:
Introduction to Data Transmission Networks

I.1 – GENERAL CONCEPTS

I.1.1 – Definition

A network is a set of geographically dispersed hardware and software resources designed to provide a service or ensure data transport. Examples include; the telephone network, the Internet, enterprise networks, etc. The techniques implemented differ based on the network's purpose and the desired quality of service.

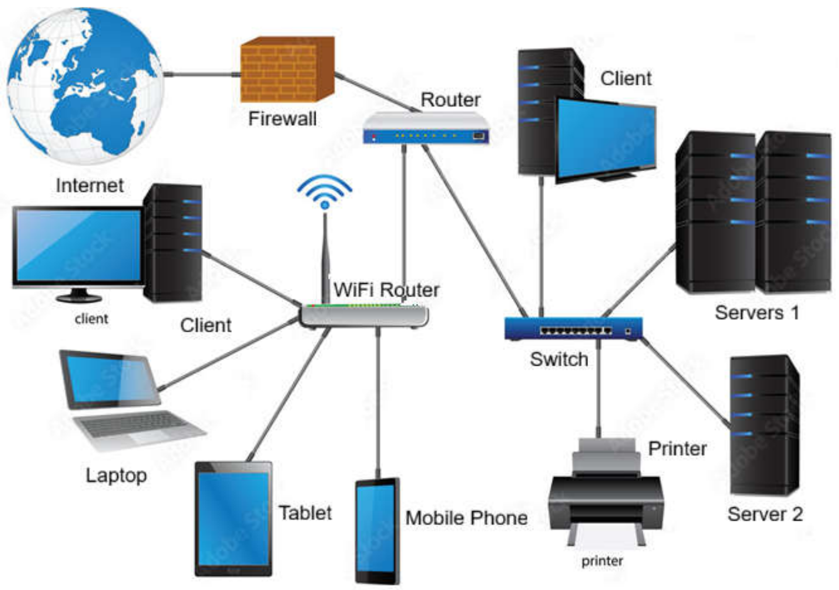

Figure I.1 *– The network: a set of shared resources.*

I.1.2 – Information Flows

Routing diverse information types—such as computer data, voice, or video—over the same network requires that:

1. Each information category has an identical representation for the transmission system (whose role is data transmission without knowledge of the transmitted information type).
2. The network accommodates the specific constraints of each information flow type (Figure I.2).

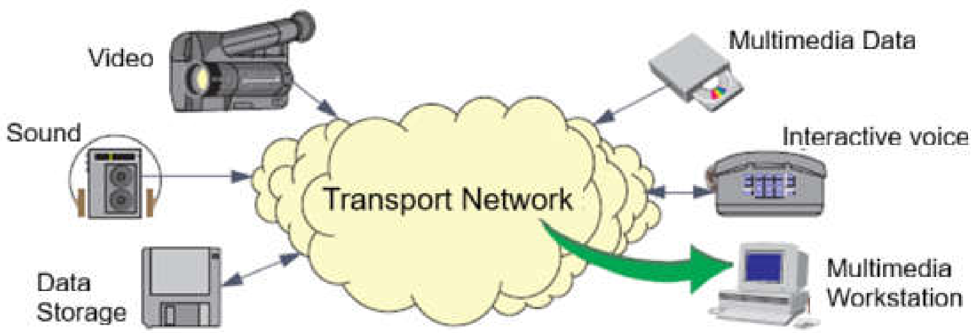

Figure I.2 *– The network and different information flows.*

I.2 – INFORMATION REPRESENTATION

I.2.1 – Types of Information

Transmitted information falls into two main categories based on its nature and processing transformations:

Author: Dr. H. Zerroiki

- **Discrete data:** Information consists of an assembly of independent, countable elements (a discontinuous sequence of values) within a finite set. Example: Text is an association of words composed of letters (elementary symbols).
- **Continuous/Analog data**: Results from the continuous variation of a physical phenomenon (Figure I.3): temperature, voice, images. A sensor provides an electrical voltage proportional to the amplitude of the analyzed physical phenomenon: an *analog signal* (varying analogously to the physical phenomenon). An analog signal can take infinite values within a defined range.

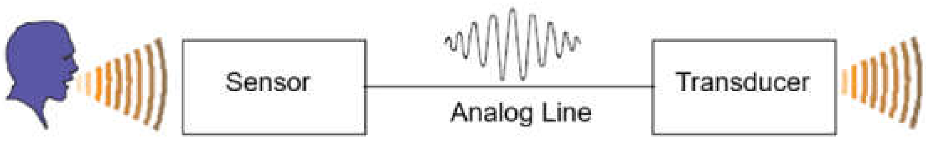

Figure I.3 *– The analog signal.*

To process this information with computer equipment, each information element must be substituted with a binary value representing its amplitude. This operation is called:

- **Information encoding (source coding)** for discrete data.
- **Digitization** for analog data.

I.2.2 – Information Encoding

a) Definition

Encoding involves transforming, transcribing, and mapping each symbol of an alphabet (element to be encoded) to a binary representation (code word). The set of code words constitutes the code (Figure I.4). This information may include machine tool commands, alphanumeric characters, etc. A code may contain:

- Digits: [0, ..., 9]
- Alphabet letters: [a, ..., z, A, ..., Z]
- Symbols: [é, è, à, ...]
- Punctuation: [, ; : . ? !]
- Semi-graphic symbols: [╣ ▌╧ ║...]
- System commands: [Line feed, Page break, End of file, ...]

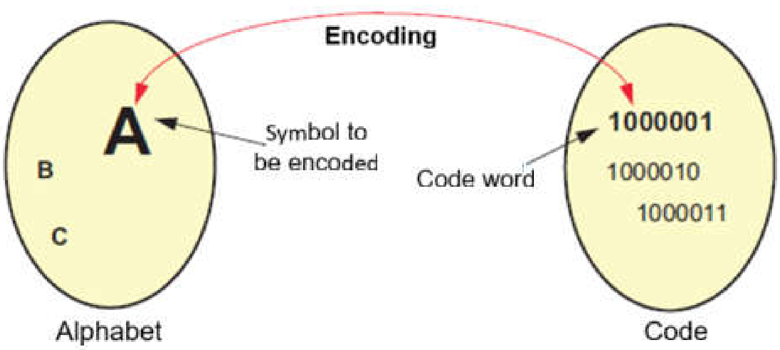

Figure I.4 *– Principle of data encoding.*

b) Lexicographic Power of a Code

The lexicographic power of a code is the number of symbols it can represent. With binary code, $\mathbf{2^n}$ symbols can be encoded using ***n* bits**. Thus, *n* bits can encode ***N* symbols** where:

$$2^{n-1} \leq N < 2^n$$

The number of bits required to encode *N* symbols is:

$$n = log_2 N$$

c) Information Quantity

The information quantity transmitted by a symbol is:

$$H = log_2\left(\frac{1}{p}\right)$$

Where *p* is the probability of the symbol's appearance.

Example: - How many bits are needed to encode all letters of the French alphabet?
- What is the information quantity per letter, assuming equiprobable appearance?

Solution:

1. Bits needed for 26 letters:

$2^{n-1} \leq 26 < 2^n$ → ***n*=5** (since $2^4=16 \leq 26 < 32=2^5$).

2. Probability *p*=1/26:

$$H = log_2(26) = \frac{log_{10}(26)}{log_{10}(2)} = \frac{1.41497}{0.30103} \approx \mathbf{4.66\ bits}$$

d) Types of Codes

Generally, ***fixed-length codes*** are used, meaning that the number of binary symbols (number of bits) used to represent a code element is identical for all elements of the code. Certain techniques, such as data compression, use ***variable-length codes***.

- **Fixed-length codes**: Each symbol uses the same number of bits (e.g., *n*-moment codes).

  BAUDOT code: **5-bit** code used in Telex networks. Encodes $\mathbf{2^5=32}$ symbols (insufficient for 26 letters + 10 digits + commands).
  ASCII code: (American Standard Code for Information Interchange): **7-bit** code encoding $\mathbf{2^7=128}$ characters. Extended to 8 bits for PC microcomputers.
  EBCDIC code: (Extended Binary Decimal Interchange Code): **8-bit** IBM code used in IBM/BULL systems.

- **Variable-length codes**: Used in data compression (e.g., Huffman coding). Code word length decreases with higher symbol probability.

  Huffman Code Construction: (Example: the following table gives Symbols with probabilities)

A	E	U	S	Y	T
0,28	0,34	0,08	0,13	0,05	0,12

– Sort symbols by descending probability (E, A, S, T, U, Y).
– Specify the symbol occurrence probability (**0.34; 0.28**; ...).
– Combine lowest probabilities (**U + Y = 0.13**).
– Build tree: Assign **0** to left branches, **1** to right branches (Figure I.5).
– Read code words from root to leaf (e.g., **A = 01**).

Author: Dr. H. Zerroiki

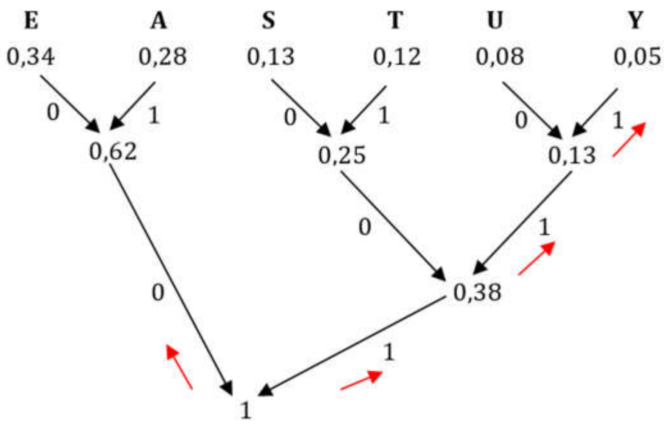

Figure I.5 *– Huffman tree.*

Efficiency: For 100 characters:

- Huffman: 100×(2×0.34+2×0.28+3×0.13+3×0.12+3×0.08+3×0.05)=238 bits
- EBCDIC: 8×100=800 bits → Compression ratio: 800/238≈3.36
- ASCII: 7×100=700 bits → Compression ratio: 700/238≈2.94

I.2.3 – Digitization

a) Principle

Digitizing an analog signal converts a continuous value sequence into a discrete, finite sequence. This involves:

1. **Sampling**: Extracting signal samples at significant instants (Figure I.6). The sampled signal ***U2(t)*** equals ***U1(t)*** instantaneously for brief durations τ repeated at sampling frequency ***Fs* = 1/*Ts***, and is **zero** between instants.
2. **Quantization**: Mapping sample amplitudes to a finite scale.
3. **Coding**: Converting quantized values to binary.

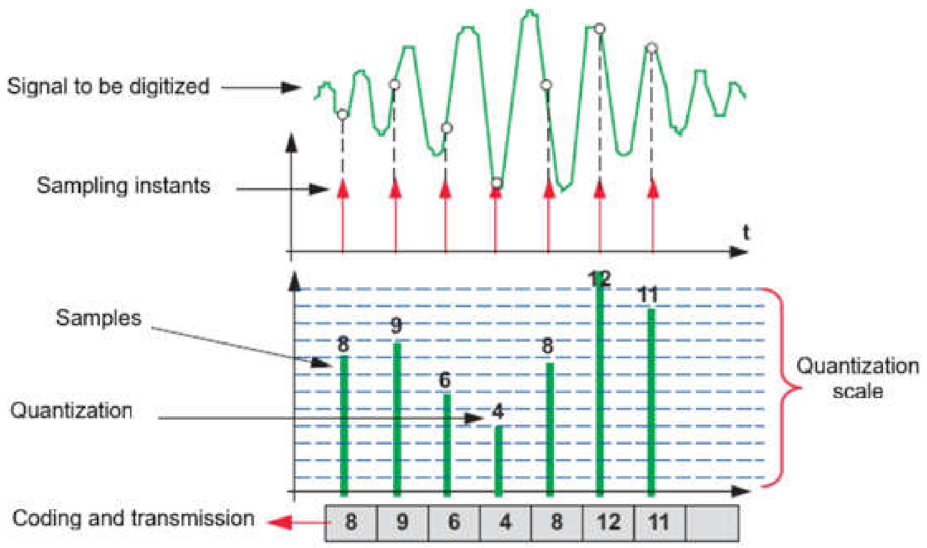

Figure I.6 *– Digitization of an analog signal.*

Key Requirements:

- Sampling interval must be constant (Nyquist frequency):

$$F_{\text{Sampling}} \geq 2\times F_{\text{Signal\_max}}$$

- Quantization scale must cover the signal's dynamic range.

Author: Dr. H. Zerroiki

I.3 – CHARACTERISTICS OF TRANSMISSION NETWORKS

I.3.1 – Bandwidth

The primary characteristic of a transmission medium (cable, fiber optic, etc.) is its ***bandwidth***—the frequency range where signals are transmitted correctly:

$$Bw = F_{max} - F_{min} \qquad \text{Unit: Hertz, (Hz)}$$

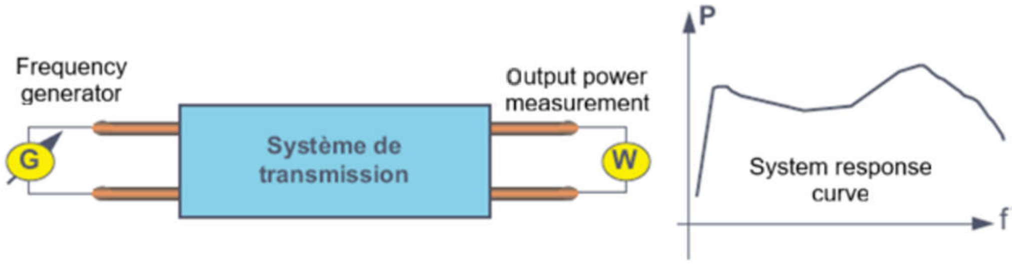

Figure I.7 *– Bandwidth measurement.*

Digital signals require wide bandwidth; analog signals use narrower bandwidth. The PSTN (Public Switched Telephone Network) offers 300–3400 Hz, limiting bandwidth to 3.1 kHz.

I.3.2 – Signal-to-Noise Ratio (SNR)

Signals may be disrupted by electrical/electromagnetic phenomena called ***Noise***. The ***Signal-to-Noise Ratio*** **(SNR)** qualifies channel noise resistance:

$$SNR_{dB} = 10.\,log_{10}\left(\frac{S}{N}\right)$$

Where ***S*** = signal power, ***N*** = noise power.

I.3.3 – Bit Rate

The ***bit rate*** R_b is the number of bits transmitted per unit time:

$$R_b = \frac{V}{t} \qquad \text{Unit: bits per second, (bps)}$$

Where ***V*** = data volume (bits), ***t*** = transmission duration (seconds).

The bit rate measures the number of binary elements transmitted over the transmission channel per unit of time.

$$R_b = 1/T_{bit}.$$

Where T_{bit} is the time taken to transmit one binary element.

Shannon's Theorem: (Maximum theoretical Bit rate (or channel capacity):

$$C = R_{max} = Bw.\,log_2(1 + SNR)$$

Where ***C*** = capacity (bps), ***Bw*** = bandwidth (Hz), ***SNR*** = linear signal-to-noise ratio.

I.3.4 – Error Rate

Disturbances (noise, distortion, Electromagnetic interference (EMI)) cause transmission errors. The ***Error rate Er*** is:

$$Er = \frac{Number\ of\ erroneous\ bits}{Total\ bits\ transmitted}$$

Example:

- Transmitted (E): → **011001001100100101001010**
- Received (R): → **011001101100101101000010**
- Errors (bold): → **011001*0110010*10100*010** → **3** errors in **24** bits

$$Er = \frac{3}{24} = 0.125$$

Typical *Er* ranges from 10^{-4} (PSTN) to 10^{-9} (LANs). For a block of ***n*** bits, the probability of correct reception is $(1-\tau e)^n$, where ***τe*** = bit error probability.

I.4 – TRANSMISSION MEDIA

Network infrastructure and service quality depend heavily on transmission media, categorized as:

- ***Guided media*** (copper, coaxial, optical fibers).
- ***Unguided media*** (radio waves, satellite links).

I.4.1 – Guided Media

***I.4.1.1 – Twisted Pair*:** Two insulated conductors twisted together. Twisting reduces inductance. Multiple pairs may be grouped in a protective sheath. Error rate: 10^{-5} to 10^{-3}; supports up to 100 Mbps.

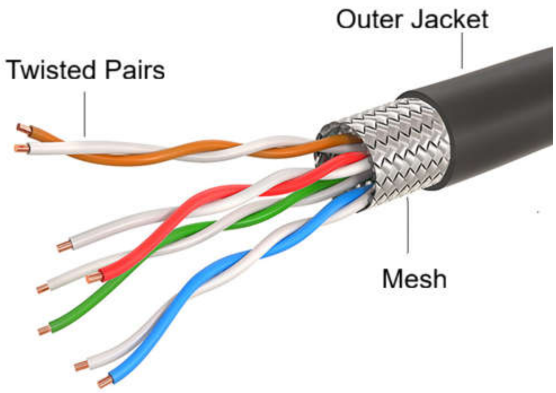

Figure I.8 *– Twisted Pair Cable.*

Cables contain 1 pair (telephone drop line), 4 pairs (local area networks LAN), or several dozen pairs (main distribution cable).

- **UTP (Unshielded Twisted Pair)**: No shielding, no protective sheath exists between the pairs of cables; range ≈ 100 m.
- **STP (Shielded Twisted Pair)**: Shielded pairs, each pair is protected by a shielded sheath, like that of coaxial cable; range ≈ 150–200 m.

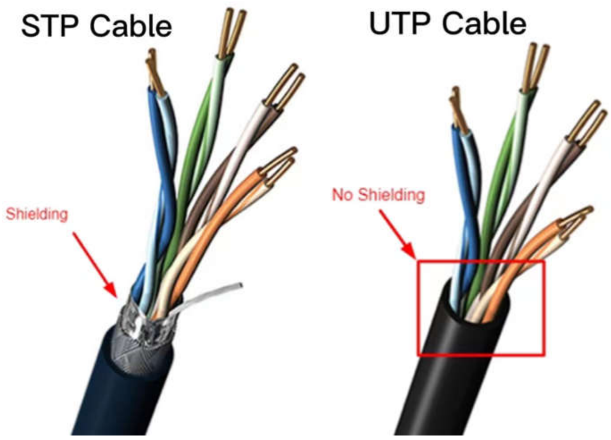

Figure I.9 *– Types of Twisted Pair Cable (UTP, STP).*

I.4.1.2 – Coaxial Cable:

A coaxial cable consists of two conductors, a central conductor surrounded by insulating layer (dielectric), metallic shield, and outer sheath. Coaxial cable has superior electrical characteristics vs. twisted pair; supports higher data rates with lower noise susceptibility.
Error rate: ≈ 10^{-9}.

Author: Dr. H. Zerroiki

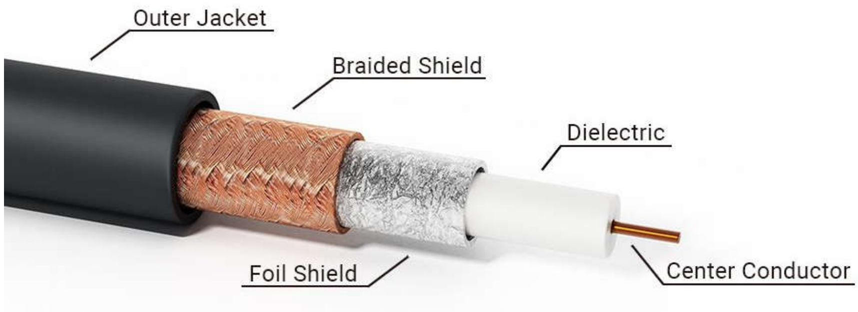

***Figure I.10** – Coaxial cable.*

- **75-ohm coaxial cable**: Used for analog long-distance transmission (e.g., CATV: TV cable).
- **50-ohm coaxial cable**: Used for digital transmission (e.g., LANs up to 10 Mbps over ~1 km).

I.4.1.3 – Optical Fiber:

Optical Fiber is a very thin Glass/plastic wire transmitting light signals. It offers a significantly higher data rate than coaxial cables and supports a "broadband" network through which television, telephone, videoconferencing and computer data can pass.

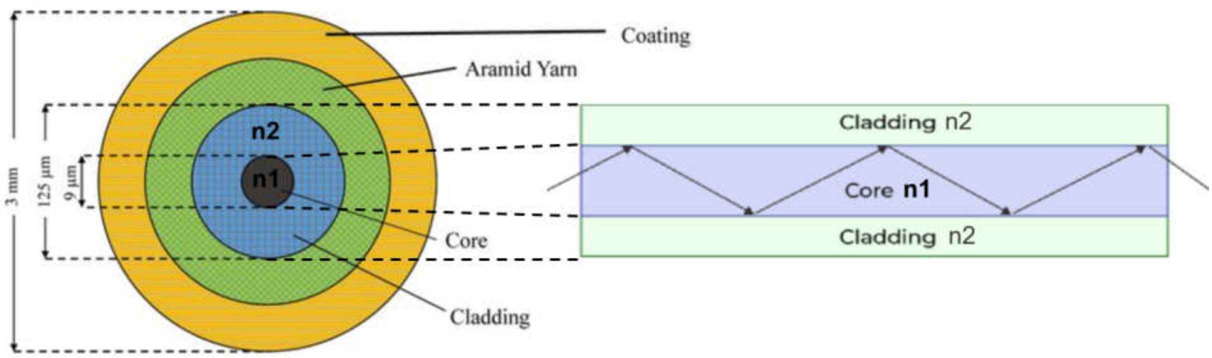

***Figure I.11** – Optical Fiber.*

Advantages:

- High bandwidth
- Electromagnetic immunity
- Low error rate (10^{-12})
- Low attenuation (0.2–0.5 dB/km)
- Compact/lightweight
- High propagation speed (single-mode)

These characteristics make optical fibers the preferred medium in the field of high-speed, long-distance telecommunications, in aeronautical and naval (submarine) applications and in data transmissions in disturbed environments.

Types:

- **Step-index fiber**: Core index ***n*1 > *n*2** cladding index; the variation in index between the core and the cladding is sudden. Light propagates via total internal reflection.

- **Graded-index fiber**: the core index decreases continuously, from the center of the core to the core/cladding interface following a parabolic law.

Author: Dr. H. Zerroiki

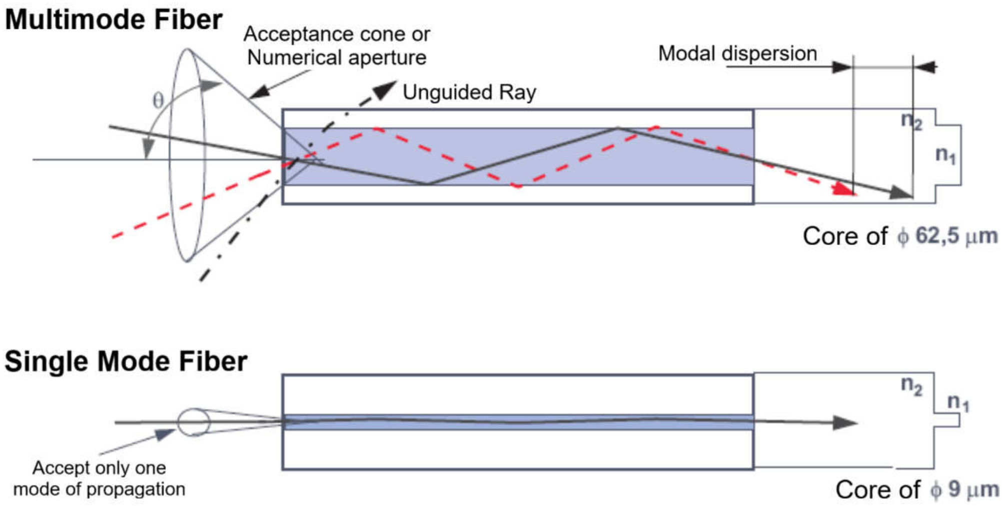

Figure I.12 *– Step-index optical Fibers.*

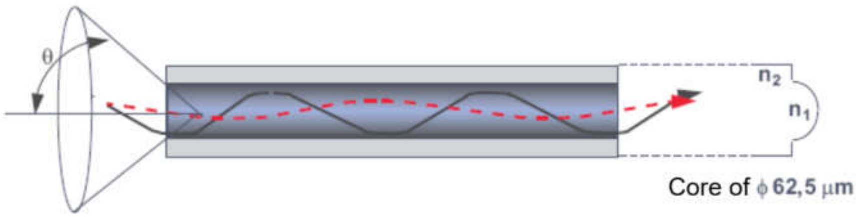

Figure I.13 *– Graded index optical Fibers.*

I.4.2 – Unguided Media (Wireless Links)

A straight conductor with high-frequency current acts as a transmitting antenna, radiating electromagnetic waves (EMW). A receiving antenna then converts this energy back into an electric current. Electromagnetic waves propagate through space at light speed. Wavelength (λ) = distance traveled during one oscillation period.

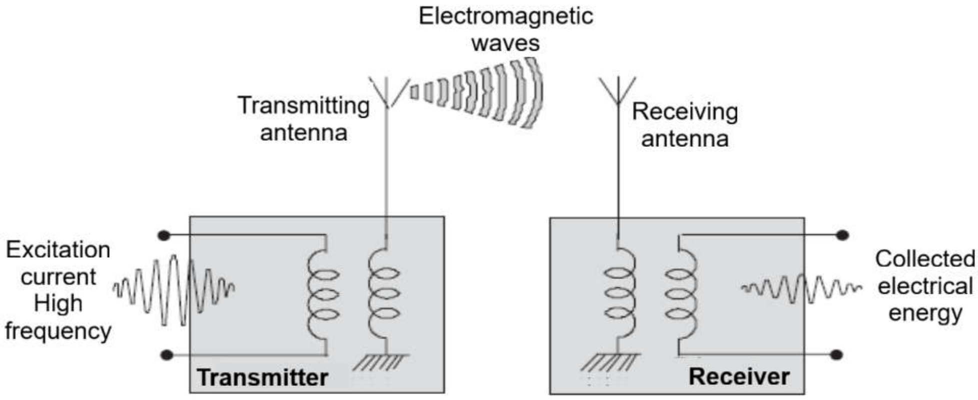

Figure I.14 *– Principle of a radio link.*

Electromagnetic waves experience little attenuation, are relatively easy to implement, and their infrastructure cost is generally low compared to the civil engineering costs incurred by laying physical cables. Electromagnetic waves applications include:

- Broadcasting (one-to-many)
- Mobile networks
- High-speed point-to-point links (microwave, satellite)

Each application uses specific frequency bands.