Wireless communication - ability to communicate over larger distances without using wires, i.e., no physical connection between TX & RX

There are three ways how this may be accomplished:
1) Radio Frequency (RF) communication - uses EM waves at radio frequencies
2) Optical communication - uses EM waves at optical frequencies
3) Acoustic wave communication - uses of acoustic waves

The most prevalent way of wireless communication - Radio communication

Generic outline of wireless communication system:

- **Source**
- **T** (Transmitter) - responsible for transformation of signal from its generic form into a current or a voltage that can be sent through the electronic system (microphone, computer keyboard, camera, etc.)
- **TX (Transmitter)** - responsible for adjusting the signals to the properties of the channel. Typically, TX performs digitization, modulation, frequency translation, amplification, etc.
- **TX antenna** - converts the electric signals coming out of the TX into electromagnetic waves that can be sent over the air
- **Channel** - represents the environment through which the EM waves travel
- **RX (Receiver)** - responsible for recovering the original signal from its distorted copy. Typical tasks performed by RX are filtering, amplification, frequency translation, demodulation, etc.
- **RX antenna** - Converts EM waves back to electronic signals
- **T** (Transmitter)
- **RX (Receiver)**
- **Channel**
- **Recieved Information**
T - Transducer responsible for converting information back into its electronic format to its original form. Typical examples of T could be a speaker, computer screen, file, etc.

Focus of this course - TX & RX circuits for communication

Block diagram of a typical TX circuit

Typical block diagram of the TX is given by

DSP domain - Signal digitization, encoding, interleaving, etc.

Modulation & Frequency translation

- Modulates the signal. Typically I/Q configuration is used in all contemporary transmitters. I/Q comes to translate the spectrum of the signal into a desired frequency band.

Power amplification - Increases the power of the transmitted signal. This is one of the last critical (and most expensive) part of the TX chain.

BE - Back end filter responsible for filtering the “out of band” emission from harmonic and intermodulation distortion.

Besides these fundamental components, transmitter chain may have many other components that perform filtering, impedance matching, etc.
**Channel Impairments**

Wireless channel distorts the signal in several ways:

1. **Attenuation**
2. **Fading**
3. **Non-linear distortion** (spectral spreading - Doppler shift)

**Attenuation**

1. **Free space**

\[ PL \approx 10 \log \left( \frac{d}{\lambda} \right)^2 \]  - path loss proportional to the square of the distance

\[
\begin{align*}
PL [\text{dB}] &= 36.5 + 20 \log d [\text{miles}] + 20 \log f [\text{MHz}] \\
PL [\text{dB}] &= 32.4 + 20 \log d [\text{km}] + 20 \log f [\text{MHz}] 
\end{align*}
\]

**Example**: Consider a wireless link operating at \( f = 1000\text{MHz} \). Calculate the path loss in dB if the transmitter and receiver are separated by 1 mile. Assume free space propagation.

\[
PL = 36.5 + 20 \log (1) + 20 \log (1000) = 96.5 \text{ dB}
\]

In linear domain:

\[
PL = 10 \log (10) = 10 \times 46.5 = 0.4667 \times 10
\]

The attenuation of the wireless channel is very large even in the free space propagation scenario.
2) Temporal propagation - large scale path loss

\[ PL(d) = PL(d_0) + m \log d + X_6 \]

- \( PL(d_0) \): path loss at some reference distance
- \( m \): slope \( \sim 40 \text{dB/dec} \)
- \( X_6 \): random component - log normal shadowing

Example: Consider cellular communication in a \( f = 850 \text{ MHz} \) band. If the cell site is 5 miles calculate the dynamic range of the UPL between \( d = 0.1 \) mile (close to the cell) and \( d = 5 \) miles (edge of the cell). Assume propagation parameters as \( PL(d_0) = 109 \text{ dB}, m = 38.4, X_6 = 0 \)

\[ PL(d=0.1) = PL(d_0) + m \log |d-0.1| = 109 + 38.4 \log |0.1| = 70.6 \text{ dB} \]

\[ PL(d=5) = PL(d_0) + m \log |d-5| = 109 + 38.4 \log |5| = 135.84 \text{ dB} \]

\[ DR = 135.84 - 70.6 = 65.24 \text{ dB} \rightarrow 3.34 \times 10^6 \text{ times} \]

* Note that RX would need to successfully operate in both cases so cellular phones need to have a very large dynamic range.
Fading

* Wireless channel is a multipath channel, where signal propagates along several different paths. At the Rx point, multiple copies of the signal add to form the composite signal. Sometimes they add constructively and the signal is amplified; but sometimes they add destructively and the signal is attenuated even cancelled. This behavior we call fading.

![Diagram of multipath propagation]

Rapid fluctuation of signal power due to fading introduced by multipath propagation.

Note: The receiver needs to be designed so that it can cope with signal fading. Some techniques that are used include: diversity, coding, interleaving and AGC.

Filling

Impulse response of the wireless channel

\[ y(t) = a_1 s_1(t-T_1) e^{j\omega_1 t} + a_2 s_2(t-T_2) e^{j\omega_2 t} + \text{noise} \]

\[ h(t) = \text{Power delay profile} \]

\[ x(t) \]

\[ 1|y(t)|^2 \]
Frequency response of the channel

\[ H(\omega) = \frac{F(f \times I(f))}{F(f \times H(f))} = \text{frequency selectivity} \]

\[ H(\omega, t) \]  
change of the wireless channel over time

Note: RX needs to cope with frequency selectivity (i.e., Aliasing) introduced by the channel \( \Rightarrow \) accomplished through the use of equalizer.

Other impairments that need to be taken into consideration:
1. Mobility - Doppler shift
2. Noise - Thermal noise + other sources of noise
3. Interference - co-channel & adjacent channel interference.

Therefore, RX has a very difficult task:
- Most of the design of the wireless system revolves around receiver complexity.
- The complexity is essentially dictated by the channel.
Block diagram of a typical RX circuit

- **BPFI** - Bandpass filter 1
- **BPFI** - High selectivity filter, whose responsibility is to reduce input noise and interference, so that LNA is not saturated.
- **LNA** - Low Noise Amplifier
- **BPFI** - Image rejection filter - attenuates interference on the image frequency.
- **LO** - Mixing stage local oscillator - downconversion from RF to IF.
- **BPFI** - Channel selection filter - highly selective filter picking up just the desired signal.
- **IF Amplifier** - Brings the signal within the desired range. It has hi linearity and input signal level, with automatic gain control (AGC) to take into account high dynamic range of the input signal.
- **Demodulator** - Demodulates received signal and recovers it from the impairments introduced by the channel. In modern receivers, this part is usually implemented in digital domain.

Most common RX architecture - superheterodyne RX (special case: zero IF receiver).

Superheterodyne principle - most of the processing is done at IF frequency. Signal is downconverted from RF to IF.