Background on wireless PHY layer
**RF Properties**

- **Understanding Radio Frequency**
  - Generation, coverage and propagation issues
  - Fundamental for wireless planning and management

- **Radio Frequency Signals**
  - Electromagnetic energy generated by high frequency alternate current (AC) in antennas
  - Antenna: converts the wired current to RF and vice versa

**Amplitude**
- Higher amplitude RF signals go farther
- Transmission Power (Watts) = Energy / Time = Joule / Sec
  - More energy (voltage) moves more electrons (current)
  - Power = Voltage * Current
**RF Properties**

- **Frequency (and Wavelength)**
  - Wireless Spectrum (see next slides)
  - Portion of wireless spectrum regulated by regional authorities and assigned to wireless technologies

![Graph showing frequency and wavelength](image)

**Wavelength** = \( \frac{c}{\text{frequency}} \)

E.g. 2.4 GHz (ISM band)

\[
\text{Wave Length} = \frac{300,000,000 \text{(m/s)}}{2,400,000,000 \text{ Hz}} = 0.125 \text{ m} = 12.5 \text{ cm}
\]

**In practice:**

Antennas work better with size = 1, \( \frac{1}{2} \), \( \frac{1}{4} \) of wavelength (try to measure antenna size of your IEEE 802.11 device)

---

**RF propagation**

- **Radio transmission coverage**

![Graph showing signal detection limit](image)

The range is a function of power transmission (Ptx)

Signal strength reduces with \( d^k \) (K=2..3, no obstacles, isotropic radiator)

\[
\text{In 3D, sphere: } V = \left(\frac{4 \pi r^3}{3}\right) \\
S = \left(4 \pi r^2\right)
\]
Wireless networks’ technology

- Radio transmission coverage

Rules of thumb:
- High frequencies are good for short distances and are affected by obstacles
- Low frequencies are good for long distances and are less affected by obstacles

Obstacles can reflect or absorb waves depending on materials and wave frequencies

RF Properties

- Phase: shift of the wave (in degrees or radians)
  - Positive phase (left-shift), early wavefront
  - Negative phase (right-shift), late wavefront

In practice:
RF echoes arriving at receivers with different phase may have positive or negative effects... Why?
RF Properties

- **Phase: shift of the wave (in degrees or radians)**
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In practice:
RF echoes arriving at receivers with different phase may have positive or negative effects... Why?
RF Properties

- **Polarization**: (physical orientation of antenna)
  - RF waves are made by two perpendicular fields:
    - Electric field and Magnetic field

  **E-plane (parallel to antenna)**
  **H-plane (perpendicular to antenna)**

**Electric Field** (parallel to antenna)

**Magnetic Field** (perpendicular to antenna)

**Radiating antenna element**

**Vertical Polarization**: typically used in WLANs

- OK: Transferred radiation OK
  - 100% radiation captured

- OK: Transferred radiation NO
  - 80% radiation captured
RF Properties

Vertical Polarization: the PCMCIA device problem

OK  Transferred radiation OK

100% radiation captured

OK  Transferred radiation NO

??% radiation captured

N.B. the polarization problem is very much important when using distant devices and directional antennas. With short distances signal reflections help!

RF Behaviors

- Radio transmission interference
Wireless transmission: Electromagnetic waves

- Different parameters of electromagnetic waves:
  - amplitude $M$ proportional to transmission energy (loudness)
  - frequency $f$ (tone) measured in Hertz (Cycle/sec)
  - phase $\varphi$ (peak shift with respect to reference signal) (rad)

![Frequency Spectrum]

- Higher Frequencies
- Lower Frequencies

Wireless transmission

- Signal Gain: (measured in Decibels, Db)
  - Increase in amplitude $M$ proportional to transmission energy
    - Active gain (amplifiers)
    - Passive gain (antennas focusing signal energy, and additive signal effects)

![Amplifier Diagram]

source

Amplifier

Amplitude

Additional energy

passive gain: a pitfall vs. regulations?
Wireless transmission

- **Signal Loss: (Db)**
  - Decrease in amplitude $M$ proportional to energy waste
    - Intentional (resistance, signal attenuation -> heat)
    - Obstacles, e.g. (walls, water for 2.4 Ghz) and distance (wireless)

Wireless signal propagation ranges

- **Transmission range**
  - communication possible
  - low error rate

- **Detection range**
  - detection of the signal possible
  - no communication possible

- **Interference range**
  - signal may not be detected
  - signal adds to the background noise

Ranges depend on receiver's sensitivity!
Wireless Signal propagation effects

- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$  
  $(d = \text{distance between sender and receiver})$
- Receiving power additionally influenced by
  - fading (frequency dependent)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges

Real world example

Raytracing examples

Low signal

high signal
**Multipath propagation**

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction

- Time dispersion: signal is dispersed over time
  - interference with “neighbor” symbols, Inter Symbol Interference (ISI)

- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

**Effects of mobility**

- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts

  - quick changes in the power received (short term fading)

- Additional changes in
  - distance to sender
  - obstacles further away

  - slow changes in the average power received (long term fading)
Voltage Standing Wave Ratio (VSWR)

- **VSWR occurs with different impedance (Ohm) = resistance to AC current flow between transmitter and antenna**
  - VSWR is the cause of “return loss” energy towards the transmitter
  - Measured as ratio between impedance (before and after)
    - E.g. 1.5:1 (impedance ratio before/after is 1.5 times the ideal value)
    - 1 = normalized ideal impedance (1:1 means perfect VSWR)
  - VSWR Causes burnout of transmitter circuits, and unstable output levels

VSWR solution:
always use sme impedance circuits, cables, connectors
(typical 50 Ω in LANs)

Intentional radiator and EIRP

- (Intentional) radiator: (def.) RF device specifically designed to generate and radiate RF signals.
  - Includes Tx RF device, cables and connectors (antenna excluded)
  - IR Power output: (subject to regulations) is the power output of last connector just before the antenna
  - Equivalent Isotropically Radiated Power (EIRP): the power radiated by the antenna (including the passive antenna gain effect of directional antennas)

Transmitter

Out imp. 50 Ω

Impedance “before”

VSWR 1:1

cable imp. 50 Ω

VSWR 1.5:1

cable imp. 75 Ω

Impedance “after”

Transmitter

Tx Out power 30mW

Cable: -3mw

Connector: -2mW

Connectors: -2mW

(IR) Power output: 30-14 = 16mW

EIRP (isotropic antenna): 16mW

EIRP (antenna gain +10dBi): 160mW
System design (under power viewpoint)

- Many factors must be considered in the design of Wireless systems:
  - Power of transmitting device
  - Loss and gain of connectivity devices (cables, connectors, attenuators, amplifiers, splitters) between transmission device and transmitter’s antenna
  - Power of the intentional radiator (last connector just before antenna)
  - Power radiated by antenna element (EIRP)
  - Propagation properties of the medium (attenuation before signal reception)
  - Loss and gain of connectivity devices (cables, connectors, attenuators, amplifiers, splitters) between receiver’s antenna and receiver device.

Power measurement

- **WATT**: electric power unit
  - 1 Watt = 1 Ampere * 1 Volt (P=V*I) also P= R*I^2 and P = L/t
    - Current (ampere) is the amount of charge (electrons) flowing as current in a wire
    - Voltage (Volt) is the “pressure” applied to the flow of charge
    - Resistance (impedance) is the obstacle to current flow
    - Power is the energy needed (in a given time unit) to apply a given “pressure” to a given “amount of charge”, by resulting in a flow of current.
  - Watt and dBm are units used for absolute power measurement

- Typical RF power for WLANs:
  - AP: 30..100 mW (up to 250 mW outdoor), PCMCIA: 15..30 mW
**Power measurement**

- **Decibel (dB):** a power measurement unit designed to express power loss
  - It is more practical to use given the logarithmic decay of wireless signals
  - It allows to make easy calculations on “resulting power”
- **Decibel (dB) measures the logarithmic relative strength between two signals (mW are a linear absolute measure of energy)**
  - \( \log_{10}(X) = Y \iff 10^Y = X \)
  - \( 1 = 10^0, \log_{10} (1) = 0 \)
  - \( 10 = 10^1, \log_{10} (10) = 1 \)
  - \( 100 = 10^2, \log_{10} (100) = 2 \)
  - \( 1000 = 10^3, \log_{10} (1000) = 3 \)
  - How strong is a 10 dB signal? (it depends on the reference signal)

- **Linear growth**
  - **“BEL” units (B)**
  - 1 = 100, \( \log_{10} (1) = 0 \)
  - 10 = 101, \( \log_{10} (10) = 1 \)
  - 100 = 102, \( \log_{10} (100) = 2 \)
  - 1000 = 103, \( \log_{10} (1000) = 3 \)

- **How strong is a 10 dB signal?** (it depends on the reference signal)
  - Positive dB value is power gain, negative dB value is power loss
  - e.g. given 7 mW power, a +10 dB signal gain is 70 mW
  - e.g. given 7 mW power, a -10 dB signal gain (loss) is 0.7 mW

- **Power Difference (in dB) between Tx and Rx signal:**
  - Power Difference (dB) = 10 * \( \log_{10}(\text{Power Tx(Watt)} / \text{Power Rx (Watt)}) \)

- Gain and Loss are relative power measurements: dB is the unit
Power measurement

- Advantage of dB: what is better?
  - A signal transmitted at 100 mW is received at 0.000005 mW
  - A signal transmitted at 100 mW is received with gain (loss) -73 dB

- Advantage of dB: what is better?
  - A signal transmitted at 100 mW is received at 0.000005 mW, then it is amplified (*100) to 0.0005 mW
  - A signal transmitted at 100 mW is received with gain (loss) -73+20 = -53 dB

<table>
<thead>
<tr>
<th>dB</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>-3 dB</td>
<td>½ power in mW (/ 2)</td>
</tr>
<tr>
<td>+3 dB</td>
<td>2x power in mW (* 2)</td>
</tr>
<tr>
<td>-10 dB</td>
<td>1/10 power in mW (/ 10)</td>
</tr>
<tr>
<td>+10 dB</td>
<td>10x power in mW (* 10)</td>
</tr>
</tbody>
</table>

Approximated table (values defined for ease of calculations)

Power measurement

- Practical example:
  - Signal Tx at 100 mW, cable –3dB loss, amplifier +10 dB gain
    - 100 mW / 2 (-3dB) = 50 mW * 10 (+10 dB) = 500 mW IR power output
  - Signal TX at 30 mW is received at the antenna as 6 mW
    - Intentional Radiator Gain (loss) = 30mW / 10 = 3mW *2 = 6 mW
    - Intentional Radiator Gain (loss) = -10 dB + 3 dB = -7 dB
  - N.B. dBs are additive measures of gain (loss): e.g. 6dB = +3+3 dB, 7dB = 10-3 dB
    - E.g. 100 mW –6 dB = 100 mW -3 -3 dB = 100 /2 /2 = 25 mW
    - E.g. 100 mW +7 dB = 100 mW +10 -3 dB = 100 *10 /2 = 500 mW
    - E.g. 10 mW + 5 dB = 10 mW (+10+10-3-3-3-3-3-3)dB = 1000/32 = 31.25 mW
    - E.g. 10 mW +11 dB = ?
    - E.g. 50 mW – 8 dB = ?

N.B. Approximated values (values defined for ease of calculations)
**Power measurement**

- **dBm**: dB-milliWatt, the absolute measure of signal power
  - Assumption: reference signal is 1 mW = 0 dBm (normalization factor)
  - Useful for gain/loss calculation without passing through mW
    - E.g. access point transmits 100 mW = 1mW (*10*10) = +20 dBm
    - PCMCIA card transmits at 30 mW = 1mW (*10*3) = +13 dBm
  - E.g. Tx= 30 mW, cable –2 dB, amplifier +9 dB:
    - 30 mW = 1mW *10 *3 = 13 dBm
    - IR power: 13 dBm –2dB +9dB = 20 dBm (100 mW)
  - In general, for converting mW to dBm and viceversa:
    - \[ P_{dBm} = 10 \log(P_{mW}) \quad \text{and} \quad P_{mW} = 10^{(P_{dBm}/10)} \]

### mW - dBm: conversion table

<table>
<thead>
<tr>
<th>dBm</th>
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<th>dBm</th>
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<tbody>
<tr>
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<td>1</td>
<td>10</td>
<td>100</td>
<td>1</td>
<td>10</td>
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<td>μW</td>
<td>mW</td>
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<table>
<thead>
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<td>62,5</td>
<td>125</td>
<td>250</td>
<td>500</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>16</td>
</tr>
<tr>
<td>μW</td>
<td>μW</td>
<td>μW</td>
<td>μW</td>
<td>mW</td>
<td>mW</td>
<td>mW</td>
<td>mW</td>
<td>mW</td>
</tr>
</tbody>
</table>
**Power measurement**

- **dBi**: dB-isotropic, the normalized measure of antenna passive gain
  - Assumption: an isotropic radiator has 100% efficiency in radiating energy in uniform way in every direction (e.g. the Sun)
  - Antennas concentrate energy in non-isotropic way, resulting in passive gain (space dependent). Ideal antenna: zero length dipole

![Diagram of antenna directivity](image)

Q: If the antenna gain is 7 dBi in (x,y,z)?

- If an antenna located in the origin (0,0,0) has twice the radiated energy of an isotropic radiator in a given point (x,y,z), then the antenna gain in (x,y,z) can be defined as +3 dBi. If the energy is 10x the isotropic radiator, the gain is +10 dBi, etc.

![Preferred direction diagram](image)
Power measurement

- **dBi**: dB-isotropic, the normalized measure of antenna passive gain
  - Real antennas always have a preferred direction where the power is greater than isotropic radiator: gain is always positive in the preferred direction!
  - Example: 1 mW IR power applied to directional antenna with +10 dBi gain in the preferred direction, would translate in EIRP?
    - \( \text{EIRP} = 1 \text{mW} + 10 \text{dBi} = (10 \times) = 10 \text{mW EIRP} \)

  N.B. this does not mean that antenna generates more power! Antenna concentrates power in preferred direction.

**dBd**: dB-dipole, the normalized antenna passive gain vs. 2.14 dBi half-wave dipole

- Reference is a half wave dipole with 2.14 dBi gain in preferred direction!
- Conversion rule:
  - \( 0 \text{ dBd} = 2.14 \text{ dBi} \), \( \text{dBd} = (\text{dBi} - 2.14) \), \( \text{dBi} = (\text{dBd} + 2.14) \)
Power monitoring (e.g. IEEE 802.11 devices)

- (received) Power monitoring in IEEE 802.11 devices is needed for making device driver to work properly (typical sensitivity range is \([-90..+10\) dBm]):
  - Detect signal (below or above the sensitivity threshold?)
  - Detect signal power (selection of coding technique... That is bitrate!)
- Received Signal Strength Indicator (RSSI)
  - Index defined for IEEE 802.11 devices (check device analyzer, if any)
  - \(\text{RSSI} = \text{function (dBm or mW received)} = \text{pure number reported to device driver!}\)
  - Unfortunately the RSSI scale is not standard, that is, device dependent!
    - This fact does not allow to compare if device A receives better than device B (assuming different manufacturer) based on RSSI measurement
  - Problem: device A indicates maximum RSSI=255 (8 bits) with \(-10\) dBm signal (0.1 mW), and device B indicates maximum RSSI=32 (5 bits) with \(-15\) dBm (0.03 mW). Q: when both A and B in \(x,y,z\) receive \(-15\) dBm, which one is better device? That is, which one would you buy if you are a system admin?

Antennas

- Illustration of general issues
  - Convert electrical energy in RF waves (transmission), and RF waves in electrical energy (reception)
  - Size of antenna is related to RF frequency of transmission and reception
  - Shape (structure) of the antenna is related to RF radiation pattern
- Radiation patterns of different antenna types
- Positioning antennas
  - Maximum coverage of workspace
  - Security issues
- Real antenna types: omni-directional, semi-directional, highly-directional
**Omnidirectional antenna**

- Omni-directional antenna: radiates RF power equally in all directions around the vertical axis.

- Most common example: dipole antenna (see Access Points)
  - See how to make it (disclaimer: do not try this at home):
    - http://www.nodomainname.co.uk/Omnicolinear/2-4collinear.htm
    - http://www.tux.org/~bball/antenna/

Q: Why TV dipole is bigger?
A: 100 Mhz vs. 2.4 Ghz

**Omnidirectional antennas: simple dipoles**

- Real antennas are not isotropic radiators but, e.g., dipoles
  - shape of antenna proportional to wavelength

  ![Radiation pattern of a simple Hertzian dipole](image)

- Example: Radiation pattern of a simple Hertzian dipole

  - side view (xy-plane)
  - side view (yz-plane)
  - top view (xz-plane)

- Gain: maximum power in the direction of the main lobe compared to the power of an isotropic radiator (with the same average power)
Omnidirectional antennas: simple dipoles

- Dipole: passive gain is due to concentration (shape) of radiation

- Dipole: active gain is obtained with power amplifiers (needs external source of energy)

- N.B. near (below) the dipole the signal is weak! And better radiation is obtained in sub-areas around the dipole!

Problem: how and when to mount omidirectional antennas? And which gain is ok?

- Low Gain Dipole (e.g. 2 dBi)
- High Gain Dipole (e.g. 8..10 dBi), very flat coverage low signal in the proximity of the antenna

How: Ceiling? Wall? Client positions? Area? Many factors influence the planning...

When:
- need for uniform radio coverage around a central point
- Outdoor: point-to-multipoint connection (star topology)
**Omnidirectional antennas: simple dipoles**

- **Antenna Tilt**: degree of inclination of antenna with respect to perpendicular axis

  High Gain Dipole (e.g. 8..10 dBi), very flat coverage mounted on the ceiling

  ![Omnidirectional Antennas Diagram](image1)

  - Room A
  - Room B

- Some antennas allow a variable degrees **downtilt**.

- Half signal dispersed “in the sky”, 2nd half better exploited.

---

**Semi-directional antennas**

- **Patch** (flat antennas mounted on walls)

- **Panel** (flat antennas mounted on walls)

- **Yagi** (rod with tines sticking out)

  ![Semi-directional Antennas Diagram](image2)

  - Side view (xy-plane) Patch
  - Side view (yz-plane) Panel
  - Top view (xz-plane) Yagi

  **Beamwidth cone**: -3dB signal boundary off-axis

**Credits**: http://www.hdtvprimer.com/ANTENNASetypes.html
highly-directional antennas

- Parabolic Dish
- Grid

<table>
<thead>
<tr>
<th>Antenna type</th>
<th>H beamwidth</th>
<th>V beamwidth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omni-dir.</td>
<td>360°</td>
<td>7°.. 80°</td>
</tr>
<tr>
<td>Patch/panel</td>
<td>30°.. 180°</td>
<td>6°.. 90°</td>
</tr>
<tr>
<td>Yagi</td>
<td>30°.. 78°</td>
<td>14°.. 64°</td>
</tr>
<tr>
<td>Parabolic dish</td>
<td>4°.. 25°</td>
<td>4°.. 21°</td>
</tr>
</tbody>
</table>

Semi-directional antenna

Beamwidth cone:
-3dB signal boundary off-axis

Common use: Point-to-point link

Out of beam alignment

Up to 60 km (LOS)

Wind effect: better to have lower gain and wider beam
highly-directional antennas

- **Line of sight (LOS):**
  - Straight line between transmitter and receiver
  - No obstructions (outdoor long range reduces reflections)
  - Polarization is more important than in indoor scenarios

- **Fresnel Zone:** RF is not laser light, RF signals diffuse energy in space
  - Ellipse shaped area centered on the LOS axis
  - Most additive RF signal is concentrated in the Fresnel Zone
  - It is important that Fresnel Zone is free from obstacles

Red zone: additive phase signal

Yellow zone: inverse phase signal

- **Fresnel Zone (FZ):**
  - Blockage of Fresnel Zone causes link disruption
  - Caused by buildings, (growing) trees, foliage, etc.
  - Rule of thumb: < 20% obstruction of Fresnel Zone
  - Practical rule: calculate the radius of FZ leaving 60% unobstructed radius
    - \( R_{60\%} = 43.3 \times \sqrt{(d/4f)} \)
    - \( R_{100\%} = 72.2 \times \sqrt{(d/4f)} \)

1st FZ

2nd FZ

Point source
highly-directional antennas

- **Fresnel Zone (FZ)**
  - N.B. the FZ radius depends only on the distance d between antennas, and frequency f of RF signal!
  - Type of antenna, beam width (degree), and gain (dBi) have no effects!
    - E.g. +13 dBi Yagi (30 degree beam) vs. +24 dBi Dish (5 degrees) have the same FZ!!!!
  - In practice: if FZ is partially obstructed, it is not useful to use higher gain antennas (with small degree beam) !!!

![Fresnel Zone Diagram](image)

Consider the Earth bulge!!!

- Very long point-to-point connections may have more than 40% FZ obstructed by Earth surface! Earth Bulge height = h (feet) = D^2/8
- Minimum antenna height (link > 7 miles) H = (43.3 \sqrt{D/4F} ) + D^2/8
Sectorized-directional antennas

- Arrays of sectorized directional antennas

  ![Diagram of top view, 3 sector and top view, 6 sector sectorized antennas](image.png)

- Space multiplexing (channel reuse)

Azimuth and Elevation antenna charts

- Charts for understanding antenna coverage pattern
  - Azimuth chart (pattern seen from front/right/behind/left))
    - Obtained with spectrum analyzer with central antenna frequency
    - Signal measured in dB around the antenna
      - E.g. Dipole pattern: almost circular
      - E.g. yagi pattern: high in front, low beside
    - N.B. distance and Tx power is not relevant (signal strength in a location is relative to every other location in the chart, like with dB)
  - Elevation chart (pattern seen front/below/behind/above)
**Antennas: diversity**

- **Grouping of 2 or more antennas**
  - multi-element antenna arrays

- **Antenna diversity**
  - switched diversity, selection diversity
    - receiver chooses antenna with largest output
  - diversity combining
    - combine output power to produce gain
    - cophasing needed to avoid cancellation (phased antenna array... Requires processor)

![Diagram of antenna diversity](image)

**Path Loss**

- **Path Loss: RF signal “dispersion” (attenuation) as a function of distance**
  - E.g. Possible formulas (36.6 or 32.4)
    - Free space: Loss (in dB) = 36.6 + (20*log10(F)) + (20*log10(D))
    - F (Mhz), D (miles)

- **Link budget issue: 6 dB rule**
  - Each 6 dB increase in EIRP (signal x 4) implies double Tx range (e.g. see table below: 2.4Ghz Path Loss vs distance)

<table>
<thead>
<tr>
<th>Distance</th>
<th>Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 meters</td>
<td>-80.23 dB</td>
</tr>
<tr>
<td>200 meters</td>
<td>-86.25 dB</td>
</tr>
<tr>
<td>500 meters</td>
<td>-94.21 dB</td>
</tr>
<tr>
<td>1000 meters</td>
<td>-100.23 dB</td>
</tr>
<tr>
<td>2000 meters</td>
<td>-106.25 dB</td>
</tr>
<tr>
<td>5000 meters</td>
<td>-114.21 dB</td>
</tr>
<tr>
<td>10000 meters</td>
<td>-120.23 dB</td>
</tr>
</tbody>
</table>
**Link Budget Calculation**

- **“Link Budget” or “System Operating Margin”**
  - Excess of signal between transmitter and receiver
  - Calculated for outdoor point-to-point connections
  - Measured in dB (relative) or dBm or mW (absolute)
  - Calculation:
    - Receiver sensitivity RS (weakest detectable signal)
      - The lower the better: e.g. IEEE 802.11 card (see device manual), -95 dBm (1Mbps), -93 dBm (2 Mbps), -90 dBm (5.5 Mbps), -87 dBm (11 Mbps)
    - Link Budget: received power (in dBm) - RS (in dBm)
    - E.g. RS = -82 dBm, received power = -50 dBm
      - Link budget = -50 – (-82) = +32 dBm
    - This means the signal has margin of +32 dB before it becomes unviable

- **Fade margin**: extra margin for link budget (to cope with multipath variation in indoor/outdoor scenarios): typical [+10..+20] dB

**Link Budget Calculation: example**

- Example: design of transmission system, needs amplifier?

```
+24 dBi
100% Fresnel zone free
(10 Km = -120 dB)
+24 dBi

-2.4 dB
-0.7 dB
-1.3 dB
-1.0 dB

Total Gain= +15 dBm + 24 dBi + 24 dBi = +63 dB

Condition: (gain + loss) > (RS + fade margin)??
(+63 -130.8) > -82 + x ???
Received Power = 67.8 dBm
Link Budget = 67.8 - (-82) = +14.2 dBm

OK! Fade margin = +14.2 dBm
No need for amplifiers or high gain antennas

Transmitter
Transmission power = 15 dBm

Receiver
```

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