Short-Range Devices, Indoor Radio Propagation

1. Signification of power, dBm, logarithms, range wide and their relation

Radio signals are electromagnetic waves. Their radiated power attenuates in free space as a logarithmic function, meaning the signal becomes weaker the further it travels. Radio frequency (RF) output power is measured in milliwatt (mW) or, more useful in a logarithmic scale of decibels (dB), or decibels referenced to one mW of power (dBm). Here are some examples of how these scales relate:

1 mW	=	0 dBm	Relations:
2 mW	=	3 dBm	A 2-fold increase in power yields 3 dB of signal
4 mW	=	6 dBm	Every 6 dBm more power means a 2-fold range in free space
10 mW	=	10 dBm	A 10-fold increase in power yields 10 dB of signal
100 mW	=	20 dBm	A 100-fold increase in power yields 20 dB of signal

2. General requirements and general limitations of specific radio signals.

Short-range wireless applications typically operate in license-free frequency bands, also known as ISM (Industrial, Scientific, Medical) with limited power. The allowed frequencies and powers in these bands vary from country to country. The most common short-range license-free frequencies worldwide are:

* 2.4 GHz band - nearly worldwide

* 900 MHz bands - America, Japan and some other countries (aka Sub-GHz band)

* 868 MHz band – e.g. for Europe and some other countries (aka Sub-GHz band)

Independent of frequency and used technology, per definition, wireless “BER” (Bit Error Rates) are always orders of magnitude higher than for wired communications.

3. Basics about antenna design (requirements, efficiency and limitations)

EnOcean AN102, AN103…

4. Specific of Indoor Radio Propagation / Attenuation / Path loss

Short-range radio propagation indoors strongly depends on the particular building shape and structure. Propagation indoors is therefore very difficult to predict and results are never as planned. Keep in mind that usually planned distances are based on ideal conditions, meaning “as long as possible” with link quality always close to its limit. Indoor installations often include many reflective obstacles leading to numerous propagation paths. The received signal is therefore (other as in free space) a mix of these reflexions. Depending on the singular phase of all these signals, their amplitude can add or subtract each other at receiver input. In multiple path environments, simply moving the antenna position slightly (e.g. one quarter-wave distance) can significantly change the received signal strength. Remember, some obstacles are mobile; environment can change and metal is not your friend. Obstacles’ material, thickness and radio penetration angles (effective path length) are important. Material attenuation factor depends on specific radio wave length: the higher the frequency, the higher the attenuation. Sub-GHz frequencies are therefore clearly more suitable. Below only few usual used, just as orientation for all 900 MHz bands (EnOcean AN001)

Material	Range reduction %	Attenuation (dB)
Wood, plaster, glass uncoated	5 - 10	3-5
Brick, press board	10 - 30	6-10
Ferro concrete 200 mm	20 - 80	15-20
Metal, aluminium lining	80 - 95	90

In free space, 6 dB loss corresponds to half range. In one room, near field up to 5 m around antenna can be in best case considered as quasi "line of sight" (LoS). Beyond this, paths tend to be more complex, requiring planning rules of thumb more aggressive, like shown below.

To ensure fade margin requirements in a line of sight (LoS) application, never exceed 50% of the manufacturer's rated maximal range. This in itself yields a 6 dB fade margin (minimal requirements!)

Doubling the distance beyond a near field of 5 m <u>indoors</u> increases path loss by 10 to 15 dB, increasing with distance (obstacles).

As a first empiric rule, you can consider for typical indoors within 20 m radius a path loss L at 0.9 GHz:

L (dB) = L_{FS} (dB) + k (dB/m) · D (m), where L_{FS} = free space loss, D = distance and k = frequency dependent constant, in this case $k = 0.9$

Below some orientation only rough estimation values for real indoor path loss in 0.9 GHz band (in absence of obstruction walls between transmitter and receiver):

$$D = 5\text{ m: } L = 46 + 0.9 \times 5 = 51\text{ dB}$$

$$D = 10\text{ m: } L = 52 + 0.9 \times 10 = 61\text{ dB}$$

$$D = 20\text{ m: } L = 58 + 0.9 \times 20 = 76\text{ dB}$$

5. Range performance is not only a function of antennas and transmitted power

The more sensitive the radio receiver, the lower the power **S**ignal it can successfully receive, stretching right down to the **N**oise floor **S/N** (EnOcean AN007 & AN008). There is so much variety in specifications for radio sensitivity, that it is difficult to make a direct comparison between products. The most used specification refers to a particular bit error rate (BER) given for an ideal environment shielded from external noise. Because receiver sensitivity indicates how faint an input signal can be to be successfully decoded, the larger the absolute value, the better. Accordingly, for signal power expressed in dBm, the larger the absolute value of the (negative) number, the better the receiver sensitivity. For example, a receiver sensitivity of −98 dBm is better than a receiver sensitivity of −95 dBm by 3 dB, or a factor of two. In other words, at a specified frequency and data rate, a receiver with −98 dBm sensitivity can hear signals that are half the power of those heard by a receiver with −95 dBm sensitivity. Another important factor, especially in a noisy environment, is its selectivity. Avoiding and filtering environmental radio interferences (noise suppression) induced by e.g. own power supply, heavy external load (ballasts, dimmers, motors) or digital circuitry is an important factor to improve the receiver performance. Means, efficient antennas are mandatory for efficient transmitting (transmission is not affected by "noise floor"!) but not enough to guarantee an efficient reception too.

6. Radio noise (interferences) recognizing and avoiding situations where the radio interferences may hamper the installation.

RF background noise comes from many sources, ranging from power supplies (EnOcean AN101) and specific (heavy) loads to high frequency digital products and all forms of other interfering radio communications. That background noise establishes a noise floor, which is the level below the desired, weak radio signals are lost in the background noise or in worst case, affects the data integrity (EnOcean AN104). The noise floor is not constant and varies by frequency. Typically, the noise floor will be lower than the receiver sensitivity of your radio, so it will not be an important factor in your system. If however you are in an environment where high degrees of parasitic RF noise may exist in your frequency band, then use the noise floor figures instead of radio receiver sensitivity in your calculations. If you suspect this is the case, a simple site survey (e.g. using a Spectrum Analyser) to determine the noise floor value can be a high payoff investment. Some sources of interference may not be immediately obvious (e.g. even by own receiver / actuator).

7. Planning with enough reserve

Fade margin is a critical term to wireless success. Fade margin describes how many dB a received signal may be reduced by, without causing system performance to fall below an acceptable value. Walking away from a newly commissioned wireless installation without understanding how much fade margin exists is the number one cause of wireless issues.

Establishing a link budget reserve of > 6 dB will provide a high degree of assurance that the system will continue to operate effectively even in a variety of changing environmental conditions.

There are a number of creative ways to estimate fade margin of a system without investing in specialty gear, e.g. using a small 6 dB attenuator: if you lose communication when you install such attenuator in-line with one of your antennas, you do not have enough fade margins.

8. Using simple mathematics and logic when planning wireless installations.

Contrary to popular opinions, no black magic is required to make a reasonable prediction of the range wide of a given radio path. After understanding some propagation basics, we can apply these simple rules of thumb. The equation for successful wireless system implementation is:

TX power + TX antenna gain - Path loss - Cable loss + RX antenna gain – 6 dB fade margin > RX Radio sensitivity or (less commonly) RF noise floor

Note that most of the equation's parameters are easily to be found in the manufacturer's specifications. That leaves only path loss and, in cases of heavy RF interference, RF noise floor as the two parameters to be estimated or with sufficient safety margin fulfilled by your installation.

9. Planning in advance with repeaters as fall back option in critical environments

EnOcean AN001.

10. Avoiding cable loss

The high frequencies do not propagate particularly well through long cable and connectors. Use short, low-loss RF coax cable with the appropriate impedance (e.g. 50 Ω) between the receiver/transmitter and your antenna and ensure that all connectors are good quality and carefully installed. Calculate 0.3 dB loss per coaxial connector in addition to the cable attenuation/meter itself. Typical attenuation figures for popular cable types are listed below.

Typical Loss in dB per 10 meter of cable length for three representative 50 Ω coax cables:

Frequency	**RG-174**	**RG-58**	**LMR-400**
900 MHz	10	3	1
2.4 GHz	N.A.	10	2

Knowing and respecting these rules will help you make a reliable planning and avoid later range wide issues in field

Disclaimer