PRAXIS GUIDE

Real-life applications of Trusted Wireless

Application note
107594_en_00

1 Description

This application note describes feasible wireless paths. First, it describes the theoretical principles, before giving examples of wireless paths that have been installed successfully in different environments.

Order No.	Designation	Frequency	Description
2901541	RAD-2400-IFS	2400 MHz	Wireless transceiver with RS-232 and RS-485 interface, can be extended with I/O extension modules, including DIN rail connector, without antenna
2904909	RAD-868-IFS	868 MHz	
Other accessories such as antennas or adapter cables			

WARNING:
This application note does **not** replace the device-specific documents.
Please follow the safety notes in the associated packing slips and data sheets.

Make sure you always use the latest documentation.
It can be downloaded at phoenixcontact.net/products.

2 Table of contents

3 Basics

3.1 Selecting antenna cables and antennas

When installing a wireless system, it is very important that you use low-loss coaxial cables. Using an unsuitable cable may lead to considerable loss in performance which cannot be compensated by high antenna gain or by high transmission power. For every 3 dB of coaxial cable loss, half the transmission power will be lost before reaching the antenna. The received signal will also be reduced.

Areas of application of the different antenna types:

Omnidirectional antenna

- Numerous devices in different directions, e.g., in mesh networks or networks with repeaters
- Versatile applications
- Applications without a line of sight
  In reflective environments the signal can be received via an indirect route.

Directional antenna

- Large distances
- Point-to-point connections
- Stationary or linear mobile applications
- Multiple point-to-point paths, decoupling due to directivity and different polarization levels
- Wireless paths with obstacles such as hills, trees, forest

Circular polarized antenna

- Highly reflective environments (e.g., industrial areas, antenna installed near ground level)

You should select the antennas based on local conditions. You can mix different antenna types. If it makes sense to use an omnidirectional antenna at one end because reflections can be expected here, you do not necessarily have to also install an omnidirectional antenna at the other end. For example, it might be useful to install a directional antenna here since the signals are coming from a specific direction.

> i In a highly reflective environment: Use antennas with circular polarization. This will avoid polarization losses. You can also combine circularly and vertically polarized antennas.

3.2 Installing antennas

The single most important item affecting wireless system performance is the antenna system. Careful attention must be given to this part of an installation or the performance of the entire system will be compromised. You should use antennas specially designed for industrial use at the intended frequency of operation.

The following recommendations apply to all antenna installations:

Mounting location

- Install the antenna in an open area as far away as possible from any obstacles such as buildings, dense deciduous forest or metal objects.
- Choose a location that provides a clear signal path in the direction of the partner antenna. Installation on the top of a mast or on a control cabinet would be ideal. This allows for as much open space as possible around the antenna.
- The higher the position of the antenna, the greater is the achievable range.
- If two antennas are located in the same place, the distance between them should be at least 0.6 m in the vertical direction and 1 m in the horizontal direction. In the case of 868 MHz wireless systems, the required minimum distance should be even greater as the transmission power is higher.

Antenna cable and fastening

- In order to minimize signal losses, keep the antenna cable as short as possible.
- Outdoor antenna cables should always run to the antenna from below.
- Run the antenna cable inside the mast or fasten it to the outside of the mast with UV-resistant cable binders.
- In particular with regard to directional antennas, it is important to ensure that the antenna is properly secured. If the antenna sways in the wind, the transmission or reception beam can move out of its target area.
- Always make sure that screws, connectors, and cables are securely tightened (use a torque spanner, if necessary).
- In outdoor applications, use RAD-TAPE-SV-19-3 vulcanizing sealing tape (Order No. 2903182) to protect adapters, cable connections, etc.

Antenna, surge protection, and grounding

- Note the polarization of the antenna. Most systems use a vertically polarized omnidirectional antenna at the master station. The partner antennas must therefore be polarized vertically. Vertical polarization means that the elements are aligned vertically to the horizon. Crossing polarization between the stations results in a signal loss of 20 dB, minimum.
- The higher the gain on an antenna, the smaller is the angle of radiation (aperture angle). For a small angle, you need to precisely align the antennas with each other.
- For outdoor applications: Use antenna surge protection with cable lengths starting from three meters. The antenna is grounded via the surge protection.
- The antenna mast must be grounded in accordance with national regulations.
- We recommend using a grounding cable with a 16 mm^2 cross section.

3.3 Equivalent isotropically radiated power (EIRP)

The equivalent isotropically radiated power (EIRP) is a gauge of the radiation power of an antenna. The EIRP value is the sum of the transmission power in dBm and the antenna gain in dBi.

Observe the maximum permissible radiated power at the antenna.

- 2.4 GHz:
  - 20 dBm (outside Europe)
  - In Europe depending on the transmission speed, default setting: 18 dBm and 125 kbps
- 868 MHz: 27 dBm

• Reduce the device transmission power via the PSI-CONF software, if necessary.

3.4 Receiver sensitivity

The receiver sensitivity determines the signal amplitude which can just about be received by the wireless module. The lower the data transmission speed of the wireless interface, the higher the receiver sensitivity and therefore the range.

Data rate of the wireless interface	Receiver sensitivity	
	RAD-2400-IFS	RAD-868-IFS
16 kbps	-106 dBm	-
125 kbps	-96 dBm	-
250 kbps	-93 dBm	-
1.2 kbps	-	-122 dBm
9.6 kbps	-	-114 dBm
19.2 kbps	-	-111 dBm
60 kbps	-	-104 dBm
120 kbps	-	-103 dBm

Example

The receiver sensitivity of a 2.4 GHz Radioline system with a data rate of 125 kbps is -96 dBm. You also need to allow for a system reserve of 10 dB. This means, a signal level of -86 dBm should be present at the antenna connection (see 3.10 “System calculation in free space”).

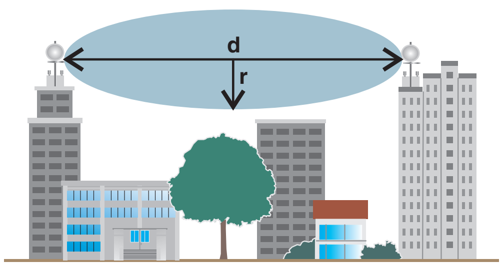
3.5 RSSI value

The RSSI value provides information on the signal strength of the wireless signal received. The value is specified in volts (0 V ... 3 V). The higher the RSSI value, the better the wireless connection. The system reserve with an RSSI value of 1.5 V is approx. 10 dB.

With all Radioline wireless modules, you can read the RSSI value from the LED bar graph. For example, a green LED corresponds to RSSI values between 1.5 V and 2 V. You can also measure the value using a multimeter at the RSSI test socket. The value you will get is significantly more exact than the LED bar graph display, and it is useful for antenna alignment.

3.6 Planning the wireless path

Fresnel zone



Wireless path distance (d)	Radius of the Fresnel zone (r)	
	2.4 GHz	868 MHz
200 m	1.5 m	4.2 m
500 m	4 m	6.6 m
1000 m	5 m	9.3 m
2000 m	8 m	13.1 m
4000 m	11 m	18.6 m
10 km	-	24.4 m
20 km	-	41.5 m

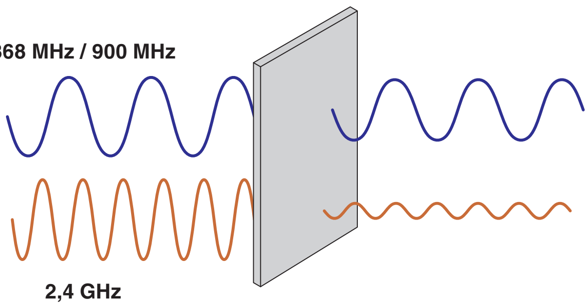
A certain area between the transmitting and receiving antennas on the wireless path is referred to as the Fresnel zone. There should be a line of sight between the antennas, especially when covering with large distances. In order to stay within the Fresnel zone, it might be necessary to install the antennas at a height of a few meters. This area should also be free from any other obstacles.

> **i** To achieve the necessary antenna height, it can be helpful to position the antenna on a hill or building.

The ideal wireless path with a direct line of sight between transmitter and receiver is not always possible. In real-life applications, obstacles that affect the wireless channel often have to be taken into account. The wireless path can work even if obstacles such as houses and trees are within the Fresnel zone. The decisive factor is the number of obstacles and the area they occupy in the Fresnel zone. In this case, test measurements should be performed.

3.7 Differences between 2.4 GHz and 868 MHz

2.4 GHz and 868 MHz wireless systems have different characteristics due to the wavelength. Lower frequencies can overcome obstacles more easily. They also support longer ranges.



The 2.4 GHz and 868 MHz frequency bands are subject to various directives. 20 dBm maximum (100 mW) may be transmitted in the 2.4 GHz frequency band. In the 868 MHz frequency band, the transmission power may reach 27 dBm (500 mW). Due to the higher transmission power in the 868 MHz frequency band, longer ranges can also be achieved.

Duty cycle in the 868 MHz band

The duty cycle or holding period refers to the legally regulated period of use for the medium. The aim of this regulation is to ensure the function of all devices operating in the 868 MHz band.

In the 869.4 MHz ... 869.65 MHz frequency band, the maximum transmission time is 10% of one hour (6 minutes). The duty cycle is not usually reached during operation, since only low volumes of data (I/O signals or serial data) are transmitted.

3.8 Range

Specifying ranges is very difficult due to the influence of various factors. Based on practical tests, it is possible to provide the following guideline values. They may be significantly higher or lower depending on the actual application. For tables with guideline values with a line of sight, refer to the next page.

The range depends on the following:

- The data rate that was set
  - 2.4 GHz: a default setting of 125 kbps
  - 868 MHz: a default setting of 9.6 kbps
- Length of the antenna cable
- Antenna used
- Line of sight
- Adherence to the Fresnel zone

Antenna, 2.4 GHz	Data rate of the wireless interface	Range
Inside buildings		
Omnidirectional antenna, 2 dBi	≤ 250 kbps	50 ... 100 m
	≤ 125 kbps	100 ... 200 m
Outside buildings, with a free line of sight		
Omnidirectional antenna, 2 dBi	≤ 250 kbps	50 ... 100 m
	≤ 125 kbps	100 ... 200 m
Omnidirectional antenna, 6 dBi	≤ 125 kbps	≤ 1500 m (Europe: ≤ 1000 m)
Panel antenna, 8 dBi or 9 dBi	≤ 125 kbps	≤ 3000 m (Europe: ≤ 2000 m)
	16 kbps	≤ 5000 m (Europe: ≤ 3000 m)
Parabolic antenna, 19 dBi	16 kbps	> 5000 m (Europe: > 3000 m)

Antenna, 868 MHz	Data rate of the wireless interface	Maximum range
Outside buildings, with a free line of sight		
Omnidirectional antenna, 4 dBi	120 kbps	4 km
	60 kbps	5 km
	19.2 kbps	8 km
	9.6 kbps	9 km
	1.2 kbps	11 km
Panel antenna, 4 dBi	120 kbps	5 km
	60 kbps	6 km
	19.2 kbps	9 km
	9.6 kbps	10 km
	1.2 kbps	13 km
Yagi antenna, 8 dBi	120 kbps	7 km
	60 kbps	8 km
	19.2 kbps	12 km
	9.6 kbps	15 km
	1.2 kbps	18 km
Yagi antenna, 12 dBi	120 kbps	8 km
	60 kbps	10 km
	19.2 kbps	15 km
	9.6 kbps	20 km
	1.2 kbps	25 km

3.9 Delay time

Among other things, the delay time depends on the following factors:

- Frequency band used
- Capacity of the frequency band
- Network structure
- Distance and data rate of the wireless interface
- Data encryption

Due to the legally required duty cycle of 10 %, the delay time in the 868 MHz band is significantly higher than in the 2.4 GHz band. However, significantly greater ranges can be achieved with the 868 MHz band.

Example for 2.4 GHz:

Point-to-point connection, data rate of 125 kbps

- I/O mode: 200 ms
- Serial data mode: 25 ms (unidirectional, telegram length: 49 bytes)

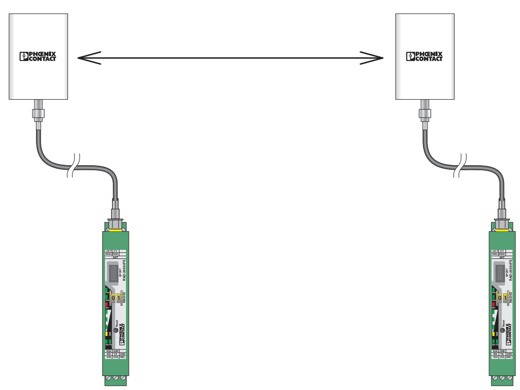
Example for 868 MHz:

Point-to-point connection, data rate of 9.6 kbps

- I/O mode: 1 second
- Serial data mode: 390 ms (unidirectional, telegram length: 17 bytes)

These are typical delay times that have been determined under laboratory conditions for frequency bands without any interference. The delay times may be higher or lower in practice. The delay time is roughly doubled with each repeater in the network.

3.10 System calculation in free space



- Antenna gain per antenna: 8 dBi
- Transmission power per wireless module: 14 dBm
- Cable attenuation per cable (3 m EF 142): 2.85 dB
- Free space path loss 400 m: 92 dB

Example calculation for 2.4 GHz with optimum free space:

- Length of the wireless path: 400 m
- Device transmission power + Antenna gain - Cable attenuation (EIRP): ≤ 20 dBm

EIRP [dBm] =
Transmitter power [dBm]
+ Gain of transmitting antennas [dBi]
- Losses of the transmitter cable [dB]

Incoming power for the receiver [dBm] =
Transmitter power [dBm]
- Losses of the transmitter cable [dB]
+ Gain of the transmitting antenna [dBi]
- Free space path loss [dB]
+ Gain of the receiving antenna [dBi]
- Attenuation of the antenna cable at the receiver [dBm]

System reserve =
receiver sensitivity [dBm]
- incoming power for the receiver [dBm]
(recommended system reserve >10 dB)

- EIRP = 19.15 dBm
- Free space path loss, D_L [dB]:
  D_L = 32.4 + 20log(R[km]) + 20log(f[MHz])
  = 32.4 + 20log(0.4 km) + 20 log(2400 MHz)
  = -92 dB
- Incoming power for the receiver = -67.7 dBm
- Receiver sensitivity = -96 dB (with a data rate of 125 kbps)
- System reserve = |-96 dB| - |-67.7 dB| = 28.3 dB
  28.3 dB > 10 dB

Conclusion: The losses of -67.7 dB are significantly lower than the receiver sensitivity of -96 dB. The desired wireless connection is therefore possible in mathematical terms.

3.11 Practical examples

It is not possible to provide basic calculation principles for obstacles in the wireless path as the obstacles and applications will vary too much. The practical examples given below are for guidance only. They cannot be directly transferred to other applications.

The bush illustrated below is two meters wide. It has an attenuation of approximately 15 dB for 2.4 GHz. For 868 MHz, the attenuation is around 8 dB.

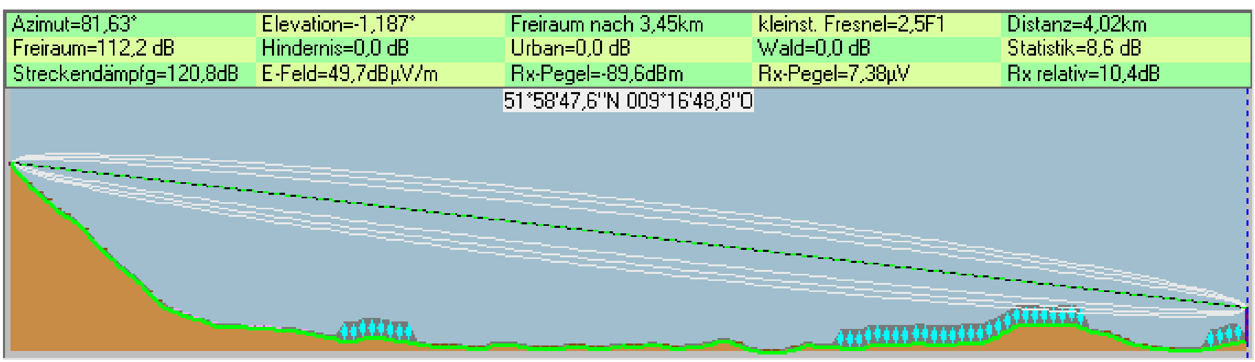
The forest illustrated below consists of dense undergrowth with a trunk diameter of approximately 5 to 20 centimeters. In our test, the 2.4 GHz wireless signal was transmitted through a 25 m forest. The attenuation was around 40 dB. For 868 MHz, the attenuation is around 22 dB.

4 Examples of wireless paths

The “Radio Mobile” freeware was used to take the following screenshots of wireless paths.
(Coude, Roger: http://www.cplus.org/rmw/download/download.html)

4.1 Wireless path 1 (2.4 GHz, point-to-point)

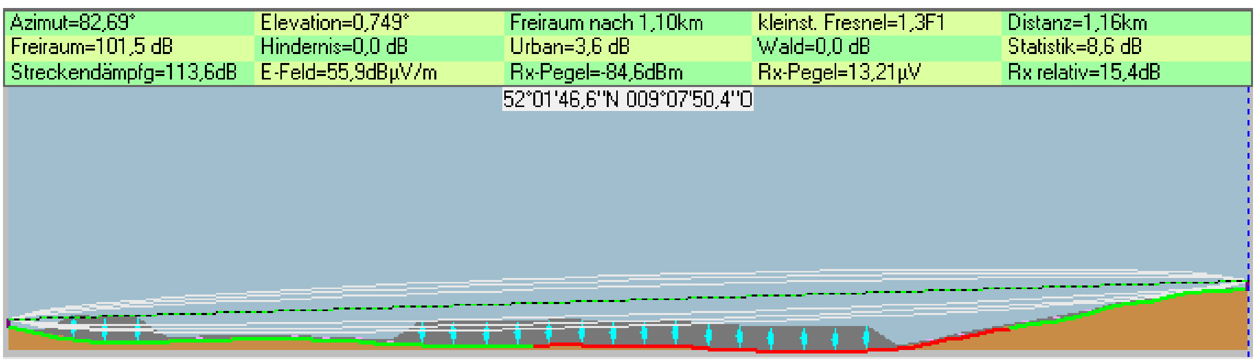
Station 1			Station 2	
Height of the station	193 m		Height of the station	100 m
Wireless module	RAD-2400-IFS (slave)		Wireless module	RAD-2400-IFS (master)
Antenna height	2.5 m (mast)		Antenna height	17 m (on the roof)
Antenna	Omnidirectional antenna, 6 dBi		Antenna	Panel antenna, 8 dBi
Antenna cable	3 m (-1.8 dB of attenuation)		Antenna cable	3 m (-1.8 dB of attenuation)
Data rate	125 kbps		Data rate	125 kbps
Transmission power	14 dBm		Transmission power	12 dBm



Obstacles	Free line of sight
Distance	approx. 4 km
Feasible	Yes (RSSI value = 1.58 V)
Relative RX (recommended reserve: 10 dB)	10.4 dB

4.2 Wireless path 2 (2.4 GHz, point-to-point)

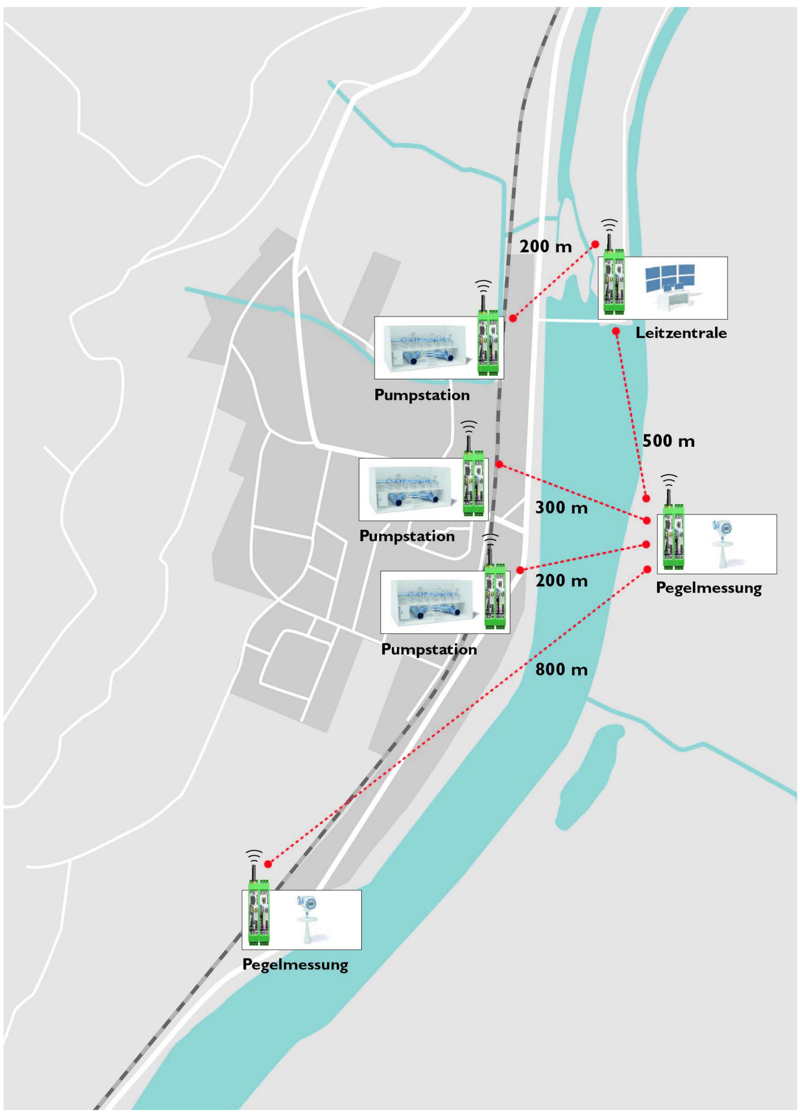
Station 1			Station 2	
Height of the station	269 m		Height of the station	286 m
Wireless module	RAD-2400-IFS (master)		Wireless module	RAD-2400-IFS (slave)
Antenna height	3 m (mast)		Antenna height	3 m (mast)
Antenna	Panel antenna, 8 dBi		Antenna	Panel antenna, 8 dBi
Antenna cable	5 m (-2.9 dB of attenuation)		Antenna cable	5 m (-2.9 dB of attenuation)
Data rate	125 kbps		Data rate	125 kbps
Transmission power	13 dBm		Transmission power	13 dBm



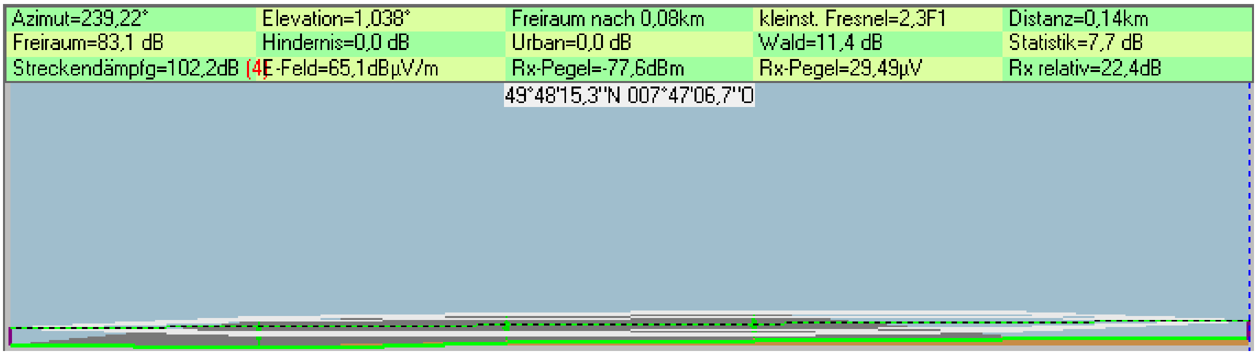
Obstacles	Few trees Because of the difference in altitude between the two stations, the buildings in the wireless path pose no problem.
Distance	approx. 1.2 km
Feasible	Yes (RSSI value = 1.78 V)
Relative RX (recommended reserve: 10 dB)	15.4 dB

4.3 Wireless path 3 (2.4 GHz, mesh network)

Station 1			Station 2	
Height of the station	124 m		Height of the station	123 m
Wireless module	RAD-2400-IFS (master)		Wireless module	RAD-2400-IFS (repeater/slave)
Antenna height	5 m (mast)		Antenna height	5 m (mast)
Antenna	Omnidirectional antenna, 6 dBi		Antenna	Omnidirectional antenna, 6 dBi
Antenna cable	5 m (-2.9 dB of attenuation)		Antenna cable	5 m (-2.9 dB of attenuation)
Data rate	125 kbps		Data rate	125 kbps
Transmission power	15 dBm		Transmission power	15 dBm



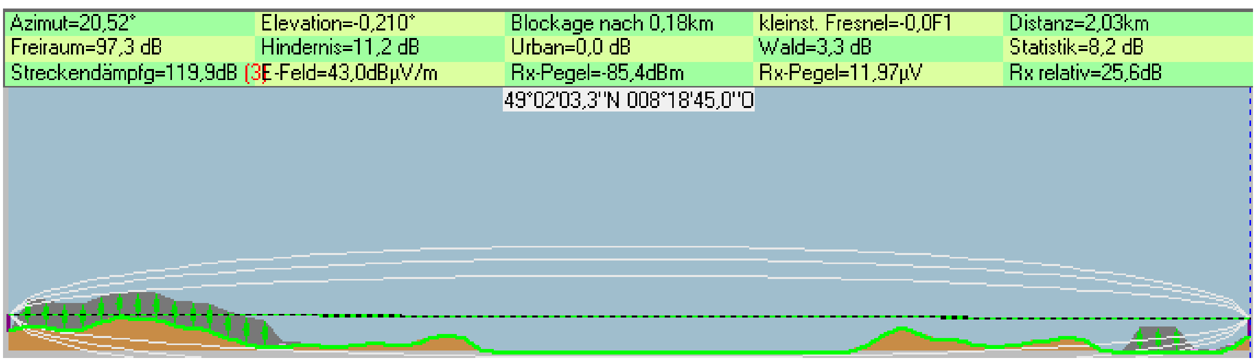
Station 1		Station 2



Obstacles	Few trees, few buildings
Distance	0.2 km ... 1.2 km
Feasible	Yes (RSSI value = 2.2 V ... 3 V) The Radioline system installed is a mesh network. Via repeaters/slaves, all remote stations are connected to the wireless master.
Relative RX (recommended reserve: 10 dB)	22.4 dB

4.4 Wireless path 4 (868 MHz, point-to-point)

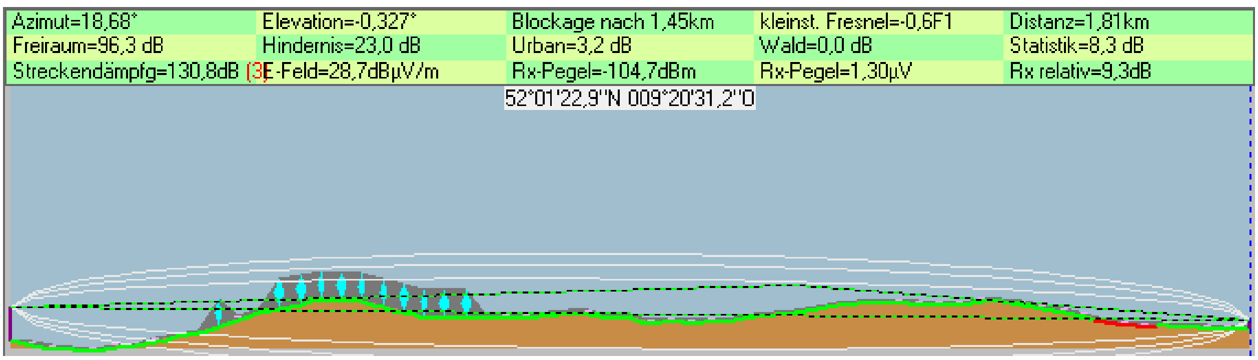
Station 1			Station 2	
Height of the station	108 m		Height of the station	109 m
Wireless module	RAD-868-IFS (master)		Wireless module	RAD-868-IFS (slave)
Antenna height	5 m (mast)		Antenna height	5 m (mast)
Antenna	Omnidirectional antenna, 4 dBi		Antenna	Yagi antenna, 12 dBi
Antenna cable	5 m (-1.6 dB of attenuation)		Antenna cable	10 m (-2.9 dB of attenuation)
Data rate	9.6 kbps		Data rate	9.6 kbps
Transmission power	25 dBm		Transmission power	18 dBm



Obstacles	approx. 350 m of forest, many trees and hills in the Fresnel zone
Distance	2 km
Feasible	Yes (RSSI value = 2.1 V)
Relative RX (recommended reserve: 10 dB)	25.6 dB

4.5 Wireless path 5 (868 MHz, point-to-point)

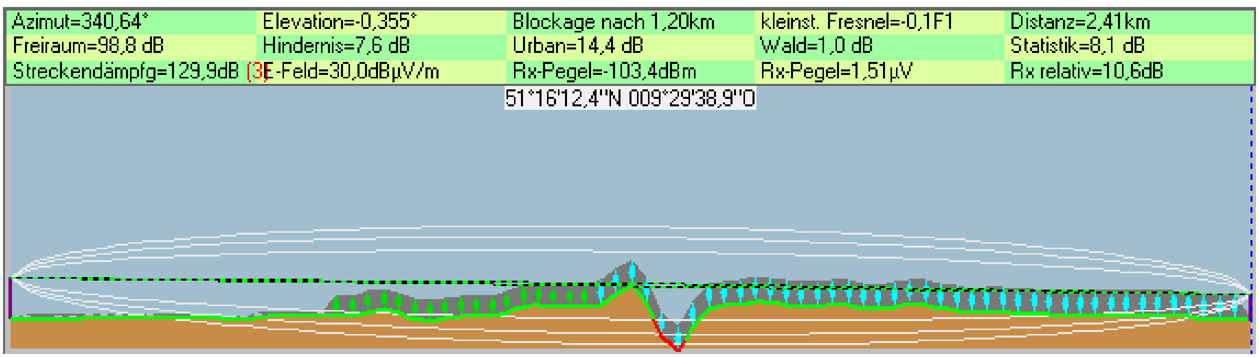
Station 1			Station 2	
Height of the station	88 m		Height of the station	93 m
Wireless module	RAD-868-IFS (master)		Wireless module	RAD-868-IFS (slave)
Antenna height	5 m (mast)		Antenna height	0.5 m (in a GFK cabinet)
Antenna	Yagi antenna, 12 dBi		Antenna	Panel antenna, 4 dBi
Antenna cable	5 m (-1.6 dB of attenuation)		Antenna cable	0.5 m (-0.4 dB of attenuation)
Data rate	9.6 kbps		Data rate	9.6 kbps
Transmission power	17 dBm		Transmission power	23 dBm



Obstacles	A few buildings, trees, and hills in the Fresnel zone
Distance	1.8 km
Feasible	Yes (RSSI value = 1.46 V) A circular polarized panel antenna mounted near ground level allows for a stable wireless connection, because it receives both horizontally and vertically polarized radio waves.
Relative RX (recommended reserve: 10 dB)	9.3 dB

4.6 Wireless path 6 (868 MHz, point-to-point)

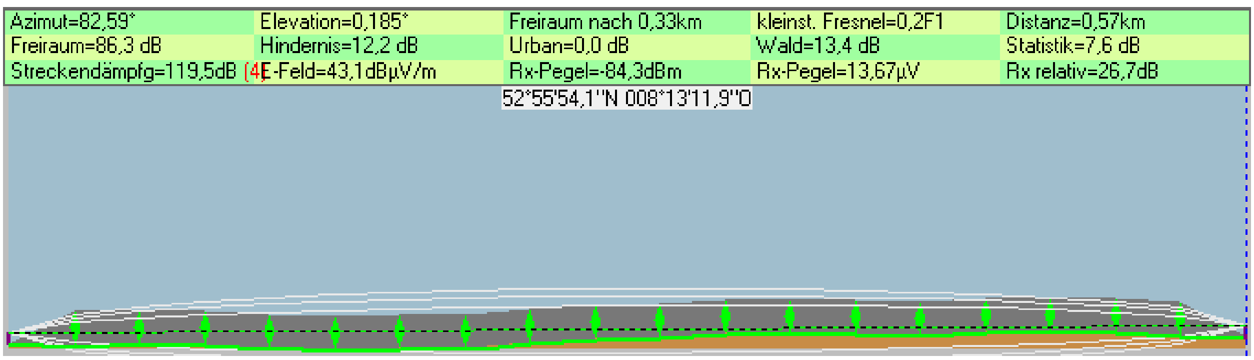
Station 1			**Station 2**	
Height of the station	145 m		Height of the station	140 m
Wireless module	RAD-868-IFS (master)		Wireless module	RAD-868-IFS (slave)
Antenna height	5 m (mast)		Antenna height	3 m (mast)
Antenna	Yagi antenna, 12 dBi		Antenna	Omnidirectional antenna, 4 dBi
Antenna cable	5 m (-1.6 dB of attenuation)		Antenna cable	5 m (-1.6 dB of attenuation)
Data rate	9.6 kbps		Data rate	9.6 kbps
Transmission power	17 dBm		Transmission power	25 dBm



Obstacles	A few buildings, trees, and a highway bridge in the Fresnel zone
Distance	2.4 km
Feasible	Yes (RSSI value = 1.6 V) It is possible for the radio waves to pass below the bridge.
Relative RX (recommended reserve: 10 dB)	10.6 dB

4.7 Wireless path 7 (868 MHz, point-to-point)

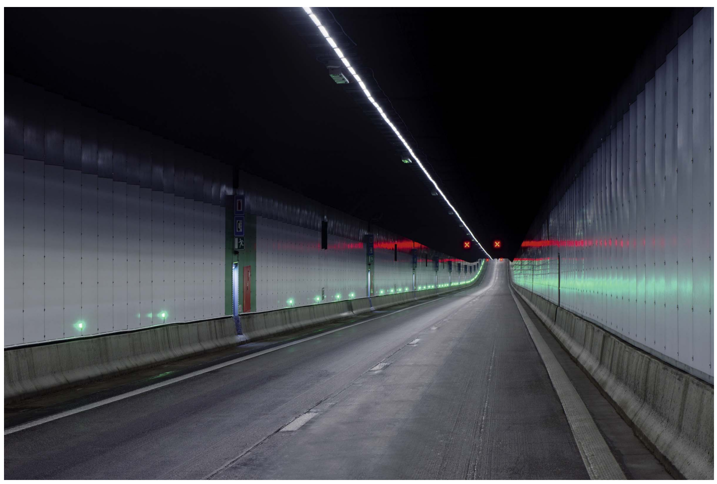
Station 1			Station 2	
Height of the station	44 m		Height of the station	46 m
Wireless module	RAD-868-IFS (master)		Wireless module	RAD-868-IFS (slave)
Antenna height	3.5 m (mast)		Antenna height	3.5 m (mast)
Antenna	Yagi antenna, 12 dBi		Antenna	Yagi antenna, 12 dBi
Antenna cable	10 m (-2.9 dB of attenuation)		Antenna cable	10 m (-2.9 dB of attenuation)
Data rate	9.6 kbps		Data rate	9.6 kbps
Transmission power	17 dBm		Transmission power	17 dBm



Obstacles	Very dense forest in the Fresnel zone
Distance	0.6 km
Feasible	Yes (RSSI value = 2 V) The Yagi antennas enable radio transmission through the forest.
Relative RX (recommended reserve: 10 dB)	26.7 dB

4.8 Wireless path 8 (868 MHz, point-to-point)

Station 1			**Station 2**	
Height of the station	0.3 m		Height of the station	4.5 m
Wireless module	RAD-868-IFS (master)		Wireless module	RAD-868-IFS (slave)
Antenna height	2 m		Antenna height	2 m
Antenna	Omnidirectional antenna, 4 dBi		Antenna	Omnidirectional antenna, 4 dBi
Antenna cable	3 m (-1 dB of attenuation)		Antenna cable	3 m (-1 dB of attenuation)
Data rate	9.6 kbps		Data rate	9.6 kbps
Transmission power	24 dBm		Transmission power	24 dBm

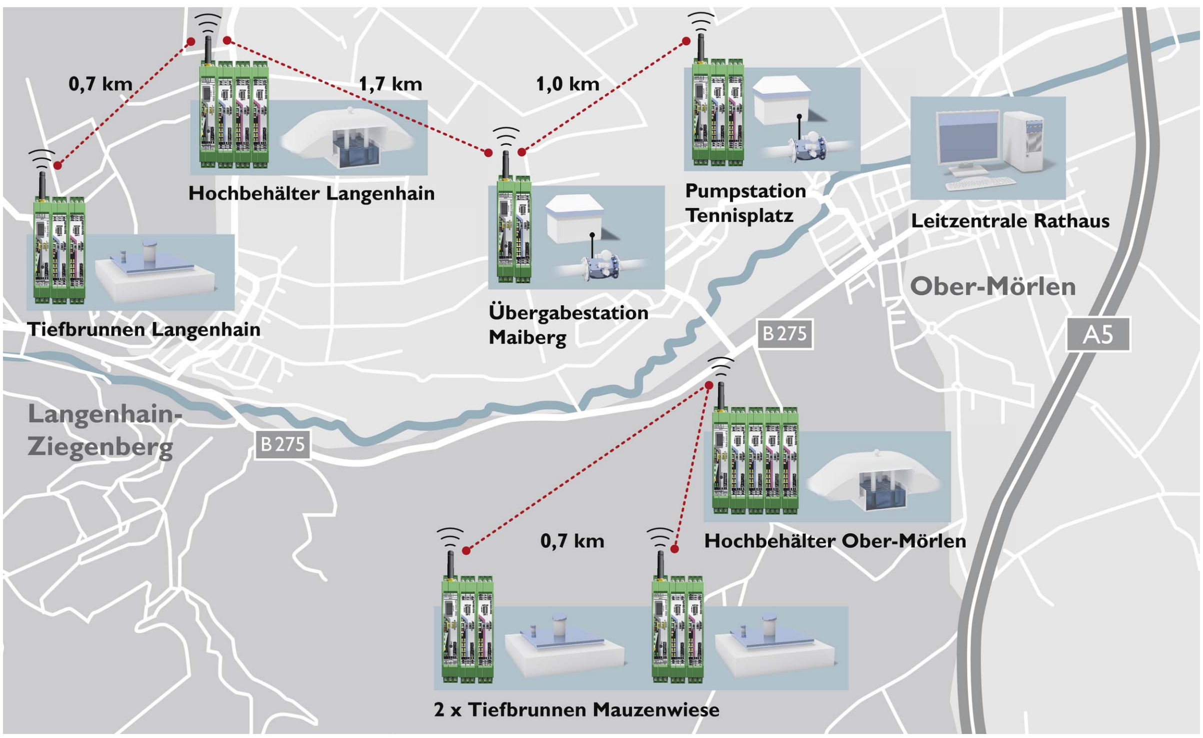


(Sample photo)

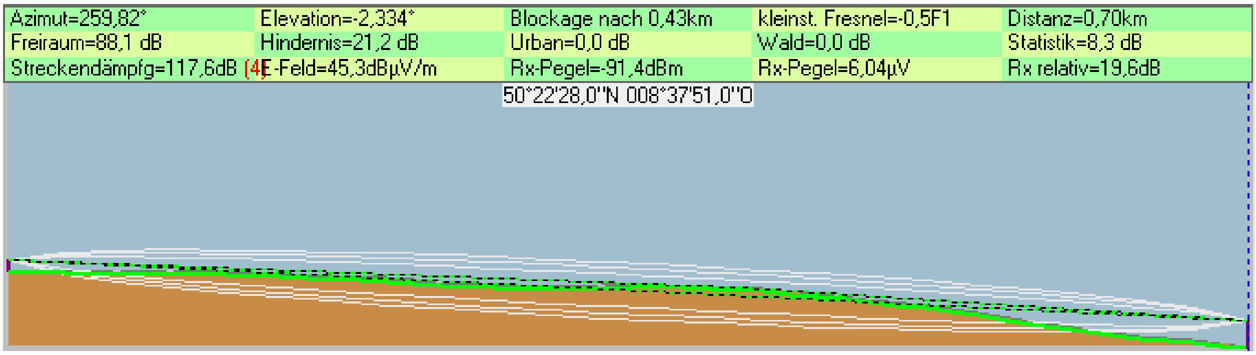
Obstacles	No line of sight The tunnel has bends and a difference in altitude between tunnel entrance and exit.
Distance	1.4 km
Feasible	Yes (RSSI value = 2.5 V) The radio waves are reflected by the tunnel walls. Similar values were achieved by using 2.4 GHz wireless modules (RAD-2400-IFS).

4.9 Wireless path 9 (868 MHz, mesh network)

Station 1			Station 2	
Height of the station	229 m		Height of the station	177 m
Wireless module	RAD-868-IFS (master)		Wireless module	RAD-868-IFS (repeater/slave)
Antenna height	5 m		Antenna height	5 m
Antenna	Omnidirectional antenna, 4 dBi		Antenna	Omnidirectional antenna, 4 dBi
Antenna cable	10 m (-2.9 dB of attenuation)		Antenna cable	15 m (-4.3 dB of attenuation)
Data rate	9.6 kbps		Data rate	9.6 kbps
Transmission power	27 dBm		Transmission power	27 dBm



Station 1		Station 2



Obstacles	No line of sight, a few hills in the wireless path
Distance	0.7 km ... 2 km
Feasible	Yes (RSSI value = 2 V ... 2.7 V) The Radioline system installed is a mesh network. Via repeaters/slaves, all remote stations are connected to the wireless master.
Relative RX (recommended reserve: 10 dB)	19.6 dB

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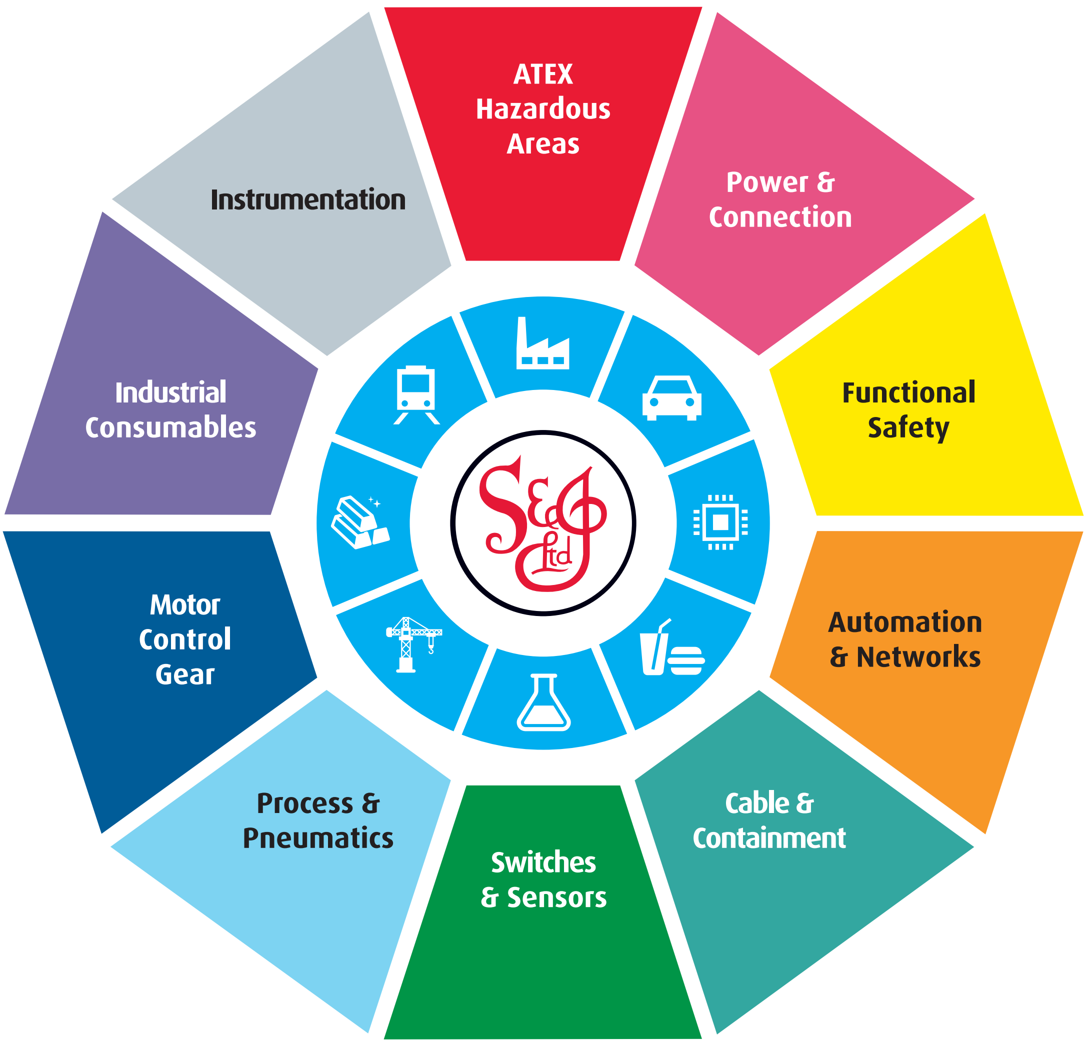

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