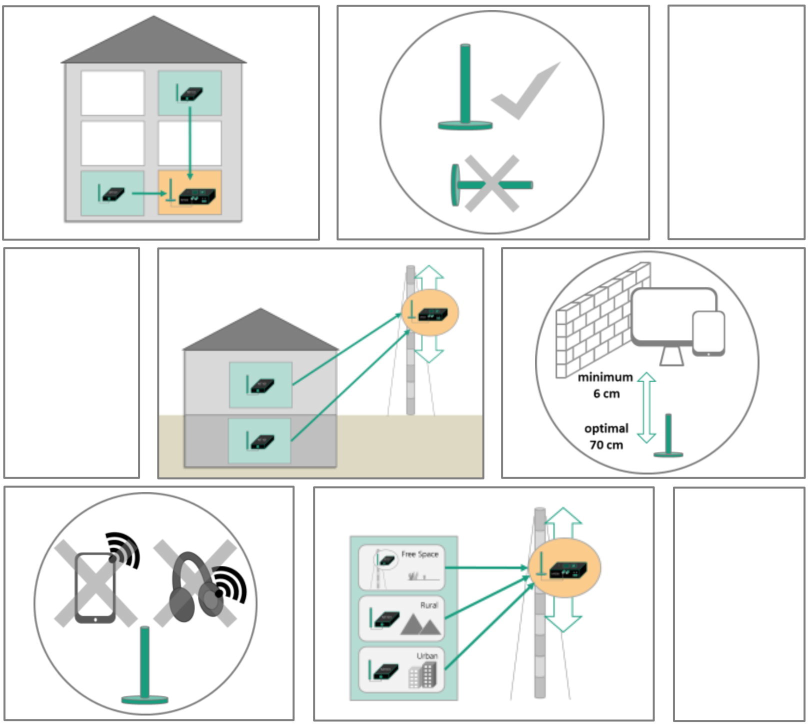
FRAUNHOFER INSTITUTE FOR INTEGRATED CIRCUITS IIS

MIOTY™ – ANTENNA SETUP

USER GUIDE



Published by
Fraunhofer Institute for Integrated Circuits IIS, Erlangen

Communication Systems Division; Dr. Gerd Kilian
Positioning and Networks Division; Josef Bernhard
Author: Prof. Dr. Thomas Lauterbach

This User Guide will help you to find the best places for the transmitters and the base station receiver of the MIOTY™ system to obtain optimum operating distance.

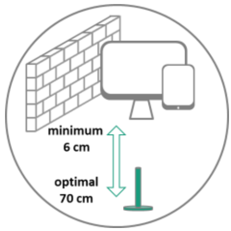
Some general rules will be provided which you should have in mind when placing the devices and you will get some indication which operating distances you may expect in typical usage scenarios.

1 Considerations for Equipment Setup

For obtaining optimum performance, the following notes should be considered when placing your MIOTY™ equipment:

Transmitter:

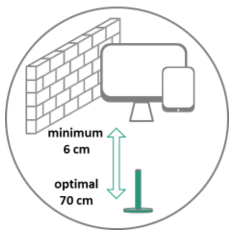
- Keep the transmitting antenna clear of other items, in particular electrically conducting ones, and of walls. The absolute minimum distance should be 6 cm, if possible 70 cm. Otherwise, items in the vicinity of the transmitter will absorb power from the radiation field which will cause the effective transmitter power and hence the operating distance to decrease.



- The transmitter antenna should be vertical. This gives the best omnidirectional radiation performance. If it has to be placed horizontally, it should not point in the direction of the receiver.

Receiver:

- Keep the receiving antenna clear of other items, in particular electrically conducting ones, of walls, and of electronic equipment (e.g. PC, monitor, LED lighting, etc.). The absolute minimum distance is 6 cm, if possible 70 cm should be maintained. Otherwise, items in the vicinity of the receiver may influence the directivity of the receiving antenna or the receiver may suffer from an increased noise level.



- The receiving antenna should not be placed in the vicinity of transmitting equipment (e.g. mobile phones, wireless headphones, etc.) because this may cause interference. If placed at elevated locations (high buildings or towers) the receiver may suffer from interference and intermodulation from high power transmitters (e.g. digital radio and television) even if they are several kilometers away.

Notes for the following chapters:

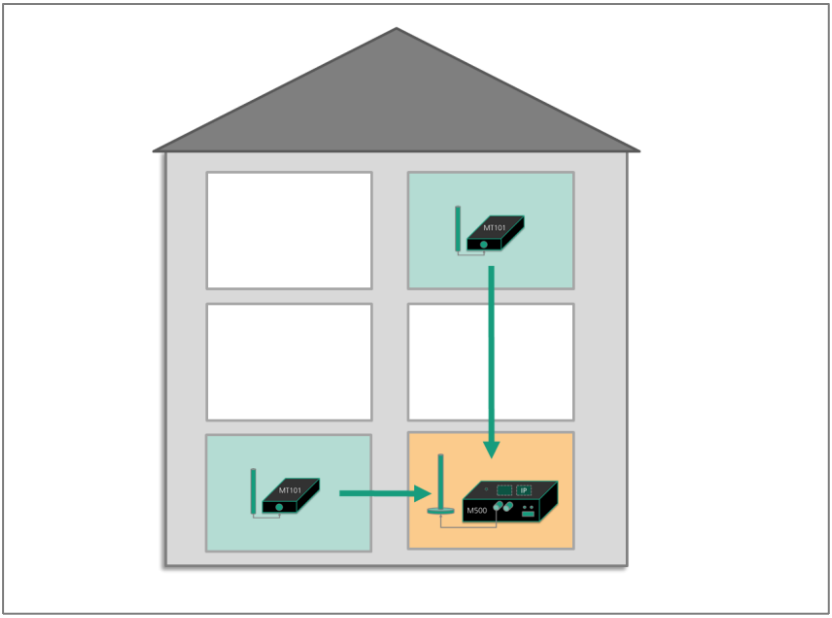
For each of the application scenarios described in chapter 2, the typical operating distances of the MIOTY™ system were determined using the channel models described in chapter 4. It should be noted that channel models provide average path losses while real values show a statistical distribution. Average external noise was only considered when the receiver is indoors or close to buildings (e.g. on rooftop). However, the actual value of external noise may be significantly lower or higher depending on the electromagnetic environment of the receiver.

Both, path loss and noise level will strongly influence the operating distance of the system. Therefore, the values presented give some indication over which distances the system is expected to work in typical situations, although practical values will differ.

For further technical details and references, see chapters 3 and 4. For each scenario in chapter 2 you will find the reference to the according figure (fig.) in chapter 4 from which the values were derived.

2 Application Scenarios

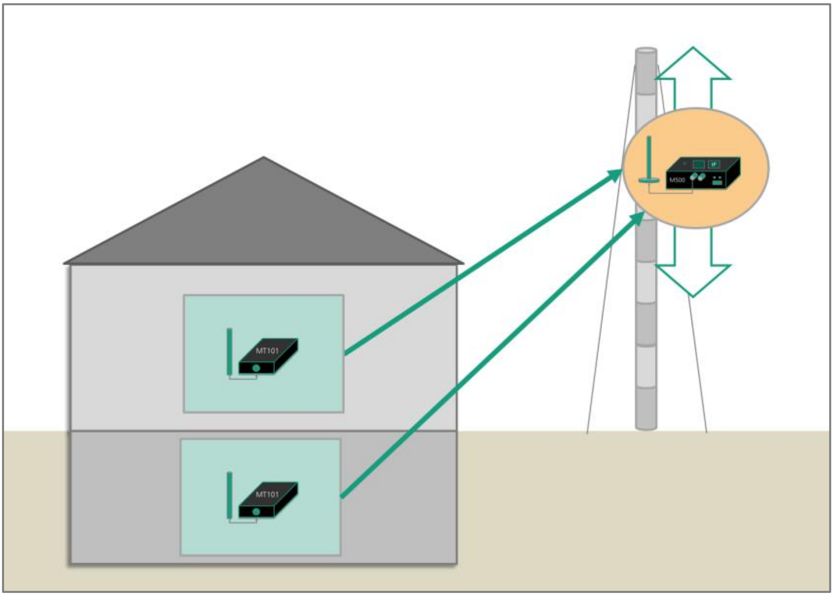
2.1 Transmitter and Receiver: Both Indoor



Typical operating distances:

Number of floors	same floor	+ 1	+ 2	+ 3	+ 4
Open-plan office building (fig. 1)	>200 m	>200 m	>200 m	>200 m	
Building with small rooms and many heavy walls (fig. 2)	60 m	50 m	40 m	35 m	32 m

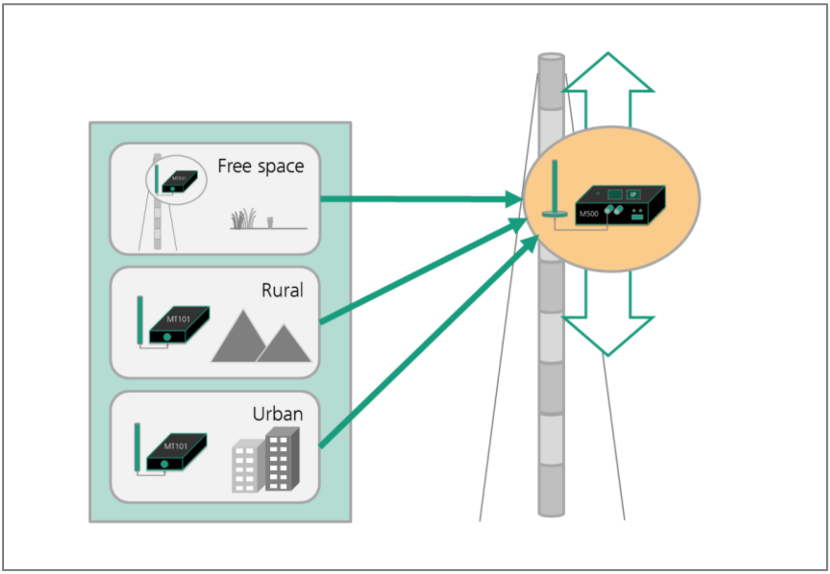
2.2 Transmitter: Indoor; Receiver: Outdoor



Typical operating distances:

Receiver position	**on rooftop (13 m)** (fig. 3)	**on tower (25 m)** non-line-of-sight to building (fig. 4)	**on tower (25 m)** line-of-sight to building (fig. 4)
Transmitter at or above ground floor	> 200 m	400 m	1800 m
Transmitter in cellar room (below street level)	130 m	150 m	250 m

2.3 Transmitter and Receiver: Both Outdoor



Typical operating distances:

Receiver position	**on rooftop (13 m)** (fig. 6)	**on tower (30 m)** (fig. 7)	**on tower (50 m)** (fig. 8)
Free space		> 25 km	> 30 km
Rural		> 10 km	> 15 km
Urban	1.8 km	6.8 km	9.0 km

3 General

3.1 Radio Link Budget

The maximum operating distance of a radio link is generally limited by the transmitter power, the path loss, the receiver sensitivity and the noise and interference level at the receiving site. Transmitter powers are indicated in dBm (dB relative to 1 mW) and the path loss is given in dB. The path loss depends on the distance between transmitter and receiver and also on the specific scenario, e.g. indoor transmission, or shadowing due to buildings or terrain.

If there is no external noise at the receiving site, the receiver performance is only limited by its sensitivity, and the MIOTY™ system will work if

$$transmitter\ power\ -\ path\ loss\ >\ receiver\ sensitivity$$

and the maximum operating distance can be found from measured or calculated path loss as a function of distance for the different scenarios. This is done for the different application scenarios described in section 2.

If noise or interference is present at the receiving site, the performance will no longer be determined by receiver sensitivity alone but a higher signal level is necessary at the receiver to maintain a certain minimum of signal-to-noise ratio. The MIOTY™ system will work if

$$transmitter\ power\ -\ path\ loss\ >\ noise\ level\ +\ SNRmin$$

If it is assumed that the receiver sensitivity is limited by thermal noise, one can express the increase of noise level (in dB) by an external noise figure.

At the frequencies around 900 MHz, where the MIOTY™ system operates, the external noise figure can be expected to be around 8 dB in a mid-sized city, according to Recommendation ITU -R P.372-13 "Radio noise" (2016). However, this value may be much higher in certain areas where electronic appliances are frequent. The frequencies used are shared with other applications (license free bands) and mutual interference cannot be avoided. This may lead to a similar reduction in operating distance as external noise does.

Reception will therefore be possible if

$$\begin{aligned} &transmitter\ power\ -\ path\ loss \\ &\qquad > receiver\ sensitivity\ +\ external\ noise\ figure \end{aligned}$$

For the calculations, an external noise figure of 10 dB was taken into account if the receiver is placed indoors or near buildings, e.g. on rooftop.

3.2 Estimation of Maximum Operating Distance

To estimate the maximum operating distance of the MIOTY™ system the path losses to be expected in typical application scenarios were calculated. It should be noted, however, that path loss as function of distance is not a definite number, but values are statistically distributed. The value of path loss at a certain distance must then be considered as the mean value μ of the distribution (often also the median value is used). The scattering of the values around the mean value is described by the standard deviation σ. Typical values for σ in path loss measurements are 5 - 10 dB.

It is often assumed that a normal distribution applies. In this case, 85 % of the values can be expected to be smaller than $\mu + \sigma$. Hence, 85 % of the transmitters will be received if

$$transmitter\ power - (mean\ path\ loss + standard\ deviation) > receiver\ sensitivity + external\ noise\ figure)$$

For the estimation of operating distance, the curve calculated for path loss versus distance can be copied and shifted up and down by σ. As an example, see figure 3 in section 4.2.1. From the intercept of the shifted curves with receiver sensitivity or noise level one can estimate the range of maximum operating distances occurring.

4 Path Loss Calculations of the Scenarios

4.1 Parameters for Calculation

The following general technical parameters were used for the calculations:

General Parameter	Value
Carrier frequency	868 MHz or 916 MHz
Transmitter power of nodes	16.0 dBm
Antenna gain – receiver	2.0 dBi
Antenna gain – transmitter	– 2.0 dBi (resulting ERP: 11.8 dBm)

The following technical parameters of the MIOTY™ system and implementation of the evaluation kit were used to define the operating distances in the tables (chapter 2):

MIOTY™ Parameter	Value
Receiver sensitivity	– 138 dBm (@PER < 1 %; SNR > – 1.0 dB)
Symbol rate	2380.371 Sym/s

4.2 Transmitter and Receiver: Both Indoor

The calculation of path loss inside buildings depends on the details of the construction, e.g. if walls and ceilings are massive (concrete, metal) or not (wood, plasterboard). Generally, the more walls and floors or ceilings the signal has to pass, the higher the path loss will be. It should also be noted that the noise level inside buildings may be high due to many electrical appliances present.

For indoor propagation there are different channel models: A one-slope model is described in ITU-R Rec. 1238-9. The parameters given are for an office building with open offices (50 m × 16 m × 2.7 m (H)) and line-of-sight between receiver and transmitter if situated on the same floor. The path loss is rather moderate and the MIOTY™ system should work inside such a building over several floors. However, there may be a high noise level in such buildings.

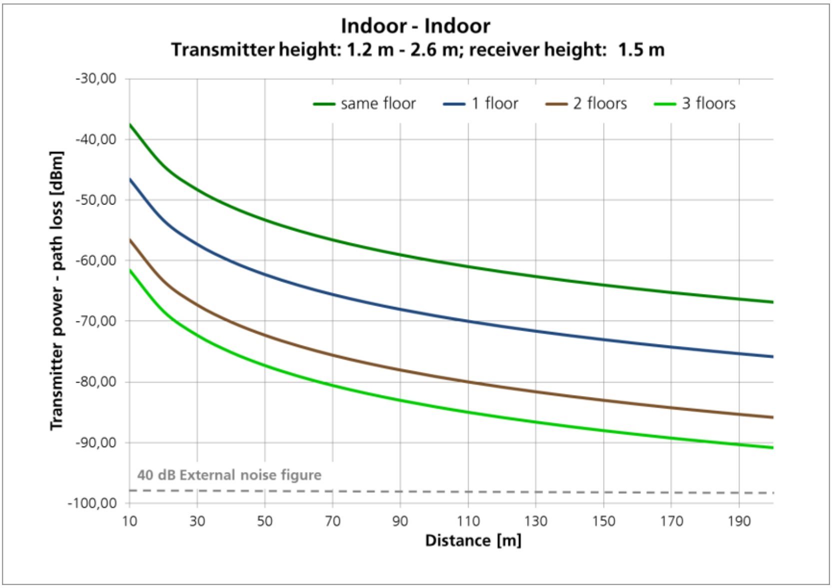


Figure 1: Open office building (ITU-R Rec. 1238-9)

Another way to describe indoor propagation is a multi wall model where it is assumed that each wall and floor that has to be penetrated by the signal contributes a certain amount of additional attenuation. Therefore the path loss depends on the number of walls and floors in the path. The multi-wall model used here is taken from section 4.7.2 of the COST 231 final report with the corrections indicated there for 900 MHz. It is assumed that the number of walls increases with the horizontal distance, and that the height of each floor is 3 m. The distance over n floors is therefore calculated as

$$d = sqrt[horizontal\ distance^2 + (n \times 3\ m)^2]$$

The number of walls is calculated as the integer fraction of (horizontal distance / spacing of walls).
For the calculation of path loss it was assumed that there is a heavy load-bearing wall every 5 meters. In such a building the operating distance of a radio communication system may be significantly reduced (operating distance in this context is defined as the distance where the calculated values of path loss – transmitter power intersects the 10 dB external noise figure line; values can be found in the table on page 5).

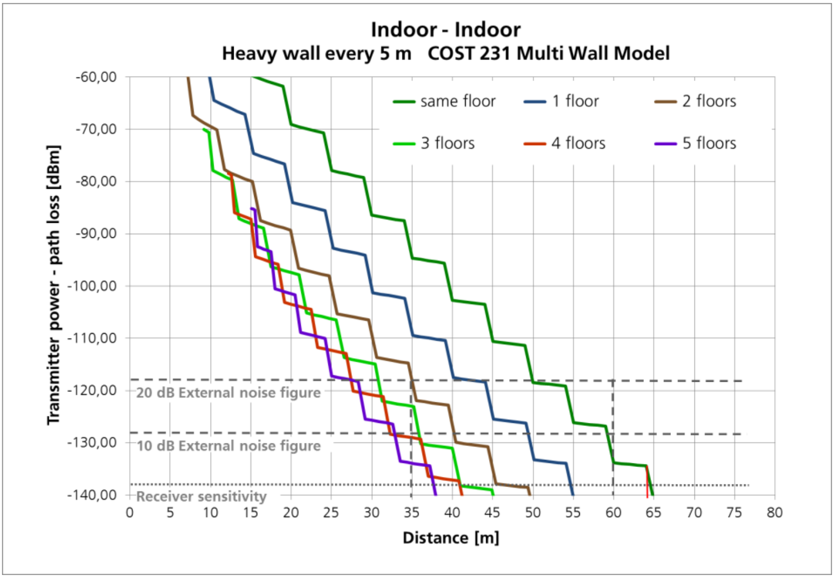


Figure 2: Building with small rooms and many heavy walls (COST 231)

A review on measurements and more advanced models of indoor-to-indoor channels can be found in section V.B of the paper of Hashemi.

References

- Recommendation ITU-R P.1238-9: Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz (2017)
- COST Action 231: Digital mobile radio towards future generation systems - Final report, European Commission, 1999, available at: https://publications.europa.eu/en/publication-detail/-/publication/f2f42003-4028-4496-af95-beaa38fd475f
- Homayoun Hashemi, The Indoor Radio Propagation Channel, Proc. of the IEEE, Vol. 81, 1993, p. 943

4.3 Transmitter: Indoor, Receiver: Outdoor

4.3.1 Receiver on rooftop level (e.g. 13 m)

For this scenario extensive measurements performed at the Fraunhofer IIS building give a realistic estimate of indoor-to-outdoor path loss in a modern office and lab building.

Path loss was calculated from the empirical power law formula

$$L = [81 + 10 \times 3.38 \times \log \frac{Distance}{10m}]\ dB$$

which was found to best fit the measured values. The remaining distribution has a standard deviation of 6.5 dB.

In this scenario the external noise figure was taken to be 10 dB and for propagation from a cellar room an additional attenuation of 25 dB was assumed (see 4.3.3).

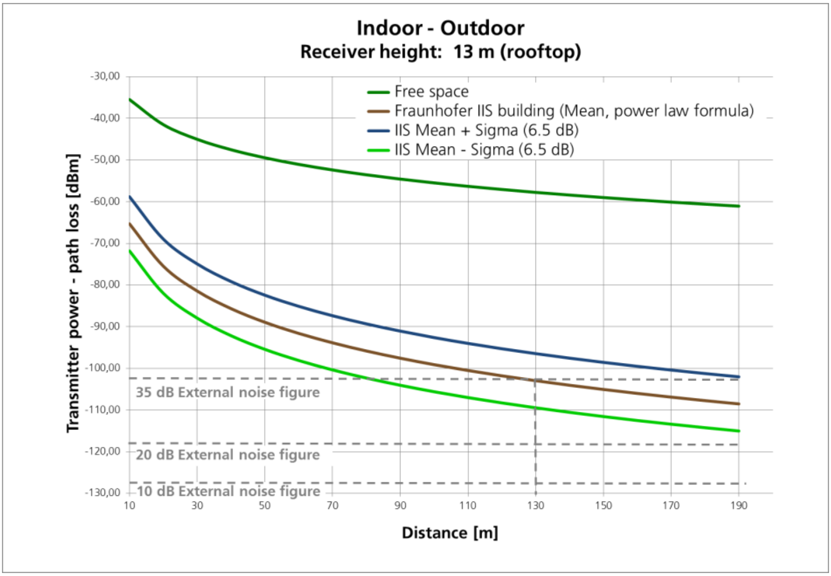


Figure 3: Receiver on rooftop and transmitter above or below street level

Reference:

Hendrik Lieske, Thomas Lauterbach, Joerg Robert, Gerd Kilian and Albert Heuberger, Indoor-to-Outdoor Radio Channel Measurements in sub-GHz Unlicensed Frequency Bands; European Conference on Smart Objects, Systems and Technologies (Smart SysTech), 2015

4.3.2 Receiver on tower (e.g. 25m)

This scenario is similar to the "Urban Macrocell" considered in planning for mobile networks, and hence the path loss is calculated from a channel model derived in this context (WINNER+ channel model O2Ib). The default value of the antenna height of the base station is 25 m in this model. Note that the standard deviation resulting in this model is 10 dB, so practical operating distances can differ significantly from the prediction. It is assumed that the transmitter is deep inside the building (10 m

from the wall). If it is closer to the outside wall, the path loss may be less (up to 5 dB).
The path loss depends significantly on shadowing. If the tower with the receiver is within line-of-sight from the building considered, i.e. not shadowed by other buildings, the path loss is much lower than otherwise.
In this scenario no external noise was considered and for propagation from a cellar room an additional attenuation of 25 dB was assumed (see 4.3.3).

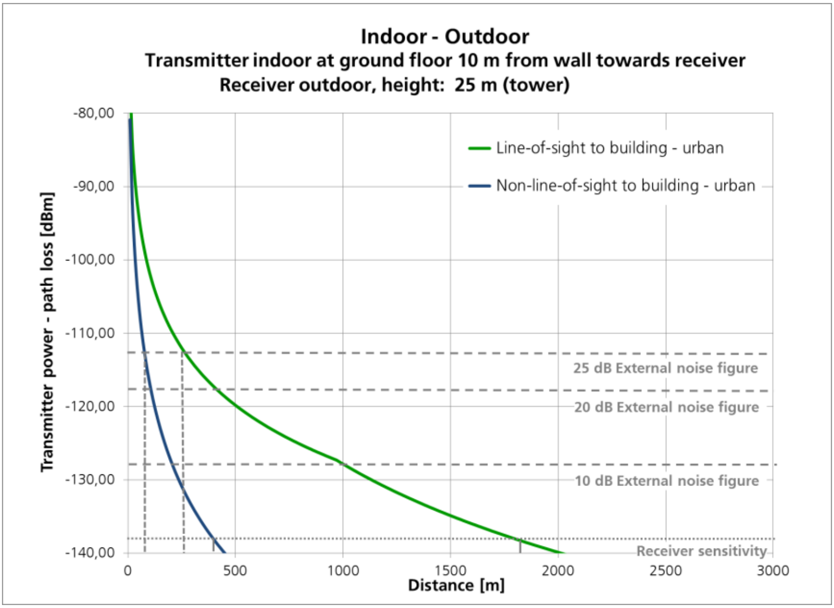


Figure 4: Receiver on tower and transmitter above or below street level

Reference:
Document D5.3: WINNER+ Final Channel Models, Table 4.1, available at: projects.celtic-initiative.org/winner+/ WINNER.../D5.3_v1.0.pdf

4.3.3 Propagation from cellar rooms

During a field trial in Nuremberg, Germany, measurements were taken from transmitters located in the same building (multi-storey residential building from the 1960s) on the first floor and in cellar rooms. The receiver was at an elevation of 35 m, and the distance to the building was approximately 275 m, non-line-of-sight.
The following results of path losses relative to a reference transmitter on the first floor were obtained (median values from measurements taken every 5 minutes over 4 days in 27 channels spaced 250 kHz):

Transmitter	**Path loss relative to transmitter on first floor**
First floor (other room)	- 2.7 dB
First cellar level (about street level)	+ 13.9 dB
Second cellar level (about 3m below street level), 1st site	+ 25.3 dB
Second cellar level (about 3m below street level), 2nd site	+ 24.9 dB

Operating the transmitters from cellar rooms may hence reduce the operating distance similar to 25 dB external noise figure.

4.4 Transmitter and Receiver: Both Outdoor

This corresponds to the classic situation of a mobile station and a base station which has been studied in detail when such systems were developed.

4.4.1 Receiver at rooftop level (e.g. 10/13 m)

Since the Okomura-Hata model often used in this context is valid only if the base station is higher than 30 m, the WINNER+ channel model UMi for an urban microcell will be used for this scenario. It takes into account that surrounding buildings may be higher than the one on which the base station is mounted. It is therefore only available for urban areas.

For non-line-of-sight, a "hexagonal layout" was considered. The model is only valid for distances up to 2 km. The default value of the antenna height of the base station is 10 m in this model, hence the calculation for 13 m may be slightly inaccurate but was included for comparison with fig. 3.

In this scenario the external noise figure was taken to be 10 dB.

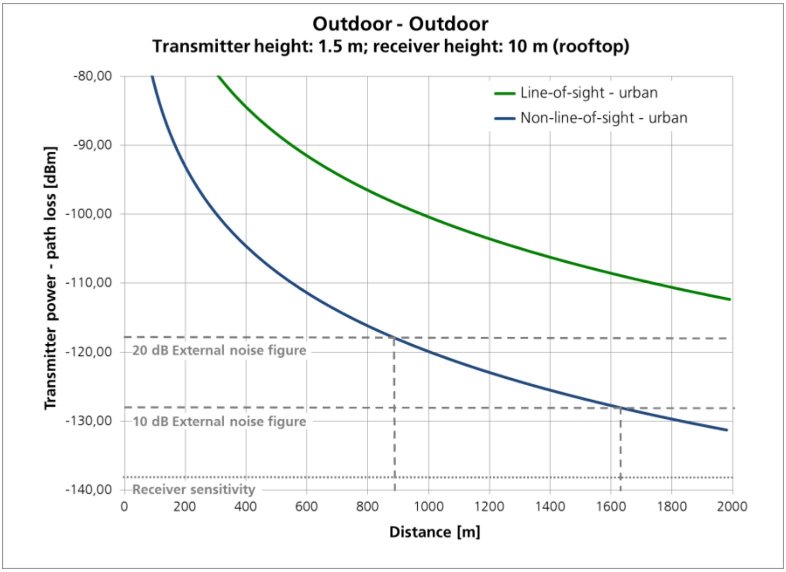


Figure 5: Receiver outdoor at height 10 m

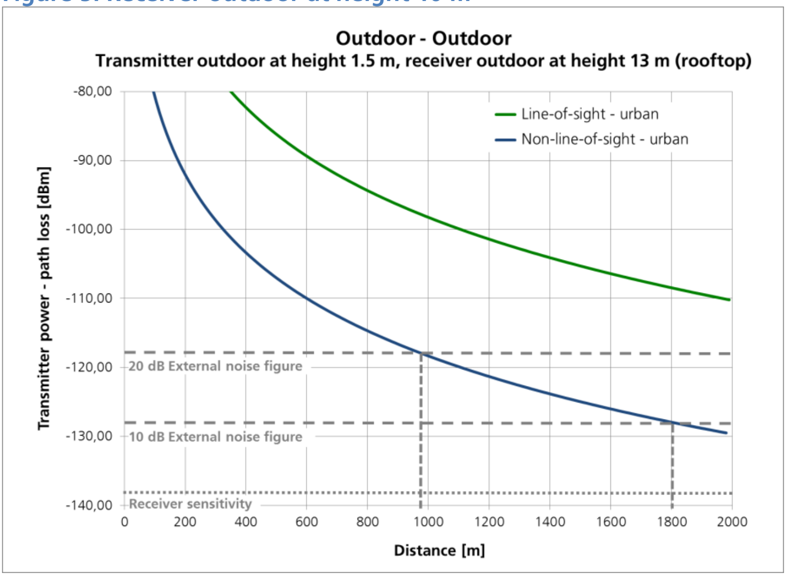


Figure 6: Receiver outdoor at height 13 m

4.4.2 Receiver on tower (e.g. 30/50 m)

For this scenario the classical Okomura-Hata channel model can be used to calculate path loss.

- Free space path loss is calculated from the Friis formula:

$$LP = 32.4\,dB + 20\ \log(Distance/km) + 20\ \log(Frequency/MHz)$$

- Rural and urban path losses are calculated from the Okumura-Hata Model.

In this scenario no external noise was considered.

Concerning the maximum operating distance, Figures 7 and 8 seem to indicate that for "Free space" and "Rural" paths the value would be well beyond 20 km. It should be noted, however, that the model is only valid up to 20 km and that it assumes that there are no dominant obstacles in the path and the terrain profile changes only slowly.

"Free space" conditions are limited to 29 and 35 km, respectively, for receiver heights of 30 m and 50 m and a transmitter height of 2 m due to the curvature of the earth and atmospheric refraction even if the terrain is smooth.

Since this will not be true in many cases, smaller values were provided in the table in 2.3.

References

- D5.3: WINNER+ Final Channel Models, Table 4.1 available at: projects.celtic-initiative.org/winner+/ WINNER.../D5.3_v1.0.pdf
- Andreas F. Molisch, Wireless Communications, John Wiley & Sons, Second Edition, 2011, section 7.6.1, available at: https://www.wiley.com/legacy/wileychi/molisch/supp2/appendices/c07_Appendices.pdf

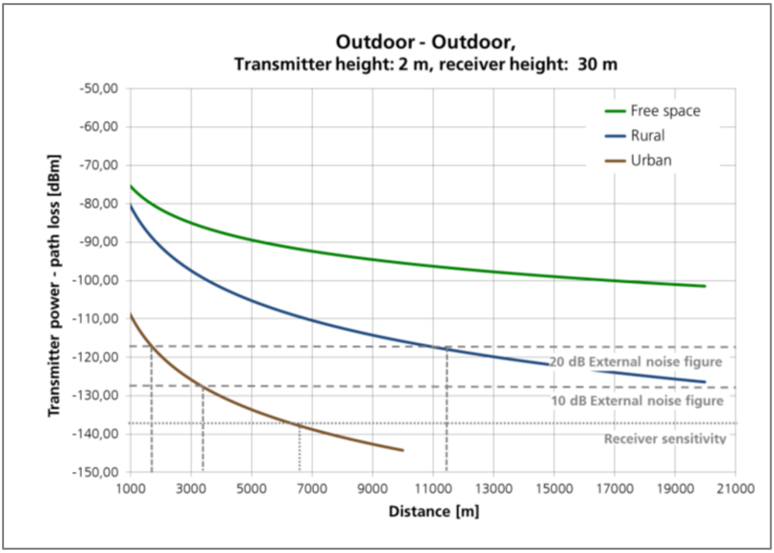


Figure 7: Receiver outdoor at height 30 m

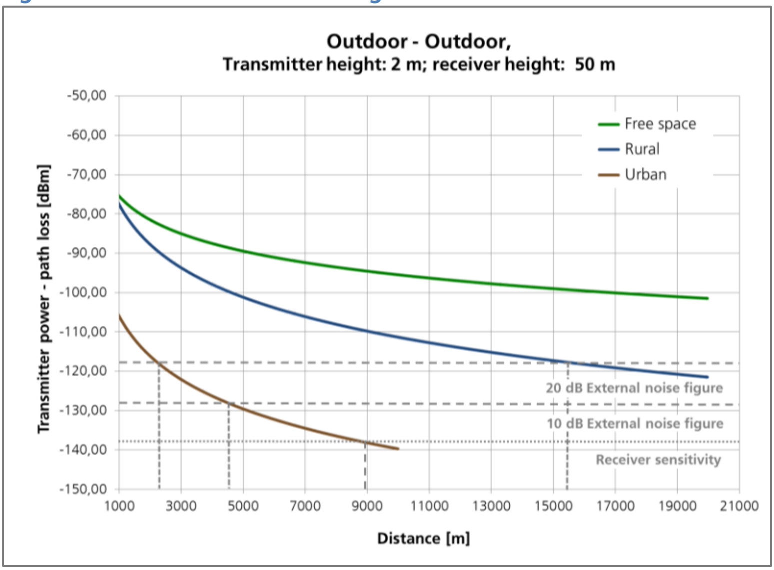


Figure 8: Receiver outdoor at height 50 m