

# Using the Dominant Path Model for Optimized Planning of Industrial Wireless Networks

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## ***Using the Dominant Path Model for Optimized Planning of Industrial Wireless Networks***

*Industrienumgebungen stellen eine besondere Umgebung für die Anwendung einer Funkausbreitungssimulation dar, da typischerweise die verwendeten Ausbreitungsmodell in Büroräumen entwickelt wurden. In der Praxis erweisen sie sich oft als zu pessimistisch, da sie begünstigende, d.h. das Signal verstärkende Effekte wie Reflektionen, nur ungenügend berücksichtigen. Wir stellen eine für Industrienumgebungen erweiterte und so realistischere Version des Dominant-Path-Modells vor und vergleichen dessen Ergebnisse mit denen anderer Modellen sowie realen Messungen.*

*WIFI, Funkausbreitungsplanung, Industrienumgebung*

## **1. Introduction**

RF coverage planning for wireless networks is an analytical technique to predict the propagation of radio frequency (RF) signals within a given area. It is usually used to plan the installation of RF devices without the need for measurements. Simulating RF coverage for wireless networks can be based on deterministic or empirical approaches. Deterministic simulation algorithms, e.g. ray-tracing, take all properties of a simulated environment and all possible wave propagation effects into account. Even though the results of a deterministic simulation are potentially very accurate, their computation takes a long time and minor imprecisions or incompleteness in the architectural model can result in significant simulation errors. In comparison an empirical simulation uses different strategies to simplify the simulation environment to deliver fast, though less precise, results.

### **1.1 Motivation**

Industrial plants are a very special kind of environment for applying empirical simulation procedures for RF coverage planning for wireless networks. Usually, indoor propagation models, e.g. the Multi Wall Model have been developed and studied in office environments. They turn out to be too pessimistic in certain environments because effects that increase the signal strength, e.g. reflections, are not sufficiently represented within the calculations. Pessimism is not only an annoyance, due to the additional hardware expenses for covering spacious environments like industrial plants, it results in unnecessary costs. Even more important it can lead to network instabilities caused by unplanned interference and thus to performance degradation which in turn can cause delays in production

processes. Section 3 presents an extensive example for this case. Here a more accurate RF simulation algorithm applied during the planning phase of the wireless network leads to non-negligible cost-savings and improved performance.

## 1.2 Contents

Section 2 presents the basic principles behind the Dominant Path Model and our extensions and modifications to apply it to an industrial environment. Section 3 aims to illustrate the problems that arise from an inappropriate RF coverage planning, and highlights the difference between the Multi Wall and the Industrial Dominant Path model.

## 2. The Industrial Dominant Path Model

The Industrial Dominant Path Model is based on the Dominant Path Model by Wölfle et al [Wöl], which was designed for office environments. It provides new methods specifically tailored for coping with industrial environments (see section 2.3).

### 2.1 General

The Dominant Path Model is an empirical approach for simulating RF coverage in different environments. It is based on physical research stating up to 90 percent of the energy between transmitter and receiver is transported along one so called dominant path. This dominant path, in contrast to the assumption of e.g. the Multi Wall Model, does not necessarily have to be the direct connection. It is able to provide more realistic and less pessimistic simulation results by including reflection and diffraction effects. The idea is to treat these effects generalized as an interaction, which saves time by not calculating every possible wave propagation path. Due to this heuristical character, the Dominant Path Model can also cope with architectural inaccuracies.

### 2.2 Functioning of the Dominant Path Model

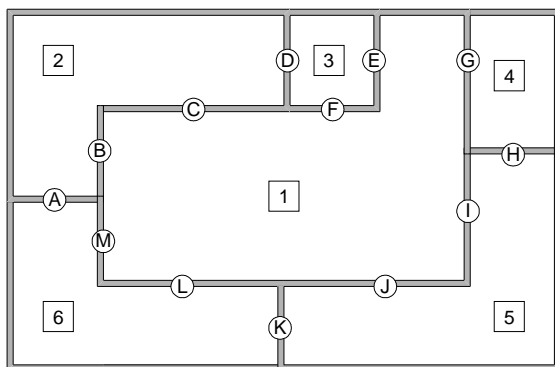


Figure 1 – Indexing walls and rooms of an environment [Wöl]

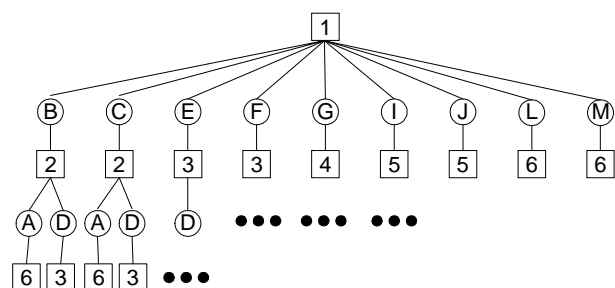


Figure 2 – Tree with room and wall indices [Wöl]

The Dominant Path Model uses rooms and walls as the smallest modelling unit. Figure 1 shows a divided environment with indexed walls and rooms.

If one or more of the rooms contain wireless access points, each of these rooms forms the root node of a search tree. The rooms, which can be reached by the root

node by intersecting one wall, form the nodes of the next tree layer, while the branches represent the intersected walls. Figure 2 shows such a search tree for the environment above (see Figure 1), starting in room 1.

The algorithm now searches the dominant paths between the rooms. While a room can have more than one connection to another room, the path of choice is always the shortest path, intersecting the fewest walls. Figure 3 shows the dominant path from the transmitter T in room 1 to the receiver R in room 5, intersecting wall I.

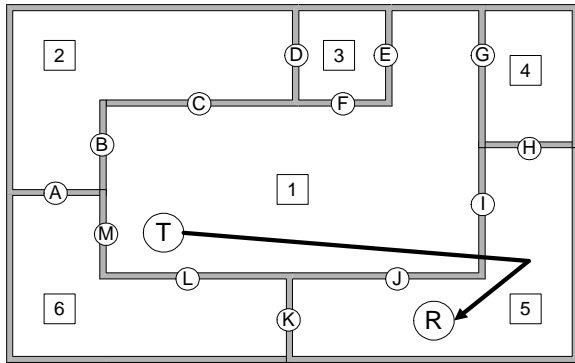


Figure 3 – Dominant path from room 1 to room 5 [Wöl]

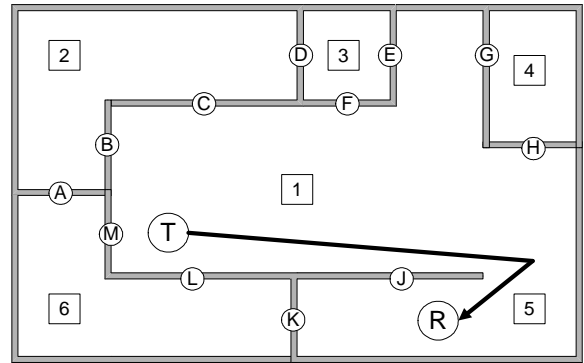


Figure 4 – Dominant path from room 1 to room 5 with wall I removed [Wöl]

After finding one or more possible dominant paths to each room, the algorithm now searches for dominant paths to each receiver. The algorithm is designed for determining a dominant path through a direct or obstructed line-of-sight between the transmitter and the receiver. If the transmitter and the receiver are in the same room, they already have a direct or an obstructed line-of-sight. If the transmitter and the receiver are in different rooms, a direct or an obstructed line-of-sight has to be established by removing the intersecting walls. Figure 4 shows an example of wall I being removed.

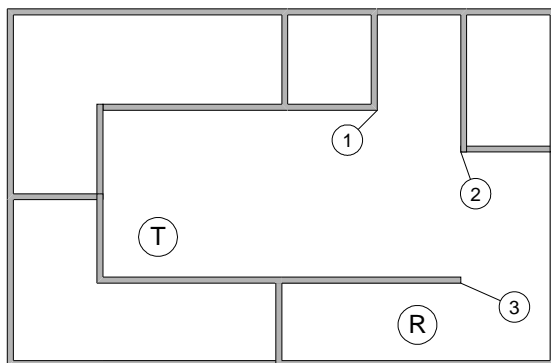


Figure 5 – Marked convex corners in an environment

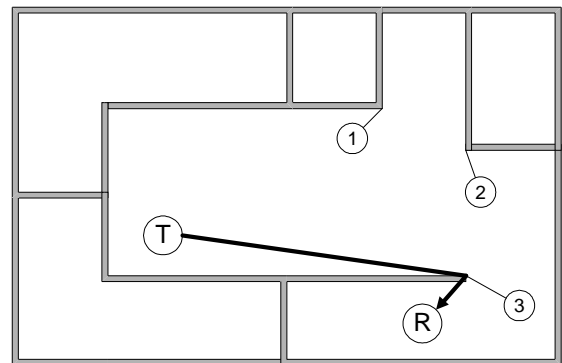


Figure 6 – Path around convex corner

If there is a direct line-of-sight between the transmitter and the receiver, the dominant path is obviously the direct connection. In the case of an obstructed line-of-sight, the dominant path has to be found by detecting so called convex corners in the environment and interacting with these corners to find a path leading around the obstruction(s) as seen in figure 5.

As a result, each path consists of a number of direct line-of-sight segments, called sequences, whose joints are described by generalized interactions. Figure 6 shows, how a connection over one or more convex corners can be established between transmitter and receiver.



Due to the large size and the reflecting material of this machinery, the Industrial Dominant Path Model treats it not solely as a source of attenuation, but also as a possibility for interaction. By means of navigating around large obstacles instead of just intersecting them the Industrial Dominant Path Model is able to provide less pessimistic simulation results for industrial environments. Figure 9 shows, how the Industrial Dominant Path Model can use obstacles in an industrial environment for interaction.

Above adding functionality for simulating RF coverage in industrial environments, the Industrial Dominant Path Model also takes a different approach to calculate the loss of field strength along the dominant paths.

The loss of field strength and the generalized interactions depend on many physical properties of the simulated area. Since it is not possible to include all of these properties in the simulated model, there has to be a heuristical approach, which concludes some of the effects to generalized parameters.

The approach of Wölfle et al is to use neural networks determining the weights of different characteristics observed in a simulated area. These neural networks are then trained with real RF measurements.

The Industrial Dominant Path Model simplifies this by means of introducing different weights, which have to be adjusted either manually according to experiences from similar environments or automatically by means of a non-linear optimization.

### 3. Example of using the Industrial Dominant Path Model

The following example shows an industrial environment which consists of a large factory building including two assembly lines. To the left and the right in the production area, two access points are intended to cover the whole range. Figure 10 shows the general RF coverage within the environment (green denotes good or very good, yellow acceptable, and red poor or no coverage). The left hand picture shows the simulation results of the Multi Wall Model, the right hand picture shows those of the Industrial Dominant Path Model.

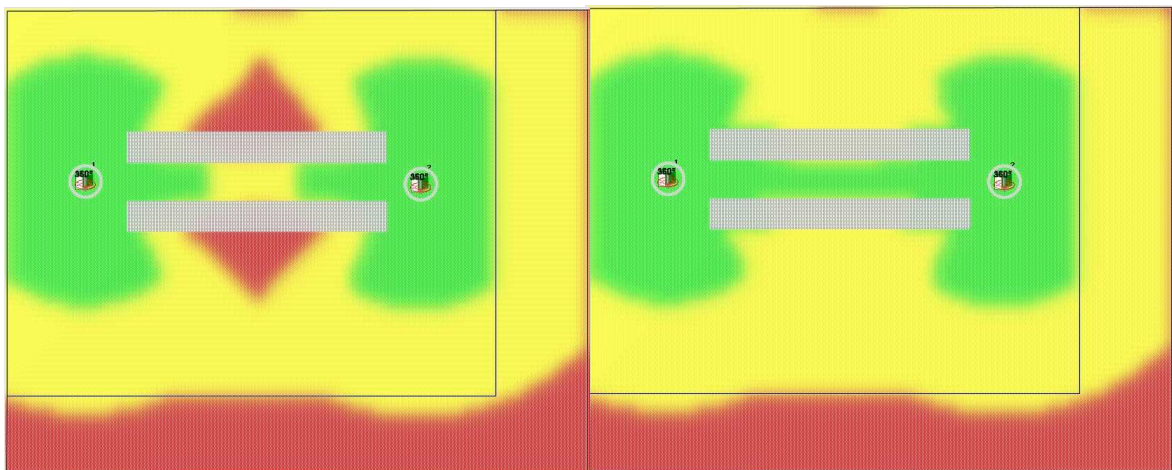


Figure 10 – Example computation of the Multi-Wall Model (left) and the Dominant Path Model (right)

The Multi Wall Model only sees the assembly lines as an obstruction, even though it is more likely, that the wave front is able to interact (my means of diffraction) around the assembly lines with fewer loss of field strength. Above that the corridor between

the assembly lines enables a physical effect called wave guiding (by means of reflection), leading to a better transmission.

To reach a complete RF coverage, according to the Multi Wall Model, the planner of the wireless network infrastructure would have to add two more access points near the red marked areas around the assembly lines. Figure 11 shows a sample simulation visualizing the field strength and how the signal of one of the additional access points would propagate. The second access point would behave symmetrically.

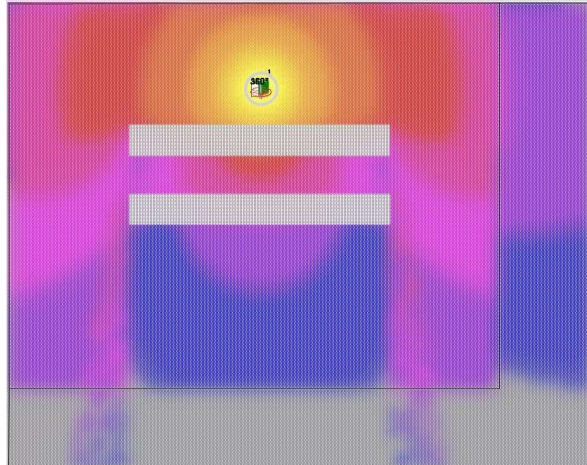


Figure 11 – Signal interference caused by an additional access point

Even though the signal strength on the other side of the assembly lines would be too weak for a connection to the network, the area is still within the range of the carrier sense (violet and blue area). Even in this scenario each of the four access points would affect every other at least through the CSMA scheme because there is no way to configure these access points on non-overlapping channels in the 2.4GHz band. As a result such a setup could unnecessarily deteriorate the network performance. In more complex scenarios this problem will get even worse. The actual performance degradation depends on the communication patterns. For instance, if two access points are configured on the same channel, two clients out of carrier sense range of each other and the other access point could send at the same time. This at least increases the noise level for the second access point possibly causing a packet loss. But in any case, only one access point will be able to send a replay at a time. And there is no control over the order in which this happens – thus, introducing an unpredictable timing behavior.

#### 4. Evaluation

The simulated environment models were created only using different types of walls. No doors were modelled, the walls were drawn through instead at these positions.

The measured field strengths were divided into three areas of poor, moderate or good reception. This was done because simply evaluating the absolute average error rates is not sufficient for adequately determining the quality of a simulation. It is also important, where especially large errors occur. A significant overestimation in the poor coverage range can potentially lead to the wrong assumption of a moderate coverage, while a large overestimation in the good reception area can be neglected.

Comparison measurements were made placing 21 measuring points and 3 access points in an office environment using common notebook hardware and an external

rod antenna. An absolute average error  $\varnothing F_{Abs}$  was calculated by accumulating the absolute differences between the simulation results and the real measure data.

The comparison of these absolute average errors showed the following results for the Industrial Dominant Path Model:

Area	Total Measures	Overestimations	Overest. > 10dB	$\varnothing F_{Abs}$	$\varnothing F$
All	63	24	2	6,15	-2,66
Poor	11	8	2	6,18	3,46
Moderate	24	12	0	4,72	-1,4
Good	28	4	0	7,38	-6,14

The Multi Wall Model showed the following results:

Area	Total Measures	Overestimations	Overest. > 10dB	$\varnothing F_{Abs}$	$\varnothing F$
All	63	10	1	9,94	-8,3
Poor	11	2	1	15,44	-11,91
Moderate	24	5	0	8,75	-7,31
Good	28	3	0	8,81	-7,73

Within the measurements a few outliers (overestimations > 10dB) were encountered. Our experience showed that overestimations of more than 10dB are a good indication for model errors (missing obstacles, reinforced concrete wall instead of gas concrete etc.).

Further comparison measurements were made placing 47 measuring points and 4 access points in an industrial environment using professional transmitters and field strength measuring application.

The comparison of the absolute average errors showed the following results for the Industrial Dominant Path Model:

Area	Total Measures	Overestimations	Overest. > 10dB	$\varnothing F_{Abs}$	$\varnothing F$
All	188	37	1	6,36	-4,56
Poor	81	25	0	8,57	-5,47
Moderate	48	10	0	8,25	-7,26
Good	10	2	1	10,5	-6,61

The Multi Wall Model showed the following results:

Area	Total Measures	Overestimations	Overest. > 10dB	$\varnothing F_{Abs}$	$\varnothing F$
All	188	21	1	7,84	-6,98
Poor	76	14	0	11,3	-9,98
Moderate	48	5	0	10,35	-9,86
Good	10	2	1	11,88	-7,99

The results were obtained within the following computation times:

Office Environment, 3 access points  $T_{Simulation} \sim 2:00$  minutes  
 Industrial Environment, 4 access points  $T_{Simulation} \sim 1:45$  minutes

The parameters of the Industrial Dominant Path Model had to be adjusted differently for office and industrial environments. Nevertheless the parameters were sufficient to adequately describe the occurring effects affecting the loss of field strength in office or industrial environments.

Comparing the simulation results of the Industrial Dominant Path Model and the results of the Multi Wall Model with real measurements showed that the Industrial Dominant Path Model is able to deliver results of better quality in both environments. The results were close enough to reality to clearly distinguish between areas with good, average and bad RF coverage. The measured signal strength even in stationary systems can vary within a range of 5dB to 10dB caused by natural effects in the environment [WJL]. Above that the measurement hardware also has a measuring error of 1dB to 3dB, since consumer hardware usually is not designed for field strength measurements and reports only a very limited number of distinct field strength values with respective rounding errors [Bar]. Seen this, the detected absolute average error rates are more than acceptable.

## **5. Conclusion**

The Industrial Dominant Path Model is an effective way of empirically simulating the RF coverage in office as well as industrial environments in a reasonable period of time. It is able to calculate interactions around the heavy machinery and shows a more accurate result. According to the results of the Industrial Dominant Path Model, adding additional access point is unnecessary, avoiding resulting signal interferences and costs.

The extension of the Dominant Path Model successfully adds the ability of applying the simulation model to industrial environments through interacting with large obstacles instead of solely treating them as a source of attenuation. Above that it showed that using a simplified parameter set also led to sufficient results.

Seen the computation time of a simulation with the Industrial Dominant Path Model, it is especially helpful as a complement to a simulation with the Multi Wall Model. The lower computation time of the Multi Wall Model enables performing environment or infrastructure model updates with almost immediate feedback of the coverage changes. This allows for a rapid deployment planning workflow. The Industrial Dominant Path Model complements this by means of the ability of fine-tuning the infrastructure deployment.

## **6. Bibliography**

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