Characterizing the industrial wireless channel at practical frequencies

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Abstract—**In this paper, the characterisation of the industrial radio channel at 900, 2400, and 5200 MHz is discussed. The industrial environment is categorized into different topographies. A measurement procedure is developed and a propagation model for the different topographies is presented.**

Keywords—**Propagation, industrial environment, path loss**

I. INTRODUCTION

The indoor radio channel has been an active area of research in recent years. Various measurements have been performed to determine propagation characteristics of electromagnetic waves in houses and in office buildings. These measurements resulted in propagation models which aid greatly in coverage prediction of wireless networks operating in these environments. The motive behind this extensive research is the increasing use of indoor wireless communications. Wireless communication standards, such as IEEE 802.11 [1], are already known to perform well in office environments.

The last few years, industrial manufacturing centers are interested to incorporate wireless communication in their production processes. Production lines in contemporary factories are often changed, improved or moved. This implies highly dynamic changes of the workplace layout over time. As a result, wired communication between two pieces of machinery require frequent rerouting of the data cables, which is costly and time consuming. A more flexible solution would be to use wireless communication between machinery. IEEE 802.11 and ZigBee [2] may be integrated in industrial environments in the near future.

Integration of wireless communication in the industrial environment however poses new challenges. Few attempts have been made to characterize the industrial environment concerning electromagnetic wave propagation. The radio channel in factories will behave much differently with respect to the radio channel in for example office buildings, due to the more open building layout and the presence of machinery and highly reflective materials such as metal. This stresses the need for developing and improving wave propagation models specifically for factory environments. In Section II, the industrial environment and measurement setup are described. In Section III, a path loss model is presented. Finally, conclusions are drawn in Section IV.

II. THE MEASUREMENTS

A. The industrial environment

Developing propagation models for industrial environments requires the determination of certain physical characteristics of workplaces which are common to most factories. In this manner, factory plan layouts can be categorized into different topographies which have similar propagation characteristics. Visits to various factories have revealed that three general types of factory topography can be identified. These topographies are partially based on [3] and are defined as follows:

1. Line-of-sight (LOS) path,
2. Non-line-of-sight (NLOS) path with light surrounding clutter at approximately the same height as the receiving antenna,
3. and Non line of sight path with heavy surrounding clutter higher than the receiving antenna.

For each of these categories a path loss model is developed which expresses the signal power loss as a function of transmitter-receiver distance in the topography under consideration.

B. Measurement setup

Propagation experiments are carried out with measurement apparatus including a transmitter and a receiver part.

The transmitter part consists of an omnidirectional transmitting antenna (Tx) mounted on a telescopic mast at about 6 m above ground level. The Tx is at approximately the same height as the metal trusses supporting the ceiling, a common location for placement of industrial wireless access points. A Rohde & Schwarz SMP22 signal generator is used to inject a continuous wave signal with constant power into the Tx. Measurements are performed at three frequencies: 868 MHz, 2400 MHz, and 5200 MHz. These frequencies lie within the license free ISM (Industrial Science Medical) band and are targeted for industrial wireless communication. The transmitter is placed at a fixed location in the measurement environment. Fig. 1 shows the transmitter configuration.

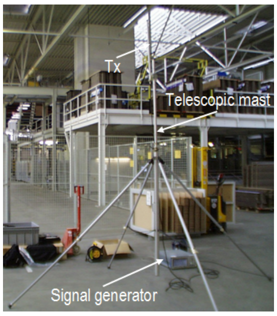

Fig. 1. Transmitter configuration

The receiver part consists of an omnidirectional receiving antenna (Rx) mounted on a plastic mast about 2 m above ground

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level. The Rx height is comparable to that of a wireless terminal mounted on a piece of machinery. The Rx is connected to a HP8561B spectrum analyser which samples the received power level at the transmitting frequency. Sampled power values are stored on a laptop through a GPIB (General Purpose Interface Bus) connection. The receiver configuration is constructed on a movable cart in order to obtain measurement data for a great number of separations between the Tx and the Rx. A tachometer is used to measure the distance travelled. Batteries connected to a DC to AC converter provide power to the mobile receiver apparatus. Fig. 2 shows the receiver configuration.

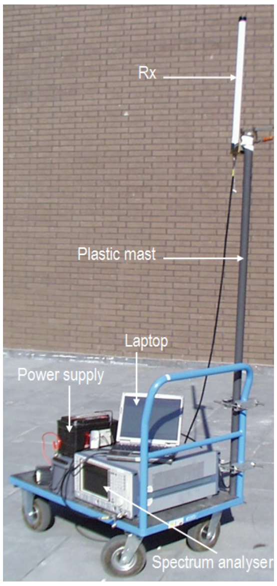

Fig. 2. Receiver configuration

III. Path loss model

An empirical path loss model is fitted to the gathered path loss samples obtained with the measurements described in Section II. Indoor path loss has been shown by many researchers to obey a one-slope model [4]:

$$PL(d) = PL(d_0) + 10n \cdot \log(\frac{d}{d_0}) + X_\sigma, \quad (1)$$

where,

- $PL(d)$ [dB] is the path loss at distance d [m] between the Tx and the Rx,
- $PL(d_0)$ [dB] is the mean path loss at an arbitrary reference distance d_0 [m],
- n [-] is the path loss exponent,
- and X_σ [dB] is a normally distributed random variable with zero mean and standard deviation σ.

The parameters $PL(d_0)$, n, and σ depend above all on the industrial topography and on the transmitted frequency. These parameters are found using a least-squares fit of the difference between measured path loss and path loss according to (1).

To illustrate this, Fig. 3 shows measured path loss samples collected at 868 MHz in four factories along with the corresponding one-slope model for each of the industrial topographies presented in Section II-A. Table I summarizes the fitted parameters of the one-slope models found in Fig. 3, for a chosen reference distance d_0 = 15 m. For each topography we obtained about 320 samples, resulting in a total of 960 collected samples.

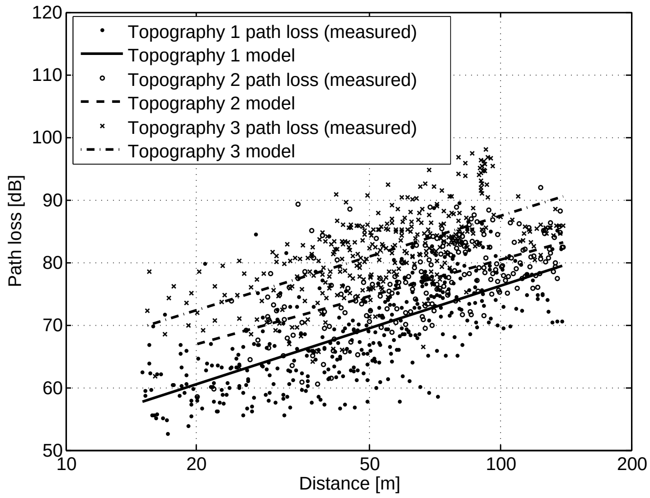

Fig. 3. Path loss at 868 MHz for different topographies

Topography	$PL(d_0)$ [dB]	n [-]	σ [dB]
1	57.7	2.3	5.7
2	64.4	2.0	5.0
3	69.7	2.2	5.2

TABLE I
Parameters one-slope model at 868 MHz for different topographies (d_0 = 15 m)

Path loss models such as (1) prove to be useful in the calculation of the range which can be achieved by a certain commercial wireless communication system in a specific industrial topography.

IV. Conclusions

In this paper, wireless propagation in industrial environments is characterized. Different industrial topographies have been proposed. A measurement procedure has been developed and a general path loss model is presented.

Acknowledgement

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In the industry, the use of wireless communication to coordinate process steps is increasing. Wireless communication standards, such as IEEE 802.11, are known to perform well in office environments. The use of these standards in industrial environments however poses more problems, due to the machinery and the highly dynamic nature of factory workplaces. Unfortunately, attempts to characterize the industrial environment concerning electromagnetic wave propagation are rather scarce in literature. In this paper we focus on developing and improving propagation models for coverage prediction of wireless networks in industrial environments. Factory buildings are subdivided in several categories based on present environmental factors which influence wave propagation significantly. Propagation models for each category are then developed by carrying out extensive measurements of the power loss between a transmitter and a receiver. These empirical models are further validated by performing simulations using an electromagnetic ray-tracing software package.

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