868 MHz Path Loss Model for an Industrial Container Terminal

Brecht De Beelde*, Emmeric Tanghe, Marwan Yusuf, David Plets, and Wout Joseph
Ghent University/IMEC, Ghent, Belgium, http://waves.intec.ugent.be

Abstract

In the shipping industry, wireless communication systems are desired for enabling digitalization and tracking advancements throughout the complete shipping process. In this paper, we present an 868 MHz path loss model for outdoor industrial container terminal environments, based on a measurement campaign using a spectrum analyzer-based channel sounder. Due to the container layout, i.e., containers are stacked in rows with gaps in between, the path loss exponent of the one-slope path loss model is very low. The container stack attenuation equals 21 dB, which is much higher than the penetration loss of objects in other industrial environments.

1 Introduction

Wireless communication is critical for the digitalization of the supply chain and logistics, e.g., to track goods in the shipping process, and to do stock inventarization. In this paper, we provide a radio channel model for propagation at 868 MHz in industrial container terminals. This allows for designing wireless communication systems that can be used for scanning and tracking containers, which avoids that containers are lost and that wrong containers are getting shipped. Also, wireless communication systems allow for better integration of planning and organization tools for container environments. The 868 MHz industrial, scientific, and medical (ISM) frequency band is used by existing wireless technologies considered for industrial Internet-of-Things, including LoRa, Z-Wave, and Dash-7.

Channel models for radio propagation in industrial environments mainly focus on indoor industrial environments [1, 2, 3]. However, a container terminal environment differs significantly from indoor environments, due to the open environment and structured layout with large metallic objects. Existing research on container terminal environments focuses on the planning aspects of containers [4, 5], as well as scheduling [6, 7], localization [8, 9] and tracking [10]. Moreover, there is an increasing interest in deploying wireless connectivity throughout the complete shipping process, e.g., inside a vessel [11, 12, 13, 14], in order to efficiently track goods.

To the best of the authors' knowledge, this is the first time a path loss model for a container terminal is presented. The outline of the paper is as follows. In Section 2, we present the methodology and measurement campaign. The channel model is provided in Section 3, and Section 4 concludes this paper.

2 Methodology

2.1 Measurement setup

We perform path loss (PL) measurements using a spectrum analyzer-based channel sounder. An omnidirectional Cobham antenna type XPO2V/1441 transmits a sine wave at frequency 868 MHz with power 15 dBm, generated by a R&S signal generator type SMB 100A. A R&S FSV30 spectrum analyzer captures the received signal via an identical Cobham antenna. The antennas have a gain of 2 dBi at 868 MHz, and the total cable losses are 3.3 dB. The Fraunhofer distance of the antennas for frequency 868 MHz is 0.068 m. The center frequency is set to 868 MHz. The resolution bandwidth of 300 Hz results in a sweep time of 0.11 s.

The transmit (TX) antenna location is fixed, and the receiving (RX) antenna is put on a mobile cart. Both antennas are vertically polarized and mounted at a height of 2 m. A tachometer connected to the cart records distance information, which is stored on a laptop together with the RX power information that is obtained from the spectrum analyzer. By moving the cart away from the transmitter at a speed of 0.1 m/s and continuously recording received power and tachometer data, we obtain the received power as a function of distance. PL is found by subtracting received power and cable losses from the sum of the TX power and antenna gains.

2.2 Measurement environment

We performed measurements along different measurement tracks, categorized into Line-of-Sight (LOS) and non-Line-of-Sight (NLOS). The floorplan of the container terminal is presented in Fig. 1. The tracks are represented by the starting point (circle) and an arrow that indicates where the cart is moved to. The containers are represented by rectangles, with a number indicating how many containers are stacked vertically. The tank containers are built based on

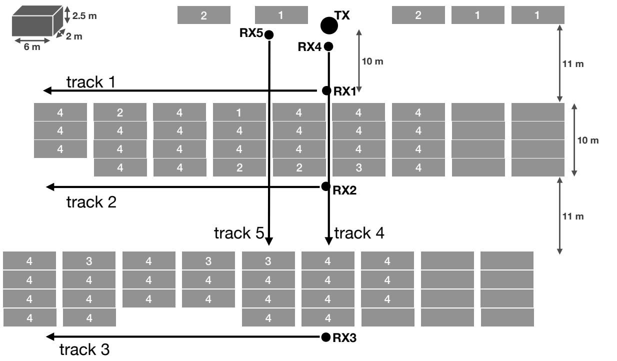

Figure 1. Container terminal floor plan.

(a) TX antenna and Line-of-Sight track 1

(b) Mobile cart with RX antenna and spectrum analyzer

Figure 2. Container terminal environment and measurement equipment.

the standards from the International Organisation for Standardization (ISO) and designed to carry liquids. The container frame measures 20 feet (6.06 m) by 8 feet (2.44 m) with a height of 8.6 feet (2.60 m), and the spacing between containers is 1 to 1.5 m. Track 1 is a LOS track where the cart moves parallel to the container stack. For NLOS tracks 2 and 3, up to two quadruple container stacks are in between the TX and RX antennas. Tracks 4 and 5 start with a LOS scenario and end with an NLOS scenario. For each measurement track, the minimum distance between the antennas and the closest surrounding metal is 0.5 m, which is larger than the far-field distance of the XPO2V/1441 antennas. Figure 2 shows a picture of the container terminal environment, as well as the measurement equipment.

3 Results

The captured PL samples are pooled and averaged over 10 wavelengths, with an average of 310 samples in one interval. The averaged PL samples are fitted to the log-distance model of (1) via a multiple linear regression analysis.

$$\mathrm{PL}(d,p) = \mathrm{PL}_0 + 10\, n \log_{10}(d) + p\mathrm{A}_{\mathrm{stack}} + \chi \qquad (1)$$

In this equation, parameter PL_0 is the path loss in dB at a reference distance of 1 m, and n (-) is the PL exponent. Variable d is the distance in meter between transmitter and receiver, p $\in \{0,1\}$ indicates whether the LOS path crosses a container stack, and $\mathrm{A}_{\mathrm{stack}}$ is the stack attenuation in dB. χ is a zero-mean normally distributed shadowing factor in dB. We also fit the LOS samples and NLOS samples to a one-slope model, i.e., the model from (1) with $p = 0$.

The fitted parameters are summarized in Table 1. For the LOS model, the LOS data samples from tracks 1, 4, and 5 is fitted to a one-slope model, i.e. the model from (1) with $p = 0$. For the NLOS model, the NLOS data samples from tracks 2 to 5 is fitted to a one-slope model, whereas the combined model combines all tracks and uses parameter $\mathrm{A}_{\mathrm{stack}}$. Figure 3 shows the measured PL samples for the different tracks, as well as the fitted LOS and NLOS models. For all tracks, there is a periodic behavior, which is attributed to the gaps in between the containers. For LOS track 1, reflected power is received, as the antenna moves parallel to the metallic container. For NLOS track 2, there is a high attenuation when the antenna is behind a container, and lower attenuation when passing a gap, i.e., shadow fading. Even though the received power is close to the noise floor of the measurement equipment, the same amount of PL samples as for track 1 is received. On the other hand, there are only a limited number of PL samples for NLOS track 3, indicated by red squares in Fig. 3. Even no PL samples were recorded between 50 m and 53 m, between 65 m and 67 m, and between 67 m and 72 m. As too many samples are missing, we did not consider the data from this track for the linear regression fit to the log-distance model. We conclude that measured PL exceeds the dynamic range of the spec-

Table 1. Fitted path loss model parameters for Line-of-Sight data, non-Line-of-Sight data and combined data set.

Model	PL_0 at 1 m	PL exponent n	A_{stack}	RMSE	p-value
LOS	53.2 dB	1.2	-	3.5 dB	< 1.5e-5
NLOS	49.9 dB	2.8	-	2.9 dB	< 6.7e-6
Combined	50.0 dB	1.4	20.8 dB	3.7 dB	<8.7e-19

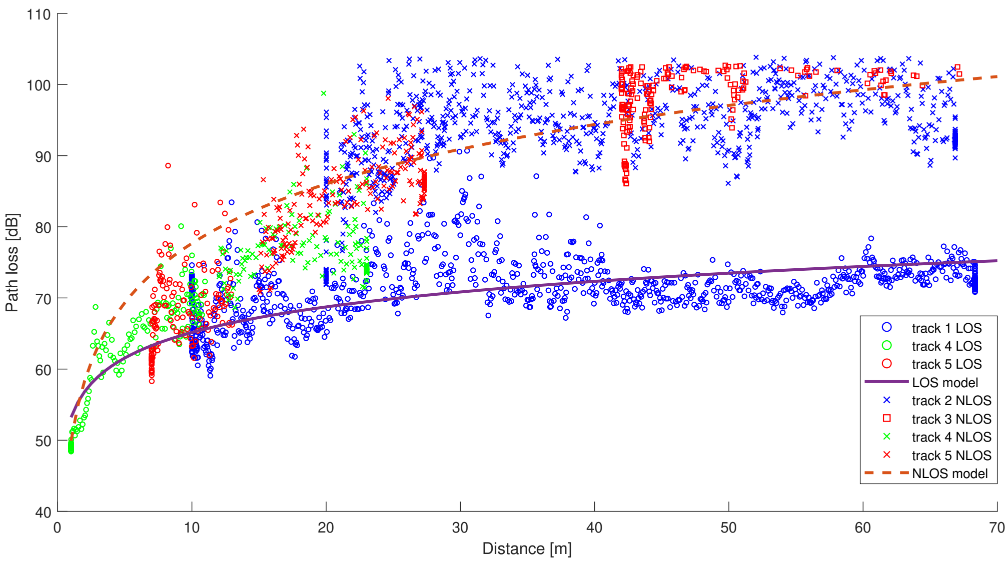

Figure 3. Measured path loss samples fitted to a one-slope model.

trum analyzer when more than one quadruple stack block the direct path between the TX and RX antennas.

Fitting the combined data of all tracks results in a stack attenuation of 20.8 dB. The distance dependence is very low, given the fitted PL exponent of just 1.4, which is in line with path loss models for indoor industrial environments [13]. The reference PL at 1 m is 50 dB and the RMSE is 3.67 dB. The coefficient of determination is 0.93.

4 Conclusion

In this paper, we have presented an 868 MHz PL model for a container terminal. The PL exponent is very low, which indicates that there is a limited distance dependence. The low dependence is caused by the specific environment layout, i.e., big metallic containers that fully block the RF signal, and 1 to 1.5 m gaps in between where the RF signal gets through. This results in a one-slope PL model with a high stack attenuation value (20.8 dB), a low PL exponent (1.4), and a reference PL value (50.0 dB) that is much higher than free space PL. The PL model can be used for the design of a wireless network for container environments, and for network planning, i.e., where access points or gateways should be placed to enable wireless communication.

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References

[1] A. F. Molisch, K. Balakrishnan, C. chin Chong, S. Emami, A. Fort, J. Karedal, J. Kunisch, H. Schantz, U. Schuster, and K. Siwiak, "Ieee 802.15.4a channel model - final report," in *Converging: Technology, work and learning. Australian Government Printing Service*. IEEE, 2004.

[2] E. Tanghe, W. Joseph, L. Verloock, L. Martens, H. Capoen, K. V. Herwegen, and W. Vantomme, "The industrial indoor channel: large-scale and temporal fading at 900, 2400, and 5200 mhz," *IEEE Transactions on Wireless Communications*, vol. 7, no. 7, pp. 2740–2751, 2008.

[3] E. Tanghe, D. P. Gaillot, M. Liénard, L. Martens, and W. Joseph, "Experimental analysis of dense multipath components in an industrial environment," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 7, pp. 3797–3805, 2014.

[4] L. Huang and J. Zhou, "Process adaptability research of intelligent upgrading for traditional container terminals," in *2021 IEEE International Conference on Electronic Technology, Communication and Information (ICETCI)*, 2021, pp. 642–645.

[5] M. A. Salido, O. Sapena, M. Rodriguez, and F. Barber, "A planning tool for minimizing reshuffles in container terminals," in *2009 21st IEEE International Conference on Tools with Artificial Intelligence*, 2009, pp. 567–571.

[6] B. Sun, J. Sun, and Q. Chen, "On container terminal logistics operational and scheduling management system based on mas," in *Proceedings of the 30th Chinese Control Conference*, 2011, pp. 5484–5489.

[7] X. Dong, T. He, and C. Zhu, "Research on scheduling the containers between container storage station and container terminal," in *2015 International Conference on Service Science (ICSS)*, 2015, pp. 32–36.

[8] T. Y. Rezapour, R. E. Atani, and M. S. Abolghasemi, "Secure positioning for shipping containers in ports and terminals using wsn," in *2014 11th International ISC Conference on Information Security and Cryptology*, 2014, pp. 10–14.

[9] A. Kaya, M. Weyn, and R. Berkvens, "Sub-ghz cooperative container stack estimation," in *2021 International Conference on COMmunication Systems NETworkS (COMSNETS)*, 2021, pp. 384–386.

[10] N. Wang and H. Li, "An automatic tracking and positioning system for automated container terminals," in *2017 4th International Conference on Transportation Information and Safety (ICTIS)*, 2017, pp. 404–408.

[11] M. Chen, K. Liu, J. Ma, X. Zeng, Z. Dong, G. Tong, and C. Liu, "Moloc: Unsupervised fingerprint roaming for device-free indoor localization in a mobile ship environment," *IEEE Internet of Things Journal*, vol. 7, no. 12, pp. 11 851–11 862, 2020.

[12] P. Fraga-Lamas, J. Varela-Barbeito, and T. M. Fernández-Caramés, "Next generation autoidentification and traceability technologies for industry 5.0: A methodology and practical use case for the shipbuilding industry," *IEEE Access*, vol. 9, pp. 140 700–140 730, 2021.

[13] B. De Beelde, E. Tanghe, M. Yusuf, D. Plets, and W. Joseph, "Radio channel modeling in a ship hull: Path loss at 868 mhz and 2.4, 5.25, and 60 ghz," *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 4, pp. 597–601, 2021.

[14] B. De Beelde, A. A. Lopéz, D. Plets, M. Yusuf, E. Tanghe, and W. Joseph, "Directive mmwave radio channel modeling in a ship hull," *International Journal of Microwave and Wireless Technologies*, p. 1–12, 2021.