Paper

Propagation Path Loss Modeling in Container Terminal Environment

Ryszard J. Katulski, Jacek Stefański, and Jarosław Sadowski

Abstract— This paper describes novel method of path loss modeling for radio communication channels in container port area. Multi-variate empirical model is presented, based on multidimensional regression analysis of real path loss measurements from container terminal environment. The measurement instruments used in propagation studies in port area are also described.

Keywords— path loss modeling, radio propagation.

1. Introduction

Container port area should be treated as a very difficult radio waves propagation environment, because lots of containers made of steel are causing very strong multipath effect and time-varying container arrangement in stacks of different height changes the path loss value in time. Path loss modeling for such area is still complex task and hasn't yet been considered in scientific research. But as the total amount of cargo carried yearly in containers by land and sea increases, the only effective way of controlling such huge number of containers is to build efficient electronic container supervision systems [1]. Nowadays almost all the major container ports have some kind of radio container monitoring, based on available radio communication standards (GSM/GPRS, UMTS, TETRA, WiFi, WiMAX, Zig-Bee, Bluetooth, many different RFID systems or other solutions in unlicensed frequency band) working in frequency range from about 0.4 GHz to 5 GHz. It should be noted that ITU-R did not present any special recommendation for propagation path loss prediction for radio link in container terminal environment. Differences in spatial arrangement and structure between container stacks and typical urban or industry area can cause relevant path loss prediction errors in case of use inadequate path loss model, so the special survey of propagation phenomenon in container terminal area becomes crucial.

This paper presents new analytical approach to path loss modeling in case of propagation in container port environment, based on empirical results from measurement campaign in Gdynia Container Terminal (Poland). Precise classification of propagation environment and selection of parameters which influence the propagation mechanism in essential way, allowed to define adequate multi-variate error function for multidimensional regression analysis. As a result of this research, new analytical relation between propagation path parameters and path loss in container terminal scenario was proposed. All measurements were carried with assumption, that propagation model has to be ade-

quate for path loss prediction in case of radio communication between container monitoring unit and base station in container terminal area.

2. Measuring Equipment

Block diagram of primary equipment set used in propagation measurements in container terminal scenario is presented in Fig 1.
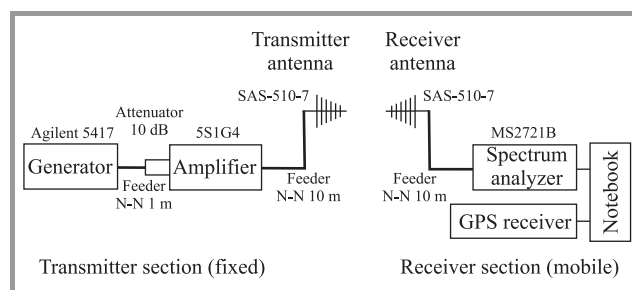

Fig. 1. Block diagram of primary measuring equipment set.

Propagation path loss measuring equipment concept was based on fixed reference signal transmitter and mobile receiver equipment placed in many different positions in the area of container terminal. Harmonic signal without modulation, with frequency in range 0.5 GHz to 4 GHz, was emitted by transmit antenna situated in various places in port. Power amplifier input was protected by precise 10 dB attenuator. The receiver section was made of handheld signal spectrum analyzer working as a sensitive received signal power meter, global positioning system (GPS) receiver and notebook with special software. All the receiver section components were battery powered. Log-periodic directional wideband antennas of the same type were used in both transmit and receiver side. These antennas were calibrated by producer and have precise parameters in whole frequency range of interest.

Firstly the measurement plan assumed four reference signal frequencies: 1, 2, 3 and 4 GHz, but during the measurement campaign additional frequency of 0.5 GHz was also put into investigation. Because the power amplifier used in transmitter section works properly only in frequency range 800 MHz to 4.2 GHz, schematic diagram of transmitter section in case of measurement at frequency 500 MHz was slightly modified: additional attenuator and power amplifier had to be removed and the output of signal generator was directly connected to antenna via 10 m long feeder.

3. Calibration Procedure

In order to precisely compute the propagation path loss from power level of signal detected by handheld spectrum analyzer, radio link power budget equation have to include parameters of all the components from Fig. 1. As the antenna's power gain at all the frequencies of interest is known (measured by manufacturer) and transmitter power level is being kept constant (output power was low enough to avoid any interference to existing radio communication systems), equivalent isotropic radiated power (EIRP) can be simply computed for every frequency.

To ensure that accuracy of measurements doesn't vary with frequency, the transmitter and receiver section was calibrated in the Gdańsk University of Technology laboratory. Firstly, the attenuation of transmitter section feeders at all the frequencies of interest was measured using vector network analyzer. The results are compared in Table 1.

Table 1
Attenuation of transmitter section feeders

Frequency [GHz]	1	2	3	4
Feeder loss between generator and additional attenuator [dB]	0.25	0.59	1.25	1.70
Feeder loss between amplifier and antenna [dB]	3.27	4.89	6.15	7.10

Although the power amplifier has smooth gain adjustment, authors decided to set the amplification to fixed value of 38 dB (amplifier setting, real amplification value was not measured) and determine the signal generator output power that is necessary to achieve required signal power at the input of transmit antenna. In laboratory conditions, spectrum analyzer from receiver section together with precise attenuator 20 dB was used instead of antenna as a power meter (Fig. 2).
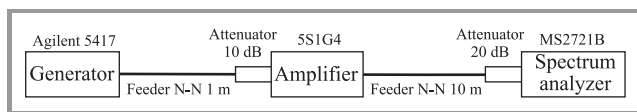

Fig. 2. Transmitter section calibration set schematic diagram.

As the receiver antenna gain in whole band of interest was precisely measured by producer, the only part of receiver section from primary block diagram (Fig. 1) with unknown parameters is the feeder between antenna and handheld spectrum analyzer.

Table 2
Attenuation of receiver section feeder

Frequency [GHz]	1	2	3	4
Feeder loss between antenna and spectrum analyzer [dB]	3.24	4.86	6.25	7.7

The MS2721B spectrum analyzer is able to measure and present received signal power level directly in dBm. Using the same device during calibration phase and in final measurement campaign should compensate eventual received signal power measurement errors. The receiver section feeder attenuation values are presented in Table 2.

Obviously, similar but not the same calibration procedure was repeated at frequency 0.5 GHz after measurement campaign to obtain the power level at the input of transmitter antenna and attenuation of feeders for this specified frequency.

Because the receiver antenna has directional spatial characteristic, path loss measurement procedure required pointing the antenna in direction of transmitter in case of line of sight (LOS) condition or in direction of maximum received signal power in case of non line of sight (NLOS) for every position of receiver section. To simplify the search of maximum signal direction, both transmit and receive antennas were fastened to movable masts with tripods, which allow to change azimuth of reception while height of antenna above terrain remained unchanged. Directional antennas were used for two reasons: firstly because authors would like to take advantage of antenna's power gain, and secondly – authors did not have omni-directional antennas working in frequency range up to 4 GHz with precisely known gain.

As the transmitter output power was kept low, the value of EIRP was far below 15 W limit. According to Polish law, electromagnetic radiation sources with EIRP less than 15 W are objects that do not affect environment or human, so nobody from the measurement team was exposed to harmful electromagnetic radiation.

To improve measurement speed and accuracy, data from spectrum analyzer (received signal power) and GPS receiver (geographic coordinates and time of each measurement) were collected by notebook. Special software running on computer with Linux operating system allowed to define the time between successive measurements, frequency and bandwidth of received signal, type of applied power detector, additional averaging of results, etc. It was also possible to record signal spectrum in each measurement point.

4. Path Loss Measurements in Container Terminal

With the help from administrative of Gdynia Container Terminal, complex survey of propagation aspect in container port was made in term from June to September 2007. Almost 5000 data sets were collected during measurements campaigns, which means about thousand measurement points for each analyzed frequency. The analyses were made in different weather conditions – sunny, cloudy and rainy days with temperature from 5°C to 20°C. In order to reduce path loss measurement errors caused by small scale fading, value of received signal power was calculated using several consecutive measurements and receiving equipment

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was always moving. Measurements were carried out in accordance with ITU-R recommendation SM.1708 [2]. Exemplary results of propagation path loss measurements in area of container terminal are shown on map in Fig. 3, where black rectangles symbolize stacks of containers, dots symbolize location of successive measurement points.
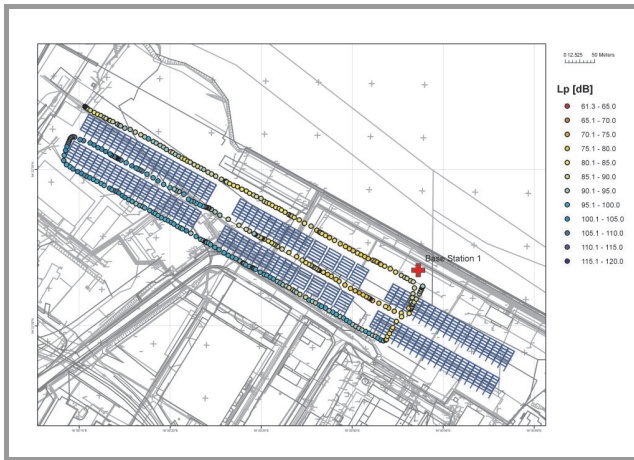

Fig. 3. Exemplary map of measurement points in container terminal.

Similar maps can be plotted for other propagation scenarios and different frequencies of interest.

5. A Novel Multi-Variate Empirical Path Loss Model

Upon the results of almost 5000 propagation path measurements in real container terminal environment, a novel analytical model was developed using multidimensional linear regression analysis with multiple independent variables. For the sake of this analysis a multi-variate error function was defined [3], [4]. The following parameters, which should affect the value of propagation path loss in port area, were chosen as independent variables in error function [5], [6]:

– frequency f;

– propagation path length d;

– path type qualification: line of sight or non line of sight condition;

– difference between transmitter antenna height above terrain level h_T and average height of container stack h_{av}, but two possible cases should be investigated separately: $h_T \geq h_{av}$ and $h_{av} > h_T$.

Because the container terminal, in which all the measurements were made, was permanently used for container transportation, safety restrictions forced authors to limit the height of receiver antenna h_R to fixed value equal 2 m. Due to fixed value of receiver antenna height, proposed propagation models do not include this height as a variable parameter.

As a result of defined error function analysis, regression coefficients for respective propagation cases were computed. Based on this, analytical formulas of propagation path loss in container terminal area can be presented.

Propagation path loss in dB in line of sight scenario:

- in case, when $h_T \geq h_{av}$ (LOS1):

$$L_{LOS1} = 55.2 + 20\lg f + 5.8\lg d - 22.1\lg(h_T - h_{av}),\tag{1}$$

- otherwise, when $h_{av} > h_T$ (LOS2):

$$L_{LOS2} = 41.9 + 20\lg f + 25.9\lg d + 4.2\lg(h_{av} - h_T).\tag{2}$$

Propagation path loss in non line of sight scenario:

- in case, when $h_T \geq h_{av}$ (NLOS1):

$$L_{NLOS1} = 32.6 + 20\lg f + 7.9\lg d + 0.8\lg(h_T - h_{av}),\tag{3}$$

- otherwise, when $h_{av} > h_T$ (NLOS2):

$$L_{NLOS2} = 38.6 + 20\lg f + 13\lg d + 5.9\lg(h_{av} - h_T).\tag{4}$$

The frequency f in Eqs. (1)–(4) should be in MHz, propagation distance d in km, height of transmit antenna and average height of container stack in m. Figures 4–7 presents propagation loss as a function of distance for exemplary frequency 2 GHz in all four scenarios.

Mean error (ME) and mean square error (MSE) are commonly being used to verify accuracy of path loss models. These errors are defined by expression (5) and (6), respectively:

$$ME = \frac{1}{N}\sum_{i=1}^{N}\left(L_{meas,i} - L_{reg,i}\right),\tag{5}$$

$$MSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(L_{meas,i} - L_{reg,i}\right)^2},\tag{6}$$

where $L_{meas,i}$ is the value of measured path loss in ith position of receiver equipment ($i = 1,\ldots,N$), $L_{reg,i}$ mean path loss value computed using Eqs. (2) to (5) for ith position, and N is the total number of considered results. Mean error value reflect the expected average difference between path loss values obtained using proposed model and real path loss measurement results, while mean square error is the ratio of dispersion of measured path loss values and describes how good the propagation model matches experimental data.

Mean errors and mean square errors for all the considered propagation path variants separately (different height of transmitter antenna, line of sight condition) and summary for all measurement results together, are presented in Table 3.

The propagation path loss calculated using proposed analytical model fits very well the results from measurement campaign for all propagation path variants, which is confirmed by very low values of mean errors and acceptably low values of mean square errors.
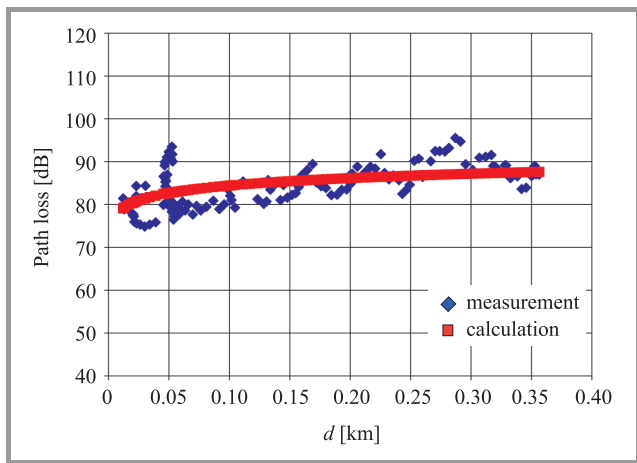
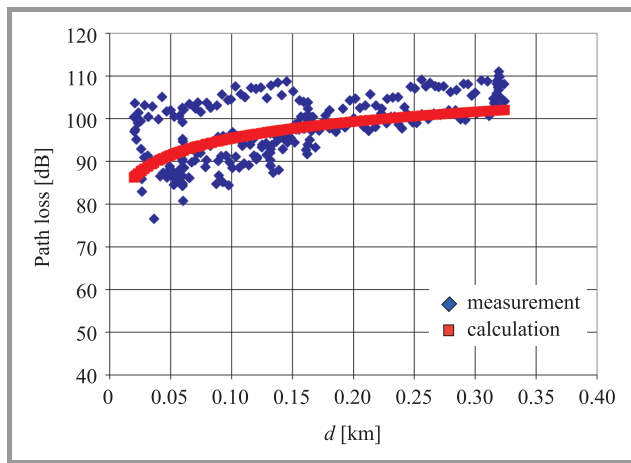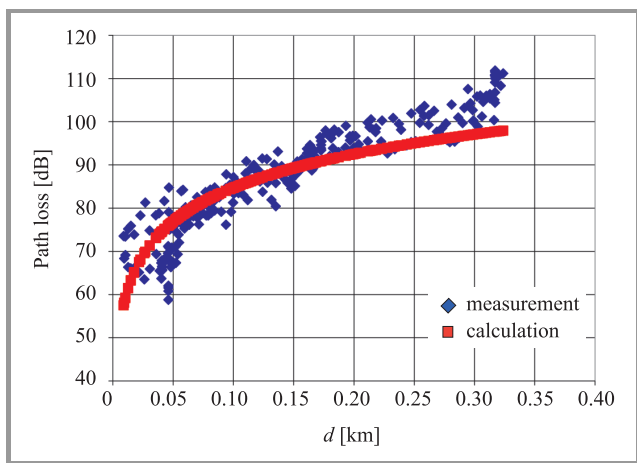**Fig. 4.** Propagation path loss at frequency 2 GHz – scenario LOS1.

Fig. 5. Propagation path loss at frequency 2 GHz – scenario LOS2.
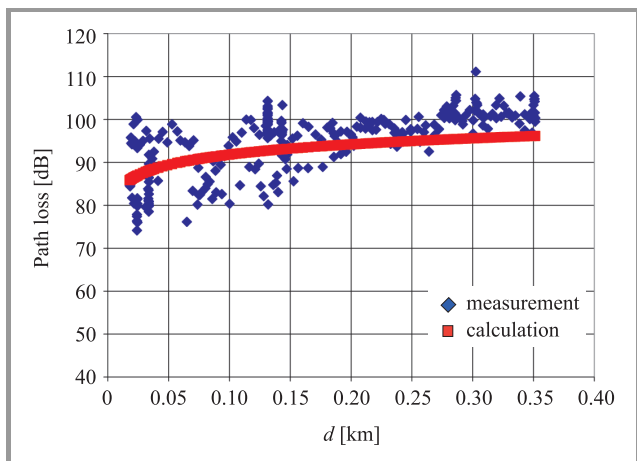

Fig. 6. Propagation path loss at frequency 2 GHz – scenario NLOS1.

Proposed model is valid for propagation path length up to 400 m, longer scenarios were not checked during measurement campaigns. Prediction of path loss at different fre-

Fig. 7. Propagation path loss at frequency 2 GHz – scenario NLOS2.

Table 3
Mean errors and mean square errors for proposed container environment propagation model

LOS				NLOS				Summary	
LOS1		LOS2		NLOS1		NLOS2			
ME	MSE	ME	MSE	ME	MSE	ME	MSE	ME	MSE
0.00	8.51	0.01	6.02	0.00	6.73	0.00	6.28	0.00	6.82
ME = 0.01, MSE = 7.22				ME = 0.00, MSE = 6.49					

quencies between 0.5 GHz and 4 GHz should be enough accurate, because the difference in calculated path loss caused by rounding frequency of interest to nearest measured frequency is not greater than about half the value of mean square error.

6. Conclusions

Radio propagation analysis in container terminal scenario, presented in this paper, was the first such measurement in Poland and unique in the worldwide area of radio communication research.

Upon the analysis of path loss measurement data, the novel container port area propagation model was proposed. This model has been verified in real propagation conditions in wide frequency range from 0.5 GHz to 4 GHz and can be used to predict propagation path loss in case of designing radio communication systems for container ports or even other container related propagation environments.

Acknowledgments

References

[1] R. Katulski, R. Niski, J. Stefanski, and J. Zurek, "Concept of the container monitoring system in Polish harbours", in *Proc. IEEE Conf. Technol. Homel. Secur. Enhan. Transp. Secur. Effic.*, Boston, USA, 2006, pp. 145–148.

[2] "Field-strength measurements along a route with geographical coordinate registrations", ITU-R Rec. SM.1708, 2005.

[3] A. Kiedrowski, "Specyfika propagacji fal radiowych w systemie dostępowym w warunkach miejskich". Ph.D. thesis, Warsaw, National Institute of Telecommunications, 2004 (in Polish).

[4] R. Katulski and A. Kiedrowski, "Empirical formulas for determination of the propagation loss in urban radio access links", in *Proc. IEEE Veh. Technol. Conf.*, Dallas, USA, 2005, pp. 1742–1746.

[5] R. Katulski and A. Kiedrowski, "Modelowanie tłumienia propagacyjnego w systemach dostępowych, w warunkach zabudowy miejskiej", *Kwart. Elektr. Telekomun.*, vol 52, no. 2, pp. 193–210, 2006 (in Polish).

[6] R. Katulski and A. Kiedrowski, "Calculation of the propagation loss in urban radio-access systems", *IEEE Anten. Propag. Mag.*, vol. 50, no. 6, pp. 65–70, 2008.

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