The Selected Propagation Models Analysis of Usefulness in Container Terminal Environment

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***Abstract*— It is particularly important to determine which propagation model is the most suitable for designing mobile radio systems in container terminal environment. The selected propagation models have been investigated. Results of the models' usefulness verification in terms of signal loss determination in such environment have been analyzed and discussed. The applied research methodology has been described too. The analysis have proved mismatching of these models to experimental data.**

Keywords: radio waves propagation; measuring research; container terminal environment; propagation models verification

I. 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 there is time-varying container arrangement in stacks of different height. There are a number of propagation models, mainly for urban, suburban or rural environments [1, 2]. There is also propagation model destined for container port environment, but this model has been developed for designing only fixed radio links [3, 4]. Modeling of basic transmission loss in mobile radio links is more complicated, so it is particularly important to determine which propagation model is the most suitable for designing such links. This issue is very important and there is a lack of an analysis in this field. To solve this problem there is a need to verify existing models based on results of measuring research. Such tests have been carried out by authors in Deepwater Container Terminal Gdansk SA. Nearly 290 thousand data of propagation cases were collected according to normative requirements [5, 6], which have to be met during the research. The analysis contained in [7] has been taken into account too.

At the outset of the paper (section II) the applied research methodology have been presented. This part describes both the measuring equipment and procedures.

Next, in section III, the selected propagation models have been shortly characterized. These models are: ITU-R P.1411 models for NLoS1 situations (in cases of propagation over roof-tops for urban and suburban areas), COST231 – Walfisch-Ikegami model and the above mentioned multi-variant empirical model for designing fixed radio links in container terminal for LOS (line-of-sight) and NLOS (non-line-of-sight) situations [3, 4].

The main part of the paper (section IV) presents results of verification of the models' usefulness in terms of designing the mobile radio networks in container terminal environment. This verification is based on mean error and standard error of estimate, which are commonly being used to verify accuracy of the path loss models.

At the end of the paper, in section V, the results have been summarized and discussed. Additionally, authors shortly present future research aimed at developing new propagation model for designing mobile radio links in container terminal environment.

II. APPLIED RESEARCH METHODOLOGY

The propagation research have been carried out in the years 2008-2009 in DCT Gdansk. The structure and power description of the measuring radio link have been presented in [8]. This link was built with fixed transmitting section, mobile receiving section and the propagation environment, which was the subject of research.

As is known, basic transmission loss L_b of this environment may be expressed using following formula [8]:

$$L_b\left[dB\right] = P_t\left[dBW\right] + G_t\left[dBi\right] - P_{MR}\left[dBW\right] - F_c\left[dB\right], \quad (1)$$

on the basis of the power gain G_t of the transmitting antenna, the power P_t on input of the transmitting antenna – set during calibration process of the transmitting section, the power P_{MR} on input of measuring receiver and the correction factor F_c – calculated during calibration process of the receiving section. It may be expressed by:

$$F_c\left[dB\right] = L_{rc}\left[dB\right] - G_r\left[dBi\right], \quad (2)$$

where L_{rc} means losses in the receiving section feeder lines and G_r is the power gain of receiving antenna.

The fixed transmitting section (Fig.1) of the test equipment consisted of signal generator connected to transmitting antenna through the RF amplifier.

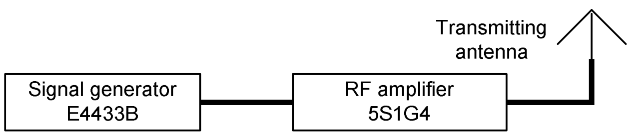

Figure 1. The block diagram of the fixed transmitting section

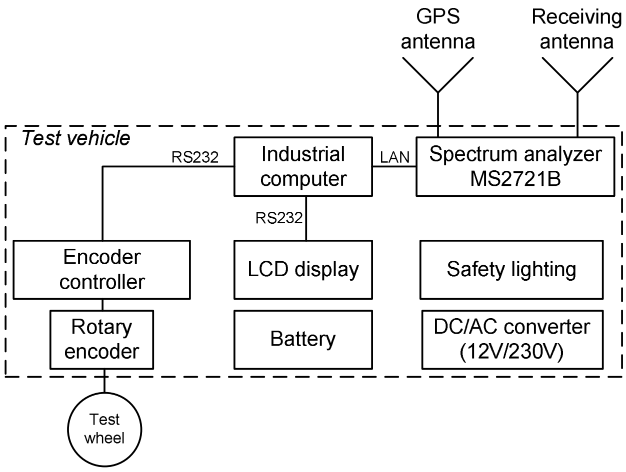

Figure 2. The block diagram of the mobile receiving section

The transmitting antenna was a monopole vertical antenna with electrical length of one-quarter of a wavelength. It has been developed and implemented in a manner, that allows to change its linear length, so it may be used to research on various frequencies.

The mobile receiving section (Fig. 2) consisted of a spectrum analyzer (with built-in GPS receiver), an industrial computer, a rotary encoder with its controller and a test wheel, a LCD display, a safety lighting and a battery with a DC/AC converter. The receiving antenna was the same type as the transmitting antenna. Whole receiving section has been carried by test vehicle (hand-cart).

The measurement results should include information about slow and fast changes of the power flux density of electromagnetic field (slow and fast fading, respectively) [7]. For obtaining 1 dB confidence interval around the real mean value, the test points have been chosen at each 0.8 λ (wavelength), over 40 λ averaging interval [6].

During the research in the DCT Gdansk nearly 290 thousand data of propagation cases have been collected. These cases concern propagation routes with various lengths, various frequencies of test signal and various heights of transmitting antenna installation.

III. CHARACTERISTICS OF SELECTED PROPAGATION MODELS

The container terminal is a non-typical radio wave propagation environment. Due to its structure, consisting of containers' stacks placed on a flat surface and cut by a uniform grid of routes, it seems to be similar to urban areas [4]. However, fact that the containers are made of corrugated steel is the reason to suppose that the conditions of radio waves propagation in such environment might be quite different. It is also important that both the layout of containers' stacks, as well as their height are variable in time. After considering above mentioned issues, four well-known propagation models have been selected, namely:

- Walfisch-Ikegami for NLOS situations [1],
- ITU-R P.1411 for NLoS1 situations (propagation over roof-tops for urban and suburban areas) [2],
- empirical model for fixed radio links in container terminal (for LOS1 and NLOS1 situations) [3, 4].

These models are going to be evaluated in terms of their usefulness for designing of mobile radio links in container terminal environment.

A. The COST231 Walfisch-Ikegami model

The COST231 Walfisch-Ikegami model allows for good path loss estimation by consideration of a number of parameters to describe the character of the urban environment, namely: average height of buildings, widths of roads, building separation and road orientation with respect to the direct radio path. Obviously, the model also takes into account such parameters as propagation path length and signal frequency. The model distinguishes between LOS and NLOS situations. The second one was selected to be evaluated. In this case the basic transmission loss is composed of free space loss, multiple screen diffraction loss and roof-top-to-street diffraction and scatter loss. Formulas used to calculate basic transmission loss are explained in detail in [1].

B. The ITU-R P.1411 model

Recommendation [2] includes propagation models destined for designing short-range outdoor radio systems for different types of environments. There have been selected two models for typical cases (NLoS1), where base station antenna is mounted above roof-top level.

The first one is the model described in section 4.2.1 of Rec. [2]. This model should be used for estimating the basic transmission loss in a highly urbanized city centers, medium-sized cities and suburban areas, where the roof-tops are all about the same height. It is a modified and extended version of the Walfisch Ikegami model. In addition, this model describes situations where the length of path covered by buildings is less than the so called "settled field distance". This situation hasn't been taken under consideration in Walfisch-Ikegami model. Mathematical formulas describing this model have been omitted due to their high complexity.

The second model has been characterized in section 4.2.2 of Rec. [2]. It may be used to calculate the basic transmission loss in suburban environment. Depending on the distance between base station and mobile station this model distinguishes three regions in terms of the dominant arrival waves at the mobile station, namely:

- direct wave dominant region, when the distance between antennas of the wireless link is very short,
- reflected wave dominant region, when the separation between base station and mobile station is relatively short,
- diffracted wave dominant region, when antennas separation is long [2].

Mathematical formulas describing the basic transmission loss have been omitted because of their complexity.

C. The model for fixed radio links in container terminal

In context of this paper, particularly noteworthy is empirical model for designing fixed radio links in container terminal. It was developed upon the results of almost five thousand of propagation path measurements in real container terminal environment. This model makes the basic transmission loss dependent on the following parameters: frequency *f*, propagation path length *d*, path type qualification: line of sight or non-line of sight condition, difference between transmitter antenna height h_T above terrain level and average height h_{av} of container stack, but two possible cases are investigated separately: $h_T \geq h_{av}$ and $h_{av} > h_T$ [3, 4].

From among four model variants, two describes the propagation situations that have occurred during the tests in the DCT Gdansk SA, namely:

- LOS1, for $h_T \geq h_{av}$:

$$L_{LOS1}[dB] = 55.2 + 20\log f[MHz] + 5.8\log d[km] - 22.1\log(h_T[m] - h_{av}[m]), \quad (3)$$

- NLOS1, for $h_T \geq h_{av}$:

$$L_{NLOS1}[dB] = 32.6 + 20\log f[MHz] + 7.9\log d[km] + 0.8\log(h_T[m] - h_{av}[m]), \quad (4)$$

This model is valid for frequency range from 500 MHz up to 4 GHz. It should be highlighted that it is destined to estimate the basic transmission loss of fixed links.

IV. STATISTICAL EVALUATION OF SELECTED MODEL

Verification of selected models' usefulness in terms of designing the mobile radio networks in container terminal environment is based on two measures of matching experimental data to mathematical models, namely: mean error (*ME*) and standard error of estimate (*SEE*). These errors are commonly being used to verify accuracy of the path loss models and they are defined by following expressions [4]:

$$ME[dB] = \frac{1}{N}\sum_{i=1}^{N}(L_{m,i}[dB] - L_{c,i}[dB]), \quad (5)$$

$$SEE[dB] = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(L_{m,i}[dB] - L_{c,i}[dB])^2}, \quad (6)$$

where $L_{m,i}$ is the value of measured basic transmission loss in *i*-th position of receiver equipment (*i*=1,...,*N*), $L_{c,i}$ means basic transmission loss value computed using propagation model for *i*-th position, and *N* is the sample size. Mean error value reflects the expected average difference between path loss values obtained using proposed model and real path loss measurement results, while standard error of estimate reflects dispersion of measured path loss values and describes how the propagation model matches to experimental data [3].

Table 1 summarizes values of mean error and standard error of estimate for selected propagation models. It may be seen that the smallest error values have been obtained for the COST231 Walfisch-Ikegami model (for medium sized city and suburban areas and for data from the range of applicability) and for the model for fixed radio links in container terminal (for NLOS1 scenario). In the first case mean error reached -2.18 dB, which means that this model overestimates basic transmission loss in relation to real values. For the second model, obtained mean error is positive and equals 3 dB, which means underestimation of propagation loss. In both cases SEE exceeds the value of 7 dB. Although the maximum acceptable standard deviation is 8 dB [9], it is expected that new propagation model for analyzed environment will allow to obtain much smaller error values. It also should be noted, that the SEE for Walfisch-Ikegami model, obtained for all data (from a range of 0.5÷4 GHz) is greater than acceptable value.

On the other hand the least matched to experimental data is the ITU-R P.1411 model for NLoS1 scenario (§4.2.1), designed to calculate path loss in a highly urbanized city centers. Mean error with the value of -9.36 dB and the standard error of estimate at the level of 14.3 dB make this model unsuitable to calculate basic transmission loss for mobile links in the container terminal environment.

TABLE I. VALUES OF MEAN ERROR AND STANDARD ERROR OF ESTIMATE FOR SELECTED PROPAGATION MODELS

Model	Scenario	Range of measurement data	Sample size	ME [dB]	SEE [dB]
COST 231 Walfisch-Ikegami	Medium sized city and suburban areas	All data	287582	-5.31	10.60
		Range of applicability	130968	-2.18	7.90
	Metropolitan centres	All data	287582	-10.12	15.96
		Range of applicability	130968	-3.93	9.26
ITU-R P.1411 NLoS1 situation (§4.2.1 of Rec. [2])	Medium sized city and suburban centres	All data	287582	-8.36	13.41
		Range of applicability	254184	-8.88	13.74
	Metropolitan centres	All data	287582	-8.77	13.90
		Range of applicability	254184	-9.36	14.30
ITU-R P.1411 NLoS1 situation (§4.2.2 of Rec. [2])	Suburban areas	All data	287582	-4.48	9.98
		Range of applicability	190581	-5.92	10.83
Model for fixed radio links in container terminal	LOS1	Range of applicability	287582	3.80	8.30
	NLOS1			3.00	7.57

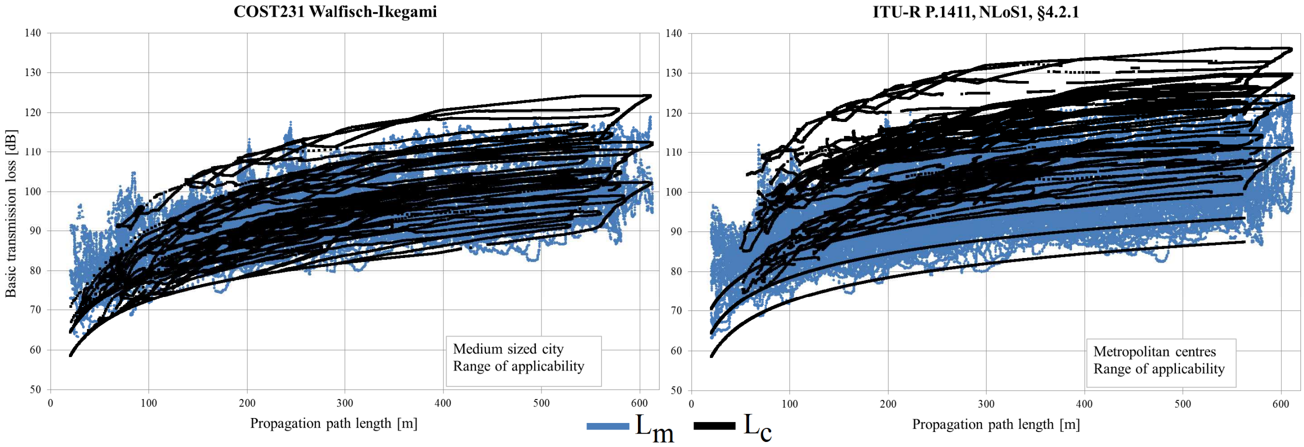

Figure 3. Basic transmission loss calculated on the basis of COST231 Walfisch-Ikegami model and ITU-R P.1411 model

In Fig. 3, the basic transmission loss graphs (including all propagation cases) for the Walfisch-Ikegami model and for the ITU R P.1411 model are presented. They have been drawn on the background of the measurement data for better illustration their matching to experimental data. The graph on the right is for the ITU-R model for NLoS1 scenario in metropolitan centers. This model is described in section 4.2.1. of Rec. [2]. As is seen the calculated values don't match well to experimental data. The graph on the left presents the results calculated on the basis of Walfisch-Ikegami model for medium sized city and suburban areas. It is the best fitted model, assuming that the parameters are from the range of applicability.

The results mentioned above allow to draw the conclusion that the propagation conditions occurring in the container terminal are different from the highly urbanized environments. They are more similar to suburban areas.

V. CONCLUSION

The analysis of the usefulness of selected propagation models to designing the mobile radio systems in the container terminal has been presented. This analysis has been done on the basis of the evaluation of selected propagation models in terms of their fit to data obtained during the tests. The research have been carried out in accordance with the recommendations [5, 6] and with taking into account the analysis contained in [7]. There are large differences in the results obtained for different propagation models. In addition the analysis have proved mismatching of these models to experimental data. Therefore, there is a need to increase accuracy of basic transmission loss estimation for mobile links in the container terminal environment. It may be done by modifying existing models or by developing new propagation model, taking into account additional independent variables, specific for the container terminal. Both methods are the goal of future research.

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