On the usefulness of selected radio waves propagation models for designing mobile wireless systems in container terminal environment

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Abstract

The selected propagation models have been investigated. Results of the models' usefulness verification in terms of signal loss determination in container terminal environment have been analyzed and discussed. The applied research methodology has been described too. Future research aimed at developing new propagation model for designing mobile radio networks in the container terminal environment have been shortly presented.

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 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]. Modelling 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. To solve this issue there is a need to verify existing models based on results of measuring research. Such tests have been carried out by authors in container terminal DCT 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 also taken into account.

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

Next, the selected propagation models have been shortly characterized. These models are: ITU-R P.1411-4 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 LOS1 and NLOS1 situations) [3, 4].

The main part of the paper 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, 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.

2. Applied research methodology

The propagation research have been carried out in the years 2008-2009 in container terminal DCT Gdansk. The structure and power description of the measuring radio link have been presented in the paper [8]. This link was built with fixed transmitting section, mobile receiving section and the propagation environment, which was the subject of research. As known, basic transmission loss of tested environment may be calculated on the basis of the power gain of the transmitting antenna, power on input of the transmitting antenna – set during calibration process of the transmitting section and the correction factor – calculated during calibration process of the receiving section as a difference between losses in the receiving section feeder lines and power gain of receiving antenna [8].

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The fixed transmitting section of the test equipment has consisted of signal generator connected to transmitting antenna through the RF amplifier. 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. 1) has consisted of spectrum analyzer (with built-in GPS receiver), industrial computer, rotary encoder with its controller and test wheel, LCD display, safety lighting and battery with 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).

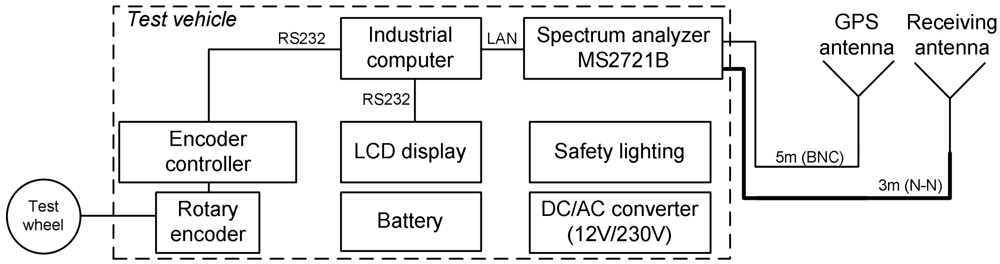

Figure 1. The block diagram of the mobile receiving section of test equipment

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 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.

3. Characteristics of selected propagation models

The container terminal is a non-typical radio wave propagation environment. Due to its structure, which consists of containers' stacks placed on a flat surface and cut by a uniform grid of routes, it seems to be similar to the 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 from urban areas. 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:

- COST231 – Walfisch-Ikegami for NLOS situations [1],
- ITU-R P.1411-4 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.

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 line-of-sight (LOS) and non-line-of-sight (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].

Recommendation [8] includes propagation models intended 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 centres, 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 so called "settled field distance". This situation hasn't been took 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, reflected wave dominant region and diffracted wave dominant region [2]. Mathematical formulas describing the basic transmission loss have been omitted because of their complexity.

In context of this paper, particularly noteworthy is empirical model for designing fixed radio links in container terminal. It has been developed upon the results of almost 5 thousand of propagation path measurements in real container terminal environment. This model makes the basic transmission loss dependent on the following parameters: signal frequency, propagation path length, path type qualification (LOS or NLOS), difference between transmitter antenna height above terrain level and average height of container stack. From among four model variants, two describes the propagation situations that were occurring during the tests in DCT Gdansk, namely LOS1 and NLOS1. Formulas used to calculate basic transmission loss in this cases are explained in detail in [3, 4].

4. 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]:

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

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. However, in both cases the standard error of estimate exceeds the value of 7 dB, which indicates a mismatch of these models to measured data.

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 centres. 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 1. 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)	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)	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

In Fig. 2 the basic transmission loss graphs (including all propagation cases) for the COST231 Walfisch-Ikegami model and for the ITU-R P.1411 model for NLoS1 scenario are presented. They have been drawn on the background of the measurement data for better illustration its matching to experimental data.

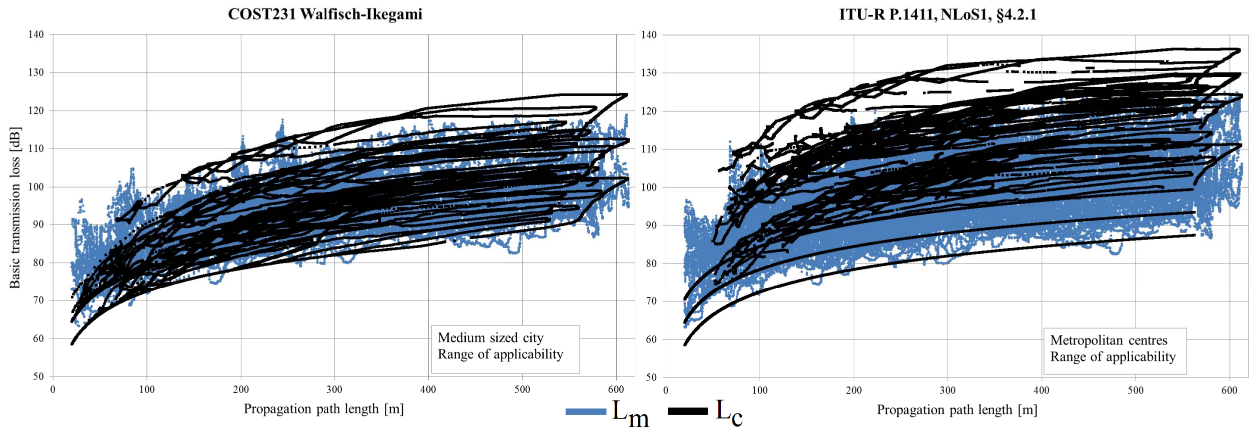

Figure 2. Basic transmission loss calculated on the basis of COST231 Walfisch-Ikegami model and ITU-R P.1411 model

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.

5. Conclusion

The analysis of the usefulness of selected propagation models to design 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.

6. Acknowledgments

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