Characteristics of Propagation Conditions in the Container Terminal Environment

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Abstract— **In the paper a characteristics of propagation conditions in the container terminal environment is presented. The investigated environment is characterized on the example of Gdansk Deepwater Container Terminal in Poland. An empirical propagation model for path loss calculation in mobile radio links in a container terminal environment is presented.**

Keywords—radiowave propagation conditions; path loss modelling; container terminal environment;

I. INTRODUCTION

The radio wave propagation medium is a factor that causes many difficulties when designing wireless networks, due to the large diversity of outdoor propagation environments, which include rural, urban, industrialized, marine and mountainous environments. The radio wave attenuation in each environment is determined by many variable phenomena and conditions. It is essential to determine the radio wave attenuation (so-called basic transmission loss [1]) with certain accuracy, in order to meet power requirements in designing of radio links.

The container terminal area should be treated as a very difficult radio wave propagation environment, because the large number of steel containers cause a very strong multipath effect and there is a time-varying container arrangement in stacks of different height. Path loss modelling for such an area remains a complex task that is not considered enough in scientific research. However, in recent years, this issue has been noticed and started to be taken more often [2-9]. This environment has been investigated in terms of path loss estimation using selected propagation models for others environments [6], their modified versions [7] and a new empirical model destined for such environment [8, 9]. The knowledge of the propagation conditions in such environment are very important for proper and reliable work of wireless communication, localization and monitoring systems [2-5].

This paper describes, in section II, the characteristics of the container terminal environment on the example of Deepwater Container Terminal in Gdansk, Poland (DCT Gdansk). This description includes the division of the terminal area into three sub-areas and the phenomena that have place in each part of investigated environment. In section III the MCT model [8, 9] is presented. This model may be used to path loss calculation in the container terminal area.

II. CHARACTERISTICS OF THE CONTAINER TERMINAL PROPAGATION ENVIRONMENT

The DCT Gdansk is built on an artificial peninsula surrounded by the Gulf of Gdansk on three sides.

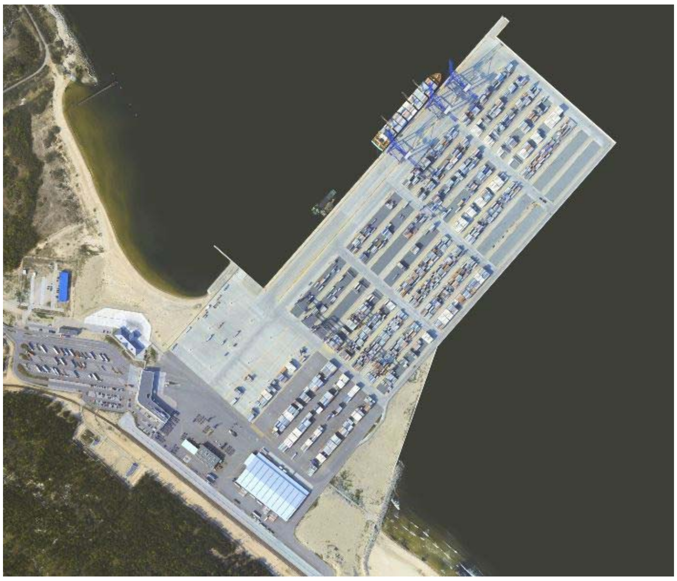

Fig. 1. An aerial view of the DCT Gdansk, Poland [10].

In Fig. 1 an aerial view of the DCT Gdansk is shown. The area where the containers are stored is about twenty hectares. The length of this area is about 650 m and its width is about 310 m. Containers are stored on so-called main container fields, whose dimensions are 139.1 m long and 19.9 m wide. The main routes between these fields are 10 m wide and the perpendicular routes are 19.15 m wide.

A standard twenty-foot container is about 6.1 m long, 2.5 m wide and 2.6 m high. For a forty-foot container the length is about 12.2 m. Their deployment is typical for this type of industrial environment and has a significant influence on radio wave propagation conditions.

The terminal consists of 32 main container fields, spaced in 8 rows, 4 fields for each row. Almost 154 stacks of the twenty-foot containers may be stored on each field, so the maximum number of all stacks does not exceed 4 928. At most, 5 containers may be in one stack, so the minimum height of a stack is 2.6 m and the maximum height of each stack does not exceed 13 m. It should be noted that the heights of container stacks are variable in time and could change significantly during one day. Therefore, up to 24 640 twenty foot containers may be stored in the terminal area. Thus, the environment under investigation has a relatively regular structure, but the variability of heights of container stacks and their arrangement have a significant influence on the variation of the path loss. There is also a diversity of conditions occurring in different places of the container terminal. For this reason, the terminal has been divided into three sub-areas, where different propagation mechanisms have a crucial influence on basic transmission loss (Fig. 2).

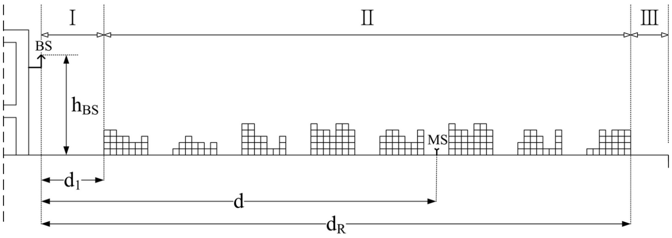

Fig. 2. Cross-section of the DCT Gdansk [8].

A. The LOS Area

The LOS Area (I) is defined for propagation path lengths (d) shorter than the distance (d_1) between the base station (BS) antenna and the first row of storage fields ($d \leq d_1$). In this case, direct wave and waves reflected from containers in the first row, or reflected from the ground, have the predominant influence on radio signal power received by the mobile station (MS). This is shown in Fig. 3 by rays marked as 1.

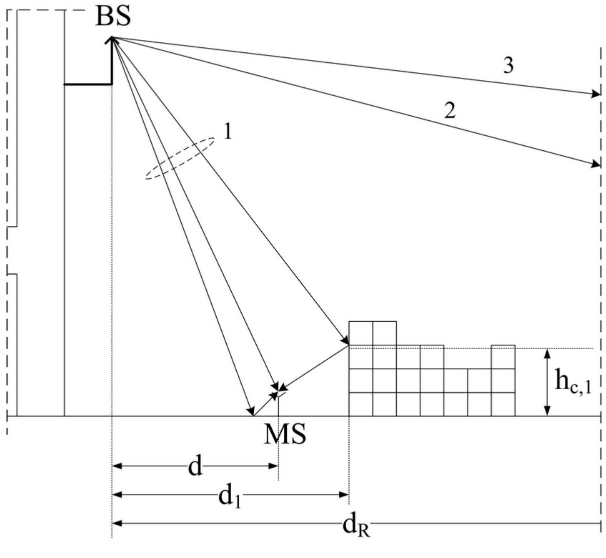

Fig. 3. An example scenario for the LOS Area [8].

In the LOS Area, the basic transmission loss depends on obvious factors such as frequency, path length, base station antenna height and the additional factor affecting the path loss: the average height of container stack ($h_{c,1}$) in the first row.

B. The Containers Area

The Containers Area (Ⅱ) is defined for propagation path lengths longer than d_1 and shorter than distance (d_R) between the base station antenna and the end of the last, Rth, row of storage fields ($d_1 < d \leq d_R$). In this case, the following phenomena have a predominant influence on the power of the received radio signal: diffraction at the edges of containers on the propagation path over the containers, especially at the edges of containers in the last, rth row of storage fields before the mobile station, and the wave reflection from the containers in the next row behind the mobile station. This is shown in Fig. 4 by rays marked as 2.

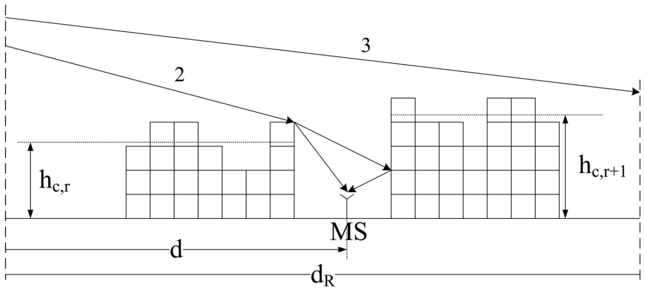

Fig. 4. An example scenario for the Containers Area [8].

Additional factors – except the obvious ones – affecting path loss in this sub-area are: average height of container stacks on the propagation path and average height of container stacks in the row behind the MS.

C. The Off-Terminal Area

The Off-Terminal Area (Ⅲ) is defined for propagation path lengths longer than d_R ($d > d_R$), where the diffraction at the edges of containers has a predominant influence on the received signal power. The mobile station receives just a small part of radio wave power due to diffraction at the edges of containers stored on fields in the last row. This is shown in Fig. 5 by rays marked as 3.

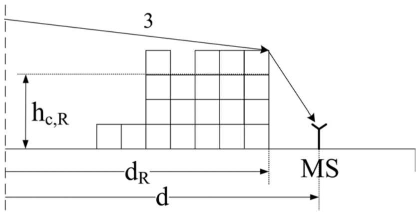

Fig. 5. An example scenario for the Off-Terminal Area [8].

Additional factors – except the obvious ones – affecting path loss, are as follows: average height of container stacks ($h_{c,t}$) throughout the terminal and degree of surface occupancy by container stacks over the entire surface of the terminal, expressed by the terminal surface occupancy ratio (S_t).

After analysis of propagation conditions, the following factors affecting the basic transmission loss in the container terminal environment were defined:

- frequency (f) of the radio signal;
- propagation path length (d), defined as the distance (in the plane) between the base station antenna and the MS;

- base station antenna height (h_{BS});
- angle (φ) of radio wave arrival between the direction of radio wave and the axis of the main routes between the storage fields (see Fig. 6);
- terminal surface occupancy ratio (S_t), defined as the ratio of surface occupied by containers to the whole terminal surface destined for container storage;
- ith row surface occupancy ratio (S_i), defined as the ratio of surface occupied by containers in the ith row to the whole surface destined for container storage in this row;
- average height of container stacks ($h_{c,t}$) throughout the terminal;
- average height of container stacks ($h_{c,i}$) in ith row;
- average height of container stacks ($h_{c,d}$) over the propagation path length;
- average height of container stacks ($h_{c,r+1}$) in the row behind the mobile station.

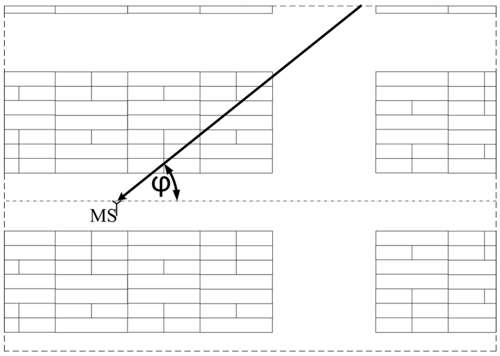

Fig. 6. Illustration of angle of radio wave arrival [8].

III. PATH LOSS CALCULATION

The path loss calculation in the container terminal environment may be done using the MCT model [8, 9] (MCT is an abbreviation for: mobile, container, terminal). The basic transmission loss (L_{MCT}) in such an environment may be expressed by the following equation:

$$L_{MCT[dB]} = \begin{cases} L_{LOS[dB]}, & \text{for} \quad d \le d_1, \\ L_{Cont[dB]}, & \text{for} \quad d_1 < d \le d_R, \\ L_{OffT[dB]}, & \text{for} \quad d > d_R. \end{cases} \tag{1}$$

It should be noted that distances d_1 and d_R are not constant and they depend on angle (φ) of radio wave arrival.
The particular components are expressed as follows:

A. for the LOS Area:

$$L_{LOS[dB]} = L_{0[dB]} - 4.2\log\left(h_{BS[m]} - h_{c,1[m]}\right) + 11.6, \tag{2}$$

where the L_0 factor is related to the direct wave, expressed by the well-known equation:

$$L_{0[dB]} = 20\log f_{[MHz]} + 20\log d_{[m]} - 27.6, \tag{3}$$

and the (h_{BS}–$h_{c,1}$) factor is related to the wave reflected from containers in the first row of storage fields;

B. for the Containers Area:

$$\begin{aligned} L_{Cont[dB]} &= 20\log f_{[MHz]} + 25\log d_{[m]} - 18\log\left(h_{BS[m]} - h_{c,d[m]}\right) + \\ &\quad + 6.2\log\left(h_{BS[m]} - h_{c,r+1[m]}\right) + 4\log \varphi_{[\circ]} - 21.8, \end{aligned} \tag{4}$$

where the (h_{BS}–$h_{c,d}$) factor is related to the path loss due to diffraction at the edges of containers on the propagation path over the containers, where:

$$h_{c,d} = \left(\sum_{i=1}^{r} h_{c,i} \cdot S_i\right) \Bigg/ \left(\sum_{i=1}^{r} S_i\right) \tag{5}$$

and the (h_{BS}–$h_{c,r+1}$) factor is related to the wave reflected from the containers in the next row behind the mobile station;

C. for the Off-Terminal Area:

$$\begin{aligned} L_{OffT[\mathrm{dB}]} &= 20\log f_{[\mathrm{MHz}]} + 30\log d_{[\mathrm{m}]} - 18\log\left(h_{BS[\mathrm{m}]} - h_{c,t[\mathrm{m}]}\right) + \\ &\quad + 13.5\log S_t + 4\log \varphi_{[\circ]} - 21.8, \end{aligned} \tag{6}$$

where the (h_{BS}–$h_{c,t}$) factor is related to the path loss due to diffraction at the edges of containers on the propagation path over the containers, where:

$$h_{c,t} = \left(\sum_{i=1}^{R} h_{c,i} \cdot S_i\right) \Bigg/ \left(\sum_{i=1}^{R} S_i\right) \tag{7}$$

and the S_t factor reflects the influence of the number of container stacks in the whole container terminal area. This factor is higher than 0 and lower than 1. It equals 1 when the whole terminal surface destined for container storage is occupied by container stacks.

In the above equations r=1,2,…,R-1 is the number of the last row of storage fields before the mobile station and R is the number of all rows of storage fields.

The ith row surface occupancy ratio (S_i) and the terminal surface occupancy ratio (S_t), reflect the number of containers stored in the ith row of main storage fields and on the whole terminal area, respectively. Considering equations (4)-(7), it may be said, that if the number of stored containers increases, the relevant surface occupancy ratio also increases, and the estimated path loss value increases too.

The MCT model is an empirical model, so (2), (4) and (6) are empirically derived expressions. The model is valid for the following ranges of parameters:

- 500 MHz $\le f \le$ 4 GHz,
- 50 m $\le d \le$ 620 m,

- 12 m $\leq h_{BS} \leq$ 36 m,

and on the assumption that:

- $h_{BS} > h_{c,1}$, $h_{BS} > h_{c,d}$, $h_{BS} > h_{c,r+1}$ and $h_{BS} > h_{c,t}$,
- $0 < \varphi \leq 90°$,
- $0 < S_t \leq 1$.

In [8] the MCT model has been verified in terms of accuracy of the path loss estimation. Results of this verification (based on measurements in DCT Gdansk) are recapitulated in Table I, where *ME* is a mean error, *SEE* is a standard error of estimate and R^2 is a coefficient of determination [11]. The *ME* value reflects the expected average difference between path loss values obtained using the MCT model and real path loss measurements, while the *SEE* is the ratio of the dispersion of measured path loss values, and describes how well the propagation model matches experimental data. The coefficient of determination (R^2) is a statistical measure which tells what part of the path loss variability is explained by the independent variables used in the model. If the coefficient of determination is closer to unity, the model better explains the variability of path loss. The minimal acceptable value of this coefficient equals 0.6. These parameters (*ME*, *SEE*, R^2) are commonly used to verify the accuracy of the path loss models [8, 12].

TABLE I. VERIFICATION RESULTS OF THE MCT PROPAGATION MODEL

Parameter	L_{LOS}	L_{Cont}	L_{OffT}	L_{MCT}
***ME* [dB]**	0.85	1.03	-0.26	0.72
***SEE* [dB]**	4.40	4.53	4.30	4.45
R^2	0.81	0.80	0.77	0.82

A mean error of 0.72 dB and a standard error of estimate equal to 4.45 dB allow estimation of the basic transmission loss with satisfactory accuracy. In addition, the MCT model explains 82% of the path loss variability in the container terminal. It is indicated by the coefficient of determination, which equals 0.82. It should be noted that from the point of view of the wireless network designer, the model accuracy for the Off-Terminal Area is most important to ensure full radio coverage. For this sub-area *ME*, *SEE* and R^2 are the smallest and equal -0.26 dB, 4.3 dB and 0.77, respectively.

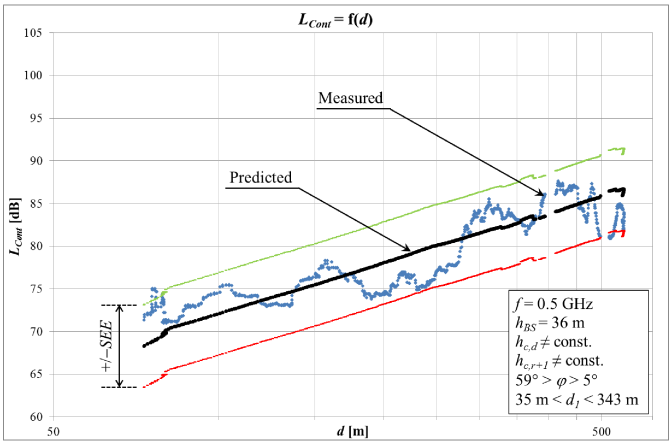

Fig. 7. An example path loss graph for the Containers Area.

In Fig. 7 an example graph of path loss for the Containers Area and various parameters of the model is presented. The predicted values are depicted, as well as the measured values. In addition, the predicted values plus *SEE* and minus *SEE* are shown (label: +/–*SEE*). The measured values seem to correspond well to regression line and in most cases it is in +/–*SEE* interval.

IV. CONCLUSIONS

The MCT model is a first propagation model for designing mobile radio networks in the container terminal environment and characterizing propagation conditions in such type of industrial environment. This model takes into account all essential factors that occur in this environment and that affect basic transmission loss of radio wave. The obtained standard error of estimate is 4.45 dB. What is more, the obtained value of the coefficient of determination is 0.82 which additionally proves the accuracy and usefulness of the MCT model.

The MCT model is a first step to elaborating a more universal model for container terminal areas. For this reason, comprehensive measurement research in different environments should be carried out. For obvious reasons this should be done in international cooperation.

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