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The Development of the ITU-R Terrestrial Clutter Loss Model

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***Abstract*—ITU-R has recently published a new Recommendation giving methods for the estimation of clutter loss at frequencies between 30 MHz and 100 GHz. This paper provides an overview of the methods. In particular, the derivation and form of the new clutter model for terrestrial paths is described in detail and remaining work is pointed out.**

***Index Terms*—antenna, propagation, measurement.**

I. Introduction

ITU-R[1] is conducting coexistence studies in preparation for World Radio Conference 2019 (WRC-19) that includes frequency bands in the mm-wave range. In these studies, ITU-R P-series (propagation) recommendations are used for determining the transmission loss for different interference scenarios between terrestrial stations, earth and airborne stations, and earth and space stations as depicted in Fig. 1. For this purpose, ITU-R Study Group 3 (SG3) is responsible for the provisioning of adequate propagation models. One main task in this work has been to assure that existing ITU-R Recommendations (P.619, P.2041, P.1409, P.452, P.2001 etc.) are valid for the full range of frequencies under consideration by WRC-19. Another important task has been to provide new models for additional transmission losses due to clutter and building entry. The clutter loss modelling is presented in this paper whereas the building entry loss (BEL) modelling is presented in an accompanying paper [1].

Clutter loss is defined as the additional transmission loss due to local clutter around either end, or both ends, of a radio link. In this context, the clutter itself is defined as any man-made structures like buildings and vehicles or vegetation. In the past, no such radio wave propagation recommendations applicable for clutter loss for frequencies in the mm-wave range were available. Successful modelling work by ITU-R SG3 resulted in the provisioning of adequate clutter loss models which were published in June 2017 [2]. The models are separated in one Earth-to-space/air part and a terrestrial part. This paper presents the elaboration of the terrestrial model which is empirical and based on extensive measurements in Aalborg, Gothenburg, and Tokyo.

[1] The Radiocommunication sector of the International Telecommunication Union.

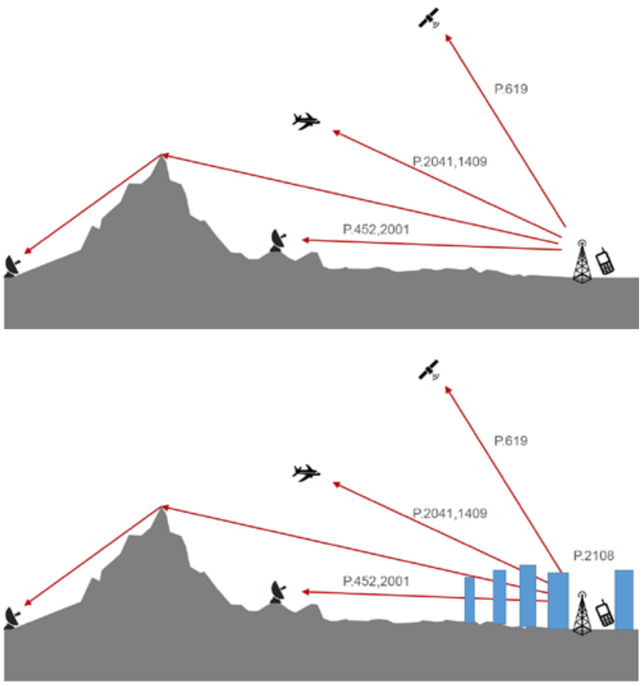

Fig. 1. Example of long range interference scenarios between IMT and terrestrial, airborne and sattelite systems indicating appropriate ITU-R P-series Recommendations.

II. ITU-R Clutter Loss Model Overwiev

The motivation for providing separate models for the terrestrial and the Earth-to-space/air cases is the difference in the main propagation elevation angle.

For the Earth-to-space scenario the probability to have a small elevation angle, relative to the horizon, is small. This justifies the chosen approach of using simple ray tracing

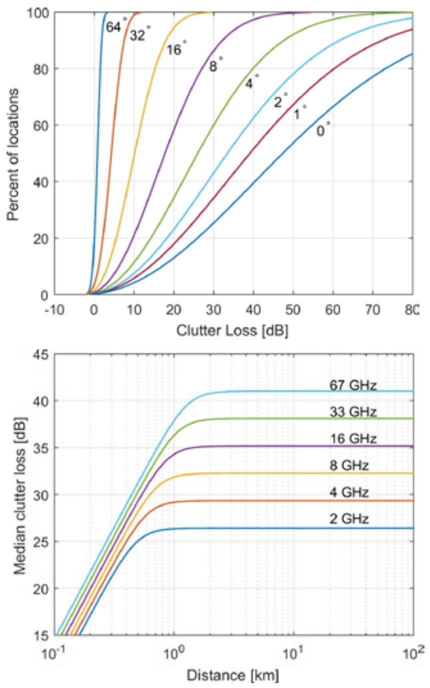

Fig. 2. Cumulative distributions of clutter loss not exceeded for 30 GHz and different elevation angles for the earth to space/air model (upper graph) and median clutter loss versus distance for the terrestrial model (lower graph). The curves are obtained from expressions provided in [2].

assuming that the corresponding propagation is dominated by lower orders reflection and diffraction.

For the terrestrial case, however, the elevation angle range is concentrated to small values around zero. In this case, corresponding over roof-top propagation is complex involving multiple diffraction and scattering effects. For this reason, the chosen approach is to base the modelling on measurements.

A. *Earth-to-space/air model*

The Earth-to-space/air model was developed based on simplified ray tracing accounting for up to two reflections off exterior walls, and a single diffraction at the roof edge, of buildings around the terminals embedded in the urban clutter [3]. The model inputs are stochastic distributions of the horizontal distances to, and roof heights of, the closest buildings. The output of the ray tracing model, for representative environments, was thereafter used for parametrization of the final empirical model shown in Fig. 2.

B. *Terrestrial model*

As the terrestrial model is empirical, extensive measurements are required to provide high confidence. For this purpose, measurement data, in the frequency range 2-67 GHz, from three independent campaigns are used to parameterize the model. Measurement data from Aalborg and Gothenburg are used for determining the long-range characteristics and measurement data from Tokyo are used for determining the short-range characteristics. The final agreed model, shown in Fig. 2, is a function of frequency for long ranges and of both frequency and distance for the short ranges.

III. TERRESTRIAL MEASUREMENT CAMPAIGNS

A. *Aalborg measurements*

Transmission loss data from an extensive measurement campaign in the frequency range 2-28 GHz in a mobile urban macrocell scenario in Aalborg, Denmark [4] have been further analyzed for the terrestrial clutter loss modelling. The measurements were performed in a residential area where the building heights and street widths are relatively homogeneously distributed around 17 m and 20 m respectively. Extensive transmission loss measurement data for over-the-roof propagation for link distances up to 1 400 m are provided for transmitter (Tx) heights between 15 m and 57 m. The focus is on the horizontal propagation case, i.e. the Tx height should be slightly larger than the surrounding roof-top heights. For this reason, a Tx height of 25 m is chosen as it is slightly larger than the surrounding roof tops. Omni directional antennas (dipole, bicone) mounted on top of a measurement van at 2.5 m above ground were used at the receiver (Rx). Two different topologies have been investigated. In the first (Tx1), the streets of the measurement route are oriented with about 45 degrees angle relative to the base station. In the second (Tx2), shown in Fig. 3, the streets are parallel and orthogonal relative to the base station. For the Tx2 scenario, the least clutter loss is expected as line-of-sight (LoS) or slightly obstructed paths are more likely.

The distance dependence of clutter loss is shown in Fig. 4 for 18 GHz. Up to about 800 m there is a clear increasing trend. For larger distances, however, the loss seems to be constant. The explanation for the low loss values at short distances is that probability for LoS or close to LoS is high. At larger distances, the probability for LoS becomes very low.

Fig. 3. Clutter loss measured at 18 GHz for the base station location Tx2 in Aalborg.

B. *Gothenbourg measurements*

A measurement campaign investigating the additional loss due to urban clutter at 28 GHz has been performed in the city of Gothenburg Sweden. The details of the measurement set-up are described in [5,6]. However, for this specific measurement campaign the receiver sensitivity has been im-

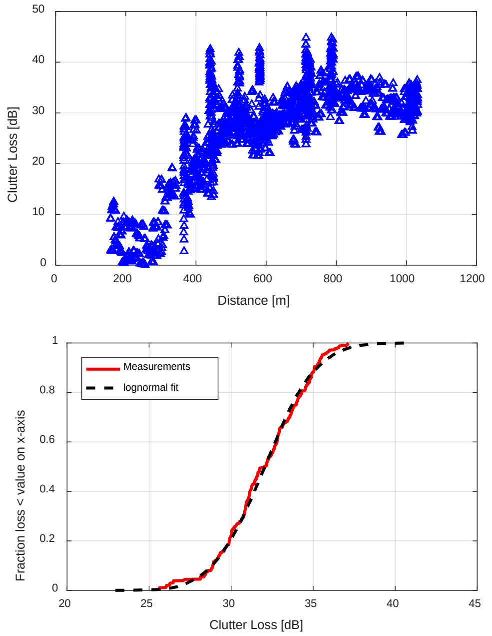

Fig. 4. Clutter loss measured at 18 GHz versus distance for the base station location Tx2 in Aalborg (upper graph) and corresponding CDF for distances > 800 m together with a lognormal fit.

proved substantially to enable measurements of urban clutter loss up to 1 700 m. Directional antennas were used at both Tx and Rx. In the Rx end, a synthesized omni-directional antenna pattern is obtained by summing the signal from a full space angle directional scan.

The Tx antenna was mounted at 25 m height above ground on a building while the Rx antenna was mounted at the roof of a car at 2 m height above ground. Corresponding measurement points and distance ranges are shown on the photographic map in Fig. 5. As seen in the figure, there is 500 m of free space from the transmitter over the river to the city area at the other side where the measurements were performed.

In Fig. 6 the clutter loss as a function of distance is shown. As for the Aalborg measurement data, there is a trend of lower loss for the shorter distances for which there is a

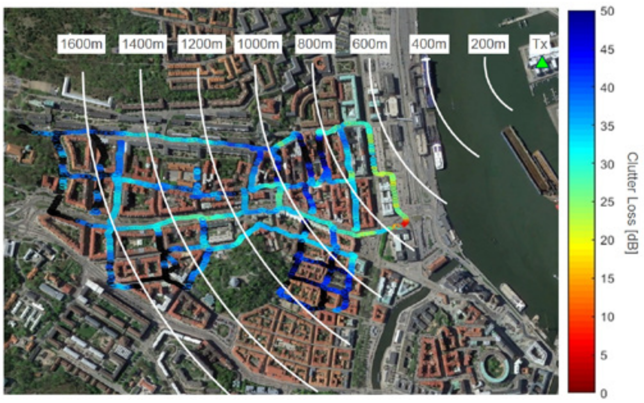

Fig. 5. Clutter loss measured at 28 GHz in Gothenbourg. The transmitter (basestation) location is marked with Tx.

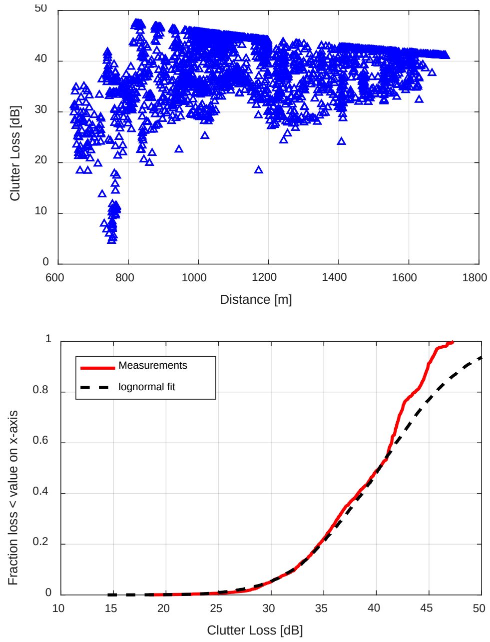

Fig. 6. Clutter loss measured in Gothenburg at 28 GHz versus distance (upper graph) and corresponding CDF for distances > 800 m together with a lognormal fit.

significant probability of locations which are in LoS or close to LoS. For distances larger than 800 m, the median loss does not show any distance dependency. Some of the measurement points are below the noise floor of the measurement equipment. This is observed as an upper cap of the measured clutter loss in Fig. 6. The saturated measurement points do, however, not affect the measured distribution below the median as seen in the lower graph in Fig. 6 where the CDF for distances larger than 800 m is shown. For this reason, values below the median are used for fitting corresponding lognormal distribution.

C. *Tokyo measurements*

A measurement campaign has been performed in an urban area of Tokyo in the frequency range 2.2 to 66.5 GHz. A photo of the measurement environment is shown in Fig. 7. The Tx antenna was installed on a building roof at about 55 m height above ground and the Rx antenna was on a measuring vehicle set at a height of 2.5 m. The red lines in Fig. 7 represent the Rx route. The measurement distance ranged between 260 and about 1 200 meters.

Directional antennas with a half power beam width (HPBW) of 30 degrees and 60 degrees were used for 66.5 GHz and other frequencies respectively at the Tx, while omnidirectional antennas were used at the Rx. The Tx antennas were directed to the Rx antenna position so that they would always be within the Tx antenna beam width. The transmitting signal was a continuous wave. Very low received power could be measured by using a high gain LNA and a narrowband receiver. The received power was acquired at a sampling frequency of 45 kHz and giving about 4 000 points of data per meter. In order to eliminate

Fig. 7. Environment chosen in Tokyo for terrestrial transmission loss measurement in the frequency range 2.2 to 66.5 GHz.

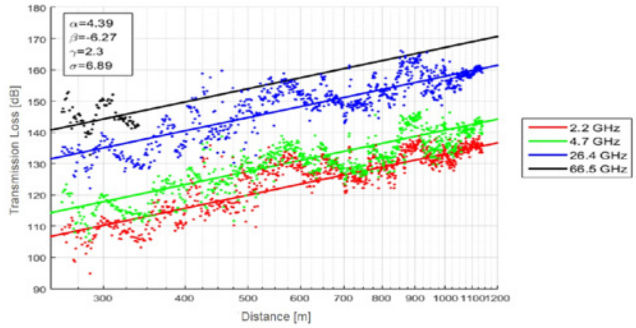

Fig. 8. Transmission loss measurements in Tokyo (from 2.2 GHz to 66.5 GHz).

the influence of fast fading, median values were calculated for every meter of the moving distance. The distance between the Tx and Rx antennas was calculated using GPS data.

Fig. 8 shows the measured transmission loss as function of Tx-Rx distance for the different frequencies together with corresponding fitted over roof-top model included in Recommendation ITU-R P.1411 [7]. The overall trend is that the loss increases with increasing distance and frequency.

IV. Model Paramaterization

A. Long-range model

For ranges larger than about 1 000 m the terrestrial clutter loss L_{cl} is modelled with a linear function

$$L_l = 23.5 + 9.6\log(f) + N(0,6) \quad [\text{dB}] \tag{1}$$

where f is the frequency in GHz and $N(0,6)$ is a normal distribution with zero mean and 6 dB standard deviation. The model parameters are determined by fitting the model to the Aalborg and Gothenburg measurements for distances larger than 800 m as shown in Fig. 9. As no clear frequency trend of the standard deviation is observed and to simplify the model, a value of 6 dB, which is in the high end of the distribution, is chosen as a conservative assumption.

B. Short-range model

For shorter ranges (0.26-1.2 km) the over roof-top model [7], which is based on the Tokyo measurements, is used with the free space loss subtracted,

$$L_s = 32.98 + 23.9\log(d) + 3\log(f) + N(0,6) \quad [\text{dB}], \tag{2}$$

where d is the distance in kilometres. To simplify combination of models, the standard deviation is harmonized with the long-range model (6 dB) which is slightly less than the value of 6.89 dB in P.1411.

C. Combined model

To provide a single continuous model for all ranges larger than 260 m, the two models are blended using received power in linear units. The resulting combined model, which also is the final terrestrial clutter loss model of Recommendation ITU-R P.2108 shown in Fig. 2, is given by

$$L_{ct} = -5\log\left(10^{-0.2L_l} + 10^{-0.2L_s}\right) + N(0,6) \quad [\text{dB}]. \tag{3}$$

When both ends of the link are embedded in clutter, the clutter loss of ITU-R P.2108 may be applied to both ends, if the total distance of the link is larger than 1 000 m, while for smaller distances, the non-line-of-sight (NLoS) models of ITU-R P.1411 should be used.

V. Motivation for Separate Models

As mentioned previously the motivation for proposing a separate model for the terrestrial scenario is that the Earth-to-space/air model might be too simplistic for the complex propagation over the multitude of roof-tops in an urban environment. To quantify the difference between the models, one may compare corresponding CDFs. Another measure is the effective average clutter loss, for aggregation of multiple transmitters, defined as

$$L_{eff} = -10\log\left(\frac{1}{N}\sum_{i=1}^{N}10^{-L_{ct_i}/10}\right) \quad [\text{dB}] \tag{4}$$

where N is the number of transmitters. This measure is particularly useful for interference scenarios with a multitude of interferers which is likely, e.g. in the case of IMT transmitters.

In Fig. 10 the corresponding outputs of the two models are shown. As the elevation angles for the terrestrial scenario are expected to be very small, zero degree elevation is chosen for the Earth-to-space/air model. The assumption that the Earth-to-space/air model is too simplistic to model the terrestrial scenario is confirmed by comparing the outputs. In the low loss end of the distributions the loss is substantially underestimated by the Earth-to-space/air model. As a consequence, the effective average loss is underestimated by up to 20 dB for the higher frequencies.

As the terrestrial model is based on extensive experimental data which have been thoroughly analyzed, this model is preferred in case of transmission, or interference, between terrestrial stations. In case of transmission, or interference, between terrestrial stations and airborne or space stations there is lack of empirical data. However, this

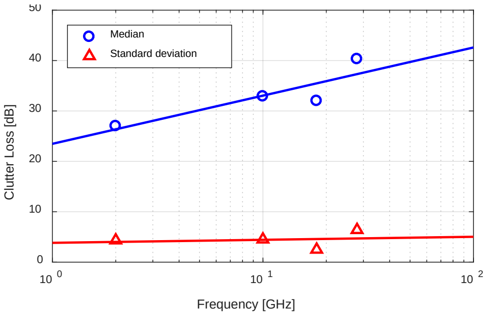

Fig. 9. Median measured clutter loss from Aalborg and Gothenburg and corresponding standard deviation for distances > 800 m versus frequency together with linear fits.

scenario is dominated by elevation angles which are substantially larger than zero for which a more simplistic ray tracing approach is expected to be sufficiently accurate.

VI. CONCUSIONS AND FUTURE WORK

Adequate propagation models for urban clutter loss in the frequency range 2 to 100 GHz have been developed by ITU-R and made publicly available in Recommendation ITU-R P.2108 [2]. For the terrestrial scenario, the modelling is based on extensive measurement data and therefore experimentally validated. This is not the case for the Earth-to-space/air model. However, assuming elevation angles that are substantially larger than zero, the lower orders of reflection and diffraction dominate, wherefore the simplistic ray tracing, which the model is based on, is expected to be sufficiently accurate.

Though the terrestrial model is expected to be accurate for scenarios which correspond to the actual measurement campaigns, additional multi frequency measurement campaigns in other urban environments would be valuable for further validation/calibration. Moreover, there are some aspects which are not addressed in the current model:

- The model accounts for terminal heights of a few meters above ground. Scenarios where the terminal is at other heights inside or outside buildings are missing.
- Clutter loss due to vegetation is not modelled.
- A common scenario is when a terminal is inside a building. In this case, there is a need for combining the clutter loss model with the building entry loss model (Recommendation ITU-R P.2109 [8]). A reasonable assumption might be to add the two contributions in logarithmic units. However, this assumption needs validation with experimental data. Moreover, addition of the two contributions is not valid for higher floors in the building as the current clutter loss model does not account for those heights.

To address also these aspects corresponding additional measurements would be required.

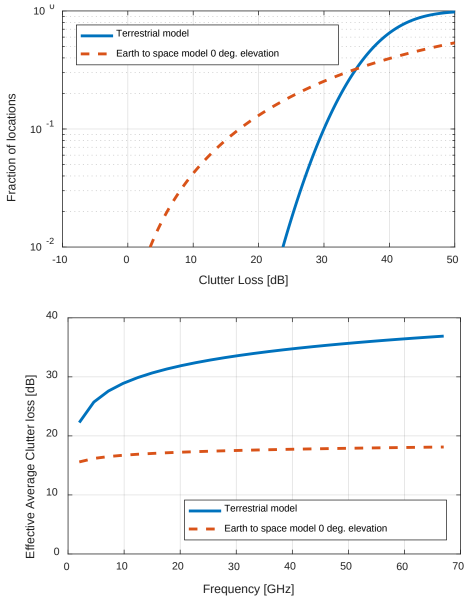

Fig. 10. CDFs of clutter loss at 30 GHz (upper graph) and effective average clutter loss versus frequency (lower graph) for the terrestrial long range model and the Earth-to-space/air model.

ACKNOWLEDGMENT

It should be noted that the development of the terrestrial clutter loss model in Recommendation ITU-R P.2108 was a collaborative effort by a large number of individuals from many organizations. In particular, contributions from Aalborg University, Ericsson, Intel, Nokia, NTT, Samsung, Telstra and UK are gratefully acknowledged. Any errors or omissions are due to the present authors.

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