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Published in:
12th European Conference on Antennas and Propagation (EuCAP 2018)

DOI (link to publication from Publisher):
10.1049/cp.2018.0720

Publication date:
2018

Document Version
Accepted author manuscript, peer reviewed version

The development of the new ITU-R model for building entry loss

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***Abstract*—The ITU-R[1] has recently published a new Recommendation giving a method for the estimation of building entry loss at frequencies between 100 MHz and 100 GHz. This paper describes the derivation and form of the new model and highlights work that remains to be done in this area.**

***Index Terms*—buildings, propagation, measurement, model**

I. Introduction

Building entry loss (BEL) i.e. the additional loss of received signal from an outdoor transmitter due to being inside a building, is an increasingly important parameter in system planning, and in spectrum sharing studies. Consumers expect seamless access to wireless services as they move indoors, while in making spectrum assignments it is often necessary to characterise the degree of isolation that may be expected between outdoor and indoor systems. It is therefore unfortunate that building entry loss is poorly-characterised, partly due to the wide variability within and between buildings (see Fig.1 below). Concern has also been expressed that the increased use of energy-efficient construction practices may be causing typical values of building entry loss to increase.

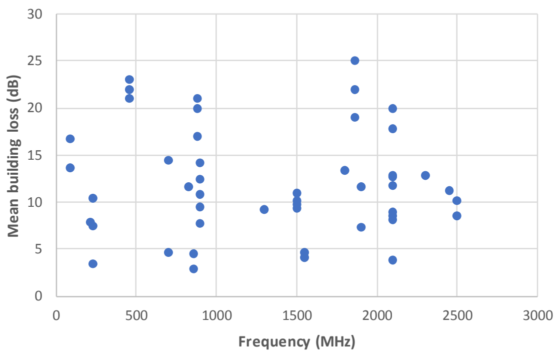

Fig. 1. Reported empirical values of building loss (Refs [7]-[14] et al)

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

The ITU-R has recently published a new Recommendation giving a method for the estimation of building entry loss at frequencies between 100 MHz and 100 GHz. This paper describes the derivation and form of the new model and highlights work that remains to be done in this area.

II. Standardisation

A. Definition of terms

Much of the apparent variation in the measurements of BEL shown in Fig.1 is due to differences of definition and in measurement method. In some empirical work, e.g. [1,7], the shadowing loss due to other local buildings is included, giving rise to a reduction in overall loss on higher floors of the subject building. In other work, a clear line-of-sight was established to the building, with references measurements taken immediately outside, e.g. [8].

The starting point for the work within the ITU-R was therefore to agree on the definition of terms and on measurement procedures, and these are now given in Annex 2 of Recommendation ITU-R P.2040 [2]. Here Building Entry Loss (BEL) is very simply defined as *"…the additional loss due to a terminal being inside a building*".

The Recommendation goes on to note that "*Building entry loss can be measured as the difference […] between the spatial median of the signal level outside the illuminated face of a building and the spatial median of the signal level inside the building at the same height above ground*". The annex also provides tables that specify the metadata that should be collected during any measurement campaign.

B. Measurement methods

In the ITU-R work, the decision was taken to consider the loss associated with a building in isolation from its surroundings; although the impact of the local environment will need to be considered in system modelling or sharing studies, it was considered that to conflate the loss due to local clutter with that due to the building would be unhelpful in deriving a useful model.

A consequent constraint in conducting measurements of building loss in urban areas is that it is necessary to ensure that the measurement path has a clear line-of-sight to the building under investigation, as, if this condition is not met, the measured data will necessarily include an unknown element of local clutter loss.

The measurement method recommended by the ITU-R requires that the '*spatial median of the signal level inside the building*' be determined. A detailed methodology is not given, but parameters such as signal bandwidth, wavelength and the required sampling rate are interrelated and should be explicitly stated. It has been found appropriate to estimate this median for each room[2] of a building. Discretising these statistical measurements on a per-room basis will also allow the future parameterisation of building loss statistics in terms of depth within the building.

It is seldom straightforward to log the instantaneous position of an indoor terminal, but it has been found that, if the antenna is carried in a semi-regular pattern (e.g. a crosshatch) to explore the room fully, the cumulative distribution of loss is reproducible to within <1dB.

In line with the ITU-R Recommendation, the building entry loss is defined relative to the median field measured immediately outside the building, either at ground level or from a window or on a balcony for higher floors. Care should be taken to ensure that measurement of this reference field is not unduly affected by the presence of the building (e.g. by reflections or antenna interaction with the antenna)

Gathering continuous statistical data on signal levels within a room is straightforward at lower frequencies where omnidirectional antennas are both practical and representative of practical terminals. At higher frequencies, e.g. in the millimetre-wave region, the use of such low-gain antennas will often reduce the dynamic range of the measurements to an unacceptable degree; it is also unlikely to represent the characteristics of real-world use, where directional, synthesized or MIMO antenna systems are likely to be used.

At such frequencies, therefore, most measurements have used mechanically-rotated directional antennas, moved between relatively few locations within each space.

III. Empirical Data

In the period 2015-2017, The ITU-R correspondence group[3] received 23 separate submissions of empirical data from new measurements by a wide range of organisations. These have been collated in a document [3] which is intended to remain a 'live' repository for measurement results as they are submitted to the ITU-R.

[2] Or equivalent zones, with sides of a few metres, in open-plan buildings

[3] CG 3J-3K-3M-8 of ITU-R Study Group 3

IV. Derivation of Model

A. Form of model

The immediate need within the ITU-R was for a model that could be applied in sharing studies to inform the allocation of new spectrum for use by 5G mobile systems (IMT-2020 in ITU terminology). Frequencies up to 86 GHz are being considered in these studies which were due to start in Spring 2017. Beyond this specific urgent requirement, however, there was a need for guidance on BEL in many application areas.

As a consequence, it was decided that a model should be developed to cover the frequency range 100 MHz to 100 GHz. A rather simple model was implied partly by the limited time available, but more importantly by the fact that very few input parameters would be available in the context of the sharing studies to be undertaken. It was agreed that the model have the following characteristics:

- Site general – only two classes of buildings to be considered; 'traditional' and 'thermally-efficient'. Clear guidance must be given on the interpretation of these terms.
- Site general – no account will be taken of indoor terminal depth within the building or of azimuth angle of incidence, as terminal locations and building incidence cannot be known in generalised sharing studies.
- Path elevation angle will be accounted for, as slant paths are likely to be important in sharing studies
- The model will predict building entry loss for arbitrary probabilities.

Within the ITU-R group, there was much discussion of the first point, relating to building classification. The option of deriving a single model for the entirety of building types was dismissed, as the spread of results (see Fig.1) was so great as to render any such model unhelpful; on the other hand, users of the model for generalised studies would not be in a position to provide detailed building data for modelling that might need to be globally applicable. As more empirical data became available, it became clear that loss values tended to fall into two distinct populations.

Buildings which had been designed to maximise thermal efficiency through the use of materials such as metallised glass and foil-backed plasterboard tended to show significantly higher losses than buildings using traditional materials. The model was therefore developed on the basis of this binary classification. It had been hoped that the classification might be made objective through the use of a parameter such as the thermal transmittance ('U-value'), but limitations of time and practicability have not yet allowed this.

B. Median loss values

The initial data analysis was concerned with characterising the median loss values. A comprehensive and systematic comparison was made of all measurement data and proposed candidate models. This analysis, which was revised many times over the period, concluded that a simple quadratic fit in terms of log(frequency) was optimum. Because the number of measurements points was different for each frequency, the median values were used to determine the fit (Fig.2).

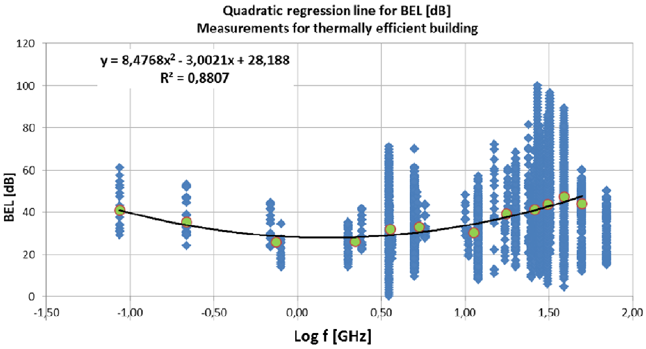

Fig. 2. Derivation of median loss as function of frequency

The tendency for the median loss to show a distict minimum at UHF frequencies was seen in many individual measurements; although the exact frequency varies with geometry and building materials, this effect appears to reflect the small size of building apertures relative to wavelength at lower frequencies and the increased material losses at higher frequencies.

C. Variability

For most applications, such as spectrum sharing studies within the ITU-R or the determination of appropriate link budgets for system planning, it is necessary to understand statistics other than the median value. For the urgent application in 5G sharing studies, the characteristics of the low-loss tail of the distribution are of particular importance.

While several empirical models have been proposed [4], [5] for building entry loss these have generally given a median loss value, with an implicit, or explicit, assumption that the loss (in dB) will have a normal distribution about this value.

Although the limited quantity of measurement data did not allow a robust characterisation of loss for probabilities below about 5%, it seemed clear that a simple Gaussian fit to the entire distribution could not be justified, and would tend to underestimate the actual loss, as seen in Fig. 3 which compares the measured results from one building at six frequencies with the lognormal CDF.

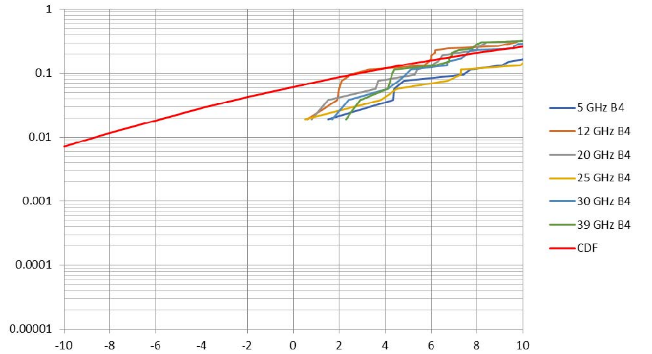

Fig. 3. Low-loss tail of empirical BEL measurements at 6 frequencies compared with lognormal CDF (source: NASA)

In the final model, a reasonable fit over the entire distribution was achieved by blending two separate lognormal distributions.

At higher frequencies, where directional antennas are required to achieve the necessary dynamic range, measurement has often involved the mechanical rotation of the indoor antenna to sample loss for all azimuths (e.g. Fig.4).

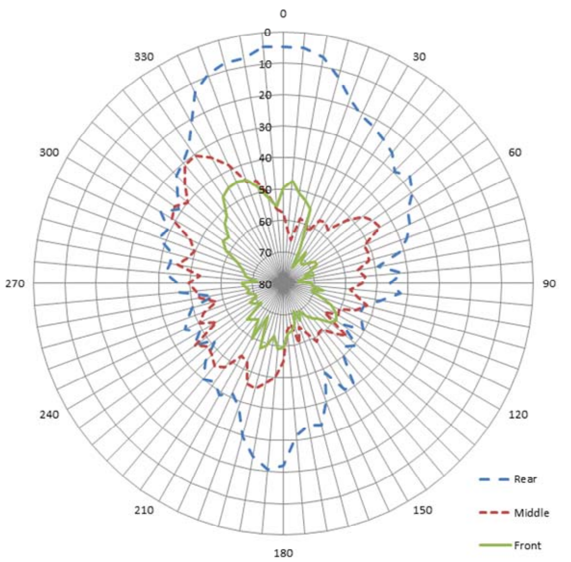

Fig. 4. Building loss at 28 GHz as a function of azimuth within a small domestic building

For an interfering path, it is unlikely to be possible to make any assumption regarding antenna pointing, and the overall building entry loss model should therefore reflect the variability seen in the plots of loss versus azimuth. The CDF of BEL is plotted in fig.5 for all azimuths in each room, and compared (dashed curves) with a Gaussian distribution having a reasonable fit to the lower half of the measured data. It can be seen that the standard deviation falls with depth inside the building (as scattered and reflected energy becomes more uniformly distributed), but that the normal distribution fails to capture the true statistics of the more significant coherent reflections.

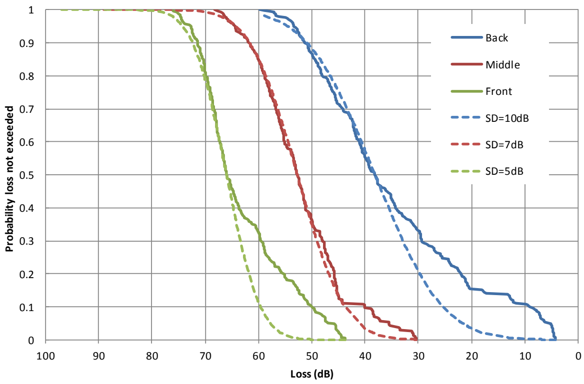

Fig. 5. CDF of BEL at 28 GHz, with normal distributions for comparison

Such azimuth-scanned measurements can be post-processed to synthesise the equivalent omnidirectional pattern. As omnidirectional antennas are unlikely to be used at these frequencies, it may be more relevant to preserve the statistics relating to the directional antenna; for rigour, however, this would imply that the antenna pattern would need to be an input parameter to any derived model. Given the constraints noted in Section IV above, this has not been done, and omnidirectional antennas are assumed throughout. Moreover, for sharing scenarios where a multitude of transmitters are equipped with high gain antennas pointing in random directions, the aggregate effective interference is expected to be very similar to that of transmitters using omnidirectional antennas.

V. Final Model

The final model is published in [6], and consists of two lognormal distributions, A(p) and B(p) as shown in Fig.6, the means and standard deviations of which are functions of frequency and include constants chosen depending on the building type ('traditional' or 'thermally-efficient'). Negative losses may be predicted for small probabilities, in agreement with empirical data, but the minimum loss is limited to -3 dB.

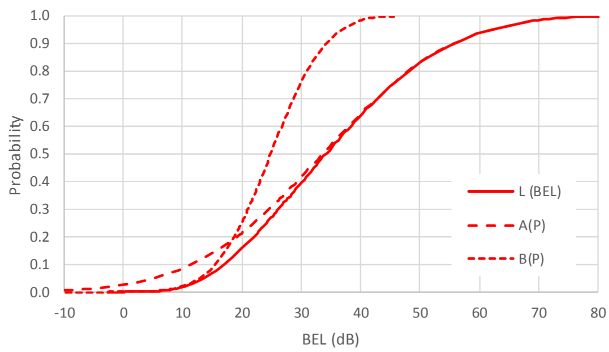

Fig. 6. Example result of final model, showing blending of distributions

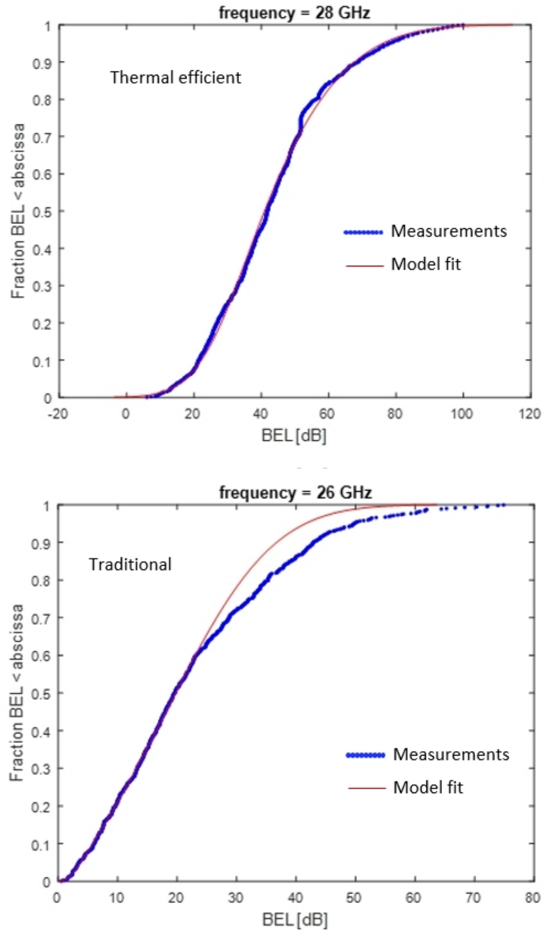

Fig. 7. Example model fits to individual measurement data sets.

In Fig.7, the final model is compared with measured loss distributions from two individual buildings; as the model is not site-specific, a perfect fit to particular measurements is not expected.

Dependence on elevation angle is taken into account by a simple correction which is a linear function of the angle of the path at the building façade, varying from 0dB for horizontal paths to 19dB for paths towards the zenith.

VI. Further Work

As noted above, this initial ITU-R model is necessarily simple, due to limitations of empirical data and time, combined with the inherent requirements of a model suitable for sharing studies.

It would be desirable to improve our understanding of the statistics of the tails of the loss distribution, which implies a need for a substantial increase in measured data; it is hoped that the guidance given in [2] will be useful in guiding other workers and allowing meaningful comparison of results.

It would also be desirable to get further insight into whether the model is valid also for the case when there is no line of sight between the outdoor terminal and the building.

The data on elevation dependence is extremely limited, and the existing model must be seen as tentative; further measurements to explore building loss on slant paths would be very valuable.

The explicit assumption of an omnidirectional indoor antenna in the present model may not be appropriate at higher frequencies, and alternatives should be studied.

The present site-general model fills a specific requirement, particularly for studies within the ITU-R. Given the substantial body of empirical data [3] now gathered on BEL, it may be useful to develop a more site-specific model which could account for parameters such as depth within the building, azimuth angle of arrival and the specifics of building construction.

It is hoped that these topics will be examined within ITU-R Study Group 3 in the coming years.

ACKNOWLEDGMENTS

It must be stressed that the work described in the paper was a collaborative effort by a large number of individuals from many organizations. In particular, contributions from Aalborg university, China, Ericsson, Huawei, NASA, Nokia, NTT, Ofcom (UK), Orange and Telstra, are gratefully acknowledged. Any errors or omissions are due to the present authors.

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