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Fixed Radio Systems;
Energy efficiency metrics and test procedures
for Point-to-point fixed radio systems

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Access, Terminals, Transmission and Multiplexing (ATTM).

Modal verbs terminology

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Introduction

The present document deals with the definition of the metrics, methodology and test conditions for the evaluation of the Energy Efficiency of Point-to-point fixed radio systems.

The tremendous growing of telecom applications is leading to a strong escalation in bandwidth needed to expand telecom solutions. Improved telecommunication networks are under deployment, and consequently the power needed to operate and cool the connected equipment is also likely to increase. As a consequence, the concept of "Energy Efficiency" is getting more and more important in the telecommunication world. Numerous definitions are in use according to the different technologies and network segments they are applied to.

Most of the standardization organizations have identified "Energy Efficiency" as a key area, looking at it from different perspectives as the standards can help providing a common base of understandings, concepts and targets.

The initial stimulus for the present document comes from the European Mandate M/462 [i.1] on the "efficient energy use in fixed and mobile information and communication networks", which among other things states that "it is vital to consider ways to maintain sustainable growth in the transmission capacity of telecommunication networks while limiting and optimizing the energy consumption". However, in line with the European Code of Conduct on Energy Consumption [i.2], it is as much important that the intention of reducing the energy consumption is pursued without hampering the technological developments and the services provided.

Although in the European Mandate M/462 [i.1] and most of the relevant technical documents, Fixed Radio access and transport infrastructures are still mostly disregarded or just mentioned without any specific treatment, the present document aims at giving a correct technical interpretation of the concept of Energy Efficiency when applied to Point-to-point fixed radio systems.

It is important to consider that unlike wired networks, the performance characteristics of a microwave radio system is prone to variations, either due to external factors (e.g. weather) or by the action of the network operator. In a given frequency band, there may be requirements for maximum radiated power levels, particular efficient modulation types, and even standards for the radiation patterns of directional antennas. These criteria are established to reduce or minimize interference among systems that share the same spectrum, and to ensure that the spectral efficiency is sufficiently high to justify the occupancy of the spectrum.

Moreover, propagation characteristics of the microwave signal can differ significantly according to the operating conditions, like frequency band and geographical location.

All the different operating conditions summarily mentioned here above have led to the development of many types of equipment that can address different applications and can work in a large variety of set-up.

It follows that any definition of the Energy Efficiency for Point-to-point fixed radio systems should not be considered without taking into account the specific characteristics of those systems collected in the present document. The present document is thus intended also to provide the necessary technical background in the event that in the future any of the Technical Committees in charge wanted to define any Energy Efficiency KPI's related to P-t-p wireless fixed radio systems.

1 Scope

The present document defines the Energy Efficiency specifically for Point-to-point fixed radio systems, taking into account the specific characteristics of that technology. The technical background and the methodology used to obtain the formula are described together with the test conditions within which carrying out the related measures.

Due to the peculiarity of fixed wireless systems, having various architectures, applications and set-ups, the target to define the Energy Efficiency with a single formula valid for all the categories of systems is very challenging and could be even technically misleading.

As consequence, the main part of the present document is intended to explain the methodology used to derive the EEER, defined as the Equipment Energy Efficiency Ratio. The provided technical description is the necessary complement of the given definition, as it helps to understand the complexity of the matter and how the formula should be used.

That is particularly important in the event that Technical Committees intend to further proceed with the present analysis and derive from the given definition any practical standardization activities.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

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The following referenced documents are necessary for the application of the present document.

Not applicable.

2.2 Informative references

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NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] European Commission - M/462 EN: "Standardisation mandate addressed to CEN, CENELEC and ETSI in the field of ICT to enable efficient energy use in fixed and mobile information and communication networks".

[i.2] European Commission, Veer 4, Feb 2011: "Code of Conduct on Energy Consumption of Broadband Equipment".

[i.3] Recommendation ITU-R F.1703 (2005): "Availability objectives for real digital fixed wireless links used in 27 500 km hypothetical reference paths and connections".

[i.4] ETSI EN 302 217-1 (V1.3.1): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 1: Overview and system-independent common characteristics".

[i.5] ETSI EN 302 217-2-2 (V2.2.1): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 2-2: Digital systems operating in frequency bands where frequency co-ordination is applied; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[i.6] Recommendation ITU-R P.530-15 (2013): "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".

[i.7] Recommendation ITU-R P.837-6 (2012): "Characteristics of precipitation for propagation modelling".

[i.8] Recommendation ITU-R P.838-3 (May 2005): "Specific attenuation model for rain for use in prediction methods".

[i.9] Recommendation ITU-T G.826 (2002): "End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections".

[i.10] ITU-R WP5C, Contribution 345, Huawei Technologies Co. Ltd., Oct 2014: "Error performance and availability issues in ITU: Background and current status".

[i.11] Bell System Technical Journal, Barnett, W. T.: "Multipath propagation at 4, 6 and 11 GHz", Vol. 51, No. 2, 311-361, Feb 1972.

[i.12] Bell System Technical Journal, Vigants A.: "Space-diversity engineering", Vol. 54, No. 1, 103-142, Jan 1975.

[i.13] Recommendation ITU-R F.1668-1 (2007): "Error performance objectives for real digital fixed wireless links used in 27.500 km hypothetical reference paths and connections".

[i.14] IETF RFC 2544 (1999): "Benchmarking Methodology for Network Interconnect Devices".

[i.15] IEC 60038: "IEC standard voltages".

[i.16] ETSI EN 300 132-2: "Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 2: Operated by -48 V direct current (dc)".

3 Symbols and abbreviations

3.1 Symbols

For the purposes of the present document, the following symbols apply:

Kn	normalized system signature parameter
p_0	multipath occurrence factor
P_{in}	input power (power consumption)
PTx	output transmitted (radio) power

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC	Alternating Current
AM	Adaptive Modulation
C	Capacity
CS	Channel Spacing
DC	Direct Current
dN1	point refractivity gradient
EE	Energy Efficiency
EEER	Equipment Energy Efficiency Ratio
f_{BAND}	Frequency Band
FS	Fixed Service
HL	Hop Length

HL_M	Maximum Hop Length
IDU	InDoor Unit
L2	Layer 2
MW	MicroWave
ODU	Outdoor Unit
QAM	Quadrature Amplitude Modulation
RF	Radio Frequency
RIC	Radio Interface Capacity
RTh	Receiver Threshold
SES	Severely Errored Second
SG	System Gain

4 Definition of the EE metrics of Point-to-point fixed radio systems

4.1 General

In general, the energy efficiency of a system should reflect its ability in exploiting the external resources (energy) needed for its operation in order to reach a certain defined level of quality in terms of performance.

The list here below summarizes the different factors that heavily influence the performance of a wireless Fixed Service system:

- Type of application: FS systems can be used in different network segments like access, short haul or long haul. Systems located in different portions of the network are required to provide different features and to work for different link lengths, capacity and quality of service, with consequent impact on their settings and power consumption.
- Frequency bands: FS applications expand from "low" frequencies at around 2 GHz up to 95 GHz or more, though the typical use can be restricted from 6 GHz to 42 GHz. It is well known that in such a wide spectrum range the propagation characteristics are rather different and heavily influence the systems behaviours.
- Environment: those generic terms can refer to different geographical areas of application, including different climatic conditions, but also different morphology like flat ground areas instead of mountainous regions, rural environment up to dense urban.
- Architectures: different systems architectures are available on the market, like all indoor, split-mount indoor-outdoor or full outdoor.
- Features: some equipment types have integrated data processing, including switch devices, monitoring capabilities or ancillary equipment, that can drive the overall power consumption of the system.

All the listed elements can have a direct and relevant impact on the power level needed by the FS systems to handle the traffic and correctly transmit the microwave signal through the hop, and that can clearly influence the evaluation of the their efficiency from the energy point of view.

4.2 Parameters affecting the EE of Point-to-point fixed radio systems

According to the considerations reported in clause 4.1, the following parameters have been identified as possible candidates in the definition of the metrics:

- Frequency band (f_{BAND})
- Bandwidth (Channel Spacing, CS)

  CS represents the amount of spectrum (Bandwidth) used for the transmission of the MW signal.

- Capacity (C)

  The transmission of a certain amount of traffic over the radio link, here called Capacity, is the main purpose of the system and thus considered one of the main important performance indicator, also because the needed capacity is the driver for the operative set-up (CS, modulation format, etc.) The relationship between capacity and bandwidth represents actually another characteristic parameter of the FS systems, the Spectral Efficiency.

- Power consumption (P_{in})

  Input DC Power (P_{in}) has been identified as power consumption parameter, thus excluding any AC-DC converter.

- Maximum Hop length (HL_M)

  The capability to reach longer distances is related both to the system technical quality and to the operative set-up (f_{BAND}, modulation format, etc.). As a consequence, the definition of maximum hop length is meaningful only when the operative conditions are clearly stated.

- Output power (PTx, dB_m)

- Receiver Thresholds (RTh, dB_m)

- System Gain (SG)

  Another noteworthy parameter for p-t-p fixed wireless links is the System Gain (SG), defined as the difference in dB between the transmitter RF output power and the practical thresholds of the receiver.

$$SG_{dB} = PTx - RTh \qquad 4.2a)$$

SG and maximum hop length are strictly related, as in principle a higher SG implies a better capability of the system to reach longer distances maintaining the needed signal level.

However, the relationship between SG and maximum hop length can be rather complicated to be defined, and is subject to variation according to the propagation conditions, mainly frequency.

It can be shown that while for frequencies above about 15 GHz the SG and HL_M are almost linearly related, for lower frequencies HL_M depends also on other significant parameters like the signature, making the SG to HL_M relation more complex.

Another difference related with the frequency range is the reference application of systems: while lower frequencies are generally used for long distance transport links (typically between 30 km and 100 km) which can anyway include mobile backhaul application, higher frequencies are more typically employed for short range links (from a few hundred meters up to a few tens of kilometres) and very often as mobile infrastructure like backhaul. The different application justifies also the fact that while for the lower frequencies the link performance in terms of quality is used as main requirement for the link design, for the higher frequencies one of the most important requirement is the link availability, as explained in the next clauses.

The different behaviour in frequency explains the reason why in the following clauses a separate analysis has been carried out for frequencies up to about 13 GHz and for 15 GHz and above.

4.3 Equipment Energy Efficiency Ratio

4.3.1 Definition of EEER

A straightforward way to define the concept of Energy Efficiency for systems within the scope of the present document, is the Equipment Energy Efficiency Ratio (EEER), defined as the simple ratio among the relevant quantities listed in clause 4.2:

$$EEER = \frac{HL_M \times C}{Log_{10}(P_{in}) \times CS} \qquad 4.3a)$$

where:

- C is the link Capacity, expressed in Mbit/s.
- HL_M is the maximum hop length that can be covered under a set of conditions, expressed in km.
- CS is the channel spacing, in MHz.
- P_{in} is the power consumption in Watt, even if in the formula its weight is in logarithmic units.

Looking at the dimensional analysis $[EEER] = \frac{[km]\times\left[\frac{bit}{s}\right]}{[W]\times[Hz]} = \frac{[km]\times[bit]}{[W]}$

However, it is important to note that the link capacity (C) is very variable according to the width of the channel used for the signal transmission. As consequence any numerical outcome of the formula 4.3a) has to be correlated with a specific value of CS. In other words, the EEER definition can be normalized with respect to the specific reference CS and that term can be removed from the formula, which thus becomes:

$$EEER = \frac{HL_M \times C}{Log_{10}(P_{in})} \qquad \text{4.3.b)}$$

and its dimensional analysis $[EEER] = [km]\times\left[\frac{bit}{s}\right]$

In the formula 4.3b) the two elements C and P_{in} are easily found for the systems under analysis, while the term HL_M has to be calculated or derived from SG. This last step can be easily performed for frequencies above about 15 GHz, where the dependency between SG and HL_M is almost linear, while can be rather complicated for lower frequencies, where other factors like signature enter into the calculation.

4.3.2 EEER applicability

There are many factors that influence the operating settings of a microwave system, and the parameters included in the EEER definition given in formula 4.3b) are strongly impacted by those operating settings or design objectives.

As consequence, the given formulation of Energy Efficiency is consistent only if associated with the specific operating conditions listed here below:

- Frequency band f_{BAND}: the propagation conditions are different in the different frequency bands. The relevance of that parameter is of immediate comprehension considering that the term HL_M is very sensitive to the frequency band it is referred to. It means the EEER given in formula 4.3b) for the fixed wireless system is not an absolute value, but is defined per each frequency band of interest.
- Channel spacing CS: it is the assumption for the definition given in formula 4.3b).
- Spectral Efficiency Class: the same way of the above point, it is possible to show that the same equipment operating with the same CS, but with different Modulation formats (alias different Spectral Efficiency Classes) would obtain different values for its EEER. That requires the EEER to be defined per each Spectrum Efficiency Class.
- Features list: the presence of different features embedded into the system, like switching or routing parts or data compression techniques, can have a not negligible impact on the P_{in} and/or on C.
- Architecture: different system architectures like full-indoor, split-mount or full-outdoor, can address different purposes/scopes, with a consequent impact on performances and power consumption.

- Work objective (similar SG): EEER can be very different for systems designed for different application purposes, like the case of equipment designed with low PTx level to target short hops compared with a solution with higher PTx level to target longer hops. This condition implies also that the SG of the systems under analysis has to be specified with no more than 10 dB of margin.

5 EEER evaluation

5.1 EEER at different frequency ranges

The EEER definition described in formula 4.3b) requires the calculation of the maximum hop length HL_M, which value can be derived from the SG.

Unfortunately, from practical exercises (see Annex A) it comes out that the question is definitely not trivial.

To solve the problem it has been considered to define some "reference deployment scenarios", and to have an overall evaluation of the system performances on them. In the intentions, these scenarios should represent the most typical conditions in the European area and the most typical application/objectives for PtP links.

Once defined such scenarios, a conversion table is provided for transforming SG into HL_M, avoiding any misinterpretation in the conversion.

The relation between the two parameters is simpler for frequencies above about 15 GHz, where the dependency is almost linear and the rain fading has a major impact on the propagation performances.

Multipath effects are predominant at lower frequencies up to about 13 GHz. However, the multipath and the rain effects are not mutually exclusive to each other and for bands around about 13 GHz to 15 GHz, depending on system parameters (system gain and signature) and propagation conditions (i.e. the chosen reference rain rate and multipath occurrence factor), one might be predominant.

Separate analysis have been carried out for frequencies up to 13 GHz (see clause 5.2) and frequencies from 15 GHz and above (see clause 5.3).

5.2 EEER for frequencies up to 13 GHz

5.2.1 Introduction

This clause focuses on the lower frequency range, while the analysis of higher frequencies is presented in clause 5.3.

One of the fundamental keys of the described methodology consists in the possibility to define in a user-friendly way the value of HL_M, considering that at lower frequencies its value is affected by both SG and System Signature (Kn).

For that purpose, it is necessary to:

1) define suitable multipath parameters among the variability of Recommendation ITU-R P.530 [i.6]; they should be of "medium" severity, so that no diversity is implied;

2) foresee the use of the "declared signature area" (according the principles in ETSI EN 302 217-1 [i.4]);

3) define a system configuration for "full indoor" systems, as that is the most common architecture used for the considered frequency bands suitable for long distance radio links designed to carry high-capacity voice and data.

The overall Recommendation ITU-R P.530 [i.6] reference parameters are actually valid for any frequency and HL_M is determined through the multipath/rain (and, when would become necessary, oxygen absorption) comprehensive approach. Before proceeding with the analysis, it is necessary to define all the reference factors that are expected go together with the use of the EEER according to the definition given in clause 4.3.1. The factors are basically of two categories:

- factors defining the reference system: this category includes the factors that identify the type of equipment under analysis;

- factors defining the reference parameters: this category includes some additional parameters and reference standards needed to specify the conditions under which the EEER is calculated and to which that specific calculation is referred to.

5.2.2 Reference factors

5.2.2.1 Reference system

The reference system is used to describe the category of system under analysis, considering the main variants of the equipment available on the market. For doing so, the following system characteristics are considered:

- Category: full indoor, capable of multichannel transmissions over a single antenna.

NOTE: For simplicity, systems with space diversity arrangement, providing longer hop lengths in critical propagation conditions, are not considered. It should be noted that systems with space diversity arrangements, reaching higher hop lengths with the same capacity at the expense of a few watts of power consumption due to a double receiver, provide in general a better value of EEER.

- Traffic: suitable for packet traffic transport.
- Architecture for packet traffic handling: including relatively simple L2 switch between at least two Ethernet ports.
- Frequency bands: any frequency band from 4 GHz to 13 GHz.
- Supporting Adaptive Modulation: from 4 QAM up to 512 QAM (or more).
- Typical application: long distance transport/backhaul.

5.2.2.2 Reference parameters

The evaluation of EEER needs a number of input parameters to be defined properly, in order to define the exact conditions used for the EEER evaluation.

- Reference ITU Recommendations.
- Signature (Kn).

NOTE 1: In the typical applications on the frequency range under analysis, it is known that the impact of selective fading is by far more influent than the effect of rain which has not been considered. Opposite approach has been considered in clause 5.3 for higher frequency ranges.

- Reference channel spacing.
- Reference link design objective: link performance/quality (e.g. SES as defined in Recommendation ITU-R F.1668 [i.13]).

NOTE 2: In the typical applications on the frequency range under analysis, the link performance in terms of quality has been selected as reference parameter as normally that requirement is more stringent than the link availability that has been used in clause 5.3 for higher frequency ranges.

- Reference antenna gain.

In clause 5.2.3 the reference factors, both reference system and reference parameters, are made explicit in order to clearly define the conditions for which the EEER calculation is applicable.

5.2.3 Reference case

5.2.3.1 Reference system

- Full indoor systems suitable for packet data transmission

  For indoor system in multi-branching arrangement, where the system baseband part can have a huge impact on power consumption, it has been considered to average the power consumption based per equivalent channel.

- Configuration: 4+0 system using 4 RF channels.

  The whole power consumption is in this case divided by 4.

For indoor systems the antenna interconnection losses are expected to be considered when whole system gain is evaluated. It is considered here, a typical guideline length of 30 m + 30 m, including both sides of the link.

According to a typical commercial waveguide the following values are used:

- 6 GHz, 7 GHz, 8 GHz → 4,9 dB / 100 m × 60 m = 2,94 dB
- 10 GHz and 11 GHz → 8,9 dB /100 m × 60 m = 5,34 dB
- Average case → 4 dB

NOTE: It has been assumed, in average, 4 dB for all cases, reflecting in higher interconnection length for lower frequency bands or higher losses solution for the feeder and vice versa, lower interconnection length for higher frequency bands or less losses solution for the feeder.

5.2.3.2 Reference parameters

Reference ITU-R recommendations:

- Rain attenuation model: Recommendation ITU-R P.530-15 [i.6].
- Performance objectives: Recommendation ITU-R F.1668-1 [i.13].
- Error performance parameters: Recommendation ITU-T G.826 [i.9].

Reference channel spacing

In practice, AM systems can be preset for a number of different CS (e.g. from 7 GHz to 56 MHz). The power consumption does not depend on the selected CS.

However it is necessary to define a specific CS as reference, because that value is used when declaring the supported capacity and the SG.

The recommendation is to use CS about 30 MHz (28 MHz to 30 MHz), as that is the most popular CS in the considered frequency bands.

Reference link design objective: SES < 10

In frequency bands up to 13 GHz, it has been considered that the link design is done using as target the concept of Severely Errored Second (SES) (According to Recommendation ITU-T G.826 [i.9], Recommendation ITU-R F.1668-1 [i.13]) instead of the link availability.

Summarizing the assumptions: ITU quality target is usually between 0,1 SES/month/km and 0,2 SES/month/km with a minimum hop length of 50 km (i.e. 50 km → 5 SES/month to 10 SES/month). As consequence, SES < 10 is used as reference value as it is considered a "normal target".

A good summary of that matter can be found in ITU-R 5C/345 [i.10].

Reference Modulation

All the discussed parameters (SG, HL_M and Capacity) depend on the modulation format with which they are evaluated; therefore, one reference modulation for their calculation has to be defined.

Considering that the power consumption (P_{in}) has little or no variation with the actual modulation format, it has been concluded that EEER should focus on "relatively high capacity" applications.

128 QAM has been chosen in the present case.

Reference antenna gain

Antennas are usually offered with different size options and that clearly influences the HL_M reachable by the system. For comparing EEER of different sources a reference antenna gain is recommended for each frequency band.

Considering that the typical value of high gain antennas at various frequencies bands is ranging from 42 dBi to 46 dBi, the reference value of 44 dBi has been used.

Capacity

The most immediate choice for defining the system capacity would have been the RIC as defined in ETSI EN 302 217-1 [i.4], but that is not the most appropriate definition for the purpose of the present analysis. EEER is an index related to the "real work" made by the equipment; therefore, it seems more appropriate to link it to the real Ethernet data capacity parameter.

This would mostly skip the capacity dedicated to error correction, which, on the other hand would already directly impact HL through the improvement of SG. Therefore, it seems appropriate not to consider error correction twice in the calculation.

Layer 2 header compression, if any, should also be excluded.

In conclusion the capacity is expected to be stated by the supplier with reference modulation and reference channel spacing.

In conclusion, the capacity is defined as:

- Ethernet layer 2 throughput at 64 bytes frames (Mbit/s).
- No interframe gaps.
- No compressions.

TX output power

When calculating Hop length the output power used is the maximum output power used for planning the link according to the conditions described above (modulation, availability, etc.).

RX threshold

When calculating Hop length the RX threshold used is the RX threshold used for planning the link according to the conditions described above (modulation, quality, etc.).

Power consumption

The power consumption is the typical power consumption at nominal environmental conditions for the equipment. For this specific case it is based on 4 channels system.

5.2.4 SG, Signature and HL_M

5.2.4.1 Methodology

The method used for deriving the reference table for system gain (SG) plus Signature (Kn) to Max Hop Length HL_M conversion is according to the Recommendation ITU-R P.530-15 [i.6].

The main factor relevant for this calculation is the p_0 parameter, defined as the "multipath occurrence factor". The description of p_0 and its impact on the fading occurrence is described in Figure 3 of Recommendation ITU-R P.530-15 [i.6].

p_0, according Recommendation ITU-R P.530-15 [i.6], is derived considering the characteristics of a given region and others parameters related to the link, such as "altitude of the lower antenna" hl (hl equal to 100 meters has been used in the calculations).

According to Recommendation ITU-R P.530-15 [i.6] analysis, the main parameter impacting the calculation of p_0, is the factor dN1, defined as the point refractivity gradient in the lowest 65 meters of the atmosphere not exceeded for 1 % of an average year.

Unfortunately, the Recommendation ITU-R P.530-15 [i.6] does not provide any indication to help in defining the "average/normal propagation conditions", mainly because outside its scope.

Anyway, it is recognized that, "average/normal propagation conditions", cannot be defined by choosing a specific value of dN1, since the term p_0, and thus the term dN1 itself, are depending also from the considered frequency band and the link length.

From another standpoint, defining a specific and unique value for p_0, results in having the same "average propagation conditions", for short and long links, and so the benefits of having better System Gain and signature would be, practically, cancelled.

To overcome this point, and trying to provide a reference case for "average conditions", the value of p_0 has been chosen according to the Vigants-Barnett [i.11] and [i.12] methods using C = 1, where the specific value for the parameter C has been identified for representing the average propagation and average terrain and climatic conditions.

The results obtained with the Vigants-Barnett [i.11], [i.12] methods are practically the same obtained using the Recommendation ITU-R P.530-15 [i.6] when the proper value for dN1 is chosen. A comparison between the two methodologies is provided in Annex C.

Looking at Tables C.1 and C.2 proposed in Annex C, it can be observed that p_0 has a value close to 0,02 for shorter links and less than 0,2 for the longer ones. These values, while maintaining the difference between short and long links in a given condition (i.e. same region and condition, same dN1 and HL), can be considered representative for average/normal propagation conditions.

It has been verified that, as expected in the case of low frequency bands, the impact of a rain rate of 60 mm/H is negligible.

5.2.4.2 Reference tables for (SG + Signature) ←→ HL_M conversion

In order to help the calculations, in the present clause the conversion between (SG + Signature) to HL_M is shown in tabular form.

Here below Table 5a, Table 5b, Table 5c, Table 5d, Table 5e and Table 5f are reported for reference frequencies respectively 4 GHz, 6 GHz, 7 GHz, 8 GHz, 10 GHz and 13 GHz.

Table 5a: Reference table for (SG + Signature) to HL_M conversion at 4 GHz

FREQUENCY 4 GHz						
Kn	0,1	0,3	0,5	0,7	0,9	1
SYSTEM GAIN [dB]	**Max hop length [km]**					
85	25,3 km	24,4 km	23,7 km	23,1 km	22,6 km	22,3 km
86	26,4 km	25,3 km	24,4 km	23,7 km	23,1 km	22,8 km
87	27,5 km	26,1 km	25,1 km	24,3 km	23,6 km	23,3 km
88	28,6 km	26,9 km	25,7 km	24,8 km	24,0 km	23,6 km
89	29,7 km	27,7 km	26,3 km	25,2 km	24,3 km	24,0 km
90	30,8 km	28,4 km	26,8 km	25,6 km	24,7 km	24,3 km
91	31,8 km	29,0 km	27,2 km	25,9 km	24,9 km	24,5 km
92	32,9 km	29,6 km	27,6 km	26,2 km	25,2 km	24,7 km
93	33,9 km	30,2 km	28,0 km	26,5 km	25,4 km	24,9 km
94	34,8 km	30,6 km	28,3 km	26,7 km	25,5 km	25,0 km
95	35,7 km	31,0 km	28,5 km	26,9 km	25,7 km	25,2 km
96	36,5 km	31,3 km	28,7 km	27,0 km	25,8 km	25,2 km
97	37,3 km	31,6 km	28,9 km	27,1 km	25,9 km	25,3 km
98	37,9 km	31,9 km	29,0 km	27,2 km	25,9 km	25,4 km
99	38,5 km	32,1 km	29,1 km	27,3 km	26,0 km	25,4 km
100	39,0 km	32,2 km	29,2 km	27,4 km	26,0 km	25,5 km
101	39,4 km	32,4 km	29,3 km	27,4 km	26,1 km	25,5 km
102	39,8 km	32,5 km	29,4 km	27,5 km	26,1 km	25,5 km
103	40,1 km	32,6 km	29,4 km	27,5 km	26,1 km	25,6 km
104	40,3 km	32,6 km	29,5 km	27,5 km	26,1 km	25,6 km
105	40,5 km	32,7 km	29,5 km	27,5 km	26,1 km	25,6 km

Table 5b: Reference table for (SG + Signature) to HL_M conversion at 6 GHz

FREQUENCY 6 GHz						
Kn	0,1	0,3	0,5	0,7	0,9	1
SYSTEM GAIN [dB]	**Max hop length [km]**					
85	20,0 km	19,7 km	19,4 km	19,2 km	18,9 km	18,8 km
86	20,9 km	20,5 km	20,2 km	19,8 km	19,5 km	19,4 km
87	21,9 km	21,4 km	20,9 km	20,5 km	20,1 km	20,0 km
88	22,8 km	22,2 km	21,6 km	21,1 km	20,7 km	20,5 km
89	23,8 km	23,0 km	22,3 km	21,7 km	21,2 km	21,0 km
90	24,8 km	23,8 km	23,0 km	22,3 km	21,7 km	21,5 km
91	25,9 km	24,6 km	23,6 km	22,8 km	22,2 km	21,9 km
92	26,9 km	25,3 km	24,2 km	23,3 km	22,6 km	22,2 km
93	27,9 km	26,1 km	24,7 km	23,7 km	22,9 km	22,5 km
94	29,0 km	26,7 km	25,2 km	24,1 km	23,2 km	22,8 km
95	30,0 km	27,3 km	25,6 km	24,4 km	23,4 km	23,0 km
96	31,0 km	27,9 km	26,0 km	24,7 km	23,7 km	23,2 km
97	31,9 km	28,4 km	26,3 km	24,9 km	23,8 km	23,4 km
98	32,8 km	28,8 km	26,6 km	25,1 km	24,0 km	23,5 km
99	33,6 km	29,2 km	26,8 km	25,3 km	24,1 km	23,6 km
100	34,4 km	29,5 km	27,0 km	25,4 km	24,2 km	23,7 km
101	35,1 km	29,7 km	27,2 km	25,5 km	24,3 km	23,8 km
102	35,7 km	30,0 km	27,3 km	25,6 km	24,4 km	23,9 km
103	36,2 km	30,2 km	27,4 km	25,7 km	24,4 km	23,9 km
104	36,7 km	30,3 km	27,5 km	25,7 km	24,5 km	23,9 km
105	37,1 km	30,4 km	27,5 km	25,8 km	24,5 km	24,0 km

Table 5c: Reference table for (SG + Signature) to HL_M conversion at 7 GHz

FREQUENCY 7 GHz						
Kn	0,1	0,3	0,5	0,7	0,9	1
SYSTEM GAIN [dB]	**Max hop length [km]**					
85	18,3 km	18,1 km	17,9 km	17,7 km	17,5 km	17,5 km
86	19,1 km	18,9 km	18,6 km	18,4 km	18,2 km	18,1 km
87	20,0 km	19,7 km	19,3 km	19,1 km	18,8 km	18,7 km
88	20,9 km	20,5 km	20,1 km	19,7 km	19,4 km	19,2 km
89	21,8 km	21,3 km	20,8 km	20,3 km	20,0 km	19,8 km
90	22,8 km	22,1 km	21,5 km	20,9 km	20,5 km	20,3 km
91	23,8 km	22,9 km	22,1 km	21,5 km	21,0 km	20,7 km
92	24,8 km	23,6 km	22,8 km	22,0 km	21,4 km	21,2 km
93	25,8 km	24,4 km	23,4 km	22,5 km	21,8 km	21,5 km
94	26,8 km	25,1 km	23,9 km	23,0 km	22,2 km	21,9 km
95	27,8 km	25,8 km	24,4 km	23,3 km	22,5 km	22,2 km
96	28,8 km	26,4 km	24,8 km	23,7 km	22,8 km	22,4 km
97	29,8 km	27,0 km	25,2 km	24,0 km	23,0 km	22,6 km
98	30,7 km	27,5 km	25,5 km	24,2 km	23,2 km	22,8 km
99	31,6 km	27,9 km	25,8 km	24,4 km	23,4 km	22,9 km
100	32,4 km	28,3 km	26,1 km	24,6 km	23,5 km	23,0 km
101	33,2 km	28,6 km	26,3 km	24,7 km	23,6 km	23,1 km
102	33,9 km	28,9 km	26,4 km	24,8 km	23,7 km	23,2 km
103	34,6 km	29,2 km	26,6 km	24,9 km	23,8 km	23,3 km
104	35,1 km	29,4 km	26,7 km	25,0 km	23,8 km	23,3 km
105	35,6 km	29,5 km	26,8 km	25,1 km	23,9 km	23,4 km

Table 5d: Reference table for (SG + Signature) to HL_M conversion at 8 GHz

FREQUENCY 8 GHz						
Kn	0,1	0,3	0,5	0,7	0,9	1
SYSTEM GAIN [dB]	**Max hop length [km]**					
85	16,9 km	16,8 km	16,6 km	16,5 km	16,4 km	16,3 km
86	17,7 km	17,5 km	17,3 km	17,2 km	17,0 km	16,9 km
87	18,5 km	18,3 km	18,0 km	17,8 km	17,6 km	17,5 km
88	19,4 km	19,0 km	18,7 km	18,5 km	18,2 km	18,1 km
89	20,2 km	19,8 km	19,5 km	19,1 km	18,8 km	18,7 km
90	21,1 km	20,6 km	20,2 km	19,7 km	19,4 km	19,2 km
91	22,1 km	21,4 km	20,8 km	20,3 km	19,9 km	19,7 km
92	23,0 km	22,2 km	21,5 km	20,9 km	20,4 km	20,2 km
93	24,0 km	22,9 km	22,1 km	21,4 km	20,9 km	20,6 km
94	25,0 km	23,7 km	22,7 km	21,9 km	21,3 km	21,0 km
95	25,9 km	24,4 km	23,3 km	22,4 km	21,6 km	21,3 km
96	26,9 km	25,1 km	23,8 km	22,8 km	22,0 km	21,6 km
97	27,9 km	25,7 km	24,2 km	23,1 km	22,2 km	21,9 km
98	28,9 km	26,3 km	24,6 km	23,4 km	22,5 km	22,1 km
99	29,8 km	26,8 km	24,9 km	23,7 km	22,7 km	22,3 km
100	30,7 km	27,2 km	25,2 km	23,9 km	22,8 km	22,4 km
101	31,5 km	27,6 km	25,5 km	24,0 km	23,0 km	22,5 km
102	32,3 km	28,0 km	25,7 km	24,2 km	23,1 km	22,6 km
103	33,0 km	28,3 km	25,9 km	24,3 km	23,2 km	22,7 km
104	33,7 km	28,5 km	26,0 km	24,4 km	23,3 km	22,8 km
105	34,3 km	28,7 km	26,1 km	24,5 km	23,3 km	22,8 km

Table 5e: Reference table for (SG + Signature) to HL_M conversion at 10 GHz

FREQUENCY 10 GHz						
Kn	0,1	0,3	0,5	0,7	0,9	1
SYSTEM GAIN [dB]	**Max hop length [km]**					
85	14,8 km	14,7 km	14,7 km	14,6 km	14,5 km	14,5 km
86	15,5 km	15,4 km	15,3 km	15,2 km	15,1 km	15,1 km
87	16,2 km	16,1 km	16,0 km	15,8 km	15,7 km	15,7 km
88	17,0 km	16,8 km	16,6 km	16,5 km	16,3 km	16,2 km
89	17,8 km	17,5 km	17,3 km	17,1 km	16,9 km	16,8 km
90	18,6 km	18,3 km	18,0 km	17,7 km	17,5 km	17,4 km
91	19,4 km	19,0 km	18,7 km	18,4 km	18,1 km	18,0 km
92	20,3 km	19,8 km	19,4 km	19,0 km	18,6 km	18,5 km
93	21,2 km	20,5 km	20,0 km	19,6 km	19,2 km	19,0 km
94	22,1 km	21,3 km	20,7 km	20,1 km	19,7 km	19,4 km
95	23,0 km	22,0 km	21,3 km	20,6 km	20,1 km	19,9 km
96	24,0 km	22,8 km	21,9 km	21,1 km	20,5 km	20,2 km
97	24,9 km	23,5 km	22,4 km	21,5 km	20,9 km	20,6 km
98	25,9 km	24,1 km	22,9 km	21,9 km	21,2 km	20,9 km
99	26,8 km	24,7 km	23,3 km	22,3 km	21,4 km	21,1 km
100	27,8 km	25,3 km	23,7 km	22,6 km	21,7 km	21,3 km
101	28,7 km	25,8 km	24,0 km	22,8 km	21,9 km	21,5 km
102	29,5 km	26,2 km	24,3 km	23,0 km	22,0 km	21,6 km
103	30,4 km	26,6 km	24,6 km	23,2 km	22,2 km	21,8 km
104	31,1 km	27,0 km	24,8 km	23,4 km	22,3 km	21,9 km
105	31,8 km	27,3 km	25,0 km	23,5 km	22,4 km	21,9 km

Table 5f: Reference table for (SG + Signature) to HL_M conversion at 13 GHz

FREQUENCY 13 GHz						
Kn	0,1	0,3	0,5	0,7	0,9	1
SYSTEM GAIN [dB]	**Max hop length [km]**					
85	12,7 km	12,6 km	12,6 km	12,6 km	12,5 km	12,5 km
86	13,3 km	13,2 km	13,2 km	13,1 km	13,1 km	13,0 km
87	13,9 km	13,8 km	13,8 km	13,7 km	13,6 km	13,6 km
88	14,5 km	14,4 km	14,4 km	14,3 km	14,2 km	14,2 km
89	15,2 km	15,1 km	15,0 km	14,9 km	14,8 km	14,7 km
90	15,9 km	15,8 km	15,6 km	15,5 km	15,4 km	15,3 km
91	16,6 km	16,5 km	16,3 km	16,1 km	15,9 km	15,9 km
92	17,4 km	17,2 km	16,9 km	16,7 km	16,5 km	16,4 km
93	18,2 km	17,9 km	17,6 km	17,3 km	17,1 km	17,0 km
94	19,0 km	18,6 km	18,2 km	17,9 km	17,6 km	17,5 km
95	19,9 km	19,3 km	18,9 km	18,5 km	18,1 km	18,0 km
96	20,7 km	20,1 km	19,5 km	19,0 km	18,6 km	18,4 km
97	21,6 km	20,8 km	20,1 km	19,6 km	19,1 km	18,9 km
98	22,5 km	21,5 km	20,7 km	20,0 km	19,5 km	19,2 km
99	23,4 km	22,2 km	21,2 km	20,5 km	19,9 km	19,6 km
100	24,3 km	22,8 km	21,7 km	20,9 km	20,2 km	19,9 km
101	25,3 km	23,4 km	22,2 km	21,2 km	20,5 km	20,1 km
102	26,2 km	24,0 km	22,6 km	21,5 km	20,7 km	20,4 km
103	27,1 km	24,5 km	22,9 km	21,8 km	20,9 km	20,5 km
104	27,9 km	25,0 km	23,2 km	22,0 km	21,1 km	20,7 km
105	28,7 km	25,4 km	23,5 km	22,2 km	21,2 km	20,8 km

5.2.4.3 Example of EEER calculation for 6 GHz

Assuming a 6 GHz system:

- System Gain = 100 dB
- Kn = 0,3
- Power consumption with four active RF channels = 400 W

- Capacity per channel = 160 Mbit/s

It follows:

- System Gain = 100 dB – 4 dB = 96 dB
- From the table it derives for Kn = 0,3, HL = 27,9 km
- Power consumption = 400 W / 4 = 100 W

$$EEER = \frac{HL_M \times C}{Log_{10}(P_{in})} = \frac{27{,}9 \times 160}{Log_{10}(100)} = 2\,232\ km \times \frac{bit}{s}$$

A system with the same power consumption and the same capacity, but with Kn = 0,9, has

$$EEER = \frac{HL_M \times C}{Log_{10}(P_{in})} = \frac{23{,}7 \times 160}{Log_{10}(100)} = 1\,896\ km \times \frac{bit}{s}$$

5.3 EEER for 15 GHz frequency range and above

5.3.1 Introduction

In a similar way to what has been said for lower frequency bands (see clause 5.2.1), it is needed to specify reference systems and parameters for the higher frequencies.

5.3.2 Reference factors

5.3.2.1 Reference system

The reference system is used to describe the category of system under analysis, considering the main variants of the equipment available on the market. For doing so, the following system characteristics are considered:

- Category: full outdoor, split mount.
- Traffic: suitable for packet traffic transport.
- Architecture for packet traffic handling: including relatively simple L2 switch between at least two Ethernet ports.
- Frequency bands: any frequency band from 15 GHz to 42 GHz.
- Supporting Adaptive Modulation: from 4 QAM up to 512 QAM (or more).
- Typical application: short haul, mobile backhaul.

5.3.2.2 Reference parameters

The evaluation of EEER needs a number of input parameters to be defined properly. That means the following parameters are expected to be specified and they define the exact conditions used for the EEER evaluation.

- Reference Recommendations ITU-R.
- Reference Rain rate(s).

  In the frequency range under analysis and for the related reference applications, it has been verified that the effect of multipath is negligible as it influences less than 3 % the link availability.

- Reference channel spacing.
- Reference link availability.

NOTE: In the typical applications on the frequency range under analysis, the link availability as defined in Recommendation ITU-R F.1703 [i.3] has been selected as reference parameter instead of the performance quality that has been used in clause 5.2.2.2 for lower frequency ranges.

- Reference antenna gain.

5.3.2.3 Reference case

5.3.2.3.1 Reference system

In the present clause the reference factors, both reference system and reference parameters, are made explicit in order to clearly define the conditions for which the EEER calculation is applicable.

About the reference system two options are considered in the present document:

1) AM, Ethernet, full outdoor, with simple L2 switch between at least two Ethernet ports where one is the Ethernet traffic over the air (simple IDU unit without any traffic processing might also refer to this category).

2) AM, Ethernet, IDU/ODU split equipment, L2 switch between at least two Ethernet ports. If complex router functions (e.g. many more ports or switching at layers higher than 2) are included, further investigations are needed, to take into account the additional power consumption related to the complexity of the router and its functionalities for packet traffic handling.

5.3.2.3.2 Reference parameters

Reference Recommendations ITU-R

- Rain rates: Recommendation ITU-R P.837-6 [i.7].
- Specific attenuation: Recommendation ITU-R P.838-3 [i.8].
- Rain attenuation model: Recommendation ITU-R P.530-15 [i.6].
- Availability objectives: Recommendation ITU-R F.1703 [i.3].

Reference Rain rate(s)

- When calculating Hop length with rain attenuation model Recommendation ITU-R P.530-15 [i.6] then the rain rate is 60 mm/h.

It might be possible to evaluate EEER for different rain-rates, being the hop length not linearly increasing with system gain, but the numerical examples show that the different rain rates do not provide additional relevant information (see Annex B).

Reference channel spacing

- The recommendation is to use CS = 28 MHz.

Reference link availability

- When calculating the Hop Length with rain attenuation model Recommendation ITU-R P.530-15 [i.6], the reference link availability to be used is 99,99 %.

Reference Modulation

All the above parameters (SG, HL_M and Capacity) depend on the modulation format with which they are evaluated; therefore, one reference modulation for their calculation has to be defined.

Considering that the power consumption (P_{in}) has little or no variation with the actual modulation format, it has been concluded that EEER should focus on "relatively high capacity" applications.

Therefore, it is recommended to use the modulation format shown in Table 5g for each frequency band.

Table 5g

Frequency (GHz)	15	18	23	26	28	32	38	42	52	55	60	65	77	94
Reference mode	128 QAM			64 QAM		32 QAM			16 QAM					

Reference antenna gain

- As per lower frequencies, the reference value of 44 dBi has been used.

Capacity

- Same as for lower frequencies (see clause 5.2.2.2).

TX output power

- Same as for lower frequencies (see clause 5.2.2.2).

RX threshold

- Same as for lower frequencies (see clause 5.2.2.2).

Power consumption

- The power consumption is the typical power consumption at nominal environmental conditions for the equipment. In case of split-mount equipment, the value includes the loss due to 100 m of foreseen IDU-ODU installation cable.

5.3.3 Reference table for SG ←→ HL_M conversion

In order to ease the calculation of HL_M, Table 5h shows the relation between System Gain (SG) and Max Hop Length (HL_M) for 15 GHz, 18 GHz, 23 GHz, 28 GHz, 32 GHz, 38 GHz and 42 GHz, at the reference conditions summarized here below.

Rain rates:	Recommendation ITU-R P.837-6 [i.7]
Specific attenuation:	Recommendation ITU-R P.838-3 [i.8]
Rain attenuation model:	Recommendation ITU-R P.530-15 [i.6]
Rain Rate adopted	60 mm/h
Availability	99,99 %
Polarization	V
Antenna Gain	44 dBi
System Gain	from 80 dB to 100 dB; 1 dB step
Frequency bands	15 GHz, 18 GHz, 23 GHz, 26 GHz, 28 GHz, 32 GHz, 38 GHz and 42 GHz
Frequency for simulation:	the highest frequency

Frequency used for the simulation is the highest value in each relevant bands considered. Frequency deviations up to 200 MHz from the chosen values do not produce any practical effect on Hop Length estimation.

The calculation takes into account the oxygen absorption (typical gas attenuation for the 20 GHz band is around 0,2 dB/km).

Table 5h: SG to HLM conversion at various frequencies

Frequency	15 GHz	18 GHz	23 GHz	26 GHz	28 GHz	32 GHz	38 GHz	42 GHz
SG	Reference conditions							
80 dB	14,5 km	9,3 km	6,9 km	5,8 km	4,8 km	4 km	3,1 km	2,7 km
81 dB	15 km	9,6 km	7,1 km	6 km	5 km	4,1 km	3,2 km	2,8 km
82 dB	15,5 km	9,9 km	7,4 km	6,2 km	5,2 km	4,2 km	3,3 km	2,9 km
83 dB	16 km	10,2 km	7,6 km	6,4 km	5,3 km	4,4 km	3,4 km	3 km
84 dB	16,6 km	10,6 km	7,8 km	6,6 km	5,5 km	4,5 km	3,5 km	3,1 km
85 dB	17,1 km	10,9 km	8,1 km	6,8 km	5,7 km	4,7 km	3,6 km	3,2 km
86 dB	17,7 km	11,2 km	8,3 km	7 km	5,9 km	4,8 km	3,7 km	3,3 km
87 dB	18,2 km	11,6 km	8,6 km	7,2 km	6,1 km	5 km	3,9 km	3,4 km
88 dB	18,8 km	11,9 km	8,8 km	7,4 km	6,2 km	5,1 km	4 km	3,5 km
89 dB	19,4 km	12,3 km	9,1 km	7,7 km	6,4 km	5,3 km	4,1 km	3,6 km
90 dB	20 km	12,6 km	9,4 km	7,9 km	6,6 km	5,5 km	4,2 km	3,7 km
91 dB	20,6 km	13 km	9,6 km	8,1 km	6,8 km	5,6 km	4,4 km	3,8 km
92 dB	21,3 km	13,3 km	9,9 km	8,3 km	7 km	5,8 km	4,5 km	4 km
93 dB	21,9 km	13,7 km	10,2 km	8,6 km	7,2 km	5,9 km	4,6 km	4,1 km
94 dB	22,6 km	14,1 km	10,4 km	8,8 km	7,4 km	6,1 km	4,8 km	4,2 km
95 dB	23,3 km	14,5 km	10,7 km	9 km	7,6 km	6,3 km	4,9 km	4,3 km
96 dB	24 km	14,8 km	11 km	9,3 km	7,8 km	6,4 km	5 km	4,4 km
97 dB	24,7 km	15,2 km	11,3 km	9,5 km	8 km	6,6 km	5,2 km	4,5 km
98 dB	25,5 km	15,6 km	11,5 km	9,8 km	8,2 km	6,8 km	5,3 km	4,7 km
99 dB	26,3 km	16 km	11,8 km	10 km	8,4 km	7 km	5,4 km	4,8 km
100 dB	27,1 km	16,4 km	12,1 km	10,2 km	8,6 km	7,1 km	5,6 km	4,9 km
101 dB	27,9 km	16,8 km	12,4 km	10,5 km	8,9 km	7,3 km	5,7 km	5 km
102 dB	28,8 km	17,3 km	12,7 km	10,8 km	9,1 km	7,5 km	5,9 km	5,2 km
103 dB	29,8 km	17,7 km	13 km	11 km	9,3 km	7,7 km	6 km	5,3 km
104 dB	30,7 km	18,1 km	13,3 km	11,3 km	9,5 km	7,9 km	6,2 km	5,4 km
105 dB	31,8 km	18,6 km	13,6 km	11,5 km	9,7 km	8 km	6,3 km	5,6 km
106 dB	32,6 km	19 km	13,9 km	11,8 km	9,9 km	8,2 km	6,5 km	5,7 km
107 dB	33,2 km	19,5 km	14,2 km	12,1 km	10,2 km	8,4 km	6,6 km	5,8 km
108 dB	33,8 km	19,9 km	14,6 km	12,3 km	10,4 km	8,6 km	6,8 km	6 km
109 dB	34,4 km	20,4 km	14,9 km	12,6 km	10,6 km	8,8 km	6,9 km	6,1 km
110 dB	34,9 km	20,9 km	15,2 km	12,9 km	10,9 km	9 km	7,1 km	6,2 km

6 Test conditions

6.1 Introduction

This clause describes the conditions under which the measurements of the capacity and power consumption for fixed wireless equipment should be performed.

6.2 Capacity

The capacity is defined in clauses 5.2.2.2 and 5.3.2.3.2.

Tests should be run according to the relevant clauses of IETF RFC 2544 [i.14] "Benchmarking Methodology for Network Interconnect Devices".

6.3 Power Consumption

P_{in} is the power consumption (in W) of the equipped equipment, measured at the electric power input interface. P_{in} is measured in determined conditions defined in clause 6.4.

6.4 Measurements

6.4.1 Measurements conditions

The power measurements should be performed in a laboratory environment under the following conditions:

- Equipment to runs at full capacity as described in clause 6.2.
- Room Temperature: 25 °C ± 2 °C.
- Room Relative Humidity: 30 % to 75 %.
- Atmospheric pressure: 86 kPa to 106 kPa.
- Operating voltage:
  - DC Powered Equipment: According to ETSI EN 300 132-2 [i.16], -54,5 V ± 1,5 V for nominal voltage of 48 V DC powered equipment. Equipment using voltage other than -48 V DC is tested at ± 1 % of the nominal voltage.
  - AC Powered Equipment: According to IEC 60038 [i.15], 230 V ± 1 % for nominal voltage of 230 V AC and frequency 50 Hz ± 1 %.
- Minimum Measurement Duration: Equipment should be allowed to stabilize to get reliable power measurement. If power varies over the measurement interval time, an average of measurement is calculated.

6.4.2 Not considered equipment

The following items are not considered part of the equipment under analysis and therefore their power consumption should not be added to the power consumption of the system:

- External rectifier (AC/DC converter).
- Room or outdoor Cabinet Ventilation and Air Conditioning Unit (VAC Unit).
- Auxiliary or redundant power unit.
- Battery charger.

7 Conclusions

The present document shows that the concept of Energy Efficiency applied to microwave point to point links is quite a complex matter that cannot be easily expressed with a simple mathematic formulation.

The different field applications and the consequent different operating conditions heavily influence the overall performance of the links and the related energy consumption.

The present document identifies the main parameters that characterize the functionality of a microwave link and their variation according to the different system architectures, propagation conditions and frequency used.

The different phenomena influencing the propagation characteristics and different field applications requires a separate analysis of the Energy Efficiency for frequencies where multipath effects have the predominant influence on the propagation and the frequencies where the rain is the main influencing factor.

Due to the peculiarity of fixed wireless systems, the target to define the Energy Efficiency with a single formula valid for all the categories of systems is very challenging and potentially misleading.

As consequence, the main part of the present document explains the methodology used to derive the EEER, the Equipment Energy Efficiency Ratio. It is highlighted that the provided technical description is the necessary complement of the given definition of EEER, as it helps to understand the complexity of the matter and how the formula should be used.

This should be considered especially in the event that any Technical Committees intend to further proceed with the present analysis and derive from the given definition of any practical figure.

Annex A: Relationship between HL_M and SG for frequencies above 15 GHz

One of the fundamental keys of the described methodology (see clause 5.2) consists in the possibility to define in a user-friendly way the relation HL_M← → SG.

Unfortunately, from practical exercises it comes out that the problem is definitely not trivial.

In order to highlight that aspect, the curves in Figure A.1 show the relation between SG and HL_M for the cases 15 GHz, 18 GHz, 23 GHz, 25 GHz, 32 GHz and 38 GHz.

The conditions taken as reference are shown in Table A.1.

Table A.1: Reference conditions

Rain Rate	42 mm/h
TX antenna	0,6 m
RX antenna	0,6 m
Polarization	V
Availability	99,995 %

The range of SG provided, is covering practically all the equipment on the market.

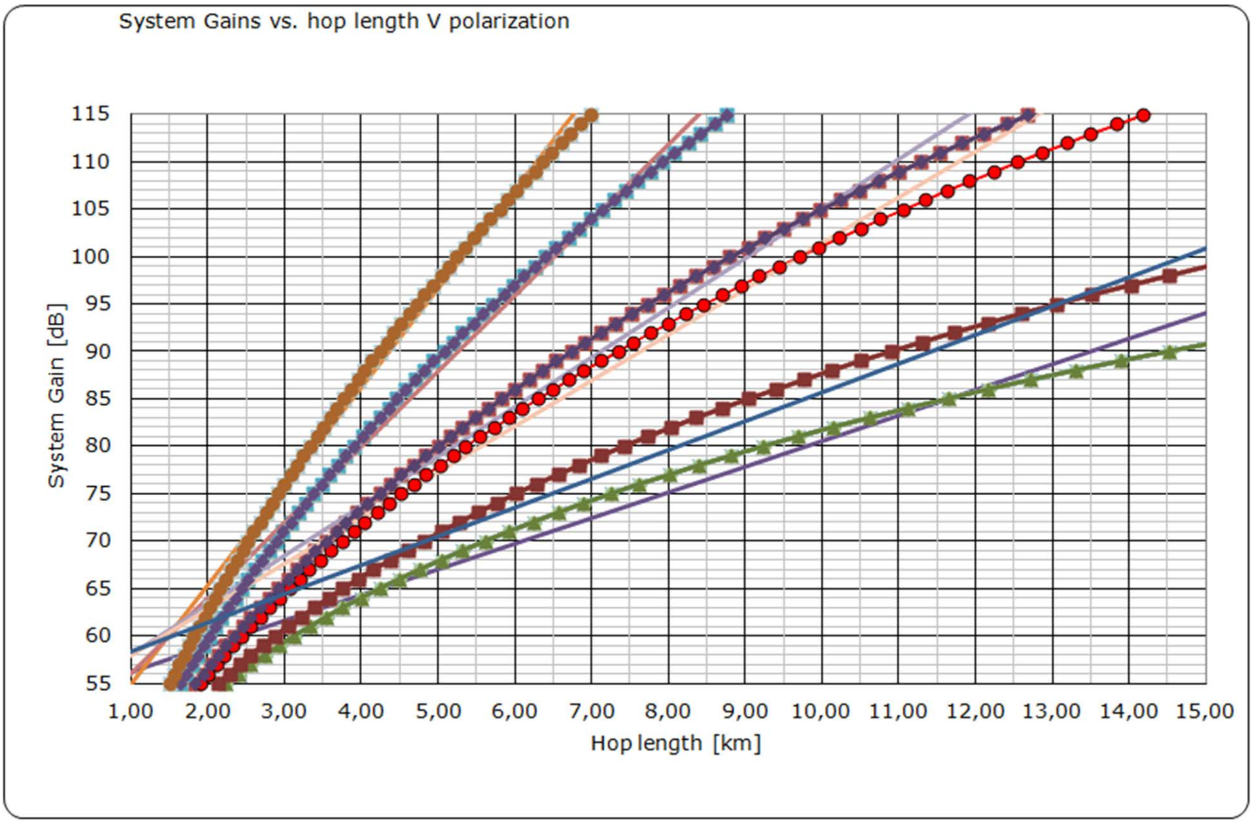

Figure A.1: System Gain versus hop length [V polarization]

All the curves in Figure A.1 have been linearly interpolated, deriving a formula linking HL as a function of SG.

$$Hop\_Length = k \times SG - y$$

where *k* and *y* are dependent on frequency and rain rate. Some values are reported in Table B.1.

The EEER formula derived is:

$$EEER = \frac{C \times (k \times SG - y)}{CS \times Power} \qquad \text{A.1)}$$

Where:

- C = Capacity [Mbit/s]
- SG = System Gain [dB]
- CS = Channel spacing [MHz]
- Power = power consumption [W]

Table A.2: Parameters for linear interpolation of HL versus SG

Frequency	15 GHz	18 GHz	23 GHz	25 GHz	32 GHz	38 GHz
k	0,370	0,330	0,207	0,191	0,125	0,096
y	19,81	18,25	11,02	10,11	6,02	4,28

Table A.3 reports the maximum error using a linear interpolation with the relevant SG range.

Table A.3: Maximum error due to interpolation

Frequency	15 GHz	18 GHz	23 GHz	25 GHz	32 GHz	38 GHz
Max Error	10 %	10 %	5 %	9 %	9 %	9 %
SG Range	63 dB	67 dB	71 dB	69 dB	67 dB	65 dB
	92 dB	104 dB	107 dB	107 dB	107 dB	107 dB

Table A.3 shows that the calculated maximum linearization error is about 5÷10 %. Therefore, the possible simplification through linearization of the curve HL/SG (formula 2) seems too risky to be followed.

Annex B: EEER examples

B.1 Practical equipment

B.1.1 Calculations and frequency bands

Some practical calculation on real equipment are reported in the present Annex, limited to representative bands of 15 GHz, 18 GHz, 23 GHz, 32 GHz, 38 GHz. The relevant formula is reported here for convenience:

$$EEER = \frac{HL_M \times C}{Log_{10}(P_{in})}$$

B.1)

B.1.2 Input parameters

a) Ethernet full outdoor equipment, simple L2 switch on board

b) RX thresholds:
   - b1) ETSI EN 302 217-2-2 (V2.2.1) [i.5]
   - b2) Normal equipment behaviour

c) TX output power:
   - c1) Normal equipment data
   - c2) c1 + 3 dB (with adequate Pin increase, in these examples assumed about +7 W or 20 %)

d) Reference antenna, propagation and variable AM data.

Table B.1 summarizes the equipment data used for the EEER calculation.

Table B.1: Systems data and assumptions for the numerical examples

Band (GHz)		15	18	23	32	38
System type		AM, Ethernet, full outdoor, simple switch				
Nominal CS (MHz)		28				
AM reference mode		128 QAM			32 QAM	
RX Threshold (dBm)	ETSI	-65,5	-64	-64	-69	-68
	Normal	-73,5	-73	-73	-77	-77
TX Power (dBm)	Normal	21	17	17	14	13
	Normal + 3 dB	24	20	20	17	16
System Gain (dBm)	ETSI RX Normal TX (dBm)	86,5	81	81	83	81
	Normal RX TX (dBm)	94,5	90	90	91	90
	ETSI RX TX + 3 dB	89,5	84	84	86	84
	Normal RX TX +3 dB	97,5	93	93	94	93
Pin (with cable)	Pin (W)	37	33,5	33,5	34	34
	Pin (dBW)	15,682	15,25	15,25	15,315	15,315
	Pin + 3dB = + 20 % (W)	44,4	40,2	40,2	40,8	40,8
	Pin + 3dB (dBW)	16,474	16,042	16,042	16,107	16,107
L2 Throughput (Mbit/s)		124			84	
L2 Throughput efficiency (Mbit/s/MHz)		4,429			3,0	

B.2 Numerical results

Mixing the two TX power and the two RX thresholds 4 sets of EEER values can be derived from different SG and different Pin:

1) Basic (ETSI threshold/normal P_{out}/normal P_{in}).

2) RX enhanced (Normal threshold/normal P_{out}/normal P_{in}).

3) TX enhanced (ETSI threshold/P_{out} + 3 dB/P_{in} + 20 %).

4) TX and RX enhanced (Normal threshold/P_{out} + 3 dB/P_{in} + 20 %).

Table B.2 summarizes the results.

NOTE: Table B.2 reports data related only to the "rain outage", for the longer HL in 15 GHz (and maybe in 18 GHz) the multipath contribution is not negligible and has not been verified. Therefore, for the lower rain rates these values should be considered informative only for the "trend" of EEER and not as absolute values.

Table B.2: HL and EEER versus rain-rate (P_{in} in dBW and W units)

Band (GHz)		15	18	23	32	38
Basic SG (ETSI RX/Normal TX)	HL35mm/h (km)	27,0	18,7	12,400	7,500	5,750
	EEERn35 (dBW)	7,625	5,430	3,601	1,469	1,126
	EEERn35 (W)	3,232	2,472	1,639	0,662	0,507
	HL60mm/h (km)	17,000	12,200	8,000	4,750	3,650
	EEERn60 (dBW)	4,801	3,543	2,323	0,930	0,715
	EEERn60 (W)	2,035	1,613	1,058	0,419	0,322
	HL100mm/h (km)	10,800	7,750	5,000	2,900	2,250
	EEERn100 (dBW)	3,050	2,251	1,452	0,568	0,441
	EEERn100 (W)	1,293	1,025	0,661	0,256	0,199
SG RX enhanced (Normal TX & RX)	HL35mm/h (km)	39,000	25,500	16,500	9,650	7,650
	EEERn35 (dBW)	11,014	7,405	4,791	1,890	1,499
	EEERn35 (W)	4,668	3,371	2,181	0,851	0,675
	HL60mm/h (km)	22,000	16,000	10,500	6,100	4,800
	EEERn60 (dBW)	6,213	4,646	3,049	1,107	0,940
	EEERn60 (W)	2,633	2,115	1,388	0,499	0,424
	HL100mm/h (km)	13,600	10,000	6,550	3,720	2,950
	EEERn100 (dBW)	3,841	2,904	1,902	0,729	0,578
	EEERn100 (W)	1,628	1,322	0,866	0,328	0,260
SG TX enhanced (ETSI RX/TX + 3 dB)	HL35mm/h (km)	30,700	20,700	13,700	8,300	6,350
	EEERn35 (dBW)	8,253	5,714	3,782	1,546	1,183
	EEERn35 (W)	3,062	2,280	1,509	0,610	0,467
	HL60mm/h (km)	18,800	13,400	8,800	5,250	4,000
	EEERn60 (dBW)	5,054	3,699	2,429	0,978	0,745
	EEERn60 (W)	1,875	1,476	0,969	0,386	0,294
	HL100mm/h (km)	11,800	8,500	5,500	3,200	2,470
	EEERn100 (dBW)	3,172	2,346	1,518	0,596	0,460
	EEERn100 (W)	1,177	0,936	0,606	0,235	0,182
SG TX&RX enhanced (Normal RX / TX +3 dB)	HL35mm/h (km)	47,500	28,500	18,000	10,500	8,300
	EEERn35 (dBW)	12,769	7,868	4,969	1,956	1,546
	EEERn35 (W)	4,738	3,140	1,983	0,772	0,610
	HL60mm/h (km)	24,100	17,300	11,400	6,600	5,250
	EEERn60 (dBW)	6,479	4,776	3,147	1,229	0,978
	EEERn60 (W)	2,404	1,906	1,256	0,485	0,386
	HL100mm/h (km)	14,700	10,850	7,100	4,050	3,200
	EEERn100 (dBW)	3,952	2,995	1,960	0,754	0,596
	EEERn100 (W)	1,466	1,195	0,782	0,298	0,235

B.3 Analysis and comments

B.3.1 P_{in} [W] versus [dBW]

Analysing the variance of EEER between two levels of P_{out} for the two possible cases the obtained results are summarized in Table B.3.

Table B.3: EEER variance with TX power and P_{in} units (dBW or W)

Conditions	Rain rate	EEER Units	Band (GHz)				
			15	18	23	32	38
EEER % variation TX + 3 dB (SG with RX ETSI Thresholds)	35 mm/h	dBW	7,61 %	4,97 %	4,79 %	4,97 %	4,77 %
		W	-5,54 %	-8,41 %	-8,61 %	-8,43 %	-8,66 %
	60 mm/h	dBW	5,01 %	4,23 %	4,37 %	4,85 %	4,03 %
		W	-8,51 %	-9,25 %	-9,09 %	-8,57 %	-9,50 %
	100 mm/h	dBW	3,853 %	4,090 %	4,371 %	4,689 %	4,197 %
		W	-9,831 %	-9,412 %	-9,091 %	-8,750 %	-9,312 %
EEER % variation TX + 3 dB (SG with higher RX Normal Thresholds)	35 mm/h	dBW	13,75 %	5,88 %	3,57 %	3,34 %	3,07 %
		W	1,47 %	-7,37 %	-10,00 %	-10,29 %	-10,60 %
	60 mm/h	dBW	4,10 %	2,71 %	3,11 %	2,80 %	3,84 %
		W	-9,54 %	-10,98 %	-10,53 %	-10,91 %	-9,71 %
	100 mm/h	dBW	2,81 %	3,05 %	2,96 %	3,40 %	3,05 %
		W	-11,02 %	-10,60 %	-10,70 %	-10,22 %	-10,63 %

Analysing the data in Table B.3, it may be noted:

- Some cases with 35 mm/h, both 15 GHz cases and 18 GHz with higher SG, are somehow "misaligned" with respect to other data; but with the longer HL obtained in these conditions the dispersive fade margin should be possibly considered.
- EEER variation for a typical (i.e. with appropriate P_{in} variation) 3 dB TX enhancement is:
  - Positive using P_{in} [dBW]
  - Negative using P_{in} [W]

  A "normal" enhanced TX power/P_{in}/HL should be considered "positive" from the EE point of view. That supports the use of P_{in} expressed in dBW.
- EEER variation is higher (or less negative) when the basic SG is lower (i.e. when ETSI thresholds are used). This seems logical; no comments on this side.
- A part from some misalignments, the variations are more or less invariant with the frequency band and with the rain-rate.
- The variation is about 1,5 % / dB in the low SG case and about 1 % / dB with higher SG.

B.3.2 EEER variation with RX threshold

Now the data between the other two cases, with same TX and different RX thresholds (ETSI and normal), can be compared. The SG difference is 8 dB to 9 dB in all bands, with no P_{in} variation.

NOTE: The EEER variance is the same using P_{in} in dBW or in W.

Table B.4 shows the variance with RX threshold.

Table B.4: EEER variance with RX threshold

Conditions	Rain rate	Band (GHz)				
		15 ΔSG = 8 dB	18 ΔSG = 9 dB	23 ΔSG = 9 dB	32 ΔSG = 8 dB	38 ΔSG = 9 dB
EEER % variation for RX enhancement (SG with Normal TX)	35 mm/h	30,77 %	26,67 %	24,85 %	22,28 %	24,84 %
	60 mm/h	22,73 %	23,75 %	23,81 %	22,13 %	23,96 %
	100 mm/h	20,59 %	22,50 %	23,66 %	22,04 %	23,73 %
EEER % variation for RX enhancement (SG with Normal TX + 3dB)	35 mm/h	35,37 %	27,37 %	23,89 %	20,95 %	23,49 %
	60 mm/h	21,99 %	22,54 %	22,81 %	20,45 %	23,81 %
	100 mm/h	19,73 %	21,66 %	22,54 %	20,99 %	22,81 %

Analysing the data reported in Table B.4, it may be noted:

- The same anomalous behaviour is present for the longest HL as in the case of Table B.3.
- A part from the anomalies, the improvement given by RX enhancement is slightly higher for the lower SG case (normal TX); the TX difference is far less important (about 0,3 % / dB)
- The variation of EEER with RX only improvement is significant larger (about 2,4 % / dB to 2,8 % / dB) with respect to TX improvement.

B.3.3 EEER absolute values versus rain-rate

Besides the absolute value, the variation of EEER with rain rate follows approximately the same trend as it is shown in the examples of Figures B.1 and B.2.

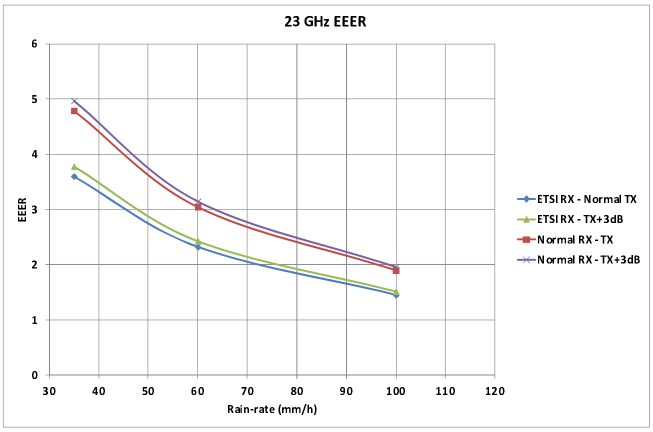

Figure B.1: Example of EEER variation with rain-rate at 23 GHz

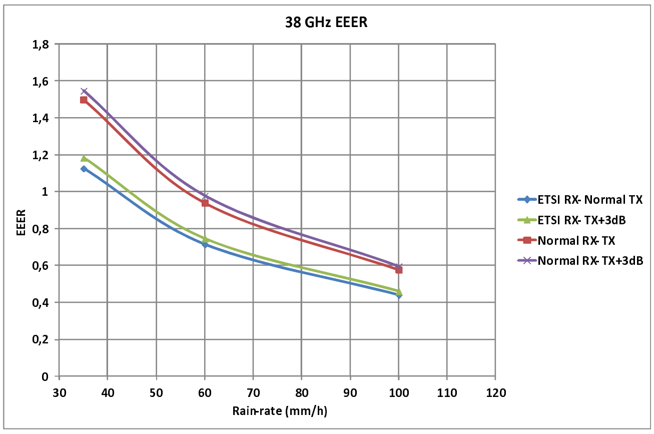

Figure B.2: Example of EEER variation with rain-rate at 38 GHz

As expected, the trend is in accordance with the attenuation predictions of Recommendation ITU-R P.530 [i.6].

B.4 Conclusions

The EEER calculations reported in the present Annex B show that the proposed methodology and the consequent formulation of B.1 seems adequate with the prescription of using P_{in} expressed in dBW.

Some recommendations are essential:

- EEER is meaningful if calculated and compared only within the same frequency band and the same system type.
- A number of input parameters and system types need to be defined and proposals have been made focused on Adaptive Modulation (Mixed-mode) systems for Ethernet traffic.

- Possibly, one rain-rate calculation is representative enough; the need for calculations with different rain rates have to be further explored.
- Possible simplification due to linearization of HL with SG, using formula A.1) defined in Annex A, should be further evaluated.

Annex C: Comparison between Vigants-Barnett and Recommendation ITU-R P.530-15 methods

C.1 4 GHz case

Table C.1: p_0 values and related differences between Vigants-Barnett with C = 1 and Recommendation ITU-R P.530 with HLl = 100 meters and dN1 = -200 (4 GHz case)

		ITU-R P530			Vigants-Barnett	Differences
F ref (GHz)	d (km)	hL (m)	Po = pw / 100	d (km)	Po = pw / 100	
		-dN1 = 160,00		C = 1		
4	25,3	100	0,038	14,00	0,039	-3 %
4	26,4	100	0,043	14,70	0,044	-3 %
4	27,5	100	0,049	16,80	0,050	-3 %
4	28,6	100	0,055	17,60	0,056	-2 %
4	29,7	100	0,062	18,40	0,063	-2 %
4	30,8	100	0,069	27,40	0,070	-2 %
4	31,8	100	0,076	28,30	0,077	-1 %
4	32,9	100	0,085	30,00	0,085	-1 %
4	33,9	100	0,093	30,00	0,093	-1 %
4	34,8	100	0,101	30,00	0,101	0 %
4	35,7	100	0,109	30,00	0,109	0 %
4	36,5	100	0,117	30,00	0,117	0 %
4	37,3	100	0,125	30,00	0,125	0 %
4	37,9	100	0,131	30,00	0,131	1 %
4	38,5	100	0,138	30,00	0,137	1 %
4	39,0	100	0,144	30,00	0,142	1 %
4	39,4	100	0,148	30,00	0,147	1 %
4	39,8	100	0,153	30,00	0,151	1 %
4	40,1	100	0,156	30,00	0,155	1 %
4	40,3	100	0,159	30,00	0,157	1 %
4	40,5	100	0,161	30,00	0,159	1 %

C.2 11 GHz case

Table C.2: p_0 values and related differences between Vigants-Barnett with C = 1 and Recommendation ITU-R P.530 with HLI = 100 meters and dN1 = -200 (11 GHz case)

		ITU-R P530			Vigants-Barnett	Differences
F ref (GHz)	**d (km)**	**hL (m)**	**Po = pw / 100**	**d (km)**	**Po = pw / 100**	
		-dN1 = 200,00		**C = 1**		
11	14,0	100	0,017	14,00	0,018	-5 %
11	14,7	100	0,020	14,70	0,021	-4 %
11	15,3	100	0,023	16,80	0,024	-4 %
11	16,1	100	0,027	17,60	0,028	-3 %
11	16,8	100	0,030	18,40	0,031	-3 %
11	17,6	100	0,035	27,40	0,036	-2 %
11	18,4	100	0,040	28,30	0,041	-2 %
11	19,2	100	0,046	30,00	0,047	-2 %
11	20,0	100	0,052	30,00	0,053	-1 %
11	20,9	100	0,060	30,00	0,060	-1 %
11	21,8	100	0,068	30,00	0,068	0 %
11	22,7	100	0,077	30,00	0,077	0 %
11	23,7	100	0,088	30,00	0,088	0 %
11	24,6	100	0,099	30,00	0,098	1 %
11	25,6	100	0,112	30,00	0,111	1 %
11	26,5	100	0,125	30,00	0,123	2 %
11	27,4	100	0,138	30,00	0,136	2 %
11	28,3	100	0,153	30,00	0,150	2 %
11	29,2	100	0,169	30,00	0,164	3 %
11	30,0	100	0,183	30,00	0,178	3 %
11	30,7	100	0,197	30,00	0,191	3 %

Annex D: Bibliography

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History

Document history		
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