CEPT ECC
Electronic Communications Committee

ECC Report 367

Generic methodology for the protection of Fixed service to complement the criteria in Recommendation ITU-R F.758-8

approved 26 September 2025

0 EXECUTIVE SUMMARY

This Report recognises the need for common guidelines in the sharing and compatibility studies with Fixed Service (FS) links, which are facing potential interference from a variety of fixed and mobile radio devices of far different emission nature. Most of those interference sources, mobile or in fixed locations, also exhibit time-varying emission levels (even if in continuous operation).

This Report mainly covers the following aspects:

1 This Report summarises the basic background of the Error Performance Objectives and Availability Performance Objectives (EPO and APO) and the methods for relevant protection criteria available in ITU Recommendations.

2 This Report develops a comprehensive methodology to evaluate the impact of interference on error performance objectives (EPO), which uses the probability distribution of the interference at the FS receiver.

The methodology provides a systematic approach to evaluate the Fractional Degradation in Performance (FDP) and is essentially based on the following concepts:

- FDP is calculated based on the degradation of the probability of outage due to fading only relative to the joint probability of outage due to fading and interference;
- Short-Term and Long-Term Components of FDP: FDP is divided into short-term (FDPST) and long-term (FDPLT) components. Short-term degradation occurs when interference exceeds the fading margin, while long-term degradation occurs when the combination of fading and interference exceeds the fading margin;
- The FDP should not exceed 10% for a co-primary service interference or 1% for non-co-primary service interference.

The FDP calculation is based on the following elements:

- Fade Margin (FM);
- Distribution of fading of the wanted signal at the fixed service (FS) receiver (Recommendation ITU-R P.530 [16]);
- Probability density function (pdf) of interference signal at the FS receiver;

When ATPC is implemented, the ATPC range is also used in the FDP calculation.

3 This Report identifies and clarifies the key arguments needing update and clarification for the correct understanding on how FS protection criteria studies should be carried out.

4 This Report presents the implementation of a generic methodology for assessing the protection of Fixed Service links to complement the long-term protection criteria contained in Recommendation ITU-R F.758-8, table 5.

While the current version of this Report provides a good basis, it is recognised that further technical aspects - such as space diversity, burst or pulse-type emissions, Adaptive Coding and Modulation (ACM)) - are not yet fully addressed. In particular, a number of measurements that analysed the impact of burst interfering signals on FS links have been presented, indicating that FS receivers can be differently affected by such a kind of interferers. These elements including measurements results which may influence the impact of time-varying or short-term interference, are currently under discussion within CEPT. Future work will further analyse the impact on FS performance considering the technical aspects mentioned above. The results of these ongoing studies are expected to inform future refinements of the methodology, where appropriate, without prejudging the relevance or applicability of the current version of this Report.

TABLE OF CONTENTS

0 Executive summary 2

1 Introduction 6
1.1 General Principles 6
1.2 Time-Varying Interference - Principles and Problematic 6

2 Definitions 7

3 General Concepts 9
3.1 Introduction 9
3.2 Background for Error Performance and Availability Objectives (EPO and APO) 9
3.2.1 Quality Criteria - EP Elements (SES and ES) 9
3.3 Availability/Unavailability Criterion - AP Elements 10
3.4 State of the Art of Performance Objectives for Fixed Service Links (APO and EPO) 10
3.4.1 Practical impact of ES, SES and Defects in FS Systems 12

4 Required technical elements for the EP and AP evaluation 14
4.1 Adaptive Technologies Impact 14
4.2 Fixed Service Error Performance Objective (EPO) 15

5 The Evaluation of the Fixed Service Protection Criteria 18
5.1 Introduction 18
5.2 Fractional Degradation In Performance (FDP) in Absence of ATPC 19
5.3 Generic FDP Methodology 19
5.3.1 Derivation of FDP formula – a Comprehensive Methodology to Evaluate the impact of Interference on Error Performance Objectives 20
5.3.2 FDP Methodology Implementation 25

6 Conclusion 26

ANNEX 1: FDP based on Recommendation ITU-R F.1108 27
A1.1 FDP Simplifications Made in Recommendation ITU-R F.1108 27
A1.2 Alternative Derivation of FDP 28

ANNEX 2: FDP Methodology - Derivation of Equation (8) and Equation (9) 30

ANNEX 3: Background on the concepts of long-term and short-term effects 32
A3.1 Long-term 32
A3.2 Short-term in environments where multipath OR rain fading dominates 33

ANNEX 4: Definition of the appropriate FS parameters for determining EP and AP protection criteria 34
A4.1 Background 34
A4.2 Permitted objective of EP degradation due to interference 34
A4.3 Impact of ATPC and ACM on the definition of the link fade margins 35
A4.4 Impact of packet data (Ethernet/IP) on the EP/AP objectives 36

ANNEX 5: List of References 38

LIST OF ABBREVIATIONS

Abbreviation	Explanation
ACM	Adaptive Coding and Modulation
ACM	Adaptive Coding and Modulation
AP	Availability Performance
APO	Availability Performance Objective
ATPC	Automatic Transmission Power Control
AWGN	Additive White Gaussian Noise
BBER	Background Block Error Ratio
BER	Bit Error Rate
CCDF	Complementary Cumulative Distribution Function
CDF	Cumulative Distribution Function
CEPT	European Conference of Postal and Telecommunications Administrations
DC	Duty Cycle
DFM	Dispersive Fade Margin
DSTEPO	EPO degradation due to short-term interference
e.i.r.p.	Equivalent Isotropically Radiated Power
EP	Error Performance
EPO	Error Performance Objective
ES	Errored Second
ETSI	European Telecommunications Standards Institute
FDP	Fractional Degradation in Performance
FDP_{LT}	Long-term Fractional Degradation in Performance
FDP_{ST}	Short-term Fractional Degradation in Performance
FFM	Flat Fade Margin
FLR	Ethernet frame loss ratio
FM	Fade Margin
FS	Fixed Service
FWS	Fixed Wireless Systems
GSO	Geostationary Orbit
HRP	High Repetition Pulse
I/N	Interference-to-Noise Ratio

Abbreviation	Explanation
IPLR	IP packet Loss Ratio
ITU-R	International Telecommunication Union – Radio communication
LOS	Line of Sight
LTC	Long-Term Criterion/Criteria
MCS	Modulation and Coding Scheme
MNO	Mobile Network Operator
NFM	Net Fade Margin
Non-GSO	Non Geostationary Orbit
NPO	Network Performance Objective
OFDM	Orthogonal Frequency Division Multiplexing
P-MP	Point-to-Multipoint
PRF	Pulse Repetition Frequency
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RSL	Received Signal Level
RX	Receiver
SDH	Synchronous Digital Hierarchy
SES	Severely Errored Second
SINR	Signal to noise ratio
SNR	Signal-to-Noise Ratio
SRD	Short Range Device
STC	Short-Term Criterion/Criteria
STM	Synchronous Transport Module
T	Pulse duration
TFM	Thermal Fade Margin
UWB	Ultra-Wide Band

1 INTRODUCTION

1.1 GENERAL PRINCIPLES

FS links, as part of the broader family of Fixed Network transmission media, are subject to stringent error performance objectives (EPO) and availability performance objectives (APO). The basic end-to-end objectives for all media are established by ITU-T recommendations, while specific objectives for radio only connections are given by ITU-R Recommendations in the F series.

Consequently, the need of limiting interference effects on fixed links have also been considered by ITU-R and the relevant limits of permitted effect of interference on the above EPO and APO, as well as the consequent protection criteria, have been regulated by other ITU-R Recommendations in the F series (or, in the past, in the SF series dealing with frequency sharing and coordination between fixed-satellite and fixed service systems).

Nowadays, the problem of defining suitable protection criteria for Fixed Service (FS) links has become a more challenging since the advent of large number and types of interfering sources, far different to satellite space stations, coming from a variety of technologies with significant time-variance, in terms of single source with various fast bursting/sweeping characteristic of emission, often randomly activated, or of aggregation of large number of devices (fixed or mobile) deployed on the territory around FS stations, or both such aspects combined.

1.2 TIME-VARYING INTERFERENCE - PRINCIPLES AND PROBLEMATIC

Some available studies on protection from time-varying interference in ITU-R Recommendations (e.g. Recommendation ITU-R F.758-8, table 1 in annex 1 [6]) are based on known interfering signals (in position and time) that are continuously transmitting. Therefore, the statistic of the level depends on the known geometrical characteristic variance in LoS (space-to-Earth) conditions. The time variance of Non-GSO interference into directional FS antennas is characterised by a fast increase of level when the satellite passes in the narrow main beam of the antenna and fast dropping when outside even sector antenna in P-MP has more significant directivity in elevation.

However, a number of new terrestrial wireless systems, such as in the mobile service or other mobile (SRD) application, WLAN/RLAN, continuously appear on the market and their time-varying emissions need to be assessed for sharing and compatibility with FS depending on their regulatory status, in the band.

The interference level variance, randomly affected by a mixture of LOS and NLOS, continuous or intermittent, fixed or mobile, emissions, may be given by random spatial and temporal variance of the devices. There is the need to evaluate, depending on the nature of the interferer, how the random factors of the interference level variance should be treated for the evaluation of the impact to FS given by relevant Recommendation ITU-R F.1094-2 [7] and Recommendation ITU-R F.1565 [11].

The time-varying interference (on the worst-month basis) affects mostly the EPO; while on the average year basis, impact on APO; it can still be considered well covered by the general guidelines in Recommendation ITU-R F.758-8 [6] through the Fade Margin increase for counteracting the threshold degradation due to the effects of the interference level not to be exceeded by more than 20% of the year.

Considering the lack of comprehensive guidelines and generic recommendation, a common approach should be developed. Therefore, this Report describes a “generic methodology” for Fractional degradation in performance (FDP) and short-term protection criteria, with case-by-case calculation, based on the general principles in relevant ITU-R Recommendations.

2 DEFINITIONS

Term	Definition
Unavailability period	When at least 10 consecutive seconds are experiencing an SES event.
Availability performance objective (APO)	The % of the time (on seconds basis) of an year when the FS link is available i.e. excluding the "unavailability" periods. It is established by Recommendation ITU-R F.1703 [13].
Error performance objective (EPO) for SES	The % of the time (on seconds basis) of the worst month, excluding the "unavailability" periods, when the FS link is experiencing an SES event. It is established by Recommendation ITU-R F.1668 [12].
Error performance objective (EPO) for ES	The % of the time (on seconds basis) of the worst month, excluding the "unavailability" periods, when the FS link is experiencing an ES event. It is established by Recommendation ITU-R F.1668 [12].
EPO and APO apportionment to different interfering sources	The subdivision of total EPO and APO (given by Recommendation ITU-R F.1668 [12] and Recommendation ITU-R F.1703 [13], respectively) into source-specific portions (including FS to FS interference) as given in Recommendation ITU-R F.1094-2 [7] and, specifically for co-primary and other sources of interference, in Recommendation ITU-R F.1565 [11].
Long-term AP degradation protection criterion	I/N protection criteria permissible for > 20% of time (on yearly basis), in all cases; predominant when static interference is concerned (Recommendation ITU-R F.758-8 [6]).
Short-term EP degradation criteria (for SES and ES)	I/N permitted to be exceeded for relatively fast time-varying interference, for very short % of the time (always < 1%) (Recommendation ITU-R F.758-8 [6]). To be evaluated when the CCDF of the interference level extends beyond the SES EP criterion given by the FDP. Note: It should affect the EP for a % (DstEPO %) quite less than the X% or the Y% given by Recommendation ITU-R F.1094-2 [7].
EP FDP degradation criteria (for SES and ES)	Criterion based on the joint probability (ideally convolution) of the I/N and propagation attenuation statistics. Note: It should affect the EP for a % (X% - DstEPO % or Y% - DstEPO %) given by Recommendation ITU-R F.1094-2 [7].
Long Term Interference power (I_{LT})	Maximum interference level for long-term availability objective.
Cumulative Distribution Function (CDF)	Probability distribution of a variable parameter; indicates the probability that the function is below certain value. By definition it is a monotonic increasing function from 0 to 1 (or 0% to 100%).
Complementary Cumulative Distribution Function (CCDF)	Probability distribution of a variable parameter; indicates the probability that the function exceeds certain value. By definition it is a monotonic decreasing function from 1 to 0 (or, in %, from 100% to 0%). CCDF = 1-CDF.
Probability Distribution function (PDF)	Probability distribution that describes the likelihood of a continuous random variable taking on a particular value within a certain range
Short-term EP degradation criteria (for SES and ES)	I/N permitted to be exceeded for relatively fast time-varying interference, for very short % of the time (always < 1%) (Recommendation ITU-R F.758-8 [6]). To be evaluated when the CDF of the interference level extends beyond the SES and ES EP criterion given by the FDP.

Term	Definition
EP FDP degradation criteria (for SES and ES)	Criterion based on the joint probability (ideally convolution) of the I/N and propagation attenuation statistics.
Long Term Interference power (I_{LT})	Maximum interference level for long-term availability objective.
Fade Margin (FM)	Generic term indication the available receiver signal level exceeding certain BER threshold the Fade Margin for SES conventionally corresponds to the BER threshold 10-6.
Flat Fade Margin (FFM)	Normally intended as the difference between the “free-space/clear sky” nominal RSL and a predefined BER RSL threshold.
Thermal Fade Margin (TFM)	See FFM (sometimes used in literature with same meaning).
Dispersive Fade Margin (DFM)	Channel-wide concept used when multipath and insufficient system equalisation limits the full exploitation of the FFM (Recommendation ITU-R F.1093 [22]).
Net Fade Margin (NFM)	When ATPC is used corresponds NFM = FFM-$ATPC_{range}$ Note: In some multipath oriented literature, NFM is used with the meaning NFM= min(FFM; DFM).
Nominal RX level (free-space/clear-sky)	The RX level of the FS link (due to free space loss only) in absence of any propagation impairment (multipath or rain induced); i.e. calculated from the link budget (system and antenna gains) with Recommendation ITU-R P.525 [16]. When ATPC is used, it is permanently reduced by the ATPC range.
ATPC range	The maximum attenuation (dB) of the FS TX level during normal propagation until the corresponding RSL drops below the ATPC threshold.
ATPC threshold	The RSL (generally above a limit where errors appear) where the ATPC loop keeps that RSL stable for a further propagation attenuation equal to ATPC range.
Pulse emissions	Trains of carrier pulses emitted according to system defined ON/OFF time periods. They might have idle periods of time when the service is not required (activity factor < 1)
Burst emission	Trains of modulated (e.g. QAM/OFDM) carrier signal emitted according to system defined ON/OFF time periods. Due to additional carrier modulation the peak power level would exceed the mean carrier level.
Activity factor	In intermittent emissions is the ratio between the sum of time periods when the radio system is in operation (carrying user traffic or producing the required action) and the total time of observation.
Duty cycle	In any cyclic pulsed emissions (e.g. radiolocation) or burst emissions (e.g. synchronisation signal in access communications techniques) is the ratio between the time the TX is ON (pulse duration T) and the continuous ON/OFF cycle duration (period = 1/PRF).

3 GENERAL CONCEPTS

3.1 INTRODUCTION

All data transmission systems must meet specific Quality of Service (QoS) standards, which are typically expressed through metrics such as packet loss, bit rate loss, throughput, and transmission delay. Achieving these QoS objectives requires maintaining a minimum signal-to-noise ratio (SNR), with each system's SNR corresponding to performance objectives related to error rates, such as bit error rate (BER), symbol error rate (SER), or second error (ES).

For systems like satellite communications, LTE, and others, performance objectives are usually measured by data rates achieved over a defined percentage of time. While these systems regularly update their performance standards (e.g. mobile systems in the 3GPP standard), the fixed service (FS) adheres to specific Error Performance Objectives (EPO) and Availability Performance Objectives (APO), as defined in Recommendation ITU-T G.826 [1], Recommendation ITU-T G.828 [3] and Recommendation ITU-T G.827 [2] for SES and ES events. Notably, the EPO and APO for FS are governed by Recommendation ITU-R F.1668-1 [12] and Recommendation ITU-R F.1703 [13], which remain in use despite evolving technologies.

It's important to note that ES and SES events are evaluated based on system anomalies and defects at the MAC and network layers, rather than errors caused by physical layer constraints such as interference or propagation effects. FS systems must meet their EPO and APO requirements, irrespective of whether degradation is caused by short-term or long-term interference, as specified by Recommendation ITU-R F.1094-2 [7].

3.2 BACKGROUND FOR ERROR PERFORMANCE AND AVAILABILITY OBJECTIVES (EPO AND APO)

3.2.1 Quality Criteria - EP Elements (SES and ES)

3.2.1.1 Definitions

The exact definition of ES/SES and their calculations are defined, for constant bit-rates payload, in Recommendation ITU-T G.826 [1] as follows:

- An errored second (ES) is defined as "*A one-second period with one or more errored blocks or at least one defect*";
- Where a block is defined as "A block is a set of consecutive bits associated with the path; each bit belongs to one and only one block. Consecutive bits may not be contiguous in time";
- A severely errored second (SES) is defined as "A one-second period which contains ≥ 30% of errored blocks (EB) or at least one defect. SES is a subset of ES";
- It should also be underlined the ES concept loses its meaning for high capacity data streams; Recommendation ITU-T G.826 [1] (in note 3 to Table 1/G.826, where the limits of Errored Seconds Ratio (ESR) are considered) says: "NOTE 3 – (ESR) objectives tend to lose significance for applications at high bit rates and are therefore not specified for paths operating at bit rates above 160 Mbit/s. Nevertheless, it is recognised that the observed performance of SDH paths is essentially error-free for long periods of time, even at Gigabit rates. Significant ESR indicates a degraded transmission system. Therefore, for maintenance purposes, ES monitoring should be implemented within any error performance measuring devices operating at these rates".

In practice, the Background Block Error Ratio (BBER) of such high capacity links might already generate an ESR also without any interference or propagation effects.

Considering that nowadays the majority of FS links are carrying (or, in any case, will soon carry) bit rates quite higher than 160 Mbit/s, but based on Ethernet/IP payload, it seems appropriate to introduce the considerations that led to apply the same error performance objectives (see also additional supporting consideration in Annex 4.

3.2.1.2 Objectives

For constant bit rate transport networks, Recommendation ITU-R F.1668-1 [12], based on Recommendation ITU-T G.826 [1] and Recommendation ITU-T G.828 [3] provides the required objectives according to the link characteristics within the network (see section 4.2).

3.3 AVAILABILITY/UNAVAILABILITY CRITERION - AP ELEMENTS

3.3.1.1 Definition

For constant bit rate connection, the Recommendation ITU-T G.827 [2] defines availability/unavailability as follows: "*A period of unavailable time (UAV) begins at the onset of ten consecutive Severely Errored Second (SES) events. These ten seconds are considered to be part of the unavailable time. A new period of available time begins at the onset of ten consecutive non-SES events (a non-SES event is a second which is an erroneous second, but not an SES or is error free). These ten seconds are considered to be part of the available time*."

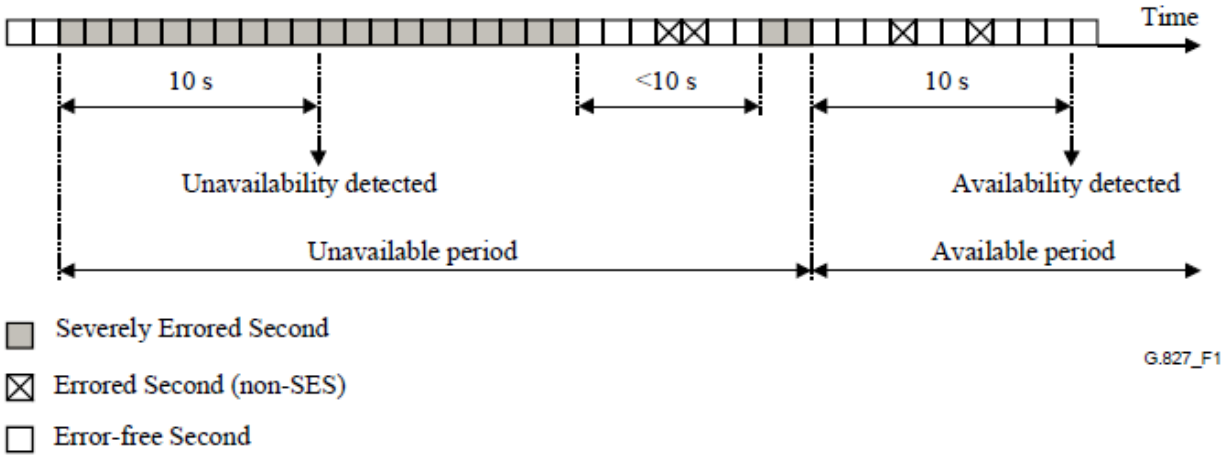


Figure 1: Example of unavailability determination (Source: ITU-T Recommendation G.827 [2])

3.3.1.2 Objectives

Recommendation ITU-R F.1703 [13] and Recommendation ITU-R F.2113 [14], based on Recommendation ITU-T G.827 [2] and Recommendation ITU-T Y.1563 [4], provide the required objectives according to the link characteristics within the network (see Annex 4).

3.4 STATE OF THE ART OF PERFORMANCE OBJECTIVES FOR FIXED SERVICE LINKS (APO AND EPO)

The Availability Performance (APO) and Error Performance (EPO) objectives for Fixed Service (FS) links are defined by the number or percentage of Severely Errored Seconds (SES), as outlined by ITU-T and ITU-R Recommendations, particularly the F series for radio-based transport networks. These objectives are meant to be statistically met over a long period, such as one year for APO or the worst month for EPO.

Although SES and ES events can be measured by the FS equipment in the field, it is difficult to simulate actual traffic. Therefore, compliance with APO and EPO objectives primarily focus on the "post processing" of the number of SES/ES counted in predefined periods of time (15 min, 24 h, 1 month and 1 year).

Modern digital receivers, with their powerful error correction capabilities, have narrowed the gap between the thresholds for SES and Errored Seconds (ES), making SES the more critical limit. This Report, therefore,

focuses on SES as the key performance criterion, as the more relaxed ES objectives have become less relevant for planning purposes. Even short bursts of interference that exceed the SES threshold count as an SES event, meaning the percentage of time for EPO/APO is based on the number of seconds affected over a month or year.

In FS systems, SES and ES are influenced on the physical layer by impairments due to propagation and interference, and by "defects" at higher-layer (typically consequence of lack of synchronisation of the FS receiver).

In Ethernet/IP FS systems, being the packet traffic asynchronous, "defects" are not mentioned in the EPO parameters definition given in Recommendation ITU-T Y.1563 [4]; in this case errors (intended as single errors) are the most significant source of impairment of the Frame Loss Ratio (FLR) or IP Packet Loss Ratio (IPLR) (see Annex 4).

The main concern for FS links is how propagation affects the Bit Error Ratio (BER), leading to SES and ES events when the receiver signal level (RSL) drops below a certain threshold.

Figure 2 shows this typical behaviour and the relevant ETSI standard BER versus Receiver Signal Level (RSL) limits. In modern digital radio, the use of powerful error correction codes create a big difference between the "undecoded" (before correction) BER and the "decoded" (after correction) BER (on which depend the ES/SES performance). Additionally, the slope of the decoded BER curves for modern systems is almost vertical (see Figure 2), such that there is only a slight difference between the ES and SES levels. As shown in the figure at a high BER, above the SES threshold (for FS conventionally fixed at BER=10-6 since the Recommendation ITU-T G.826 [1] entered into force), FS link synchronisation may become an issue resulting in increased anomalies and defects.

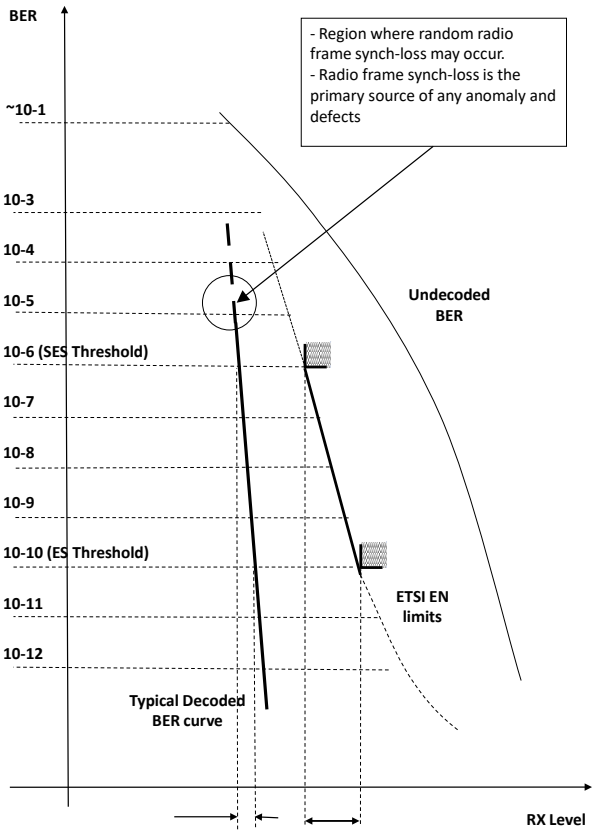


Figure 2: Typical modern system BER/RSL behaviour

Figure 2 shows that, in practice, when the "decoded" BER is still relatively low (e.g. BER $= 10^{-6}$, assumed today as SES threshold on which to calculate the link fade margin in the planning procedure), the "undecoded" BER (gaussian distribution) is already critical (e.g. well below than 10^{-3}) and, with minimal RSL level reduction from

the BER $= 10^{-6}$ threshold, the synchronisation is lost, thus causing a number of "defects". Therefore, in practice, SES due to BER and defects can be identified, for FS links purpose, only by exceeding the BER threshold; other “defects” can derive only from failures or malfunctions in the FS equipment or in ancillary functions (e.g. routers), which effects are not included in the ITU-R EP and AP objectives.

Therefore, for all practical planning purpose, the BER 10^{-6} threshold (meaning that of the reference modulation when ACM systems are concerned) could be used as trigger for SES occurrence and, accordingly, for evaluating the CNR used in the coexistence methodology.

It should be noted that some of the older recommendations like Recommendation ITU-R F.1494 [9] are based on FS systems where there was a significant difference (around 3 dB or more) between the SES and ES thresholds.

3.4.1 Practical impact of ES, SES and Defects in FS Systems

Modern FS systems increasingly use Adaptive Coded Modulation (ACM) and ATPC, which dynamically adjust transmission rates or power to account for varying propagation conditions. While these techniques can improve overall network efficiency, they have little effect on the committed traffic capacity required to meet APO/EPO objectives in presence of “intra-system” interference only during FS planning procedure. In ATPC-enabled systems (in some case imposed by licensing rule), power is reduced during favourable conditions, when detected by the corresponding receiver, to minimize intra-systems interference, but the full FFM is restored only during high propagation losses.

For proper planning, the BER threshold of the reference modulation should be used to trigger SES occurrence, and the Net Fade Margin (NFM) should be considered when ATPC is applied.

3.4.1.1 Propagation impact to Availability performance (AP) and Error performance (EP)

The major impact on AP and EP is obviously given by the propagation impairment which is also described, on statistical basis, by ITU-R (P. Series) Recommendations. Those Recommendations are widely used for planning the link for fulfilling the APO and EPO.

The planning methods, based only on the propagation statistic effects given in Recommendation ITU-R P.530 [15], define, on a link-by-link basis, the required Flat Fade Margin (FFM, sometime referred also as Thermal Fade Margin, TFM) necessary for respecting the required APO and EPO on that link.

The FFM is also represented by the difference between the “nominal” RSL (often referred as “free-space/clear sky” RSL, calculated from the link budget, according to Recommendation ITU-R P.525, section 2 of annex 1 [16]) and the RSL corresponding to the BER=10^{-6} threshold of the FS link.

The FFM is consequently the basis on which the effect of interference should be evaluated; in practice, the FFM is the margin in the FS link that can be statistically reduced by the propagation and, when time varying interference levels are considered, by effects of interference levels reaching levels significantly higher than noise level; however, when ATPC is used on the FS link, a lower margin is available for evaluating the effects of those higher interference levels. Figure 6 gives visual example of the various fade margins to be considered.

It is worth to mention that when multipath propagation is predominant, also the Dispersive Fade Margin (DFM, evaluated through the FS equipment signature method in Recommendation ITU-R F.1093 [22]) should be considered and, if DFM < FFM, DFM should be used in the link planning. However, modern FS systems implement powerful digital equalisers that in almost all cases guarantee that DFM >> FFM. Links where this cannot be guaranteed, typically use space diversity techniques.

It should be mentioned that the propagation model for interfering path may be different from the Recommendation ITU-R P.530 [15] used for LOS FS links; its selection depends on the specific interference sources and relevant scenarios which are not in the scope of this Report.

3.4.1.2 ATPC impact to AP and EP

Adaptive Transmit Power Control (ATPC) is a common feature in fixed links equipment placed on the market; it aims to reduce interference to other fixed links in the same area, so improving the possible link density/frequency reuse of the network.

It should be noted that ATPC use is facultative and decided by the operator, when appropriate; however, there are cases where administrations impose the use of ATPC for licensing the link.

When propagation permits (i.e. for around 99% of the time) the TX output power is reduced up to the selected $ATPC_{RANGE}$ (dB) and, consequently, also the "free-space/clear sky condition" RSL is reduced -the same amount; the TX power and, consequently, the full FFM are restored to their nominal planned value only when the RSL drops below the ATPC activation threshold (i.e. for around the remaining 1% of the time). These concepts are graphically shown in Figure 6.

When properly designed, ATPC it does not have any impact on APO and EPO effects due to propagation considered in the link planning. However, it has significant impact when considering the effects of high level external interference presence, because the full FFM is normally not available when the interference level increases beyond the Net Fade Margin (NFM)[1]. NFM is defined in Recommendation ITU-R F.1108 [8] as:

NFM = FFM - $ATPC_{RANGE}$ (all values in dB)

Annex 4 provides the necessary background on ATPC.

[1] Please note that in multipath and signature literature sometimes the term "Net Fade Margin" was used meaning NFM = min(DFM; FFM); to be used in link planning for dominant multipath situations (see e.g. Recommendation ITU-R F.1093 [22]).

4 REQUIRED TECHNICAL ELEMENTS FOR THE EP AND AP EVALUATION

4.1 ADAPTIVE TECHNOLOGIES IMPACT

The protection criteria of the fixed service depend on its performance criteria defined in terms of errored second (ES) and severely errored second (SES).

In order to achieve the quality of service objectives, a minimum signal to noise ratio (SNR) is necessary for activating a SES or an ES. Depending on the characteristics of this system, its functionalities and its transmission techniques, combined to a certain level of interference, each SNR leads to certain performance degradation to be evaluated against the objective.

Once the performance target is set, which typically is throughput or BER for digital transmission systems, and depending on the characteristics of transmitting systems, the corresponding SNR is to be inferred.

Therefore, in order to determine the spectral efficiency or BER curves, the technical characteristics of the FS transmitter are required. Hence the need of having the necessary information on the current uses of FS systems in order to review their associated performance effects.

In the rest of this Report, the protection criteria of FS will be derived throughout the SNR level distribution.

The performance protection criteria is evaluated in terms of C/(N+I), which consider purely the physical layer event acting on the desired signal. In other terms, if during one second, the degradation of SNR (Signal to Noise Ratio[2]) has to be assessed exceeds the associated Fade margin, this second will be considered as errored.

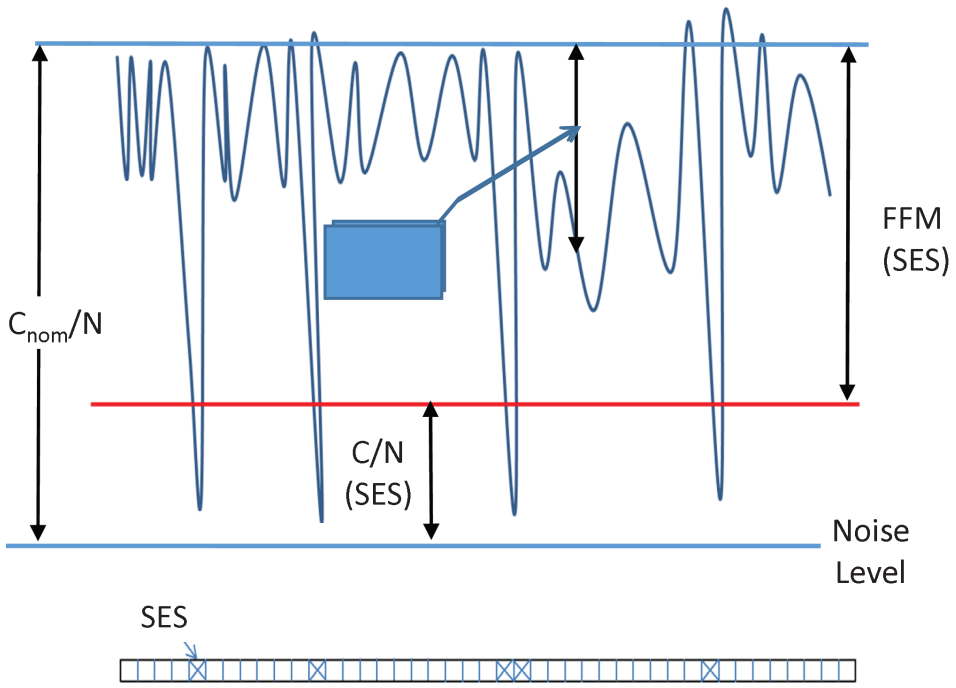


Figure 3: Example of multipath propagation effect on C/N variance and SES performance (note the Recommendation ITU-R P.530 [15] up-fading effects beyond the Recommendation ITU-R P.525 [16] nominal RSL)

[2] Please note that in the presence of Interference the SNR becomes SINR (Signal to Interference Plus Noise Ratio); this can also be referred as C/N or C/(I+N)

Hence, the assumption that EPO can be expressed in terms of time percentage of exceedance of the FFM and by the SNR degradation $EPO = \Pr\left(\Delta\mathrm{SNR} = \frac{\Delta C}{N} > FFM\right)$ which can be determined from the cdf of the C/N degradation.

In order to achieve the quality-of-service objectives, a minimum signal to noise ratio (SINR) is necessary. Depending on the characteristics of this system, its functionalities and its transmission techniques, each SNR leads to performance objective.

Once the performance target is set, which typically is throughput or BER for digital transmission systems, and depending on the characteristics of transmitting systems, the corresponding SNR is to be inferred. Figure 4 gives an example of the spectral efficiency curve of different Modulation and Coding Scheme (MCS), which allows, depending on the bandwidth, to deduce the threshold SNR.

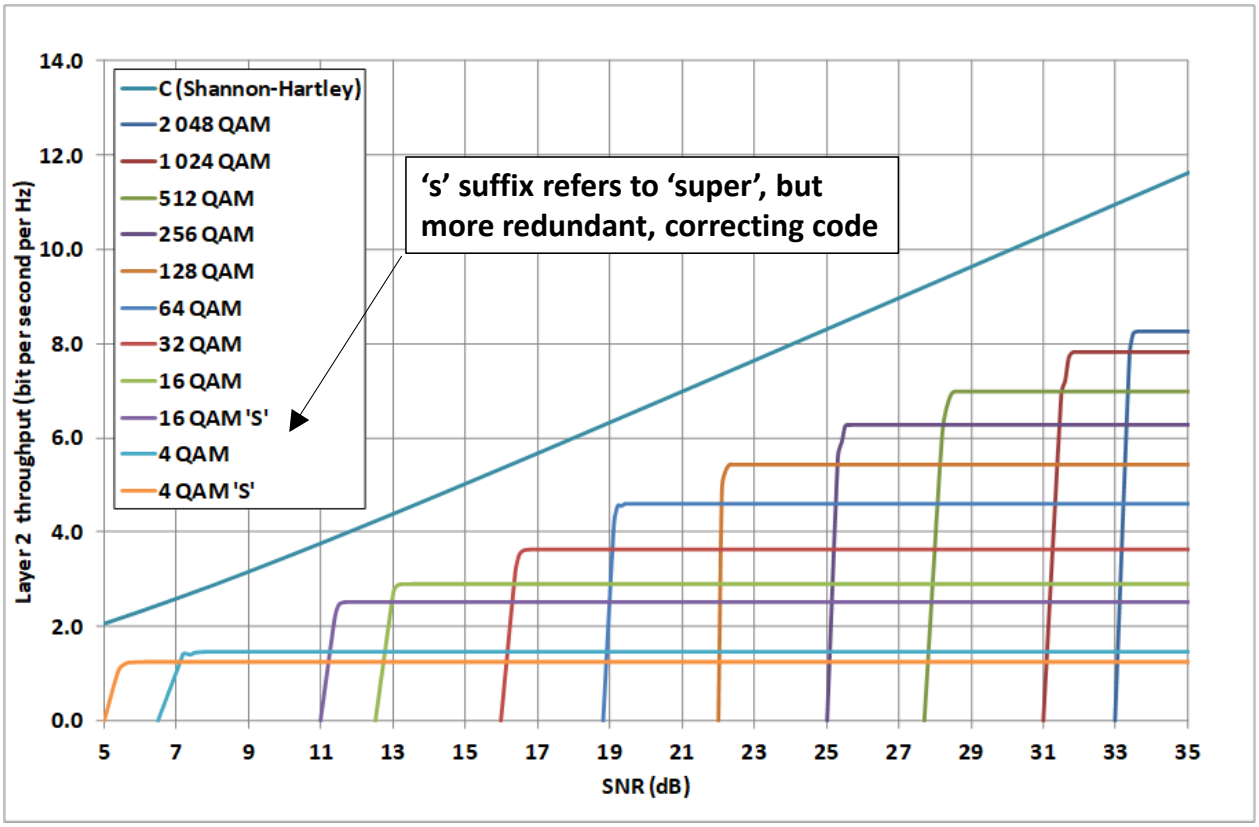


Figure 4: Throughput of a set of Coding and Modulation Combinations for AWGN channels

4.2 FIXED SERVICE ERROR PERFORMANCE OBJECTIVE (EPO)

Recommendation ITU-R F.1668-1 [12] specifies error performance objectives (EPO) for real digital fixed wireless links which may form part of the national portion of a 27500 km hypothetical reference path (HRP). Although it has been a long time since the ITU recommendation was revised, it is assumed here that the recommendation is still representative also for current 6 GHz FS radio links.

Examples of calculations of the error performance parameters ESR (Errored Second Ratio), SESR (Severely Errored Second Ratio) and BBER (Background Block Error Ratio) can be found in Recommendation ITU-R F.1668, annex 3 [12]. The example of calculation below refers to a generic national portion configuration as shown in the Figure 5.

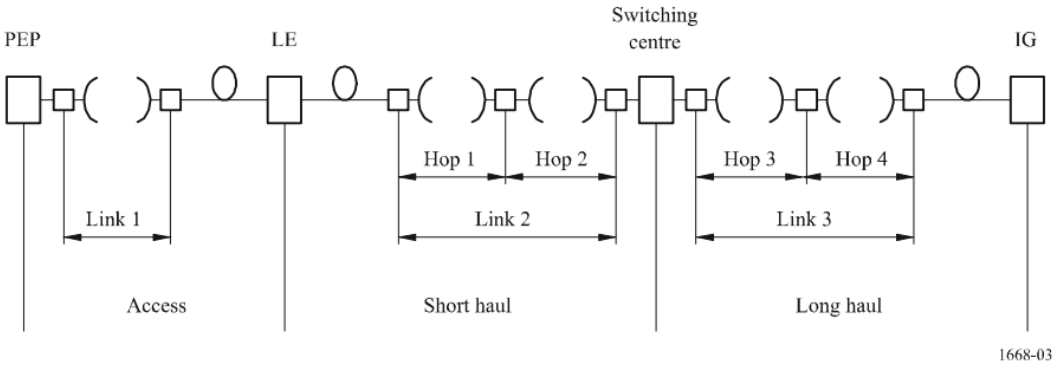


Figure 5: Generic national portion configuration (Source: Recommendation ITU-R F.1668, figure 3 [12])

Example 1: real link in the Long haul portion of the network, designed in accordance with Recommendation ITU-T G.828 [3].

Length of the Long Haul section, Link L_3 = 500 km

SDH transmission rate: synchronous transport module, STM-1 (155.52 Mbit/s):

- ESR = 0.04 A = 0.04 (A_1 + 0.002) × 500/100;
- SESR = 0.002 A = 0.002 (A_1 + 0.002) × 500/100;
- BBER = 0.0001 A = 0.0001 (A_1 + 0.002) × 500/100.

In this case, the objectives are length dependent. In Table 1, the limits for A_1=0,01 and A_1=0,02 are shown.

Table 1: Long Haul section EPO

A_1 value	ESR	SESR	BBER
0,01	2,40E-03	1,20E-04	6,00E-06
	(=6221 ES/month)	(=311 SES/month)	(= 124416 EB/month)
0,02	4,40E-03	2,20E-04	1,10E-05
	(=11405 ES/month)	(=570 SES/month)	(= 228096 EB/month)

If it is assumed that the national Long Haul section, with a total route length of 500 km, consists of 10 different individual radio link routes, the EPO per radio link is:

- ES = 622 ES/month up to 1 140 ES/month;
- SES = 31 SES/month up to 57 SES/month;
- BBE = 12 442 EB/month up to 22 810 EB/month.

Example 2: real link in the long-distance part of the network between the cities Malmö and Kiruna in Sweden. The great circle distance between the cities is 1400 km. EPO for a network designed in accordance with Recommendation ITU-T G.828 [3] is as follows:

Length of the Long Haul section, Link L_3 = 1400 km

SDH transmission rate: synchronous transport module, STM-1 (155.52 Mbit/s):

- ESR = 0.04 A = 0.04 (A_1 + 0.002) × 1400/100;
- SESR = 0.002 A = 0.002 (A_1 + 0.002) × 1400/100;
- BBER = 0.0001 A = 0.0001 (A_1 + 0.002) × 1400/100.

In this case, the objectives are length dependent. In Table 2, the limits for A_1=0,01 and A_1=0,02 are shown:

Table 2: Long Haul section EPO

A_1 value	ESR	SESR	BBER
0,01	6,72E-03	3,36E-04	1,68E-05
	(=17418 ES/month)	(=871 SES/month)	(= 348365 EB/month)
0,02	1,23E-02	6,16E-04	3,08E-05
	(=31933 ES/month)	(=1597 SES/month)	(= 638669 EB/month)

Approximately 40 individual hops are needed to bridge the 1400 km between Malmö and Kiruna, the EPO per radio link is:

- ES = 435 ES/month up to 798 ES/month;
- SES = 21 SES/month up to 40 SES/month;
- BBE = 8709 EB/month up to 15966 EB/month.

The SES values calculated above, 21 SES/month and 40 SES/month, correspond to an availability of 99.9992% and 99.9985% with respect to BER 10^{-6}.

A general criterion when dimensioning and planning a radio link may be that the time per worst month that the radio link's received signal strength is below the receiver's BER 10-6 threshold must not exceed the SES value. Typically, it is also necessary when planning radio link connections to keep some margin in the allocation of EPO, in order to handle natural reduction of performance, e.g. antennas that becomes mis-aligned due to wind, aging equipment, etc. There is no clear industry standard that provides guidance in this regard.

There may also be paths with difficult wave propagation conditions where it may be necessary to allocate a larger EPO. This means that other paths in the radio link network must have a correspondingly better performance in order to meet end-to-end requirements.

It should be noted that in this context the EPOs could be seen as a minimum requirement for initial planning and it is thus reasonable for an operator to dimension a radio link network with a margin to the ITU's requirements.

The allowable degradation in performance of FS systems due to interference from other services sharing the same frequency bands on a primary basis are expressed as a permissible fraction (10%) of the total Error Performance Objectives (EPO) and are defined in Recommendation ITU-R F.1565 [11] and Recommendation ITU-R F.1495 [10] for the real FS systems which may form part of the national portion of a 27500 km HRP.

5 THE EVALUATION OF THE FIXED SERVICE PROTECTION CRITERIA

5.1 INTRODUCTION

When time-varying interference is concerned, Recommendation ITU-R F.758-8 [6] considers that the Fractional Degradation in Performance (FDP) method, provided in Recommendation ITU-R F.1108-4 [8] is appropriate for determining the EP long-term protection criterion. It must be noted that the use of the FDP methodology does not put into question the use of the long-term protection criteria defined in Recommendation ITU-R F.758-8, table 5.The FDP principle is based on the joint probability that the critical C/N ES threshold of the FS modulation is reached by the contemporaneous sum of the ΔC(t) variance (FS link propagation attenuation effect over time) added to the increase of Δ[N+I(t)] level beyond the N level (I level variance over time effect); Figure 6 graphically shows the two contributions effect on the nominal FFM of the link, when multipath effects are considered. When multipath is the dominant effect, it produces “down-fading” (nominal free space level attenuation) and “up-fading” (nominal free space level enhancement) as described in Recommendation ITU-R P.530 [15] for specific % of time. Note that, when rain is the dominant effect, up-fading is negligible.

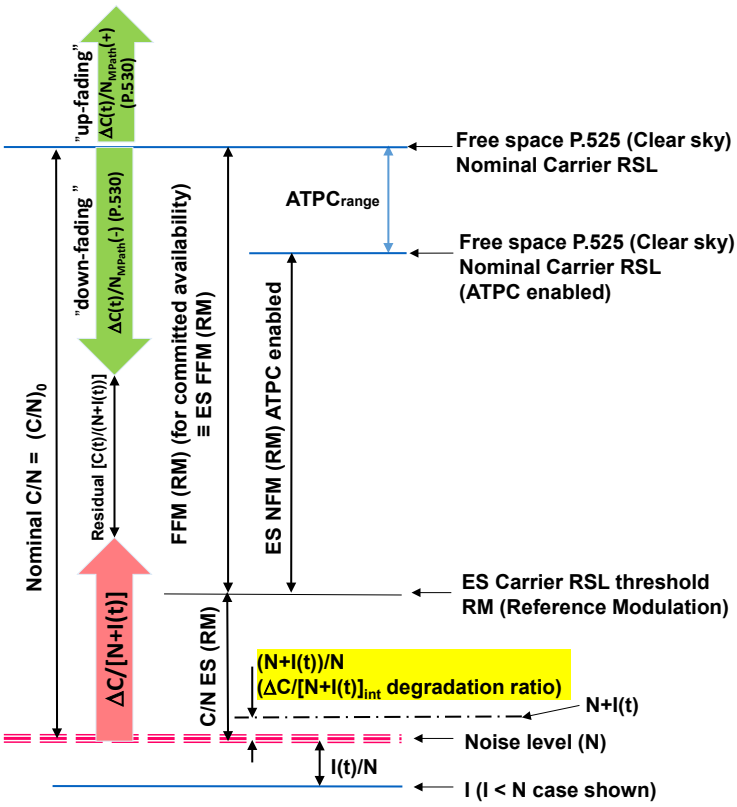


Figure 6: C(t) and [N+I(t)/N] time variance basis for FDP concept (dominant multipath effect)

In cases where the rain fade on the desired and interfering paths may not be uncorrelated, both Recommendation ITU-R F.758-8 [6] and Recommendation ITU-R F.1108-4 [8] say that, when rain is the dominant propagation effect, FDP needs further study.

The data rate and the BER of a FS link receiver are strongly related to the SNR and the ratio of the carrier power to noise. However, propagation conditions (such as multi-path fading, rain fading, and diffraction fading, etc.) and interference reduce the FS received signal-to-noise ratio. Thus, a fixed service system needs an adequate flat fade margin (FFM), to deal with these potential disruptions so that the link can satisfy APO and EPO requirements. The amount of FFM provides for the maximum (clear sky) SNR which is reduced according to the propagation statistic; therefore, the performance degradation can be evaluated in terms of SNR degradation statistic without interference with respect to the same evaluation taking into account also the additional SNR degradation due to the combined I/N statistic.

In case ATPC in applied, it is necessary to consider the "Net Fade Margin" (NFM):

- NFM = FFM - $\mathrm{ATPC}_{\mathrm{range}}$, (dB)

It is worth mentioning that when multipath propagation is predominant dispersive fading can occur. However, modern FS systems implement powerful digital equalisers that in almost all cases guarantee that DFM >> FFM. Links where this cannot be guaranteed, typically use space diversity technique. Therefore, the following methodology can be based only on FFM and, when ATPC is implemented, NFM.

The methodology has to be differently applied according to the presence or not of ATPC function for taking into account the different FFM and NFM as well as the ATPC activation threshold.

5.2 FRACTIONAL DEGRADATION IN PERFORMANCE (FDP) IN ABSENCE OF ATPC

Recommendation ITU-R F.1108 [8] uses the notation TFM (thermal fade margin) in place of the FFM (flat fade margin) used elsewhere in this Report with the same meaning.

The fractional degradation in performance (FDP) represents the relative incremental degradation due to interference i.e. the interference contribution to this degradation which results in the relative increase of P_0, $\Delta P_{0,i} = (P_i - P_0)/P_0$ due to the interference. Where P_0 and P_i, are respectively, the outage probability in the absence and the presence of interference.

The Recommendation ITU-R F.1108 [8] defines the FDP, section 5 annex 3, as follows:

The FDP is the fractional increase in the percentage of time that the controlling performance criterion will not be met because of the presence of interference. Denoting the value in the absence of interference by P_0, the FDP could be expressed as FDP = (P_i /P_0) –1.

The simplified expression of FDP derived by Recommendation ITU-R F.1108 [8], $\mathrm{FDP} = \sum \Delta P_{0,i} = \sum \frac{I_i f_i}{N}$ corresponds to a special case i.e. where the fading is modelled by a linear expression (see Annex 1 for details on the derivation of the formulas).

5.3 GENERIC FDP METHODOLOGY

A comprehensive methodology to evaluate the impact of interference on error performance objectives (EPO) has been developed which uses the probability distribution of the interference at the FS receiver. The methodology provides a systematic approach to evaluate the FDP and is essentially based on the following concepts:

- Fractional Degradation in Performance (FDP): FDP is calculated based on the degradation of the probability of outage due to fading only relative to the joint probability of outage due to fading and interference;
- Short-Term and Long-Term Components of FDP: FDP is divided into short-term (FDPST) and long-term (FDPLT) components. Short-term degradation occurs when interference exceeds the fading margin, while long-term degradation occurs when the combination of fading and interference exceeds the fading margin;
- The FDP should not exceed 10% for a co-primary service interference or 1% for non-co-primary service interference.

The FDP calculation is based on the following elements:

- Fade Margin (FM);
- distribution of fading of the wanted signal at the fixed service (FS) receiver (Recommendation ITU-R P.530 [15]);
- probability density function (pdf) of interference signal at the FS receiver.

When ATPC is implemented, the ATPC range is also used in the FDP calculation.

Additionally, the objectives of FDP (FDP should not exceed 10% for a co-primary service interference or 1% for non-co-primary service interference) are complementary to the long-term protection criteria defined in Table 5 of Rec. ITU-R F.758-8.

5.3.1 Derivation of FDP formula – a Comprehensive Methodology to Evaluate the impact of Interference on Error Performance Objectives

From Recommendation ITU-R F.758-8 [6]:

- "For interference from co-primary sources, the total degradation in error performances and availability objectives due to a combination of short-term and long-term interference should be limited to 10%; for interference from sources which are not co-primary, the total degradation should be limited to 1%";
- "Separate consideration is given to short-term interference, which is the term used to describe the highest levels of interference power that occur for less than 1 per cent of the time, and to long-term interference, which addresses the remaining portion of the interference power distribution";
- "Short-term interference requires separate consideration because the interference power may be high enough to produce degradation even when the desired signal is unfaded. Such interference must occur rarely enough and in events of short duration for the interference to be acceptable. A short-term interference criterion is set based on the interference power necessary to cause a particular error performance defect (such as an errored second) when the desired signal is unfaded";
- "Because permissible error performance defects can only occur for percentages of time that are much smaller than 1% of the time if error performance objectives are to be met, short-term interference studies require knowledge of the interference power that is exceeded for percentages of time much less than 1 per cent".

Figure 7 shows a plot of the received signal-to-noise ratio (SNR) for an FS, without ACM, link that employs ATPC. In case of ATPC, the nominal received power is the received power in clear sky (Recommendation ITU-R P.525 [16]) situation due to the maximum transmit power minus the ATPC range.

ATPC is decomposed into a part having ATPC threshold and ATPC range. The ATPC threshold is the level at which ATPC starts to compensate for the fading. When fade takes place, once the ATPC threshold is reached, the ATPC mechanism compensate the fade up to a maximum ATPC range value.

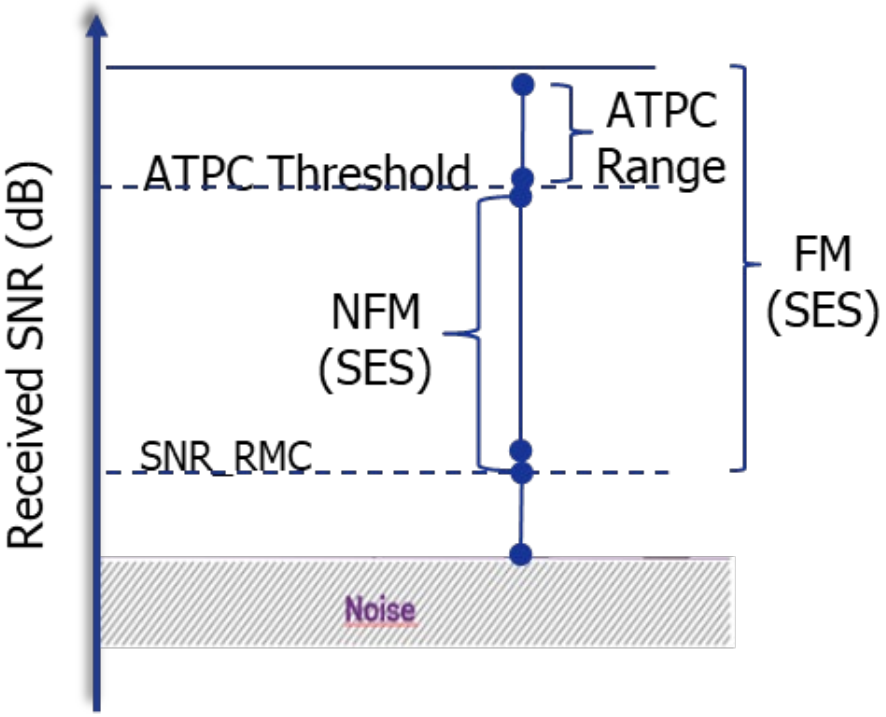


Figure 7: ATPC threshold and ATPC range

The full interference probability distribution shall be considered in the calculation of the total degradation. The total apportionment of EPOs derived from the fractional degradation in performance (FDP) from long and short-term interference should not exceed 10%; (co-primary services) and 1% for non-co-primary interference.

The following derivations assume that fading and interference events are statistically independent. Note that in a rain dominated environment the fading on the desired and interfering paths could be correlated. The correlation degree depends on the lengths and directions of interfering and desired paths; further study is needed at ITU-R level.

In cases where this independence assumption does not hold, it is recommended that the Fractional Degradation in Performance (FDP) be calculated, as a conservative approach (which should be used for a rain dominated environment e.g. for links above 15 GHz), as follows:

$$\mathrm{FDP} = (\frac{\mathrm{i}}{\mathrm{n}})_{\mathrm{av}} = \sum \mathrm{f_x} \frac{\mathrm{i_x}}{\mathrm{n}}$$

where:

- f_x is the fraction of time the interference has a power level i_x
- $\frac{\mathrm{I_x}}{\mathrm{N}} = 10 \times \log(\frac{\mathrm{i_x}}{\mathrm{n}})$ [dB]
  Refer to Recommendation ITU-R F.1108, annex 3 [8] for further guidance on this formulation.

5.3.1.1 FDP derivation assuming FS link with no ATPC

As described in Recommendation ITU-R F.1108 [8], the FDP is given by

$$FDP = \frac{P_{O,i} - P_{O,0}}{P_{O,0}} = \frac{P_{O,i}}{P_{O,0}} - 1 \quad (1)$$

where:

- $P_{o,0}=Prob(f \geq FM)$ is the probability of outage due to fading only.
- $Prob(f \geq FM) = \int_{f=FM}^{+\infty} pdf_f(f)df$
- f is the fade in dB
- $pdf_f(f)$ = the fade probability density function based on, e.g., Recommendation ITU-R P.530 [15], and its support is from $+\infty$ to $-\infty$.
- FM is the Fading Margin in dB estimated based on Recommendation ITU-R P.530 [15] according to the Performance Objectives (EPO) parameters.
- $P_{o,i}$ =The probability of outage from fading and interference and is given by the joint probability in equation 2. This is written in a format that was derived in Recommendation ITU-R F.1108 [8].

$$P_{O,i} = \int_0^{+\infty} pdf_z(z) Prob(f \geq FM - 10\log(1+z))dz \quad (2)$$

where:

- $z = \frac{i}{n}$, and $\frac{i}{n}$ is the numerical interference to noise ratio in linear scale;
- $pdf_z(z)$ is the probability density function of the interference to noise ratio distribution and its support is from 0 to $+\infty + \infty;+\infty$
- FDP >0.

The FDP equation can be divided into two components, a short-term and long-term:

$$FDP = FDP_{LT} + FDP_{ST} = \frac{P_{O,i}LT - Po,0}{P_{O,0}} + \frac{P_{O,i}ST - Po,0}{Po,0} \quad (3)$$

where:

- FDP_{ST} = The short-term fractional degradation in performance occurs when the interference degradation exceeds the FM. This is referred to as short-term degradation because high levels of interference occur with low probability.

$$FDP_{ST} = \frac{P_{O,i_ST}}{Po,0} - 1 = \frac{P_{O,i}ST - Po,0}{Po,0} \quad (4)$$

FDP_{LT} = The long-term fractional degradation in performance occurs when the interference degradation is less than the FM, but the combination of fading and interference exceed the FM. It is referred to as long-term because low levels of interference occur with higher probability.

$$FDP_{LT} = \frac{P_{O,i_LT}}{P_{O,0}} - 1 = \frac{P_{O,i}LT - P_{O,0}}{P_{O,0}} \quad (5)$$

P_{O,i_ST} is the joint probability of outage from fading and interference when the interference degradation is greater or equal than the FM (or $z \geq \left(\frac{i}{n}\right)_{st}$ and $\left(\frac{i}{n}\right)_{st} = 10^{\frac{FM}{10}} - 1$ and is given by:

$$P_{O,i}ST = \int_{z=(i/n)_{st}}^{+\infty} pdf_z(z) Prob(f \geq FM - 10\,log(1+z))dz + (1-\gamma) \times P_{o,0} \quad (6)$$

The joint probability of fading and interference is considered to account also for upfading events when an interference degradation higher than the fade margin is needed to produce outage.

where:

- $\gamma = Prob\ (z \geq (i/n)_{st})$ is a normalization term and is added so that the FDP equation can retain the format defined in Recommendation ITU-R F.1108 [8];
- P_{o,i_LT} is the joint probability of outage from fading and interference when the interference degradation is less than the FM (or $z < \left(\frac{i}{n}\right)_{st}$) and is given by:

$$P_{O,i}LT = \int_{z=0}^{z=(i/n)_{st}} pdf_z(z) Prob(f \geq FM - 10\,log(1+z))dz + \gamma \times P_{o,0} \quad (7)$$

where:

- $(i/n)_{st}$ = FM (Fade Margin).

Note that both equations (8) and (9) take into account both upfading and downfading events by considering both positive and negative fading in the distribution of the fade f.

The FDP % should not exceed 10% (co-primary service) or 1% (non-co-primary service)[3].

5.3.1.2 FDP derivation assuming FS link with ATPC

When the FS link uses power control, the probability of outage $P_{O,i\ ATPC}$ from fading and interference calculation needs to be divided into two parts: when the fading is below the ATPC range and when it is above it.

When the fade f is below the ATPC range, the margin is kept constant to the NFM, therefore outage occurs when the degradation due interference is larger than NFM. This probability becomes $Prob(f \leq ATPC\ Range) Prob(10\log(1+z) \geq NFM)$.

When the fade f is above the ATPC Range, outage occurs when the degradation due interference is larger than FM. This probability becomes $\int_{ATPC\ range}^{+\infty} pdf_f(f) Prob(10\log(1+z) > FM - f)df$.

---

[3] According to Recommendation ITU-R F.1494 [9], in multipath dominated frequency bands, a representative apportionment of short-term and long-term degradation is 10% and 90% of the maximum FDP (10%).

In case of frequency bands dominated by rain the apportionment of the link is assumed as 20% due to long-term interference and 80% due to short-term interference (see Recommendation ITU-R F.1495 [10])

Combining the two parts above, the probability of outage becomes (see detailed derivation in Annex 2).

$$P_{O,i\ ATPC} = Prob(f \le ATPC\ Range)Prob(10\log(1+z) \ge NFM) + \int_{ATPC\ range}^{+\infty} pdf_f(f)Prob(10\log(1+z) > FM - f)df \quad (10)$$

Eq. (11) takes into account both up-fading and down-fading events by considering both positive and negative fading in the distribution of the fade f.

The integral in the second term in eq. (12) can be rewritten by swapping the integrals as (see detailed derivation in Annex 2),

$$\int_{ATPC\ range}^{+\infty} pdf_f(f)Prob(10\log(1+z) > FM - f)df = \int_0^{+\infty} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z)))dz \quad (13)$$

In order to the separate between short-term and long-term interference, the integral in z in eq. (14) can be split as

$$\int_0^{+\infty} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z))dz = \int_0^{(i/n)_{st}} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z)))dz + \int_{(i/n)_{st}}^{+\infty} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z)))dz \quad (15)$$

where:

- $\left(\frac{i}{n}\right)_{st} = 10^{\frac{NFM}{10}} - 1$ is the threshold when the degradation due to interference is greater or equal to the NFM. Eq. (16)can be further simplified as

$$\int_0^{(i/n)_{st}} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z)))dz + \int_{(i/n)_{st}}^{+\infty} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z)))dz = \int_0^{(i/n)_{st}} pdf_z(z)Prob(f > FM - 10\,log(1+z))dz + \int_{(i/n)_{st}}^{+\infty} pdf_z(z)Prob(f > ATPC\,range)dz \quad (17)$$

$$= \int_0^{(i/n)_{st}} pdf_z(z)Prob(f > FM - 10\,log(1+z))dz + Prob(10\log(1+z) > NFM)\ Prob(f > ATPC\,range) \quad (18)$$

where the identity $ATPC\,range = FM - 10\,log(1 + (i/n)_{st})$ was used in eq. (19) and $\int_{(i/n)_{st}}^{+\infty} pdf_z(z)dz = Prob(10\log(1+z) > NFM)$ in eq. (20).

Finally, the probability of outage due to long-term interference is the first term of eq. (21)

$$P_{O,i\ ATPC}LT = \int_0^{(i/n)_{st}} pdf_z(z)Prob(f > FM - 10\,log(1+z))dz + \gamma \times P_{o,0} \quad (22)$$

which is the same formula as the probability of outage due to long-term interference without ATPC defined in eq. (23). However, note that here

$\left(\frac{i}{n}\right)_{st} = 10^{\frac{FM - ATPC_{range}}{10}} - 1$ whereas, in case of no ATPC, $\left(\frac{i}{n}\right)_{st} = 10^{\frac{FM}{10}} - 1$ and $\gamma = Prob\ (z \ge (i/n)_{st})$.

The probability of outage due to short-term interference the sum of the first term in eq. (24) and the second term in eq. (25).

$$\begin{aligned} &P_{O,i\ ATPC}ST \\ &= Prob(f \le ATPC\ Range)Prob(10\log(1+z) \ge NFM) \\ &+ Prob(10\log(1+z) > NFM)\ Prob(f > \text{ATPC range}) + (1-\gamma) \times P_{o,0} \\ &= Prob(10\log(1+z) \ge NFM) + (1-\gamma) \times P_{o,0} \end{aligned}$$

Finally,

$$P_{O,iATPC}ST = \gamma + (1-\gamma) \times P_{o,0} = P_{o,0} + \gamma(1-P_{o,0}) \quad (26)$$

where:

- $\gamma = Prob\ (z \ge (i/n)_{st})$ is a normalization term and is added so that the FDP equations can retain the format defined in Recommendation ITU-R F.1108 [8].

The total, $P_{O,i\ ATPC}$, can be calculated as (see eq.(27))

$$P_{O,i\ ATPC} = \big(1 - Prob(f > ATPC\ Range)\big) \times \gamma + \int_0^{+\infty} pdf_z(z) Prob(f > Max(\textit{ATPC range}, FM - 10\,log(1+z)))dz$$

The FDP equation is then defined as:

$$\text{FDP} = \text{FDP}_{\text{LT}} + \text{FDP}_{\text{ST}} = \frac{P_{O,i}LT - \text{Po},0}{\text{Po},0} + \frac{P_{O,i}ST - \text{Po},0}{\text{Po},0} \quad (28)$$

where:

- FDP_{ST} = The short-term fractional degradation in performance occurs when the degradation due to interference exceeds the NFM. This is referred to as short-term degradation because high levels of interference occur with low probability;

$$\text{FDP}_{\text{ST}} = \frac{P_{O,i_ST}}{\text{Po},0} - 1 = \frac{P_{O,i}ST - \text{Po},0}{\text{Po},0} \quad (29)$$

- FDP_{LT} = The long-term fractional degradation in performance occurs when the degradation due to interference is less than the NFM. It is referred to as long-term because low levels of interference occur with higher probability;

$$\text{FDP}_{\text{LT}} = \frac{P_{O,i_LT}}{\text{Po},0} - 1 = \frac{P_{O,i}LT - \text{Po},0}{\text{Po},0} \quad (30)$$

- P_{O,i_LT} and P_{o,i_ST} are the probability of outage from long-term and short-term interference degradation defined in eqs. (31) and (32), respectively;
- $P_{O,0}$=$Prob(f \ge FM)$ is the probability of outage due to fading only (same as in 5.3.1.1 - without ATPC).

The FDP % should not exceed 10% (co-primary service) or 1% (non-co-primary service) [4].

[4] According to Recommendation ITU-R F.1494 [9], in multipath dominated frequency bands, a representative apportionment of short term and long-term degradation is 10% and 90% of the maximum FDP (10%).

In case of frequency bands dominated by rain the apportionment of the link is assumed as 20% due to long-term interference and 80% due to short-term interference (see. Recommendation ITU-R F.1495 [11])

5.3.2 FDP Methodology Implementation

In the context of the implementation of the FDP methodology based on the Monte Carlo approach, different cases are envisaged:

- Fixed interferers, known positions -> 1 FDP;
  - Mobile interferers, with unknown or known positions, can be added at each time step if needed so that the unique FDP includes the “mobile” component of the interferers;
- Fixed interferers, unknown positions -> “Space-only” Monte Carlo, “M” space topologies, “M” FDPs;
  - Mobile interferers, with unknown or known positions, can be added at each time step if needed so that the “M” FDPs include the “mobile” component of the interferers;
- Mobile interferers, known positions -> 1 FDP;
- Mobile interferers, unknown positions -> “Standard” Monte Carlo, 1 FDP.

The FDP methodology can be used in the context of both joint location/time Monte Carlo (conventional Monte Carlo) and/or separated location/time Monte Carlo. The latter method is specifically intended for cases with population of interferers including fixed interferers with unknown positions, to capture the various possible topologies including variations in interfering signals and potential attenuations. The case where the surrounding spatial configuration (e.g., clutter) is unknown is to be studied. The acceptable percentage of topologies that may exceed a 10% FDP threshold value need to be evaluated further, taking into account factors such as the likelihood of those topologies happening in practice. It is to be noted that no ECC or ITU-R Recommendations provide guidance on such acceptable percentage.

The key element on both approaches is the I/N distribution(s). However, deriving this distribution is not always straightforward. The I/N distribution should capture sufficient aspects of variations in time and should take into account the probability statistics of all potential attenuations (e.g. propagation losses, clutter losses, penetration losses that have their own ITU-R reference recommendations on the occurrence probability) along the interference path to the victim receiver.

6 CONCLUSION

The main findings of this Report are presented in the Executive summary (Section 0).

ANNEX 1: FDP BASED ON RECOMMENDATION ITU-R F.1108

A1.1 FDP SIMPLIFICATIONS MADE IN RECOMMENDATION ITU-R F.1108

The Recommendation ITU-R F.1108 [8] approximates the outage probability in presence of interference by:

$$P_i = Cst.\left[10^{-\frac{DFM}{10}} + 10^{-\frac{TFM}{10}} + 10^{-\frac{C/I-CNC}{10}}\right] \qquad (2.2.1)$$

where:

- Cst: A constant depending on climate, terrain and link parameters;
- DFM: Dispersive fade margin (dB);
- TFM: Thermal fade margin (dB);
- C/I: Ratio of unfaded signal power to the noise-equivalent value of interference power (dB);
- CNC: Value of critical carrier-to-noise ratio at which the performance criterion is just met (dB).

According to Recommendation ITU-R F.1108 [8] (dated year 2005) the following apply:

- Modern digital systems usually have dispersive fade margins larger than their thermal fade margins, and are getting better ($\mathrm{DFM} \gg \mathrm{TFM}$). Hence, $10^{-\mathrm{DFM}/10} \ll 10^{-\mathrm{TFM}/10}$;
- The difference in decibels between the unfaded carrier-to-noise ratio and the critical carrier-to-noise ratio (CNC) is the thermal noise fade margin (TFM), i.e.; $\frac{C}{N} - CNC = \mathrm{TFM}$.

The first statement, DFM>>TFM, may not be valid for all current (year 2021) radio link systems that use wide channels and high modulation rates (i.e. in cases where DFM < TFM). However, during normal wave propagation conditions, under which short-term interference is evaluated, a typical radio link is normally not exposed to dispersive fading (other than in the special case of clear specular reflection in water surface). With this as an argument, the DFM can continue to be neglected (as in Recommendation ITU-R F.1108 [8]) in the simplification of the equation below.

The incremental FDP, $\Delta P_{0,i}$, due to this interference would be given by:

$$\Delta P_{0,i} = \frac{P_i - P_0}{P_0} =. \frac{Cst\left[10^{-\frac{DFM}{10}} + 10^{-\frac{TFM}{10}} + 10^{-\frac{\frac{C}{I}-CNC}{10}}\right] - Cst\left[10^{-\frac{DFM}{10}} + 10^{-\frac{TFM}{10}}\right]}{Cst.\left[10^{-\frac{DFM}{10}} + 10^{-\frac{TFM}{10}}\right]}$$

By applying the first hypothesis $10^{-DFM/10} \ll 10^{-TFM/10}$, the incremental FDP, $\Delta P_{0,i}$ becomes

$$\Delta P_{0,i} = \frac{P_i - P_0}{P_0} =. \frac{Cst\left[10^{-\frac{TFM}{10}} + 10^{-\frac{\frac{C}{I}-CNC}{10}}\right] - Cst\left[10^{-\frac{TFM}{10}}\right]}{Cst.\left[10^{-\frac{TFM}{10}}\right]} = 10^{-\frac{\frac{C}{I}-CNC-TFM}{10}}$$

By applying the second bullet point $\frac{C}{N} - CNC = \mathrm{TFM}$, the incremental FDP $\Delta P_{0,i}$ becomes

$$\Delta P_{0,i} = 10^{-\frac{\frac{C}{I}-\frac{C}{N}+\frac{C}{N}-CNC-TFM}{10}} = 10^{-\frac{\frac{C}{I}-\frac{C}{N}}{10}} = 10^{\frac{I/N}{10}} = \frac{i}{n}$$

Hence, if an interferer caused an interference power I_i for a fraction of a month, f_i, and was absent for the remainder of the month, the incremental FDP due to this interference would be given by:

$$\Delta P_{0,i} = \frac{I_i f_i}{N}$$

The FDP due to a set of events, where the i-th event consists of the fraction of time that the interference had a power I_i, is given as:

$$\mathrm{FDP} = \sum \Delta P_{0,i} = \sum \frac{I_i f_i}{N}$$

A1.2 ALTERNATIVE DERIVATION OF FDP

It should be reminded that two error performance objectives are recommended (ES and SES); both are relevant to different thresholds of the FS receiver. Therefore, in principle, two different evaluations are needed.

In the following formulas the variables in “CAPITAL” letters are used where dB units are used and “lowercase” letters where linear unit are used.

The degradation of a FS link performance due to interference can be assessed by its SNR degradation compared to that in absence of interference, using the following formula:

$$\Delta SNR_I = SNR_{clear\ sky} - SNR_{with\ interference} = \frac{C}{N} - \frac{C}{N+I} = \frac{N+I}{N} = 10\log_{10}(1 + i/n) \qquad (4.1)$$

The propagation effect acts on the useful signal by attenuating it c/f, leading then to an SNR degradation due to fading only:

$$\Delta SNR = SNR_{clear\ sky} - SNR_{fading} = 10\log\left(\frac{c}{n}.\frac{n}{\frac{c}{f}}\right) = 10\log(f) = F$$

Where F is the propagation attenuation versus time in dB and f in linear (Recommendation ITU-R P.1853-1 [23] provides propagation attenuation time series based on Recommendation ITU-R P.530 [15]). The propagation effect F that degrades the quality of the transmitted signal are mainly due to the multi-path effect and the rain. The multi-path fading is predominant, for frequency ranges below 15 GHz, over that of rain and conversely above 15 GHz. In the above equations, the FDP is derived by considering only the interference, as the interference was considered negligible (per the second bullet point above). In this section, the fading will also be taken into account in the FDP derivation.

The snr, in linear, in presence of fading and interference is expressed by the following formula:

$$snr_{interf+fading} = \frac{c/f}{n+i} = \frac{cr}{n+i}$$

Where $r = 1/f$ is the fading factor which is equal to $\mathrm{r} = 10^{-\mathrm{A}/10}$, and A is the fade depth (dB).

The performance criterion is not met when the snr is below the minimum required SNR needed to meet the performance requirement $snr_{threshold}$.

Then, the performance criterion would not be met if:

$$\frac{r.c}{n+i} \leq snr_{threshold}$$

This implies

$$r \leq \frac{snr_{threshold}}{c}(n+i)$$

When the interference power and fading are not constant and respectively follow the probability density functions $p_i(i)$ and $p_r(r)$, the outage probability due to the cumulative effect of interference and fading is:

$$P_{0,i} = P(snr \leq snr_{threshold}) = P\left(r \leq \frac{snr_{threshold}}{c}(n+i)\right) = \int_0^{+\infty} \int_0^{\frac{snr_{threshold}}{c}(n+i)} p_r(r) p_i(i) dr di \qquad \text{(B)}$$

Which could be expressed also by the probability that the cumulative effect of the link attenuations due to degradation caused by interference $\Delta\frac{C}{N_I}$, fading due to propagation (F) be higher than the FS link available margin FFM, as expressed in the following equation:

$$\mathrm{P_{o,i}} = P(F(t) + \frac{\Delta C}{N_I}(t) > FFM)$$

And

$$P_{0,0} = P(snr \leq snr_{threshold}) = P\left(r \leq \frac{snr_{threshold}}{c} n\right) = \int_0^{\frac{snr_{threshold}}{c} n} p_r(r) dr$$

If the special cases mentioned in Recommendation ITU-R F.1108 [8] is considered, the same results could be found:

- In the particular case where $p_r(r) = \beta$,

$P_{0,i} = \beta \times \frac{snr_{threshold}}{c}(n + I_{av})$ and $P_{0,0} = \beta \times \frac{snr_{threshold}}{c} \times n$ et ainsi FDP = $\frac{I_{av}}{n}$

where:

- $I_{av} = \int_0^{\infty} i\, p_i\,(i) di$

In the particular case where $p_r(r) = \gamma . r$, the FDP becomes $\int_0^{\infty} \left(\frac{2i}{n} + \frac{i^2}{n^2}\right) p_i(i) di$

The Fractional degradation in performances FDP (%), defined in Recommendation ITU-R F.1108 [8], by the percentage of performance degradation of the total link APO objective (%) due to interference compared to that without interference, can be derived as follows:

$$FDP = \frac{P_i - P_0}{P_0} \times 100\ (\%) \qquad (7)$$

ANNEX 2: FDP METHODOLOGY - DERIVATION OF EQUATION (8) AND EQUATION (9)

Equation (8)

Derivation of

$$P_{O,i} = \int_{-\infty}^{+\infty} pdf_f(f) Prob(10\log(1+z) > NFM + ATPC(f) - f) df \qquad (1)$$

$$= Prob(f \le ATPC\ Range) Prob(10\log(1+z) > NFM) + \int_{ATPC_{range}}^{+\infty} pdf_f(f) Prob(10\log(1+z) > FM - f) df$$

where:

$$ATPC(f) = \begin{cases} f, & f \le ATPC_range \\ ATPC_range, & f > ATPC_range \end{cases} \qquad (2)$$

Combining (1) and (2) the following is obtained:

$$P_{O,i}$$
$$= \int_{-\infty}^{ATPC_{range}} pdf_f(f) Prob(10\log(1+z) > NFM + f - f) df$$
$$+ \int_{ATPC_{range}}^{+\infty} pdf_f(f) Prob\big(10\log(1+z) > NFM + ATPC_{range} - f\big) df$$

$$= \int_{-\infty}^{ATPC_{range}} pdf_f(f) Prob(10\log(1+z) > NFM) df + \int_{ATPC_{range}}^{+\infty} pdf_f(f) Prob(10\log(1+z) > FM - f) df$$

$$= \int_{-\infty}^{ATPC_{range}} pdf_f(f) df\ Prob(10\log(1+z) > NFM) + \int_{ATPC_{range}}^{+\infty} pdf_f(f) Prob(10\log(1+z) > FM - f) df$$

$$= Prob(f \le ATPC\ Range) Prob(10\log(1+z) > NFM) + \int_{ATPC_{range}}^{+\infty} pdf_f(f) Prob(10\log(1+z) > FM - f) df$$

Equation (9)

Derivation of the following equality

$$\int_{ATPC\,range}^{+\infty} pdf_f(f)Prob(10\log(1+z) > FM - f)df$$
$$= \int_0^{+\infty} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z)))dz$$

$$\int_{ATPC\,range}^{+\infty} pdf_f(f)Prob(10\log(1+z) > FM - f)df$$

$$= \int_{ATPC\,range}^{+\infty} pdf_f(f)Prob\left(z > 10^{\frac{FM-f}{10}} - 1\right)\,df$$

$$= \int_{ATPC\,range}^{+\infty} pdf_f(f) \int_{10^{\frac{FM-f}{10}}-1}^{+\infty} pdf_z(z)\ dz\ df$$

$$= \int_{-\infty}^{+\infty} pdf_f(f)\mathbf{1}(f > ATPC\,range) \int_0^{+\infty} pdf_z(z)\ \mathbf{1}\left(z > 10^{\frac{FM-f}{10}} - 1\right) dz\ df$$

$$= \int_{-\infty}^{+\infty} \int_0^{+\infty} pdf_f(f)\ pdf_z(z)\ \mathbf{1}(f > ATPC\,range)\mathbf{1}\left(z > 10^{\frac{FM-f}{10}} - 1\right) dz\ df$$

$$= \int_0^{+\infty} \int_{-\infty}^{+\infty} pdf_f(f)\ pdf_z(z)\ \mathbf{1}(f > ATPC\,range)\mathbf{1}\left(z > 10^{\frac{FM-f}{10}} - 1\right) df\ dz$$

$$= \int_0^{+\infty} \int_{-\infty}^{+\infty} pdf_f(f)\ pdf_z(z)\ \mathbf{1}(f > ATPC\,range)\mathbf{1}(f > FM - 10\log(z+1))df\ dz$$

$$= \int_0^{+\infty} \int_{-\infty}^{+\infty} pdf_f(f)\ pdf_z(z)\ \mathbf{1}(f > Max(ATPC\,range, FM - 10\log(z+1))df\ dz$$

$$= \int_0^{+\infty} pdf_z(z)Prob(f > Max(ATPC\,range,\ FM - 10\,log(1+z)))dz$$

Where $1(x > y) = \begin{cases} 1, & x > y \\ 0, & x \le y \end{cases}$ is the indicator function.

ANNEX 3: BACKGROUND ON THE CONCEPTS OF LONG-TERM AND SHORT-TERM EFFECTS

According to Recommendation ITU-R F.758-8 [6] a number of different criteria are necessary for protection of FS links.

Abstract from Recommendation ITU-R F.758-8, annex 1, section 4 [6]:

"The number and values of the interference criteria necessary to protect a fixed wireless system will depend on the characteristics of the fixed wireless system and the interferer. In case of time varying interference, a single interference criterion may not be adequate; two or three values, corresponding to a long term (20% of time[5]) and short terms (< 1% of time) have been specified in some Recommendations.

It should be noted that the events where error performance is degraded are events of very short duration because of the stringent requirements of error performance objectives.

The number of short-term interference criteria corresponds to the number of error performance criteria that are appropriate for the sharing scenario. The exact percentage of time associated with a short-term interference criterion is related to a performance objective for the system under consideration; more information on fulfilling short-term interference objectives can be found in Recommendations ITU-R F.1494, ITU-R F.1495 and ITU-R F.1606, all of which deal with protection criteria applicable to time-varying interference.

The error performance and availability objectives should be fulfilled independently whether they are resulting from long-term or short-term interference."

A3.1 LONG-TERM

The I/N ratio to be respected for fulfilling the “long-term” criterion (not to be exceeded for more than 20%() of the time of the "average year") is defined in the Recommendation ITU-R F.758-8, table 5 [6]. For fixed location interfering sources, the APO is more stringent than EPO, while, when time-varying/mobile interference is concerned, a more complex situation has to be considered; Recommendation ITU-R F.758-8, section 1.1.2.2 "Practical applications" [6], helps to explain the difference in light of the fixed ("constantly present") or variable interference (mobile).

Abstract from Recommendation ITU-R F.758-8, annex 1, section 1.1.2.2 [6]:

"According to the principles described above, whenever a sharing or compatibility situation with FS systems arises, different studies are necessary for separately evaluating the impact of the interference on FS availability (on year basis) and FS error performance (on month basis).

However, in some practical cases, both studies are not necessarily due to the expected physical situation of the wanted and unwanted paths.

In particular, when the interference into FS victim is constantly present (e.g. from a GSO space station), it is generally assumed that the acceptable level of interference should be sufficiently low for not affecting the FS system availability threshold, on a yearly basis. In this case, ensuring the suitable FS availability degradation, it is generally assumed that any related ‘error performance’ degradation would be within the acceptable limits (in any month) and no specific study is required.

On the contrary, when the interference into the FS victim is relatively fast varying (e.g. from a non-GSO space station), it is generally assumed that, due to uncorrelated wanted and unwanted paths, the acceptable interference level may be higher, so that the ‘error performance’ degradation would predominate over the

[5] **Historical background on the 20% of the time used for long-term interference effects**: It should be noted that F.758 does not provide technical justification on the selection of 20% of the time as boundary for defining the long-term effect. However, F.758 was first published in 1992 having in mind the background of previous works in CCIR Report 569-4 (1990) [27] where the 20% figure was introduced as: “to estimate the basic transmission loss exceeded for all but 20% of the time, the free-space loss is increased by 1.5 dB”, except when the path geometry shows grazing or near-grazing conditions of ter rain along the path (i.e. within 2/3 of the first Fresnel zone). Then, diffraction may produce attenuation below free-space values”. Therefore, Recommendation ITU-R F.758 assumed and maintained the budgetary 20% of the time threshold for the long-term guideline. CCIR Report 569-4 (1990) was a basic reference in ITU-R P.452 until version 4 (1990).

possible ‘availability’ degradation. In this case, the ‘error performance’ degradation study should be carried out on the ‘worst month’ basis (see example in Recommendation ITU-R F.1108 and Recommendation ITU-R F.1495).

In principle, it is expected that, when the variability of the interference is slowing down (quasi static situations), there might be a speed threshold where both ‘availability’ and ‘error performance’ degradations might be equally impacted. In such cases, specific studies should be carried out for both cases with their appropriate time basis.”

Recommendation ITU-R F.758-8, table 5 [6], "Guidance in the choice of I/N values for long-term interference", defines the long-term protection criteria by I/N.

A3.2 SHORT-TERM IN ENVIRONMENTS WHERE MULTIPATH OR RAIN FADING DOMINATES

Also in this case, the text in Recommendation ITU-R F.758, annex 1, section 4 [6] should be analysed "Considerations on allowable performance/availability degradations due to interference and related interference criteria".

Abstracts from Recommendation ITU-R F.758-8, annex 1, section 4 [6]:

- **Generic guidelines about short-term concept:** *"Short-term interference requires separate consideration because the interference power may be high enough to produce degradation even when the desired signal is unfaded. Such interference must occur rarely enough and in events of short duration for the interference to be acceptable. A short-term interference criterion is set based on the interference power necessary to cause a particular error performance defect (such as an errored second) when the desired signal is unfaded. This is the approach taken in RR Appendix 7, and Recommendations ITU-R SM.1448, ITU-R F.1494, ITU-R F.1495, ITU-R F.1606, ITU-R F.1669 and ITU-R SF.1650.*
  Because permissible error performance defects can only occur for percentages of time that are much smaller than 1% of the time if error performance objectives are to be met, short-term interference studies require knowledge of the interference power that is exceeded for percentages of time much less than 1 per cent. The interference criterion for a particular error performance defect is specified by the power level (relative to the receiver noise) and the percentage of time allocated for this defect.”
- **Specific guidelines on single FDP method combining long and short-term requirements:** *“In sharing and compatibility studies in the frequency bands where multipath fading is the dominant propagation impairment for FS receivers (mostly in frequency bands below about 15 GHz), the fadings on the desired and interfering paths are uncorrelated. Under these conditions, Recommendation ITU-R F.1108 introduced the Fractional Degradation in Performance (FDP) method, which shows that it is appropriate to use the average value of the interference power as the critical value for long-term interference power. However, in this calculation, the average power must be determined while excluding periods of time when the interference power levels exceed the limit used for the short-term interference criteria. (Recommendation ITU-R F.1108 gives a relevant example applied to N-GSO.)”*

The text above further clarify that:

1 The “short-term” criterion, when rain is the dominant propagation effect and wanted and interfering paths are likely to have correlated attenuations, is only that calculated for the FS RX signal level “unfaded”, when, for a % of time << 1%, the interference level may exceed the net fade margin (NFM), i.e. 0 dB propagation fading on the FS link. In any case when the I/N CDF might exceed about 20 dB, it may be appropriate to consider short-term effects.

2 Recommendation ITU-R F.1495 [10] further recognise, in that case, the need for two “short-term” criteria related to different NFM (one related to NFM_{ES} for ES objective and one, with even lower % of the time, related to NFM_{SES} for SES objective); however, for modern high-capacity FS links the two NFM_{ES} and NFM_{SES} are coincident.

The FDP methodology, mentioned in Recommendation ITU-R F.758 [6] and described in Recommendation ITU-R F.1108 for cases where multipath is dominant, further detailed in this Report, gives the EP protection criterion valid from 100% of the time down to the above <<1% of time calculated as “short-term” criterion, when it is applicable (see Recommendation ITU-R F.1108, annex 3, section 4 [8]).

ANNEX 4: DEFINITION OF THE APPROPRIATE FS PARAMETERS FOR DETERMINING EP AND AP PROTECTION CRITERIA

A4.1 BACKGROUND

For constant bit rate transport networks, Recommendation ITU-T G.826 [1] and Recommendation ITU-T G.828 [3] provide the required "global" EP objectives (EPO) for a "Hypothetical Reference Connection of 27500 km", composed by any transport media (i.e. cascades of Optica Fibre, FS, or any other media links); that connection is subdivided into multiple portions of international (transit and terminating) and national paths. Similarly, Recommendation ITU-T G.827 [2] provides the "global" AP objectives on the same reference connections.

Recommendation ITU-R F.1668-1 [12], based on those ITU-T recommendations provides the appropriate EPO apportionment for "real radio links" connection of 2500 km only within the same country and subdivided in cascaded access, short-haul and long-haul sections. It provides the subsequent apportioning down to a single "real hop". Similarly, Recommendation ITU-R F.1703 [13] provides the appropriate APO apportionment for "real radio links" on the same reference connection.

The actual calculation of the protection criteria depends on the actual FS link characteristics as deployed in the field:

- Network position: for the ITU-R EPO and APO of PDH/SDH "constant bit rate" transport are different for different portions of the fixed networks given in Recommendation ITU-R F.1703 [13] and Recommendation ITU-R F.1668 [12]; e.g. international portions are more stringent than national ones, long-haul portions are more stringent than short-haul or access ones;
- Propagation Physics : the protection criteria depend on the link fade margin, which is established by the expected propagation statistic; Links with lower FM have less protection from interference;
- Physical FS receiver positioning: E.g. antenna height and pointing elevation; these have impact on the sharing/compatibility scenarios determining the minimum coupling loss (MCL) for reducing the interference levels at FS receiver input;
- In addition, modern FS systems implement technologies such as ACM and ATPC that introduce additional degree of variability in terms of NFM (ATPC) and payload capacity (ACM); these, while not affecting the "unperturbed" FS link EP objectives, also have an active role in defining the appropriate interference protection objectives.

Also, from the time varying interfering signals point of view, there are a number of elements that may differently affect the FS receiver response; in particular, when aggregation of large number of interfering devices in fixed and mobile location, often with burst/pulsed transmitting signals, care should be taken in evaluating the corresponding protection criteria.

A4.2 PERMITTED OBJECTIVE OF EP DEGRADATION DUE TO INTERFERENCE

A4.2.1 Overall Objectives

The EPO global limits for real FWS links is defined by Recommendation ITU-R F.1668-1 [12]; their % allocation to the FWS operation itself (i.e. X% =89% due to link planning with other nearby FWS), to interference from co-primary services sharing the same band (i.e. Y%=10%) and to other non-co-primary source of interference (Z%=1%) is given by Recommendation ITU-R F.1094-2. Recommendation ITU-R F.1565 [11]describes the methodology for deriving the allowed degradation of EP on real links, on the basis of Y% allocated to interference from co-primary services and of Z% allocated to non co-primary services and systems/applications.

It should be noted that in F.1565 [11] the term "link" refers to a chain of a number of "single hops"; therefore, for defining the permitted degradation per single TX/RX connection (hop), F.1565 [11] offers also the guidelines on how the "link" limit could be brought down to a single hop (default methodology is the division by the expected number of "hops").

Furthermore, it should be considered that Recommendation ITU-R F.1565 [11], as well as Recommendation ITU-R F.1668 [12], also provides various EPO degradation options as function of the typology of the real "link"

length (e.g. up to 1000 km or higher, from which the number of single hops can be derived), link capacity (from 1.5 to 3500 Mbit/s), and link placement in the network portion of HRP (e.g. access, national or international portions, intermediate or terminating country, EPO according Recommendation ITU-T G.826 [1] or Recommendation ITU-T G.828 [3] quality). Alternatively, operator surveys may provide the performance targets for each of the links in a multi-hop network.

Also in this case there is a need to preliminarly define the “typical” link typology (or a statistic distribution of typologies). This would also permit to define “typical” FWS equipment FFM (or their statistic distribution).

However, it should be underlined that the limits of ES and SES due to interference given in Recommendation ITU-R F.1565 may be necessary when short-term effects are to be evaluated as an apportionment (B%) of the overall EP allowance; long-term and FDP effects are generally calculated through direct evaluation of the degradation % with respect to the not interfered situation of the link (e.g. the FDP due to co-primary interference should remain within the 10%, or within A%, where A%=10% - B%, in case the short-term effect is given its specific apportionment of the maximum 10%).

A4.2.2 Long-term and short-term effects

The time-varying interference may produce different effects on a victim FS system; EP degradation may be produced by long-term effects and, when the interference level statistic, with probability << 1% of the time, can reach an I/N approaching the available NFM, short-term effects may also be considered.

In any case the sum of long and short-term effects should not exceed the overall EP degradation permitted by Recommendation ITU-R F.1094-2 and Recommendation ITU-R F.1565-1. Annex 2 provides background on appropriate case selection.

In the first case, Recommendation ITU-R F.758-8, section 2.2 of annex 1 [6] suggest that the apportionment should be considered on the basis of the actual probability that all interfering services/applications may contemporaneously have same highest impact on a FS link; this is usually very unlike when considering that sharing studies are made on typically worst case conditions. Therefore, unless for special cases, apportionment is in generally not necessary and the overall Y% or Z% provided by Recommendation ITU-R F.1094-2 can be used as a whole.

A4.3 IMPACT OF ATPC AND ACM ON THE DEFINITION OF THE LINK FADE MARGINS

The typical receiver level values, based on the usual link planning for meeting the required APO and EPO objectives, that are relevant for defining short-term EP interference protection criteria, in the worst month, are shown in Figure 8. It should be noted that, for completeness, both ES and SES thresholds and FMs are shown; however, in practice, in modern equipment ES and SES thresholds are nearly coincident (see section 3.4) and only SES are generally considered in sharing and compatibility studies.

The various levels shown take into account that modern digital P-P systems operate also with dynamic adaptation functionalities according to the propagation situation; in particular ATPC function is often used for enhancing the area spectrum utilisation and ACM function is used for enhancing the traffic capacity when the propagation attenuation is better than that causing any EP event that would affect the actual modulation used in that moment.

Background on ACM and ATPC operation and link planning/licensing for PP links is given in ECC Report 198 [18]; it gives the basic guideline of planning ACM links based only on the "reference modulation" FFM needed for the required APO/EPO and on the transmitter requirement of never exceeding the "reference modulation" absolute power emission mask during any ACM and ATPC operation.

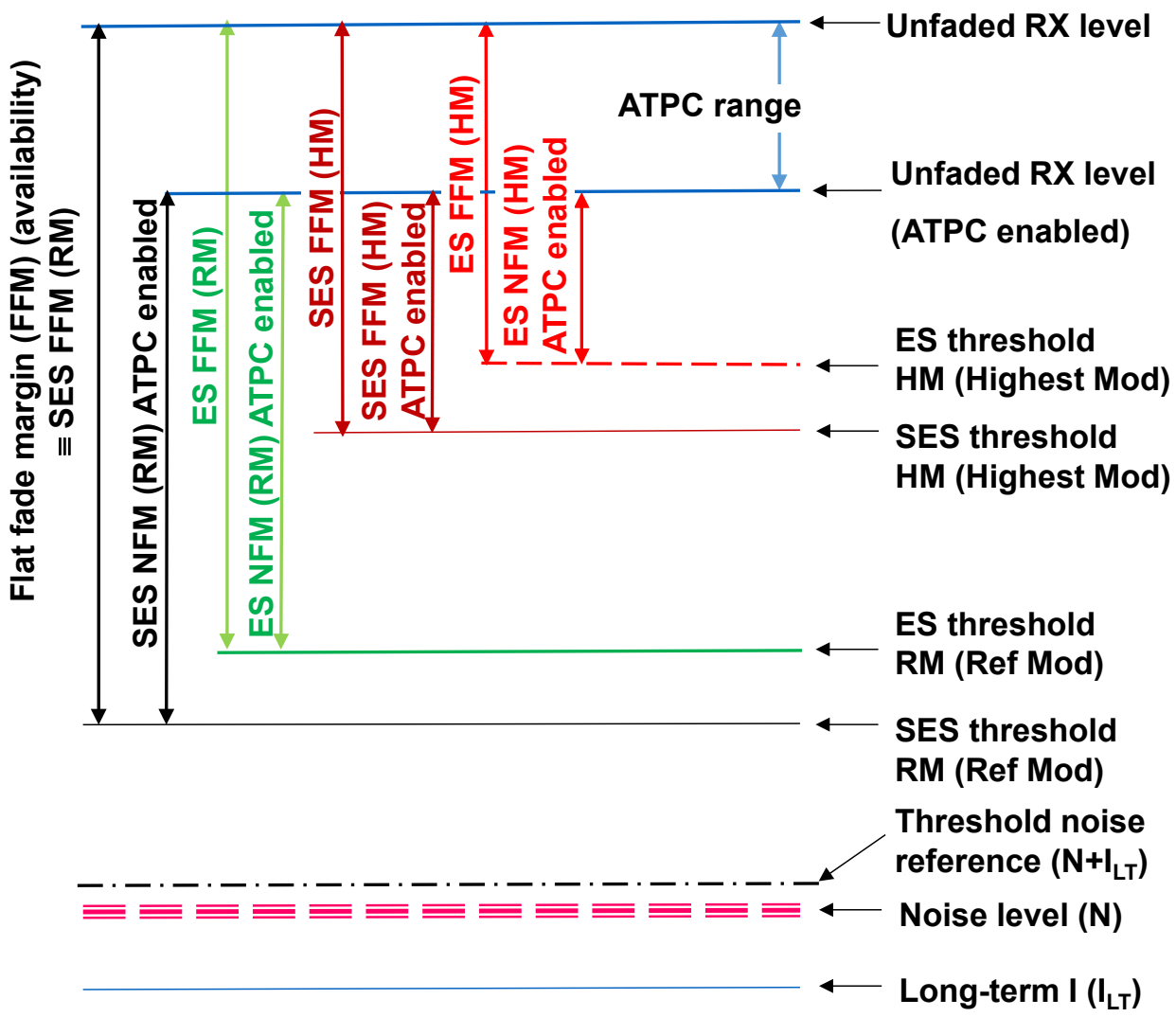


Figure 8: Received levels definitions for P-P hops

If ATPC is used, the relevant NFM (ATPC enabled) should be used because ATPC is generally reactive to the receiver signal level only. In any case, a TX power increase due to interference cannot be expected.

At the time of writing this Report, studies are ongoing within CEPT to evaluate the use of Adaptive Coding and Modulation (ACM) mechanisms in fixed links, as well as the impact of interference on ACM and the resulting challenges for FS operation.

A4.4 IMPACT OF PACKET DATA (ETHERNET/IP) ON THE EP/AP OBJECTIVES

When FS transport packet data (Ethernet/IP frames and higher layer applications) Recommendation ITU-T Y.1563 [4] and Recommendation ITU-T Y.1541 [5] provide relevant parameters and EP objectives.

The SES (here SES_{ETH}) and the unavailability (10 consecutive SES_{ETH}) concept are quite similar also in the AP impact.

The basic difference is the absence of ES concept (that in G.826 [1] already loses its significance for transport rate higher than 160 Mb/s), that is substituted by the Ethernet or IP Frame Loss Ratio (FLR and IPLR).

Ethernet frame loss ratio (FLR) is “The ratio of total lost Ethernet frame outcomes to total transmitted Ethernet frames in a population of interest. In point-to-multipoint configurations, it can also be useful to compare the

successful frame transfers among destinations using the destination with the largest number of successful frame transfers as the reference".

Recommendation ITU-T Y.1563 [4] and Recommendation ITU-T Y.1541 [5] define parameters for assessing the performance of Ethernet/IP transport networks. Instead of the "Errored Seconds" (ES), the "Ethernet Frame Loss Ratio" (FLR) and "Internet Protocol Loss Ratio" (IPLR) are used to measure errors. FLR indicates how many Ethernet frames are lost, directly affecting service quality, as faulty frames are discarded.

There are no specific international standards for Ethernet-based networks, but Recommendation ITU-R F.2113 [14] differentiates between high-performance long-haul connections and lower-performance short-haul ones. Recommendation ITU-T Y.1541 [5] sets an upper IPLR limit of 10^{-3}, with provisional classes down to 10^{-5}.

Provided that the BER/FER relationship shows that FER is worse than BER (see formal conversion for 64 octets frames case is given in ETSI EN 302 217-2 [24] and real traffic examples in Recommendation ITU-R F.2113 [14]), and that several applications, embedded in Ethernet/IP frames, are intolerant to FLR/IPLR or the consequence on packet time delay, when real time audio/video, on-line gaming, fast mobility are concerned), it is worldwide common practice in MNOs to design their network for the same EPO used insofar in all Recommendation ITU-T G.826 [1] case, based on a Bit Error Ratio threshold of 10^{-6}.

ANNEX 5: LIST OF REFERENCES

[1] Recommendation ITU-T G.826 (12/2002): “End-to-end error performance parameters and objectives for international, constant bit-rate digital paths and connections”

[2] Recommendation ITU-T G.827 (09/2003): “Availability performance parameters and objectives for end-to-end international constant bit-rate digital paths”

[3] Recommendation ITU-T G.828 (03/2000): “Error performance parameters and objectives for international, constant bit-rate synchronous digital paths”

[4] Recommendation ITU-T Y.1563 (01/2009): “Ethernet frame transfer and availability performance”

[5] Recommendation ITU-T Y.1541 (11/2011): “Network performance objectives for IP-based services”

[6] Recommendation ITU-R F.758 (02/2025): “System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference”

[7] Recommendation ITU-R F.1094-2: “Maximum allowable error performance and availability degradations to digital fixed wireless systems arising from radio interference from emissions and radiations from other sources!

[8] Recommendation ITU-R F.1108-4 (01/2005): “Determination of the criteria to protect fixed service receivers from the emissions of space stations operating in non-geostationary orbits in shared frequency bands”

[9] Recommendation ITU-R F.1494-0: “Interference criteria to protect the fixed service from time varying aggregate interference from other services sharing the 10.7-12.75 GHz band on a co-primary basis”

[10] Recommendation ITU-R F.1495-2 (03/2012): “Interference criteria to protect the fixed service from time varying aggregate interference from other radiocommunication services sharing the 17.7-19.3 GHz band on a co-primary basis”

[11] Recommendation ITU-R F.1565-1 (11/2019): “Performance degradation due to interference from other services sharing the same frequency bands on a co-primary basis, or from other sources of interference, with real digital fixed wireless systems used in the international and national portions of a 27 500 km hypothetical reference path at or above the primary rate”

[12] Recommendation ITU-R F.1668-1: “Error performance objectives for real digital fixed wireless links used in 27 500 km hypothetical reference paths and connections”

[13] Recommendation ITU-R F.1703-0: “Availability objectives for real digital fixed wireless links used in 27 500 km hypothetical reference paths and connections”

[14] Recommendation ITU-R F.2113-0: “Error performance and availability objectives and requirements for real point-to-point packet-based radio links”

[15] Recommendation ITU-R P.530-17 (12/2017): “Propagation data and prediction methods required for the design of terrestrial line-of-sight systems”

[16] Recommendation ITU-R P.525: “Calculation of free-space attenuation”

[17] Recommendation ITU-R F.1606-0 (02/2003): “Interference criteria to protect fixed wireless systems from time varying aggregate interference produced by non-geostationary satellites operating in other services sharing the 37-40 GHz and 40.5-42.5 GHz bands on a co-primary basis”

[18] ECC Report 198: “Adaptive modulation and ATPC operations in fixed point-to-point systems - Guideline on coordination procedures”, approved May 2013

[19] 3db-access: IMPULSE RADIO UWB PRINCIPLES AND REGULATION (here)

[20] R. J. Fontana and E. A. Richley, "Observations on Low Data Rate, Short Pulse UWB Systems," 2007 IEEE International Conference on Ultra-Wideband, Singapore, 2007, pp. 334-338

[21] H- W. Pflug, J. Romme, K. Philipps, H. de Groot: “Method to Estimate Impulse-Radio Ultra-Wideband Peak Power”, IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, VOL. 59, NO. 4, APRIL 2011

[22] Recommendation ITU-R F.1093: “Effects of multipath propagation on the design and operation of line-of-sight digital fixed wireless systems”

[23] Recommendation ITU-R P.1853-1: “Time series synthesis of tropospheric impairments”

[24] ETSI EN 302 217-2 (V3.4.1 (2025-07)): “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”

[25] Recommendation SF.1006 (04/1993): “Determination of the interference potential between earth stations of the fixed-satellite service and stations in the fixed service”

[26] Radio Regulations, editions of 2024

[27] CCIR Report 569-4: The Evaluation of Propagation Factors n Interference Problems Between Stations on The Surface of the Earth at Frequencies above about 0.5 GHz” Note: Available at page 565 of the Reports of the CCIR, 1990; Annex to Volume V; Propagation in non-ionized media.