

ITU-T

TELECOMMUNICATION
STANDARDIZATION SECTOR
OF ITU

G.697

(11/2016)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA,
DIGITAL SYSTEMS AND NETWORKS

Transmission media and optical systems characteristics –
Characteristics of optical systems

Optical monitoring for dense wavelength division multiplexing systems

Recommendation ITU-T G.697

ITU-T

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Recommendation ITU-T G.697

Optical monitoring for dense wavelength division multiplexing systems

Summary

Recommendation ITU-T G.697 defines optical monitoring (OM) that can help in dense wavelength division multiplexing (DWDM) systems to perform the following activities:

- configuration management for system and channel activation, addition of new channels, etc.;
- fault management to detect and to isolate faults;
- degradation management in order to keep the system running and to detect degradations before a fault occurs.

DWDM technology is improving at a rapid pace, continuously stretching the channel count, channel speeds and reach limits. Long-haul multi-span DWDM systems are capable of taking optical signals thousands of kilometres without electrical terminations or regeneration.

This continuing trend is driving the increasing importance of OM, which is the subject of this Recommendation.

This edition of this Recommendation provides additional information on OM for 40 Gbit/s and 100 Gbit/s signals, adds beat noise method to the clause for optical signal-to-noise ratio (OSNR) measurements, and introduces a new clause on security considerations.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T G.697	2004-06-13	15	11.1002/1000/7322
2.0	ITU-T G.697	2009-11-13	15	11.1002/1000/10394
2.1	ITU-T G.697 (2009) Cor. 1	2011-02-25	15	11.1002/1000/11327
3.0	ITU-T G.697	2012-02-13	15	11.1002/1000/11483
4.0	ITU-T G.697	2016-11-13	15	11.1002/1000/13079

* To access the Recommendation, type the URL <http://handle.itu.int/> in the address field of your web browser, followed by the Recommendation's unique ID. For example, <http://handle.itu.int/11.1002/1000/11830-en>.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

NOTE

In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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As of the date of approval of this Recommendation, ITU had received notice of intellectual property, protected by patents, which may be required to implement this Recommendation. However, implementers are cautioned that this may not represent the latest information and are therefore strongly urged to consult the TSB patent database at <http://www.itu.int/ITU-T/ipr/>.

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Recommendation ITU-T G.697

Optical monitoring for dense wavelength division multiplexing systems

1 Scope

The purpose of this Recommendation is to indicate a minimum, but not exhaustive, set of optical parameters that can be used to perform optical monitoring (OM) functions in dense wavelength division multiplexing (DWDM) systems and optical network elements [ONEs, e.g., reconfigurable optical add-drop multiplexers (ROADMs)], particularly relevant to those network elements without optical-electrical-optical conversions. In order to achieve this objective, this Recommendation:

- 1) indicates methods for measuring the optical signal degradation;
- 2) classifies those methods by type;
- 3) defines suitable optical parameters to detect optical signal degradation; and
- 4) describes the applications or conditions where these optical parameters can be relevant.

This Recommendation refers to DWDM systems and ONEs with optical channels with bit rates up to approximately 10 Gbit/s using non-return to zero (NRZ) or return to zero (RZ) line coding and bit rates at approximately 40 Gbit/s and 100 Gbit/s using advanced modulation formats, such as (dual polarization) quadrature phase shift keying. Bit rates above 100 Gbit/s and systems employing other modulation formats are for further study.

2 References

2.1 Normative references

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

- [ITU-T G.650.2] Recommendation ITU-T G.650.2 (2015), *Definitions and test methods for statistical and non-linear related attributes of single-mode fibre and cable*.
- [ITU-T G.652] Recommendation ITU-T G.652 (2016), *Characteristics of a single-mode optical fibre and cable*.
- [ITU-T G.653] Recommendation ITU-T G.653 (2010), *Characteristics of a dispersion-shifted single-mode optical fibre and cable*.
- [ITU-T G.655] Recommendation ITU-T G.655 (2009), *Characteristics of a non-zero dispersion-shifted single-mode optical fibre and cable*.
- [ITU-T G.663] Recommendation ITU-T G.663 (2011), *Application-related aspects of optical amplifier devices and subsystems*.
- [ITU-T G.664] Recommendation ITU-T G.664 (2012), *Optical safety procedures and requirements for optical transmission systems*.
- [ITU-T G.692] Recommendation ITU-T G.692 (2005), *Optical interfaces for multichannel systems with optical amplifiers*.

- [ITU-T O.201] Recommendation ITU-T O.201 (2003), *Q-factor test equipment to estimate the transmission performance of optical channels*.
- [ITU-T X.805] Recommendation ITU-T X.805 (2003), *Security architecture for systems providing end-to-end communications*.

3 Terms and definitions

3.1 Terms defined elsewhere

This Recommendation uses the following term defined in [ITU-T G.650.2]:

- stimulated Brillouin scattering (SBS)

This Recommendation uses the following terms defined in [ITU-T G.663]:

- polarization mode dispersion (PMD) (1st and higher orders)
- four-wave mixing (FWM)
- amplified spontaneous emission (ASE) noise in optical amplification (OA)
- chromatic dispersion
- reflections (see reflectance)
- cross-phase modulation (XPM)
- self-phase modulation (SPM)
- stimulated Raman scattering (SRS)

This Recommendation uses the following term defined in [ITU-T G.692]:

- Frequency (or wavelength) deviation from nominal (see central frequency deviation)

This Recommendation uses the following term defined in [ITU-T O.201]:

- Q-factor

This Recommendation uses the following terms defined in [ITU-T G-Sup.39]:

- optical signal-to-noise ratio (OSNR)
- inter-channel crosstalk
- interferometric crosstalk

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 chromatic dispersion slope: The slope of the curve of chromatic dispersion coefficient versus wavelength.

3.2.2 fully regenerated optical network: Optical network where optical-electrical-optical conversion is performed in each network element using re-amplification, reshaping and retiming (3R) regeneration.

3.2.3 transparent optical network element: An optical network element where there is no optical-electrical-optical conversion of the optical signal.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

3R	Re-amplification, Reshaping and Retiming
ASE	Amplified Spontaneous Emission
BER	Bit Error Ratio
CWDM	Coarse Wavelength Division Multiplexing
DCM	Dispersion Compensation Module
Demux	Demultiplexer
DGD	Differential Group Delay
DSP	Digital Signal Processing
DWDM	Dense Wavelength Division Multiplexing
EME	Embedded Monitoring Equipment
EMP	External Monitoring Point
ESR	Errored Second Ratio
FEC	Forward Error Correction
FWM	Four-Wave Mixing
Mux	Multiplexer
NOC	Network Operations Centre
NRZ	Non-Return to Zero
OA	Optical Amplification
OADM	Optical Add-Drop Multiplexer
OD	Optical Demultiplexing
O/E	Optical to Electrical
OM	Optical Monitoring
ONE	Optical Network Element
OSA	Optical Spectrum Analyser
OSNR	Optical Signal-to-Noise Ratio
OTDR	Optical Time Domain Reflectometer
OTN	Optical Transport Network
PDL	Polarization-Dependent Loss
PMD	Polarization Mode Dispersion
ROADM	Reconfigurable Optical Add-Drop Multiplexer
RZ	Return to Zero
SBS	Stimulated Brillouin Scattering
SDH	Synchronous Digital Hierarchy

SESR	Severely Errored Second Ratio
SLA	Service Level Agreement
SPM	Self-Phase Modulation
SRS	Stimulated Raman Scattering
XPM	cross-Phase Modulation

5 Optical monitoring overview

The management of existing synchronous digital hierarchy (SDH) networks relies on monitoring digital parameters such as bit error ratio (BER), errored second ratio (ESR) and severely errored second ratio (SESR), which are measured at the electrical layer (at 3R regenerators), as described in [b-ITU-T G.826].

A similar approach is used in the optical transport network (OTN), using ITU-T G.709 framing, for monitoring the end-to-end connections and the optical connections at the electrical level.

While these methods give a reliable measure of the end-to-end performance of an optical channel, they cannot be applied inside a transparent optical domain where no 3R regenerators are available to terminate the frame overhead. Therefore, they may not provide sufficient information to isolate the root cause of problems in complex DWDM networks.

Moreover, the rapid progress in optical technology is leading to ever-increasing channel counts and transmission speeds and to longer all-optical connections inside an optical domain.

This leads to the increasing influence of linear and non-linear distortions, which makes system commissioning an increasingly complex task.

An optimum solution for an OTN combines:

- proper network design to limit noise sources, dispersion and intermodulation effects;
- suitable alarms for the active optical components and the optical fibre links within the network for fault detection and isolation;
- the use of appropriate OM throughout the network to monitor the most critical optical parameters.

Individually, these three actions cannot guarantee a suitable optical quality but, when combined, they provide a suitable solution for the management of OTNs.

An appropriate level of OM gives some visibility inside optical networks ensuring that channel paths are properly configured and optical parameters are appropriate for reliable service delivery. The collection of OM data in a network operations centre (NOC) makes the management of complex DWDM networks easier.

The objectives of OM are to detect anomalies, defects, degradations and faults affecting the quality of the optical layer. The optical parameters to be monitored should be established and defined according to specific requirements.

The ability to improve end-to-end monitoring with distributed OM may have both reliability and cost benefits for configuration management and fault/degradation management, since some defects, degradations and faults affecting the quality of the optical layer are more easily detected and isolated through OM.

Aging effects, changes in noise due to changes in the temperature and humidity, are impairments that can seriously degrade the quality of the signal transmission. OM makes it possible to detect these degradations in a reliable way.

OM is a proactive process that can help to manage service level agreements (SLAs) and to mitigate operational costs (although often at the expense of increased equipment costs). OM is increasingly important in the maintenance of a high degree of equipment reliability, coupled with the ability to diagnose degradations and failures quickly, and locate and repair network problems. The technique is also becoming more and more challenging as network complexity increases.

OM is an important complement to the monitoring techniques applied at the digital client layers of the optical layer network.

OM is a key element in the management of the optical networks, since it is possible to manage only what it is possible to measure.

While OM is implemented (and in service) in many current optical transmission systems, there are significant differences in OM requirements between them. This is due to the presence of different transmission and control system designs, and different strategies for impairment management in the various systems. For this reason, a general requirement for a set of parameters with a defined accuracy as a reliable indicator of the operational condition of such a system cannot be generalized. Even within a single system, the parameters that are of importance may vary between different network elements and the monitoring requirements, even for internal control, are different for the various network elements. Consequently, a general requirement for supervision of particular parameters will normally lead to a sub-optimal (and, therefore, non-cost-effective) solution. An appropriate optical supervision scheme will, for this reason, always be related to the particular transmission and control system design, engineering rules and implementation of impairment management of such a system. However, based on what is feasible from the technological point of view and on what network operators need, some monitoring choices can be identified, as outlined in this Recommendation.

6 Classification of monitoring methods

Clauses 6.1 to 6.6 describe two different forms of signal monitoring, namely time domain and frequency domain methods, and explain the differences between signal monitoring and equipment monitoring, as well as the differences between embedded and external monitoring devices.

6.1 Signal monitoring

This Recommendation is limited to non-intrusive measurements that allow in-service monitoring of the optical signal quality.

The measurements defined in this Recommendation do not measure every single impairment listed in Table 1 for up to 10 Gbit/s systems or Table 2 for 40 Gbit/s and 100 Gbit/s systems, but rather the effect of these impairments on the parameters that can be measured.

A distinction between frequency and time domain measurement methods can be made.

6.1.1 Time domain methods

Methods which analyse the behaviour of the optical signal in the time domain tend to be closer to the full BER measurement than those in the frequency domain. These methods are sensitive to both noise and distortion effects. Sampling oscilloscopes and Q-factor metres, as described in [b-ITU-T O.201], are representative of sampling methods (synchronous methods). However, time domain methods generally need optical demultiplexing (OD), optical to electrical conversion and, in the case of sampling methods, synchronization to the bit rate. Also, the difference in the characteristics of the reference receiver compared to the system receiver and the effect of residual dispersion at the measurement point, as discussed in clause III.2, has to be considered.

NOTE – The above description of sampling oscilloscopes and Q-factor metres is for up to 10 Gbit/s NRZ or RZ signals. Sampling oscilloscope and Q-factor measurements may not provide useful results for 40 Gbit/s or 100 Gbit/s signals with advanced modulation formats.

6.1.2 Frequency (or wavelength) domain methods

Frequency/wavelength domain methods of OM analyse the spectral characteristics of the optical signal. These spectral methods have in common that they do not sample the signal or synchronize to it, thereby eliminating the entire reference receiver. Typically, they employ a spectrum analyser device, which may be of varying resolution, and may or may not sense all channels simultaneously.

The simplest form of a spectral analysis is simple power monitoring of each channel. This can be done with, for example, a diffraction grating and detector array to sense all of the channel powers simultaneously. At the expense of an increase in the complexity and resolution, this method can also be extended to look at the precise shape of the signal spectrum.

The fundamental property of these spectral methods is that they are averaging methods that, by definition, do not sense the pulse distortion. This means that quality monitoring by spectral methods will be insensitive to all of the effects due to distortions.

6.2 Equipment monitoring (indirect methods)

Indirect methods make use of an empirical correlation between equipment failures and signal quality. Equipment failures, such as power supply failures and laser temperature, may be detected by built-in self-test functions. These indicators are likely to be very system and implementation dependent.

Indirect methods mainly indicate that the system is operating, and it is assumed that the signal quality is also degraded, when an equipment parameter is outside the specified range.

However, a correct equipment parameter is no guarantee of signal integrity, since there may be other impairments that affect the signal quality (e.g., fibre attenuation).

6.3 Fibre link monitoring

An optical time domain reflectometer (OTDR), which may be embedded, can detect and locate fibre link failures, such as fibre cut and abnormal attenuation. Fibre link monitoring indicates the current state of fibre link, and can be used to detect and to isolate fibre link faults. However, a normal fibre link status is no guarantee of signal integrity, since there may be other impairments that affect the signal quality.

6.4 Monitoring based on received signals

Coherent receivers are commonly used in 40 Gbit/s and 100 Gbit/s systems using advanced modulation formats. Digital signal processing (DSP) in coherent receivers may include chromatic dispersion compensation, nonlinear compensation, polarization equalization, and forward error correction (FEC) processing. From these processing steps, parameters can be extracted that provide information on the transmission quality of the optical path (transmitter to receiver) of the received channel. Some optical impairments, such as chromatic dispersion and differential group delay, could be estimated from the DSP. However, chromatic dispersion or differential group delay are not expected to be likely faults in a DWDM network using coherent receivers.

6.5 Embedded monitoring equipment

Embedded monitoring equipment (EME) is usually tightly integrated with the management functions of an optical network element (ONE). For cost reasons, embedded monitoring is usually limited to a few basic parameters.